Understanding Smart Cities as Social Machines

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ABSTRACT

Smart Cities denote a stronger integration of information technology into the organisation of a city and the interaction and participation of its citizens. In developing the concept further, we propose to understand Smart Cities through the lens of Social Machines and thus stronger focus on the city as a socio-technical construct. We draw from an interdisciplinary background of computer science and urban planning to reexamine and combine existing theories and find a common understanding. We substantiate our claim to the validity of the concept of Smart-City-as-a-Social-Machine with a thorough literature study and comparison. We discuss the resulting system complexity issues and ways to address them. We further propose areas where this understanding can be useful in furthering research on both the Smart City and the Social Machine topics.

Keywords

Smart City, Social Machines, Cities, Participation, Citizen Engagement, Sustainability, Urban Interactions, Urban Planning, Urbanization, Megamachine

1. INTRODUCTION

Cities are interesting and cities are complex. Cities have always been a mixing place for people and systems, be they social, structural, cultural, legal, governmental, technological, or others. Cities are where people and multiple technology systems meet. Cities can thus be understood as complex organisms. Cities also face increasing pressure for adaptation and change. This leads to the reinvention of cities, where sustainability and other new requirements mandate a stronger systems thinking and a more data-driven operation of cities. A current driver and strong technological impetus is the concept of a Smart City. In brief, a Smart City integrates information and communication technology into its structure to manage and improve its services and the general running of the city [38]. As we will later show, the initial view of Smart Cities as merely using e-services and e-government falls short of the mark. A broader definition calls for pervasive monitoring and computing [20] Yet, a view only as a cyber-physical system misses a lot of the potential and the necessary dimensions to truly understand and design them in a participatory matter. We believe that for a wider application and better development, the definition should incorporate more facets, especially a stronger citizen involvement [28, 29, 1]. Not only does it help in opening up a new way to understand the city, but by giving the social aspect a center stage, it can also lead the way to more citizen-oriented building, development, and operation of cities.

One reason for this being the need for major changes in the way we operate and ultimately in how we construct our cities, which would be virtually impossible if its citizens were not an active part of these processes [22]. Furthermore, when participatory processes are successful they may open up new ways to understand the city. Robust participatory processes can also lead to innovation in the building, development and operation of cities [23]. Therefore, we suggest that inviting end users to co-create the future technologies of the city [22, 36] is a crucial part of any understanding of it as a Social Machine.

Our interdisciplinary working group draws from architecture and urban planning as well as computer science and HCI disciplines. We envision a citizen-centric operation of city services, away from a purely bureaucratic or technological point of view, ultimately giving citizens more control

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and influence of the city, its services and data and enabling a meaningful interaction.

We contrast this to the concept of Social Machines. The term Social Machine describes a class of large-scale socio-technical systems that combine human and machine computations and interactions into a new system with emergent characteristics that usually is Web-mediated [27, 35, 33]. We see a lot of overlap in the two areas as understood in our research. Smart Cities of certain characteristics can be understood as Social Machines of a higher complexity marked by less strict boundaries. This links to earlier concepts of the city-as-megamachine [26] and the information society [25] which is tied to an understanding of the city as a singular convergence of technology, politics and civilisation. Another established concept is the role of cities as knowledge hubs driving and dissemination, research, and innovation in the concept of *urban machinery* [14]. If a city can be understood as a machine, then a Web-enabled Smart City with its inhabitants can be understood as a social machine. Furthermore, the Web as an open programmable platform with a huge transformative potential is now ubiquitous and of course also used by cities to drive development and include citizens.

Given the interdisciplinary nature of our working group, we believe we can make a valuable contribution to the definition and refinement of the concept of Social Machines that can have an impact on real-world developments and implementations of urban planning and city system approaches. Yet, it is not straightforward to apply the Social Machine concept one-to-one to Smart Cities. To show a fruitful and useful as well as valid match, we will present our deliberations on how to connect the topics on a conceptual level, but also to apply them in understanding and examining real-world systems to fully explore its potential. Both terms of Smart City and Social Machine are still subject to individual interpretations. For the latter, because the term and research field is still reasonably new; and for the former, because there is a multitude of facets of what makes a city smart, combined with multiple approaches from research fields as well as from industrial solutions.

As an initial synthesis, Smart Cities can be understood as Social Machines of system-of-systems due to their socio-technical nature and the way they – at least theoretically – allow for participation in systems and services that are increasingly Web-driven.

In the remainder of the paper, we will share our deliberations on the overlap and contact points of the two concepts and show how they can enrich each other, but also point to certain issues that prevent a full mapping and can show potential for future research towards more complex Social Machines. As there is no previous work on this specific topic available we start with a thorough literature review and a solid theoretical grounding of the concept.

1.1 Defining Smart Sustainable Participatory Liveable Cities

There exist a multitude of definitions of what a Smart City is, usually with small or larger variations, but a certain core understanding persists. We are just pointing to two overviews of conceptualisations [12, 28] out of a number of them. Many definitions are technological in nature, many are strongly industry-driven, some are coming from a planning angle, and some aim at a synthesis. Of the latter, the Smart City dimensions of technology, people, institutions [28] or at a higher abstraction level of technics, politics and civilisation [25] are often used.

A city as an organism comprises the buildings, roads, subways, and other built environment, its natural environment in terms of topology, water, flora (and some fauna) together with machinery and finally, citizens and inhabitants. Seen on this level, a city is a highly complex organism with a multitude of dimensions that can be understood from a variety of viewpoints [32] [5]. We just need to look at how cities get built or analysed or lived in and can find support from fields of urban planning, urban studies, architecture, civil engineering, water engineering, telecommunications, sociology, psychology, history, logistics, transportation, living, culture, citizen engagement, and many more.

This is reflected in recent literature that is understanding cities not only in terms of place and space, but also in terms of systems, structure, networks, flows, and processes [5]. From the side of network science, a brief motivating takeaway would be that cities are dynamic complex systems that form networks that in turn process information [18].

Our working definition is that a Smart City is not just a system of sensors, actuators, and big data analytics laid over a city basic infrastructure as many industrial approaches do, which only progress the technological side without looking at emerging factors and leaps of complexity. Instead, we claim that a Smart City needs the support and participation of its inhabitants [13] to not only facilitate technical solutions, but looks at more encompassing methods to ultimately also consider quality of (daily) life. Therefore, a Smart City in our definition should put a strong emphasis on the community living within it, thus making it a strong case to view to through the theoretical framework lens of a Social Machine. Participation [16] [8] in this context means both involvement in general planning stages, but also interaction and influence in daily life [3, 10, 36, 13].

Another important issue that is addressed also on the urban level is sustainability and urban responses to climate change [15, 19]. In a well-structured approach, these should go hand-in-hand with working towards a livable city. Participation then becomes a key factor as emission mitigation also requires behaviour change. This is a strong current driver for cities to change their way of doing business, often integrating Smart City technology. Such as approach can be found, for example, in the MIT City Science Initiative[1] which proposes developing urban strategies with the objectives of reduction in CO_2 emissions, reduction in traffic congestion, improvement in liveability, and improvement in creativity.

In the following, we will use the term *Smart City* as meaning *Smart Sustainable Participatory Liveable City* with a focus on inhabitants and participation in addition to technology and infrastructure.

2. THINKING THE SMART CITY AS A SOCIAL MACHINE

Our definition and approach is based on our own deliberations and a comparison and validation of the Smart City concept against definitions of Social Machines. We start by examining key definitions and features and refine our notion of Smart City as a Social Machine alongside it.

[1] http://cities.media.mit.edu/about/initiative

The conceptualization of the *Smart City as a Social Machine* is rooted in a Mumfordian understanding of the city as a singular convergence of technics, politics and civilisation. For Mumford, urbanisation itself was, and continues to be, a highly complex social process that relies heavily upon a deep integration with the available technology [26]. In his critique of post-war authoritarian tendencies, Mumford introduced the concept of the city-as-megamachine, where individuals are functional cogs in a machine that serves not the higher order of human actualisation but rather increased production and rampant consumption for no other purpose than itself.

May [25] further links the megamachine concept to the growth of the information society, without which there would be no Smart City at all, particularly to Mumford?s conceptualisation of the dynamic tension between authoritarian (enclosure) and democratic (disclosure) technics throughout the history of urbanisation. The deeper integration of ICT into the urban space (both figuratively and literally) brings with it a number of issues worthy of closer consideration. First and foremost, what is the point? Should the Smart City-as-Social-Machine be yoked to the goals of capital accumulation, consumer experiences, and economic growth or should it instead be focused on giving individuals and society at large more tools to realise their own goals, even if that means more creative anarchy and loss of control.

It is still very much an open question to what extent Smart Cities will serve to reinforce dominant patterns of social relations and political structures, or will provide opportunities for more radical reimagining of social, economic, and political realities. As Batty et al. [6] noted, "in this (Smart Cities) it is likely that participation in formulating policies might be very different from the past when futures were dictated by the elite, primarily because of its access to information." What is clear is that Smart-Cities-as-Social-Machines possess a disruptive potential to existing forms of both technical top-down and participatory bottom-up planning methods and structures. Planning is still very much an elite enterprise, but the potential for opening up the source code of planning to the citizens is much higher in a Smart City, provided that the political and social structures are sufficiently amenable to broader engagement and decision authority from outside the usual elite planning circles.

We posit that Smart-Cities-as-Social-Machines possess the latent potential to push *participatory urban development* to the 8^{th} rung of Arnstein's ladder [4], toward full citizen control. To date, much of the Smart City thinking in relation to citizen engagement is rather truncated, focusing primarily on token policies of consultation and placation. However, with the distributed power of Social Machines, including development, observation, and analysis, Smart Cities that embrace the potentiality may be able to move away from traditional predict-plan-provide models of urban planning toward more decentralised forms of problem solving and strategic planning that more closely resembles the development of open source software where complex planning issues are solved in a distributed, Web-mediated space.

2.1 Grounding in Related Work

To show the validity of our concept Smart-City-as-a-Social-Machine also against the standing definitions of the Social Machines research, we carefully back our claim up in the following comparisons. The broad aspects of a Social Machine are social processes, merged with computation, happening on the Web.

Looking at the classification framework and especially the map of related areas of [33], we see the concept of Social Machines stand out since none of the other related areas fit very well, such as social computing, human computation, crowdsourcing, collective intelligence, and less related topics. These terms all focus on too narrow an area, often with a singular goal definition already built in. In contrast, the Social Machine conceptualisation is a very powerful and versatile one that is able to serve as an adequate model for Smart Cities.

A lot of work has already been done to apply the Social Machine concept to a number of systems [33, 37, 24]. We take this as a starting point to ground and compare the Smart City concept in the literature. However, much of the existing available work has been of a theoretical nature and focused on single systems such as Facebook, Twitter, Wikipedia, and other examples of single-site services that combine technology and humans into socio-technical entities with emergent features.

A simple convincing definition is given in [35] as "social participation with machine-based computation", which already fits well into the Participatory Smart City paradigm. We can take the view that society arises from social processes. Then the first notion of Social Machines [7] defined the topic as "[to use computers] to create abstract social machines on the Web: processes in which the people do the creative work and the machine does the administration". We argue that creative work is not only generation of online content, but includes understanding and visualising data and preparing complex decision making processes, generating insight; in short, researching and acting on issues. Related, as mentioned in [35], the distinction of creative and administrative activity is not always clear but revolves around "community engagement, issues of human-machine collaboration, the socially-distributed nature of particular tasks". A more elaborate definition is discussed in [35], citing [34]: "Social machines are Web-based socio-technical systems in which the human and technological elements play the role of participant machinery with respect to the mechanistic realisation of system-level processes".

[35] gives the example of clocks that can be understood from a certain point of view as social machines, especially by "providing the technological impetus for the transformation of society". Thus not only the mere technological implementation, but also the social and societal changes and transformation processes caused by it need to be considered.

This is a strong argument and in a similar way, cities are crystallisation points of societal issues and transformation processes. Research in architecture has long acknowledged this [26] and in fact, modern approaches to city planning place a focus on exactly such influences. Undoubtedly, cities run complementary to human social processes and within human social and societal environments.

Other transformation processes can be considered as Social Machines as well. For example, crowdsourced mathematical activities in the form of question answering or collaboration sites change and transform the way mathematics research is done [24]. Similarly, with the advent of Smart Cities, cities are becoming more and more Web-oriented and social and thus offer increased potential for deeper insight and participation. Approaches towards Smart Cities can

then unearth many hidden facets of social and other processes that were hidden before.

In short, the Web can enable more participatory (and collaborative) processes within Smart Cities. We are aware that this is a typical promise of technology that does not happen automatically, but needs to be well executed as, for example, part of urban planning processes [22, 39].

A main aspect of Social Machines is that they include humans in computations through the Web. Obviously, a Smart City is not a fully Web-based system itself. Instead, selected features and aspects arise on the Web to allow a view into the Smart City itself. On the other hand, many aspects of Smart Cities can be managed by using IoT technology for automatisation, management, and control of key infrastructure and services. These are already covered by research into cyber-physical systems. At the same time, not all of the Social Machine that is a Smart City is very obvious on the Web. It may even be argued that many parts are hidden away, but those things that remain accessible on the surface hold a strong a multi-faceted aspect in them. And even those factors that operate rather invisible under the surface, such as automatic metering, traffic measurements etc., are used to make an impact onto the city itself and are increasingly used as feedback to the inhabitants.

2.2 System Complexity

As we showed earlier, for smart cities the boundaries are less clearly marked and thus an observation needs to take more sources into account. A Smart City can be a system of systems, distributed over multiple systems, and often not even all that integrated. We propose two ways of understanding this complexity and to also open up further angles for Social Machine research. One is to separate aspects of the Smart City and the other is more integrative towards a system of systems ecosystem approach.

We claim that instead of viewing each Web-surfaced system (and the overall system that is the Smart City) of a Smart City individually (such as automatic metering, e-services, participation methods, social networks, etc.), we should take a broader view that encompasses all these systems as *manifestations of the city* behind them.

In the definition and derivation of a taxonomy of Social Machines [35], it is apparent that there is a struggle because Social Machines occur at many very different abstraction levels. The examples given range from the Web to social media to the organisation of a meeting. Similarly, a Smart City cannot be understood as only one fixed type of Social Machine. Indeed, it also spans multiple abstraction levels For example, in the concept hierarchy [35] Smart Cities in general would be arranged on the framework or infrastructure levels.

And similar to other Social Machines where boundaries are hard to identify, we can see a Smart City using other types of Social Machines as well by incorporating or embedding them into its structure. For example, a global social network is not part of a Smart City and the reverse also does not hold. But there are aspects done on the 'initiatives' stage of the hierarchy that very well fit within the city scope. Another interesting aspect of the Smart City as a Social Machine approach is that the Smart City does not necessarily have to be exclusively built by the city government or other public institutions. Instead, it opens up the way to include additional traditional small-scale Social Machines into the big picture. A Smart City is then not only a local organism, but also includes Social Machines built elsewhere, as long as they are meaningfully connected to the city itself. And incidentally, a Smart City does not just incorporate its citizens or inhabitants. There are other ways it can influence people, either those who are visitors or by influencing or inspiring them from afar. Such people may not directly contribute to the local Smart City infrastructure, but definitely form part of the Social Machine of a city that can manifest in multiple other Social Machines that are not strongly geographically limited.

A promising way out of the complexity issue is to take insight from other complex systems. Even something as complex, multilevel, and multifaceted as e-government has been convincingly described as a Social Machine [37]. This can then certainly be extended to city government and running of a city through e-services. With this in mind, the application of the concept to Smart Cities, which in most cases include e-government services as one aspect of their nature, seems very feasible.

We build on this [37] and define the Smart City as a Social Machine that is actually an ecosystem of Social Machines and also lives as the intersection of Social Machines at multiple scales. Their claim is that an "ecosystem which encompasses governments, citizens and communities is both evolving and adaptive, and the only way to examine and understand the development of Web-enabled government". This fits very well with our understanding of Smart Cities and this view thus is a valuable support to our approach.

We thus understand Smart Cities as a complex ecosystem at different levels of components, systems, and system-of-systems. In the context of digital ecosystems research [21], the scenario can then be described as follows. Supporting the different city services, a number of Social Machines have already evolved in interaction between system providers, users and machines, and the Smart City can be looked upon as a loosely integrated set of such Social Machines similar to how digital ecosystems have been conceptualised: a semi-controlled infrastructure with a number of data sources, application services based on these sources, the digital infrastructures needed to bring data and services to the users, and the users themselves.

3. APPLICATIONS

The increasing breadth and complexity of cities can pose a challenge of understanding and channeling their impact on our lives. Of course, a part of the complexity also arises from transformations into Smart Cities. This is all the more motivation to assist, monitor, and understand the transformation and development process with suitable frameworks and tools. The Smart-City-as-a-Social-Machine concept may be a useful tool to bridge computer science and urban planning approaches.

We should also bear in mind that many systems considered as social machines tend to have their users repurpose them or adapt to tasks that were not originally intended to by their developers. Examples can be simple such as hashtags on Twitter or highly complex such as the role of social media in political uprisings. Being open and supporting emergent new behaviour and modes of interaction thus also appears to be an important feature to consider [27]. Apart from a mere conceptual tool, it can also be further developed into better understanding of the life city. In line with

work from the Web Science [17] and Web Observatory [9] approaches, the Smart City can form a rich test bed to further the respective approaches. An interesting angle for further research would be stronger integration with Web Observatories. This may complement existing work towards e.g. city analytics as data-driven insights into the city [30, 31, 2] and also existing observatory work on systems that constitute a part of the Smart City. We see this as a challenge to extend the observation of Social Machines [11] towards more complex systems, such as those posed by the Smart City.

A conceptual grasp of Smart-City-as-a-Social-Machine can also fertilise projects with new angles of approach and allow for new approaches to provide services for a Smart City, especially looking at increasing citizen participation towards more social Smart City. This is especially important as facilitating citizen engagement and meaningful participation in decision making processes is a task that is notoriously hard to achieve in a sustainable fashion.

We submit that a Smart-City-as-Social-Machine is even harder to research and observe than single-service Social Machines. Yet this should not prevent us from posing this sort of aggregate and complex Social Machine as a new challenge. For the time being, individual smaller aspects of the Smart-City-as-a-Social-Machine can be explored, while keeping an eye towards the larger aggregation that leads the way to interesting larger conceptualisations. This ties in well with one of the conclusions from [35] that this "establishes the basis for more profound forms of social change in which social machines progressively alter the organization and dynamics of our future society."

4. CONCLUSION AND FUTURE WORK

In future work, we plan to further explore the connection of Social Machines to Smart City concepts as evidenced by the city-as-a-megamachine [26] and the city as part of the (social) information society [25]. Combined with participatory social processes and technological aspects for the Smart City, we aim to develop the concept of Smart-City-as-a-Social-Machine further to use it to understand its use in solving complex urban, social, and computational problems at a decentralised urban scale. We see this concept as a valid driver to answer questions about tasks and processes, both short-term and long-term, that happen inside the Smart-City-as-a-Social-Machine through a new angle.

In this approach, Social Machines can help bridge the gap between computer science and urban planning by providing a joint understanding of systems and processes defined by the individual disciplines. They can be used as an addition to a toolset to develop and understand Smart Cities and their transformation processes and also be included in institutional learning [39].

Before we can fully define what can be instrumented, measured, and observed in a Smart City, we need to test and validate the concept of Smart-City-as-a-Social-Machine against real-life examples. Existing observatory work can be a starting point to then ramp up the complexity and also define the relationship and priority of individual components within the whole system. A continuation into open research and open data cities would be fruitful.

Other questions include the actual characteristics of citizens in a Smart City, whether this is built on existing services or infrastructure, or if it can happen in a more self-organised, emerging, adaptive fashion. Finally, issues of inclusion of those not connected, engaged, or consciously opting out need to be explored, especially for such a basic thing of life as the city one lives in.

To conclude, the notion of Smart-City-as-a-Social-Machine can be an important tool to improve the understanding of cities away from a purely technological view towards a more inclusive social and societal view. We have discussed the initial definition of this concept, drawing from an interdisciplinary approach, and have shown the applicability of Social Machines also for this complex scenario. We further proposed two ways of understanding this complexity and also opened up further angles for Social Machine research.

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