

Governance and Design of Urban Infostructures

Analysing Key Socio-Technical Systems for the Vulnerability and Resilience of Cities

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Abstract Information, communication and knowledge creation are at the core of urban stakeholder interactions enabling the identification of vulnerabilities and the design of adequate responses to them. Urban infostructures play a crucial role within these processes, interfacing between a city's ecological, social, technical, economic and political networks. Against this backdrop, this paper discusses the governance and design of urban infostructures from a socio-technical systems perspective. It, therefore, reviews pertinent technology components, as well as institutional and discursive frameworks and their respective influence on the identification and assessment of vulnerabilities and resilience building in cities. It concludes that approaches to developing urban infostructures should be a major concern when addressing urban resilience. There is a need to fully account for the hybrid character of urban infostructures as socio-technical systems, while also seizing opportunities for targeted transformation.

Keywords Cities · Vulnerability · Resilience · Socio-technical systems · Local government · Information infrastructures · Spatial data infrastructures · Knowledge · Discourse

Zur Governance und Gestaltung urbaner Infostrukturen

Eine Analyse sozio-technischer Schlüsselsysteme für die Vulnerabilität und Resilienz von Städten

Zusammenfassung Information, Kommunikation und Wissensgenese stehen im Mittelpunkt von Interaktionen städtischer Akteure, die zur Identifikation von Vulnerabilitäten und zur Gestaltung passender Gegenmaßnahmen führen. Dabei spielen urbane Informationsinfrastrukturen eine maßgebliche Rolle, da sie zwischen den ökologischen, sozialen, technischen, ökonomischen und politischen Netzwerken einer Stadt vermitteln. Vor diesem Hintergrund behandelt der vorliegende Aufsatz die Steuerung und den Aufbau urbaner Informationsinfrastrukturen als sozio-technische Systeme. Daher werden wesentliche Technologiekomponenten sowie institutionelle und diskursive Rahmenbedingungen betrachtet und hinsichtlich ihres Einflusses auf die Identifikation und Bewertung urbaner Vulnerabilitäten und auf den Aufbau urbaner Resilienz hin untersucht. Daraus wird gefolgert, dass Ansätze zur Entwicklung urbaner Informationsinfrastrukturen ein zentrales Anliegen sein sollten, wenn es um die Resilienz von Städten geht. Dies erfordert dem hybriden Charakter urbaner Infrastrukturen als sozio-technische Systeme umfassend Rechnung zu tragen, und gleichzeitig Gelegenheiten für eine gezielte Transformation zu nutzen.

Schlüsselwörter Stadt · Vulnerabilität · Resilienz · Sozio-technisches System · Kommunale Verwaltung · Informationsinfrastruktur · Geodateninfrastruktur · Wissen · Diskurs

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1 Introduction

Cities are facing major sustainability challenges ranging from climate change and resource scarcity to socio-demographic change, social cohesion and financial instability in spatially differentiated contexts of growth or shrinkage. Such challenges show complex interrelations between the social, economic and environmental domains, and the physical structures and governance practices in cities. Various pressures may cumulate in space and time, dynamically reinforcing each other. For instance, in typical high density districts adjacent to European cities' historic centres. Here an energy inefficient building stock, urban heat island effects, high noise levels and low air quality levels coincide with ageing and social segregation to shape a specific amalgamation of threats and risks for local inhabitants and urban stakeholders in general (e.g. carbon footprint, real estate development, health services). Moreover, these challenges imply considerable uncertainties, including sudden disruptive events as well as slow structural change that (may) negatively affect urban sustainability (cf. Höjer/Gullberg/Pettersson 2011).

This situation has profound implications for the development and usage of networked information and communication technologies (ICT) in cities. Local governments and their stakeholders more than ever rely on data and information that is considered to be relevant and reliable, and that could support them in collectively identifying and locating problems, setting priorities and defining effective actions. In particular, these expectations and demands emerge as we experience how technologies are evolving in ways that substantially alter the means by which data can be handled and used—not only within local governments and other organisations, but throughout most of society. Technologies and solutions for spatial data retrieval, storage and access, discovery and processing, simulation, evaluation and visualisation, as well as for exchange and communication through increasingly wired and mobile networks, are all subject to processes of innovation and harmonisation (cf. Foth 2009; Deakin 2011). Different technology choices and usages may thus have far-reaching implications for stakeholders' perceptions and interpretations of urban realities, their capability to anticipate and explore urban futures, and their capacity to adapt.

The described conjunction of societal challenges and technological innovations in cities provides the starting point for this paper. In particular, it raises the question of how technology options, discursive frameworks and institutional settings combine in particular places to form what will be termed here an “urban infostructure” (UI) (cf. Nedović-Budić/Budhathoki 2006: 401; Henningsson/Henriksen 2011: 357). The focus is on implications of urban infostructures for the identification and assessment of vulnerabilities, and for the adaptive and transformative capacity of cities.

To address these issues, we first delineate how we understand the concepts of “vulnerability” and “resilience” in the context of urban development, deriving the basic criteria for assessing the role of infostructures (Sect. 2). We then draw on the concepts of socio-technical systems and infostructures in order to establish a framework for analysis (Sect. 3). From this, key technology issues and choices (Sect. 4) and current regimes dealing with infostructure development in cities are reviewed (Sect. 5). Finally, on the basis of this discussion, some overall conclusions concerning future approaches to the governance and design of urban infostructures are presented.

2 Vulnerabilities and Resilience in Cities

Regarding the uncertainties and complex challenges for cities sketched above, urban and regional research shows a growing interest in exploring the concepts of vulnerability and resilience. These seem to offer useful starting points for understanding some of the mechanisms that hinder or enable cities to cope with structural change, disruptive events and situations of crisis. However, despite the increasing size and disciplinary diversity of the literature on this topic there is still no widely shared understanding of these concepts. Indeed, such are the differences in interpretation that some researchers already argue that the utility of “resilience” for guiding research is endangered by ambiguity. For instance, Brand and Jax (2007) identify no less than ten different conceptualisations of resilience depending on the system(s) of reference and degree of normative orientation. Yet, they equally recognise the value of such vague concepts as boundary objects for communication and coordination across disciplines, providing a common perspective for analysis and action (cf. Becker 2010). Looking at the scientific trajectories of vulnerability and resilience it seems that a focus on *cities and information systems* is likely to benefit from the latter quality, while also encouraging first steps towards more integrated approaches.

2.1 Identifying and Assessing Urban Vulnerabilities

The broader scientific interest in defining vulnerability has largely been driven by the recognition of natural disasters and global environmental change as all encompassing threats to society. The concept first emerged in the context of studies dealing with various impacts of hazards on communities and geographical regions. Here, vulnerability was conceived of as a dynamic relation between a social-ecological system's components, leading to a “reduced capacity to anticipate, cope with, resist and recover from the impact of natural hazard” (Blaikie/Cannon/Davis et al. 1994: 9). This perspective has been taken up and applied

to analyse multiple types of systems and their sensitivity to threats resulting from both disruptive events and slow variables, including studies on disaster risk-reduction, food security, equity and social justice, as well as sustainability (Vogel/Moser/Kasperson et al. 2007). Vulnerability therefore provides a lens for research and practice through which critical interrelations between ecological, social, and technical systems that could threaten integral functioning can be identified. Additionally, it offers a means of grasping the corresponding thresholds for preventing irreversible harm.

This epistemological perspective is used for a *positivist* vulnerability analysis of e.g. urban structures or people at risk. At the same time, vulnerabilities are regarded as *socially constructed* since their identification and assessment shows interpretative flexibility between different stakeholder communities, depending on the characteristics of communication and knowledge transfer processes within particular local contexts and cultures (Bijker 2009). Vulnerability thus represents a contested terrain in urban and regional development as different interpretations and valuations of what constitutes a threat and what makes a city or region vulnerable to it have to be negotiated. In this process it is necessary to draw on the broadest possible range of available knowledge from both experts and laymen, including different types of knowledge (i.e. tacit, explicit and embedded knowledge—cf. Nonaka 1994), different forms of knowledge (i.e. system, target and transformational knowledge—cf. Pohl/Hirsch Hadorn 2007), as well as new knowledge co-creation (cf. Walker/Carpenter/Anderies et al. 2002; Vogel/Moser/Kasperson et al. 2007). It equally points to the importance of space as a common denominator for different sectoral processes, enabling a cross-scale analysis of the spatial concentration, distribution and overlaps of various types of pressures i.e. a mapping of vulnerabilities (Eakin/Luers 2006).

With a view to the use of information and communication technologies (ICT) in cities, a vulnerability perspective thus implies two interrelated aspects. On the one hand, ICT can exert a significant influence on stakeholder perceptions and valuations as they create spatial reference, link heterogeneous data sources, incorporate multiple types and forms of knowledge, and channel communication and interaction between stakeholders. On the other hand, ICT itself also should be subject to vulnerability considerations that include social practices (Kizza 2009: 89). This already highlights the duality of infrastructures consisting of technical and social components, as discussed in Sect. 3.

2.2 Conceiving of and Building Urban Resilience

The concept of resilience emerged out of the debate on vulnerabilities of ecosystems; as an attempt to identify conditions for maintaining their identity and functions. It

has, however, been swiftly extended to embrace other systems and their interrelations (cf. Gunderson 1999; Berkes/Colding/Folke 2003). When used with reference to cities, resilience is seen to be especially concerned with time and place-specific interdependencies between *ecological* (ecosystem services, metabolic flows), *social* (governance, organisations), and *technical* networks (ICT, built environment, infrastructures) that may cause vulnerabilities (Resilience Alliance 2007; Alessa/Kliskey/Altaweel 2009; Ernstson/van der Leeuw/Redman et al. 2010). Furthermore, to handle the problem of spatial scale, Ernstson/van der Leeuw/Redman et al. (2010: 533) suggest distinguishing between resilience *in* cities (focused on a local-to-regional scale), and a resilience *of* cities (operating at the scale of city networks). Based on this conception of cities as a subject of resilience, there is an equally broad range of disturbances linked to ecological, social, technological, economic, and political processes and their combinations that should be addressed (Müller 2011: 4).

In this discussion, the initial focus on a single stable equilibrium has increasingly been criticised, with calls for non-linear dynamics across temporal and spatial scales to be *also* taken into account—emphasising the role of thresholds, uncertainty and surprise (Folke 2006: 256; Deppisch/Schaerffer 2011: 30). This recognition of complex behaviour clearly requires going beyond anticipation in order to be able to self-organise and, if needed, create new configurations that structurally differ from the original state. Following Wildavsky's (1988) distinction between management approaches oriented at either anticipation or resilience, as well as Holling's understanding of "engineering resilience" versus "ecological resilience" (1996), two response strategies are reflected in current resilience thinking (Walker/Carpenter/Anderies et al. 2002; Foster 2006; Resilience Alliance 2007):

- *Anticipation strategies*: focused on known and predictable problems, aimed at increasing capacity to withstand stress and prepare for failure in order to quickly return to equilibrium, and
- *Adaptation strategies*: focused on unknown and unpredictable problems, aimed at developing capacities to learn, self-organise and transform *in case* thresholds are exceeded under conditions that are far from equilibrium.

Both strategies are regarded as a necessary and sufficient condition for enhancing a system's resilience. It should be emphasised here that strategies aimed at resilience are not conceived to *eliminate* vulnerabilities. Rather, both concepts maintain a dialectic relation (Aguirre 2007), since instability and dynamic development are key prerequisites for innovation (Bijker 2009:1). Ultimately, resilience is the result of an ongoing process of vulnerability emergence, identification and assessment.

Most importantly, resilience has gradually evolved from being a merely descriptive concept to one which increasingly denotes a *normative orientation* of systemic development, one closely linked to long-term flexibility and uncertainty (Brand/Jax 2007: 5). Striving for resilience is thus frequently understood as a necessary way of dealing with sustainability challenges. It is therefore also advocated as a governance and management concept (cf. Folke 2006; Ernstson/van der Leeuw/Redman et al. 2010) and has already been adopted to design public policy approaches aimed at “building” resilience (e.g. for UK Marvin/Medd 2005: 46). Basic principles for this include in particular

- redundancy (as opposed to efficiency), creating robust and sensitive regulation through overlapping mechanisms,
- functional diversity, spreading risks and benefits widely to retain overall consistency in performance,
- dynamic equilibrium (not avoiding instability) to generate opportunities for change,
- dialogue and innovation across scales, establishing long-distance ties between stakeholders in different sectors and at various levels (Holling 1996; La Porte 2006; Ernstson/van der Leeuw/Redman et al. 2010; Ahern 2011).

In practice, it will thus essentially depend on the capability of actors to account and prepare for the complexity of such interrelations (Marvin/Medd 2005; Deppisch/Schaerffer 2011). This highly ambitious goal can only be approached by drawing intensively on ICT, given the fast growing data volumes to be processed. In particular as cities are innovation hubs (where a diversity of cognitive dimensions enhances the accumulation of knowledge) and because information sharing creates the channels through which energy and matter flow, particular attention should be paid to the role of information processing and communication (Ernstson/van der Leeuw/Redman et al. 2010: 537). In other words, resilient cities need to “rapidly acquire information about their environments, quickly adapt their behaviours and structures to changing circumstances, communicate easily and thoroughly with others, and broadly mobilize networks of expertise and material support” (La Porte 2006: 142).

In sum, the above points to a number of critical issues for reviewing the role of ICT regarding the identification and assessment of vulnerabilities, as well as the creation of anticipative and adaptive capacity in cities:

- Representation of the city as a time and place-specific interrelation between ecological, social, and technical networks (“resilience of what”),
- type and range of disturbances represented (“resilience to what”),
- type and range of knowledge represented,

- spatial relation of data across sectors and scale levels
- recognition and valuation of complex system behaviour, and
- adherence to governance principles supporting anticipation and adaptation.

In the following, we refer to these issues in a discussion of the social and technical components that constitute an urban infostructure.

3 Socio-Technical Composition of Urban Infostructures

To illustrate the hybrid character of our subject and derive a framework for analysis, we will draw on the concepts of socio-technical systems (STS) and infostructures. Developed in the fields of history and the sociology of technology, socio-technical systems are of crucial relevance to various strands of sustainability studies (cf. Smith/Stirling/Berkhout 2005; Grin/Rotmans/Schot 2010; van den Bergh/Truffer/Kallis 2011). The starting point of discussions is the recognition that technological innovation can only be understood and explained by accounting for its historical embeddedness in social practice. Socio-technical systems appear to tie together not only technology components, but also a range of actors (individuals and organisations) and their respective cognitive and normative references through specific practices and routines in terms of design, regulation, provision, financing and usage (cf. Cooper/Foster 1971; Bijker/Hughes/Pinch 1987; Basalla 1988).

An *infostructure* represents a particular kind of socio-technical system. It enables multiple usages of networked ICT to create and exchange information, and evolves as a shared, open and heterogeneous configuration, always building upon an existing base, without clear-cut boundaries (Star/Ruhleder 1996: 113; Hanseth/Monteiro 1998: 40). For instance, the ongoing development of spatial data infrastructures (SDI) illustrates this process, although their focus is on *data*, which tends to de-emphasise its actual usage. Nevertheless, spatial data infrastructures have been defined as dynamic partnerships constituted by data, technical standards, access networks, policies and people, with the aim of facilitating and coordinating the exchange and sharing of spatial data among stakeholders at different political and administrative levels (Rajabifard/Feeney/Williamson 2002: 12). Infostructures therefore embrace the conception of spatial data infrastructures, but they also highlight the usage of data in various communities of practice. To specify that, the process of infostructure building is considered here in given places (i.e. cities) while also simplifying terminology, we refer to *urban infostructures*.

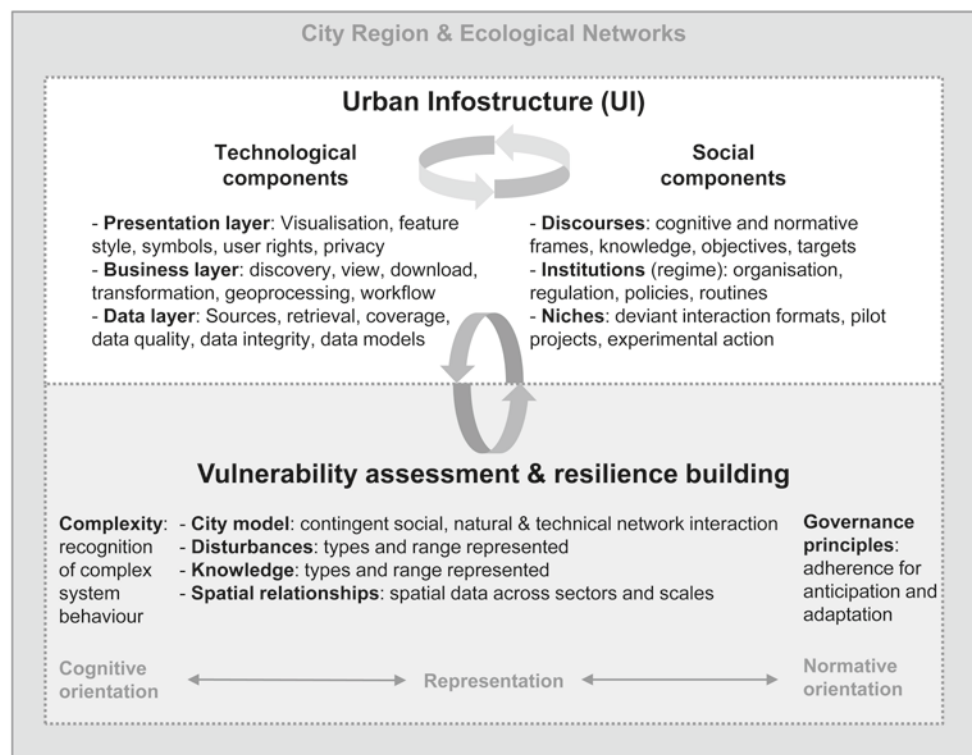
Complex socio-technical systems such as urban infostructures can achieve temporarily stable configurations on the basis of continuous internal adjustment and negotiation. They can therefore provide optimised benefits for all parties involved at a given time. Nonetheless, such regimes tend to become institutionalised and therefore offer strong resistance to external change. In terms of vulnerability and resilience, this represents a major challenge since it would heavily reduce or undermine efforts in terms of both anticipation and adaptation.

Nevertheless, research on the transformation of large-scale socio-technical systems illustrates how short-term innovations and long-term trends can contribute to increasingly de-stabilise an established regime, forcing actors to respond and adapt. Furthermore, positive feedback loops and cumulative effects can create an accelerating dynamic that ultimately leads to a new system configuration, further adjustment of institutional embedding and re-stabilisation (cf. Kemp/Rotmans 2005; Smith/Stirling/Berkhout 2005). Therefore, transforming socio-technical systems requires particular synergies emerging from pressures from above and below. This is not to suggest a hierarchical view, but to point to the need to adopt a multi-level perspective in which the regime is located at the meso-level (Geels 2010). “From above” does, then, refer to the long-term cognitive and normative framing through broader societal discourses at a macro-level. “From below” refers to alternative prac-

tices and divergent behaviour emerging spontaneously in niches and at the level of the individual.

The literature on socio-technical systems thus provides a useful guide for addressing the role of urban infostructures regarding vulnerability assessment and resilience building in cities. In the first place, it draws attention to the interdependencies between different social and technological components that combined form a specific urban infostructure. Whether such systems enhance or curb strategies of anticipation and adaptation is therefore not only conditioned by the technologies employed, but also by local actors and practices dealing with these technologies. Both may affect the representations used (city model, disturbances, knowledge, spatial relations), as well as the incorporation of cognitive (complex behaviour) and normative orientations (governance principles). Second, research on socio-technical systems also identifies the driving factors that can cause a given urban infostructure to transform. This permits an assessment of its overall dynamics and readiness to perform adaptations. The focus is on the knowledge and value orientations that guide local stakeholder actions, and the role of innovative practices that create pressure for changes in the established system configuration. Regarding social components, we therefore focus on discourses, institutions and niches. As for the technical components, we distinguish between a data layer, business layer and presentation layer to reflect a large variety of actual and potential configurations (see Fig. 1).

Fig. 1 Technological and social components of an urban infostructure which affect vulnerability assessment and resilience building



4 Urban Infostructure Technology Options

Urban infostructures comprise hardware and software components provided by local governments, businesses, civil society organisations and also individual citizens (e.g. smart phones). Currently, the spectrum ranges from client-server-architectures with locally installed and proprietary software to more sophisticated hard- and software environments based on a distributed architecture. To address these different technological components, we discuss the possible implications of the data, business, and presentation layers for vulnerability assessment and resilience building in cities.

Across all layers, a basic condition for enabling urban infostructure functionalities and achieving interoperability is the consideration of norms and standards, especially of the International Organization for Standardization (ISO) and the Open Geospatial Consortium (OGC). Although higher level policy initiatives demand the application of these standards (e.g. INSPIRE 2008: 13; GDI-DE 2010: 14), this is not yet common practice at the local level. For example, in Germany only 25 % of the largest cities (above 200.000 inhabitants) currently apply the ISO norm for meta-data, which is, however, a precondition for data discovery and usage. The degree to which norms and standards are adopted locally will, therefore, affect especially city representations and cognitive orientations.

4.1 Data Layer

Data has to be stored constantly to ensure its availability over time. It is structured and described in multiple ways, ranging from simple files to relational databases (de Groot 2005: 925). Files have their own data models, they do not support multi-user access and the stored data may be in inconsistent states. On the contrary, relational database systems work with data models that are independent from the accessing client applications, and they provide mechanisms to ensure data integrity, access control, multi-user access, and creation of data views (Brinkhoff 2008: 7). In addition, spatial properties of real-world phenomena may be stored by specific extensions that offer spatial data types and geometric functions (Malinowski/Zimányi 2008: 134; Brinkhoff 2008: 118 ff.).

The data layer design thus defines the basic ability of an urban infostructure to support data access and geo-referencing, and to incorporate newly retrieved data from various sources. It is the common ground for an interoperable exchange of data across organisational and territorial boundaries, and for recognition of and response to complex and even spontaneous behaviour (e.g. real-time data). An enhanced database allows broader representations of the city (sectoral characteristics, disturbances, knowledge about the place, spatial relations). It is therefore also critical in

terms of data loss, data consistency, and data access (Brinkhoff 2008: 7). The overall vulnerability of this layer itself can be reduced through scheduled backup copies that are stored locally or at additional data replication servers (Erl 2009: 345)—ideally located at urban infostructure network nodes in regions with a different hazard profile. Problems regarding the amount and quality of data (e.g. data gaps) may be solved by geometric functions or through the business or presentation layers, provided that the corresponding know-how is available (see below). Further, redundant data storage would thus be an important contribution, but this requires full transparency and interoperability in data exchange.

Currently, most cities primarily use legacy databases to store data and much data is still stored in proprietary formats only (e.g. excel files). Additional costs are an important factor here. Expenses for server hardware, commercial software licences, staff time, electricity and server location requirements (e.g. secured buildings) need to be calculated for both the primary and backup servers. Furthermore, additional staff training is required for handling new database software. Overall, there is a need to develop more sophisticated domain and data models in cities that would allow the management and storage of all data facets. But this will hardly be achieved on the basis of current legal obligations or cost/benefit considerations.

4.2 Business Layer

Data access and sharing is organised through the business layer. It primarily consists of components for data and knowledge discovery or exploration. Usually, stored and real-time data, as well as stakeholder actions and inputs are processed to accomplish a business goal with a set of business rules. Local client-server-architectures are business layer designs focused on achieving goals only within certain organisational units. Yet, these localized solutions create problems of access and coordination, especially in the case of larger municipalities who perform multiple tasks spanning geographical and organisational boundaries (Binildas/Barai/Caselli 2008: 8 and 12). Here, the combination of data and its interpretation and exploration are less flexible and data exchange is time intensive, but the layers' implementation aligns well with the institutional setting and is therefore straightforward.

In distributed systems like service-oriented architectures (SOA) the business logic is provided by web services via a network. These web services bridge the gap between the data layer's resources and the presentation layer's applications. The SOA approach can improve the efficiency and workflow of an urban infostructure (e.g. INSPIRE 2008: 12; GDI-DE 2010: 15), liberating resources for other tasks. It enables distributed data access, searchability and carto-

graphic visualisations of data. Further enhancements may include incorporating functionality for data interpretation, transaction, and exploration by geoprocessing services or workflow management services (Bernard 2009: 112). However, it requires a rather different implementation approach based on standards and cooperation between a potentially large number of stakeholders and this implies a considerable increase of transaction costs.

Nevertheless, the business layer is key to broaden representation and address sectoral interrelations, especially through data discovery and download services. It equally enables or constrains the incorporation of new knowledge and the development of functional diversity in response to a large variety of user needs. Depending on its openness, flexibility, and modularity, the continuous creation and adaptation of new services could provide a means to: explore and understand complex behaviour through knowledge discovery (modelling, simulation; cf. Müller/Bernard/Vogel 2010), identify vulnerabilities and thresholds and to build adaptive capacity. This could be further enhanced by sensor networks for monitoring urban conditions (Botts/Percivall/Reed et al. 2007: 4) or by coupling spatial web services with e-government services (Schwarzbach/Ment/Bothmer et al. 2009: 20) and Web 2.0 applications. At the same time, the multiplication of use cases based on business layer abilities also affects the vulnerability of the city to failure of required urban infostructure functionality, underlining its role as a critical infrastructure. The reliability and availability of web services may be increased by alternative network solutions (wired, wireless, satellite), but also by redundant implementations (e.g. Erl 2009: 345).

Currently, most cities use local client-server-architectures based on legacy software to different extents, but they increasingly turn towards a SOA business logic, one often running in parallel. Apart from standards and transaction costs, in practice additional operating costs (e.g. maintenance, energy, server locations, backend software licences, web service replications) and knowledge gaps concerning web service administration and parameterization also represent an important barrier here. Furthermore, defining service access rights for internal and external usage confronts stakeholders with difficult questions of information control and transparency that ultimately require a political response, but are often solved at a technical level.

4.3 Presentation Layer

The presentation layer is the interface between stakeholders and the urban infostructure. It consists of client applications that primarily permit access to business layer components. Clients comprise thin and thick clients as well as browser and mobile clients. Thick clients are desktop systems that host software; thin clients are lightweight applications that

focus on the consumption of a web-based business logic (Kumar/Narayan/Ng 2010: 29 ff.). Interaction then commonly occurs via graphical user interfaces (GUI) that support the input of new data and the steering of data retrieval, as well as discovery and exploration.

The presentation layer design may thus have major implications for urban vulnerability identification and resilience building. It enables or constrains the visualisation, perception and interpretation of raw data and it equally affects knowledge incorporation for defining queries, and complexity reduction to prepare human decision making. Furthermore, web-based collaboration platforms can offer interactive functionalities that enable stakeholder dialogue across boundaries and scales. Consequently, the conception of the presentation layer would require close collaboration with all potential users in order to ensure utility and usability, as well as informed decision making. Yet, such processes are also more demanding in terms of knowledge, time and financial resources. In turn, increased and interactive usage of advanced graphical user interfaces also creates a new intrinsic vulnerability in the urban infostructure that can be addressed by offering a diversity of user interfaces and access points, or flexible clients that are able to consume a variety of web service interfaces.

Currently, the use of thin clients, web-based graphical user interfaces and also mobile devices is not common practice in local governments. Hence, in most cases cities employ the readymade graphical user interfaces of thick client applications like GIS for data input and visualisation although this also implies usability losses and higher costs for software licenses and stronger hardware. While the limited use of mobile devices can certainly be explained by the related equipment costs, the inert turn towards thin clients and standardised web service interfaces indicates that there are other factors at play. These will be further explored in the following section.

5 Institutional and Discursive Frameworks of Urban Infostructures in Germany

Having discussed the pertinent technology options for the conception and design of urban infostructures that may affect the identification of vulnerabilities and resilience in cities – and hence to a certain extent vulnerabilities and resilience in cities themselves – we now turn to the principal social system components that interact with these and which are largely place-specific. How local governments are structured and which topics dominate the agendas of the different actors concerned varies not only between countries and regions, but even between neighbouring cities. For empirical reference and illustration, we will thus draw on the results of a recent study of strategies and practices for local spatial data

infrastructure development in Germany. In line with various authors addressing social components of local spatial data infrastructure (cf. Carrera/Ferreira 2007; Geudens/Macharis/Crompvoets et al. 2009; Hansen/Schröder/Hvingel et al. 2011; de Man 2011), this research explored the discursive and institutional settings within which urban infostructures are currently being developed. It was based on an online survey of 180 cities with above 50.000 inhabitants (50 % of the cities responded) and eight selected in-depth case studies (cf. Wolfram 2010a; Wolfram 2011). With a view to opportunities for comparison and transfer from a socio-technical systems perspective the focus here is on three characteristics, namely institutional settings, discourses and niches.

5.1 Institutional Settings and Key Actors

Within local government, the conception, design and development of the overall infostructure is largely driven and managed by three organisational units with complementary roles. In the first place, these are the *IT-departments*, in charge of IT procurement, harmonisation and overall architecture. They are usually located within a larger local government section for cross-departmental tasks, responsible e.g. for work flow, human resources and accounting. Core motives are thus to regulate heterogeneous IT-demands from sectoral departments, to improve the efficiency of business processes and to enhance electronic service delivery in the frame of local e-government strategies and pertinent regulations (e.g. EU Services Directive).

Second, departments which were originally responsible for *surveying and cadastres* play a crucial role. Due to the dynamic evolution of technologies and regulations concerning spatial data, the competencies concentrated in these units have become increasingly important to cross-departmental tasks. Originally responding only to internal demands (of urban planners) and external requests (for cartographic information), surveying units also started to attend to spatial data demands arising from other departments, the need to comply with the INSPIRE directive, as well as the growing expectations of civil society stakeholders regarding spatial data provision. Driven by the respective heads of unit, often autodidacts with a strong personal motivation, these units have thus seen their profile rise. This has, in particular, been achieved through the employment of additional staff (younger geoinformatics experts) and the adoption of new responsibilities under the heading of “geoinformation management”, while the close coordination with IT-departments ensures that SDI technology requirements are effectively met and prioritised. However, while fostering a spatialisation of urban IT, this shift has also underlined an emerging tension between the specific skills of the individuals in charge (mostly trained surveyors), and the actual requirements arising from the new tasks adopted. Further-

more, their organisational assignment to the urban planning department has usually been left unchanged, which tends to undermine coordination and exchange. This problem has been addressed in only a few cities where an inter-departmental SDI/IT unit, or a new independent spatial data agency has been created.

The third key category of actor in urban infostructure development is the external *IT agencies* i.e. public bodies with a private management structure. Their activities were outsourced from local government IT-departments in the 1990s to increase cost-efficiency of technical service provision. Although principally responding to service demands from the IT and surveying departments, these agencies and their staff are particularly important as consultants, providing technical expertise and knowledge in terms of IT and spatial data infrastructure that in turn guides urban infostructure development within local government. Yet, since their guidance is based on a contractual relationship around technology and service solutions, it tends to neglect broader policy implications and strategic orientations. Therefore, in line with their business logic, these agencies contribute to an orientation of urban infostructure development to technological requirements and efficient public service delivery, thus distracting from a wide range of other potential goals.

Whereas the above actors appear to dominate urban infostructure conception, design and implementation within local government, there is the large group of sectoral departments that plays a rather secondary role in this process, although they are the ones (potentially) providing most of the raw data and making practical use of the system. Yet, only some of these departments have actively turned to IT and GIS adoption to fulfil their tasks, especially in the domains of infrastructures, environment, urban planning and economic development (in this order). Initially, they often developed their own “insular” IT solutions, tailored to respective responsibilities and task-specific needs, while being obliged to also use the joint infostructure set up by the IT and surveying departments in parallel (“dual mode”). In turn, many other departments are still largely operating without any enhanced IT support. Furthermore, the IT education of their staff tends to be minimal, often compensated for by internal delegation to a single IT or GIS specialist. As a result, there is a substantial lack of understanding regarding broader technological developments and their possible implications for sectoral tasks, in particular at the level of managerial staff (heads of unit or department).

Hence, we recognise a wide-spread disconnection between sectoral responsibilities for data collection and information usage on the one hand, and centralised responsibilities for IT system rationalisation on the other (Wolfram 2011: 247). This is particularly problematic as there is also little awareness amongst local politicians (mayors, councilors) and thus a lack of political initiatives promoting urban

infrastructure or spatial data infrastructure creation. In Germany, only half of the cities have developed a formal strategy for a local spatial data infrastructure thus far (Wolfram 2010a: 41). In the absence of a strategic policy framework, departments tend to prioritise their own respective duties. This usually implies a considerable potential for conflict as sectoral departments often reject the regulatory approach of the IT and surveying units, perceiving it as an additional obligation that does not fully address their specific needs. Sometimes this even leads to avoidance strategies. However, where the process of urban infrastructure development is driven by an independent agency, the modes of interaction change fundamentally. In these cases, order and instruction are replaced by information, awareness raising, negotiation and consultation, as both sides recognise their mutual dependence (Wolfram 2011: 248).

In terms of stakeholders outside local government, the only key actors are private IT system and software providers, ranging from large multinational companies to small local enterprises. Given the fact that IT or SDI procurement decisions within local government are taken by IT and surveying departments, private sector technology developments and marketing efforts are geared largely towards the cost/benefit criteria of this target group. Furthermore, following a commercial logic, their technology solutions always open up certain possibilities for users, while at the same time closing off others (despite some scope for adaptation to local requirements). This basic market mechanism tends to limit real co-creation of IT-solutions, and, in particular, direct engagement with sectoral departments and other potential users.

To complete the picture, it should be underlined that there are other actors of marginal importance to current urban infrastructure development practices (Wolfram 2010a: 46). This includes in particular bordering municipalities and higher government tiers. Although of crucial importance in enabling multi-scale assessments for a variety of tasks, there are only a few examples of inter-municipal urban infrastructure in Germany at present (3 %). Also civil society still barely plays a role. Citizens and businesses are regularly invoked as important addressees of public services by local governments, but cases of active involvement in urban infrastructure conception and design are rather rare (5–10 %) (Wolfram 2010a: 46).

5.2 Discursive Frames

Given the actor constellation and institutional settings outlined above, it comes as no surprise that current thinking and discussions on spatial data infrastructures and urban infrastructure is moving within rather narrow boundaries. It hardly relates to overall urban policy goals and major urban challenges (such as sustainability, climate change, resource efficiency or social cohesion) that would emphasise more

specific considerations of vulnerability and resilience. Instead, the topic is framed mainly by three interrelated discourses and their respective storylines, focused heavily on efficiency and service quality. Discourse is understood here as a language-based “specific ensemble of ideas, concepts and categorizations that are produced, reproduced and transformed in a particular set of practices and through which meaning is given to physical and social realities” (Hajer 1995: 44; cf. Hajer/Wagenaar 2003).

In the first place, there is a *new public management* discourse. This official doctrine adopted by local governments implies a clear orientation to measurable service outputs and contractual steering of performance. When applied to urban infrastructure development, emphasis is thus put on internal control and reporting linked to legal obligations, reducing the urban infrastructure to a simple management tool (Wolfram 2010a: 51).

Second, there is a broader discourse on *e-government* as a driver for modernising public administration, which also involves system and solution providers from the private sector. Here the role of IT is to enable cost savings, efficient work flows and an improved quality of public service delivery. Starting from a given portfolio of duties and tasks, a more exploratory design and usage of IT is thus not envisaged. In practice, this orientation is well reflected in the priorities local actors set when implementing e-government policies—focusing first on a simple digitalisation of existing routines (cf. Grabow/Siegfried 2006).

Third, reinforced through the INSPIRE process and EC directive, there is a parallel discourse on local *SDI development* involving a multi-level stakeholder community across the public and private sectors. This includes especially environmental policy makers, professional groups, practitioners and technology providers working with spatial data and GIS. Overlap with the discourses sketched above is quite weak here. Local SDI development thus usually represents an independent strand of urban infrastructure design, rather loosely coordinated with e-government policies. Only 20 % of SDI concepts are formally integrated with e-government (Wolfram 2010a: 41). Its core discursive tenets do, however, provide some important new orientations. Most importantly, it highlights the possibility to illuminate spatial relations and link sectoral data through spatial referencing. Furthermore, it specifically connects the role of standards and interoperability to the objective of broader data access and sharing. Thinking in terms of spatial data infrastructures may therefore partly reinforce the above mentioned discourses if it is framed by them i.e. using GIS for realising “spatially-enabled e-government”. Yet, since SDI development also outlines innovation opportunities through data integration across scales and sectors, it implicitly questions the boundaries between stakeholders, including data providers and users both inside and outside local governments. It seems that this

outlook represents a substantial challenge for current “new public management” or “e-government” thinking and has, therefore, found a weak resonance thus far.

Asking officials across departments to identify their specific objectives linked to the usage of spatial data technologies, they prioritise “efficiency” and “competency” of public administration, as well as an “improved public service delivery”. In turn, “good governance” and “urban competitiveness” are regarded as far less important (Wolfram 2010a: 52). The infostructure and information services devised are therefore not only limited in terms of territorial coverage (municipality) but are also conceived mainly for internal use by city departments. Data access is therefore largely restricted to the intranet, and sometimes even limited within local government where significant differences exist between departments. Also public information services remain limited in data scope and depth if compared to the actual availability of non-sensitive data (privacy, confidentiality). Nevertheless, examples exist where local actors have opted for more open urban infostructure developments, enabling inter-municipal exchange, data-rich public information services, as well as direct stakeholder interaction, thus proving the feasibility of alternative pathways (Wolfram 2010b: 49).

With a view to the leading individuals in this process, we have already acknowledged a biased view implied by their respective specialist education. In terms of discursive evolution, this effect is further intensified by common practices of knowledge acquisition. Regarding the principal knowledge sources used for obtaining guidance and orientation in SDI development, actors refer to professional training and conferences organised by software and solution providers, to professional journals and peer-to-peer exchange through city networks and partnerships. In short, they reference sources that basically reproduce the SDI discourse, but have little to offer regarding its relative isolation in terms of urban infostructure development. This is particularly critical since the same actors identify the availability of know-how (in terms of technology *and* organisation) as a key driver for SDI development (78 %) (Wolfram 2010a: 39). Furthermore, neither cross-scale exchanges with upper government tiers (except for city-states) nor a more thorough engagement with civil society are sought. In particular, opportunities for knowledge transfers with local scientific organisations (universities, research institutes) are neglected, even though in cases where this has happened it has been particularly fruitful for changing the path of urban infostructure development (Wolfram 2011: 250).

Ultimately, then, opinions and preferences regarding urban infostructure conception and design are formed, and decisions for implementation taken, within the local actor triangle between IT departments, surveying departments (geoinformation management) and IT agencies. Even if formal decisions may sometimes require the involvement of

other actors (especially sectoral departments), this strong interest coalition draws on shared beliefs and “speaks the same language”, so that individual positions are strengthened by creating a broader legitimacy. This shapes an effective implementation network that ensures regulatory power and enforcement, harmonised system procurement and interoperability as well as budgetary coverage. However, it remains largely insensitive to contexts of usage.

5.3 Niches and Experimental Practices

While the above analysis of the present regime in Germany suggests a rather static picture of institutions and discourses around urban infostructure, there are also initiatives that aim to modify this setting, or to find ways of dealing with it in order to implement novel urban infostructure components. The most widespread example of this is the intermediary boards and committees newly created to enable coordination between those stakeholders considered to be relevant. Substantial differences exist, however, regarding the constitution, remit and objectives of such interaction forms. In some cities, they represent mainly a tool for harmonisation of data and systems, thus extending the control of the IT and geoinformation departments over sectoral data providers and users within local government. Yet, in some cases such forums are also used to open up a broader debate about urban infostructure by involving civil society stakeholders (e.g. chambers of commerce, academia). Here typical objectives are to identify and develop new usages addressing key policy goals, or to simply create a more competitive business location. Therefore, depending on the legitimacy provided, the types of knowledge incorporated and the transfer opportunities created, new forms of interaction can influence the direction of urban infostructure design and implementation processes significantly.

Pilot projects represent the second important mechanism that enables experimentation and innovation. Pilot projects create temporary structures of management and cooperation between a variety of stakeholders including regulators, data owners, end users and technology experts. They concentrate resources for the realisation of a certain urban infostructure use cases in a given timeframe, sometimes even across sectors. All parties involved in such projects confirm that they function as catalysts for knowledge transfers and learning at the individual and organisational levels and may even create momentum for a durable adaptation of routines. Nevertheless, this presupposes a strategic framework that makes sense of the single project in a long-term and multi-level perspective, while also ensuring targeted feedback. Unfortunately, local governments usually lack such a framework, so that most pilots remain singularities of “creative tinkering” with little to no impact on future behaviour (Wolfram 2011: 247).

6 Conclusions: Towards Integrated Approaches for Urban Infostructure Governance and Design

Regarding the range of technology options and the specific characteristics of the local actor constellations dealing with them, it appears that current practices of urban infostructure development and implementation diverge substantially in terms of their capacity to address fully vulnerabilities and resilience in cities. This can be discerned in all aspects identified as relevant for this purpose i.e. concerning representation (city model, disturbances, knowledge, spatial relationships) as well as cognitive and normative orientation (complex behaviour, governance principles). In this sense, the following key conditions and mechanisms that create strong path dependencies for urban infostructure evolution should be highlighted:

- Legacy systems: Urban infostructure development has to deal with technology designs that often reflect a different if not fundamentally reverse orientation, created over several decades i.e. isolated data silos, linear processing, limited number of highly specialised use cases, etc.
- Local actor networks and coalitions: Control over urban infostructure development is exercised by particular actor networks and individuals in charge of local IT adoption. In turn, a large number of stakeholders are either not involved at all or play a rather passive role as recipients of information services.
- Dominant discourses: Urban infostructure development is framed largely by arguments that centre on using IT for optimisation of the existing regime and practices, whereas innovation and learning are hardly addressed. Moreover, urban infostructures are not linked directly to the key sustainability challenges cities are facing.

Nevertheless, we also recognise that there is a wide range of technological solutions available that increasingly allow vulnerability and resilience considerations to be built into an urban infostructure. Moreover, in some cases niche practices have shown the existing potential for triggering changes. Against this backdrop, one could envisage future approaches to urban infostructure conception and design that allow these limitations and opportunities to be addressed in an integrated manner. In this, “resilience” could certainly provide a normative orientation, but it could equally serve as a boundary object that helps to connect the perspectives of a variety of stakeholders from the initial idea of a new application or use case to its implementation and appropriation. With a view to the specific characteristics and dynamics of socio-technical systems, future urban infostructure development approaches should thus include the following basic features:

Strategic Cooperation and Exchange Between Stakeholders Urban infostructure development should be regarded as a social process or major transdisciplinary project. Therefore collaboration should occur not only within local government, involving all sectoral departments, but also across territorial boundaries (city regions) and, in particular, with civil society. Such cooperation and exchange should fulfil a number of cognitive, social and governance functions in parallel. It should enable stakeholders to transfer knowledge on problems and visions, obtain cross-scale and cross-domain understanding of barriers and drivers, create a strategy to take immediate actions and thereby develop a shared discourse for orientation. In particular, this could be linked to a broader trend in public policy discourse around new forms of societal decision making, following the shift from government to governance. Emphasising networked deliberation and joint-learning could thus also provide integrated urban infostructure development with a different purpose and source of legitimacy (de Man 2011). An example of a concrete methodology for this task is the *transition arena* approach that aims to provide a free space for thinking in order to escape the regime logic and promote alternatives (Rotmans/Loorbach 2008). Arenas are thus constituted through careful selection of autonomous and progressive individuals, focusing more on innovation capacity and less on balanced interest representation. Correspondingly, independent intermediaries such as universities or associations can also play a crucial role here (Hodson/Marvin 2010).

Open Innovation for Designing Use Cases Urban infostructure development needs to recognise that future uses and problems cannot be completely anticipated in the design phase of a system. However, if users are supported in adopting an active role as contributors, control becomes increasingly distributed among all stakeholders in the design process. Such a “culture of participation” would put the owners of problems in charge and let them define how technical systems are used (Fischer/Herrmann 2011: 2). Moreover, despite the dependence of the upper layers on the data layer and the focus on data introduced by the SDI concept, more emphasis needs to be placed on actual data usage, ultimately enabled by the business and presentation layers. As in prototypical development (Kleuker 2011: 27 f.), this requires bringing end user functionality and requirements analysis closer together by providing basic structures and building blocks early on in the design process. This facilitates tailorability, customisation and user-driven adaptability. In technical terms, such a process of “seeding, evolutionary growth, and reseeded” (Fischer/Ostwald 2002) could be supported by Computer-Aided Software Engineering (CASE) tools, which offer e.g. comprehensive graphical modelling and design tools, as well as code engineering mechanisms, and thereby allow full traceability

from requirements to deployment. Some CASE tools can be plugged into Integrated Development Environments (IDE). These may, for instance, enable “refactoring” to restructure the source code and to ease its reusability or “round-trip engineering” to synchronise class diagram representations with the source code (Kleuker 2011: 120 f. and 232). Both mechanisms are helpful to adapt the software e.g. in the case of changing requirements. Furthermore, GUI builders are also available for Integrated Development Environments to ease the discussions between developers and stakeholders regarding front end design. The focus should be on cross-departmental and cross-stakeholder use cases to reflect interrelations between social, natural and technical networks, as well as different types of pressures and risks. Such pilots would enhance the incorporation of different types of knowledge and a gradual extension of the data layer, as well as a more dynamic creation of new functionalities in support of anticipation and adaptation.

Contingency, Reflexivity and Self-Organisation In order to turn learning and adaptation into routine activities, urban infostructure development approaches need to be particularly sensitive to the contingent character of cities as places; i.e. time and space-specific manifestations of complex network interrelations. Attempts to replicate certain model solutions and use cases that (at least claim to) represent “good practice” elsewhere should be avoided. Rather, a sensitivity to local particularity, variability and uncertainty is crucial to enhance transparent and collective processes of vulnerability assessment and resilience building. Contingency should, therefore, not only inform the above mentioned approaches to strategic cooperation and open use case design but also complementary process activities. It should be integral to the overall urban infostructure functionalities implemented on the business and presentation layers. In terms of process, this requires ensuring continuous stakeholder feedback through monitoring and external evaluation of the design process and pilot projects. The more open and distributed the system becomes, the more important it will be to reflect changes in the local system structure and environment. This will help actors to respond and reorganise the urban infostructure, perhaps even spontaneously. Regarding technology components, this could be underpinned by geo-computation methods that cover spatial artificial intelligence techniques such as evolutionary algorithms, genetic programming, artificial neural networks, cellular automata or fuzzy systems (Malczewski 2004: 37).

Clearly, there is considerable room for manoeuvre when approaching integrated urban infostructure development. As local stakeholders’ initial capacity to exploit this space differs greatly from city to city due to knowledge and resource disparities as well as cultural differences, the divergence between local urban infostructure impacts on urban vul-

nerabilities and resilience are likely to increase rather than diminish. While some will see their adaptive and transformative capabilities enhanced, others may suffer significant setbacks as the urban infostructure itself turns into a structural weakness. Therefore, conceiving of urban infostructure as a hybrid socio-technical system may contribute to the emergence of a more reflexive approach to their governance and design.

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