Chapter 26
Expanding the Wave of Smartness: Smart Buildings, Another Frontier of the Digital Revolution

Valentina Frighi

Abstract Smart buildings can be considered the future development direction of constructions: IoT, which extended connections and intelligence to real-life objects, led to a revolution in building practices, making it necessary to obtain edifices equipped with new original features. Seeking to respond to climate-related challenges of the twenty-first century, the technologies triggered by the digital revolution led smart buildings to become the natural evolution of the "sustainable" or NZEB buildings, introducing a series of innovations toward positive changes, continuing the path of hybridization with other disciplines which characterized this digital era. Indeed, the term "smart buildings" conventionally refers to all buildings that show some kind of innovations, concerning technical plants but also building envelope components or the building system as a whole. Besides, it can be said that in the wake of recent directives issued by the EU concerning the Green Deal, the Renovation Wave, and the New European Bauhaus, the technological culture of architecture has evolved, affecting also the aesthetic domain. Therefore, the paper aims to understand the new paradigms of current architecture, analyzing the advantages brought in terms of innovative methods and tools for controlling the quality of construction projects and processes, but also considering new digital techniques for design and representation, smart high-performance materials, adaptive and innovative technologies and/or sensors; thus trying to understand how architectural objects became inspiring examples of the combination of technological innovation and design, and how they can play an important role in terms of environmental sustainability and reduced consumption of resources.

Keywords Smart buildings · Digital revolution · Building envelope · Smart materials · Technological innovation

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E. Arbizzani et al. (eds.), *Technological Imagination in the Green and Digital Transition*, The Urban Book Series, https://doi.org/10.1007/978-3-031-29515-7_26

26.1 Introduction

Current living habits, also due to the current situation, have bewilderingly changed compared to what we used to do in the past, making clear that the pre-pandemic living and work patterns will not hold once the situation will be solved. The past years have caused us to fundamentally re-evaluate the importance of the buildings we live and work in, so as the impact they have on our lives, our well-being, and our relationships with the surrounding environment.

Simultaneously, the word "smart" started to be considered ever more not only as a hybrid situation in which we are allowed to work according to the most appropriate methods and locations, thanks to the connection, but also as a way of control and optimize our setting environment. This has led us to reappraise how we conceive buildings, especially concerning the diffusion of information and control technologies into traditional constructions.

At the same time, the increasing focus on environmental and societal issues, in the wake of recent directives issued by the European Commission concerning the Green Deal (European Commission 2019), the Renovation Wave (European Commission 2020), and the New European Bauhaus (European Commission 2021a), underlines the importance of effective and inclusive tools to support and foster the energy transition, toward more inclusive, sustainable, affordable, and secure solutions to global challenges.

The comprehension of the value of digitization within the construction sector (Fig. 26.1), progressively led the technological culture of architecture to evolve, involving also the aesthetic domain in the definition of new paradigms; thus, the built environment evolved accordingly: from simple dwellings to buildings equipped with advanced technologies, made available by the innovations of the Fourth (and then Fifth) Industrial Revolution and especially by the Internet of Things (IoT).

26.2 Smart Buildings as a Frontier of the Digital Revolution

The digital transformation process which began about 30 years ago within the Architecture, Engineering, and Construction (AEC) sector, produced great buildings improvement: on the one hand through the transition from analog to digital tools and computer-aided design, and on the other hand, thanks to the technological advancements introduced by the last Industrial Revolutions.

Digitalization changes how buildings will be planned, constructed, used, and managed, empowering technologies and connecting the several stakeholders involved in the design process.

In light of the continuous hybridization among different disciplines which characterized this digital era, coupled with the pivotal role of digitalization for the competitiveness and sustainability of the construction sector (European commission 2021b),

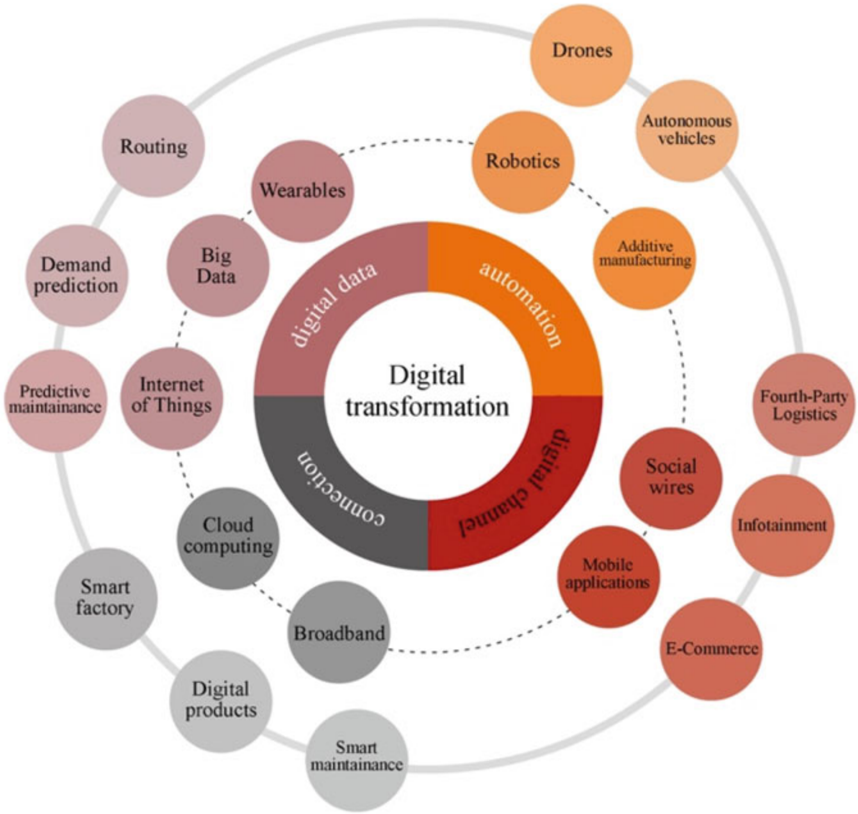

Fig. 26.1 Driver of the digitalization process. *Source* Author's elaboration on Roland Beger and BDI (2015)

we can say that smart buildings can be considered the natural evolution of the concept of "sustainable" or NZEB buildings, introducing a series of innovations toward positive changes and a more respectful vision of construction (Fig. 26.2).

But what can be considered a "smart building?" The concept of intelligence in buildings was introduced approximately around the 1990s (Derek and Clements-Croome 1997) when Information and Communication Technologies (ICTs) started to be applied to buildings, fostered by the first automations within the building sector enabled by the so-called Building Management Systems (BMS). However, it is only in the new millennium, with the spread of data storage and analytics systems, the introduction of open protocols, the "wireless transition" and, above all, the ubiquity of the IoT, that the concept of Smart Buildings begins to shape as we know it today (Bucknam et al. 2014).

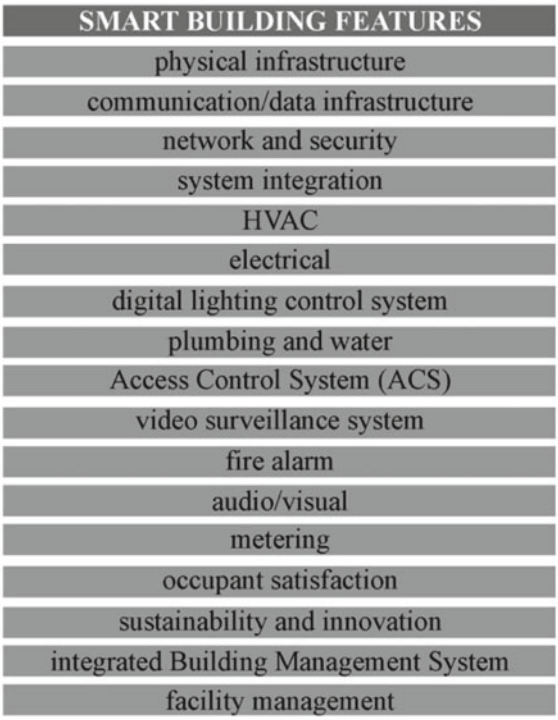

Fig. 26.2 Smart buildings' features. *Source* The Author

"Smart building" indeed is an umbrella term that has recently come into use to describe many different technologies that are being integrated into buildings. However, there is no clear definition of what makes a building "smart" (Hoy and Brigham 2016). In general terms, we can say that a smart building is a building that shows some kind of innovations, concerning technical plants but also building envelope components or the building system as a whole. It usually provides extra facilities if compared to a "standard building," such as connected device systems (composed of sensors and actuators) or IoT technologies, which allow visualizing several parameters in real-time concerning building state (such as the temperature of the rooms, the state of the equipment, the consumption of heating and electricity).

Moreover, the recent and rapid evolution of artificial intelligence (AI) and machine learning (ML) has equipped buildings with the ability to learn (Alanne and Seppo 2022) from previous settings, making adaptability at a system level a reality, also recurring to digital twin (DT) as training environments.

So, the result is the use of the word "smart" referring to the intelligence of things, intending to address the increased ability of systems (in this case, buildings) in doing something.

Smart buildings indeed redefine the use of common infrastructure in light of new technologies, thanks to modeling tools and connected devices which made it possible to conceive less energy-intensive and more environmentally friendly systems.

26.3 The "Smart" Goes Through the Envelope

A domain which offered fertile ground to coalesce much of the current discourse is those of building skin (Trubiano 2013), the place in which several factors (formal, performance, material, and mutual integration) come to a synthesis.

As interface among external and internal factors, to which is entrusted the achievement and the subsequent maintenance of certain conditions, this liminal surface must now be designed in a flexible and dynamic way to allow its adaption to the ever-changing variations of the surrounding context.

Conceiving the envelope as a responsive, multifunctional element rather than a static, single-behavior boundary, led to a paradigm shift in the envelope design field, determining the need for a wider analysis of the interactions between the building and the environment (Perino and Serra 2015), evaluating performance and mutual role in terms of constraints and intentions, generally measured quantitatively.

However, it must be said that focusing exclusively on the performance functionality of the building envelope can mean privileging the technological determinism of matters. Even though building envelopes are, by definition, central to the thermal and environmental regulation of a building's interior, the materials with which they are built contribute not only to their functionality but also to their formal value. It is through the materials and systems which shape the envelope that buildings relate to the surrounding, being immersed in it and dialogue also with the social and cultural context.

This adaptability capacity, which can be translated into the generation of architecture equipped with responsive abilities, produces a revolution in consolidated formal paradigms, determining the birth of complex systems in which the technological components are distinctive ad essential competences that significantly contribute to the definition of new architectural languages. Thus, the performance and functional-technological issues acquire a new aesthetic-formal value, becoming generators of a design process whose results are building organisms able to go beyond different cultures and architectural traditions.

So, is it quite clear that materials can be conceived as one of the most important "smartest" parts of a building, being often driven by innovation and technology (Sinopoli 2015). Yet, is it true that they would not allow meeting the expectations if installed incorrectly; the lack of coordination often results in the generation of severe performance issues during the construction phase, although products equipped with very high performance.

Indeed, among the latest "game-changers" (Sinopoli 2015) there are also innovative methods and tools for controlling the quality of construction projects and processes, so as digital techniques for design and representation, smart high-performance materials, and/or adaptive and innovative technologies that allow us to challenge how we think about building envelopes, making emerging an alternative paradigm for a theory of building.

26.4 Materials and Methods: Which Technologies Fit the Smart Building?

As in the case of any type of construction, when we talk about smart buildings the materials that can be used are plenty; industry and academia indeed, constantly work to develop innovative materials and building systems able to reconfigure themselves to meet external and internal changes in climate and user behavior (Barozzi et al. 2016), to create “living environments” (Abdullah and Al-Alwan 2019).

The quick spread of innovative technologies has been followed by the development of classification systems, to catalog and systematize technologies which fit the smart building (Carlucci 2021). Among the others, one of the most used (Attia et al. 2020; Casini 2016; Frighi 2022) is the one that identifies different families of building envelope typologies, according to the technology they adopt. The most common are: (i) dynamic shadings, (ii) adaptive glazing (chromogenic façades), and (iii) dynamic façades.

The first can be defined as the direct evolution of fixed shading systems typical of vernacular architecture (Al Dakheel et al. 2020); it comprises elements, devices, and technologies mainly aimed at selectively control the incident solar radiation in a dynamic way, thus possibly recurring to automated or intelligent systems.

The second refers to façades which employ chromogenic materials, mainly smart glass technologies, whose functioning is based on the change of their optical properties in relation to different kinds of inputs (e.g., solar radiation, temperature variation, application of voltage, use of hydrogen) (Fig. 26.3).

The third family refers to sets of heterogeneous components, elements, and/or materials able to vary their performance features over time, even recurring to technologies generally used in other industrial sectors (such as nanotechnologies, aerogel, vacuum insulated panels, self-cleaning technologies, or phase change materials) or equipped with the ability to change their behavior by reacting to external stimulus (of environmental nature or based on control systems that resort on sensors and actuators) thus varying one or more of their properties. Changes are, in general, direct and reversible. This is the case, for instance, of shape-memory materials (Mohamed 2017).

Downing the scale to the technologies included in the abovementioned domains, in the first case we mainly refer to building components, such as shading systems, shutters, louvers, or to general elements whose purpose is to regulate interaction among inside and outside, mainly in terms of thermal comfort and visual performance. The second family instead mainly involves glazed advanced systems, which range from reflective, selective, or low emissive glazing and goes through vacuum insulated glass, TIM glass, and heating glass, toward chromogenic glazing technologies and, again, innovative emerging solutions equipped with adaptive functions (generally control and manage more than prevent/reject solar radiation). While the third family concerns façade systems as a whole, considering simply ventilated façades, active façades (Villegas et al. 2020), or, again, innovative systems that involve advanced

Fig. 26.3 Metallic louvers, office buildings in Lisbon. *Source* The Author

materials and technologies equipped with smart functions in terms of purpose, operation mode, or adaptivity toward the external variations, considering also the relevant physics of the system or the adaptation scale (Loonen et al. 2013).

26.5 Expanding the Wave of Smartness: Conclusion and Future Developments

Architecture has always been a representation of the society, being the physical environment in which people live and work; from simple shelters conceived to offer protection, buildings have evolved following the modification of way of life, and users' needs as well, being shaped by climate conditions, materials readily available, and the value of the society building them. Accordingly, as new technologies rapidly developed, changing the needs of people and communities, construction continuously evolved; aided by computer design, architecture becomes ever more articulated in brave new shapes, previously unthinkable, capable of providing unprecedented behavior that goes beyond the simplification of traditional solutions, often determined by the assembly of regular elements.

The great potential new smart materials technologies have, can dramatically change the process of design and construction; a building envelope can then be thought as having multiple configurations, depending on the time of the day, the season, and the use, which may result in a certain architectural quality (Meagher 2015).

Smart buildings, whose technological components acquire new aesthetic-formal value, are thus becoming the driving force for the development of new ideas and architectural forms while giving buildings the much-needed resilience capacity (e.g., anticipating potential risk factors, developing future scenarios, or testing new performance responses).

Besides, the use of innovative materials, separated from their adoption according to conventional forms and meanings, generates a sort of new cross-cutting linguistic means, expression of a global architectural language capable to adapt to the continuously changing needs of a hybrid contemporaneity.

Although many twists and turns, this process has been unstoppable, so future development and architectural directions should focus on the production of materials, components, and systems that can support this process of evolution within the domain of architectural technology.

Certainly, the current ability to gather and collect a great amount of data, coupled with an explosion in IoT applications, can be considered somewhat of a solved problem, but this only represents a first step toward the expansion of the "smartness' wave"; the following is understanding what kind of information data is telling us, to inform better decisions, and managing that information in a way which makes data easy to access and to analyze. Since cognitive buildings are still on the distant horizon, we must find a way to merge the digital components of smart buildings with the traditional analog components of building operation, focusing on how we deliver information to building operators, what this information tells them, how they can use it and how they can feedback their knowledge to the system. We need to start from the perspective of someone using a building and think about what they want to know and then find a way of describing and connecting that information.

The task of tackling current challenges concurrently is a daunting one, but the correct application of smart building technology is undoubtedly part of the solution.

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