Smart Streets as a Cyber-Physical Social Platform

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Smart streets are part of a cyber-physical social infrastructure in the public realm, including data obtained from sensors, the interconnection between different services, technologies and social actors, intelligence derived from analysis of the data, and optimisation of operations within a street. Cyber-physical systems (CPS) integrate computation with physical objects and processes, a literal co-mingling of the physical world and the cyber world (including computation, communication, and control systems). A cyber-physical social platform represents a recent expansion of CPS that bridges the gap between human intelligence and machine intelligence by including a social domain characterised by human participation and interactions.

Keywords: streets ; smart streets ; sensors ; cyber-physical systems ; cyber-physical social systems smart cities ; platformization

1. Introduction

By 2050, over 68% of the world's population will live in urban areas [1]. As well as economic benefits, increased urbanisation presents significant challenges to governments and municipal authorities. Cities consume over two-thirds of the world's energy and are responsible for over 60% of greenhouse gas emissions [1]. Furthermore, increased urbanisation can lead to significant urban health issues related to road traffic injuries, air and noise pollution, and barriers to safe physical activity, amongst others [1]. Against this backdrop, many urban areas are struggling with the strain urbanisation is putting on a decaying infrastructure [2]. In response, the concept of the smart city has emerged and gained traction over the last three decades; while there is an ongoing debate on the definition of a smart city, it certainly involves the diffusion of information and communication technology (ICT) to improve how different urban subsystems operate to meet the needs of people and communities [3][4]. The challenge with smart cities is one of scale. Working at city scale requires an often unprecedented investment of public funds, coordination, and a suitably long-term horizon which presents significant governance, economic, and technology challenges, amongst others [5][6]. Furthermore, the focus on cities also neglects the needs of those who live in small and rural communities [7]. Unsurprisingly, streets have been proposed as a more generalisable, atomised, and therefore more manageable unit of development for improving urban subsystems and meeting the needs of both urban and rural communities [8][9]. Streets typically represent the largest portion of the public realm in towns and cities. As well as a thoroughfare for traveling from one point to another, streets play an important role in public health and safety, quality of life, environmental sustainability, social equity, and the economy [10][11][12]. Streets also play a less visible role; they incorporate much of the critical urban infrastructure to support towns and cities including, for example, telecommunication, water, energy, and waste [13]. More importantly, in the context of this paper, streets allow the live testing, experimentation, and evaluation of smart city technologies in a small-scale yet realistic setting. The digitalisation of streets is an under-researched area and smart streets are at an early stage of maturity. This article reflects the extant literature and the research challenges for smart city and CPSS projects, as well as our direct experience working on several digital town projects. This reflection suggests a dearth of conceptual tools to inform the envisioning of smart streets and related research projects, a prevalence of site-specific and use case-dependent conceptualisations and implementations that hinder wider generalisation, a lack of general design principles for integrating the social aspect into intelligent public infrastructure, as well as a failure to consider CPSS from a multidisciplinary perspective. The aim of this article is to raise awareness, stimulate discussion, and propose some initial avenues of research on smart streets.

2. History

As discussed above, streets are not merely thoroughfares that connect one point with another. The public perform a wide range of activities in streets that can be categorised as (i) mandatory (e.g., going to work or school and shopping), (ii) selective (wandering or sitting and watching street life), and (iii) social activities (having conversations) while human behaviour in streets can be classified as (i) moving, (ii) visual perception, and (iii) resting behaviours, which can occur discreetly, successively, or concurrently [14]. As such, it is a public realm that is actively and passively consumed depending on how it is structured as a public space. These structures highly influence the norms for how such a space is moved through and consumed by individuals or groups [15]. Streets are multidimensional spaces from one property line to another and comprise a number of tangible and intangible elements that need to be taken into account. Furthermore, they can be apportioned into three common zone types: the building edge, sidewalks, and roadbeds [11]. These zones may include distinct sub-zones and different design features and serve different functions. For example, sidewalks may include frontage (building edge), clear paths, street furniture, and buffers [11]. Sidewalks serve a transportation function in that they are both spaces of access, enabling people to move from one place to another facilitating access between properties and to people. They also serve a function for stationery activities, e.g., retail and infrastructure [16][17]. In addition to this, they play a critical bordering role providing citizens and pedestrians safety from vehicles and other risks [18]. Similarly, roadbeds may include transit facilities, ancillary lanes for cyclists or delivery vehicles, parking for motor vehicles and cyclists, and planting, amongst others [11]. Within these elements service street furniture and infrastructure are provided both on the surface and substrate. It is important to note that poorly planned streets can inhibit use and streets can be the site of conflict, anti-social behaviour, and undesirable activities [19]. Lynn et al. [9] define a smart street as... a basic unit of urban space that leverages cyber-physical infrastructure to provide enhanced services to stakeholders, and through stakeholder use of the street, generates data to optimize its services, capabilities, and value to stakeholders. Lynn et al. [9] proceed to define eight examples of smart street technology categories; namely, (i) connectivity, (ii) smart street information systems, (iii) traffic and transit management, (iv) accessibility, safety, and security, (v) smart street furniture, (vi) climate protection, environmental monitoring, and weather mitigation, (vii) environmental sustainability, and (viii) other technologies that encourage street activity [11]. It is important to note that these technology categories are not mutually exclusive and may complement or even depend on each other. While it is inferred from this definition and the associated technology categories that the street create value through stakeholder engagement, the definition is ambiguous with respect to two inter-related issues: (i) social interaction and (ii) the degree to which the street is an open or closed loop system. Firstly, given the range of human behaviours and activities on a street, the social interaction between different human actors, between human actors and technical artifacts, and between computers as social actors needs to be more explicit. Secondly, Cassandras [20][21] has stated that to (i) avoid unintended consequences (and presumably malfeasance), (ii) provide intelligent support for decision making, and (iii) integrate humans in the loop while recognising human actors may have different, potentially conflicting, motivations requires governance and therefore a closed loop. Accordingly, Cassandras [21] says that municipal governments view smart city systems as cyber-physical social systems (CPSS) when developing and implementing the policies necessary to provide incentives and deliver the value of CPSS to smart cities[22][23][24][25][26][27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45][46][47][48][49][50][51][52][53][54][55][56][57][58][59][60][61][62][63].

3. Applications

Our conceptualisation of smart streets brings together concepts from two emergent literature bases; namely, cyber-physical social systems and platforms, into a general conceptual framework. In the last three decades, we have seen the emergence of the Internet of Things (IoT) and with it a renewed and increased interest in cyber-physical systems (CPS). Such systems integrate computation with physical objects and processes, a literal co-mingling of the physical world and the cyber world (including computation, communication, and control systems) [64]. CPS has been cited as the computation substrate that will connect future public critical infrastructure to intelligent systems and software [7]. More recently, the literature on CPS has expanded to integrate social systems, bridging the gap between human intelligence and machine intelligence by including a social domain characterised by human participation and interactions [65]. In such cyber-physical social systems (CPSS), humans, software, and physical objects (through sensors) are linked through a CPSS to meet a given actor's social interaction demands and react to the physical world [65]. Central to the concept of CPSS is at least one physical component responsible for sensing and actuation, one cyber component for computations, and one social component for actuating social functions [66]. Place is an important and increasingly complex construct in the CPSS literature, including physical spaces, virtual spaces, social networks [65][67], and the overlay of these spaces through technologies such as augmented and extended reality. Given the role of purpose and place in CPSS, context awareness is a critical component of CPSS [65]. Commonly cited CPSS use cases are unsurprisingly related to places, including smart homes, but also to larger urban spaces, e.g., smart cities [21][65][68][69]. Indeed the latter has attracted the attention of leading technology companies worldwide, most notably and somewhat controversially, Google's Sidewalk Toronto project [51]. Platforms and the related term, platformisation, are widely referenced in both the scholarly literature and the media, while once platforms were largely defined from a production or computational perspective, they increasingly have wider political, figurative, and architectural connotations [70]. Meyer and Lehnard [71] define product platforms as ...a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced. In this conceptualisation, a product architecture is the combination of subsystems and interfaces [71]. What distinguishes a platform architecture from a product architecture is its capacity to enable the creation of derivative products [71], while Meyer and Lehnard note that services, both in the real world and online, are not inconsistent with this conceptualisation of the platform or platform architectures [71], their conceptualisation represents a finished product or completed service. More recently, we have seen the emergence and adoption of Web 2.0 and the so-called Third IT Platform, while the former emphasised the role of users through co-creation, participation, ease of use, and interoperability [71][72], the latter heralded a cyber-physical future that emphasised interdependencies between mobile computing, social media, cloud computing, information/analytics, and the IoT [73]. Here, as Ramaswamy and Oczan [74] note, digitalised platforms differ in that: ...the offering is no longer “finished” in the traditional sense, and the creation of value continues in a joint space of interactional value creation, between engaging actors (often consumers and their social networks) interacting with organizing actors (often the firm and its associated organisational ecosystem). The traditional notion of offerings as goods and services to be optimized in terms of a fixed set of features and attributes is inadequate in connecting with the new opportunities for creating value in an age of digitalized interactions. This wider conceptualisation of a platform is one in which a multitude of actors can interact with digital systems and one another to create value. In this way, the platform is a multi-sided network in which goods, services, and increasingly data are exchanged between the actors to create value [75]. In addition to providing an enabling infrastructure and system core, the platform plays a vital role mediating between different groups of actors [75]. While platforms can be merely conceived as product platforms in line with Meyer and Lehnard [71] in that they provide an extensible codebase to which third party modules can be added, the socio-technical view of digitalised platforms conceives the platform as comprising technical elements (software and hardware) and associated organisational processes and standards. The agency of the user is a critical difference between non-digital and digital platforms. As de Reuver et al. [75] note, non-digital platforms assume a stable core and a variable periphery governed by an overall design hierarchy typically determined by the platform owner or sponsor, but digital platforms are not necessarily constrained by such design hierarchies. The separation of concerns combined with the ability to reprogram, re-edit, and re-use data and code, particularly in the context of open source software and open data, enables platforms to evolve and new applications to emerge in ways often unplanned and unexpected. Indeed, the generative dynamics of digital platforms, particularly when coupled with openness, are seen not only as a key enabler of the platform evolution but as a critical success factor in adoption. Poniatowski et al. [75], building on de Reuver et al. and Van Alstyne et al., conceptualise digitalised platforms as comprising three layers—platform infrastructure, platform core, and platform periphery. Infrastructure implies an underlying socio-technical system characterised by ubiquity, reliability, invisibility, gateways, and breakdown. Similar to other infrastructures, for example electricity grids, it is defined by control. Similarly, platform infrastructure is the foundation of any platform, is largely hidden from third parties, and is controlled by the platform sponsor [75]. The platform core sits on the platform infrastructure and is controlled by the platform core owner, who may or may not be the platform owner [75]. Third parties participate and contribute to the platform through the platform periphery, again controlled by the platform owner [75]. This model can be illustrated by reference to Amazon. Amazon both are the platform sponsor for Amazon Web Services and the platform core that comprises Amazon.com, which includes Amazon’s own retail business but also a periphery comprising other retailers and service providers. It is important that a platform may have multiple platform cores. Again, in the context of Amazon, Amazon Web Services leverages Amazon platform infrastructure to support its cloud business which comprises platform-as-a-service, software-as-a-service, etc. This infrastructure is both used by Amazon and by a wide range of third parties.

4. Current Status

Unlike purely digitised platforms, the term ‘cyber-physical social platform’ implies a platform infrastructure comprising physical and cyber platform elements upon which a platform core resides, that can enact physical, computational, and social processes by itself or through the interaction of other entities through the platform periphery. This conceptual framework is general in that it is capable of being used to understand and explore smart street-related research questions or problems in conjunction with widely accepted levels of generalisation (abstraction) in different academic disciplines, including both the social sciences and computer sciences. Addressing the issues with earlier definitions of smart streets [9], we adopt an updated definition of smart streets that accommodates social networks between humans, computers, and humans and computers, and reflects the literature on CPSS. However, while a closed loop is desirable from the perspective of municipal authorities who have a legal responsibility for the public realm that is the street, it leaves the issue of whether the system per se is open or closed, undetermined in order to support a general level of abstraction for theoretical and practical exploration. Accordingly, we define smart streets as a basic unit of urban space that leverages cyber-physical social infrastructure to provide and enable enhanced services to and between stakeholders, and through stakeholder use of the street, generates data to optimise its services, capabilities, and value to stakeholders. The conceptual framework provides a sufficiently general abstraction of smart streets to facilitate sense making without getting into a non-generalisable level of granularity or worrying about specific definitions of smart streets or indeed cyber-physical social platforms. In this framework, five core entities are identified and defined: Social Actors, Artifacts, Networks, Places, and Infrastructure.

The diffusion of ICT to improve the subsystems in the lived environment and meet the needs of people and communities is only going to increase in importance and proliferation. Research on so-called smart city technologies and cyber-physical social systems is hindered by reductionist approaches and access to real-world city-scale testbeds. In this article, we focus on the street as a more feasible starting point and building block for smart city research. We make three primary contributions. Firstly, following a review of the smart street and CPSS literature, we extend the definition of smart streets to accommodate social networks between humans, computers, and humans and computers, as well as representing the literature on cyber-physical social systems. Secondly, we propose a novel general framework for conceptualising a smart street as a cyber-physical social platform that integrates concepts from smart streets, digital platforms, and the cyber-physical social system literature. Thirdly, we elicit and discuss six avenues for future research on smart streets as cyber-physical social platforms that addresses gaps and failings in existing computer science, social science, and IS research. The underlying motivation for this article has been to raise awareness, stimulate discussion, and propose some initial avenues of research. In this respect, the concept of smart streets as cyber-physical social platforms opens up exciting new avenues for research, not only for computer scientists, but those from urban engineering, cognitive sciences, and social sciences to collaborate in an inter- and multi-disciplinary way to explore and populate with clarity and depth.

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