L'integrazione delle infrastrutture urbane fisiche e digitali: il ruolo dei "Big Data"

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Abstract. Le molte evoluzioni nell'ambito della gestione delle informazioni, l'affermarsi dei concetti di Big Data e IoT (internet of things), lo sviluppo e la diffusione della sensoristica stanno aprendo a innovativi scenari e delineando nuove questioni rispetto alle attività conoscitive e decisionali, con declinazioni specifiche se considerate in relazione all'ambito applicativo delle infrastrutture e dei beni edilizi e urbani.
A partire da queste premesse, obiettivo del paper è delineare l'attuale quadro dei fattori tecnologici di innovazione e proporre alcune ipotesi circa i potenziali scenari futuri dei servizi di supporto alla gestione e allo sviluppo del territorio e dei manufatti edilizi a partire da diverse possibili forme di integrazione tra infrastrutture urbane fisiche e digitali. Nell'ambito delle infrastrutture, l'analisi del ruolo dell'informazione rispetto all'interazione tra materiale e immateriale pone una serie di questioni interpretative che il paper tratteggia.

Parole chiave: Big Data, Infrastrutture digitali, Internet of Things, Manutenzione urbana

Introduzione

Le evoluzioni tecniche e scientifiche nel campo della gestione dell'informazione stanno rapidamente ridefinendo paradigmi e confini di riferimento, scale di applicazione, strumentazioni e loro campi d'azione. Concetti come Big Data e IoT "internet of things" stanno sostituendo i tradizionali concetti di data base, di knowledge management, di rete, le dinamiche di decisione, le modalità di simulazione e previsione dei fenomeni e le capacità di risposta dei sistemi. Sebbene il termine "Big Data" sia stato utilizzato spesso impropriamente negli ultimi anni, esso rappresenta un fenomeno culturale, tecnologico e educativo di rilevanza cruciale nell'attuale prospettiva di ricerca. Il rapporto "Big Data, Big Impact" del Davos World Economic Forum del 2012, ha identificato i dati come una nuova classe di beni economici alla stregua della valuta o dell'oro (Lohr, 2012). L'uso dei "Big Data" inizia ad essere oggetto di studi anche nell'ambito della città per meglio comprendere le dinamiche urbane[1] e nella gestione delle infrastrutture[2]; ed è proprio la scala del territorio e delle sue infrastrutture che appare in questo momento la più adatta a rendere fecondo di possibili innovazioni il rapporto tra ambiente costruito e Big Data.
Queste evoluzioni prefigurano innovative possibili forme di integrazione tra infrastrutture urbane fisiche e digitali che disegnano potenziali scenari futuri dei servizi di supporto alla gestione e allo sviluppo del territorio. L'insieme di queste evoluzioni si inquadra all'interno di una logica "design-driven innovation" (Verganti, 2009) laddove si profilano modifiche dei paradigmi rispetto ai quali le infrastrutture sono gestite e utilizzate; modifiche di paradigmi che non sono direttamente richieste o attese dagli utilizzatori ma che, alla fine, potranno comportare un miglioramento della qualità dei servizi e la generazione di nuovi contenuti della domanda (Acklin, 2010).

Lo scenario delle evoluzioni tecnologiche: sensori, Big Data e Internet of Things

Una visione delle innovazioni possibili nella concezione e nella gestione delle infrastrutture della città e delle linee di ricerca e sperimentazione non può prescindere dall'interpretazione del dinamico scenario delle evoluzioni tecnologiche che connotano la contemporaneità.
Il recente sviluppo della sensoristica consente oggi di raccogliere dati facilmente ed economicamente su diversi aspetti dell'ambiente costruito, aprendo inedite possibilità di monitoraggio sia degli ambienti, che delle strutture. Per quanto riguarda il monitoraggio ambientale del costruito oggi si possono reperire sul mer-

The integration of physical and digital urban infrastructures: the role of "Big data"

Abstract. The several innovations in the field of information management, the establishment of the big data and IoT (Internet of Things) concepts and the wide development and dissemination of sensing technologies are opening up innovative scenarios and outlining new research topics in the area of knowledge gathering and decision making, with specific forms when applied on either infrastructures or buildings, or urban properties.
On this bases, the aim of the paper is to outline the state of the art of technological innovations and propose some hypotheses about potential future scenarios for the support services to the management and development of real estate and urban areas. The development of such services is envisioned through the integration of the physical and digital urban infrastructures. The analysis of the role of information in the interaction between tangible and intangible infrastructures poses a number of interpretational issues that the paper outlines.

Keywords: Big data, Digital infrastructures, Internet of things, Urban maintenance

Introduction

The technical and scientific developments in the field of information management are rapidly redefining paradigms and reference boundaries, as well as scales of application, tools and their application fields. Concepts like big data and IoT "Internet of Things" are replacing traditional notions of databases, knowledge management, networking, dynamics of the decision, methods for the simulation and prediction of phenomena, reaction capacity of the systems.
Although the term "big data" has been often improperly used in recent years, it is a cultural, technological and educational phenomenon of crucial importance in the current research perspective. In the report "Big Data, Big Impact" from the Davos World Economic Forum of 2012, the data has been identified as a new class of economic goods in the same way as currency or gold (Lohr, 2012).
The use of big data is becoming a new subject for studies aiming to better understand both the urban dynamics[1] and the infrastructure management[2]; and it is indeed the scale of urban areas and pertinent infrastructures where it appears nowadays possible to take advantage of innovative relationship between the built environment and big data.
These developments should be able to provide new possible forms of in-

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TAB. 1 | Tipologie di sensori disponibili per il monitoraggio delle condizioni dell'ambiente costruito, con uso e caratteristiche

Summary of sensor types for monitoring environmental conditions of the built environment with pertinent use and features

cato, a bassi costi, sensori (Kumat et al., 2016) che consentono di controllare in tempo reale la maggior parte degli indicatori di prestazione (Tab. 1).

Molti dei sensori messi a punto per gli edifici si prestano ad essere impiegati anche per la raccolta di dati alla scala urbana, affiancando quelli specificatamente dedicati alla raccolta dei dati relativi alle prestazioni delle infrastrutture come ad esempio i dati sull'utilizzo dei mezzi pubblici (Seaborn et al., 2014) o quelli sull'uso del bike sharing (Wood et al., 2011), etc.

Accanto ai sensori, un'altra importante, e ampiamente usata, fonte di dati per il monitoraggio dell'ambiente costruito è rappresentata dagli smartphones, che possono essere considerati a tutti gli effetti dei sensori portatili "gratuiti". Gli smartphone di nuova generazione rendono oggi potenzialmente disponibili a titolo gratuito una grossa mole di dati ambientali attraverso i sensori di cui sono dotati: accelerometri, Wi-Fi e sistemi di posizionamento globale (GPSs). L'accesso a questi dati costituisce un'opportunità senza precedenti per il monitoraggio delle condizioni ambientali degli edifici (eMarketer, 2014).

Oltre al monitoraggio del costruito in termini di ambiente, sia alla scala dell'edificio che a quella urbana, le possibilità di raccolta di informazioni si estendono anche alle strutture. Recentemente hanno trovato crescente spazio le applicazioni di nuove tecnologie per il monitoraggio strutturale (CSIC website2), sia in fase di costruzione che in fase di uso e gestione, quali: Radio-Frequency Identification (RFID) per la tracciabilità di componenti e delle relative informazioni all'interno di costruzioni complesse (Srinivasan et al., 2013), wireless sensor networks e sensori a basso consumo energetico basati su micro sistemi elettromeccanici (MEMS) per il controllo dei comportamenti delle strutture, fibre

tegration between physical and digital urban infrastructures, from which potential future scenarios can derive for the support services to the management and development of territory and urban areas. The comprehensive set of these developments can be considered a design-driven innovation (Verganti, 2009), as it is leading to a change of paradigm in the way the infrastructures are managed and used, that users do not expect, but that eventually will improve the quality of the services (Acklin, 2010).

The scenario of technological developments: sensors, big data and the internet of things

A vision of the possible innovations in the design and management of city infrastructures, as well as possible lines of research and experimentation cannot be divided from the interpretation of the contemporary dynamic scenario of technological developments.

The recent development of sensor technologies allows nowadays to easily and economically collect data on various aspects of the built environment, opening up to new possibilities for monitoring both the environments and the structures. With regards to environmental monitoring of the built environment today low costs sensors can be found on the market (Kumat et al., 2016) that allow to control in real time a vast range of the performance indicators (Tab. 1).

Many of the sensors developed for buildings can also be used for collecting data at the urban scale, alongside those specifically dedicated to data gathering on infrastructures performances, such as the use of public transport (Seaborn et al., 2014), bike sharing (Wood et al., 2011), etc.

TAB. 1 |

Sensor types	Use and features of sensors	Source
Temperature	Measure the temperature [°C]. Average range of values for standard sensors: −25 to 70 °C. Average resolution: 0.5 °C	(1) (2) (3) (4) (5)
Humidity	Measure the humidity [%]. Average range of values for standard sensors: 0 to 100%. Average resolution: 1%	(1) (2) (4)
Lighting	Measure the illumination [lx]. Average range of values for standard sensors: 200 to 1900 lx. Average resolution: 7.68 lx	(1) (2) (3) (4) (5)
Energy consumption	Smart meters/Power plug meters. System for temporal tracking of energy consumption per item [kW h]. Average range of values for standard sensors: dependent to the size, type and use of the building	(1) (2) (3) (4) (5)
Occupancy/ people movement	Systems for crowd counting, through WiFi, GSM or Bluetooth signals, or through volume recognition with depth sensors [Number of people]. Average range of values for standard sensors: dependent on the size, type and use of the building	(5) (6) (7) (8)
Air quality	Measure the concentration of CO_2 and TVOC [ppm] in the indoor environment. Average range of values for standard sensors: 0 to 2000 ppm. Average resolution: 20 ppm	(2) (4) (9) (10) (11)
Noise pollution	Measure the intensity of a sound [dB]. Average accuracy ±1dB (type 1 ANSI) ±2dB (type 2 ANSI)	(12)

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TAB. 2 | Le 5 V dei BIG DATA
The 5 V of BIG DATA

V	Volume	Exponential growth of data dimension
V	Variety	Different data format (e.g.: text, numeric data, audio, video, graphs, etc.)
V	Velocity	Continuous data flows for real-time information processing
V	Variability	Variable data structure and data interpretation, according to different users
V	Value	Increased business value due to the possibility to answer questions unachievable without data

ottiche per il monitoraggio di micro deformazioni strutturali (CSIC website3; Casas and Cruz, 2003) e tecniche di computer vision per mappare le fasi costruttive di un'infrastruttura al fine di create un archivio descrittivo della sua realizzazione (Stent et al., 2015).

Il patrimonio informativo che questa mole di dati genera introduce il tema centrale dei Big Data.

Il concetto di Big Data, introdotto per la prima volta nel 1998 da John Mashey (Laney, 2001; Diebold, 2012), è sintetizzabile come un patrimonio informativo ad alto volume, velocità e varietà che richiede forme innovative e sostenibili di elaborazione delle informazioni al fine di incrementare la conoscenza e migliorare il processo decisionale (Gartner, 2012) (Tab. 2).

La necessità di forme innovative di acquisizione ed elaborazione delle informazioni in termini di connessioni multiple e di ampliamento delle capacità di conoscenza, di decisione e di reazione apre ad un ulteriore ambito di innovazione, riferibile al concetto di Internet of Things (IoT).

Il concetto di IoT, che potrebbe aprire la strada ad un nuovo modo di monitorare e reagire (Santucci, 2009), è riferibile ad un sistema integrato di piccoli device e sensori posti sugli oggetti, e delinea nuove forme di comunicazione tra le persone e le cose e tra le cose stesse. Queste possibilità stanno crescendo significativamente negli ultimi anni grazie all'impulso portato dallo sviluppo delle tecniche di Machine-to-Machine (M2M) communication e di cloud computing (Zhu et al., 2011).

Secondo Haas et al. (2015), l'IoT è caratterizzata da tre componenti principali: (i) oggetti digitali con sensori integrati; (ii) hub o sistemi informatici che raccolgono i dati generati e ne fanno uso; (iii) una rete di comunicazione per connettere gli oggetti e i data storage, per consentire l'interazione tra tutti gli elementi coinvolti. Questa predisposizione strutturale gode di alcune proprietà intrinseche, quali l'interconnettività, l'eterogeneità, la dinamicità e la scalabilità.

Dunque, attraverso nuove forme di rilevamento, trasmissione e interconnessione dei dati, l'IoT offre potenzialmente nuovi mezzi e modelli per la conoscenza e il controllo dell'ambiente costruito. In questa direzione è interessante considerare, per il tema della gestione delle infrastrutture, le potenzialità insite in una possibile rete globale nella quale, in uno scenario di computing ubiquo (Bandyopadhyay et al., 2011; Darianian and Michael, 2008), le varie entità fisiche, attraverso dispositivi ad esse connessi (RFID, tag, sensori, attuatori) e schemi di indirizzamento, sono in grado di interagire tra loro e cooperare con altri "componenti intelligenti" limitrofi per raggiungere obiettivi comuni (Giusto et al., 2010) (Sommaruga et al., 2011).

Questi dispositivi, se applicati ai manufatti edilizi e urbani, possono incrementare le proprietà degli "oggetti muti" fornendogli capacità di rilevazione, calcolo, comunicazione e archiviazione dati.

In questa prospettiva, la concretizzazione del paradigma dell'IoT dipenderà dalla effettiva possibilità di integrazione dei sistemi RFID, che tracciano e dirigono "senza contatto" (comunicazione in prossimità) ed automaticamente gli elementi (Near Field

Beside sensors, another important and widely used, data source for monitoring the built environment are the smartphones, which can be considered multi-purposes "free portable sensors". Indeed the last generation smartphones can potentially make available for free a consistent amount of environmental data, through the sensors they are equipped with, such as: accelerometers, Wi-fi and global positioning systems (GPSs). The access to these data is an unprecedented opportunity to monitor the environmental conditions of the built environment (eMarketer, 2014).

In addition to the monitoring of the built environment, at the scale of both buildings and urban areas, the possibilities of data gathering are also extended to structures. In recent years growing attention has been payed to applications of new technologies for structural monitoring (CSIC website2), during the phases of either construction, or use and management, such as: Radio-Frequency Identification (RFID) for the traceability of components and the related information within complex constructions (Srinivasan et al., 2013), wireless sensor networks and low-energy consumption sensors, based on micro electromechanical systems (MEMS) to monitor the structural behaviour, fibre-optic for the micro monitoring of structural deformations (CSIC website3; Casas and Cruz, 2003) and computer vision techniques to map the construction phases of infrastructures in order to create a descriptive archive of their construction (Stent et al., 2015).

The amount of information that this massive data gathering generates introduces the central theme of big data.

The concept of big data, introduced for the first time in 1998 by John Mashey (Laney, 2001; Diebold, 2012), is summarized as a body of data at high volume, velocity and variety requiring innovative and sustainable forms of information processing in order to improve knowledge and improve the decision-making process (Gartner, 2012) (Tab. 2).

The need for innovative forms of data gathering and processing, in terms of multiple connections, of knowledge expansion, and decision-making improvement, opens up a further field of innovation that refers to the concept of the IoT.

The IoT, which could open new ways of performing sensing and responding assets management (Santucci, 2009), refers to an integrated system of small devices and sensors placed on the objects that outlines new forms of communication between people and things and between things among themselves. These possibilities are growing significantly in recent years due to the contribution provided by the recently developed techniques of Machine-to-Machine (M2M) communications and cloud computing (Zhu et al., 2011).

According to Haas et al. (2015), the IoT is characterized by three main components: (i) digital objects with integrated sensors; (ii) hub or computer systems that collect and use the data generated; (iii) a communication network for connecting objects and data storage solutions, to allow the interaction between all the elements. This structural layout has some intrinsic properties, such as interconnectivity, diversity, dynamism and scalability.

Therefore, through new forms of data sensing, transmitting and networking, Communication NFC) (Dong et al., 2010; Ngai, 2008), con le reti di sensori wireless (Wireless Sensor and Actuator Networks WSAN), che raccolgono, trasmettono e processano in modo integrato le informazioni distribuite (Ni et al., 2005) e con le tecnologie intelligenti che, sfruttando sistemi a intelligenza artificiale, sistemi M2M e sistemi intelligenti di elaborazione dei segnali (Atzori et al., 2010), permettono, usando "una conoscenza ampliata", di affrontare problemi di varia natura. Secondo Perera et al. (2013), nel 2020 ci saranno circa 50-100 miliardi di dispositivi connessi ad Internet, che permetteranno una crescente raccolta di Big Data dai vari nodi e la loro trasmissione attraverso cloud per l'archiviazione e il trattamento degli stessi (Rajeshwari, 2015). Al momento la ricerca in ambito IoT è ancora in fase iniziale e non vi sono ancora degli standard consolidati in materia; sono disponibili standard che propongono linee guida sull'architettura delle reti IoT (Tab. 3).

TAB. 3 |

EPCglobal. Brussels, Belgium	Joint venture, founded by GS1 (the international organization that coordinates the diffusion and the proper implementation of the GS1 standards system) that drafted the EPCglobal Architecture Framework, a result of the studies conducted by the Auto-ID Lab at MIT. The attention of EPCglobal is mainly focused on the development of the Electronic Product Code (EPC) to support the widespread use of RFID technology in modern commercial networks all over the world, and on the creation of global standards for the RFID EPCglobal Network integrated system. These standards are mainly aimed at improving the object visibility, namely its traceability and the awareness of its status (Atzori et al., 2010). GS1 is represented nationally by the Italian Indicod-Ecr, which deals with the implementation and diffusion of GS1 standards and other globally adopted communication standards
IEEE Standard Association (IEEE-SA). USA	Founded by the Institute of Electrical and Electronics Engineers (IEEE) which works to promote the innovation and the technological excellence in the world, with the aim of developing common standards at a global level. The IEEE-SA has published several studies in the field of IoT, such as the IEEE-SA IoT Ecosystem Study, which studies the IoT field from three main point of view: Market, Technology and Standards, and IEEE P2413, Draft Standard for an Architectural Framework for the Internet of Things. This draft defines a framework to structure the IoT system's architecture and it describes its different domains
International Telecommunication Union – Telecommunication Standardization Bureau (ITU-T). Geneva, Switzerland	Founded by the International Telecommunication Union (ITU), the United Nations agency specialized in ICTs, with the aim of providing specifications or standards, internationally accepted, in the field of information and communication technologies. In particular, the Study Group 20 is the one that works to satisfy the needs of standardization of IoT technologies and of the IoT applications to the Smart Cities and Communities (SC&C)
Ubiquitous ID Center. Tokyo, Japan	The Japanese organization in charge of developing and disseminating infrastructure for the automatic identification of physical objects and places in order to create ubiquitous computing environments. The Ubiquitous ID Center has developed the Ubiquitous ID Architecture based on the use of ucode tag

TAB. 3 | Standard IoT
IoT standards

the IoT potentially offers innovative ways for knowing and controlling the built environment. With regards to infrastructure management it is interesting to consider the potentialities of a possible global network in which, within a scenario of ubiquitous computing (Bandyopadhyay et al., 2011; Darianian and Michael, 2008), the various physical entities, through connected devices (RFID, tags, sensors, actuators) and logical frameworks, are able to interact and cooperate with other neighbouring "intelligent components", to achieve common goals (Giusto et al., 2010; Sommaruga et al., 2011).
These devices, when applied to building and urban assets, can increase the properties of "dumb objects" providing them with detection capability, computing, communication and storage of data.
From this perspective, the implementation of the paradigm of IoT depends on the effective possibility of integration between RFID systems, that track and direct automatically and "contactless" (communication in the vicinity) the elements (Near Field Communication NFC) (Dong et al., 2010; Ngai, 2008), and wireless sensor networks (wireless sensor and Actuator networks WSAN), that collect, transmit and process distributed data in an integrated way (Ni et al., 2005). The integration of these systems along with intelligent technologies based on artificial intelligence, machine-to-machine systems and intelligent systems for signal processing (Atzori et al., 2010), allows to deal with problems of various kinds, using "an expanded knowledge". According to Perera et al. (2013), in 2020 there will be around 50-100 billion devices connected to the Internet, which will allow a growing collection of data through various sensing nodes and their transmission via cloud networks for storage and further processing of the same (Rajeshwaris, 2015).
At present the research into the field of IoT is at an early stage and there are not yet common and consolidated standards; several standard have been issued offering guidelines to define the architecture of IoT networks (Tab. 3).

Experimental applications

The big data start to find experimental applications also in the context of buildings and infrastructure management.
For example, Holleczek et al. (2014) presented an approach for integrating two sources of data on the Singapore's urban mobility in order to identify gaps in the public transport network connections: the location of mobile phones and the use of smart cards for public transport. Saints and Ratti (2014) have used the spatial-temporal data (GPS) of taxi locations to estimate potential shared rides between users with similar origin-destination paths.
With reference to the use of big data for energy management Martani et al. (2012) have proposed to compare the energy consumption (collected through Smart thermostats) and the number of WiFi connections (as proxy for the presence of people) for individual rooms of the MIT campus in order to detect the areas of greatest energy inefficiencies.
Further on, Ratti and Claudel (2015) have proposed an adaptive system for localized heating that directs the heat only where it detects the presence of people through WiFi connections.

Applicazioni sperimentali

Il tema dei Big Data inizia a trovare applicazioni sperimentali nell'ambito della gestione di edifici e infrastrutture. Per esempio, Holleczek et al. (2014) hanno presentato un approccio per l'elaborazione di due fonti di dati sulla mobilità urbana di Singapore al fine di individuare lacune nelle connessioni della rete di trasporti pubblici: la localizzazione di telefoni cellulari e l'utilizzo delle smart card per il trasporto pubblico. Santi e Ratti (2014) hanno usato dati spazio-temporali (GPS) sulla localizzazione dei taxi per stimare potenziali corse condivise fra utenti con simili O-D (origin-destination). Con riferimento invece all'uso dei Big Data per la gestione dell'energia Martani et al. (2012) hanno proposto di confrontare nei locali del campus del MIT i consumi di energia per la climatizzazione (raccolti con Smart thermostats) ed il numero di connessioni wifi (come proxy della presenza di persone) al fine di rilevare le aree di inefficienza nell'uso dell'energia. In seguito Ratti e Claudel (2015) hanno proposto un sistema adattivo per il riscaldamento localizzato che indirizza il calore solo dove individua la presenza di persone attraverso le connessioni wifi.

Sicuramente, considerando i servizi a scala urbana, il ruolo delle amministrazioni cittadine diviene cruciale ai fini della implementazione dell'IoT. Infatti le città e i loro servizi rappresentano una piattaforma ideale per lo sviluppo e la ricerca dell'IoT, nonché un banco di prova per testare – anche con il coinvolgimento di altri soggetti interessati quali: gestori di reti e infrastrutture pubbliche e private, produttori di sistemi hardware e software per il monitoraggio e la comunicazione, associazioni di categoria quali referenti dell'utenza diffusa, ecc. – l'effettiva capacità del modello IoT di intercettare ed identificare le richieste, le esigenze e i bisogni espressi dal sistema complesso cittadino e di proporre automaticamente opportune soluzioni, (Vermesan e Friess, 2013). Tra i casi virtuosi europei, è possibile citare la città di Santander che ha intrapreso il progetto Smart Santander[3], nel quale si propone di implementare una infrastruttura IoT con l'installazione di dispositivi sparsi in diverse città. Questa sperimentazione mira simultaneamente alla valutazione dei servizi urbani e allo sviluppo di vari esperimenti di ricerca (Vermesan e Friess, 2013, nella direzione della creazione di ambienti urbani gestiti con il supporto di entità interconnesse[4].

Quali nuovi modelli per le infrastrutture urbane?

Lo scenario tecnologico delineato apre ad una riflessione sul tema dei sistemi per la gestione "smart" delle infrastrutture, materiali e immateriali, basati sul principio del sensing and responding, ovvero su un processo di attribuzione automatizzata di reazioni prestabilite a condizioni rilevate. L'implementazione di un processo automatizzato di risposta adattiva in tempo reale richiede la disponibilità di due elementi: un sistema in grado di monitorare il costruito in modo capillare e continuo (smart applications per il monitoraggio) e un modello di risposta alle condizioni rilevate, capace di processare patrimoni informativi ad alto volume, alta velocità e alta varietà.

Rispetto a queste prospettive la maggior parte delle attuali esperienze processa grandi quantità di dati per comprendere e analizzare le infrastrutture e il loro uso, e solo in parte (Ratti e Claudel, 2015) per reagire in tempo reale alle condizioni rilevate. Infatti, uno dei limiti principali all'uso dei Big Data per la gestione automatizzata di molti servizi, per i quali oggi è facile ed economico raccogliere dati, è che i modelli di analisi dati, utilizzati allo scopo di attivare reazioni prestabilite, non hanno ancora conosciuto uno sviluppo e un abbattimento dei costi, e quindi una diffusione, paragonabile

As a matter of fact, considering the services at the urban scale, the role of city authorities is crucial for the implementation of the IoT. In fact, the cities and their services represent an ideal platform for the research and development of IoT, as well as the ideal case to test – even with the involvement of other interested parties as: public and private infrastructures operators, supplier of hardware and software for monitoring and communication, associations representing diffused user, etc. – the actual capacity of the IoT model to identify the demands, requirements and needs expressed by complex cities and automatically propose appropriate solutions, (Vermesan e Friess, 2013).

The city of Santander has successfully implemented a EU FP7 project named Smart Santander[3], with the aim to implement an IoT infrastructure that involve the installation of thousands of devices spread across several cities. This trial aims simultaneously to evaluate municipal services and develop various research experiments (Vermesan e Friess, 2013), at the scope of creating urban environments managed with the support of interconnected entities[4].

Which new models for urban infrastructures?

The outlined technological scenario opens a prospective for the "smart" management of tangible and intangible infrastructures, based on the principle of sensing and responding. The sensing and responding is a process of automated assignment of predetermined reactions to observed conditions. The implementation of an automated process of real-time adaptive response requires two elements: a system able to monitor the built environment in a widespread and continuous way (smart applications for monitoring) and a model of response to the observed conditions able to systematically process a body of data characterized by high volume, high velocity and high variety.

Most of the current experiences make actually focus on processing large amounts of data mainly to understand and analyze the infrastructure and their use, and only rarely (Ratti and Claudel, 2015) to react in real time to observed conditions. In fact, one of the main limits to the use of big data for the automated management of services is that the data analysis models, used to activate predetermined reactions, have not known yet a development and a cost reduction comparable to that which has characterized the sensors' development and expansion (Kumar et al., 2016). In other words today it seems easier and cheaper to collect data, rather than to perform data interpretation. Even more difficult it is then rearranging the management processes of the built environment in relation to complex interactions systems (between data and data, between data and physical entities and between different physical entities). Therefore, what the technology potentially offers, if not supported by a vision of possible models of application to infrastructure management, risks to generate a redundancy of data, that could become of little use.

The logic of such models could be developed in line with the basic principle of the sensing and responding approach, articulated with respect to two factors: the temporal dimension and the graduality of the implementation. At this regard, it is possible to

TAB. 4 | Ipotesi di nuovi modelli per la gestione delle infrastrutture urbane
Hypothesis of new models for the urban infrastructure management

a quello dei sensori (Kumar et al., 2016). Ossia ad oggi appare più semplice ed economico raccogliere dati che non interpretarli e ridisegnare i processi di gestione dell'ambiente costruito in relazione a sistemi di interazioni complesse (tra dati e dati, tra dati ed entità fisiche e tra entità fisiche diverse).

Quindi ciò che potenzialmente offre la tecnologia, se non affiancato ad una visione di possibili modelli di applicazione alla gestione delle infrastrutture, rischia di generare una sovrabbondanza/ridondanza di dati che potrebbero diventare poco utili.

TAB. 4 |

Model	Description	Examples of application
Automatic sensing and responding	This is currently the most widespread and tested mechanism that is mainly applied to non-complex systems having few variables to measure and control and in which it is not expectable a propagation of effects of the actuating to other parameters or conditions. When a condition, monitored by one or more sensors, is reached then an a priori defined automatic procedure is activated. The aim of this model is to create the conditions for an automatic adjustment of non-complex processes in domains that are restricted to few variables.	- Switching off of air conditioning systems when it is reached a defined temperature in the rooms; - automatic activation of dimming systems in relation to direct solar irradiation; - request of maintenance intervention when defined control conditions (pressure drop for filter cleaning, temperatures for lubrication …) are reached; - automatic shutdown of rotating equipments (e.g. gas turbines for energy production) when defined vibration levels are reached; - automatic real-time reporting of the availabile parking place on a publically accessible portal; - automatic reporting of the location and availability of cars (car sharing) on a publically accessible portal.
Sensing and responding with imposed constraints	Model in which the principle of automatic activation of a procedure, based on a detected measurement, is conditioned by the simultaneous satisfaction of one or more predefined constraint conditions. The aim of the constraint conditions is to avoid that the automatic activation of the procedure can cause direct or indirect consequences on other elements (normally but not exclusively) of the same system. It is applied to bounded systems of low-medium complexity, in which they are well known the cause - effect mechanisms linked to some a priori predictable conditions.	- Activation of maintenance activities for an infrastructure to the achievement of preset conditions (condition based maintenance) but subordinating the intervention to budget constraints; - automatic activation of the gas-discharge fire extinguishing system, subordinated to the absence of people in the environments.
Sensing and responding with external decision and validation of the proposal	Model that starts from the mechanism of sensing and responding with imposed constraints but it does not involve the automatic implementation of the response to the stimulus that, although it is a priori defined and implemented in the system, it has to be submitted to verification and validation by a decision maker. It is applied to medium complexity systems, in which it is difficult to predict a priori all the interaction scenarios of the system with other potentially connected systems. The aim of this model is to manage the risk linked to the uncertainty generated by gaps of knowledge and/or interpretation of contexts and phenomena.	- Fire detection systems in which the alarm is automatically suggested by the system but it is not directly sent to the sound diffusion system. It has instead to be verified by a responsible person who, decides whether or not to activate the evacuation signal; - accident detection systems in highway with activation of a traffic control mechanisms from a decisional command center; - rail traffic control systems; - systems for pollutants monitoring in urban areas with actions on the management (limitation, partly or completely block) of cars traffic.
Sensing and knowing	Construction of cognitive frameworks based on the structured acquisition and restitution of a large number of data that are interconnected with each other and subjected to monitoring. The main objective is to describe synthetic frameworks of complex realities, referable to a predefined number of domains whose behavior can be represented and predicted on a statistical basis. The aim of this model is, based on the knowledge coming from the analysis of heterogeneous data, to allow the adoption of choices by appropriate decision makers (individual or networked).	- Command centre for the management of urban metabolism processes; - management of critical situations at the territorial scale through the elaboration and the comparison of alternative scenarios; - design of new infrastructures and simulation of their interactions with the existing; - construction of dashboards for effective decision-making at the territorial scale; - setting and constant updating (benchmarking) of sets of indicators for the assessment of integrated infrastructure performances.
Sensing and knowing in case of emergency	In case of exceptional events, characterized by several variables and by behaviors that are not stable and not always predictable on a statistical basis, this model involves the construction of information frameworks which are based on the simultaneous gathering and processing of large datasets. These data are representative of phenomena for which there might be interconnections even though not yet evident. The aim of this model is to increase the urban resilience, allowing decision makers (individual or networked) to manage risks in real-time through the adoption of choices based on: constantly updated data, instantaneous simulations, detection of the overcoming of threshold conditions.	-Shared control rooms (civil defense, infrastructure managers, public security, health, etc.) for the management of crisis situations; - management of critical infrastructures (communications, transports, health, energy,).
Sensing and learning/self learning	Construction of interpretative and descriptive frameworks that are based on the interpretation and analysis of a large number of data, respect to which correlations between different variables and quantities subjected to monitoring shall be identified. The aim of this model is to build - through the data analysis or the application of genetic algorithms based on the self-learning approach - interpretative models of complex networks for which it is not immediate to understand the relationships and dependencies between various measured parameters.	- Integrated management of transport infrastructures at the urban and suburban scale taking into account also data on events or conditions external to the considered transports systems (weekdays, holidays, sporting events, manifestations …); - detection of multi-risk scenarios in contexts characterized by high complexity and high level of systems' interconnection.

TAB. 5 | Esempi di classificazioni delle infrastrutture urbane
Examples of classifications of urban infrastructures

La logica di tali modelli potrebbe essere sviluppata in relazione al principio di base del "sensing and responding" da declinare in rapporto a due fattori: la dimensione temporale e la gradualità degli automatismi di attuazione. In questo senso è possibile proporre una ipotesi di lavoro che riconosce 6 livelli di declinazione del tema sensing and responding in relazione all'utilizzo dei Big Data e dell'IoT (Tab. 4, nella pagina precedente):
- sensing and responding automatico;
- sensing and responding con vincoli imposti;
- sensing and responding con decisione esterna e validazione della proposta;
- sensing and knowing;
- sensing and knowing in emergency;
- sensing and learning/self learning.

Prospettive di ricerca

Rispetto allo scenario tratteggiato non appare appropriato formulare delle conclusioni dal momento che gli scenari delle possibili applicazioni sono molteplici e tutti forieri di innovazioni e modificazioni dei paradigmi e delle prassi tradizionali caratterizzanti la progettazione e gestione delle infrastrutture urbane. Appare quindi più opportuno, a chiusura delle riflessioni esposte, individuare possibili ambiti di ricerca e sperimentazione che, per la natura pluri e trans-disciplinare che contraddistingue i temi trattati, necessitano, tra le tante competenze interessate, quelle tipiche della metaprogettazione, progettazione e gestione dei manufatti e dei processi.

Tra le prospettive di ricerca è possibile evidenziare come particolarmente interessanti e ricche di sviluppo alcune aree tematiche e spunti di approfondimento:
- una rivisitazione della nozione stessa di infrastruttura, alla luce di nuove chiavi interpretative e modelli operativi applicabili ai concetti di capitale fisso sociale ed economico, con la definizione di nuove categorie di entità immateriali e materiali e delle loro relazioni in riferimento a un duplice piano di lettura: da una parte il rapporto tra oggetti fisici, costituenti le infrastrutture tradizionalmente intese e gestite (Tab. 5) e le informazioni che, per la natura dei processi urbani, assumono il connotato di Big Data; dall'altra la materialità delle tecnologie hardware di ICT "information and communication technology" e IoT in relazione all'immaterialità dei flussi di dati da queste generati e gestiti;
- l'indagine sui possibili nuovi modelli e processi di gestione della conoscenza e dei flussi di persone, materie, energia, nel pas-

TAB. 5 |

By generic function (1)	By tangibility (2)	By structure (3)	By urban functional areas (4)
Economical	**Tangible**	**Networks (band)**	**Functional areas**
Road and rail networks Airports Harbours Sewerage Aqueducts and power lines Gas networks Irrigation River transport	Energy networks Telecommunications networks Transport networks Water distribution networks	Rail networks Road networks Waterways Communication networks Energy and water distribution networks	Technology infrastructure Road networks Waterways Public green Urban equipment Transport infrastructure Other urban functional areas
Social	**Intangible**	**Objects (points)**	**Urban objects**
Hospitals Schools public housing Waste treatment Police and Fire protection Sports facilities urban green (parks) homes for the elderly Facilities for residential care Public safety systems	Facilities for research Facilities for education	Hospitals Schools Stations Bridges Galleries Power plants Radio stations Museums Sports facilities	Public lighting networks and traffic lights Power Grids Gas networks Water networks Heating/ cooling networks Sewerage Telecommunication networks Roads and related areas Sidewalks, pedestrian areas and other areas for public use Parking lots Rivers, canals and water routes Parks, gardens and forests Fixed and movable furniture Infrastructure for public transport

(1) Hansen Niles M., The structure and determinants of local public investment expenditures. *Review of economics and statistics*, 2, (1965): 150-162.
(2) Di Palma M., Mazziotta C., Rosa G., Infrastrutture e sviluppo. Primi risultati: indicatori quantitativi a confronto (1987-95). Roma: Confindustria, 1998. Quaderni sul Mezzogiorno e le politiche territoriali, n.4.
(3) Biehl D., *The contribution of infrastructure to regional development*, Final report, COMMISSION OF THE EUROPEAN COMMUNITIES, 1986.
(4) UNI 11447:2012 Servizi di facility management urbano - Linee guida per l'impostazione e la programmazione degli appalti.

saggio da un modello di governo delle infrastrutture basato su procedure definite in relazione a processi lineari e su centri di decisione puntuali, a scenari caratterizzati dall'informazione condivisa e dal concetto di rete;

– la valutazione di possibili nuove forme di resilienza urbana (Hyslop M., 2007), perseguibile attraverso una visione di sistema dei servizi infrastrutturali, capaci di rispondere proattivamente e con immediatezza a bisogni emergenti attraverso un knowledge management basato sull'analisi, l'aggregazione, la ricerca e la correlazione incrociata di grandi insiemi di dati (Boyd D., 2012) e attraverso (almeno per alcune categorie di servizi come per esempio la manutenzione[5] nelle sue diverse forme) l'attivazione di risorse operative diffuse sul territorio;
– l'interpretazione degli edifici e delle loro parti quali nodi di una rete e terminali informativi (IoT) all'interno di un flusso di informazioni bidirezionale (in-out) rispetto alla città. Gli edifici sono messi a sistema, sono introdotti nella rete e diventano delle unità di raccolta di informazioni in entrata e di scambio di informazioni in uscita contribuendo ad incrementare i livelli di conoscenza ed il controllo dei processi di gestione della città anche per quanto riguarda la manutenzione urbana;
– infine la rivisitazione dei tradizionali approcci di risk assessment e risk management applicati alle infrastrutture e al territorio alla luce di nuove disponibilità di informazioni (in grandi quantità, da una pluralità di fonti e in tempo reale) che portano a ridefinire ruoli e modalità della simulazione, della previsione e della reattività dei sistemi.

NOTE

[1] http://senseable.mit.edu/datadrives

[2] http://www-smartinfrastructure.eng.cam.ac.uk/news/big-data-2013-the-art-of-the-possible

[3] http://www.smartsantander.eu

[4] Si consideri ad esempio il D.Lgs. 32/2010 (Attuazione della direttiva 2007/2/CE, che istituisce un'infrastruttura per l'informazione territoriale nella Comunità europea - INSPIRE).

[5] UNI 11447:2012 Servizi di facility management urbano - Linee guida per l'impostazione e la programmazione degli appalti.

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propose a hypothesis that recognizes 6 levels of declination for the sensing and responding approach in relation to the use of big data and IOT (Tab. 4):
- automatic sensing and responding;
- sensing and responding with constraints;
- sensing and responding with external decisions and validations of the proposal;
- sensing and knowing;
- sensing and knowing in emergency;
- sensing and learning/self learning.

Research perspectives

With respect to the outlined state of the art, it does not appear appropriate to draw definitive conclusions. Indeed there are multiple scenarios of possible applications, all bringing innovations and modifications to the traditional paradigms and practices that characterized the design and the management of urban infrastructures. Therefore, it seems more appropriate, as closing considerations, to identify possible areas of research and application. These areas, due to the multi and trans-disciplinary nature that characterizes the discussed topics, will certainly require the expertise that are typical of the meta-design, design and management of products and processes.

Among the numerous research perspectives, it is possible to highlight some thematic areas and topics that are particularly interesting and potentially rich of development:
- a review of the notion of infrastructure, in light of new interpretative keys and operational models applicable to the concepts of fixed social and economic capital. The definition of the new categories of tangible and intangible entities and their relationships with reference to a double prospective: on one hand, the relationship between physical objects, which constitute the infrastructure as traditionally understood and managed (Tab. 5), and the information that, due to the nature of urban processes, assumes the features of big data. On the other hand, the tangibility of the hardware of ICT (information and communication technology) and of the IoT in relation to the intangibility of the data flows that these generate and manage;
- the analysis on new possible models and processes of management of knowledge and people flows , as well as materials and energy, during the transition from a traditional infrastructure management model, based on procedures defined for linear processes and single decision centers, to models characterized by the shared information and by the concept of network;
- the assessment of new possible forms of urban resilience (Hyslop M., 2007), achievable through a systemic vision of the infrastructural services, able to proactively and immediately respond to the emerging needs through a knowledge management based on the analysis, the aggregation, the research and the cross correlation of large data sets (the actual essence of the concept of big data) (Boyd D., 2012) and through (at least for some categories of services such as maintenance[5] in its various shapes) local operational resources;

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- the implementation of a network approach for cities where buildings and their parts are nodes and information terminals (the concept of IoT) within a bidirectional information flow (in and out). The buildings are integrated (connected) into the urban network of infrastructures and become units of collection of inputs and exchange of outputs, contributing to increase the levels of knowledge and the control of the city's management process also with regards to the urban maintenance;
- finally, a review of the traditional approaches of risk assessment and risk management applied to the infrastructure and to the territory in light of new information availabilities (in large quantities, from a plurality of sources and in real time) that lead to redefine the roles and the modalities of simulation, forecasting and responding of systems.

NOTES

[1] http://senseable.mit.edu/datadrives/

[2] http://www-smartinfrastructure.eng.cam.ac.uk/news/big-data-2013-the-art-of-the-possible

[3] http://www.smartsantander.eu

[4] The DIRECTIVE 2007/2/EC establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) can be considered as an example.

[5] UNI 11447:2012 Urban Facility Management Services - Guidelines to set and program contracts.