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Handbook of Research on Developing Smart Cities Based on Digital Twins

Matteo Del Giudice
Politecnico di Torino, Italy

Anna Osello
Politecnico di Torino, Italy

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List of Contributors

Acquaviva, Andrea / *Università di Bologna, Italy* 425
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The term smart city is often synonymous with a sustainable city. The word smart implies the use of digital technology that serves to make processes and services more efficient and to connect the different actors on the urban scene. However, this is no guarantee of sustainability. A city can become sustainable if it changes its metabolism and from linear to circular as in nature's ecosystems. For this to happen, it is necessary to overcome the paradigm of quantitative economic growth based on the infinite substitutability between natural and economic capital. If smart city governance stakeholders primarily pursue profit according to the logic of the free market, the city may be smarter and efficient in the use of energy and resources, but it is not sustainable, often not even inclusive. The challenge of sustainability implies a paradigm shift and the use of digital technologies at the service of the collective good. In this context, after a general analysis of the characteristics of smart cities, the chapter focuses on an Italian case study, Turin Smart City.

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For the near future, forecasts predict an uncontrolled growth of urbanization in the world, in which cities are fragmented and uneven systems in relation to fast evolving environmental, economic, and social phenomena. The traditional urban planning approach, essentially theoretical-predictive, adapts poorly to face future challenges. Hence, the need to rethink how to govern the transformations of cities, which can be described by models of urban metabolism. The city sensing has changed the way cities are explored and used. With the transition from digitalization to datafication, through the computational approach, georeferenced big data can be analysed and exploited by algorithms. They originate a generative computational urban planning process, which can achieve a higher quality of the project and provide cities with adaptive capability. This process exploits data provided by public administrations, companies, and citizens who take part in an inclusive and adaptive urban planning.

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Digital twin has gained a great interest during the last few years from academia and industry because of the development in IT technology, communication field, and sensor technology. The general vision of the DT is to provide a detailed physical and functional description of a component, product, and systems. Nevertheless, the digital twin is a highly dynamic concept growing in complexity during the product life cycle, which leads to an enormous amount of data and information. Motivated by these, this chapter investigates the concepts and architecture of DT to cover its challenges and explore its applications in various fields such as smart cities, smart manufacturing and factories, and healthcare sectors. In the end, the challenges and research areas will be presented.

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This chapter describes the results of a sociological investigation carried out within an EU-funded project. The project was aimed at creating a tool to visualise and compute energy data at an urban district level, with the broader aim to optimise the local district heating (DH) network's distribution policies. This chapter identifies the features of the main categories of actors (from the DH operator to final users) having a role within that network. Special attention is paid to the identification of the barriers and frictions preventing a stronger collaboration and communication among these actors to happen. It is argued that the identification and resolution, in situated and complex socio-technical systems, of these non-strictly-technical problems may be, at least in some cases, a pre-requisite for any ICT-based solution to deploy its full potential.

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Planheat Tool: A Bottom-Up Approach at District Level to Plan Low Carbon Future Scenarios 84
Matteo Porta, Rina Consulting, Italy

More than two thirds of the European population live in urban areas. Cities are places where both problems emerge and solutions are found. They are fertile ground for science and technology, for culture and innovation, for individual and collective creativity, and for mitigating the impact of climate change. Cities are communities where to study environmental, social, economic impact of new energy technologies. A tool to unlock the planning potential of EU cities has been developed thanks to the collaboration of different EU research centers, SMEs and consultancy firms led by Rina Consulting involved in Planheat EU Project (funded by the European Union's H2020 Programme under grant agreement 723757).

PLANHEAT Consortium developed and validated an integrated and easy-to-use, GIS-based, and open source tool to support local authorities in selecting, simulating and comparing alternative low carbon and economically sustainable scenarios for heating and cooling.

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Dominik T. Matt, Fraunhofer Italia Research, Italy & Free University of Bolzano, Italy

The architecture, engineering, and construction (AEC) sector is facing the digital transformation by promoting the building information modelling (BIM) as a standard methodology for the digital managing of information along the whole lifecycle of a construction work. Although small-medium enterprises (SMEs) and public administrations (PAs) are aware of the BIM benefit, they ask for pilot actions and tools for testing BIM applications in their daily activities in order to measure benefits and difficulties in detail. This chapter discusses the BIM Simulation Lab initiative which aims at establishing a laboratory for an effective and efficient BIM implementation, by promoting a physical space and specific services for supporting the territory in the DT. The authors describe the concept of the lab and they introduce an assessment method that adopts an indirect approach of the BIM benefit assessment leveraging principles from construction cost estimation and probabilistic risk management.

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The post-shock scenario is outlined: an uncertain future with a “new normality.” The embryos of the new paradigm are alongside the powerful discontinuity generated by COVID-19. With examples and anecdotes from Shanghai and China, a transformation already underway is portrayed. No more perfect shock could be thought to reconsider the role of humans on this planet, on our cities. There is a crucial need for resilience of local systems, for short chains, for autonomous energy and food self-sufficiency, for decentralizing essential products. Security and contingency plans are needed and must operate on a global scale, but at the same time at the country and the city level. The future must be reinvented, acting in depth, for shifting from “exploitation” to “cooperation” with natural systems. Topics are education, work, services, transport, food safety.

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In the era of connections and information and communication technologies, the building industry is facing the challenge of digitization at the building and urban scale. Several researches have been carried out to generate virtual city models to manage and represent a variety of data to reach the smart city concept. Therefore, the development of building/urban digital twins is directly linked to the definition of innovative methods and tools that are able to collect, organize, query heterogeneous data to make it available for the various involved actors. This chapter aims at presenting the district information modelling methodology that is strictly related to the digital twin concept, starting with data domains, arriving at the various tools developed to reach the users' needs.

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KPIs to Drive Smart City Assessment 172
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Developing evaluation methods using key performance indicators (KPIs) to drive smart cities assessment represents a very interesting topic that have been deeply analysed over time. The aim of the chapter is to present several different approaches towards the assessment of cities' performance, discussing advantages and disadvantages of such methods that could be integrated in order to get more farsighted results in terms of decision-making strategies. For this reason, the chapter firstly analyses the different context in which KPIs are applied, defining the fields of application and describing the characteristics of such indicators. Then, two examples of European projects using indicators for evaluation purposes are studied in detail, highlighting the different level of application of indicators, used for assessments at city level in the first project (INDICATE) and at a district/building level in the second one (DIMMER). At the end, the use of KPIs as metrics of evaluation to develop multi-criteria decision approaches (MCDA) is discussed by introducing several examples.

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Today an increasing number of cities are equipping themselves with three-dimensional urban modelling and simulation platforms for energy management to integrate both spatial and semantic data for enabling better decision-making. The work presented in this chapter is the result of the study carried out by Politecnico di Torino within the Energy Efficient Buildings (EEB) project. Collected data on urban and building scale are managed in specialized, independent, and heterogeneous domains such as GIS, BIM, and IoT devices for energy and electrical monitoring. Possible relationships among these datasets in the perspective of system integration have been carried out according to a rich matrix of experimentations. Specific tools, including innovative visualization technologies and web services, are put in place to allow final users to benefit from this data. The infrastructure is intended to establish a common interoperable ground among heterogeneous networks to achieve the goal of smart cities digital twins.

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Daniela De Luca, Politecnico di Torino, Italy
Monica Dettori, Politecnico di Torino, Italy
Matteo Del Giudice, Politecnico di Torino, Italy
Anna Osello, Politecnico di Torino, Italy

In the era of the fourth industrial revolution, the cyber physical systems, intended as enabling tools to generate an autonomous system, able to facilitate the relationships between different and distant objects and subjects, allow to digitalize the production system, in order to better outline what constitutes the smart factory. The benefit of such systems is the ability to associate to physical objects and virtual or

digital models useful information related to the analyzed object, such as life cycle, geometry, mechanical properties, and parameters related to management and maintenance. This contribution aims to evaluate building information modeling methodology in the industrial context, as a cyber-physical system, developing flexible 3D parametric models as a data set, where information can be visualized and optimized management, using different visualization tools. The research has underlined the importance to share information between virtual and real worlds through virtual and augmented reality (VAR) systems.

Chapter 12
Smart City and Digital Twins: Definitions, Methodologies, and Applications 243
Sara Giaveno, Politecnico di Torino, Italy

The chapter proposed aims at facing the various implications underlying the smart city concept based on digital twins. The structure of the text is articulated in three main themes: the use of the term "smart city" and the role that technologies had in its definition; the "3D city model" meaning and the integration procedures between BIM (building information modeling) and GIS (geographic information system); the classification of 3D city models by use cases. The chapter can provide researchers with a detailed dissertation aimed at clarifying both the theoretical and technical features belonging to smart city and its related innovative technologies.

Chapter 13
BIM Bin: Waste Management Through BIM and Digital Twin 265
Ricardo Codinhoto, University of Bath, UK
Olivia Becher, Oxford University, UK
Jonathan Neil Heron, University of Bath, UK
Vincenzo Donato, Università degli Studi di Firenze, Italy

A groundswell of opinion exist about the present and future use of smart cities and digital twin technologies and processes and, despite increasing use of information modelling, artificial intelligence, and internet of things, many challenges remain in designing and implement integrated smart systems in large scale contexts. Often, the big picture is shadowed by fragmented processes, and there is a disconnect between the problem and the solution. This chapter aims to address this inverted approach, based on a solution looking for a problem by focusing on the problems of developing integrated solutions for smart cities based on digital twins. The narrative in this chapter is informed by a research project exploring the digitalisation of facilities management processes in Bath, UK. The conclusion is that the development of digital twins goes far beyond linking digital models to sensors.

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Dynamic Sensor Data 295
Fabrizio Massara, CSI Piemonte, Italy
Tatsiana Hubina, CSI Piemonte, Italy
Sara Mannoni, CSI Piemonte, Italy
Adelaide Ramassotto, CSI Piemonte, Italy
Fabrizio Barbero, CSI Piemonte, Italy

This work presents the developments of representing a part of the city districts of Manchester, UK and Turin, IT initiated within the FP7 DIMMER project completed in 2016 and continued in the last years by the Center of Excellence GIS of CSI Piemonte. The DIMMER system integrates BIM (building information modelling) and district level 3D models with real-time data from sensors and user feedback to analyze and correlate buildings utilization and provide real-time feedback about energy-related behaviors. The emerging standard 3D Tiles endorsed by the OGC was applied to represent CityGML data of two districts of Turin, Italy and Manchester, UK. 3D Tiles allows for a high level of detail (LOD) visualization that displays increasing detail of geometric features and their alphanumeric properties. Currently, the OGC 3D Tiles technology is mature, and the OGC CityGML specification will be soon updated to version three, with the adoption of exciting innovations like the support of time-dependent properties defined Dynamizers.

Chapter 15
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Valentina Villa, Politecnico di Torino, Italy
Bernardino Chiaia, Politecnico di Torino, Italy

Industry 4.0 is encouraging the introduction of pioneering technologies even in the construction industry. Along with the development of high technology, such as augmented reality, virtual reality, and cloud computing, the development of digital twin has been growing. This contribution aims to present the potential of digital twin in the construction field, suggesting a framework that outlines the many different possible applications in construction, with reference to school buildings. First, it summarizes the current overview of digital twin applications in building construction. Then it shows that significant steps that are being taken beyond the digital model, even if the implementation of the digital twin concept in its full meaning is still a long way off. The research is moving in this direction and the evolution of the current state of the art, combined with the experience gained in the industrial sector, will soon bring a new revolution in the construction industry.

Chapter 16
Exploiting BIM and Sensor Data Through Web-Based CAFM: The AR4FM Project 341
Umberto Di Staso, Territorium Online, Italy
Marco Piovano, Fraunhofer Italia Research, Italy
Ambra Barbini, Fraunhofer Italia Research, Italy
Dominik T. Matt, Fraunhofer Italia Research, Italy & Free University of Bozen-Bolzano, Italy

Technological progress and the evolution of the directives concerning the construction sector have led to a significant digitalization of information concerning buildings. One of the challenges that have arisen concerns the use of data in the phases of the life cycle following the construction. How can this information be exploited? Is it possible to use it directly in a facility management tool that is within the reach of expert users and not? The aim of this chapter is reporting the developed framework to support the management and maintenance operations in buildings, defined within the project AR4FM - Augmented Reality for Facility Management. In particular, AR4FM aims to create an innovative software ecosystem that uses the most modern technologies to support facility management (FM) operations through a set of bespoke applications. The first tool is the web-based ICT platform usable through web-browser, while the second tool refers to a mobile App, called AR4FM mobile app, which will enable visualization for both mobile and wearable devices, such as smart-glasses.

Chapter 17
From Sketches and Installations to Bioinspired 5D Printing Models: Representation Interactions for Smart Cities 365
Silvia Titotto, Federal University of ABC, Brazil

This chapter opens up discussions upon the relevance of interaction of representations and data visualization modes for smart cities design, planning, and development that occur beyond paper and computer drawing. Although many practitioners usually relate smart cities and digital twins design exclusively to CAD/CAM/CAE and BIM methods, processes, and tools, a wider pool of techniques and forms of expression might be the key to a more accurate and comprehensive way of simulating the several kinds of alterations that happen in the planned built environment. The chapter deals with the study of concepts that relate to both physical and virtual prototyping, which underlines an interdisciplinary approach to design and the impact of integrating biologically inspired principles from different backgrounds to the field of smart cities design. In this regard, biomimetics and additive manufacturing may play key roles in smart city's modeling design and the frontier technology of 5D printing reveals real-time decision-making programmable 4D printing process as a potential future development.

Chapter 18
Quality of Urban Walking Routes: Interaction of Knowledge Systems for Integrated Representations 388
Maurizio Marco Bocconcino, Politecnico di Torino, Italy
Mariapaola Vozzola, Politecnico di Torino, Italy
Anna Rabbia, Fondazione Sviluppo e Crescita CRT Torino, Italy

The northern area of Turin is involved in complex processes of transformation and regeneration articulated in a plurality of functions that support social revitalization and housing policies alongside temporary residential and commercial interventions. A specific district of Turin, Pietra Alta, is presented as an application case of the indicators and graphic codes that the methodological approach of the research is gradually outlining. The results, guided and supported by effective modes of representation, broaden the understanding of the hierarchy and criteria of the needs to move independently on foot and confirm that, given a safe and comfortable environment, people seek utility, a sense of belonging, and pleasantness as additional and distinct needs to enhance their experience of living in the city. Using survey data and assuming relief given by geo-referenced interviews, the proposed work emphasizes the integration of residents' perceptions and objective measures to understand the impact of environmental features on the behavior of neighborhood residents.

Chapter 19
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Niccolò Rapetti, Politecnico di Torino, Italy
Vittorio Verda, Politecnico di Torino, Italy
Elisa Guelpa, Politecnico di Torino, Italy
Laura Rietto, Politecnico di Torino, Italy
Enrico Macii, Politecnico di Torino, Italy
Andrea Acquaviva, Università di Bologna, Italy
Alexandr Krylovskiy, Fraunhofer Institute for Applied Information Technology, Germany
Marco Jahn, Fraunhofer Institute for Applied Information Technology, Germany

This chapter presents a novel distributed software infrastructure to enable energy management and simulation of novel control strategies in smart cities. In this context, the following heterogeneous information, describing the different entities in a city, needs to be taken into account to form a unified district information model: internet-of-things (IoT) devices, building information model, system information model, and georeferenced information system. IoT devices are crucial to monitor in (near-) real-time both building energy trends and environmental data. Thus, the proposed solution fulfills the integration and interoperability of such data sources providing also a correlation among them. Such correlation is the key feature to unlock management and simulation of novel energy policies aimed at optimizing the energy usage accounting also for its impact on building comfort. The platform has been deployed in a real-world district and a novel control policy for the heating distribution network has been developed and tested. Finally, experimental results are presented and discussed.

Chapter 20
Customized Data Capture for BIM: Using APIs and Visual Programming 448
Kjartan Gudmundsson, KTH Royal Institute of Technology, Sweden
Giuseppe Digregorio, KTH Royal Institute of Technology, Sweden
Jiayu Cui, KTH Royal Institute of Technology, Sweden

Building information models (BIMs) make it possible to share structured data in the planning and building process and during the live cycle of the building. The models can be enrichened with information in all stages from planning to end-of-life. Predefined information requirements, data structures, and file formats allow the model to be used for design, cost planning, and time scheduling as well as analysis of building performance, and ideally also for facilities management. This chapter describes the possibilities of using application programming interfaces (APIs) to enhance the usefulness of BIM models. This provides the user with the possibility of creating own applications with real time bidirectional data exchange. Of particular interest is the exchange of data with web-based data sources. The applicability is illustrated with examples of environmental analysis based on web-based data and the use of web-based forms to enrichen BIM models with data input from building users.

Chapter 21
Participatory Design of Use Cases for an IoT Open Platform to Support Smart Urban
Development: Approach and Method 469

Alice Schweigkofler, Fraunhofer Italia Research, Italy
Katrien Romagnoli, Fraunhofer Italia Research, Italy
Gabriel Sanz Salas, Systems s.r.l., Italy
Dieter Steiner, Fraunhofer Italia Research, Italy
Michael Riedl, Fraunhofer Italia Research, Italy
Dominik Matt, University of Bolzano-Bozen, Italy

The chapter describes the approach for the South Tyrolean city of Meran in the creation of use cases and the implementation of an urban agenda (roadmap) for the development of the city from a smart city perspective, with the involvement of citizens, experts, and local administrators. A list of key services, based on a technical and economic pre-feasibility study and social impact assessment, has been developed and will be able to be provided through a digital platform. In particular, the example of the concrete development of a use case about public lighting is presented in detail: starting from the identification of the use case to the execution of the installation of 100 intelligent streetlights and 5 test-sites for the monitoring of water consumption up to the visualization of the collected data.

Chapter 22
Building Stock Energy Models and ICT Solutions for Urban Energy Systems 490
Ilaria Ballarini, Politecnico di Torino, Italy
Vincenzo Corrado, Politecnico di Torino, Italy
Matteo Piro, Politecnico di Torino, Italy

The existing building stock presents a high potential of energy savings and CO2 emissions reductions. To this purpose, literature provides novel city-scale building-oriented studies, aimed at developing suitable tools for stakeholders, city planners, and decision-makers. To achieve an effective urban energy planning, urban energy systems (UES) models are developed; they employ a multi-domain approach, embracing the complex interactions in urban areas, such as energy flows, environmental indicators, social and economic factors. To perform an advanced modelling and to simulate the complexity of the UES, ICT (information and communications technology) represents nowadays the right answer to the needs of integration of data, tools, and actors in different domains. The chapter investigates the current studies in the field of building stock energy modeling and the application of advanced technologies to develop UES models. As an exemplification, the technological approach followed in the SEMANCO project to support urban scale energy modelling is presented.

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Álvaro Sicilia, ARC, Engineering and Architecture La Salle, Ramon Llull University, Spain
Gonçal Costa, ARC, Engineering and Architecture La Salle, Ramon Llull University, Spain
Leandro Madrazo, ARC, Engineering and Architecture La Salle, Ramon Llull University, Spain

The assessment of building energy performance requires data from multiple domains (energy, architecture, planning, economy) and scales (building, district, city) to be processed with a diversity of applications used by experts from various fields. In order to properly assess the performance of the building stock, and to develop and apply the most effective energy efficiency measures, it is necessary to adopt a comprehensive, holistic approach. In this chapter, three research projects are presented which apply Semantic Web technologies to create energy data models from multiple data sources and domains in order

to support decision making in energy efficient building renovation projects: SEMANCO, OptEEmAL, and OPTIMUS. A final reflection on the results achieved in these projects and their links to ongoing research on digital twins is presented.

Chapter 24
BIM Tools for the Energy Analysis of Urban Transformation Projects and the Application to the Development of Healthcare Infrastructures 540
Ezio Nicolas Bruno Urbina, Istituto Giannina Gaslini, Italy
Elisa Spallarossa, Archimede s.r.l., Italy

The aim of INDICATE was the creation of an innovative interactive software capable of providing designers, urban planners, and companies a "decision support system" in all urban development phases of a city: from the construction of a single building to the design of a master plan. Galliera test site experience was developed following the idea of using the INDICATE tool on Genoa site to understand how the tool can work in the planning stages, as if the preliminary design of the new hospital were not already defined, to understand the optimal solution to select from the energy point of view. The chapter shows how a tool such as INDICATE would have proven absolutely useful to comprehend the different energetic and economic impacts of different options and of different new building shapes. The experience gained with the INDICATE project and BIM implementation within other projects and realities of the authors could also be adopted to develop the implementation of the BIM in another important hospital in Genoa, the Giannina Gaslini Pediatric Hospital.

Chapter 25
Digital Twin for Maintenance Information Management: Scenarios and Perspectives for Sustainable Smart Cities 575
Umberto Mecca, Politecnico di Torino, Italy
Giuseppe Moglia, Politecnico di Torino, Italy
Francesco Prizzon, Politecnico di Torino, Italy
Manuela Rebaudengo, Politecnico di Torino, Italy

BIM and the construction sector have long been an inseparable pair: in many European Countries it is a consolidated practice while in others there is a big debate about it but. Although there are important signs of a turning point, it still does not seem to be really feasible. In Italy, the leverage for transformation is certainly the public works sector, but this is not enough: to really talk about a whole digitization of the AEC sector, it is necessary to "attract" the private sector, where more than 50% of investments are invested. The chapter will attempt, starting from an Italian framework overview, to assess the main perceived obstacles of the applicability of a BIM model for facility management. The tool chosen by the authors as a preliminary approach to the problem, the SWOT analysis, allows an effective synthesis of the strengths and weaknesses resulting from such implementation.

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Preface

INTRODUCTION

In recent years, humanity has witnessed climate change causing exceptional events such as the global warming that are also due to the behavior of human beings themselves. Since the beginning of the Industrial Revolution at the end of 18th century, people have burned more and more fossil fuels and changed vast areas of land from forests to farmland. Moreover, the world's leading climate scientists think human activities are almost certainly the main cause of the warming observed since the middle of the 20th century. Population growth is having an increasing influence on climate change also. Due to the constant increase in energy and CO_2 emissions, we are witnessing an ecosystem reaction characterized by a holistic process, which is difficult to control with cause-effect mechanisms.

The scientific community considers that in 2050, two thirds of the world population will live in towns, consuming over 70% of energy and emitting just as much greenhouse gases. As city populations grow, the demand for services but also pressure on resources increases. This demand puts a strain on energy, water, waste, mobility and any other services that would be essential to a city's prosperity and sustainability(https://ec.europa.eu/digital-single-market/en/smart-cities-smart-living). In this sense, the scientific community is debating how to manage the coexistence between the natural environment and the artificial environment built by human beings who are increasingly concentrated in cities.

The advent of the fourth industrial revolution offers the opportunity to rethink in an innovative way the management of resources, the design of the built environment through new methods and tools using Information and Communication Technologies (ICTs). The advent of connected, smart technologies for the built environment may promise a significant value that have to be reached to develop digital city models. Of course, as at international level the role of digital twin is strictly related to massive amount of data that needs to be collected and then processed. This topic proposes several challenges in terms of digital technologies capability, computing, interoperability, simulation, calibration and representation. Thus, the building industry is crossing a digital transition from traditional design processes to information modeling.

In this context, the integration of several data domains can lead to the creation of an extensive repository able to provide a series of useful pointers towards energy saving and reduction of CO_2 emissions, enhancing the livability of the city. The above is reflected in the concepts of smart cities, smart buildings and smart living. Over time, the scientific community has given a series of definitions linked to the concept of the smart city, including many subsystems (economy, environment, governance, living, mobility, people). Certainly the issue of governance has a priority in strategic terms to improve the coexistence of the natural and built environment through different strategies that can be summarized in three actions: knowing, understanding and interpreting (Testoni, 2016).

Public and private actors will be able to learn about and understand emerging problems related to the environment, technology and well-being in order to govern and solve the needs that the urban reality poses on a daily basis. In this context, the amount of data that networks make available constitutes the disruptive technology, typical of the 4th industrial revolution, which offers the opportunity for public administrations to take decisions, strategies and courses of action with greater definition and faster than in the past. The topic of data therefore becomes central in terms of volume, speed, reliability and variety. The classification of data and the relationship between them generates information that must be put into a system for the development of smart cities. For this reason, the construction industry must go through the digital transition in order to innovate its supply chain by applying new technologies for the economic, social and cultural purposes of the community. People need to become active participants in the smart city development process, which becomes a new way of life to increase awareness of being a community using resources that need to be managed in a system to ensure sustainable development.

As mentioned above, the basis of this digital transformation is the value assigned to data, which, when related to each other, becomes information that needs to be used to increase knowledge and awareness in people, thus achieving the objectives of smart cities.

The book provides a valuable benefit to researchers and developers in various fields such as:

- Building Information Modelling (BIM) that aims at improving the building process and, as innovative methodology. It is focused on the information management of all technical resources that are able/essential to represent the complexity of a building. It is based on a development of a 3D parametric model of buildings, enriched with semantic information such as measures, materials and costs;
- Geographic Information System (GIS) that provides geographical location of buildings, energy distribution networks and/or other elements and it is used for data automation and compilation, management, analysis and modelling of advanced cartography;
- Building Energy model (BEM), that focuses on building performance management. BEM models are able to develop energy performance behavior by characterizing the building and system components with essential information for the building envelope, the heating/cooling systems, the occupancy schedule and so on;
- Building Automation Systems (BAS), that consists of a temperature and humidity sensor framework aiming to collect data, improve occupant comfort and efficient operation of building systems, reduce energy consumption and operating costs.

Clearly, Internet of Things (IoT) platforms are fundamental considering of information sharing concerning the smart city topic, providing seamless access to data independently from the hardware devices and making possible the interoperability with other data sources (IGI Global, 2019).

the book has a multidisciplinary approach since the smart city and the digital twin topics are a cross-cutting issues that are investigated by many actors who address this issues with different and complementary points of view. For this reason, the book is addressed to:

- Researchers carrying out research on building industry, energy and computer science fields
- Public administrators, managing cadastral and building information using 3D visualization of “static characteristics” (e.g.: construction period, heating system etc.) and buildings selection;

- Building managers who wish to optimize the operation and maintenance phase of the building creating refurbishment scenarios
- Energy professionals keen on improving energy management with innovative strategy for energy optimization

The book can be considered a valid medium for disseminating innovative data management methods related to smart city topics.

THE CHALLENGES

The idea of smart city has been investigated in recent years by the international community to meet the requirements of sustainable development. It consists on a motivator for the development of policies that contribute to a better society, and consequently to improvements in citizens' quality of life (De Guimaraes, 2020).

In order to define new policies to be applied in the Architecture, Engineer and Construction (AEC) Industry, it is necessary to describe reality through one or more models that are able to: i) gather data related to various topics; ii) organize the information in a logical way; iii) visualize the information through interfaces; iv) simulate alternative scenarios; v) provide answers based on data processing.

These characteristics are typical of a digital twin that can be defined as a realistic digital representation of assets, processes or systems in the built or natural environment. Many people see it as a simple digital replica of a real thing – a 'twin', but "what distinguishes a digital twin from any other digital model or replica is its connection to its physical twin ", with 'connection' meaning there is some type of relationship and association between the physical and digital. The concept of digital twins is not new: Nasa has run complex simulations of spacecraft for decades. However, the advance of the 'fourth industrial revolution' is making cyber-physical systems in the built environment practical, useful and affordable, and digital twins are a key part of this. (Bolton A, 2018). According to the definition of Dr. Grieves in 2002, a Digital twin has to be composed by three main parts: a) physical products in Real Space, b) virtual products in Virtual Space, and c) the connections of data and information that ties the virtual and real products together. (Grieves, 2014).

Considering the Built environment field, a digital twin has to represent physical reality at a level of accuracy suited to its purpose. The extent of realism depends on three essentials: i) Data – the quality of the data on which the twin is based. ii) Model – the fidelity of the algorithms, the validity of the assumptions and the competence of the code at the heart of the digital representation; iii) Visualization – the quality of presentation of the output. Digital twins may be developed for a range of purposes, operate at different scales or adopt different approaches to modelling. A number of digital twins have already begun to appear within the built environment, serving a variety of purposes. However, few digital twins at present are connected or share data across organizations, sectors or geographies. Lack of interoperability is a key constraint. (Bolton A, 2018).

Thus, the need to develop a digital representation of a physical environment for optimizing a city's data management is in line with the objectives of energy saving and technological innovation. For this reason, the book focuses on the role of digital twin for the development of smart city, referring to the built environment. The book aims to enhance the value of interdisciplinarity and interoperability for the development of smart city concepts, addressing the sectors of Architecture, Engineer and Construction

(AEC) Industry and in particular to the representation field. In recent years these fields have been innovating the way to represent data which is collected in heterogeneous databases such as Building Information Models (BIMs), Geographic Information Systems (GISs) and Building Management systems (BMSs).

These are connected in an innovative way, providing information at district level to achieve smart city objectives. For this reason, the book proposes a methodology based on the development of a digital twin for the building industry able to facilitate the use of data for connected cities and communities. Starting from the outcomes of some European projects (e.g. DIMMER, INDICATE, SEMANCO), several research fields are investigated from building to district level, paying particular attention to software engineering. Thanks to the synergy of the different skills involved a series of results are presented to suggest new policies at both building and district level, focusing on the development of strategies to create a smart city based on digital twins.

The challenges faced by the authors of the various contributions have therefore focused on the elaboration of virtual models with different purposes and uses, on the interaction of various heterogeneous data domains, evaluating the effectiveness of collaboration between the stakeholders involved in the construction industry.

Thus, the volume emphasizes among the most important challenges:

- Digital transformation oriented to data management;
- The development of a new generation of design tools based on parametric modeling and interoperability between software applications required by the construction industry;
- Interoperability at the technological, decision-making and process levels;
- The development of digital twin models aimed at energy savings;
- The enhancement of citizens' awareness as an active part of the smart city development process.

Clearly, the connection between graphical and alphanumerical databases plays a key role through the adoption of ICT hardware and software infrastructures.

For the above reasons, this publication contains different contributions focused on the description of methods, processes and tools that can be adopted to achieve smart city goals. It aims at collecting all pertinent project knowledge that supports their adoption and utilization, related to the development of a web-based ICT platform where different sets of static and dynamic data are collected, processed and displayed through various visualization tools as well as energy efficiency and cost analysis engines. As representation language is always considered a mean to communicate and share a design idea among the actors involved, this book enhances the value of data visualization to support the management of heterogeneous information. The interaction of different data from building to district scale allows the definition of an information system able to share data in relation to the scale of visualization, taking into account the user needs. As the data sharing methods considered have been investigated by three EU research projects, the book presents the effectiveness of dissemination activities that gathered feedback on the results.

This book can also be used as a valid example in the field of local community. In fact, one of the objectives of the projects was to raise awareness about eco-sustainability among the young generations through a gamification approach.

SEARCHING FOR A SOLUTION

The research presented in this volume showed that the challenges listed above were addressed with different approaches, adopting different procedures, models and standardizations that led to the analysis of the objectives identified by the smart city idea through the scientific method.

In line with the directions specified by the European Commission, the various contributions have shown aspects related to the smart city such as a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business (https://ec.europa.eu/digital-single-market/en/smart-cities-smart-living).

The results shown by the authors in the various manuscripts refer to European Commission guidelines and can be outlined as follows:

- Contribute to the opening of a market for ICT-based customized solutions integrating numerous products from different vendors and offering services from design of integrated systems to the operation and maintenance phases;
- Establish a collaboration framework between the ICT and the building industry aimed at exploiting opportunities for the development of ICT-based systems in compliance with the Energy Performance of Buildings Directive;
- Reduce energy consumption and CO2 emissions, in line with the policy framework for facilitating the transition to an energy-efficient and low-carbon economy through ICT.

It is obvious that, for a complex system such as digital twin, standardization takes on an essential role in the communication of data that need to be exchanged, while interoperability, in its wide meaning of capability of two or more systems or components to exchange information and to use the exchanged information, represents the key element for problem solution. (Osello,2012).

In addition, the ability to develop a new generation of design tools based on data sharing and user collaboration will require the construction industry to increase its maturity by acquiring critical evaluation, detailed description of data and processes, and development of advanced prototypes.

The development of smart cities based on the elaboration of digital twin will require in the near future the necessary training of people with new skills and abilities related to the many aspects of the world of construction, ICTs, energy saving.

In conclusion, the solutions proposed in the book suggest the way for the construction industry to resiliently adapt to the challenges thrown up by the digital age.

ORGANIZATION OF THE BOOK

The book is organized into 25 chapters and they are grouped by topic into four main areas: general, drawing, ICT, environment. A brief description of each of the chapters follows:

Chapter 1 describes the concept of smart city by associating it with sustainability issues. The city needs to be considered in continuous mutation, overcoming the paradigm of quantitative economic growth based on the infinite substitutability between natural and economic capital, adopting digital technologies at the service of the collective welfare.

Chapter 2 shows how effectively Big Data Analysis, as one of the most crucial contemporary tools employable in enquiring and updating, virtually and continuously, both the urban metabolism and its complexity, could "improve the art of urban planning", as Rogers stated.

Chapter 3 investigates the concepts and architecture of Digital Twin to cover its challenges and explore its applications in various fields such as smart cities, smart manufacturing and factories and healthcare sectors.

Chapter 4 describes the results of a sociological survey conducted as part of an EU-funded project to visualize and calculate energy data at the urban district level in order to optimize the distribution policies of the local District Heating (DH) network. The chapter identifies the characteristics of the main categories of actors (from DH operator to end users) that play a role within the network, identifying the barriers and frictions that prevent greater collaboration and communication between these actors.

Chapter 5 presents an integrated GIS-based and open source urban planning tool to support local authorities in selecting, simulating and comparing alternative low-carbon and economically sustainable heating and cooling scenarios. The achieved results are obtained thanks to the collaboration with several EU research centers, SMEs and consulting companies led by Rina Consulting involved in the Planheat EU project.

Chapter 6 discusses the BIM Simulation Lab initiative which aims at establishing a laboratory for an effective and efficient BIM implementation, by promoting a physical space and specific services for supporting the territory in the DT. The authors describe the concept of the lab and they introduce an assessment method that adopts an indirect approach of the BIM benefit assessment leveraging principles from construction cost estimation and probabilistic risk management.

Chapter 7 addresses the post-pandemic issue from Covid 19, with examples and anecdotes from Shanghai and China. The analysis of the situation generated by the health crisis is addressed in the study, highlighting a crucial need for resilience of local systems, short chains, autonomous energy and food self-sufficiency, and decentralization of essential products. The authors point to a future that needs to be reinvented, acting in depth, to move from "exploitation" to "cooperation" with natural systems.

Chapter 8 aims at presenting the District Information Modelling methodology that is strictly related to the Digital Twin concept, starting from heterogeneous data domains, arriving at the various tools developed to reach the users' needs. The chapter considers the digital transition phase of the building industry at the building and urban scale. Through collaboration with several research units within the EU DIMMER project, the chapter extends the BIM methodology at the urban scale to manage and represent a variety of data to reach the smart city concept.

Chapter 9 presents several different approaches towards the assessment of cities' performance, discussing advantages and disadvantages of such methods to get more farsighted results in terms of decision-making strategies. The chapter analyses the different context in which KPIs are applied, defining the fields of application and describing the characteristics of such indicators. Two examples of European projects using indicators for evaluation purposes are studied at city level in the first project (INDICATE) and at a district/building level in the second one (DIMMER).

Chapter 10 presents the result of the study carried out by Politecnico di Torino within the Energy Efficient Buildings (EEB) project. Collected data on urban and building scale are managed in specialized, independent and heterogeneous domains such as GIS, BIM and IoT devices for energy and electrical monitoring. Possible relationships among these datasets in the perspective of system integration have been carried out according to a rich matrix of experimentations.

Chapter 11 aims to evaluate Building Information Modeling methodology in the industrial context, as a cyber-physical system, developing flexible 3D parametric models as a data set, where information can be visualized and optimized management, using different visualization tools. The research has underlined the importance to share information between virtual and real worlds through Virtual and Augmented Reality (VAR) systems in the era of the fourth industrial revolution.

Chapter 12 aims at facing the various implications underlying the Smart City concept based on Digital Twins. The structure of the text is articulated in three main themes: the use of the term "Smart city" and the role that technologies had in its definition; the "3D city model" meaning and the integration procedures between BIM (Building Information Modeling) and GIS (Geographic Information System); the classification of 3D city models by use cases.

Chapter 13 addresses the approach, based on a solution looking for a problem by focusing on the problems of developing integrated solutions for smart cities based on digital twins. The narrative is based on a research project exploring the digitalization of facilities management processes in Bath, the UK The conclusion is that the development of digital twins goes far beyond linking digital models to sensors.

Chapter 14 presents the developments of representing a part of the city districts of Manchester, UK and Turin, IT initiated within the FP7 DIMMER project completed in 2016 and continued in the last years by the Center of Excellence GIS of CSI Piemonte. The use of BIM and GIS at district level have been investigated together with real-time data gathered from sensors and user feedback to analyze and correlate buildings utilization and provide real-time feedback about energy-related behaviors. The emerging standard 3D Tiles endorsed by the OGC was applied to represent CityGML data of two districts of Turin, Italy and Manchester, UK.

Chapter 15 aims to present the potential of Digital Twin in the construction field, suggesting a framework that outlines the many different possible applications in construction, with reference to school buildings. First, it summarizes the current overview of Digital Twin applications in building construction. Then it shows that significant steps that are being taken beyond the digital model.

Chapter 16 reports the developed framework to support the management and maintenance operations in buildings, defined within the project AR4FM - Augmented Reality for Facility Management. It focuses on an innovative software ecosystem that uses the most modern technologies to support Facility Management (FM) operations through a set of bespoke applications. The first tool is the Web-based ICT Platform usable through web-browser, while the second tool refers to a mobile App, called AR4FM Mobile App, which will enable visualization for both mobile and wearable devices, such as Smart-Glasses.

Chapter 17 opens up discussions upon the relevance of interaction of representations and data visualization modes for smart cities design, planning, and development that occur beyond paper and computer drawing. The chapter deals with the study of concepts that relate to both physical and virtual prototyping, evaluating the frontier technology of 4D/5D printing which underlines an interdisciplinary approach to design and the impact of integrating biologically inspired principles from different backgrounds to the field of smart cities design.

Chapter 18 emphasizes the integration of residents' perceptions and objective measures to understand the impact of environmental features on the behavior of neighborhood residents, using survey data and assuming relief given by geo-referenced interviews. The study focuses on a specific district of Turin involved in complex processes of transformation and regeneration, through the use of some indicators and graphic codes. The results broaden the understanding of the hierarchy and criteria of the needs for autonomous mobility on foot of people in relation to the urban environment, assessing their safety and welfare

Chapter 19 presents a novel distributed software infrastructure to enable energy management and simulation of novel control strategies in Smart Cities. In this context, the following heterogeneous information, describing the different entities in a city, needs to be taken into account to form a unified District Information Model: Internet-of-Things (IoT) devices, Building Information Model, System Information Model and Georeferenced Information System. The proposed solution fulfills the integration and interoperability of such data sources providing a correlation among them. The platform has been deployed in a real-world district.

Chapter 20 describes the possibilities of using Application Programming Interfaces (APIs) to enhance the usefulness of BIM models. This provides the user with the possibility of creating own applications with real time bidirectional data exchange. Of particular interest is the exchange of data with web based data sources. The applicability is illustrated with examples of environmental analysis based on web-based data and the use of web-based forms to enrichen BIM models with data input from building users

Chapter 21 describes the approach for the South Tyrolean city of Meran in the creation of use cases and the implementation of an urban agenda (roadmap) for the development of the city from a smart city perspective, with the involvement of citizens, experts and local administrators. A list of key services, based on a technical and economic pre-feasibility study and social impact assessment, has been developed for a subsequent digital platform. The example of the concrete development of a use case about public lighting is presented in detail: starting from the identification of the use case, to the execution of the installation of streetlights and sensors for the monitoring of water consumption, up to the visualization of the collected data.

Chapter 22 investigates the current studies in the field of building stock energy modeling and the application of advanced technologies to develop UES models. As an exemplification, the technological approach followed in the SEMANCO project to support urban scale energy modelling is presented. To achieve an effective urban energy planning, Urban Energy Systems (UES) models are developed; they employ a multi-domain approach, embracing the complex interactions in urban areas, such as energy flows, environmental indicators, social and economic factors.

Chapter 23 presents three research projects which apply Semantic Web technologies to create energy data models from multiple data sources and domains in order to support decision making in energy efficient building renovation projects: SEMANCO, OptEEmAL, and OPTIMUS. A final reflection on the results achieved in these projects and their links to ongoing research on digital twins is presented. The assessment of building energy performance required data from multiple domains (energy, architecture, planning, economy) and scales (building, district, city) to be processed with a diversity of applications used by experts from various fields.

Chapter 24 describes the obtained results within the INDICATE project that focused on the creation of an innovative interactive software capable of providing designers, urban planners and companies a "decision support system" in all urban development phases of a city: from the construction of a single building to the design of a master plan. Galliera test site experience was developed following the idea of using the INDICATE tool on Genoa site, to understand how the tool can work in the planning stages, as if the preliminary design of the new hospital were not already defined, to understand the optimal solution to select from the energy point of view.

Chapter 25 assesses the main perceived obstacles of the applicability of a BIM model for Facility Management, starting from an Italian framework overview. The tool chosen by the authors as a preliminary approach to the problem, the SWOT analysis, allows an effective synthesis of the strengths and weaknesses resulting from such implementation. Various aspects are described in the contribution such as the need to attract the private sector to ensure the digitalization of the AEC sector, where more than 50% of investments are invested in the era of digitalization.

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