Contribution to the Knowledge Development for Smart Cities

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Abstract

The complexity inherent to cities and urban systems is the core challenge in the attempts to measure their "smartness". Numerous debates about Smart Cities reveal opinions split among scientific groups, stakeholders and urban actors, all competing for the Smart City idea. The debate about the direction towards which cities should develop is as persistent as the magnitude of the impact that the on-going, worldwide urbanisation has on the environment and quality of life. Despite the different viewpoints regarding components defining a Smart City, there seems to be consensus on the need for urgent transformation beyond a simple reproduction of state-of-the-art. To achieve this transformation, an in-depth understanding of the existing and potential interactions between the urban energy systems and their context is required for effective solutions containing the prospect of fitting the complex nature of urban environments. "Making" a Smart City is an attempt to embed new concepts, processes, and technologies coupling specific knowledge with specific actions in the first place. However, it also raises difficult questions. Taking a wider urban context as an argumentative background, this article navigates between the inconsistencies in definitions of

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Smart City and development concepts in search for answers and approaches that would be capable to disentangle the complex and interlinked urban networks, systems, and respective forces in play. The article highlights the ambiguous relationship between the individually framed technological development and its urban context, exposed by specific Austrian examples that provide an insight into concrete challenges, barriers and solutions. Finally, the article proposes to explore the Smart City as a relational system between concepts, technologies and processes that reflect on the importance of knowledge exchange in a multi-layered urban set-up.

Keywords
Urbanisation · Energy · Progress · Smart City · Knowledge · Complexity

1 Urbanisation and City Labels

The proportion of world's inhabitants living in urban agglomerations is increasing rapidly. This inexorable speed of urban development presents many challenges and opportunities at the same time placing "the city" into the centre of attention. Composed of people, ideas, businesses, culture, buildings, public places and infrastructure, cities function as innovation hubs and multi-minded, complex systems. Cities enable a dense concentration of activities and contain an inherent talent to spark new ideas and technological breakthroughs. The access to a quick exchange of information and knowledge paired with the availability of human capital in cities form the essential ingredients for urban success (Glaeser 2011). This, in turn, feeds the dynamics of urban transformation and reinvention. However, cities are also notorious for their steadily growing appetite for energy, increasingly negative impact on the environment and being the focal point of conflicting interests. According to UN-Habitat, the world's cities emit 70 % of the global CO_2, while covering 2 % of its surface (United Nations Human Settlements Programme 2011). The increasing urban hunger for energy has been recorded in numerous reports and expressed by facts and figures (Larsen et al. 2011; United Nations Human Settlements Programme 2011). Balancing between growth and sustainability, consumption habits and available resources, climate change and urban resilience are ever more becoming the focal challenges of the 21st century.

Thus, it is no surprise that a number of concepts and ideas have emerged in the past few decades, centered on the topic of the city and presenting "the city as its own solution" (Davis 2011). These concepts carry a broad variety of labels: the e-Topia (Mitchell 1999), the intelligent city (Komninos 2002), the electric city (Conference 2012; Urban Age Electric City), the green city (My Green City 2011), the post oil city (ARCH+ 2011), the resilient city (Balbo et al. 2012), the Smart City (Mitchell 1999; Hollands 2008), the instant city (Wright 2008), etc. While the concepts behind each of the listed city labels present different connotations, topics, aims, and disciplines, they share a common suggestion that urban transformation is taking place and a significant change is both inevitable and necessary. The common sense complements various development initiatives, road maps, strategies and research telling the vital urgency of the transformation of urbanity towards a human habitat more compatible with the environment. At the same time, we cannot neglect the fact that the actual underpinning of these concepts with a critical mass of implemented examples, qualified enough to claim the status of “smart”, “intelligent”, “resilient” or “green” are still a relative rarity. Among the named concepts, the Smart City is currently one of the most dominant (e.g. research calls of the European Commission, national and international stakeholder platforms), partly because the related ideas provide huge market opportunities for companies active in infrastructure, information and communication services and technologies. Critical awareness about the self-acclaimed success that Smart City labels can entail leads towards search for knowledge-based and contested proof that the claimed success is indeed being lived. The factor making the proof even more complicated is the lack of a consistent Smart City definition.

2 Between Smart Cities and Smart City Definitions

In search for a reliable Smart City definition one gets swamped by numerous examples of Smart Cities, from Cairo, to Dubai, Vienna, Southampton and Yokohama, to name only a few. The range of cities, claiming the status of “smart” is as varied, as its definitions. The most common definition stresses the significance of the digital development, centred on the role of Information and Communication Technologies (ICT): “this all-encompassing digital system will create new linkages between cities and within cities” (Mitchell 1999, p. 19). The legitimacy of purely technological “hardwired” (Paskaleva 2009) urban progress has been questioned by some scholars (Hollands 2008) and since expanded to a broader definition of a Smart City. One of the most cited European projects (Giffinger et al. 2007) offers a Smart City definition encompassing smart economy, smart governance, smart mobility, smart environment, smart living and smart people. This definition overlaps with Paskaleva’s view that Smart Cities are people-based, human and progressive in their deployment of digital technologies. With its Smart Cities and Communities Initiative launched in 2010, the European Commission has placed the focus of Smart Cities on the development and demonstration of urban energy efficiency, low carbon technologies, energy security while linking them with socio-economic advantages, quality of life, local employment and business and citizen empowerment (setis.ec.europa.eu 2012). This point of view is also shared by Saringer-Bory et al. (2012) when trying to define the crucial research questions to be addressed in Smart City development. It is this definition that the following sections of the article reflect upon, while focusing on the complexity of urban energy systems, their relationship with the urban context and the role of knowledge within. According to this definition, Smart City is not only intelligent, but also integrative, linked, efficient, effective, adaptive and attractive.

3 Complexity of Urban Energy Systems

One of the major challenges in adapting urban energy systems to present and future needs is the high level of complexity they entail. This complexity is mainly caused by simultaneous presence of different energy vectors available within a city: electricity, gas, heat and cold, and the related energy infrastructures for conversion, storage, and distribution. Multi-layered factors determine the performance of these integrated energy systems:

- an increasing share of distributed non-controllable and fluctuating energy sources (including renewables like solar or wind energy) beside traditional centralised generation plants,
- the variety of consumers (residential and non-residential buildings, industries, mobility services) who more than ever could play an active role in the energy system (via e.g. on-site renewable energy production, waste heat availability, demand side management),
- energy storage (e.g. thermal energy and electricity storages including batteries of electric vehicles) that can be installed on a central location (e.g. at a generation plant) or distributed within the network and at the customer end, and
- distribution networks (electricity and gas grids, district heating and cooling networks) that can appear at different scales (e.g. city-wide and micro-networks) and in different quality (e.g. temperature, voltage level).

Each of the infrastructure components consists of many sub-components ("system of systems") adding their own complexity. Furthermore, availability of various technologies bare complex interactions between the different components and energy vectors (Fig. 1). For example, the coupling of electricity and heat via cogeneration processes (Combined Heat and Power—CHP—plants) creates an interface between thermal and electricity grids. Such interfaces have optimisation potential that would enable bi-directional balancing of thermal and electrical energy, e.g. introducing heat pumps to generate heat when electricity from renewables is in excess or operating CHP when electricity prices are high. Other interfaces include the transformation of surplus electricity from wind or PV into hydrogen as an alternative fuel. Biogas, another alternative fuel, can be used to cover the demand for mobility either directly (in combustion engines) or by being used in CHP plants to produce heat and electricity for electric vehicles.

In addition to the internal complexity of an energy system, further interactions and interfaces have to be considered, e.g., to ICT networks, water, waste, the quality of life of citizens and socio-economic conditions as well, as different stakeholders with partly conflicting interests need to be involved (including energy utilities, industries and construction companies, building owners and operators, city administration, developers and last but not least the Inhabitants). For example,

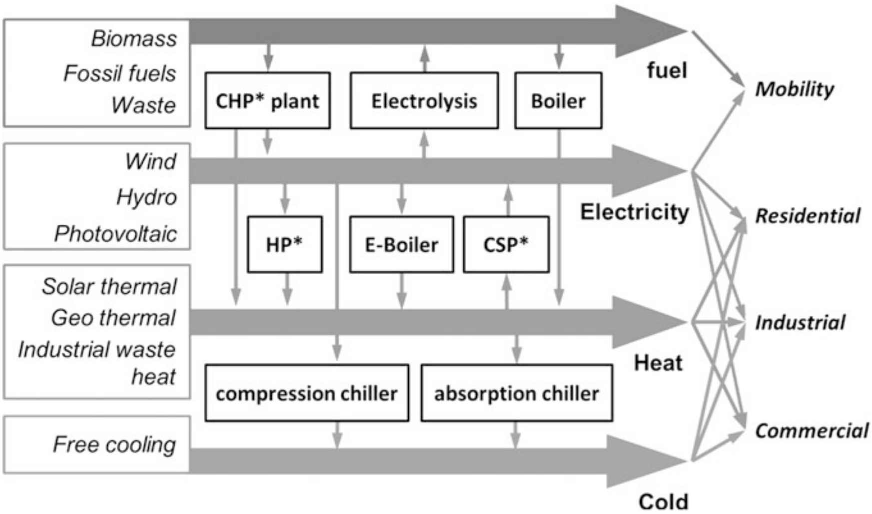

Fig. 1 Principal interfaces in the urban energy infrastructure, *HP* heat pump, *CHP* combined heat and power

urban planning parameters and processes are closely related to the technical and economic feasibility of urban energy systems and thermal networks in particular. This calls for an integrated planning exercise for these systems.

Many European cities have a long history. Their existing infrastructure has evolved over centuries and has been designed and implemented under different boundary conditions as well as different socio-cultural and economic contexts. To some extent this infrastructure is outdated but not easily replaceable. In addition, energy infrastructure is being planned, financed and operated within given contractual conditions. For example, operating plants and infrastructure have first to be completely financed before being replaced or re-powered. Also a network designed for operating under given conditions cannot be easily operated under different conditions. In addition, investment costs for installing new energy infrastructure in order to make the energy system future proof are rather high and the task of amending these conditions to facilitate further development of innovative energy concepts, therefore, is not an easy one.

From a technical point of view, possibilities for supply and demand side management targeting reduction of the peak loads and adaptation to fluctuating energy resources are restricted by the limitations in the current control systems (hydraulic limitations, e.g., for control of valves, and limited metering technologies). From a legal point of view on the demand-side activities, the possibilities for implementing load shifting measures in buildings often interfere with current contractual settings and customer comfort requirements.

4 Achieving Transformation Beyond the State-of-the-Art. How Do Cities Need to Change?

It is clear that handling the questions related to the way cities need to change requires knowledge that goes beyond the state-of-the-art and tools that make it possible to deal with the high degree of complexity. Different analyses of the performance and achievements of the latest progress in terms of sustainable neighbourhood developments (Pol and Lippert 2010; Di Nucci et al. 2010; Koch 2011; Robinson and Quiroga 2009; Marique and Reiter 2011) reveal that there is no example of excelling a neighbourhood with respect to all evaluation criteria. This is not only related to the contingency of implementation barriers and the fact that most of the developments are highly linked to and, therefore, hindered by existing infrastructure, standard implementation processes, and budget limitations, but mainly to the inherent complexity of the planning tasks. The promises of a Smart City by such examples of urban development like Masdar City serve as highlights for integrated planning. We shouldn't forget though, that the majority of existing cities are not being built from scratch and will need to go through the process of sustainable, step-by-step adaptation. Despite this fact, the future of Masdar City development and the lessons that it might teach still contain a potential of exposing challenges and solutions to be taken into account, developed further and implemented at the next attempt of Smart City planning.

A glance at the topics being addressed in current urban research reveals the rarity of such projects that reflect the existing complexity of urban energy systems. Research activities are still highly fragmented, depending on technologies, applications, levels of detail for analysis or the state of innovation. Such circumstances are partly caused by the fragmented nature of research funding schemes and mono-disciplinarity of the main university curricula. An analysis of 77 Austrian projects (Saringer-Bory et al. 2012) exposed the number of projects that would address the overall energy conversion chain being small (Fig. 2). Research activities focused on isolated aspects of energy systems and networks, technologies and components outweigh truly integrated, trans- and inter-disciplinary research. A new window is being opened by the latest Framework Program 7 Calls of the European Commission, which demand explicity for integrated research activities, addressing a number of interrelated urban energy issues. The future will show how ground-breaking, far-reaching and successful the outcomes of the funded projects will be.

The question of how to address the complexity of urban energy systems leads to an inevitable oxymoron. Handling complexity often calls for simplification, but how much simplification is acceptable before losing the sense of complexity? How to structure without dividing and how to follow a holistic perspective without in-depth understanding of the parts within the whole? A certain classification is necessary, even when we call for integration; the only point is how to do it. Within

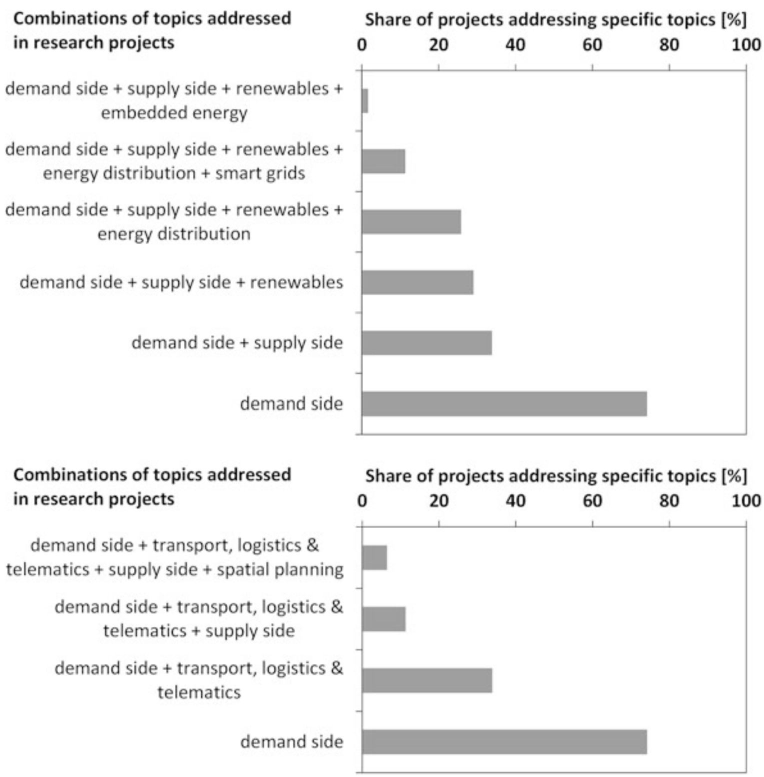

Fig. 2 Combinations of topics addressed in research projects

the different dimensions of knowledge for the Smart City, the work of (Saringer-Bory et al. 2012) could help to identify three fundamental knowledge dimensions that still allow for handling integration and dealing with complexity and inter-disciplinarity: concepts, technologies, and processes.

The first knowledge dimension encompasses concepts. Concepts are representations of urban structures and the innovations behind them. Concepts might be formulated in terms of an overall vision for an urban system or even of a detailed plan for a neighbourhood or a city. They express the idea of the Smart City and, therefore, should be at the core of research activities in the Smart City. But concepts are not reality yet. To be implemented, concepts and visions rely on two other pillars: technologies allowing for the physical realisation of the concepts (i.e. the "hard facts") and the processes enabling their implementation (i.e., the "how to"). It is easy to verify that each research project that would omit activities in one of these three dimensions would not be considered as Smart City project.

4.1 Concepts

The development of smart concepts for urban structures involves traditional urban and spatial planning activities with an emphasis on optimisation of the overall performance of the city. This includes aspects like zoning, neighbourhood master-planning, functional end-use mix definition as well as the planning of technical supply and disposal infrastructure for energy, water, waste water, waste, and transport. Even if these activities are traditionally embedded in university curricula, assigned to clear professional profiles and endorsed by planning codes and practice, knowledge is still needed to handle the complexity of the related strategic and operational planning activities. A concrete example would consist in planning urban green spaces beyond simply satisfying the minimal requirements specified in urban planning codes. The task would consist of looking into detail (using appropriate assessment methods based on modelling) at the potential impact of green spaces on the urban micro-climate, building energy demand, and possibilities to use renewable energy sources, acoustics, and quality of life.

4.2 Technologies

The technological backbone of the Smart City knowledge involves all technological developments and innovations that lead to an increased urban system efficiency and to a reduced amount of greenhouse gas emissions. This includes demand-side (building, energy and transport technologies) and supply-side measures (e.g. use of renewable energy sources, cascade use of resources) as well as innovations in Information and Communication Technologies (e.g. smart metering, operational optimisation systems, and mobile information systems). Therefore, further knowledge and research are needed for technologies at the interface between the different urban subsystems enabling their integration, e.g., building integrated energy conversion and storage technologies, network infrastructure technologies (e.g., process automation), and technologies allowing for cascade use of resources.

4.3 Processes

Conventional planning and implementation processes are no longer suitable to support the realisation of the Smart City. Knowledge is necessary on the theory and practice of these processes, ranging from stakeholder processes (e.g., decision making, public or targeted consultation) to the development of business models as well as the theory of long-term socio-economic processes or user behaviour. In particular, the legislative framework, rules and standards related to urban and spatial planning tasks have to be reviewed and assessed in order to provide recommendations on the way this framework would need to be adapted to enable the realisation of the smart city.

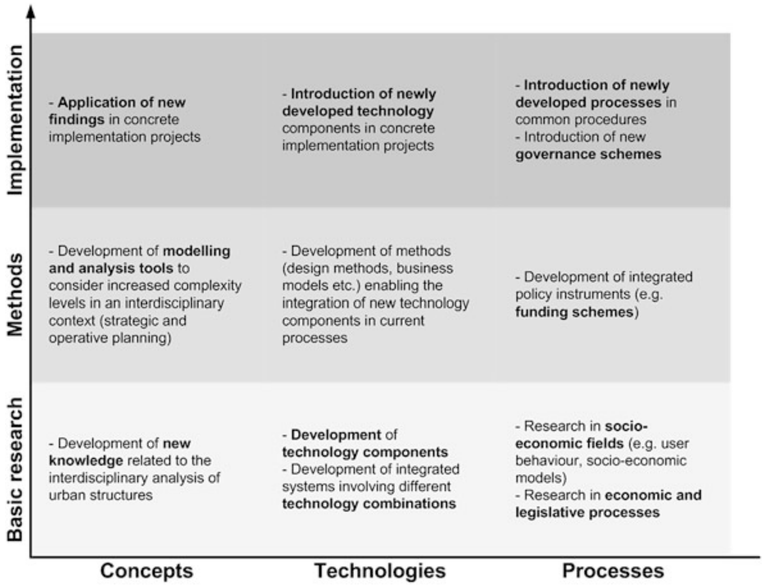

Fig. 3 Dimensions and levels of knowledge

Last but not least, the knowledge dimensions are to be associated with different levels of knowledge or R&D activities. Fundamentals are the basis for further knowledge development. This involves the most theoretical research activities in an interdisciplinary framework. To bring this fundamental knowledge towards implementation, there is a second level of knowledge dealing with methods and the models behind them. The application of the methods and implementation of the theoretical knowledge involve practical knowledge and real-life experience. This is the third level of knowledge that is requested for the realisation of the Smart City. Each of the three knowledge dimensions can be associated to one of the three different levels, leading to the matrix in Fig. 3.

5 Barriers to Achieving Transformation Beyond State-of-the-Art—Experiences from Austrian Research

5.1 A New Urban Planning Practice Is Needed

Implementation of holistic transformation processes—as necessary for Smart City development—is still at the very beginning in most cities. Even though broad basic knowledge in terms of necessary technical improvements and energy system specifications for Smart City development has been acquired already and research is being driven forward rapidly, implementation is challenging. One of the major challenges of triggering Smart City development is the necessity for interdisciplinary planning practices, especially for long-term developments, linking urban planning issues with the development of smart energy systems and with decisions on investments in infrastructure in general.

So far urban planning is being characterised by sectorial approach, with planning for each specific technical sector made separately (e.g. land use planning or zoning, development planning, supply of technical and social infrastructure, power supply). Even within sectors, internal competition between stakeholders takes place restricting chances for optimisation (e.g., the optimisation of urban heat supply strategies might compete with the interests of gas network operators). In such cases sub-optimal business solutions might hinder the diffusion of concepts that are optimal from a macroeconomic point of view.

The current planning practice, thereby, is hindering the holistic planning and optimisation of urban systems if not eliminating it altogether. Only by implementing joint, interdisciplinary planning processes, different options may be explored before setting basic framework conditions. Such an approach would allow for a greater scope of optimisation and open possibilities for introduction of new concepts and ideas to develop locally suitable, realistic specifications for smart development of cities and urban quarters. In addition, new approaches are needed to handle potential conflicts of interest (e.g., between local energy planning authorities and district heating network operators). Equally important is the development of new business models for energy related services to overcome traditional business models predominantly based on bilateral client-vendor relationships.

Such a situation calls for integrated planning and integrated decision-making processes. Isolated planning tasks that follow priorities set by the standard practices of separate disciplines (e.g., urban planners, energy system experts, landscape planners, sociologists, etc.) need to define urban development measures jointly, be it for a city or an urban district. This approach would lead to joint consideration and balance of issues concerning urban planning and architecture, energy systems, economy, ecology, and society, it would also allow for energy cascading and provide the foundation for developing considerably smarter solutions in comparison to the current standard practice.[1]

5.2 From General Barriers to Examples of Specific Problems

The current planning practice is not the only barrier to Smart City planning on the ground, there are a number of framework conditions—most often legislation—to be reshaped or adapted in support of Smart City developments.

One important example of specific problems of smart urban development is the improvement of the thermal quality of buildings by implementing renovation

[1]In the course of the FP7 project TRANSFORM (starting date 1.1.2013) this approach is being applied and evaluated for selected urban living labs in several European cities.

measures, especially for large multi-storey buildings. Although the economic feasibility of energy efficiency measures has been proven, the discrepancy between the bearers of the investment costs and those who benefit from the measures is still not solved. This so-called investor-user-dilemma describes the fact that house owners have to invest in a renovation providing lower energy costs and higher living comfort for tenants, without being able to profit from this improvement directly themselves in the current legislative framework conditions. Only in the long run do real estate owners benefit from the valorisation of their property. This issue plays a major role in the rental housing stock (multi-family buildings), hindering the broad improvement of thermal building quality so far (Amann et al. 2012).

Another problem related to the thermal quality of buildings (and other measures for improvement and modernisation) beyond pure maintenance arises in houses with several owners of flats. In the case of such co-ownership structures, decisions for improvement usually depend on the decision of a qualified majority. In some specific cases such decisions are even attached to the unanimity principle, making the decision process overly complicated (Amann and Weiler 2009).

A further example for barriers in Smart City development is the Viennese law of parking garages enforcing mandatory provision of parking space in new buildings. The law dictates a minimum number of car parking spaces (on site) for new building developments in Vienna instead of opening up the opportunity to use collective garages, or to encourage other forms of mobility. To date, only a few exceptions from the law have been implemented in Vienna [e.g., in the model for car-free residential housing in Vienna, the budget usually used for garages has been spent for shared facilities and more generously designed green spaces (Moser and Stocker 2008)]. In contrast to the governing general policy objectives to modify the modal split to favour public transport and other environmentally friendly modes of transport, the regulation causes higher production costs of living space and supports car traffic.

These few specific examples reveal the different barriers caused by counteracting effects of legislation and regulations. The range of issues and challenges to be solved in Smart City development is increasing. Nevertheless, at the same time the general awareness for such interdependencies rises allowing for a cautiously optimistic perspective into the future development of our urban environments.

6 Conclusions

Urban transition towards Smart Cities requires far-reaching changes in the structural, conceptual, technological and process related dimensions. The high level of complexity of urban development dynamics, energy systems, and technologies demands building up a profound understanding of the rapidly changing, living system—the city. To achieve the transformation of becoming smart, different forms of knowledge need to be advanced, exchanged, integrated and transferred among researchers, stakeholders, citizens and authorities, to be finally turned into actions, demonstrated and validated in concrete examples.

Smart City carries a good potential to become more than a sum of its physical parts compiled of passive homes and digital technologies. It indeed entails a promise that a sustainable form of urbanity can be achieved and the process of a significant change has started.

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