Smart City Transcendent - Understanding the smart city by transcending ontology

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This paper provides a conception of the smart city which takes into account what the smart city brings into the world which is new and original. This approach provides a means of dealing with the complex influences humans and digital systems will have on each other in the mature smart cities of the future. I will first review traditional accounts of the smart city and derive from them the essential characteristics common to these visions. I will then show how these characteristics can be best understood through Actor-network theory and construct an account of the smart city as an autopoietic system in which humans and devices are co-constituting actants. Finally I shall develop this into an original conception of the smart city as a new type of thing - an "integrated domain."

Accounts of Smart Cities

There is no single definition of what constitutes a smart city. Accounts divide into three schools regarding definitions of the smart city. One school defines the smart city in terms of what we can do with it. Here we find topics such as innovation policy (Komninos, Schaffers, & Pallot, 2011), smart governance (Vinod Kumar, 2015), urban planning (Zygiaris, 2013), improved sustainability (Bowerman, Braverman, Taylor, Todosow, & Von Wimmersperg, 2000) and similar large-scale management tasks. Others define the smart city in terms of its material construction. Here the focus is mainly on devices comprising the Internet of Things and their interactions. Some focus on issues of designing smart sensors and other components, such as weight detectors in roads (Hancke, Silva, & Hancke, 2013). Others focus on the interactions between components, such as sensor networks (Filipponi et al., 2010) and human-sensor interactions (Pettersson et al., 2011). Others attempt to make sense of both usage and components through the development of organisational models. For example, Jin proposes a four-layer model of sensors, networks, cloud-based data management and service delivery (Jin, Gubbi, Marusic, & Palaniswami, 2014). Organising smart city components and operation into layers is fairly common. Balakrishna's four-layer model (Balakrishna, 2012) is almost identical to Jin's, while others adopt a three-layer (Atzori, Iera, Morabito, & Nitti, 2012) or five-layer (Pettersson et al., 2011) model. In contrast, some have attempted more conceptual organisational models. For example, Filiponi (Filipponi et al., 2010) suggests a vertical model based on our understanding of the space in which activity occurs, such as car, home, office and civic space.

Attempting to make sense of this range, *Smart Cities: Definitions, Dimensions, Performance, and Initiatives* (Albino, Berardi, & Dangelico, 2015) examined twenty-two accounts and cross-referenced these with urban developments which labelled themselves as smart cities. Their conclusion was that a single definition was impossible because of wide variations in the meaning of common terms. Attempts to include everything inevitably cover too much or too little. At one extreme we have very broad statements, such as a smart city is that which uses “social, mobile and sensor-based technologies … to create more productive alignments between%1 (growing) demand and (constrained) resources.” (Hartswood, Grimpe, Jirotka, & Anderson, 2014, p. 3). At the other extreme, *Getting Smarter About Smart Cities* defines a smart city as:

“using networked, digital technologies and urban big data to tackle a range of issues, such as improving governance and service delivery, creating more resilient critical infrastructure, growing the local economy, becoming more sustainable, producing better mobility, gaining transparency and accountability, enhancing quality of life, and increasing safety and security.” (Kitchin, 2016, p. 9).

Deployment of smart city technology is more likely to be accomplished by industry than by academic researchers. It is therefore worth considering the vision of the smart city which industry offers. Cobham Plc is a major player in the smart city sector, with annual turnover of $US3 billion (Cobham PLC, 2011). Their Tactical Communications and Surveillance division provides a range of smart city technologies. Their smart city sales brochure (Cobham PLC, 2014) offers a 5-layer model, ranging from an “IP mesh” which allows any type of sensor to communicate with any other, through several layers of device type, including integration of personal devices as sensors (with and without user knowledge), through to management systems.

Certain characteristics are held in common throughout all these accounts. They agree that smart cities require a ubiquitous heterogeneous sensor network which provides information about the inhabitants, their environment and service delivery. This has been referred to as an “IP mesh” (Cobham PLC, 2011, p. 3) and as an “underlying sensor fabric” (Balakrishna, 2012, p. 224). These sensors must report their data to other devices. Some of these communication patterns can be predesigned, while others must be created on an ad hoc basis in response to the movement of the inhabitants and machines such as drones, robots and cars (Guo, Wang, Zhang, Yu, & Zhou, 2013; Pettersson et al., 2011). There is general agreement these devices will be embedded in the civic environment, the home and other personal spaces (such as the car), worn on the person and implanted within the body. While many accounts assume that all data processing will occur in the cloud, this is not inevitable. A contrasting view can be seen in the concepts of fog computing (Bonomi, Milito, Zhu, & Addepalli, 2012; Petrolo, Loscrì, & Mitton, 2015) and user-controlled personal data stores (Service Systems Group, 2015b). Under these views significant data processing can be done locally, either within sensor devices themselves or through locally situated data processing units (Service Systems Group, 2015a). Indeed, such local processing is likely to be more secure and efficient (Dainow, 2015; Langheinrich, 2001).

The aim of this paper to provide a comprehensive definition of the smart city which can serve as the foundation for ethical analysis by reconceptualising the smart city. Current ethical concerns for the smart city tend to be limited to specific issues associated with specific technologies within the smart city, such as cars (Jaisingh, El-Khatib, & Akalu, 2016) or location detection (Martínez-Ballesté, Pérez-Martínez, & Solanas, 2013). My aim is to provide a comprehensive framework for analysis of any ethical issue, especially issues which are emergent from the interaction of multiple systems and which therefore cannot be predicted from any one sub-system. This requires developing a new vision of the smart city which is able to account for the complex nature of interactions within it.

The City of the Future

We must first place the smart city within a future studies framework. This is because the smart city does not yet exist, but is rather in an early stage of development. Given that the smart city does not yet exist, current technologies related to smart cities must be regarded as interim steps towards what will be the ultimate deployed solutions in mature smart cities of the future. We must therefore regard current smart city technologies as in flux, as unfinished, and their features as mutable and almost certainly subject to change. Furthermore, our current understanding of the path to the mature smart city is highly uncertain. The issue of ad hoc networking illustrates that even the direction of innovation is in dispute. Much concern in smart city development focuses on issues of communication between devices. It is widely recognised that mobile devices, autonomous systems and moving people will all necessitate the dynamic creation and uncreation of unpredictable network patterns. Known as "ad hoc networking", some see great advantages in this (Boldrini, Conti, Delmastro, & Passarella, 2010; Guo, Wang, Zhang, Yu, & Zhou, 2013) seeking only to make it reliable and secure, while others (Pettersson et al., 2011) see its chaotic and unpredictable nature as something which needs to be controlled. Clearly, it is difficult to anticipate the ultimate role of ad hoc networking in the smart city at a stage when we cannot even agree on whether it should be promoted or inhibited.

Teleological accounts, concerned with urban governance, typically focus on the ways in which smart cities can solve today's problems. However, it is unlikely that the contentious issues of smart city governance are predictable in any detail. Prior to the invention of the world wide web, no one could have anticipated the need for domain name registries, nor the political fighting which would emerge around them. We can therefore anticipate that at least some important forms of governance of mature smart cities are yet to be imagined. Similarly the most pressing issues confronting mature smart cities will include those we cannot yet anticipate because they will derive from the unknown nature of currently unpredicted technologies and the currently unpredictable patterns of usage which will evolve around them. Considering that new technologies always create negative side-effects (Cardwell, 1994; Derry & Williams, 1993), it is inevitable that the solutions we deploy in creating the smart city will generate problems of their own – which we also cannot predict.

Placing the smart city within a futures perspective therefore means understanding that we do not know how it will be made, how it will operate, or how it will be managed. Conceptions of this future unknown smart city must therefore frame themselves in terms which are not dependent upon knowledge of the specific details of future smart technologies. Fundamental to the futures approach is an understanding that the smart city is not today's city with some digital tech laid over the top of it, any more than the modern city is just a Victorian one with cars instead of horses. The mature smart city will be a fundamentally different type of environment from any we have previously seen. The key change will be the presence of ubiquitous ICT technologies. Through all of history the human built environment has been a largely dumb. It has not had the ability to do things to us except in the most gross fashion and it has not had the capability to know us. The capacity of the environment to obtain data and to respond to human action represents a fundamentally new type of built environment for human living.

We can therefore understand the characteristics of the smart city best if we consider it as a form of built environment. Accounts of smart cities focused on the technical infrastructure typically treat it as consisting of intelligent devices embedded within dumb materials. However, the number, ubiquity, heterogeneity and invisibility of most devices will cause humans to understand and act towards the object in which the devices are embedded rather than the devices themselves, and in many cases deal with aggregations of devices rather than individual ones. Attempting to account for this interaction between human and device in terms of component types and processes is impossible on two grounds. Firstly, we cannot know the nature of these future devices or what patterns of usage humans will develop towards them. Secondly, the number and heterogeneity of these devices and variability of human relations with them across differing contexts renders attempts to understand on the basis of technical type impossibly complex. We must therefore cease to talk in terms of technical components and instead identify the functional characteristics which can unite the various heterogeneous technical forms.

The following will identify the essential functional characteristics of the smart city. Thereafter I will use these to synthesise a conception of the smart city as a new type of being.

Ambient Intelligence

'Ambient intelligence' is defined as technology which embeds input, processing or response ubiquitously through the environment (Ikonen, Kanerva, Kouri, Stahl, & Wakunuma, 2010). With its ubiquitous sensor mesh the smart city is the ideal type for ambient intelligence. As a lived experience, people will know the smart city not as individual components and discrete processes isolated within atomised sections of their lives. Instead the smart city will be experienced as a seamless experience as one moves from house to car to work, from one context to another. People will not think of themselves as moving from one discrete situation to another, they will simply experience themselves as going about their daily life, an unbroken stream of changing contexts seamlessly merging from one to the other. The following quotes from the auto industry illustrate current steps in this direction:

Matt Jones, Director of Future Technology at Jaguar Land Rover:

"We very quickly discovered that customer expectations really aren't based on our Jaguar Land Rover competition - they're based on the smartphone. They're based on the tablet. They're based on the home entertainment experience…. Consumers expect to be able to download an app, get into the car and discover a seamless integration between the device and the automobile." (Bedigian, 2016, p. 7)

John Schnoes, Programme Director of Vehicle Information Technology at Nissan:

"It all comes down to smart device connectivity. People are really looking to have that sort of seamless experience when they've been working on their phone and then they walk into their car and they expect the platform to know what they've been doing." (Bedigian, 2016, p. 8)

Emergent in-car systems reveal that cars will communicate with their environment in a deep fashion. Usage-Based Insurance systems analyse driver behaviour, including time of day, acceleration rates, cornering and locations travelled in order to dynamically set insurance premiums. Emerging collision-detection systems can automatically contact emergency services with essential details, including the identities of the occupants and which seatbelts were fastened. Car maintenance systems will access user calendars to determine the best time for maintenance appointments. Already today, the Ford SyNC systems can accesses the driver's medical data to remind them when to take their medicine (Jaisingh et al., 2016).

We can see similar cross-context connectivity trends at the urban management level. For example, Restore NV provides demand management systems, such as those controlling electrical grids, including five of Europe's largest grid operators (Restore NV, 2016). Their newly announced smart city electricity management system, FlexPond, monitors individual home appliances to predict electrical load within individual homes (Restore NV, 2017). This information can be cross-referenced with local weather patterns and the number and type of household occupants to greatly improve demand prediction (Hancke et al., 2013).

Other smart city systems treat personal digital devices as mobile components of the smart city infrastructure. This is not limited to using such devices merely as sensors or as personal identifiers. Patterns and content of social interaction between people can be analysed to anticipate movement patterns, shared use of resources, and even as a way of determining appropriate security levels to create between devices (Atzori et al., 2012). Others have tested analysis of social networking to guide structuring of ad hoc networks (Boldrini et al., 2010). China plans to take this further, creating a "social credit system" by monitoring many aspects of personal conduct, including honesty and conformance to socialist behaviour. A key aim is to reduce social diversity. This system will offer rewards and punishments through differential access to smart city services (State Council of People's Republic of China, 2014). Some smart city services will even penetrate the physical body. Already being tested, body sensor networks embedded into the environment communicate with implanted medical devices, such as heart monitors, to anticipate and react to medical emergencies (Lo, Thiemjarus, King, & Yang, 2005). Such health sensor networks can also monitor some vital signs externally, such as skin temperature, respiration, sleep patterns and diet (Hancke et al., 2013; Y. Kim, Kim, & Lee, 2008).

The picture which emerges is one in which smart city services must take data from a ubiquitous digital ecosystem, in which digital devices are embedded throughout the fabric of the built environment - "transforming everyday objects into information appliances," (Botta, de Donato, Persico, & Pescapé, 2016, p. 691) but also including devices carried by people and embedded within their bodies (Balakrishna, 2012; Botta et al., 2016; Filipponi et al., 2010; Jin et al., 2014; Pettersson et al., 2011). This data will be integrated across contexts, technology forms and purposes so as to create an integrated sensing and response environment (Psyllidis, 2015). Such an "intelligent information infrastructure" (ITU-T, 2008, p. 2) is clearly an ideal type for ambient intelligence.

Artificial Intelligence

Central to the vision of the smart city is algorithmic intelligence, or "soft AI" (e.g.: expert systems and software agents) (Ikonen et al., 2010; Komninos, 2006). It has been estimated that a typical smart city will contain around 1 trillion nanoscale devices (Balakrishna, 2012). A central paradigm implied within the concept of the smart city is that the smart city will generate new data and novel possibilities for action as a result of the integration of data from disparate domains (Picon, 2015). There is a general acceptance that this will require machine learning and other forms of soft AI (Balakrishna, 2012; Nam & Pardo, 2011). In addition to common expectations that soft AI will provide core functionality through cloud computing and big data, it has been suggested soft AI will need to be embedded at local level to support ad hoc networking and to facilitate more rapid system responses due to the sheer scale of data (Komninos et al., 2011).

Robotics

Robotics refers to ICT devices possessing the ability to move autonomously (Ikonen et al., 2010). Self-driving cars (and possibly drones) are expected to exist within smart cities (Balakrishna, 2012; Jaisingh et al., 2016; Petrolo et al., 2015). The home will see robotic devices such as vacuum cleaners and similar devices, sometimes known as mobile IoT (Gubbi, Buyya, Marusic, & Palaniswami, 2013). The specific details of which robotic devices will exist within the smart city need not concern us for the purposes of this analysis. The important point is that the smart city environment will involve both humans and machines moving within the same spaces. Just as the introduction of the car eventually led to the rise of pedestrian crossings, so an environment of moving machines will require adjustments in human behaviour to take them into account.

The smart city as a socio-technical system

The vision which has emerged of the smart city places technical artefacts and humans as equally powerful actants. Digital devices will communicate amongst themselves and engage in negotiations (Atzori et al., 2012; State Council of People’s Republic of China, 2014) as they create ad hoc networks, including event-driven networks (Filipponi et al., 2010), contextual networks (Boldrini et al., 2010) and social networks (Atzori et al., 2012; Boldrini et al., 2010). Thus the network structure of the smart city will be created by the devices as well as by the humans. Device activity will respond to human activity. Humans will respond to these responses. Furthermore, digital devices will have their own needs, which will require consideration by humans. Accordingly we can view digital devices as causal agents in a smart city on the same causal level as humans.

Systems theory has dominated urban planning since the 1960’s (Taylor, 2005) and permeates approaches to the smart city (Söderström, Paasche, & Klauser, 2014), which is seen as a complex system, or system of systems (Albino et al., 2015; Chourabi et al., 2012). Actor-network theory (ANT) (Latour, 2005) provides a theoretical framework for incorporating the smart city’s digital agents and their needs into an interactive relationship with humans. By treating both devices and humans as co-existing within the same structure, ANT provides a framework by which we can attribute to artefacts causative properties within the human dimension and vice versa (Tabak, 2015). A further advantage of ANT is the lack of need to specify the details of each node within the network (Law, 1992). This suits a both a heterogeneous device mix and a futures approach which accepts that we cannot know what final forms smart city technology will take. In addition, ANT has been used to account for pathways in ICT innovation (R. Kim & Kaplan, 2005; Lamb & Kling, 2003) and so applying it to smart cities can be linked to that research. This offers the potential for an explanatory framework which can account for the dynamics of the innovation which will lead to the mature smart city.

The arrival of an intelligent responsive environment, especially one containing autonomously mobile agents, requires changes which must affect people. This will inevitably bring the needs of the digital agent into conflict with the needs of the individual or society, just as cars require roads and regulations which gives them effective rights over people in some circumstances. Ambient intelligence systems may also require changes in human behaviour, raising the possibility that our environment will train us to suit its needs (Soraker & Brey, 2007). In other cases, we can anticipate that personalisation of shared spaces will result in differences between people regarding how much any particular personalisation suits them. This may range from the trivial, such as ambient temperature, to the existential, such as access to sensor networks required for medical implants. As the Chinese social credit system shows, some people will be forced to make compromises in order to accommodate aspects of personalisation preferred by others within the shared space. It is not inevitable that spaces will be personalised to suit the majority, or that minority needs will be accommodated. It is possible that environmental personalisation will become a zone of contention and power dynamics. Given the potential impact alteration of spaces can have on the individual, control of personalisation of shared spaces could easily become a path to domination of others. Hence control of the digital actants within the smart city's actor-network can be expected to grant influence and power over the human actants.

The fact digital actants have their own needs which require changes by humans raises the issue of secondary rights. Digital objects, while requiring humans change, do not, in and of themselves, originate that need. They are operational units whose existence is caused by humans and to whom the benefit of their activity is given to humans. They are not self-originating and they are not in receipt of the benefit of their activity. As a result, while it appears that the object is competing with the person, in actual fact the object stands in proxy to another individual - the beneficial owner. While the situation may look like competition of rights between the individual and the object, it is in fact competition between one individual and another in which the device stands as proxy for the second individual. In such circumstances it is not a new situation. However, the rise of AI systems may mean that, while other humans benefit from the satisfaction of digital needs, they did not originate those needs. Instead we may encounter needs that were generated by the AI system as a result of its own development and self-learning. Given the expected complexity and scale of a smart city's ambient intelligence, there are likely to be many contexts in which we cannot distinguish between human-originated and self-determined needs of digital actants. It is likely that some needs will arise via a combination of human-originated and self-determined needs. It is likely that many human goals will be accomplished via methodologies which were self-determined by autonomous systems. Where a self-determined methodology has negative effects on other people, we can expect some form of resistance. Such a situation represents an interactive process between human and digital system, in which human decision-making contends with the autonomous decisions of a digital actant. In that ANT considers nodes as "black boxes" (Tabak, 2015, p. 37) and does not need to specify their internal details, it is not confounded by the issue of whether an activity derives from the device or some beneficial owner.

By treating the human and the digital components of the smart city as equal actants within the same environment, ANT also offers a dimension of analysis which is essential for a full understanding of the interactions of the human and the digital – the perspective of the digital device. By its very nature, a digital device cannot know the physical world. What a device knows is what its sensors generated as input. For example, a thermostat does not respond to the temperature but what the sensors tell it the temperature is. If the sensor malfunctions, or we game it, the thermostat control will still respond to what the sensor tells it, not what the material reality is. Hence digital devices do not know the physical world, but inhabit a totally digital environment. What they know of us and how much they know is determined by our representation in digital terms. Smart city systems will not respond to us; they will respond to our digital representations. If those digital representations are incorrect or incomplete, then the analysis of us will be compromised and the delivery of services will suffer.

Accordingly, ANT offers us a conception of the smart city as a complex network of heterogeneous actants. Under this view we recognise that these actants may be a single digital device, an individual person, a group of people, a group of devices, or a mixture of both. We can build on this conception by considering the logic which must be inherent within operational smart cities in order for them to exist.

Doing so will provide a more detailed understanding of the nature of the smart city system, revealing its essential quality of autopoiesis.

Autopoiesis in the Smart City

The concept of autopoiesis originates in theoretical biology in the 1970's (Varela, Maturana, & Uribe, 1974) and accounts for living things, such as cells and bodies, as self-sustaining systems. The concept was made accessible to the social sciences by Luhmann (Luhmann, 1986) in the 1980's. Systems theory holds that the defining characteristics of a system are not determined by the properties of the components but by the patterns of their relationships (Varela et al., 1974). Autopoietic systems are those which are self-maintaining in the face of changing stimuli, either changes inside the system or within the system's environment. To be autopoietic, systems must also regenerate the essential patterns which characterise that system and internally generate the components and processes required to maintain it (Maturana, 1981).

The original theories of autopoiesis were designed for biology and seemed limited to that field by the necessary characteristic that an autopoietic system generate its own components (Maturana, 1981; Varela, Maturana, & Uribe, 1981), a process known as "material self-production" (Di Paolo, 2005, p. 433). However, this issue is really one of the minimum granularity in one's ontological schema. Living systems are the ideal type for theories of autopoiesis, but they do not create atoms or many of the molecules they depend on. No autopoietic system generates the materials from which the components considered necessary for characterisation of that system as autopoietic are created. All autopoietic systems exchange input and output with their environment (Luhmann, 1986). Hence autopoietic systems need only self-generate the components which are the most proximate cause of their characteristics and self-maintenance.

Building on this approach, Luhmann reworked the concept of autopoiesis to bring it into the social sciences (Luhmann, 1986). Under his account social systems are autopoietic systems which use communication as their characteristic form of autopoietic generation. The atoms from which social systems are constituted are communications, which are recursively produced and reproduced. Luhmann defines communications as being composed of three elements; information, utterance and understanding. As such, a communication is an event. A social system as autopoietic is a "network of events which produces itself … the reproduction of events by events." (Luhmann, 1986, p. 175). The critical point is that the elements of an autopoietic system which make it autopoietic are those which maintain autopoiesis in the face of destabilising forces and which give rise to characteristics of autopoiesis which distinguish it from other autopoietic systems. The basic unit of social autopoiesis is this communicative triad of information, understanding, and utterance (Luhmann, 1986).

This pattern is easily visible within the smart city. It is the minimum necessary characteristic of digital device interaction able to constitute any of the essential operational characteristics which can constitute a defining characteristic of an ambient intelligence. Within ambient intelligence this communicative pattern is visible as the ability to accept input ("information"), process it in some way ("understanding") and consequently produce output ("utterance"). In order for any device to participate in an ambient intelligence it must be able to perform these three processes. The actant within the autopoietic system is thus defined by its ability to accept input, process it and respond. The response becomes input for a connected node and thus the process perpetuates.

However, smart cities will not be constituted by closed communicative systems in which digital devices communicate only with each other. As we have seen, the smart city will be characterized by the close integration of digital devices and humans (Bicocchi et al., 2013). Much of the digital device's input will derive from humans, both as intentional commands and as unconscious input (such as movement and reactions to digital service delivery). Hence both devices and humans will react to each other and stimulate new responses in turn. In this way both humans and digital devices will be seen to engage in communicative patterns amongst their own kind and across the human-digital divide. Furthermore, once begun, this system becomes self-referential and recursive, as each responds to the response of the other, and so the system becomes self-sustaining and autopoietic.

If we accept this communicative triad as the atomic unit of a living smart city, there exists a temptation to see this as two societies, one human and one digital, communicating within themselves and only interacting with the other by means of constituting its environment – humans embedded in a digital environment and digital devices surrounded by humans. However, significant portions of human communicative action will be mediated by the digital environment, while that digital environment's communicative patterns will respond in myriad ways to every human action. Under such circumstance, few communicative triads can be said to be purely human or digital; the overall patterns of communicative flow will be the result of both human and digital components. Some have highlighted the tight interaction of the ICT and human communities in smart cities under the terms 'collective sensing', 'collective awareness' and 'collective action' (Bicocchi et al., 2013). However, such analysis does not incorporate the deep fusing of both collectives which must occur. I am not suggesting this fusion constitutes some form of hybrid human-machine society, or that we should redefine the term 'society' to include digital systems. Some have used the term 'smart society' to characterise the society within a smart city (Hartswood et al., 2014), but this refers to a human society using smart city services. This is a useful definition to maintain because it refers to real issues and to a clearly definable zone of concern. I therefore believe we need a new term for this new phenomena, one which refers to an autopoietic system constituted of communicative triads between nodes which may be digital, human or both. I propose to call this an 'integrated domain'.

Defining integrated domains

An integrated domain is a socio-technical system in which humans and digital devices co-mingle in a manner such that it becomes impossible (or even meaningless) to identify the origins of patterns within the system as being either human or digital. An integrated domain is autopoietic. The autopoiesis of an integrated domain derives from a close coupling of nodes such that output from one node cannot avoid generating a reaction in another node, combined with the unavoidable structure of the atomic node, which is the communicative triad event. An integrated domain consists of two collectives integrated into a mutually dependant and co-creative partnership. One collective consists of a human smart society. This is a form of human society existing within an ambient digital environment, such that human perceptions, actions and intersubjectivity are unavoidably mediated and influenced by this ambient digital environment. The other (non-human) collective consists of an autopoietic system of digital devices and networks based on the communicative triad. However, neither collective possesses strict boundaries against the other, but rather the two intermingle. We can thus describe each as separate for theoretical purposes, but it is not possible to account for characteristics of, or phenomena within, either without reference to nodes within the other. Any discussion of the nature and processes within smart society on the human side or the smart city digital components must draw on aspects of the other, and so any explanatory discussion of either must occur at the higher ontological level of the integrated domain.

The concept of autopoiesis includes a persistent demand for regeneration (Varela et al., 1981). This holds true for integrated domains as well. However, whereas in a living organism it is the material constituents which need regeneration, in an integrated domain it is the communicative triads. Communicative triads are events, not states (Luhmann, 1986). Patterns of communication thus form an actor-network in which the nodes are events constituted of communicative triads, whose material base may be a human, a digital device, or a group of either or both. It is essential that groups of people and/or devices can be treated as equal actants within this model because groups will interact and communicate with individual devices or people in the smart city, and vice versa. An example of a combined group which would yet constitute a single node is a car in motion. The car is composed of a wide range of interacting devices. Much of the operation of these devices will be influenced by the actions of the driver, and vice versa. However, this complex system may communicate data aggregated from many of these systems in combination with the driver’s actions to a single device, such as a traffic light. Similarly, a single device, such as a traffic light, can be expected to communicate with dozens, if not hundreds, of similarly complex entities. We thus see that the communicative system is integrated not just across differences of materiality, but also spans (or ignores) multiple ontological levels.

Social machines

The primary unit of the integrated domain is the communicative triad. This is a three-stage process consisting of input, processing and output. It constitutes an individual node within the network structure of the integrated domain. This network structure is dynamic, variable and self-sustaining. Under this view the smart city is seen as a system possessing autopoiesis. Each node is not a state, but a process or an event and their influence on the system’s patterns is not determined by their material base. The material base of each node may be an individual processing unit, such as an single digital device or an individual person, or it may be constituted by a grouping of devices, people or even a combination of both. Each node may also be constituted by the aggregated activity of a group of sub-nodes. These sub-nodes may themselves may be constituted by another group, an overlapping set of groups or an individual person or device. It is likely that the cascade effect of events and responses, combined with the volume and complexity of communication will make it impossible, or even meaningless, to ask whether a feature of note is the product of one node or many, human or digital. The communicative triad therefore constitutes both the atomic unit for, and the essential pattern of, interactions within the smart city. It provides us with a framework for handling the way in which smart city processes can transcend normally distinct ontological boundaries and frequently renders them meaningless. This deep interconnectedness of materially indeterminate nodes combines with ad hoc networking and human response variability to create a highly complex network structure.

As an autopoietic system, many of the communicative triads will be concerned with internal states of operation within both digital assets and humans. In the case of digital assets, much of the communication can be expected to be concerned with issues such as maintenance and management of digital technology. This monitoring represents self-awareness. This is not awareness in the human sense, implying sentience.

However, as a system, the integrated domain is aware of its internal processes. Through the component of the human, the integrated domain possesses the human level of understanding and meaning-giving. An integrated domain is therefore a self-aware, autopoietic system composed of actants who may be digital or human, individual or group.

We are already witnessing early examples of hybrid systems which combine human and digital devices under the label of "social machines". Social machines are defined as "socio-technical systems which involve the participation of human individuals and technological components…able to extend the reach of both human and machine intelligence [by] supporting capabilities that less integrated systems might find difficult to accomplish" (Smart, Simperl, & Shadbolt, 2014, pp. 55–56). Social machines are the early fore-runners of the integrated domain which will form the fabric of future smart cities.

Conclusions

The close integration of a huge number range of devices and systems makes any model of the smart city which depends upon material differences impossibly complex and inevitably incomplete. The deep integration of various ontological levels, from the individual nano-sensor to the global cloud, makes it impossible to comprehend causes of individual actions within the smart city. Both of these issues are further magnified by the expectation and need of the human lived experience to transcend these technical distinctions. Discussion of smart cities in terms of enablers of human activity, such as urban management, do not adequately incorporate into their models the deep fusion of digital cognitive processes with human deliberations. This confronts us with the necessity for a model which does away with such distinctions. Instead we have postulated the smart city as an "integrated domain". Under this view the digital and the human, the individual and the group, all hold equal status as nodes within a complex, dynamic autopoietic system known as a smart city. The concept of the smart city as an integrated domain provides a framework through which it is possible to consider issues which transcend traditional IT boundaries, issues deriving from complex interactions of multiple agents of multiple types. It provides a unified model by which to account for bidirectional interactions between management-level civic aims and individual device functions, between groups and individuals, between digital devices and humans. It further provides us with the ability to anticipate issues within mature smart cities without knowing the details of the technologies to come. Models like this, which seek to incorporate the human and the digital into integrated systems, offer our best hope of anticipating the future issues of smart cities.

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