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smart cities

Communication

Applying a Systems Perspective on the Notion of the Smart City

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Abstract: This paper focuses on the need for a widened definition of the notion of technology within the smart city discourse, with a particular focus on the "built environment". The first part of the paper describes how current tendencies in urban design and architecture are inclined to prioritize high tech-solutions at the expense of low-tech functionalities and omits that information and communication technology (ICT) contrasts the art of building cities as an adaptable and habitually smart technology in itself. It continues with an elaboration on the need for expanding the limits of system boundaries for a better understanding of the energy and material telecouplings that are linked to ICT solutions and account for some perils inherent in smart technologies, such as rebound effects and the difficulty of measuring the environmental impacts of ICT solutions on a city level. The second part of the paper highlights how low-tech technologies and nature-based solutions can make cities smarter, representing a new technology portfolio in national and international policies for safeguarding biodiversity and the delivery of a range of ecosystem services, promoting the necessary climate-change adaption that cities need to prioritize to confer resilience.

Keywords: smart city; ICT; built environment; digital technology; urban design and architecture; biodiversity; nature-based solutions; resilience

1. Introduction

As a group of researchers in sustainability science with a special interest in sustainable urban development, we have been invited to contribute to the current Special Issue devoted to "Smart Cities, Smart Homes and Sustainable Built Environment". As a first general reflection we cannot but assert that "smart cities" has become a current buzzword in the sustainability debate. A Scopus search reveals that publications on smart cities have tripled during the last two years, and many urban conferences are brimming with presentations, seminars and even whole venues devoted to smart cities. Buzzwords, however, have a tendency to be words that in referring to possible futures 'evoke good things that no-one could possibly disagree with'; hence, buzzwords gain legitimacy and influence through their vague and neutral qualities as well as their ability to embrace a multitude of possible meanings [1]. To us, this calls for careful scrutiny of how such buzzwords are applied and interpreted.

Smart cities comprise many positive-sounding phenomena such as smart governance, smart energy, smart building, smart mobility, smart infrastructure, smart healthcare, and even smart citizens. While "smart" means different things to different people, it does not hinder planners, policy makers, and corporations to use the prefix as if everyone agrees what "smart" actually entails. Few people question whether "smart" technologies actually are that smart.

To the authors of this paper, we argue that a truly *smart* city is determined by whether it is sustainable or not. We use a broad definition of smart city as "a city in which ICT is merged with traditional infrastructure, coordinated and integrated using new digital technologies" [2] (p. 481). Many proponents of smart city development uncritically take it as a given good for creating sustainable cities. During the Habitat III conference on Urban Sustainability in 2016, the smart city notion entered the scene as a promising paradigm for a transition towards both urban resilience and urban sustainability [3]. In fact, it is the fastest growing discourse within the wider umbrella of urban sustainability [4,5]. As an interdisciplinary group of researchers in environmental psychology, urban ecology, institutional analysis, and urban planning, we caution against a too one-sided view of smart-city development as entirely positive and contributing to sustainable development and/or sustainability [6]. For one thing, recent research shows that information and communication technology (ICT) has a far from environment-friendly carbon impact [7]. Smart technologies may also trigger problems that are "wicked"; i.e., problems that lack simplistic solutions and straightforward planning responses [8].

In this communication paper we focus on the need for a widened definition of technology within the smart city discourse—a definition that comes close to the original meaning of the term in Greek as 'techne, knowledge of techniques, skills, and processes' of building cities. With a particular focus on the "built environment", we highlight perspectives of technologies that we think deserve greater attention among policy makers, planners, and developers. As a theoretical departure point, we adopt a broad view of the built environment as an overlapping zone between culture and nature that corresponds to the definition of a social–ecological system [9], that consists of a set of critical natural, socioeconomic, and cultural resources (or, capitals). The flow and use of these resources are regulated by a combination of ecological and social systems [10], where the social systems also include the technical systems. We also conceive of "smartness" as something that is being added to cities via the application of some form of digital technology [11].

We begin this paper by describing how current tendencies in urban design and architecture tend to prioritize high tech-solutions at the expense of low-tech functionalities and describe how ICT may induce changes in social practice and human behavior, omitting that ICT contrasts the art of building cities as an adaptable and habitually smart technology in itself. We also discuss the need for expanding the limits of system boundaries for a better understanding of the energy and material telecouplings that are linked to ICT solutions and which transgress the physical boundaries of cities. In conjunction, we elaborate on some of the risks inherent in smart technologies, as in the form of rebound effects and the difficulty of measuring the environmental impacts of ICT solutions on a city level.

In the second part of the paper, we highlight how low-tech technologies and nature-based solutions can make cities smarter, representing a new technology portfolio in national and international policies for safeguarding biodiversity and the delivery of a range of ecosystem services, promoting the necessary climate-change adaption that cities need to prioritize to confer resilience. Before concluding, we pose a major sustainability question, as we see it, to which extent the natural resources that go into the smart technology are eroding the resiliency of ecosystems to generate essential life-supporting services to humankind.

2. The Boundary Conditions of Smartness in Smart Cities

In urban design, current tendencies to prioritize high tech-solutions often occur at the expense of low-tech functionalities that are traditionally "built into" the physical landscape, e.g., water irrigation, air ventilation and the support for human navigation [11]. Naturally, the aim of high tech-solutions is not to counteract low-tech ones, but to increase precision and efficiency. However, if the effects of a new high tech-solution are studied in isolation, unintended consequences risk being overlooked. A telling example is the electric scooters, or e-scooters, that have been introduced in many of the world's cities and are changing cityscapes everywhere under the label "smart transportation". E-scooters that are rechargeable battery-driven are often launched as having no contribution to air pollution, noise, walkability or greenhouse gas emissions. However, the accuracy of this statement is highly questioned. E-scooters seldom replace car travels and the environmental impact from battery production and disposal, as well as the management involved in picking them up and relocating them are larger than expected. At the moment, the number of peer-reviewed scientific studies on e-scooters is small [12], but see Hollingsworth et al. [13]. Without comprehensive evidence from a systems perspective, we cannot conclude that e-scooters represent smart transportation".

Crucial for sustainability is the use of natural resources and the minimizing of hazardous waste to air, water and soil. There are numerous ways to make analyses and calculations of the degree of sustainability a city achieves. To assess if the smart city is more sustainable and resilient and meet environmental targets better than other cities, the methods of calculations and the definition of the system boundary is crucial [14]. It is difficult to assess the true environmental impact of the use of ICT on a city level. Smart phone devices are an obvious part of the ICT system and are nearly always taken into consideration. However, other subsystems included in the physical infrastructure of digital technology are often not highlighted, such as routers, cables, fiber optics, satellites, antennas servers in data centers that harbor all the data that is meant to save energy in the city, and that can be located very far from the city. Challenges include how to collect correct life-cycle inventory data and how to deal with allocation issues. Potential for energy savings through ICT technology in cities have been found mainly regarding the operation of transport and heating of buildings [15]. However, the effects are often studied in isolation and the combined direct and indirect dynamic impacts of ICT on interacting global systems, such as economic and energy systems, is also of importance when reflecting on the environmental impact and sustainability of smart cities [16].

Calculating the indirect impact of ICT is also challenging as it is affected by the initially defined baseline, differentiating between potential and actual impact and system effects such as rebound effects [17]. Even as technology becomes more and more energy efficient, a rebound effect can occur with increased use of the technology, which leads to an overall increase in energy use [18]. Decreasing energy consumption from the ICT data centers is recommended to reduce environmental impacts arising from electricity consumption for ICT products and services [19]. Such measures may preferably also be directed at software and hardware design and use patterns (see e.g., [20]), but focus is often on the efficiency and sustainability of energy supply. In Sweden, data centers are currently being located to minimize both the environmental impact and cost of electricity use for ICT-companies. However, even though they will mainly use "green" electricity from hydro power plants, they will likely add to the nationwide total energy use.

Even if advances in ICT has a positive potential to reduce carbon emission, it simultaneously contributes to energy use and emissions and these rebound effects are of importance when assessing impact [16]. A life cycle perspective can also be applied to the appliances that are distributed among the buildings and inhabitants of the smart city. Kramers et al. [15] account for this by using a citizen consumption-based life cycle perspective for allocating and calculating energy use, while also acknowledging the challenges and the need to use other indicators. For ICT, the more direct impacts related to e.g., natural resource use, global warming, biodiversity loss and toxicity may have significant contribution along the life cycle. However, as such technologies are introduced to fundamentally reshape urban services, rebound effects also need to be captured in order to give a comprehensive picture of the positive and negative—and the net—effects on the environment. In extension, more research is needed on how to harvest the sustainability potential of the technology and limit the magnitude of potential rebound effects through interventions over the whole life cycle (see e.g., [21]).

Recent research shows that the ICT sector is far from being environment-friendly when considering its embodied carbon impact [7,22], which mainly originate in the material sector and the electricity sector. As for direct energy consumption, already in 2007, the ICT and related electronic appliances consumed 4% of global electric energy, and this figure grew to 4.7% in 2012 [18]. Projections estimate that in the worst-case scenario, ICT electricity usage could contribute to 23% of the globally emitted carbon dioxide emissions in 2030 [23]. Internet use in general is becoming a threat to sustainable development according to studies in European Union countries [24]. Consider new data center developments, for example, a central part of Internet's infrastructure. They will have large environmental impact as building projects. Their buildings are responsible for large environmental impacts on global and local scale/level due to land and material use. They also pose a new question to the discussion on the sustainability of smart cities: How should data centers be spatially allocated? One example is a new development of 130 hectares of data centers planned in the Swedish city of Gävle. This will increase the consumption of electricity with 600 Megawatts and approximately 1TWh/year (estimated from energy use from similar data centers [25,26] and information from the Swedish authority Svenska Kraftnät [27]) meaning it will more than double the city's total energy use. Furthermore, during the building phase, more than 23,000 m^2 of productive forest will be transformed into hard surfaces. Only the production of the concrete in the slab (estimated to be 250–300 mm thick) in the buildings will emit around 1,300,000–2,500,000 kg CO_2e if the level of emissions from the production of the concrete is calculated as 1.1–1.7 kgCO_2e/kg, excluding the impact from the steel reinforcement, other parts of the building, the production on site, transports of material or operation of the building. We do not at this stage conclude whether this project is smart or not, but again call for systems analyses that highlight otherwise hidden costs of smart city development.

Some argue for an inverted U-shaped relationship between ICT and CO_2 emissions, were ICT development first leads to increasing carbon dioxide emissions in a country, but after reaching a threshold level instead leads to decreases [28]. However, this is a version of the environmental Kuznets curve that has been heavily contested [29–33]. In Figure 1, we show instead how the country-level data used by [28] quite strikingly do not support the notion of a U-curve relationship between ICT development and CO_2 emissions in any absolute terms. While most countries massively increased their ICT development between 1995 and 2005, very little differences in CO_2 emissions were observed, but the curve rather "shifted". Here, the concept of telecouplings might be of help. Telecouplings describe how long-distance socioeconomic and environmental interactions are important for addressing sustainability [34]. In a telecoupling framework, Xiong et al. [35] show how countries' contributions to the embedded COs emissions of international trade are related to their positions in the global value chain. In other words, international comparisons of environmental performance might be related to relative economic or ICT development. This highlights the danger of drawing too narrow system borders when analyzing the smart city phenomenon.

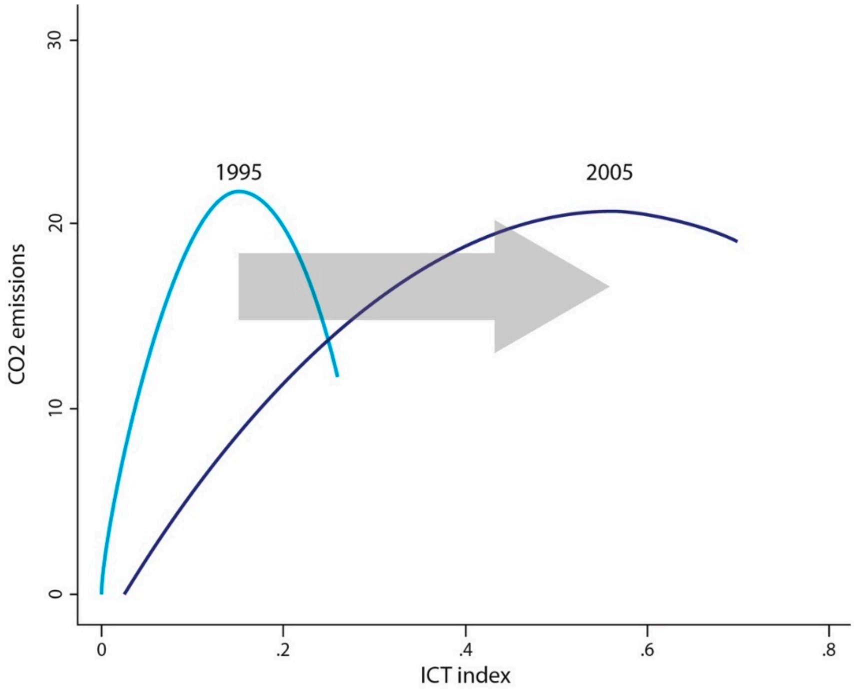

Figure 1. Among 142 countries, despite massive increases in information and communication technology (ICT) development between 1995 and 2005, little absolute changes in CO_2 emissions were observed. The environmental Kuznets curve rather "shifted". Modified from Figure 1 in Añón Higón et al. [28].

3. Non-Smart Technologies Can Make Cities Smarter

As reflected in the discussion above, people currently put much hope in solving the huge environmental challenges they are facing today through developing new technology, but it may be a sobering exercise to first acknowledge how it is mainly through technology we have been able to generate these crises. This may also lead us to question what we mean by technology. Today, technology is often narrowly defined to what ethnographers, who study humans and their relation to the environment as mediated by their tools, would describe as implements. Implements can be set in contrast to facilities [36]. Implements are characterized by high energy, specialization and optimization; one may think of the set of electric kitchen utensils we have at home that each can do only one thing but with high precision. Facilities on the other hand, are characterized by the opposite; they are often low energy, generic and adaptable. This includes the functionality of the urban form [37]; one may think of street networks which typically are multifunctional and have proven able to sustain many generations of evolution in vehicle technology. Hence, we see how the street network constitutes a form of technology, albeit low-tech, with traits that we tend to associate with resilience of cities. The built fabric of cities possesses these attractive traits because each generation has both adjusted it and added to it in accordance with their experiences and needs, making it a sophisticated matter replete with knowledge and accumulated experience [11,38]. We therefore argue that while there may be reason to make use of new digital technology in our cities, that we may call smart, it should not be uncritically introduced in ways that risk conflict with such older generic technologies.

In a context in which we must urgently find new ways to redirect urban processes toward more sustainable trajectories, a move to a greater dependency on technologies that are vulnerable to failure and that demonstrate short lifespans risks being short-sighted [39]. Still, most new technologies involve some risk taking in order to be able to demonstrate their potential to contribute to sustainability. Focusing attention on constructing urban form that generates benefits and limit adverse outcomes for urban inhabitants and the planet might provide more leverage for real sustainability transformations. Urban form can greatly influence energy use [40,41], consumption patterns [42], social segregation [43], crime [44], air pollution [45], land use and ecosystem services [46,47], and food production [48–50].

Urban form also conditions how a city is perceived and experienced by its inhabitants [51], and how they move through it [52–54]. Pedestrian movement, as well as other kinds of human flows in urban space, represent important drivers of urban processes [55,56]. For example, it shapes different kinds of copresence of people in different urban spaces, creating particular situations of varying potential for social integration [57], local markets [58] or encounters between people and urban nature [53,59]. To what degree new transportation technologies, such as driverless vehicles and e-scooters, are generating new conditions of copresence is very much an open question. As they operate within a low-tech technology that already conditions much of urban life, we anticipate that new movement patterns facilitated by new transportation technologies will create new socio–spatial interactions with potential repercussions for, among other things, social integration, local markets or human–nature interaction.

To draw a distinction between built and unbuilt land in a city is very much an arbitrary exercise [60]; rather much of the built environment also includes both blue and green infrastructure [61]. Smart urban planning and design, however, need increasingly be more environmentally functional oriented to more effectively tackle climate change and biodiversity loss in cities. A critical strategy is to make city inhabitants more ecologically literate about what role nature plays for human and societal wellbeing [62]. Today we know that nature in urban areas yield ecological benefits, not only directly but also through the role they play in shaping human attitudes toward the environment and environmental protection far beyond city borders [63]. A criterion for this, though, is that urban residents also have the possibility to experience nature in their immediate environments [62]. Hartig and Kahn [63] argue that urbanization and city densification (in combination with increased daily screen time) may trigger baseline shifts in collectively shared environmental attitudes, as urban dwellers may be blocked from nature experiences during their daily habits. By refuting opportunities for people to experience nature in everyday life in densely built cities people become increasingly environmentally illiterate, leading to environmental generational amnesia. This helps to explain inaction on environmental problems; people do not feel the urgency or magnitude of problems because the experiential baseline has shifted [63].

Initiatives of bringing nature into the built environment of cities is not a new endeavor; however, the benefits of integrating nature-based solutions to human well-being have been more clearly articulated during recent years. The combination of spatial structure (configurative properties of urban form) and social structure (population density, socio economic profile of the population etc.) creates conditions that will favor certain social-ecological processes and disfavor others. Over its time of existence, the interplay between a city's ecological, social, cultural and economic processes becomes explicitly formulated in its built fabric [11]. Such differentiation results in urban systems assuming development trajectories that are difficult but not impossible to transform [64]. Human beings have, however, for long tried to design technologies that imitate functions of nature [65]. An example at hand is "biomimetic architecture", which imitates nature's functions and applies them to architecture for climate adaptation, efficient energy consumption and other useful functions [66]. The integration of nature-based solutions (NBS) is today mainstreamed in many national and international policies and programs, representing a "technology portfolio" for improving biodiversity and the delivery of a range of ecosystem services in the built environment. Among others, NBS promote climate change adaption, water and wastewater treatment, resource recovery and the reuse and restoration of degraded ecosystems [67].

4. Concluding Remarks

As the authors behind this paper see it, sustainable urban planning faces three major challenges at moment: mitigating global warming and other global environmental issues by reducing cities' energy consumption and impact on the biosphere [41,68], maintaining social-ecological services that grant resilience against shocks and unforeseen events [69,70], and providing environments that support urban dwellers' health and wellbeing [53,71]. Hence, whether a city should qualify as smart should ultimately be determined by its ability to sustainably address these issues, which requires exposing conflicts between them [54]. Moreover, the first challenge of increasing energy efficiency, while being the motivator behind much of the smart city discourse, often suffers from inadequate conceptualizations of system boundaries that disregard telecouplings that are intensified by ICT technology. Focusing solely on one of these challenges, or even a narrow slice of one of them, risks producing problems down the line. Instead, we should recognize that in traditional city building, low-tech technologies exist from which we can derive valuable lessons for all three challenges and their interactions. It is within this expanded social-ecological and socio-technical system that we can carefully consider where new technologies might fit in in ways that are truly smart.

In order to engage with urban issues at their root, we need to perceive of the built fabric of cities as an advanced, even intelligent, technology, and have that as our starting point for pursuing sustainability. This include nature-based solutions that are increasingly critical to nurture given a changing climate and a global obliteration of biodiversity and ecosystem services with negative repercussions for social-ecological resilience. The saying 'don't put all your eggs in one basket' is a well-known redundancy recommendation in economics. In a resilience context, planners and policy makers need in a similar vein to nurture slower forms of technologies (e.g., analog alternatives) to maintain redundancy in cities to deal with unanticipated events and crises. As an increased digitalization of city functions is circumvented by a great deal of questions [62], we recommend planners to hurry slowly in creating the extra layer of cyber complexity to the urban fabric.

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