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Urban Resilience Thinking. Dealing with Epistemic Uncertainty in Smart City Development

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1 ABSTRACT

The term resilience is used in various contexts where it is mostly considered within the boundaries of the system under consideration. Relevance of resilience thinking is emphasized in the UN Sustainable Development Goals– especially Sustainable Cities and Communities and Climate Action– and the UN Sendai Framework for Disaster Risk Reduction, which explicitly mentions resilience as a keypriority. Thus, resilience and system transformations must be considered together if sustainability developments should prevail in the long-term.

We propose Urban Resilience Thinkingas a design approach that sensitizes for transformational dynamics on different temporal scales from the short-term to thelong-term, for relations between physical resilience and socio-cultural issues of urban well-being, and for interdependencies between local urban resilience and global sustainability. Crucial to Urban Resilience Thinking is the consideration of potential multiple stable states in urban socio-technical systems, which poses questions with regard to dynamics of transformation between stable states, but also – more fundamentally – with regard to the criteria and values that define notions of systemic stability, risk and resilience.

In a world of changing boundary conditions (e.g. climate change) and fundamentally changing socio-technical urban systems, neither the frequency nor the consequences of various future risks can be reliably determined. This can be illustrated by the unpredictability of future urban supply risks, e.g. power supply, in smart cities with increasingly digitalized, automated and more interconnected services systems including critical services. Adding to such looming epistemic uncertainty we point to the phenomenon of creeping urban risks, such as risks associated with the built up of smart urban infrastructure, which are likely to shapefuture urban risk cultures through citizens' gradual accommodation to emergent risks. Eventually, and in spite of short-term reactions to immediate risks in smart cities, it is creeping urban risks that deserve more research attention.

Keywords: socio-technical systems, Smart City, resilience thinking, smart grid, urban risk cultures

2 URBAN RESILIENCE THINKING

For cities and urban development, the concept of resilience is presently gaining increasing importance as an approach to answer challenges of climate change and associated future urban risks and uncertainties on interrelated levels and subsystems of urban socio-technical organization. However, we should not take resilience as a simple and straight forward concept, but rather consider it in a critical and reflexive manner. The aim is not to implement resilience, but rather to use the concept as a thinking tool for sustainable urban planning and development.

2.1 From Single Equilibrium to Multiple Stable States

The origins of the concept of resilience are contested. It was already in use in psychology as early as the 1940s in reference to vulnerable individuals' and groups' capacities to deal withthe negative effects of adverse life events. Other disciplines such as physics, material sciences, and engineering have also been using the termsince the 1960s and 1970s, for example to characterize the endurance of materials in response to physical stress such as pressure or deformation. As Béné and Doyen (2018)note, around the 1960s ecologists then picked up the concept and started to use it to describe properties of ecosystem dynamics around equilibria, defining resilience, for example, as "a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist"(Holling 1973, p. 17).

Over the past two decades, the concept of 'resilience' has become increasingly important in systems thinking for studying transformative dynamics and the reactions to them within biological, environmental, technological, or social systems. In such disparate systemic considerations resilience approaches have been addressing a general problem of earlier single equilibrium approaches. According to the latter, systems develop around ahomeostaticstate, which gets exposed to negative and positive, destabilizing and re-stabilizingimpacts. According to such homeostatic understandings the functionality and durability, or the degradation and eventual collapse, of a system, or of a complex of interrelated and interdependent systems, is defined by the possibilities of regaining equlibrium after a destabilizing event has occurred.

By contrast, the concept of resilience, considers systems as defined bymultiple stable statesin which systemic dynamics may cause fluctuations between such states. Unbalancing of one stable state, therefore, not necessarily leads to collapse, but may cause systemic transformation into a different stable state. For ecosystems, for example, "this idea stemmed from observations that variability, disturbance and unpredictability are not exceptions that ecological dynamics strive to redress, but rather are the underlying rules for bio-physical dynamics" (Cote and Nightingale 2012, p. 476). With this shift,socio-political agendas and scientific approaches of how to deal with systemic forces of change diverge quite fundamentally: from the modernistic attempt to identify control functions that would allow to maintain, or return to, a single equilibrium state to resilience capacities emphasize adaptation capacities to the changing conditions of multiple stable states and to in-between transititional phases.

2.2 Towards Critical and Reflexive Urban Resilience Thinking

The term resilience has gained considerable influence on urban planning and design for smart cities(Carvalho 2015), it is present in public and media discourses, and it is excercisingmounting influence on institutional development and funding programs for scientific research, it is being applied to aspects of urban design, to legislation and administration, and it turns into an object even of moral and philosophical propositions. Resilience is thereby presently turning into what Michel Foucault (1980, p. 194) once termed an 'apparatus' (sometimes translated also as dispositif), i.e. a formation or network between the elements of discourses, practices, objects, laws etc. "that at a given historical moment has as its major function the response to an urgency." The notion of apparatus may help to develop a reflexive approach in resilience thinking that wards off potential pitfalls of ideological, normative and other biases.

With a view to its societal and political consequences, the concept of resilience has been criticized on at least three accounts. From a modernist stance it is criticized that the adaptive emphasis of the mode of governance that rises from the resilience apparatus de-politicizes adverse conditions by emphasizing the "naturalness of nature", thereby turning the ideological construction of nature into an "object and means of government" (Braun 2014, p. 60). What is more, from the viewpoint of social justice and equal opportunities it has been noted that resilience politics may cause an inappropriate deferrence of responsibility from the realm of politics to individual citizens. Whereas the social welfare state used to be accountable to provide for a population's well-being and access to basic services, resilience measures may focus ever strongly on fostering the capacities of individuals to operate under adverse conditions. And from a critique of neoliberal market practices it has been pointed to how resilience measures seem to develop in ever closer alliance with technology focused solutions for societal problems by succeeding to leverage "governmentally sanctioned infrastructure funding and legal mechanisms to ensure large-scale, low-risk private investments" (Adams 2014, p. 134).

However, clear advantages and critical potential of thinking with the concept of resilience lie in its recognition of presuming the existence of multiple stable system states and insisting therefore on change and transformation as rule rather than exception. Thisbuilds on a historically informed perspective of the longue durée. The continuity of citiesas forms of human settlement with specific functions for their larger reproducing systems with respective ecological, economical, political and cultural dimensions can be considered as evolving on the basis of a number of core characteristics over the past several hundred, or even several thousand years (Frank and Gills 1993). While such macro-historic approaches are debatable and come with their own pitfalls, they shed light on the value-laden and normative impregnation of any attempt at defining a given historical stable state as single, or 'natural'. The historical perspective and the multiple stable states approach, therefore, politicize the concept of resilience by urging questions such as "To whose benefit is this a stable state?", "How and why are alternatives available, or being foreclosed?" "What is to be gained and lost by whom, if forces of transformation are pushed or restrained?"

One need not go into the depths of milleniato bringto underscore that no single equilibrium exists in socio-technical systems. If history tells anything,notions of stability and transformation are a question of scales and temporalities. Cities, in partiuclar, may be conditioned for centuries by their geological settings and long-term physical infrastructure, within which other areas of social, political and cultural life change at medium rhythm, and yet other domains, such as technological innovation, enforce change at ever quickening pace. Approaching urban transformation through the lense of resilience thinking, therefore, gains additional bearing when considering the linkages and interactions between sectoral (environmental, technical, social, cultural etc.)subsystems in terms of social-ecological systems(Berkes and Folke 2002; Folke 2006), or socio-technical systems(Hughes 1990; Pfaffenberger 1988, 1992), and when considering the different temporalities involved in respective dynamics.

Urban resilience thinking, then, has to deal with the absence of definite knowledge about the direction of systemic change, and withan awareness of the impossibility to infer potential future stable system states from the system's history. This raises a set of hoary challenges of not only epistemic, but social and political nature, concerning the definition and representation of societal problems and the distribution of limited social resources to adress them. After all, calls for resilience and resilience measures pose the question: Stable states for whom, and consequently resilience for whom? And at what level? And what arethe objectives of resilience? A plethora of examples from urban contexts can show how what is resilient, or sustainable, in one sector, may have negative impact on sustainability and resilience of another sector, or level, or of the system as a whole.

3 RESILIENCE OF FUTURE URBAN ENERGY SUPPLIES

Uncertainties and risk of future urban energy supply systems that we address here through resilience thinking fall out of established categoriesof risk management. Uncertainties to which resilience thinking can be appliedare epistemic in the sense that scientists either have no single explanatory model or even several competing theories about their future manifestation(Snowden 2002).

3.1 The Temporalities of Epistemic Uncertainty

Expected lifecycles for technological innovation on the level of new urban infrastructure, such as smart distributed and renewable urban energy systems, face temporalities of almost inconsiderable scale whereunknown future boundary conditions of urban systemslead to epistemic uncertainties, because the future stable states of highly integrated socio-technical systems of urban technologies escape reasonable quantification or qualitiative description. In the case of smart distributed and renewable energy systems, quantitative and qualtitative epistemic uncertainties derive from a lack of knowledge about changing boundary conditions, like climate change, from ignorance aboutfuture use-patterns for yet to be invented power-consuming technologies and their dissimination, from the impossibility to forecast more abstract hazards produced by complex and integrated future socio-technical systems (Snowden 2002), or from uncertainty about ethics, values, or political struggles that will be associated with energy in the future.What is more, energy scenario based approximation is bound to decrease with expanding time spans, as is impressively demonstrated by millenial scenarios of future nuclear waste disposals (Ialenti 2020).Historically and conceptually informed in this way, resilience thinking needs to consider risk and vulnerability not as quantitative values, but as "collective constructs" (Douglas and Wildavsky 2010, p. 186). The notion of multiple stable states and the importance given to considering stability and transformation across different temporalities emphasizeshow urban risk and vulnerabilty, for example related to black outs of urban energy supply systems, actually depend on the perception and reception of society and therefore reflect cultural specificity and are susceptible to change(Kubicek et al. 2013; Mohun 2016).

3.2 Resilience Thinking and Systemic Considerations about Urban Risk Mitigation

Ottenburger et al. (2020) suggest that beyond technical and economic aspects, systemic risk perspectives need to contribute to smart grid planning and operation. Here, statistical probabilities of occurrence are complemented by considerations about socio-technical impacts of disrupted (critical) services on urban populations. Principles from resilience research, such as elasticity in the design and operation of technical systems as well as forms of non-digital urban self-coping capacities must be more strongly integrated into future risk mitigation considerations.And with regard to the adaptive capacities of urban societies,Kropp et al. (2021) suggest that socio-technical impacts ask for socio-technical answers in terms of urban social and cultural innovation.

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Such innovative considerations clearly show the limitations of accustomed classification of urban risks into cateogries ofHigh Probability Low Impact (HPLI) and Low Probability High Impact (LPHI)which broadly rely on technical answers to events in both risk categories within the scope of sectoral containment of risk. In contrast to Reliability Engineering, which is mostly concerned with HPLI risks,Resilience Engineering is concerned with LPHI risks. The key thesis in our resilience thinking approach, therefore, is: if systems of urban critical infrastructures converge and become increasingly meshed, for example in urban smart grids, thus leading to a rising amount of potential cascades, the handling of smart urban risks, which can eventually produce high damages (high impact risks), must become an essential aspect in the development of resilient socio-technical systems.

4 CREEPING HIGH IMPACTRISKS IN LONG-TERM SYSTEMIC EVOLUTION

Creeping risks develop over longer time scales. They build up through a quite paradoxical social mechanism that involves, on the one hand, the gradual, and often unnoticed, accumulation of changes in urban everyday life, and, on the other hand, the gradual, and often unnoticed, accommodation to such changes. We will discuss the former with regard to the risk driving phenomenon of massification and the latter with regard to the risk driving phenomenon of accommodation.

4.1 "Massification"

In our terms, massification refers to supply risks resulting from an unrestrained multiplication ofmarket participants and consumers, and of interconnected technical objects, for example in smart homes, smart vehicles etc. Unrestricted multiplication of smart devices and use frequency is bound to translate into unforeseen feedback loops when reaching the limits of an expandable, but eventually finite physical environment of the technological infrastructure. It may therfore causea creeping deterioration in service performance and quality of life. Massification, therefore,unfolds from a sublime and initial stage with risks that are hard to assess or even address, to noticable and later impending drawbacks on the quality of services, on quality of urban life and eventually system disintegration whichmay leadeither to increasedmitigation efforts or, indeed, to risk cultures of accommodation.

One example to illustrate this dynamic in the context of urban smart grids is the largely unexperienced, but often favourably discussed concept ofdemand side management (DSM). Itaims at dealing with supply limits or physical system limits through price signal-oriented mechanisms, peak shaving, or nudging. However, besides opening the possibility for price manipulations (Li and Han 2011), DSM may prove incompatible with the paradigm of consumer rights and liberal markets. Or it may exploit social digital divides by economically prioritizing distribution in times of power scarcity, instead of maintaining fair power distribution (Ottenburger et al. 2020).

Going beyond such sectoral solutions, a systemic and resilient handling of future urban high impact risks should consider massification as an evolving socio-technical risk driving force. This need is illustrated by urban heat island phenomena due to climate change, which will likely cause extended use of existing and addition of new air conditioning units that may stretch urban renewable power demand beyond supply capacities (Radhi and Sharples 2013; Santamouris 2014). With urban heat rising over the coming decades, DSM solutions for grid stability may fail as the need to cool private homes and offices overrules price incentives. And even if the overall power demand can be satisfied in an economic sense, capacities of the urban distribution grid might physically fail to supply power, leading to local blackouts on the low or medium voltage level. This consideration of 'fairness' in power allocation brings urban resilience thinking full circle to the political, normative and value-laden baggage of notions as stable system states.

4.2 "'Accommodation"

Some risk mitigating technologies maycreate the paradoxical effect of producing new risks (Jablonowski 2007, p. 123; Büscher and Mascareño 2014, p. 71). Risk driving effects of massification thus cause a paradoxical space for future risk culture between, on the one side, the normative vision of smart urban technology as guarantor for efficiency, improvement and urban well-being (Raimi and Carrico 2016), and, on the other side, likely drawbacks, new risks and risk cultures of accommodation. The paradoxical situation "in which the condition of possibility is also the condition of impossibility" (Kessler and Daase 2008, p. 212) also seems to apply to the relation between risk mitigating smart technology and the risk driving dynamic of ensuing massification in urban smart grids.

From an urban planning perspective the paradox of, on the one hand, intended improvements and risk mitigation, and, on the other hand, improvements accompanied by drawbacks and new risks is usually treated in terms of the social acceptance and ethical acceptability of risks created by innovative technologies (Taebi 2017). Acceptance and acceptability approaches require a prospective awareness of future risks in question. However, future risks often cannot be foreseen, or awareness of potential risks does not become part of a wider public debate that would allow treating them socially and politically in terms of acceptability and acceptance. Instead, for risks that emerge paradoxically in parallel with expected improvements there is the evident danger of creeping accommodation to gradually routinized risks. Accommodation to risk proceeds along the standard pattern of organizational behavior where “past successes contribute to the persistence of a given path of action through focusing on the same strategies”, thus leading to a “path of convergence which diminishes awareness of important forces of divergence” (Cunha and Putnam 2019, p. 95). As emergent risks rarely show their fully-fledged potentials creeping accommodation, latency and suspended salience to new risks reign supreme. Indeed, accommodation to risk can be understood as a “process of learning and routinizing [that] is positioned on the level of individual experiences of risk-taking.” (Zinn 2020, p. 102) As Levitas (2000, p. 203) shows, monetary compensations for taking risks, for example through insurance, can lead to risk accommodation, but compensations for risk taking are also offered on more mundane and less institutionalized levels: many risks are accommodated into everyday behavior against rational consideration, for example for the sake of comfort and efficiency.

4.3 A historical analogy

The effects of massification and accommodation with regard to high impact economic and health risks become evident if we draw on a well-known analogy between the historical example of the advance of individual motorized mobility in the car-friendly city and the advance of smart grids in the computer-friendly city. In Germany, the intra and inter urban road system has increased massively over the past century. To take one example, the highway system today is about five times as long as it used to be in the 1960s, and even if we consider added highway width to compensate for the increase of registered passenger cars up to the present by factor ten, we must still acknowledge that through dynamics ofmassification in terms of use frequency the length of reported traffic jams has increased by a factor well over 50.000! This dynamic of massification in traffic, combined with rigorous expansion of road space into agricultural, natural and recreational spaces within and without cities, has turned into a drama of densification, intensification and system overload within a finite physical system. With hindsight one can say that while no one was able to foresee the risk of massification at the inception of the modern German road system, with progressive systemic evolution individual motorized mobility creepingly has turned into a non-negligible risk and today manifests as a high impact risk threatening the quality of life of many people who suffer from traffic stress, congestions, and waiting times, not to speak of environmental degradations, injuries and casualties caused by accidents or health issues due to air and noise pollution (Moore et al. 2003). Paradoxically, the forces of creeping accommodation still obscure this evident risk trajectory.

If we reason by analogy the above example creates a sombre prospect about potential effects of massification on smart urban grids, where an apparent necessity may involuntarily create considerable risks:In order to combat global climate change cities as major emitters of CO2 must seek transition to renewable energy sources, which will necessitate a new system of innumerable small and distributed (private) electricity producers that are coordinated by smart meters asnecessary system components for load balancing in urban smart grids under conditions of diverse, distributed and fluctuating power provision. However, their stabilizing effect on the level of infrastructure is compromised bynew security threats(Singh et al. 2020)they open the gate to risk driving effects of massification through innumerable market participants and consumers who put to use smart auxiliary appliances on secondary, tertiary and further levels of urban socio-technical systems.In more abstract terms, the historical analogy of the car-friendly city and the computer-friendly city demonstrates how massification in combination with accommodation leads to high impact risks as the system load surpasses certain physical and socio-cultural system capacities.

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5 CONCLUSION

By including the notion of multiple system states and the notion of dynamic and transformation accross different temporalities, extending from the longue durée of the evolution of urban socio-technical systems to the micro-seconds of urban smart grid management, urban resilience thinking draws attention to the normative and value-laden nature of any the conception of 'stable system states'.For dealing with future stable states of urban socio-technical systems it has therefore become evident that with regard to epistemic uncertaintyno authoritative quantitative estimates can be given on the probability, frequency, or impact of future urban energy supply risks. This, in turn, leads to the conclusion that decisions aboutthe allocation of present-day social resources to future problems are bound to be marked by the imprints of contemporary political contestations. The qualities of future risk cultures are quite impossible to foresee, but a larger societal debate on potential paradoxes, drawbacks and conditions of emergence for urban smart risks should not be barred by creeping accommodation to risk.

From the perspective of prospective resilience thinking the socio-technical framing of the conditions of emergence of the future requires not only social aspects to be integrated into technical systems, but also an increased attention to building a diversity of complementary and parallel non-technological and non-digital coping capacities, for example neighborhood energy storage systems (Ottenburger and Ufer 2019), or locally rooted systems of solidarity and mutual support (Ufer 2018). Building resilient structures in smart citiesthat can answer to urban transformations with multiple conceivable and presently unconeivable future stable states, therefore, should aim at enhancing socio-technical resilience and socio-cultural innovation.

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