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'An economic feasibility study of Smart Building investments: the Italian scenario'

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This work represents the conclusion of my academic career, the ending note of a long and challenging journey. For the achievement of this accomplishment, I shall thank all those who supported me in these five years.

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Abstract

The real estate industry is currently under profound renovation, influenced by the wave of contemporary trends that are disrupting and reshaping a vast number of major markets. Digitalization and sustainable development are redefining the industry boundaries, altering the dynamics that have historically characterized real estate as a whole. Moreover, urgent answers are needed to deal with the ever-growing problem of urbanization and the generational turnover asking for radical changes in the way people interact with their surroundings. In this evolving landscape, the concept of Smart Building emerges as a powerful solution that adapts to the challenges of modern society, offering an unprecedent scope of possibilities and services, enabled by the advent of the Internet of Things (IoT). However, despite the increasing interest towards smart buildings from a large body of literature, several issues still remain uncovered. On a theoretical basis, a formal and comprehensive definition of smart buildings has not been provided yet, leaving space to a bouquet of possible interpretations of the concept. Moreover, in light of the structural complexity that characterizes the smart building ecosystem, some difficulties manifest from any attempt to comprehensively assess its performance outputs, both quantitively and qualitatively. On the basis of the current divergencies the topic presents, this thesis investigates the state-of-the-art literature around the smart building argument, by leveraging on the understanding of the main trends affecting its diffusion in order to provide its own definition of the term, together with an overview of its related scope of applications. What follows is a study of the Italian investment market for smart buildings, by consulting cases of applications at residential and commercial level in order to picture a contextualized overview of its current state of development.

Sommario

Il settore immobiliare sta attualmente attraversando un periodo di forte cambiamento, afflitto dall'ondata di trend che stanno distruggendo e rimodellando svariati mercati. Digitalizzazione e sostenibilità stanno ridefinendo i confini del settore, alterando le dinamiche e le logiche che ne hanno da sempre contraddistinto il funzionamento. Allo stesso tempo, risposte immediate devono essere garantite per affrontare l'avanzata dell'urbanizzazione e il turnover generazionale che sta attualmente ridefinendo l'interazione tra persone e strutture. In questo quadro evolutivo, il concetto di smart building si candida ad assumere un ruolo fondamentale nell'affrontare le sfide della società moderna, garantendo un ventaglio di possibilità inedito, supportato dalla prepotente introduzione dell'IoT (Internet of Things) all'interno degli edifici. Tuttavia, nonostante l'aumento di interesse nei confronti di tale tematica, diverse questioni rimangono tutt'oggi irrisolte. Da un lato, a livello accademico, non è ancora stata riconosciuta una definizione formale e inclusiva del concetto di smart building, lasciando spazio a diverse interpretazioni. Dall'altro, alla luce della complessità strutturale che caratterizza il mercato dello smart building, emergono innumerevoli difficoltà nel valutarne integralmente i risultati e benefici conseguiti, sia attraverso un approccio quantitativo sia assumendo una logica prettamente qualitativa. Sulla base delle attuali divergenze di fondo, la tesi indaga sullo stato dell'arte della letteratura attorno al concetto di smart building, inizialmente valutando i trend che hanno contribuito al suo sviluppo per poi giungere ad una definizione esaustiva del termine, affiancata da una mappatura delle aree di intervento ad esso correlate. Il lavoro viene supportato dallo studio del mercato italiano sugli investimenti in ottica smart building, identificando casi di successo nel panorama nazionale, sia a livello residenziale che commerciale, al fine di giungere ad una valutazione di contesto dell'effettivo stato di avanzamento di tale soluzione.

Executive Summary

Purpose of the Study

Real estate industry is under sectoral transformation, affected by the new wave of technological innovation brought by digital transformation, which is currently redefining the principles that have characterized the functioning of said industry. However, technological transformation alone does not provide the whole picture of an industry reshaping, as it merely acts as an enabler of solutions, implemented in order to achieve superior objectives. In this perspective, the concept of smart building emerges from the confluence of several macro-trends – among which the most important are digital transformation, sustainable development, increasing urbanization and millennials impact – into a new idea of built infrastructure, not anymore internally bounded, but able to work with elements outside its four walls. Awareness of the importance of developing smart buildings is increasing among investors, yet there is not a unique vision of how a smart building is intended nor a definite structure of all the attributes that can shape its development: as a matter of fact, there is still a lot of confusion in today's market around its definition, the features and functionality of key enabling technologies, and the distinction from legacy automation and control solutions (Lilis *et al.*, 2017; Navigant Research, 2019).

On the basis of these premises, the thesis aims at investigating the reference environment around which the concept of smart building has developed and the set of properties and attributes that define it. The complete understanding over the features and boundaries of a smart buildings provide the basis for assessing its performances and evaluating the feasibility in case of investment. The analysis of application cases at both residential and commercial level helps supporting the study by providing (when available) quantitative evidence of the performance outputs achievable from a smart building investment.

Research Questions

In order to accomplish the aforementioned objectives, the theoretical and empirical activity of this thesis should be organized according to some key guidelines, in the form of research questions. The purpose of research questions lies in the way they provide the direction of the study, supporting the selection of the most appropriate sources of information. Main research questions have been used to define the direction of the thesis:

1) *What drivers should be accounted in order to comprehensively and exhaustively define the concept of smart building and characterize its scope?*

2) *What are the main elements that have to be included in order to provide an integrated evaluation of the impact of smart technology and systems on a building's performances?*

Literature Review

The literature review of this study evaluates, through a dynamic approach, the state of the art of the concept of smart building. The section articulates into two main modules: the first one identifies and evaluates the reference context around which the smart building started developing, by understanding the main trends that affected its diffusion; the second one provides this work's definition of the concept of smart building, distinguishing between technology-oriented and goal-oriented perspectives, while subsequently identifying the main areas of intervention that characterize its scope of adoption.

The first module evaluates the scenario around which the concept of smart building has been imagined, by means of a divergent approach aimed at singularly target each trend that effectively contributed to reshape the industry boundaries and gave form and power to the building revolution. In this perspective the analysis brought to the identification of three main trend categories, each one briefly discussed with a specific focus on their interaction with real estate and building sectors:

1. *Technological trends*, related to the fourth industrial revolution, which constitute the enabling platform upon which smart buildings are developed (Granelli, 2016). In particular, among the several innovations catalogued under the industry 4.0 ecosystem, the thesis only examines the ones that highly contributed in defining the basis and architectural infrastructure for the introduction of smart buildings into both residential and commercial property markets, enhancing performances and creating additional value for stakeholders. In regards, the following technological trends have been determined and exhaustively discussed: *internet of things* (*IoT*), *big data and analytics*, *cloud computing and storage,* and *cybersecurity* (Rübmann *et al.*, 2015). For each technology, a brief introductory analysis is carried out, followed by the assessment of its importance for the design and management of the building new infrastructure;

2. *Macro-economic and environmental trends*, mainly inherent to the sustainability issue, divided according to its three pillars (*economic, environmental and social sustainability*). Each of the three spheres of sustainability has been initially analysed from a generic and individual perspective, with a successive overview of the interactions and dynamics with the other two pillars (Clune and Zehnder, 2018; Beattie, 2019; Purvis, Mao and Robinson, 2019); afterwards, the impact of sustainability practices has focused on the building sector and how business models and strategies have adapted to such change of perspective. In this part, the concept of sustainable building has been introduced, discussing how several sustainable initiatives can be implemented within its structure, other than the 'evergreen' attempts to reduce energy consumption.

3. *Socio-demographic trends*, which affected development in the building sector, by accelerating technological advancement and increasing the overall demand for built environments, driving the research towards customizable and flexible spaces. In regards, two major forces are reshaping the way buildings are modelled: the increasing *urbanization* (which drives the demand for flexibility and space optimization within buildings), as well as the demand for enhanced connectivity and services, as a consequence of the shift towards a prevalently *millennial workforce* (Bansal, Shrivastava and Singh, 2015; Deloitte, 2019). A first general overview of each trend is followed by an of understanding of its influence on the building sector.

The second module of the literature review is organized in two main sections, one focused on the discussion around the definition of smart building, the other centred on the identification and characterization of its investment-oriented scope.

In the first part, the thesis investigates the extant literature and collects some of the interpretations provided for assessing the concept of smart building. From the evaluation of collected contributions, each one provided on the basis of the specific research field of the article, it is possible to identify two branches when referring to a potential smart building definition. On the one hand, a first branch defines smart buildings by leveraging on their *technological features and peculiarities*, addressing the importance of the most recent innovation waves that dramatically changed the building landscape and the way different building end devices interact and connect to each other (Sinopoli, 2010; Berawi *et al.*, 2017; Digital Transformation Monitor, 2017). On the other hand, a second branch aims at depicting smart buildings by leveraging on the *benefits associated to their adoption* rather than the technological infrastructure upon which a smart building lays its foundation, providing a less technical but 'visionary' overview of what newer buildings may potentially be able to provide to owners and end users (Herrenkohl, 2017; Fletcher, Santhanam and Varanasi, 2018; Tomlinson, 2019). As a result of the opposing perspectives that arise by reviewing some of the main publications on smart buildings, two main classifications of smart building definitions arise, being them either *technology-oriented* or *goal-oriented* (although hybrid approaches are also possible). In light of the revision of literature contributions, the definition embraced within the thesis is the following (Energy&Strategy, 2020):

"*The term Smart Building refers to an environment in which existing building devices and solutions are managed intelligently and automatically, by means of the adoption of a connected management & control platform, with the aim of optimizing resource use and consumption, occupant experience, wellness and security, while also enabling the integration with the electricity system the building belongs to*"

The definition properly includes all the main elements that delineate the concept of smart building, by equally depicting aspects of both technologies adopted and benefits sought.

The section subsequently articulates into a discussion of the main findings gathered up by looking at the smart building definition. The discussion has been structured according to a two-steps process:

- In the first part of the discussion, the Big Picture of the smart building definition is illustrated, also evaluating the relation between its main functions and each category of stakeholders (Energy&Strategy, 2020);

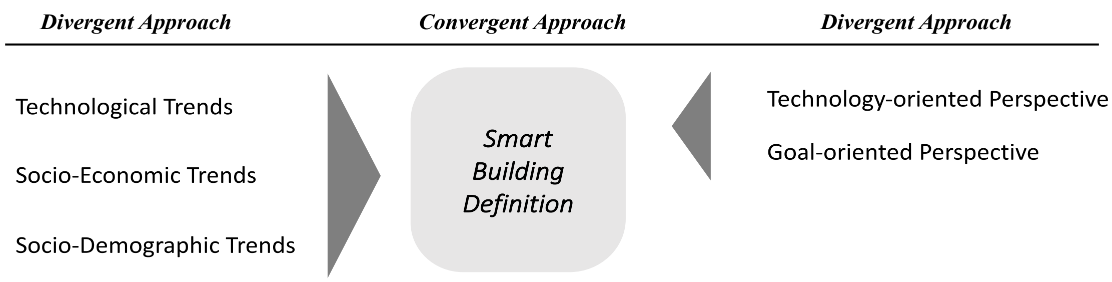
- In the second part of the discussion, the definition is fragmented into its more essential components, which are (Energy&Strategy, 2020):

    - *'Building devices and solutions'*, divided among energy generation, energy efficiency, safety&security and occupant satisfaction and well-being;

    - *'Automation technologies'*, which comprehends the hardware infrastructure enabling the intelligent functioning of the building, such as sensors and actuators;

    - *'Building Management Platform'*, which contains the software involved in the collection, elaboration and analysis of data generated by hardware components;

    - *'Connectivity'*, which determines the communication infrastructure, classified into either wired or wireless, that has been adopted in order to allow every other component to properly communicate.



FigureES 1. The divergent-convergent approach for converging to the definition of smart building

In the second part, after having formalized the smart building definition, a scope analysis of its theoretical 'infrastructure' is conducted, by following an investment logic aimed at identifying the most important advantages associated to its adoption. It is important to mention how not all the benefits of a smart building investment are ascribable to clear economic (thus, numerical) outputs, despite the evidence of correlation with a company's financial performances (Singh, 2018). The classification of a smart building by means of its benefits enhancement opportunities represents the foundation supporting the evaluation of company's case studies for assessing the economic implications of an investment into intelligent buildings. The following sections are addressed in order to provide a comprehensive structure of the scope of a smart building:

- *Resource efficiency*, under which lie all the interventions done with the purpose of addressing excessive resource consumption and usage, establishing it around optimal levels of efficiency. The main areas of intervention identified are:
    - *Energy consumption*: one of the most relevant areas of intervention, aimed at improving energy performances by reducing consumption. Two main types of interventions are addressed, *energy efficiency* and *energy generation*;
    - *Space utilization*: it concerns the interventions aimed at optimizing the space occupied for building activities, enabling innovative business models such as ABW ('Activity-Based Working') and 'agile organization' (King, 2016);
    - *Human resource management*: it examines the effects of smart technology on workers' productivity within buildings. One example of employee performance boost is the reduction in the number of 'illness days', by leveraging on better workplace parameters such as indoor air quality and lighting (King, 2016);
    - *Operations and maintenance*: it evaluates the effects of predictive maintenance and control on a building performances. The benefits ascribable to intelligent performance monitoring are increasing business continuity and maximized asset value generation (Locatee and Memoori, 2019);
    - *Waste and water management*: it examines the impact of smart building technology on how waste and water management issues are addressed (Locatee and Memoori, 2019).

- *Occupant experience*, under which lie all the interventions and solutions aimed at providing the ideal living conditions within a building, tailored on occupants' needs and preferences and boost the overall experience level. The benefits obtainable by such interventions are related to the level of occupants' satisfaction, which in turn may reflect on their productivity. Smart building solutions focused on enabling a personalized workplace experience can be beneficial for all occupants (Locatee and Memoori, 2019). In order to classify occupant-related solutions, two main areas of intervention are identified: the improvement of occupant health and wellbeing and the optimization of number and nature of interactions and collaboration among occupants.
- *Risk mitigation*, under which lie all the interventions aimed at reducing risks and enhancing security within a building. Difficulties arise in determining exact calculations of investment return from safety&security projects, as the benefits lie in the reduced number of threats, which in turn brings to reduced losses. Among the several applications referring to the concept of risk reduction, two main branches are distinguished (Locatee and Memoori, 2019):
    - Safety solutions, which includes access control and visitor management, and threat detection;
    - Security solutions, divided between physical security and cybersecurity investments;

Case Study Analysis

This section illustrates five cases of smart building application, with the Italian market as reference environment. Indeed, the market has registered a significant growth in the last years, with an overall amount of investments assessed around 3.6 bln €, also favoured from the increasing concern on the topic of regulatory bodies. Despite the rising concern, the Italian market is still characterized by great complexity: as a clear and comprehensive definition of smart building has not been acknowledged yet, the uncertainty around the concept seems to directly reflect on the current fragmentation of the related legislative structure as well. As a growing yet inefficient environment, the Italian market represents a valuable reference domain for carrying out a case study analysis.

The research methodology of the thesis empirical activity is articulated into two parts. A first subsection provides the procedure adopted in order to search for, identify and target potential cases of smart buildings in Italy, alongside the actors that has contributed for the development and management of the targeted cases. The process of identification of meaningful smart building investment cases consists of three main consecutive phases, namely *keywords searching* (search for possible cases by using specific words or any combination of them), *screening* (qualitative analysis aimed at distinguishing proper smart buildings from inexact interpretations) and *categorization* (segmentation by building category, according to which buildings have been differentiated between residential and commercial investment cases). A second subsection provides the procedure for which the structure of the questionnaire to be submitted to the targeted actors has been delineated. The structure of the questionnaire has been organized in order for it to be indistinctively addressable for each building category, therefore covering for commercial as well as residential applications. The questionnaire articulates into four sections:

- *Preliminary information;*
- *Investment analysis;*
- *Company's investments and strategy in the smart building market;*
- *Regulations, incentives and certifications.*

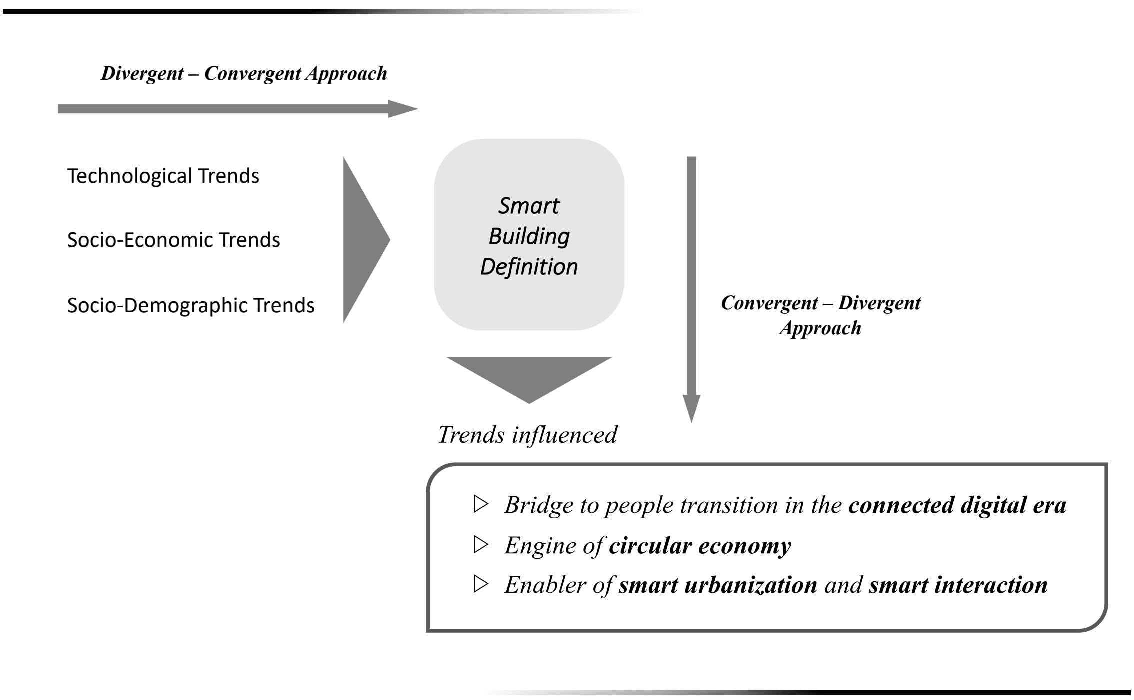
On the basis of the research methodology deployed during the empirical study of the thesis, five cases of smart building in the Italian territory have been outlined, for each of which a picturing of the main characteristics, interventions and innovations is provided, together with a strategic overview of the main advantages generated from the investment. Moreover, two cases present an assessment of the economic impact of smart technology investments on the building performances, by means of the implementation of a NPV (Net Present Value). The five cases selected for the analysis are the following: *Condominio Via Verro (Milan, residential building); Corso Como Place (Milan, commercial office building); Diamond Tower (Milan, commercial office building); NOI Tech Park (Bolzano, innovation park); Fondazione Agnelli (Turin, co-working office space)*.

Discussion and Conclusions

This section collects and elaborates the results and insights from the previous sections. It articulates into three distinct blocks.

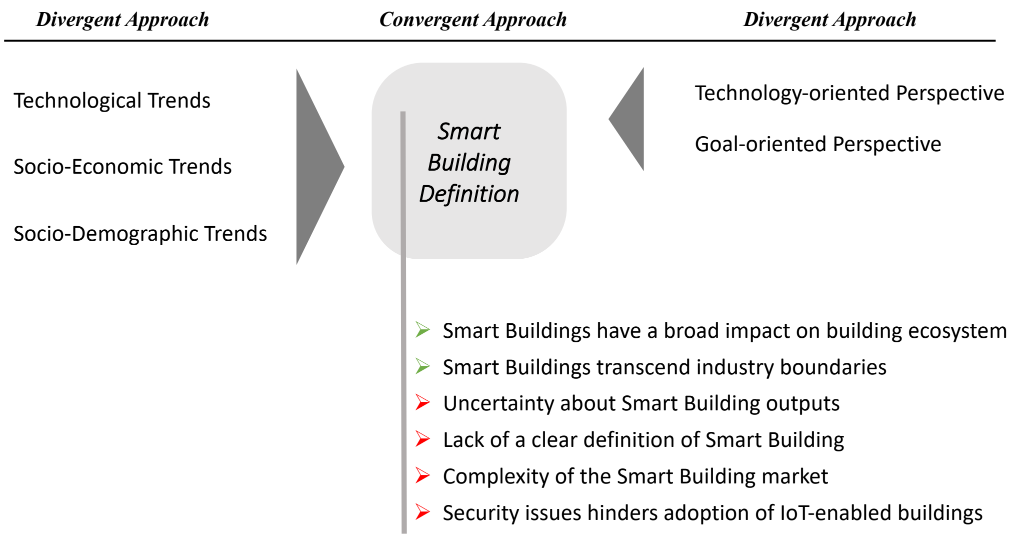
The first block proposes an understanding over the main theoretical results brought throughout this work's review of the extant literature, through a detailed summary of its most important outcomes. The argumentation is composed of two main branches:

- The first branch explains the relevance and actuality of smart buildings by highlighting the main impacts on current society and building ecosystem. On the basis of the approach adopted in order to structure the literature review, by taking a convergent-divergent approach, that is to unravel the concept of smart building in order to understand the trends it generates or directly contributes to reinforce, relevant outcomes can be found, as summarized in *FigureES 2*. By looking at the figure, it can be affirmed how smart buildings encompass different trends, fitting diverse models and frameworks, but also provide an innovative approach into the relation between humans and built environments, elevating their coordination at a completely different level.



FigureES 2. The influence of smart buildings on current society needs and trends

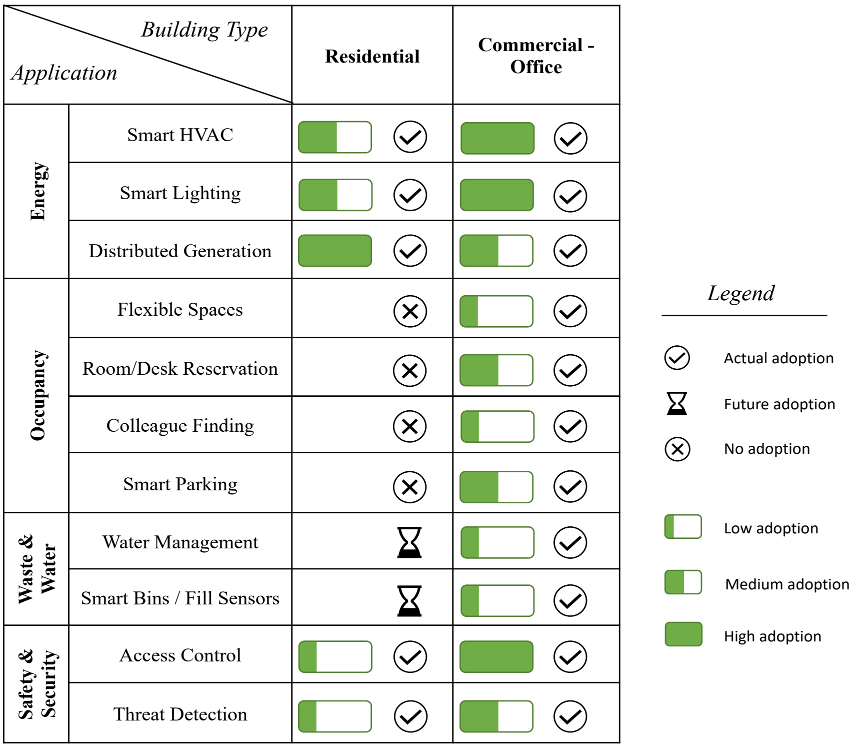
- The second one contributes to show an overview of the smart building landscape. By leveraging on the literature study provided in this work, this part focuses on understanding the main opportunities and challenges that lie ahead in the smart building landscape, synthetized into *FigureES 3*.



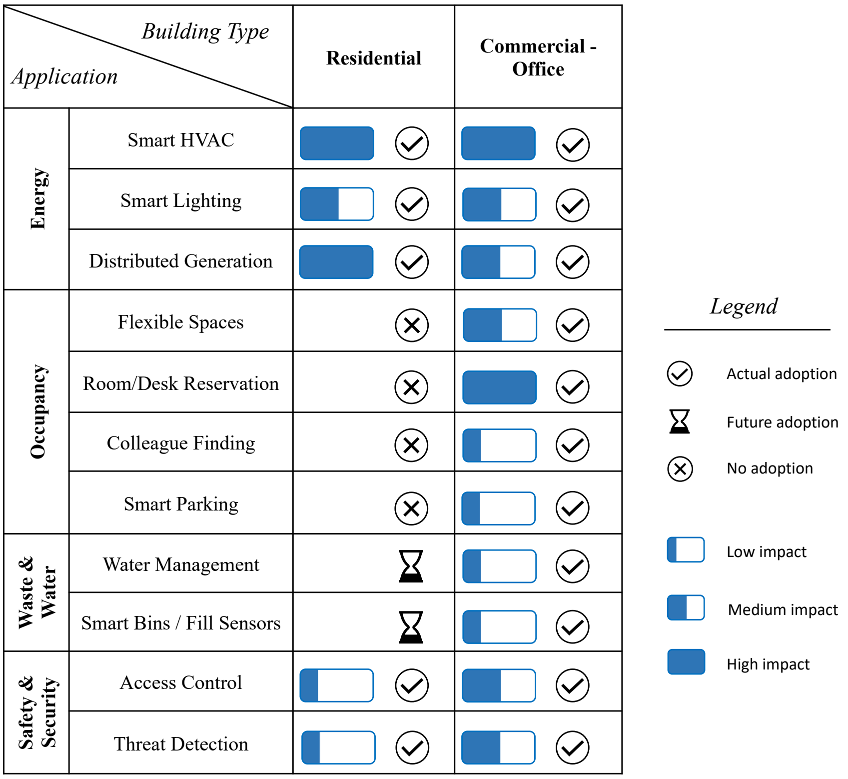
FigureES 3. Main outcomes from the literature: opportunities and challenges

The second block aims at deepening into the analysis of the dynamics that govern smart building investments, by leveraging on results – quantitative and qualitative – obtained from both primary and secondary sources. The discussion is composed of two main parts:

- The first one provides an outlook of the smart building investment market in Italy. By relying on some of the sources collected, a panoramic of the rate of adoption of smart building applications is provided, together with an assessment of the impacts each application has on a building's performances. The output of the analysis is delivered in the form of two tables. In providing the following figures, some estimations and approximations have been done, given the uncertain profile of several of the analysed invoices, both in terms of adoption rate and impact assessed.



FigureES 4. Rate of adoption of smart applications on the basis of building category



FigureES 5. Impact levels of smart applications on the basis of building categories

- This second one provides some further evidences through a contextualized analysis of the business cases presented in section II, collecting the main results of the case study and proposing a both qualitative and quantitative analysis of its most relevant outcomes.

The third block provides the conclusions of the thesis and comprehends two distinct parts. The first part aims at highlighting the innovative contribution brought by the thesis, while the second part reports the set of assumptions and limitations of the study, which are then leveraged in order to propose future developments.

- The *degree of novelty* brought by the thesis derives from the attempt of analysing the impact of a smart building by considering all of the different outputs that can be generated from its investment. The thesis assumes a holistic perspective by targeting every process that smart buildings may affect. Moreover, the thesis supports and applies the adopted perspective through the analysis of five use cases that provide evidence of some of the theorized outputs, both qualitatively and quantitatively. Besides, the thesis proposes a unique approach in delivering its own definition of the term 'smart building', by leveraging on the analysis of the main trends that characterized the diffusion of the concept, as well as on the two different perspectives – technology oriented or goal oriented – that could be assumed for determining its meaning.

- *Assumptions and limitations* of the research have to be found in the information gathering process for the design of suitable smart building business cases. In particular the following limitations are presented:
  - *Limitation to the research area*: this study presents and analyses cases of buildings in the Italian territory, although valuable insights might come from cross-countries evaluations;
  - *Limitation to the typology of building considered*: cases of facilities such as airports and hospitals have not been evaluated in this study, as their dynamics highly differ from those of conventional buildings;
  - *Main approximations in the investment analysis (where provided)*: data used for the case analysis are mostly presented in the form of aggregated invoices.

For what concerns possible future developments of the work, efforts should be concentrated into two directions, one dependent on the other:

- At business level, companies should try to optimally exploit the vast set of data gathered through monitoring processes. Currently, most of a firm's efforts are dedicated to the collection and processing of data on building energy performances, while the focus should be gradually extended also to other branches of the analysis, for which quantifiable results are not available yet;

- At both business and academic research level, efforts should be put in the realization of theoretical and empirical models aimed at mapping smart building performance outputs, following (as much as possible) generalized use cases classified according to the set of technologies implemented. Such approach would provide advance knowledge on the possible outcomes of a future specific investment.

Introduction

The real estate sector qualifies as one of the most influential domains in terms of investments and expenses, providing a unique combination of both tangible and intangible benefits to property owners. A first aspect that strongly defines real estate is its asset intensiveness (paired with a significant amount of capital required), which has historically provided inflation adjusted returns (Glickman, 2014). For this and several other reasons, real estate thus represents a valuable alternative to investors, who have to adjust their property investment strategies according to the variables influencing and shaping the overall value of a building. As a matter of fact, the main task of individuals and companies striving to succeed in real estate markets is to understand which choices (in terms of building selection, construction and design) have the greatest impact on the generated expected return (Glickman, 2014).

Provided that the features and dynamics characterizing property markets vary according to the type of building considered, a first distinction between commercial and residential real estate has to be deployed. In particular, “commercial real estate (CRE) is property used exclusively for business purposes or to provide a workspace rather than a living space. Most often, commercial real estate is leased to tenants to conduct business. This category of real estate ranges from a single gas station to a huge shopping centre. Commercial real estate includes retailers of all kinds, office space, hotels, strip malls, restaurants, and convenience stores” (Chen, 2019). At the same time, “Residential real estate is an area developed for people to live on. As defined by local zoning ordinances, residential real estate cannot be used for commercial or industrial purposes. Such laws vary from location to location and can restrict how many buildings are allowed on a single block and what kinds of municipal services reach those buildings” (Bankrate, 2020).

Although there are some common aspects of an investment in either commercial or residential property, structural differences emerge especially for what concerns the benefits sought by its inhabitants. In particular, considering the case of a commercial property, its tenants may seek to generate value from a wider variety of elements, having the opportunity to profit from scale effects (as well as optimize resources), thus enhancing the full potential of a building. Accordingly, it may be common sense to say that greater complexity has to be managed for commercial real estate. However, despite the high attention toward the subject, the market dynamics influencing real estate have showed little to no changes in the way they are determined as well as in the logics behind a building investment, until recent years. In fact, till the beginning of the 21st century, the identification of a favourable location has been considered to be the one and most relevant factor in defining a building selection strategy, being it either for residential or commercial purpose (Reutskaja *et al.*, 2018; E, Talasila and Pasumarthy, 2019). Indeed, this results as a direct consequence of one of the unique characteristics of real estate as an asset class, *immobility* (Kiel and Zabel, 2008). Considering the large focus of economists on location as the critical factor where to concentrate most of the analysis, given the traditional footprint that generally characterizes real estate markets, the sector on average has registered a slower pace of innovation compared to others, at least until recent years. Although location still heavily contributes to the overall value of a property investment, new sources of advantage emerged in the latest years which changed the general perspective about real estate, adding on complexity in the evaluation of a strategic investment decision. Again, this results to be particularly true if considering cases of investments in commercial real estate. In particular, the reshaping of the sector has to be ascribed mostly to two major trends: *digital transformation* and *sustainability*.

- *Digital transformation* qualifies as a megatrend that is actually disrupting many industries, providing new opportunities and challenges to traditionally stable business models, by means of adoption of digital technologies into the strategic, organizational and operational spheres of a firm. Digital transformation appears as a comprehensive and broader process, enabled by digitalization, which sets as the last wave of technological innovation brought by ICT, following those of integration and automation (Fletcher, Santhanam and Varanasi, 2018; Vial, 2019). The pervasive penetration of digital technologies into real estate posed the basis for a complete reconfiguration of the way buildings are intended and designed, enabling unexplored opportunities of optimizing its performances, as well as substantially reshaping the number and depth of interactions between humans and their surroundings;

- The concept of sustainability as a trend can be referred as the need to change how value creation is achieved, in a way that could add benefits to all the parts directly or indirectly involved in the value generation process, at economic, social and environmental level. As will be exhaustively addressed in the following sections of the thesis, during the last decade sustainability has emerged as a topic of massive concern among scholars, and the concept of sustainable development has been accepted as a superior solution compared to those of traditional business models. However, given the usually higher cost and complexity associated to such solutions, considering how private investors would evaluate their adoption only in presence of a clear economic incentive, the penetration of sustainable business models into the marketplace has been poor (L. Krause and Bitter, 2012). The issue of sustainability is particularly compelling in emerging countries, as the large-scale gathering of the population in the cities spawns a large number of housing demands, boosting the investment in the real estate market. In addition to promoting urban construction and economic development, real estate investment also involves upstream and downstream industries such as building materials, construction, steel, and cement industries. This leads to an increasing consumption of energy and, as a direct consequence, carbon emissions (Chen, Kamran and Fan, 2019). In Europe, the concept of *environmental sustainability* has been the first and most critical issue to be addressed in real estate, as statistics show how the building sector is one of the major contributors to greenhouse gas emissions generated from energy consumption.

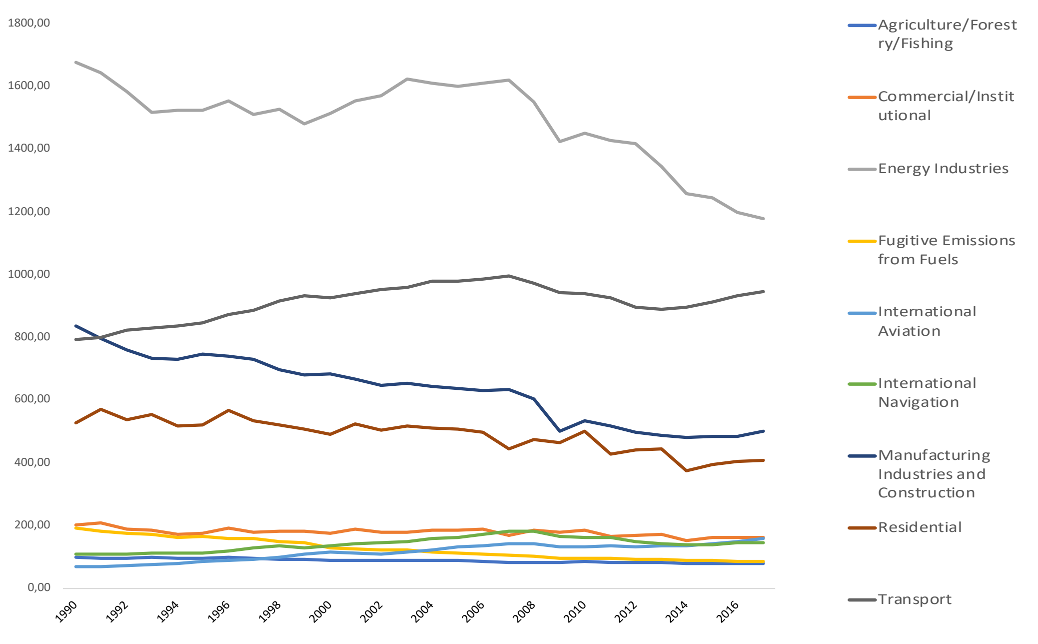


Figure 1. Greenhouse gas emissions from energy consumption, by sector

The embodiment of digital transformation and sustainability into real estate has given rise to a new source of value in building, which does not see location as its fundamental determinant. By enhancing the potential of technology as enabler of new business opportunities, considering the growing need for the creation of sustainable value over time, the focus of investors has moved towards a different idea of building, also known as *smart building*. Accordingly, this thesis investigates the environment around which the concept of smart building has been framed, in order to propose a definition of the term inclusive of all of the attributes that progressively qualify its innovative nature. To truly describe the pervasiveness of the concept, the definition of smart building should encompass two different perspectives, one considering its foundation technological infrastructure (*technology-oriented perspective*), the other evaluating the set of goals and benefits enabled by its adoption (*goal-oriented perspective*). As a matter of facts, the definition provides a picture of the state of art of a smart building, in which the marriage between technology and objectives is strengthening in favor of a more human-centric vision of infrastructure. In addition, in order to validate the profound impact smart buildings are having on society, the thesis carries out a feasibility study of the economic potential of such solution, by investigating current performances with respect to the Italian scenario.

In order to accomplish the aforementioned objectives, the theoretical and empirical activity of this thesis should be organized according to some key guidelines, in the form of research questions. The purpose of research questions lies in the way they provide the direction of the study, supporting the selection of the most appropriate sources of information. Main research questions have been used to define the direction of the thesis:

1) *RQ1. What drivers should be accounted in order to comprehensively and exhaustively define the concept of smart building and characterize its scope?*

   This question addresses one of the major issues of current literature around smart buildings, that is the lack of a formal and exhaustive definition of the term. Without any reference interpretation that successfully contributes to map all of the attributes of a smart building, the thesis excavates the current state-of-the-art by assuming a divergent approach, that is to initially address each feature singularly, in order to successively converge into a holistic picture.

2) *RQ2. What are the main elements that have to be included in order to provide an integrated evaluation of the impact of smart technology and systems on a building's performances?*

   This question addresses the current lack of a unified analysis that gathers all of the factors contributing to assess the actual performances of a smart building. Indeed, it should support the search for all the dimensions that smart buildings successfully influence, either being economic, environmental or social, also including those that are only indirectly affected.

Section I: Literature Review

This section aims at providing an overview of the set of principles around which the concept of smart building is framed. By identifying the reference environment, as well as understanding the main trends affecting its diffusion, it is possible to draft a broad and comprehensive definition of smart building. What follows is the assessment of the scope of a smart building, by means of a benefit-sought classification of its main attributes.

1 Main Trends and Reference Context

Real estate is rapidly moving toward a radical change, aligning with several other industries in which digitalization has pervasively reshaped the way to do (and even intend) business. The most relevant disruption is the shift toward the concept of smart building, which results from the convergence of diverse influences and innovations into a new idea of built infrastructure, not anymore internally bounded, but able to work with elements outside its four walls (Siemens, 2016). Awareness of the importance of developing smart buildings is increasing among investors, yet there is not a unique vision of how a smart building is intended nor a definite structure of all the advantages disclosed by its adoption: as a matter of fact, there is still a lot of confusion in today's market around its definition, the features and functionality of key enabling technologies, and the distinction from legacy automation and control solutions (Navigant Research, 2019). Nevertheless, while the adoption of smart solutions in building increases, the boundaries of several segments in the construction industry are blurring, adding more complexity as the new converging market matures. This brings uncertainty on how the sector is going to be redefined at the end of such transformation, and, consequently, it is more and more difficult for companies to take the right adjustments in order to safely navigate in an evolving space (Pieper *et al.*, 2018). Therefore, to provide a fully comprehensive definition of smart building and to better understand the direction it will give to the market, it is first recommendable to identify what trends and sectoral innovations brought to the adoption of such solution. In order to analyse what trends and innovations affected the transition of the market towards smart buildings, it is not sufficient to consider the impact of technologies as an enabler of solutions. Therefore, the analysis is structured in a way that considers the impact on building transformation of elements from different trend perspectives, which offer considerable new opportunities to companies, sectors, countries, and individuals embracing them successfully (McKinsey & Company, 2019). Therefore, a first partition can be made, and three trend categories are identified:

1. *Technological trends*, related to the advent of the fourth industrial revolution (also called industry 4.0), which is reshaping the way business is conducted, opening the possibility of new opportunities for companies to generate value;
2. *Macro-economic and environmental trends*, mostly ascribable to the sustainability issue, divided according to its three pillars (economic, environmental and social sustainability);
3. *Socio-demographic trends*, related to increasing urbanization, millennials occupying working positions, and connectivity as an effect of globalization;

This section of the study initially takes on a *divergent approach*: each trend category is addressed individually, aimed at giving a linear perspective of the macroenvironment around which the concept of smart building has proliferated. Subsequently, following a *convergent approach*, the outputs of each singular trend analysis are focused into the 'epicentre' of the study, the concept of smart building. Although taken singularly, it is worth noting that each trend is not to be seen as an isolated entity, but as a phenomenon which is structurally interconnected with the others mentioned above. To show how different categories are intrinsically connected, the following example is provided.

As an alternative to replace the current linear system, the implementation of *circular economy* (the most prominent output of sustainable development influences) strongly depends on information disclosure along the value chain, for which operational gaps still exist (Kraaijenhagen, Van Oppen and Bocken, 2016). In this perspective, a solution to address implementation challenges of circular economy is represented by the exploitation of the pervasive connectivity potential granted by the Internet of Things. "The convergence of the digital and material world could provide the infrastructure required for implementing feedback-rich systems throughout the product lifetime, facilitating information transparency and process circularity, and thus, advancing the adoption of the

CE" (Ellen McArthur Foundation, 2015; Kraaijenhagen, Van Oppen and Bocken, 2016). Moreover, remote control technologies allow to exploit (continuously) generated information to expand the service offered, therefore IoT can be also recognised as an enabler of additional value generation (Alcayaga, Wiener and Hansen, 2019). This example, although simplistic, shows how the connection between diverse trends represents a stronger and more exhaustive evidence of a business opportunity potential.

1.1 Technological Trends

Technology is the fundamental engine that enables the business transformation currently ongoing worldwide. Known as industry 4.0 or fourth industrial revolution, this phenomenon is modifying every aspect of the economic, social, cultural as well as human environment. It goes without saying that it is critical for companies to understand what opportunities lie behind each technology wave and to develop key strategic competencies in order to profit (but also defend) from a changing environment (Granelli, 2016). Specifically, industry 4.0 may be defined as a "socio-technical process affecting the physical, digital, and biological domains, based on the innovative and effective exploitation of a wide range of new and emerging prevalently digital technologies through their fusion and interaction" (Schwab, 2016). Although the initial concern towards industry 4.0 was limited to the manufacturing industry, it rapidly extended to services, stressing the idea of digital technologies as *horizontal technologies*, in a way that highlights their pervasiveness, scalability and flexibility. Indeed, digital technologies are able to penetrate each kind of domain, from products and services to processes, from business to everyday life (Granelli, 2016; Mariani and Borghi, 2019). Furthermore, the advent of digitization allows many new businesses to provide 'information goods' with marginal costs close to zero, and enables the creation of many interdependencies among sectors with little to no transportation or replication cost (Schwab, 2016).

Digital technologies thus represent the qualifying factor of the revolution, the enabler of the industry 4.0 ecosystem. According to a research conducted by Accenture in 2016 on the most important technological trends, it is shown how digital economy will represent 25% of the world economy in 2020, while it was only 15% in 2005 (Accenture, 2016). Considering the technical side of the industry 4.0 ecosystem, the whole set of enabling digital technologies characterizing the revolution can be classified into *nine foundational pillars*, as explained by the Boston Consulting Group in its renowned paper "Industry 4.0 – The Future of Productivity and Growth in Manufacturing Industries" (Rübmann *et al.*, 2015). Despite that each technology appears to be reported separately from the others, they are indeed interconnected and interdependent in their application (Culot *et al.*, 2020). As proposed in a recent systematic review on the topic, all the key enabling technologies of Industry 4.0 appear to be characterized by the interaction between the physical world and the digital one (Mariani and Borghi, 2019). The technological scope of industry 4.0 is thus represented by: *autonomous robots, simulation, horizontal and vertical integration systems, industrial IoTs, cybersecurity, cloud, additive manufacturing, augmented reality, big data, and analytics*. It is worth noting how several pillars' definitions – that were originally defined on the basis of their relation with the manufacturing sector – have now encompassed other economic sectors, aligning to a changing context in which sectoral boundaries are rapidly vanishing (Evans and Annunziata, 2012; Rübmann *et al.*, 2015; Culot *et al.*, 2020).

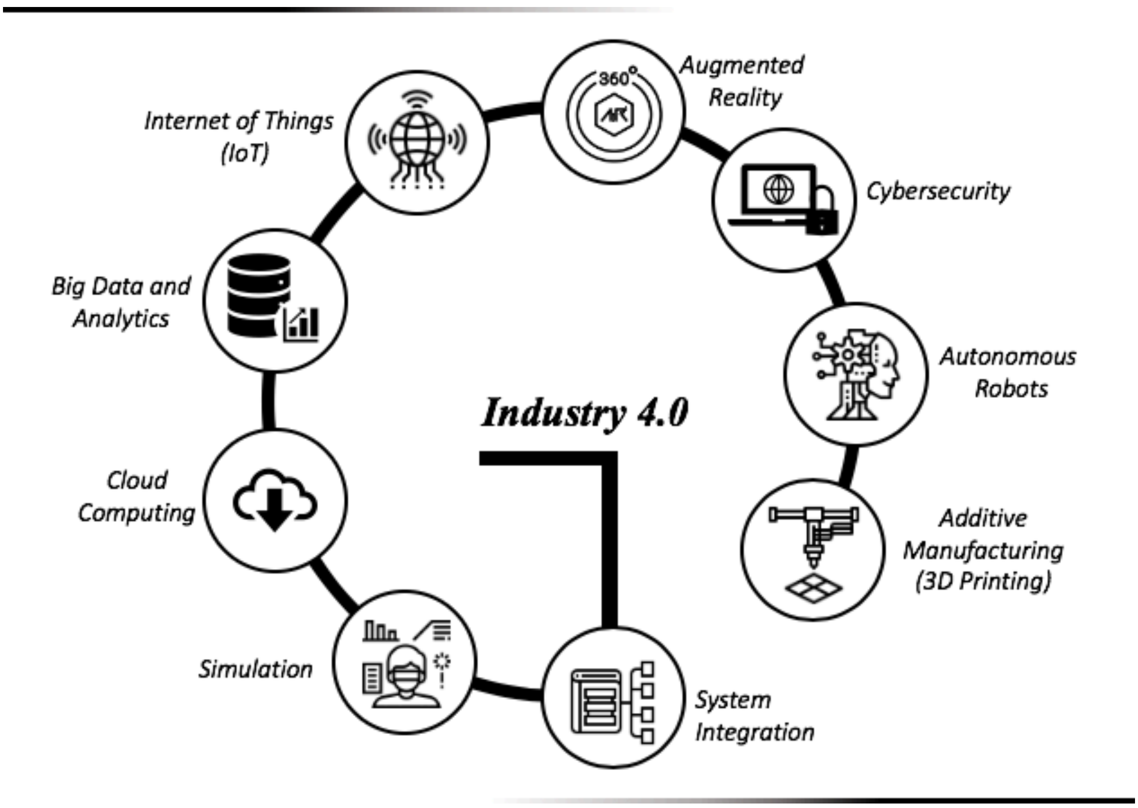


Figure 2. Industry 4.0 nine pillars (adapted from (Rübmann *et al.*, 2015)*)*

The impact of industry 4.0 has been considerable in real estate, defining the basis and architectural infrastructure for the introduction of smart buildings into both residential and commercial property markets. Clearly, not all of the nine foundational pillars of the revolution resulted to be equally worth considering within the context of building transformation. However, it is remarkable to notice how some of them have had disruptive effects on the way a building is designed and managed, as well as on how to optimize performances and create additional value. In particular, the following section concerns the impact on the building sector of the following technological trends: *internet of things* (*IoT*), *big data and analytics*, *cloud computing and storage,* and *cybersecurity*.

1.1.1 Internet of Things (IoT)

Smart buildings may represent the most prominent example of the disruptive power that IoT can exert on several businesses, disclosing new value generation opportunities with unprecedented easiness, fundamentally changing the way to interact with the surrounding environment (Manyika *et al.*, 2015). Therefore, it is important to delve into the concept of IoT, and in this perspective, a comprehensive and well-rounded definition of the Internet of Things is provided by Gartner (Gartner, 2020e): "*The Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment*". Another, more extensive, is given by Deloitte (Kejriwal and Mahajan, 2016): "*The IoT is a suite of technologies and applications that equip devices and locations to generate all kinds of information – and to connect those devices and locations for instant data analysis and, ideally, 'smart' action. Conceptually, the IoT implies physical objects being able to utilize the Internet backbone to communicate data about their condition, position, or other attributes*". From the aforementioned definitions, some insights can be caught about IoT that allow its full comprehension. First of all, it is a "network of physical objects". More specifically, it is a network of sensors, defined as devices that create electronic signals as consequence of a certain physical condition or event. Thus, the aim of each sensor is that of providing a piece of information in the form of signals. In order to properly function, sensors have always been complemented with actuators, receiving signals as input and converting them into information useful in decision making, returning a certain command as output, such as the increase/decrease of temperature of a certain environment according to the registered ambient temperature (Holdowsky *et al.*, 2014). What IoT adds (as a communication architecture) is the capability of sensors to independently 'interact' by connecting to the communication backbone, i.e. the Internet (Petersen *et al.*, 2015). This creates the basis for a pervasive network of connected devices, each one being able to generate and 'communicate' information about itself and its environment, in the form of data.

One way of understanding the process of value creation from an IoT perspective is that of using an *Information Value Loop*, a generic process with five stages (represented by five distinct actions), each one connected to the following by a certain set of enabling technologies, as represented in *Figure 3*. As explained by Deloitte in its technical primer about IoT, the five stages are (Holdowsky *et al.*, 2014; Kejriwal and Mahajan, 2016):

- *create*: "the use of sensors to generate information about a physical event or state". Information is generated in the form of electronic signals through the adoption of *sensors;*
- *communicate*: "the transmission of information from one place to another". Communication of electronic signals is performed through *networks*;
- *aggregate*: "the gathering together of information created at different times or from different sources". Information from different sources at different times is gathered under a unique *standard*;
- *analyze*: "the discernment of patterns or relationships among phenomena that leads to descriptions, predictions, or prescriptions for action". Relationships among phenomena are evaluated thanks to the presence of analytical tools or *augmented intelligence*;
- *act*: "initiating, maintaining, or changing a physical event or state". The ability to independently prescribe an action is possible in case of machines with improved compliance or *augmented behavior*.

The main reasoning behind the circular pattern of the information value loop is that each action brings to a new improved one, on the basis of the information created, communicated, aggregated and analyzed during the learning process, granting the circle to never end (Raynor and Cotteleer, 2015).

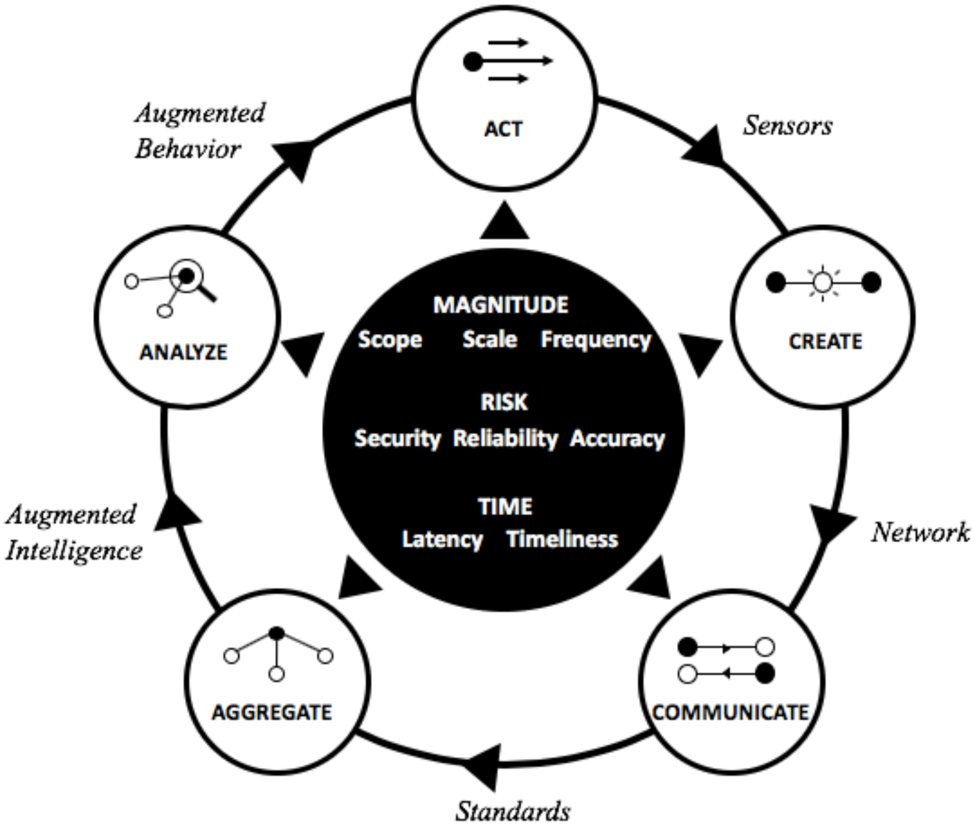


Figure 3: Information Value Loop (adapted from (Holdowsky *et al.*, 2014)*)*

Despite the generic nature of the process, its application in the case of IoT is becoming more and more relevant, by means of a confluence of advancements in specific technologies, enabling the realization of complete systems that are relevant for a human-centric environment. In particular, the sharp decrease of sensors' cost heavily boosted the adoption of IoT technology to support broad business applications. According to a recent report from Microsoft, the growth of sensor market size (and increased availability) has made cost drop of nearly 200% between 2004 and 2018, establishing to 0.44$ / sensor (Microsoft, 2019). Additionally, improvements have also been achieved in terms of sensors size (smaller sensors find a higher range of possible applications, i.e. a wider inclusion into smartphones and other electronical devices) and 'smartness' (increase in computational power) (Holdowsky *et al.*, 2014). Maturity of the sensor market and consequent increase in the adoption of IoT solutions, together with other technology improvements (such as increased processing power, network bandwidth and cloud storage), will enable the setting of a large digital ecosystem in which many environments can achieve great advantage, especially at business-to-business level (Manyika *et al.*, 2015). Specifically, commercial real estate has already been heavily influenced by IoT, which "adds new ways for the CRE sector to create value for customers, differentiate from competitors, and even find new sources of revenue" (Kejriwal and Mahajan, 2016). As shown by Memoori in its report "The IoT in Smart Commercial Buildings 2018-2022", office buildings will register the highest number of IoT-related devices installations in 2022, as proof of the superior potential related to solutions in this branch of Real Estate (Memoori, 2018).

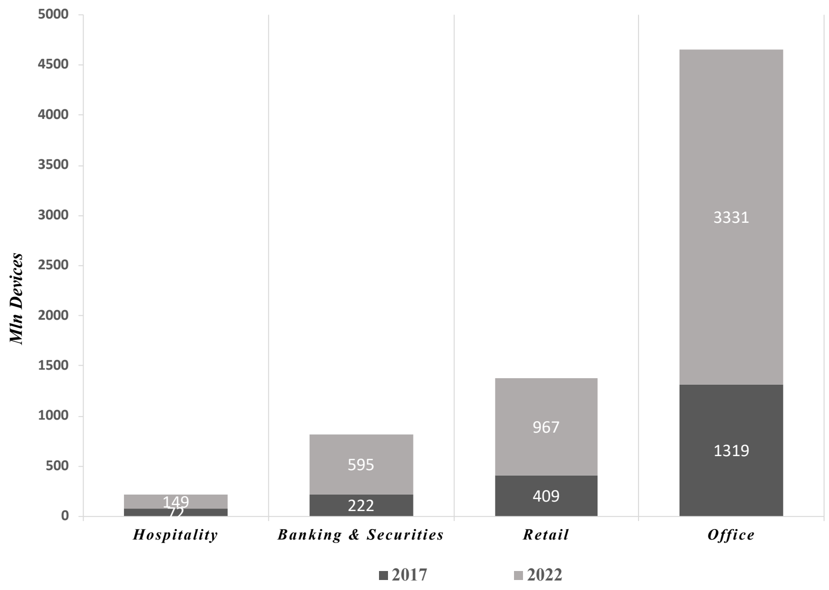


Figure 4. Commercial Smart Building Related IoT Device Projections, 2017-2022 (adapted from (Memoori, 2018)*)*

While the primary focus of CRE companies when first looking at IoT is on cost saving through operational efficiency rather than connectivity exploitation (also proved by the initial use cases of Internet of Things in buildings), the potential behind the technology has to be found on several new revenue opportunities as well, and its impact on performances lies in the level of integration with a building BMS (Kejriwal and Mahajan, 2016). Therefore, the following paragraphs aim at mapping all of the possible ways to generate value within a building thanks to IoT.

1.1.1.1 Building performance optimization through increased efficiency

The analytics capability of a BMS, embedded within the concept of IoT as “a platform to enable data creation, communications, aggregation, and analysis of building technology performance”, results in a (virtual) space where to create data-rich environments for better visualizing the whole figure of a building, and therefore take better decisions and actions, either automatically or manually (Kejriwal and Mahajan, 2016; Talon and Strother, 2017a). A first result brought by the interaction between BMS, IoT, commercial building equipment and controls is the ability to increase efficiency thanks to data collection and analysis from sensors, in different ways:

- *Energy savings*: it may be the most clear and definite source of economic benefit that is driving smart buildings development, since the in-building operational improvements effectively translate into reductions on energy bills, therefore accounting for a transparent monetization of ROI (Talon and Strother, 2017a). Indeed, tenants can use data collected by light, temperature, motion and occupancy sensors to provide real-time regulation of lighting and HVAC, limiting energy cost and creating the best internal conditions for tenants to operate (Kejriwal and Mahajan, 2016). Moreover, data collection, analytics and connectivity enable, through machine learning capabilities, to define autonomous decisions according to predicted events, where building systems adapt their parameters on the basis of expected behaviors (Wellener *et al.*, 2018). As an example, “climate control will predictively adapt to weather changes and occupancy levels, lighting fixtures will brighten and darken alongside ambient sunlight, dynamically maximizing energy savings” (Fletcher, Santhanam and Varanasi, 2018). As a last note, a connected and integrated control of facilities enable to move from buildings as energy consumers to energy ‘prosumers’, incorporating building-to-building and building-to-grid communication. The introduction of distributed energy production and storage adds on complexity, which, if successfully managed, guarantees the same amount of benefits to users (Fletcher, Santhanam and Varanasi, 2018; Navigant Research, 2019);

- *Predictive operations & maintenance*: thanks to data tracking opportunities enabled by IoT, it is possible to preempt building issues that facility managers would solve with appropriate corrective actions. This would reduce the inactivity time as well as limit the repair and maintenance efforts required for solving the issue. Furthermore, asset-tracking capabilities enable the identification of which spaces need, for example, cleaning: time optimization brings to the re-definition of contracts with client service companies, bringing to additional savings (Wellener *et al.*, 2018);

- *Space optimization*: predictive awareness of people positions and occupancy level at each side of a building introduces a completely new source of revenue, that is space optimization, both at building design phase and for daily routine activities. Indeed, IoT enabled data collection strengthens the concept of *smart working*, allowing for enhanced flexibility of workspaces and other facility services. Conference room and desks availability will be monitored in real time, making spaces available if bookings are deleted or actually unoccupied. By taking a range of variables into account for workers allocation, flexible work space assignments allow to actually increase the number of people per desk/office, and the number of cars per parking slot as well (Fletcher, Santhanam and Varanasi, 2018; Interlogica Press, 2019). As a consequence, there would be a reduction of the space needed (for the same number of people).

- *Waste management*: rainwater reuse, smart bins and robotic sorting are all solutions that are beneficial from both an economic and environmental standpoint, and their application is boosted thanks to the adoption of IoT technology, such as fill sensors, able to detect fill levels and separate the materials that can be either reused or recycled (Kejriwal and Mahajan, 2016);

- *Safety and security management*: there has been a growing trend related to facility access control security and privacy, as well as external emergency monitoring. IoT-enabled buildings offer an integrated and fully connected security system, thanks to real-time monitoring (Fletcher, Santhanam and Varanasi, 2018). The result is a diminished number of threats, and a consequent reduction in losses. Nevertheless, the security gain from IoT solutions is ‘alleviated’ by increasing exposure to cyber-attacks, for which additional cybersecurity investments are needed. As will be discussed in the following sections, cybersecurity is becoming a competitive advantage in several industries, in line with the increasing adoption of IoT (Kejriwal and Mahajan, 2016; Digital Transformation Monitor, 2017; Talon and Strother, 2017a; Fletcher, Santhanam and Varanasi, 2018)

1.1.1.2 Creating new value for employees, tenants and ecosystem

IoT applications offer more solutions than those represented by resource efficiency and optimization. Indeed, thanks to connectivity, commercial real estate companies have the possibility to enrich and differentiate the services they provide, on the basis of workers, tenants and, more in general, of an ecosystem peculiar characteristics (Fletcher, Santhanam and Varanasi, 2018). According to a report by Navigant Research about costumer expectations and investment trends around smart buildings and IoT technology, 44% of respondents believe that cost savings will be the most important factor driving investments, with 22% focused on improving the level of occupants satisfaction and 19% seeking improvements in O&M (Talon and Strother, 2017a). Therefore, results show how investments in smart building technology will comprehend a wider scope of applications, with a growing focus on service innovation for tenants as well as occupant health and productivity. CRE companies, through IoT differentiation strategies, could charge a premium price to tenants that ask for customized services (Kejriwal and Mahajan, 2016).

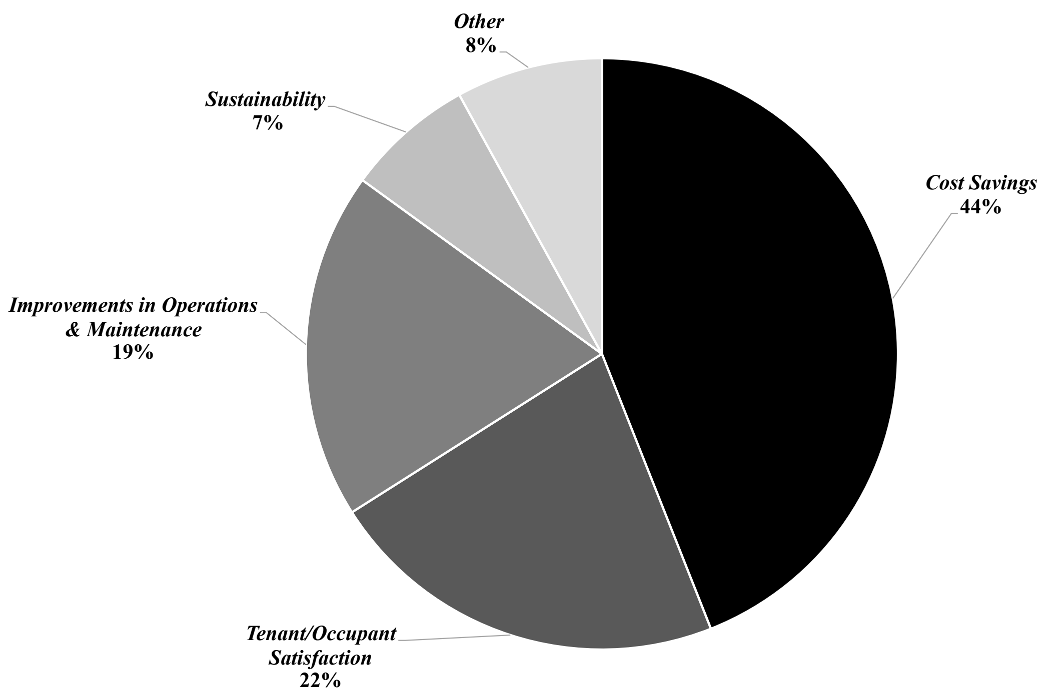


Figure 5. Most Important Drivers for Investment in Intelligent Building Technologies (adapted from (Talon and Strother, 2017a)

Recently, great attention has been put on the link between occupant productivity and working environment: businesses are increasingly understanding the value behind a positive employee experience, with use cases leveraging connectivity to offer space personalization, bio-adaptability of the environment and predictive awareness of individual needs. Indeed, buildings that emphasize the user experience will provide occupants with greater personal control over their surroundings. Lighting systems will adjust light intensity and color to adapt for individual preferences, according to the time of the day. Climate systems will respond to occupants as well, automatically adjusting the temperature in conference rooms to the ideal average between attendees (Fletcher, Santhanam and Varanasi, 2018). The objective of companies looking at customized and connected digital spaces is that of increasing employee health and productivity, as well as talent attraction and retention power. Moreover, further benefits could be gained from enhancing collaboration among workers. According to an article of the Harvard Business Review, direct interaction is the most important activity within an office, and its research brings to the conclusion that "creating collisions – chance encounters and unplanned interactions between knowledge workers, both inside and outside the organization – improves performance". With the objective of increasing encounters among occupants, and thanks to IoT applications (such as virtual digital assistants, wireless content sharing, smart boards and smart conference rooms), companies are able to further raise collaboration in connected and effortless environments. (Waber, Magnolfi and Lindsay, 2014; Wellener *et al.*, 2018).

Information from IoT-enabled smart buildings offers new solutions for tenants as well, as they may be interested in, for example, smarter site location solutions. Indeed, on the basis of data leveraged from IoT at different sites, new patterns emerge that enable optimal decisions for tenants, enabling analytics-as-a-service as a new revenue model for CRE companies (Kejriwal and Mahajan, 2016).

From a broader perspective, data managed and collected at building level may be used to enhance connection at higher level (i.e. smart city), creating an environment of linked systems that will foster sustainability initiatives. In particular, data related to energy, water and waste management can be used to boost efforts towards environmental initiatives to lower carbon footprint (Wellener *et al.*, 2018). Distributed energy systems are gaining more and more importance in the overall power production and consumption market, as they provide sensible information that utilities can exploit to enhance higher efficiency at smart grid level. Through the adoption of smart, IoT-enabled devices, data from decentralized resources will be critical to face rising market complexity and to provide new business models for utilities for improving customer services throughout the grid. In fact, with distributed generation, bi-directional flows of both electricity and data are challenging the traditional grid structure: therefore, IoT represents a solution for real-time monitoring of power flows and information gathering (Astarloa *et al.*, 2017).

1.1.1.3 Challenges to IoT adoption

Although it can generate invaluable data in every industry, IoT still registers some challenges in its implementation. Market complexity is still an issue, in different ways. Moreover, new threats are emerging (i.e. increased number of cyberattacks), potentially causing business disruption at different levels of a company.

First of all, a *lack of interoperability* is present in the current environment, as most of the sensors are designed for customized applications, leading to failures in communication, delivery, storage and security of data generated (Holdowsky *et al.*, 2014; Manyika *et al.*, 2015; Nord, Koohang and Paliszkiewicz, 2019). Therefore, problems are to be found mostly at the *aggregate* stage of the Information Value Loop.

Secondly, *system integration* is often underestimated by companies, especially by CRE firms at building design phase, as they are mostly interested in achieving short term cost reduction and optimization results at local level, rather than considering future collaboration for the analysis of the high volumes of data that can be created thanks to IoT technology. Solutions may be represented by: the development of advanced mobile computer capabilities, the use of appropriate integration software and platforms and the use of common protocols and standards (Kejriwal and Mahajan, 2016). Considering IoT enabled data analysis, difficulties arise in generating aggregated information, being IoT data unstructured, while older Building Management Systems (BMS) are usually able to handle structured ones. In this perspective, other issues are represented by data frequency, timeliness (for which real-time processing capabilities are needed to draw meaningful conclusions) and relevance (Holdowsky *et al.*, 2014; Kejriwal and Mahajan, 2016).

At a higher level, *scalability* may represent a key challenge that can hinder the development of IoT technologies. Scalability is the ability to increase the number of new connected devices, without diminishing the performance level of IoT services. "A key challenge related to scalability is to support a large number of various devices with memory, processing, bandwidth and other resource constraints" (Čolaković and Hadžialić, 2018). A solution may be represented by the adoption of highly scalable cloud-based platforms, that would provide enough space for data collection, storage and analysis (Čolaković and Hadžialić, 2018).

Another challenge, more pervasive at different levels of the Information Value Loop, is represented by *security*. As will be comprehensively discussed, security issues are advancing as IoT technology gain more and more interest among users: as organizations work to aggregate large, diverse networks of connected devices into core systems and processes, there will likely be new security and privacy concerns to address. According to Hitachi, "indeed, because the IoT creates a technological connectivity across virtually every part of the organization and presents more entry points for hacking, many believe that the cyber stakes are inherently higher in the Internet of Things" (Hitachi, 2017). With IoT, data security risks will at minimum range from privacy violations up to, potentially, the hacking of important public systems. According to Deloitte, "organizations will have to determine what information is appropriate for IoT enablement, what potential risks the assets and information may represent, and how they can ensure that solutions are secure, vigilant, and resilient" (Deloitte, 2016).

Last, although the impact of IoT applications has considerable benefits in terms of energy efficiency and power production management, environmental issues still need to be addressed. As the growth in size of IoT market is exponential, more connected devices would demand for higher amounts of energy. Power and energy storage technologies still need to adapt to emerging IoT requirements, considering sensors size and their communication opportunities. Moreover, as the interest towards IoT continues to increase, the amount of electronic waste could represent a future threat as well. Therefore, topics such as renewable energy production and sensors' size reduction are of primal concern, as they would help to sensibly reduce the environmental impact associated to the technology (Čolaković and Hadžialić, 2018).

1.1.2 Big Data and Analytics

The shift towards IoT technology, which enables communication and interaction between various devices, has heavily changed the way data are generated, collected and managed. Among others, such disruption has deeply affected the way data are used inside buildings as well. Big Data has recently emerged as a new digital paradigm, addressing the issue of data overflow that companies are facing as a consequence of their collection activity over the years through their information systems (Brynjolfsson, 2010; Urbinati *et al.*, 2019). With IoT and smart sensors, the speed of data generation has exponentially increased, pushing the need for business to understand how to collect and organize the amount of data created from various sources and in different knowledge forms, in a sustainable way (Chen, Chiang and Storey, 2012; Urbinati *et al.*, 2019). Therefore, in the current environment, the concept of Big Data and Analytics has raised in importance, inherently with the increase in adoption of IoT applications. The amount of data processed grows at unprecedented pace, as also verified by its market size increase, from 7,6 bln$ in 2011 up to a projection of 103 bln$ in 2027 (Albertson, 2018).

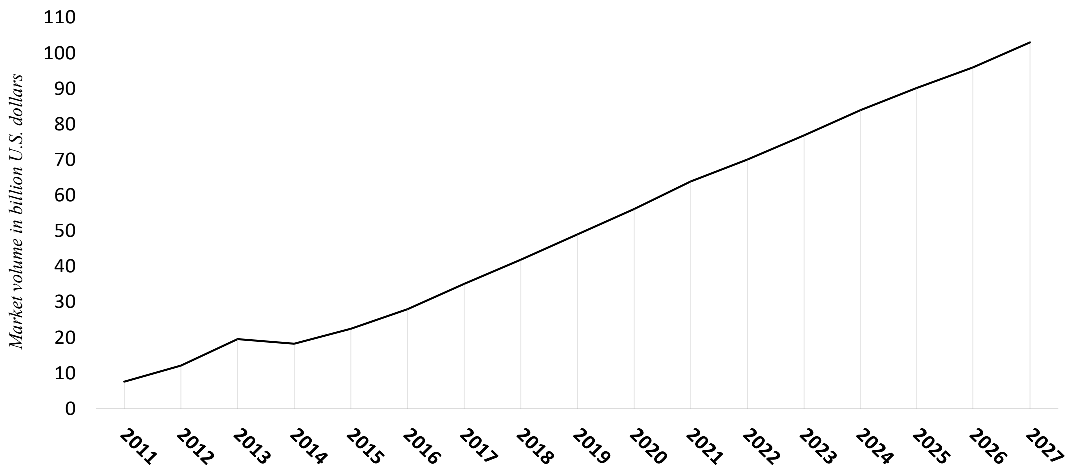


Figure 6. Big data market size revenue forecast worldwide from 2011 to 2027[1] *(adapted from* (Albertson, 2018)*)*

[1] The data collection period has been from 2014 to 2018, thus values from 2018 (included) to 2027 are market estimations of potential revenues concerning Big Data.

1.1.2.1 Conceptual definition and analysis

To better clarify the meaning of the concept of Big Data, a clear and comprehensive definition is provided by Gartner: "*Big data is high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation*" (Gartner, 2020a). From the abovementioned definition, some meaningful insights can be caught about the main characteristics of Big Data. Indeed, it refers to datasets, large in volume, diverse in type and reference source, and quickly assembled (Chandy, Hassan and Mukherji, 2017; Urbinati *et al.*, 2019). Each of these features contribute to understand the disruptive nature of Big Data, and it is therefore worth analyzing each one in detail:

- *'High-volume'*: volume refers to the size of data, which is increasingly growing. Companies are willing to collect and analyze large amounts of data to create value, either by acting on their existing businesses, reducing the distance between customers' preferences and product features, or by exploring new opportunities, creating new revenue models (Ghasemaghaei, 2019; Ghasemaghaei and Calic, 2020);
- *'High-velocity'*: velocity refers to the speed of generating and analyzing data. The rate of data generation has been boosted by the increase in adoption of digital devices such as sensors and smartphones, which has consequently generated a need for real-time data aggregation and analysis solutions (Ghasemaghaei, 2019);
- *'High-variety'*: variety refers to the diversity of data types, which generically distinguish between *structured* and *unstructured* data. While structured data consist of information already elaborated and transformed into numbers, unstructured data represents every kind of heterogeneous representation of information, such as pictures, audio and sensor data (Ghasemaghaei, 2019);

By analyzing the concept of data-variety, the difference between traditional data and Big Data is reflected by the significant shift between structured transactional data to unstructured behavioral data, which sensors contribute to create. Therefore, the breakthroughs of IoT and Big Data technologies are profoundly connected (with unstructured data representing about 80% of existing data), as digital advancement gives firms access to data from external sources, beyond internal business transactions (Erevelles, Fukawa and Swayne, 2016; Urbinati *et al.*, 2019; Ghasemaghaei and Calic, 2020). As a further feature, data '*veracity*' is also considered to be relevant in an environment such as that of Big Data. As businesses reliance on data processing keeps growing, the impact of inaccurate or incorrect information will increase as well, especially considering the raise in adoption of artificial intelligence and autonomous data-driven decision making (Accenture, 2018; Ghasemaghaei, 2019). According to Accenture, "without establishing the veracity, or accuracy, of that data, businesses leave themselves open to a new kind of vulnerability – a threat that's critically overlooked. A recent study estimated that 97% of business decisions are made using data that the company's own managers consider of unacceptable quality" (Nagle, Redman and Sammon, 2017; Accenture, 2018). Such vulnerability would bring to low-value insights, or even manipulated decision making, justifying the results brought by Gartner which confirms how several Big Data projects bring to disappointing results, despite the continuous growth of related investments (Gartner, 2016). In order for Big Data to represent a potential value source for companies, *analytics* tools and 'information processing' capabilities shall be addressed. Analytics represents the complementary 'soul' of data, and *Big Data analytics* refers to analytical techniques used in large and complex applications, thus requiring "advanced and unique storage, management, analysis, and visualization technologies" (Chen, Chiang and Storey, 2012).

1.1.2.2 Big Data application in buildings: opportunities and challenges

By observing how businesses are rapidly increasing its adoption, Big Data has apparently been among the most emerging trends in recent years, and a frontier of opportunities for companies (Yadegaridehkordi *et al.*, 2020). However, what is missing is a clear identification of the economic advantage achievable through data collection and analysis, and in this perspective, existing literature has not yet provided strategic frameworks that give a direction about how value and competitive advantage are generated by relying on Big Data (Urbinati *et al.*, 2019). Therefore, the following section provides some insights on how value from Big Data can be captured, with a specific focus on its application in buildings. As already mentioned before, it is worth reporting that value is especially enhanced by the conjunction of Big Data and other digital technologies, such as IoT, cloud computing and cybersecurity (Luo *et al.*, 2019; Yassine *et al.*, 2019; Chen, 2020).

A first area of application of Big Data within buildings is related to energy efficiency: in combination with IoT technology, it can be utilized to derive knowledge and supporting services for companies to reduce their facility energy consumption, by enhancing their artificial intelligence (AI) capabilities (Ghasemaghaei, 2019; Luo *et al.*, 2019). It is commonly acknowledged how buildings contribute to a large portion of a country energy consumption, therefore generating a relevant amount of greenhouse gas emissions. A solution to reduce consumption and related emission levels is represented by accurate day-ahead prediction of energy demand, which grants benefits to companies in terms of both equipment scheduling (lighting, HVAC) and building energy management. In this regards, an innovative contribution is brought by Luo *et al.*: "with the appropriate algorithms and communication mechanisms, IoT-based big data analytics platform can be constructed to monitor and characterize energy behaviors in various buildings" (Luo *et al.*, 2019). Compared to other applications based only on machine learning, which allow prediction based on historical weather profiles (i.e. outdoor air temperature, humidity, solar radiation and wind speed), the advantage behind IoT Big Data platforms lie in the additional set of variables that can be collected and stored, such as temperature difference between inside and outside of building surfaces, temperature difference between outdoor and indoor air, as well as building operating schedules (including occupants, equipment and lightning) (Luo *et al.*, 2019). Accurate predictions of the temperature and lightning scheduling followed within a building may lead to optimal energy consumption, considering factors related to both energy waste and occupants' wellness. The benefits associated to this solution do positively affect external stakeholders as well: indeed, occupants can adjust their decisions on the basis of real-time data provision, and energy companies can easily respond to market fluctuations accordingly (Bibri, 2018). This would generate a positive effect on smart grid (and, more in general, smart energy systems) management and monitoring (Lund *et al.*, 2017).

Another field of application of Big Data within buildings is represented by occupancy detection: the possible improvements achievable for companies thanks to the integration of comprehensive occupancy information are still not fully explored (Elkhoukhi *et al.*, 2018). Through recent market penetration of wireless sensors networks, many industries and researchers have confirmed the potential of IoT as an enabler to the development of intelligent and context-aware services and applications. However, with the development of sensing and communication technologies, more sensor data will be available for learning, thus demanding for a higher level of Big Data analytics (Chen, Jiang and Xie, 2018; Elkhoukhi *et al.*, 2018). According to Elkhouhi *et al.*, “the integration of IoT and Big data technologies into a holistic platform together with machine learning algorithms could enable new potentials in smart buildings for real-time occupancy detection” (Elkhoukhi *et al.*, 2018). The scope of advantages related to IoT Big Data-enabled occupancy detection moves beyond the sole concept of energy efficiency, ranging from occupant wellness and satisfaction, space optimization, and smart working.

A last example of how Big Data can have a massive impact on a building performance is represented by security, and its penetration is largely affected by the need to counter vulnerability issues of IoT to cybersecurity breaches (Amanullah *et al.*, 2020). IoT security is related to the securing of the entire IoT architecture deployment from attacks, with various factors that must be taken into account for developing appropriate measures. Indeed, the current characteristics of data generated through IoT makes it difficult for existing tools and techniques to detect cyberattacks, as they lack processing power at large scale. Furthermore, the additional opportunities provided by the cloud have fastened the advancement of Crimeware-as-a-Service (CaaS), which opens possibilities for cybercriminals with limited skills and expertise to launch automated cyberattacks (Amanullah *et al.*, 2020). As IoT enables sensors and devices in a smart environment to communicate with each other and facilitates information sharing across platforms, the inclusion of deep learning and Big Data technologies becomes mandatory to handle the challenges of volume, velocity, variety, and veracity of data generated by IoT devices (Amanullah *et al.*, 2020).

1.1.3 Cloud Computing

The cloud has completely redefined the way companies organize and manage their business, and is currently influencing other technology trends as well, leading for emerging across-industry use cases that apply to unique and specific challenges. It has been a game-changing factor, disclosing completely unexplored business opportunities for companies.

1.1.3.1 Conceptual definition and analysis

First intended as a virtual space for exploiting data storage capabilities, cloud computing has been associated a completely different and wider range of features. Indeed, according to Deloitte, "the cloud is more than a place or a destination for data and applications to drive down the cost of computing power and storage or to create elasticity for variable demand" (Deloitte, 2018a). In order to fully depict the concept of cloud computing, Gartner defines it as "a style of computing in which scalable and elastic IT-enabled capabilities are delivered as a service using internet technologies" (Gartner, 2020b). The 'as-a-service' model has been deepened through the years, as different typologies have been adopted by companies. In particular, three main types of services are derived (Bibri, 2018):

- *Software-as-a-service (SaaS)*: "software that is owned, delivered and managed remotely by one or more providers. The provider delivers software based on one set of common code and data definitions that is consumed in a one-to-many model by all contracted customers at any time on a pay-for-use basis or as a subscription based on use metrics" (Gartner, 2020g);

- *Platform-as-a-service (PaaS)*: "a type of cloud offering that delivers application infrastructure (middleware) capabilities as a service. Gartner tracks multiple types of PaaS (xPaaS), including, among many more, application platform as a service (aPaaS), integration PaaS (iPaaS), API management PaaS (apimPaaS), function PaaS (fPaaS), business analytics PaaS (baPaaS), IoT PaaS and database PaaS (dbPaaS). PaaS capability can be delivered as provider-managed or self-managed, multitenant or dedicated" (Gartner, 2020f);

- *Infrastructure-as-a-service (IaaS)*: "a standardized, highly automated offering in which computing resources owned by a service provider, complemented by storage and networking capabilities, are offered to customers on demand. Resources are scalable and elastic in near real time and metered by use. Self-service interfaces, including an API and a graphical user interface (GUI), are exposed directly to customers. Resources may be single-tenant or multitenant, and are hosted by the service provider or on-premises in a customer's data center" (Gartner, 2020d).

From Gartner's definition, two main traits of cloud computing, which differentiate it from previous technologies, are provided: *scalability* and *flexibility* of IT-enabled capabilities. Considering how every device connected to the cloud can share its data within an open space, thus creating common and connected datasets, it is possible to implement a decision taken at a single distributed environment and scale it up through all the enterprise, or even beyond its boundaries, enhancing synchronization. An example is represented by cloud computing proliferation as part of a smart city infrastructure (an example of large-scale energy consumption environments), where smart sustainable urban areas can have higher possibilities to perform more effectively and efficiently, by means of to the advanced technological features underlying the functioning of cloud computing model (Rivera, 2017; Bibri, 2018; Deloitte, 2018a). Furthermore, cloud computing technology has other evident benefits, as it aims at sharing resources and maximizing their effectiveness, therefore reducing the costs of ICT operations in terms of human, technical and organizational capital. In addition, cloud computing is structured on a service-oriented logic, adapting and rapidly processing large and complex data to deliver customized solutions to clients, transforming product offerings into services. Such disruptive approach implies the combination of physical and intellectual capital to create platforms that would provide a completely new set of opportunities for customers and clients (Dutton *et al.*, 2010; Bibri, 2018).

It is relevant to mention how the adoption of cloud computing has also facilitated the introduction of other disruptive technologies, such as IoT, Big Data and analytics, and machine learning. Indeed, "although IoT, Big Data and cloud computing are three distinct approaches that have evolved independently, they are becoming more and more interconnected over time" (Luo *et al.*, 2019).

1.1.3.2 Impact of cloud computing in buildings

Cloud computing has had an impact on nearly every business category, thus finding great use in facility management as well. There are multiple implementations of cloud computing within the technological and information architecture of a building, given its level of integration with other new paradigms such as IoT, Big Data and machine learning. In particular, cloud computing allows facility management to rely on external competences, importing strategic implementation solutions that could be leveraged from other successful smart use cases. Moreover, it allows to share information among different stakeholders, so that preventive decisions may be taken (either manually or automatically) in response to signals and trend behaviors (IoTedge, 2019). One of the main applications of cloud computing within building (that has been comprehensively studied by academics) is related to its integration with BMS (building management systems), and, more in particular, BEMS (building energy management systems). There are two approaches for building integration between cloud and BEMS within a building:

- in the first scenario, also defined as *Cloud-Based BEMS*, all subsystems, sensors nodes and actuators that control the building equipment are directly connected to the energy cloud through the Internet. The functions of a BEMS will be entirely exported in the cloud (referred as 'energy cloud'), so that the digital cloud infrastructure would completely replace the traditional one. While this approach provides great flexibility for energy cloud service design and offering, some problems emerge, as the need for reliable communication between smart buildings and energy cloud; the difficulties associated to implementation of cloud services that manage a variety of sensor data, as well as those related to high communication traffic that hinders scalability potential; high security risks (Rivera, 2017);

- in the second scenario, referred as *Cloud-Enabled BEMS*, smart buildings' BEMSs functions and real time monitoring are managed at a local level as a regular in-house BEMS, with the addition of the connection with the energy cloud for special services. Therefore, the energy cloud is a marginal element, with the following tasks: "collect information from smart buildings, find optimization updates to tune the energy control mechanisms in these buildings, and provide software and configuration updates for local cloud-enabled BEMS periodically". Several advantages are associated with this solution, such as low-latency control services, better communication, reliability, security and scalability support (Rivera, 2017).

1.1.4 Cybersecurity

The advent of Industry 4.0, which enabled the transition towards a world of smart devices (each connected to the others and the Internet as well), has also exponentially increased the number, variety and impact of cyberattacks (Corallo, Lazoi and Lezzi, 2020). According to a recent survey from Deloitte, cyber risk is predicted to be the top priority for managers, with 36% of respondents believing it will represent the biggest threat to a company development (Deloitte, 2018b). The frequency and impact of a cyberattack vary according to a range of factors such as attack typology, country profile, firm dimension, reference industry, as well as the readiness of the targeted company to prevent, counter and resist an attack, namely cybersecurity (Berkman *et al.*, 2018; Corallo, Lazoi and Lezzi, 2020). The fundamental objective of any comprehensive cybersecurity initiative is to protect those company's resources (i.e. information) that are targeted by cyber criminals, either by reducing exposure, or by increasing speed and accuracy of threat response, thus reducing the amount of breaches (Domaintools, 2019).

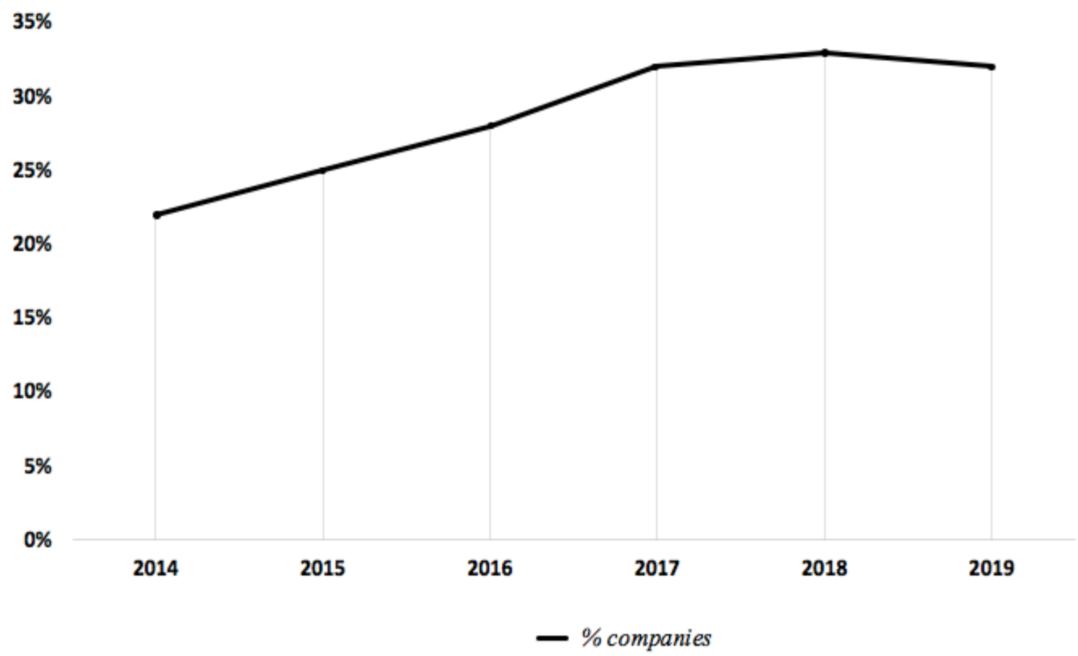


Figure 7. Share of global organizations that experienced major cyberattacks in the last two years, from 2014 to 2019 (adapted from (Wesselman and Koot, 2019)*)*

1.1.4.1 Conceptual definition and analysis

To formally define it, "cybersecurity is the combination of people, policies, processes and technologies employed by an enterprise to protect its cyber assets. Cybersecurity is optimized to levels that business leaders define, balancing the resources required with usability/manageability and the amount of risk offset. Subsets of cybersecurity include IT security, IoT security, information security and OT security" (Gartner, 2020c). Hence, it is fundamental for businesses to understand their internal level of cybersecurity awareness, in order to leverage existing resources and employing the necessary amount to reduce relevant losses coming from cyber hacks (Berkman *et al.*, 2018). Moreover, information and technology strategies of a company should integrate and align with cybersecurity programs and investments, in order to optimize performance levels (Waslo *et al.*, 2017; Corallo, Lazoi and Lezzi, 2020). As explained in the aforementioned definition, business leaders should determine the level of cybersecurity adoption, and in this perspective, according to Deloitte, 64% of firm leaders have stated how their current cybersecurity adequacy needs improving (Deloitte, 2018b). To face pressure from multiple stakeholders, considering the emerging realization of its reputation vulnerability, the aim of a firm is to adopt measures to counter increasing cybersecurity threats. Some of the initiatives include: the introduction of directors with IT backgrounds, hiring Chief Information Security Officers, the creation of IT committees, acquiring or developing new systems with adequate security, and purchasing insurance. The enhancement of 'cybersecurity awareness' can reduce the main threats coming from cyber security risk and regulatory pressures, therefore potentially resulting in higher firm value (Berkman *et al.*, 2018). Considering the several initiatives previously mentioned, it is clear how a mindset shift is necessary in the way cyber risks and related impacts are perceived. This shift will affect organizational transformation at every level, as well as the set of priorities to be considered when making a decision. In this perspective, a general framework of the main risk function priorities is provided by Deloitte (generally valid for each risk category), in which three top priorities are detected as a survey result among top managers (Deloitte, 2018b):

1. *Priority 1*: identification of the existing and new risks proactively;
2. *Priority 2*: risk mitigation;
3. *Priority 3*: raising risk awareness.

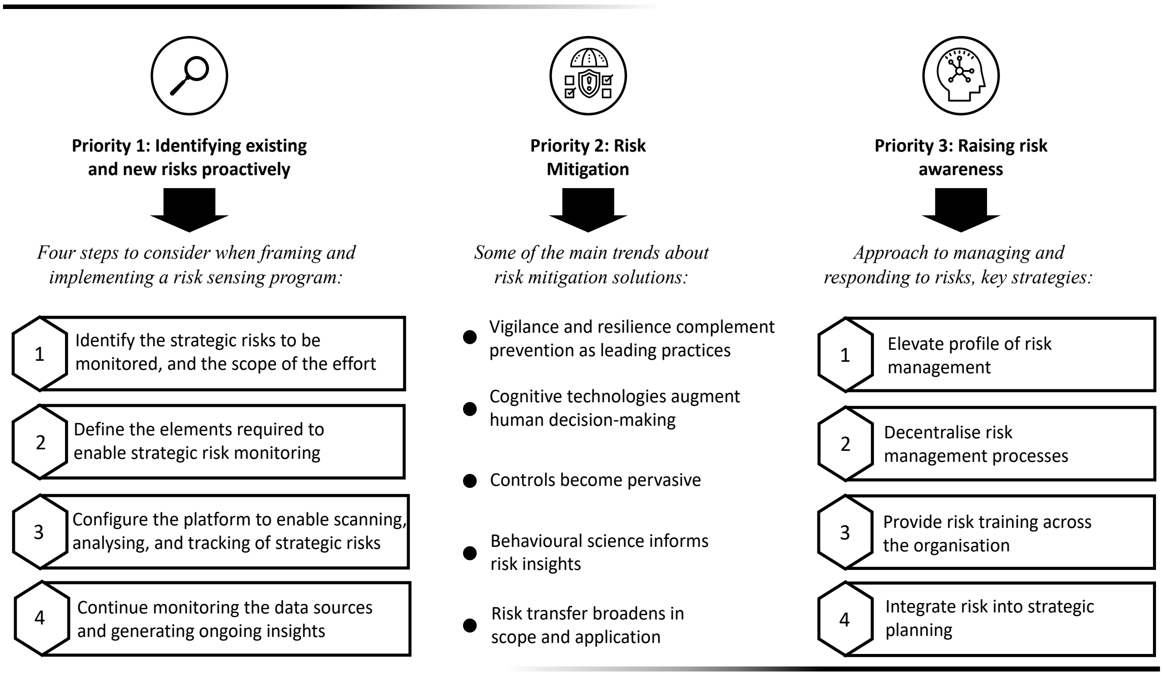


Figure 8. Key risk function priorities (adapted from (Deloitte, 2018b)*)*

1.1.4.2 IoT and Cybersecurity: possible threats and security measures

As also previously mentioned, in recent years, IoT technology has registered an unprecedented growth, given its ubiquitous connectivity potential, which offers (through different types of services) several advantages to companies that decide to adopt it. The pervasiveness of IoT at nearly every level of human life and economy has exponentially raised the demand for connected devices and services (Abomhara and Køien, 2015). In particular, in the building sector, there has been registered a constant growth related to IoT, in line with the market penetration of smart buildings and, more in general, smart systems (Amanullah *et al.*, 2020). Despite the presence of several benefits brought by IoT applications, some issues are worth considering when deciding to adopt the technology, among which security threats find a relevant spot, as connected devices or machines are extremely valuable to cyber criminals, in different ways (Abomhara and Køien, 2015):

- Most IoT devices work without human supervision, given their capability to operate under completely remote control. This results in easy access opportunities for attackers;

- Provided that IoT devices are able to communicate over wireless networks, an attacker could obtain sensible information by intercepting signals;
- Given the low power and computing resource capabilities of most IoT devices (especially smart IoT sensors), difficulty arises in the implementation of complex security schemes.

More in general, cyber-attacks could reach any IoT environment, creating critical issues to systems operation, which would either bring to potential damages or relevant economic losses. Examples include hacks on home automation systems and taking control of heating systems, air conditioning, lighting and physical security systems. Data collected from sensors embedded in heating or lighting systems, coupled with machine learning capabilities, enable to adapt internal parameters on the basis of the inhabitant habits. As a consequence, this could inform the intruder about the occupants' position, whether they are at home or outside. It is certainly easy to imagine the amount of damage caused if any connected devices were attacked or corrupted, and it is well-acknowledged how adopting any IoT technology within homes, work, or business environments opens doors to new security problems. By enlarging the scope of possible threats (as well as their potential impact on society and economy), cyber-attacks could be launched against any public infrastructure like utility systems (power systems or water treatment plants) to stop water or electricity supply to inhabitants. Compliant with some of the potential implications that a cyber-attack could cause, users and suppliers must consider and be cautious with such security and privacy concerns (Abomhara and Køien, 2015; Lund *et al.*, 2017; Bibri, 2018; Amanullah *et al.*, 2020).

After having examined some of the potential implications and related effects of cyber threats, this paragraph aims at briefly introduce some of the possible solutions or area of intervention relatively to IoT security. There are different aspects that should be taken into account when deciding to implement IoT security solutions. According to Amanullah *et al.,* in order to develop IoT security solutions, there are some requirements that need to be gained (Amanullah *et al.*, 2020). Indeed, thanks to the implementation and leveraging of deep learning and Big Data technologies (which are profoundly linked with IoT into a unique system), a "pool of security breaches" can be filled and subsequently analyzed, which could be reconducted to the main IoT security requirements. In particular, there are five requirements to which most of security breaches relate to (Cho, Yeo and Kim, 2011; Khan and Salah, 2018; Khattak *et al.*, 2019; Amanullah *et al.*, 2020):

1. *Confidentiality*: "Confidentiality enables information to be transmitted securely during all communications. When information is transmitted without authentication or encryption, adversaries are given the chance to violate the privacy of the owner";

2. *Integrity*: "integrity guarantees that data received has not been manipulated during transmission". Thanks to Big Data technology, support for controls about data quality is provided, enabling users to perform data integrity checks on their IoT systems;

3. *Availability*: "Availability in IoT systems refer to ensuring that legitimate users are able to access the system and that unauthorized access is denied". Big Data technologies may enable omnipresence to users, being also able to run on multiple nodes, thus ensuring high availability of application;

4. *Authentication*: "Authentication refers to ensure the identity of the peer which IoT devices communicate with. Furthermore, it is also concerned with valid users gaining appropriate access for network tasks such as control of IoT devices and networks". Authentication measures can be incorporated by Big Data technologies;

5. *Access control*: "Access control in IoT system should act as a means of ensuring that the authenticated nodes are limited to access what they are privileged to and nothing more". In addition, Big Data technologies can provide access control support for its applications (with a different access control list for each application), by means of the necessary introduction of a filter for its effective realization.

In conclusion, continuous monitoring of network communication between IoT devices and system can support the detection and mitigation of security breaches at an early stage. Thanks to deep learning characteristics – being able to monitor and handle large datasets, provide higher accuracy in data classification, and learn from complex data at a higher speed – it is possible to do preventive security evaluations.

1.1.4.3 Cybersecurity in buildings

As IoT applications adoption increases, so do investments in smart or intelligent buildings and, consequently, cybersecurity threats. In order to provide the several functionalities disclosed thanks to smart devices, standardized and open technologies are usually adopted. Indeed, smart IoT sensors represent an innovative yet already fundamental component in buildings, since their adoption grants companies to leverage data acquired and stored in an unprecedented way, enhancing connectivity and integration among devices. Nevertheless, as already discussed in the previous sections, adoption of IoT sensors and other solutions come with its own risks, as it exposes building occupants to cyber threats (Boyes, 2013; Ciholas *et al.*, 2019).

As recognized standards and procedures are yet to be provided, attackers increasingly target buildings as a potential vehicle for disrupting firm development, as they can be a potentially weak access point to infiltrate and obtain sensible information on the physical and digital systems which govern the entire building. As will be comprehensively discussed in the following sections, according to a recent literature review on the topic, cyber-attacks at building systems can be launched at three different layers, which an intelligent building can be divided into: the *field layer*, the *automation layer* and the *management layer* (Ciholas *et al.*, 2019).

- Field layer comprehends all sensors, actuators and controllers that interact with the building environment as well as each other. At field layer, attacks can be divided between physical attacks (i.e. vandalism, burglary, theft) and wireless attacks (given the increasing adoption of wireless sensors and devices, there is no need to physically interact with the ‘target’ to launch an attack (Ciholas *et al.*, 2019);

- Automation and management layers usually encounter similar typologies of attacks, and in particular four categories may be identified: *denial of service attacks* (as smart buildings often have constrained computational power), *protocol-specific attacks* (most diffused protocols were not diffused with security concerns, given the isolated nature of connection within buildings, at least until recent years), *configuration & legacy vulnerabilities*, and *privacy attacks* (Ciholas *et al.*, 2019).

1.2 Macro-Economic and Environmental Trends

Relationships in modern business are permeated with principles of ethics through social security, justice and equality with the objective of reaching higher levels of welfare. These commitments are, somehow, imposed on companies by society as proof that the foundation of economic development is heavily linked to people and environment (Stojanović *et al.*, 2018). In recent years, there has been a growing concern for the environmental issue, mostly ascribable to climate change, paired with interests towards increasing poverty as well as disparity and social inequality between societies. As a consequence, the concepts of sustainability and sustainable development have increasingly gained popularity and attention towards national and international institutions, policy makers, as well as practitioners and academics. Several definitions have been provided for the term ‘sustainability’, yet consensus among scholars has not been found. Instead, a formally acknowledged definition for ‘sustainable development’ has been provided by the Brundtland Commission in 1987, stating that “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Keeble, 1988). For instance, the ubiquity of the notion of sustainability brought to its association in different topics, ranging from social responsibility to environmental management and business sustainability. However, different references to the notion of sustainability did not bring to an integrated vision of the concept: indeed, different discourses over sustainability have mostly been threated separately (Busco *et al.*, 2013). Despite the growing concern towards sustainability and its relevance in the current literature studies, discussion is still left open with several research questions and interpretations (Purvis, Mao and Robinson, 2019). A comprehensively acknowledged framework (which proposes an integrated perspective of the topic), although not uniformly recognized throughout the literature, refers to the ‘*three pillars*’ or ‘*three spheres*’ of sustainability, namely *environmental*, *economic* and *social sustainability*. The fundament idea behind this framework is that, in order to support sustainable development, companies should achieve true balance of trade-offs between formally equally desirable goals within the three pillars. Although each pillar needs to be evaluated in an integrated perspective to achieve true sustainable development, their co-existence still implies tensions and challenges that need to be addressed and properly managed (Clune and Zehnder, 2018; Beattie, 2019; Purvis, Mao and Robinson, 2019). Another iconic framework related to sustainable development is represented by the set of Sustainable Development Goals (SDGs) formally acknowledged by the United Nations in 2012 (United Nations, 2012). Whilst much of the current sustainability research literature may focus on SDGs, the three pillar framework are explicitly embodied in their formulation (Clune and Zehnder, 2018). Given the increasing pressures from national and international authorities, and from society in general, firms are gradually integrating principles of both social and environmental responsibility within their strategies, structures and management systems (Busco *et al.*, 2013). The following subsections aim to deepen into the three pillars of sustainable development, both individually and – in an integrated perspective – by evaluating tensions, trade-offs and synergies between the economic, social and environmental dimensions. Subsequently, the impact of sustainability practices into the building sector – one of the most relevant sectors in terms of contribution to greenhouse gas emissions – will be analysed, with a focus on the main areas of concern and on how business models and strategies have adapted to such change of perspective.

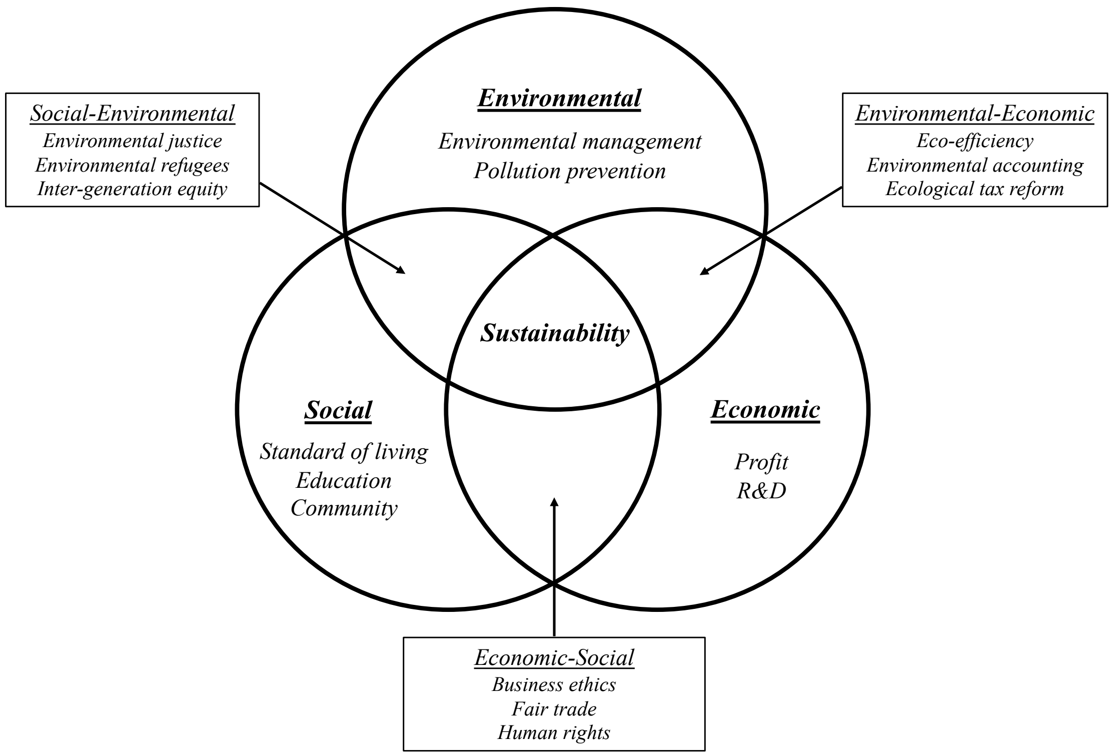


Figure 9. The three pillars of sustainability (adapted from (Rodriguez *et al.*, 2002)*)*

1.2.1 Environmental Sustainability

It is widely acknowledged how, when sustainable development is concerned, the most prominent related topic is that of environmental sustainability, notwithstanding that the multidimensional nature of sustainability has never been argued (Busco *et al.*, 2013; Gupta and Gupta, 2020). The word ‘environmental’ is often associated with human interaction and impact on natural ecosystem. It fairly distinguishes from the term ‘ecological’, which refers to some broader interactions with nature rather than limiting to the human experience. Therefore, it can be argued how environmental sustainability is a subset of ecological sustainability (Morelli, 2011). As reported in the Brundtland Report ‘Our common future’ in 1987, the concept of environmental sustainability is defined as “meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them” (Keeble, 1988). The attention towards environmental sustainability raised in importance during last decades, with increased concern for the amount of greenhouse gas emissions generated every year as well as the overuse of earth’s finite resources, such as fossil fuels and production materials. This raising awareness is justified by the alarming trends seeing the world economy roughly double between 2010 and 2030, with a consequent significant stress on resources and related prices (Sartor *et al.*, 2014). There is a need for business transformation, which has to compete against powerful oppositional interests that gain benefit from the status quo, or even worsen the damages to the environment (Messerli *et al.*, 2019). In the United Nations Conference on Human Environment which took place in Stockholm in 1972, the concept of earth carrying capacity has been outlined, in particular it has been stated how “the capacity of the Earth to produce vital renewable resources must be maintained and, wherever practicable, restored or improved” (Vlasin, 1973). Although several attempts have been done to formally agree upon worldwide environmental sustainability goals at country level, despite the several paradigms that emerged in recent years to establish guidelines and strategies, no real obligation has been univocally approved. Indeed, each country still has its own set of approaches, visions, models and tools available, according to its priorities and reference environment. Only at European level, all twenty-seven countries agreed upon a set of common target goals to be achieved by 2020, and, successively, by 2030 and 2050.

1.2.1.1 Environmental sustainability in Europe

At European level, important decisions have been taken in order to push sustainable practices in each country, especially at environmental level. Indeed, the introduction of the '20-20-20 package' in 2007 (and enacted in legislation in 2009) with the setting of three key targets to be achieved by 2020, have moved companies towards green practices, in order to achieve the following goals by 2020 (European Commission, 2020a):

- 20% cut in *greenhouse gas emissions* (from 1990 levels, mandatory);
- 20% of EU energy from *renewables* (mandatory);
- 20% improvement in *energy efficiency* (not mandatory).

Several actions in different areas have been discussed at EU level in order to meet the targets, especially with the aim of creating concern among companies and countries about their emissions profile, as well as awareness about what energy efficiency solutions can be implemented according to each firm's characteristics. Great attention has been put on the energy sector, as power generation from fossil fuels represent the single largest emitter of carbon to the atmosphere. Renewable energy represents a solution for utilities and companies to reduce emissions: the average EU target varies on the basis of each country energy profile, from 10% in Malta to 49% in Sweden (Peña and Rodríguez, 2019).

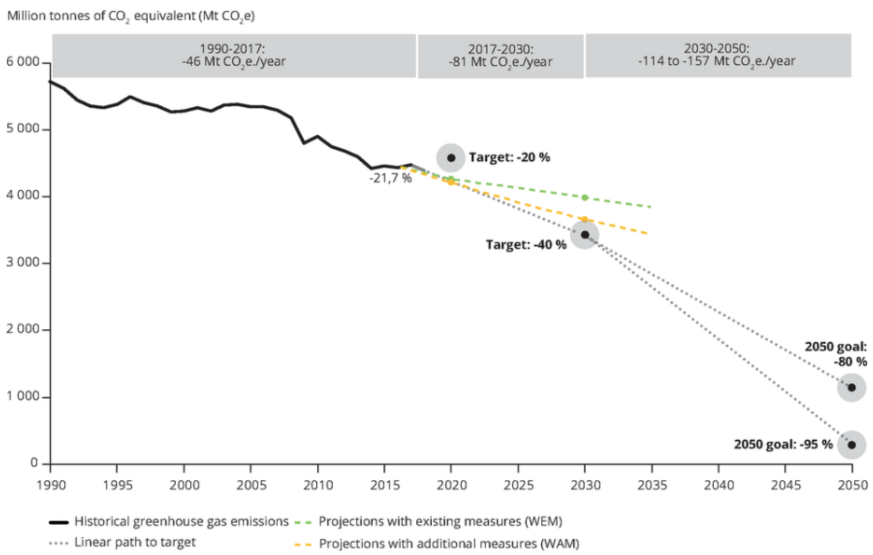


Figure 10. Greenhouse gas emission trend projections and target in Europe (source: (European Environment Agency, 2019)*)*

In order to achieve both the first and second target of the 20-20-20 Climate and Energy Package, companies might be willing to increase their energy efficiency levels, as such interventions are not usually considered on an investment planning logic. Indeed, through energy efficiency solutions, firms would be able to diminish the amount of emissions generated, while simultaneously increasing the country's share of renewables (as long as their energy mix is majorly built on fossil fuels). While most of the obligations related to energy efficiency are applied to big companies or utilities, it is the contribution of small medium enterprises (SME) that may represent the turning factor toward the achievement of the 20% energy consumption reduction target. In conclusion, the achievement of the targets included in the package highlights additional benefits for a country, both at economic and social level. On the one hand, the increase in share of renewables reduces Europe's dependency on imported energy, therefore lowering its sensitivity to market oscillations of primary energy by main exporters, as in the case of Russia's natural gas supply disruptions (Sartor *et al.*, 2014). On the other hand, achieving the goals of the package pushed new industries growth, thus creating new job opportunities and increasing Europe competitiveness (European Commission, 2020a). It can be observed how the 20-20-20 Climate and Energy Package has a specific focus on environmental aspects of sustainability, yet it contributes to enhance economic and social sustainable development, while also pushing for higher levels of technological innovation.

Currently, European Union is on track to meet the 20% emissions reduction target in 2020, with an overall reduction of 23% between 1990 and 2018, and its planning the set of strategies in order to meet the objectives included in the 2030 climate and energy framework. In particular, the framework (first adopted in 2014, then revised upwards in 2018) determines three adjusted key targets to be achieved in the period between 2021 and 2030, consisting of (European Commission, 2020b):

- At least 40% reduction in *greenhouse gas emissions* (compared to 1990 levels);
- At least 32% share of *renewable energy* (the original target was set at 27%, then revised upwards to 32% in 2018);
- At least 32.5% improvement in *energy efficiency* (the original target was set at 27%, then revised upwards to 32.5% in 2018).

1.2.2 Social Sustainability

The social pillar was included later into debates around sustainable development, as social issues were often neglected in favor of environmental and economic challenges and related solutions, both at academic, governmental and business level. However, it is now widely accepted as equally important, alongside environmental and economic sustainability (Eizenberg and Jabareen, 2017). As a matter of fact, social and cultural commitment has been identified as an essential element for enhancing “vibrant and inclusive communities” (Woodcraft *et al.*, 2012). There are several interpretations and theorizations verting around the concept of social sustainability, as many as its number of fields of application. In a report from Social Life, Woodcraft *et al.* state how social sustainability should be seen as “a process for creating sustainable, successful places that promote wellbeing, by understanding what people need from the places in which they live and work. Social sustainability combines design of the physical realm with design of the social world – infrastructure to support social and cultural life, social amenities, systems for citizen engagement and space for people and places to evolve” (Woodcraft *et al.*, 2012; Woodcraft, 2015). By referring to the literature, despite the high number of possible interpretations of the concept, there seems to be consensus on the inclusive nature of social sustainability, incorporating themes such as social capital, human capital and well-being (Woodcraft, 2012). At firm level, there is growing interest towards the incorporation of socially sustainable practices into business operations, ranging from increase of employee well-being and active participation to accurate selection of supply chain partners and transparency to every stakeholder. Indeed, as also claimed for environmentally sustainable practices, there is raising awareness that socially sustainable commitment may enhance a company’s financial performances (see, for example, how improved living conditions and increased participation within offices could boost employee productivity) (Davis-Sramek *et al.*, 2020). Moreover, the link between the social sustainability dimensions of business (human resource management) and society (poverty and inequality issues) should also be deepened, despite the scarce interest manifested by the literature. The level and disparity of population income in a certain area may affect the organizational behavior of companies located in that area, therefore providing the context for social exchange between people. It is then argued that a relationship of interdependence between society and companies effectively exists, and that the two spheres influence and support each other (Roca-Puig, 2019).

1.2.3 Economic Sustainability

To provide a general explanation of the concept, which the pillar refers to, Perrels argues that economic sustainability "can be understood as the conditions, under which a certain level of production and consumption can be sustained forever" (Perrels, 2018). The economic pillar of sustainability thus requires that a firm or country manages its resources efficiently and in a way that enables to consistently generate an operating profit. Indeed, a negative value of operating profit (EBIT) implies that a company would not be able to generate enough value to compensate for the cost of resources it carries to run its own business. However, profit alone is not sufficient to achieve true economic sustainability: a firm should be compliant with all its stakeholders, have proper corporate governance and risk management practices. Moreover, in order to sustain a company's profitability in the long term, responsible consumption and production shall be encouraged, therefore bridging this pillar with both social and environmental ones (Beattie, 2019). As a matter of fact, the use of finite resources (materials, energy fuels, land, water) that contribute to a company's economic growth shall be limited in order to guarantee future profit generation and balanced growth rate, while at the same time preserve natural equilibrium. Significant examples are represented by packaging material reduction, waste water recollection and use of renewable energy sources within the current energy mix of a company (Perrels, 2018; Beattie, 2019). As proof of the aforementioned statements, several studies have confirmed how environmental and social performances of a company positively affects its economic performance in the long term, bringing to a profit increase: according to a recent study on sustainable practices by Banerjee, Gupta and Mudalige, "environmentally sustainable practices (ESP) are negatively associated with financial constraints of firms…The findings are even stronger for firms operating in countries with high institutional qualities, in high emission and highly competitive industries" (Banerjee, Gupta and Mudalige, 2019). Nevertheless, a branch of the literature came up with opposite results, highlighting that tensions may exist between the two dimensions – on the one hand, social and environmental performances, while on the other end, economic results. According to Schwab and Zahidi, "the perceived trade-offs between economic, social and environmental factors may emerge from a short-term and narrow view of growth but can be mitigated by adopting a holistic and longer-term approach to growth" (Schwab and Zahidi, 2019). As a matter of fact, some economies came to the conclusion that a firm, in order to be growing, inclusive and environmentally sustainable at the same time, should apply innovative and visionary leadership in order to satisfy such win-win-win condition (Talon and Strother, 2017a; Schwab and Zahidi, 2019). The relationships between social, financial and environmental dimensions represent tensions that must be adequately managed when implementing integrated sustainability. In particular, there have been several controversies around the integration of the economic pillar with both environmental and social dimensions (Busco *et al.*, 2013). On the one hand, by following a country and corporate perspective, assuming the position of the United Nations (UN), it is the economic pillar that enables the meeting between a firm strategies and sustainability practices, having a counterweight effect to the extremely strict requirements that could be imposed to them. On the other end, a relevant strand of the early literature, particularly critical toward the current perception of global economy, sees the economic pillar as a way of systematically change the overall picture, by subordinating it to both social and environmental spheres (Clune and Zehnder, 2018; Beattie, 2019). The object of debate between the two parties is mostly ascribable to the understanding of 'economic growth'. As argued by Clune and Zehnder, a branch of the literature is not willing to accept growth as a future line for granting sustainability: "*this contrasts heavily with the understanding pushed by the UN, where growth is imperative. Rather than being met with scepticism, a growth-focused economic pillar is central to their sustainable development narrative; here, growth is key to meeting the social and environmental goals through trickle-down effects. The presentation of an economic pillar centered on growth, equal in importance to social and environmental pillars of sustainability, as an unquestioned, unprobed necessity cements this framing of the pillars as common sense*" (Clune and Zehnder, 2018).

In conclusion, the economic pillar thus represents the fundamental factor that unites the growth-based perspective of companies and countries with the environmental and social perspectives of early literature. However, the confusion around a clear conceptualization of the 'economic' meaning, together with the different interpretations as the consequence of a competing scenario, bring to the belief that a coherent singular concept may not be reachable, and that sustainable development should be qualified in the logic of a common integrated view of literature and economic world (Clune and Zehnder, 2018).

1.2.4 Sustainable Development in Buildings

It has been globally acknowledged how buildings represent a sensible topic as far as concerns the sustainable debate, from both an environmental and social perspective. Buildings currently contribute for more than 40% to global energy usage, and as much as one third to greenhouse gas emissions. Moreover, as 90% of people daily lives are spent indoor, constructed environments heavily influence productivity, health and overall well-being, therefore representing one of the fields of study where innovative social practices may bring to the most beneficial outcomes (Ramboll, 2019). While the focus on sustainable buildings was originally centered around environmental constraints (as also deductible by the introduction of European and national policies), translating in the form of energy efficiency solutions, the term is constantly evolving towards a mature definition, incorporating social as well as economic aspects of a building throughout its entire lifecycle (Ramboll, 2019). The increase in demand for sustainable buildings has been driven by several factors that concurred to create the most suitable environment for the adoption of this new paradigm. Indeed, the great potential behind sustainable buildings has been unlocked by the convergence of distinct forces, ranging from sustainability challenges, encompassing issues at every pillar of sustainable development (i.e. environmental, social and economic spheres), to technological advancements at different levels of the building and construction supply chain, highlighted by market breakthroughs such as new building materials, building information modelling (BIM) and smart building (Zabihi, Habib and Mirsaeedie, 2012; Ramboll, 2019). It can be then observed how technological innovation acts as an enabler of solutions, with the aim of achieving sustainability objectives for the building and construction environment. Building environments have the potential of enhancing sustainable development at each level, being it either economic, environmental or even social, by means of the different solutions that technology, and in particular digitalization, has made available for real estate companies, tenants and homeowners.

The following section will deepen the analysis on the contribution of sustainable building design and practices, by remarking the impact on each pillar of sustainable development, in regards of the potential intervention areas that may see practical applications and solutions.

1.2.4.1 Buildings as engine of enhanced environmental sustainability

There are several fields of application where environmentally sustainable practices can be introduced within building (usually also mentioned as 'green buildings'). As reported in a recent survey by Dodge Data & Analytics, where interviewed companies were asked to evaluate the relevance of different environmental reasons for building green[2], reduction of energy consumption was usually graded as top priority (confirmed by 66% of respondents both in 2015 and 2018), with energy efficiency and production from renewables on the line as among the most prominent and financially feasible solutions. As shown in the graphic below, remarkable growth in importance has been given to reducing water consumption, lowering greenhouse gas emissions (although such reason is strictly correlated to reducing energy consumption) and improving indoor air quality (Petrullo *et al.*, 2018).

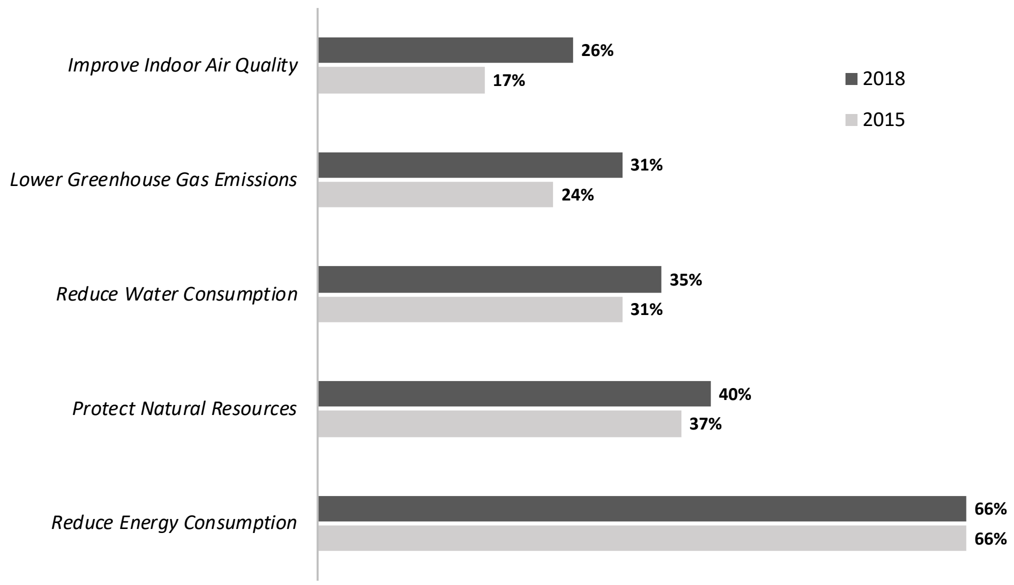


Figure 11. Top Environmental Reasons for Building Green (adapted from (Petrullo *et al.*, 2018)*)*

[2] The survey has been conducted in 2018, with interviewed people being asked to rate several reasons on a five-point scale, then select the two most relevant among those rated as important. Obtained results were then compared to 2015 outputs in order to track prospective trends (Petrullo *et al.*, 2018).

It is therefore important to remark the growth of those originally classified as secondary objectives when referring to building environmental sustainability, as proof that a more holistic approach in building design, development and customization has been commonly adopted worldwide. In particular, the sharp increase in interest towards improved indoor air quality is coherently correlated to an always higher concern for health and wellness factors inside buildings (as explained in the following subsection). Overall, the focus towards a wider range of factors is justified by increased data collection and analytics opportunities that shed light on companies' environmental performances, strengthening the inclusion of key sustainability indicators (such as energy and water consumption, total waste, greenhouse gas emissions) into strategic planning and design (Petrullo *et al.*, 2018; Ramboll, 2019). While most of the data generated and collected refers to a building 'use phase', in order to comprehensively assess its environmental impact, it is necessary to track information at every stage of a building lifecycle, therefore including: extraction of raw materials, construction, demolition and eventual disposal/recycling/reuse. The environmental impacts of material resources could then be reported at various stages of a building lifecycle, collected by basing on Life Cycle Analysis (LCA). Therefore, an efficient use of resources (of each kind, from construction material to energy) should be addressed at every stage of the building lifecycle, and, in regards, an integrated approach is fundamental in order to maximize optimization efforts. As also reported by Ramboll, according to survey respondents 'Life Cycle Thinking and Management' represents the biggest trend in both 2017 and 2019, registering a total of 71% in 2019 (Herczeg *et al.*, 2014; Ramboll, 2019).

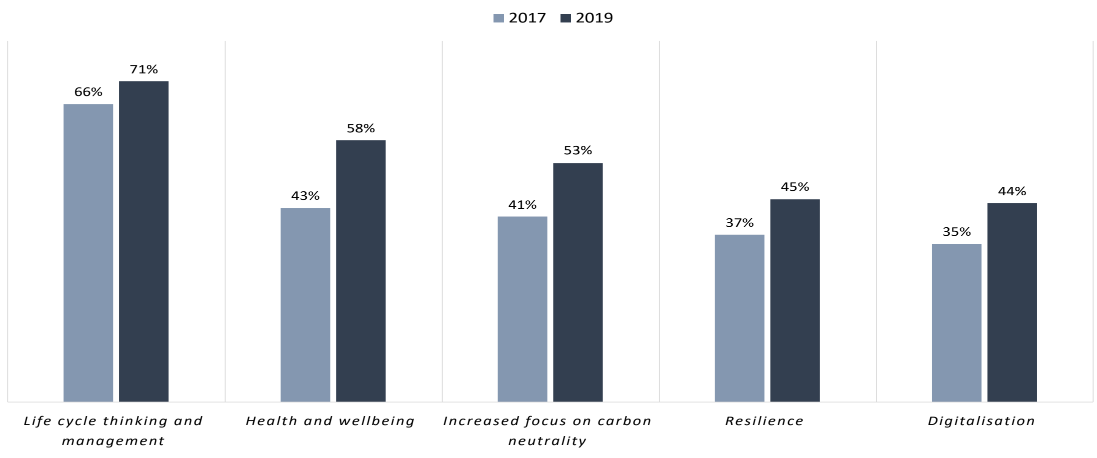


Figure 12. Top trends driving sustainable building activities in 2017 and 2019 (adapted from (Ramboll, 2019)*)*

1.2.4.2 Buildings as catalysts of wellness and social integration

It has been commonly acknowledged (and empirically assessed as well) how building environments may have a direct effect on occupants' well-being, both physically and mentally. More generally, built spaces have an influence on society at different levels, in different ways. Therefore, a significant body of literature research focused on how sustainable buildings affect the way people live, learn and work. In the last decade, there has been a growing trend towards occupants' health and well-being, underlining the importance of livability as a condition to be achieved in order to raise a building attractiveness (Clements-Croome, 2015; Ramboll, 2019; McArthur and Powell, 2020). Dodge Data & Analytics recently made a survey with the aim of understanding the most important social reasons for building green[3]: during the period of data collection (2012, 2015 and 2018), there has been registered a positive trend towards the inclusion of a wider set of social reasons rated as important by respondents (Petrullo *et al.*, 2018).

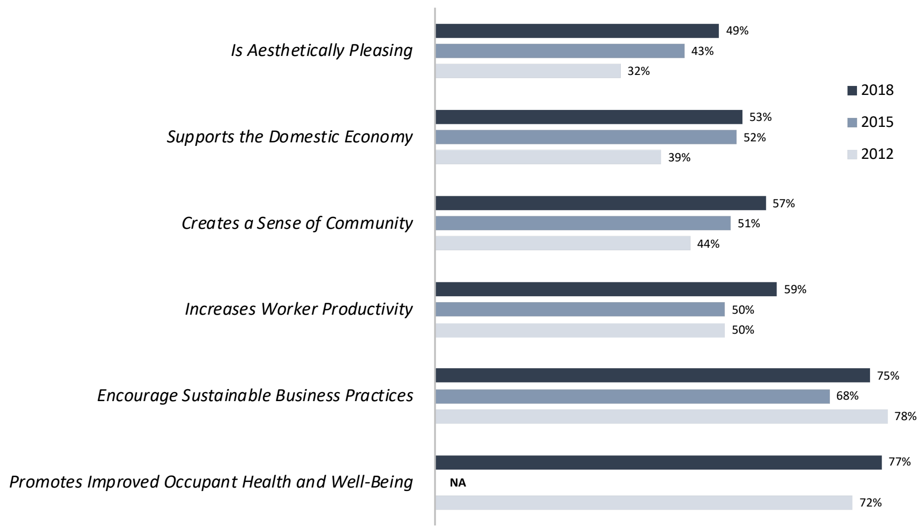


Figure 13. Social reasons for building green (adapted from (Petrullo *et al.*, 2018)*)*

[3] The survey has been conducted in 2018, with interviewed people being asked to rate several reasons on a five-point scale, then select the two most relevant among those rated as important. Obtained results were then compared to 2015 and 2012 outputs in order to track prospective trends (data about occupant health and well-being was added back to the study after having being dropped in 2015, as proof of its enhanced appeal to companies) (Petrullo *et al.*, 2018).

While it is univocally acknowledged that the renewed interest towards the social dimension is relevant for every building category, such outcome is particularly critical when considering commercial buildings, and specifically working environments or office spaces. The two most relevant social reasons for building green, with about three quarters of respondents rating them as important, are the increased health and well-being of occupants and the influential effect towards other companies or individuals by encouraging further sustainable business practices (Petrullo *et al.*, 2018). In particular, occupant health and well-being in the built environment registered a sharp improvement in 2018 after having been dropped in 2015, as also indicated by the increased adoption of certification programs and systems (WELL, Fitwel) as well as the recent focus of the academic literature on the topic (Clements-Croome, 2015; McArthur and Powell, 2020). In regard, several researches study whether positive correlation exists between building 'greenness' and employee wellness, comparing human performances (such as absenteeism, number of sick day) in a traditional building with those in a sustainable building (Clements-Croome, 2015; WGBC, 2015). It has been confirmed how environmental factors may operate as stressors on people, affecting them in multiple ways: air quality, temperature, humidity, light as well as noise and odors influence occupants both physiologically and mentally (Clements-Croome, 2015). According to Clements-Croome, "if an environment is to be conducive to health and well-being, it should display the following characteristics: a fresh thermal environment; ventilation rates sufficient to provide fresh air with good distribution and acceptable levels of CO2; good natural lighting; acceptable acoustic climate; no lighting glare; spatial settings to suit various types of working; ergonomic workplaces that have been designed to minimize musculoskeletal disorders; the landscaped surroundings should be properly considered as part of the design; minimum pollution from external sources, including noise." (Clements-Croome, 2015). In line with the higher interest towards health and well-being, an increasing number of respondents (from 50% in 2012 and 2015 to 59% in 2018) believes that building green may as well positively affect occupants' productivity, and in this regard, several studies show evidence of existing correlation between a worker's performance level and his/her personal wellness (and, consequently, greener building environments). Indeed, for an organization to reach its objectives, it is fundamental that workers' productivity sets at optimal levels, and if the human benefits of sustainable buildings were quantified, the expected ROI would proportionally raise (Clements-Croome, 2015; WGBC, 2015).

1.2.4.3 The economic implications of sustainable buildings

Although implementation costs are still seen as one of the main barriers to a sustainable building implementation, one of the most important drivers of a related investment (in a market economy) is about its financial benefits. Indeed, if business cases begin to generate positive outputs from an economic perspective, the number and scale of solutions will emerge and grow exponentially (Petrullo *et al.*, 2018; Ramboll, 2019). Despite the raising importance of both environmental and social objectives, the implementation of sustainable practices still remains heavily related to their economic feasibility. There are several revenue mechanisms enabled by means of an investment in sustainable spaces, many of which are somehow accountable in order to draft a reliable picture of a potential return on asset:

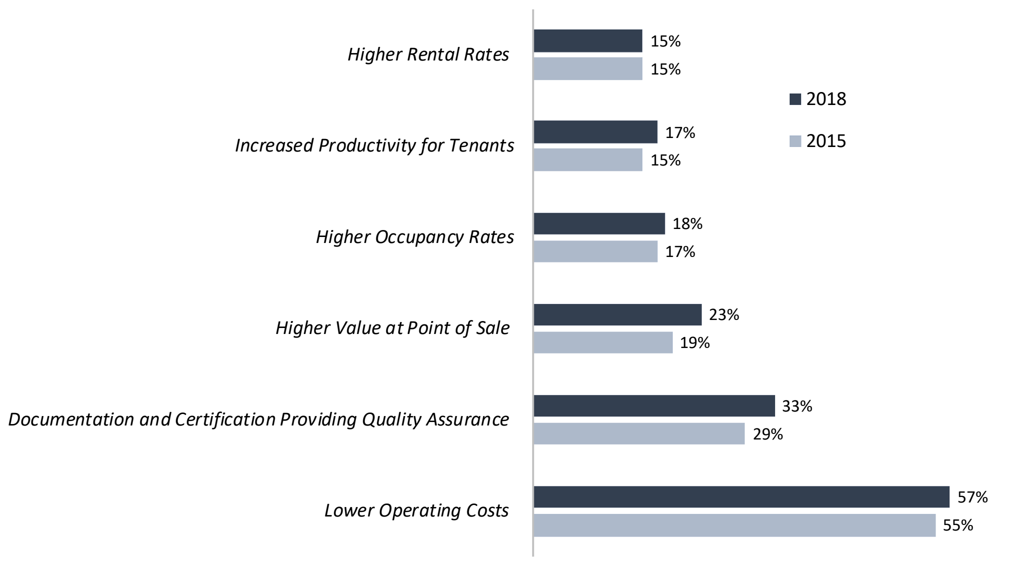


Figure 14. Main benefits of sustainable buildings[4] *(adapted from* (Petrullo *et al.*, 2018)*)*

[4] The figure shows the metrics used to quantify the economic benefits of sustainable buildings, identified according to the aspects that interviewed people (among those that declared to effectively use metrics to determine said returns) selected and rated as important. Data has been collected in 2015 and 2018, in order to obtain prospective trends.

- *Lower Operating Costs*: the first economic objective sought by real estate companies and tenants when deciding to go for a sustainable building (and also acknowledged as the most obvious in terms of perceived value added) is the attempt of optimizing operating costs. Among the cost invoices included, the most relevant are energy consumption (HVAC, lighting), water management, waste management, cleaning and O&M services (sustainability throughout the total life cycle of a building could be further addressed with carefully selected materials and robust solutions that reduce risk and costs associated with cleaning, maintenance and recyclability). The quantification of ROI by analyzing energy cost savings (and, more in general, the reduction of operating costs) is transparent, yet it does not represent the whole picture, as other forms of indirect revenues may represent the true 'hidden' advantage behind sustainable buildings (Talon, 2016; Ramboll, 2019);

- *Higher Occupancy Rates*: as sustainable buildings represent a relevant investment in terms of brand, image and quality, one of the advantages for real estate companies is the reduction of vacancy rates in the long run, but also the enhancement towards higher and faster occupancy at the beginning of the building life (shorter set-up time). Indeed, the reduction of vacancy rates represents a transparent return as well, yet the main challenge is to capture the potential value added in advance (in terms of exact timeline estimations), in order to present sustainable building projects in a credible and consistent way (Talon, 2016; Ramboll, 2019);

- *Higher Property Value*: by following a similar pattern to that previously mentioned, the appreciation towards sustainable buildings (being it an attractive option for tenants and/or property buyers) reflects into a higher property value, therefore calling for higher rental prices. The price increase, although logically expectable, does not follow generally acknowledged estimations, as the market around sustainable buildings is still not completely defined nor stabilized. The obtainment of environmental certifications, such as BREEAM or LEED (each of which has its own set of schemes and targets to be achieved) may represent a first step for a precise estimation of the value increase for sustainable spaces (Ramboll, 2019; McArthur and Powell, 2020);

- *Incentives/Restrictions*: another driver of enhanced revenues – easily quantifiable – is represented by regulatory incentive schemes, obtainable through sustainable solutions for buildings and facilities (such as photovoltaic energy generation, energy efficiency applications). There are several types of incentives related to sustainable solutions, from tax detention and super amortization to green/white certificates, each of which is easily accountable and easily predictable. Following the same logic, those who do not dedicate enough resources to sustainable projects may incur in penalties and other forms of restrictions. As a consequence, the ROI of a building investment would be negatively affected, thus representing a differential revenue for companies pursuing sustainability (Ramboll, 2019; McArthur and Powell, 2020);

Some of the benefits related to sustainable buildings are clearly identifiable and directly accountable for a dedicated financial analysis (although not each of them may be addressed in advance, in order to perform an investment opportunity evaluation). However, there are some 'hidden' factors which present some difficulties (or requires too much effort and resources) to be translated into financial information. Among the others, the following represent some of the most relevant:

- *Increase of Occupant Productivity*: as already addressed, a high quality and sustainable building may greatly affect occupants' health and well-being, and evidence of a direct interaction between overall wellness and productivity has already been confirmed by academics. However, it is difficult to quantify productivity improvements and related financial implications, thereby limiting the expected return on investment (WGBC, 2015; Talon, 2016; Ramboll, 2019);

- *Increase in Talent/Employee Attraction and Retention Power*: another 'hidden' benefit of a sustainable building investment is that of exerting a higher attraction power to new employees, therefore increasing the chances of hiring more suitable candidates for open positions, while also decreasing the eventuality of them eventually leaving the job (WGBC, 2015; Petrullo *et al.*, 2018; Ramboll, 2019);

- *Brand Image Strengthening*: last, sustainable buildings reinforce the green image of a firm's brand, which adds for higher power and attractiveness in front of stakeholders (Petrullo *et al.*, 2018; Ramboll, 2019).

1.3 Socio-Demographic Trends

Although quite generic in their impact over different industries, socio-demographic trends have also affected development in the building sector, by accelerating technological advancement and increasing the overall demand for built environments, driving the research towards customizable and flexible spaces. In particular, two major forces are reshaping the way buildings are modelled: the increasing *urbanization* and the demand for enhanced connectivity and services, as consequence of a generational turnover into society (i.e. the shift towards a *millennial workforce*), especially within the working environment. This section aims to give an overview of socio-demographic forces and account the related consequences for the development of smart buildings.

1.3.1 Growing Urbanization

Urbanization represents a major global change that is overwhelmingly affecting current society, nevertheless having a massive impact on several industries. By 2030 it has been estimated that approximately 60% of the global population will be leaving in cities, with a high focus on the growth of developing economies. While cities are the main fuel to foster economic development (in terms of mobilized economic, human, technological and informational capital), a multitude of key problems arise as the consequence of increased urbanization, such as "high urban densities, traffic congestion, energy inadequacy, unplanned development and lack of basic services" (Bansal, Shrivastava and Singh, 2015). Therefore, the concept of 'Smart Urbanization' is rapidly replacing more traditional approaches, as it is the key for safer and sustainable cities. Among the challenges of fast urbanization, *optimal space management* and *urban planning* represent sensible topics for which buildings contribution may have a great effect, by means of the recent technological breakthroughs that are reshaping the way in which built environments are managed. In particular, Information and Communication Technologies (ICT), specifically driven by the escalating adoption of IoT solutions, are crucial to allow for a total reconfiguration of office buildings and working facilities, reducing the amount of square meters needed per employee (Krishna and Matturi, 2013; Bansal, Shrivastava and Singh, 2015).

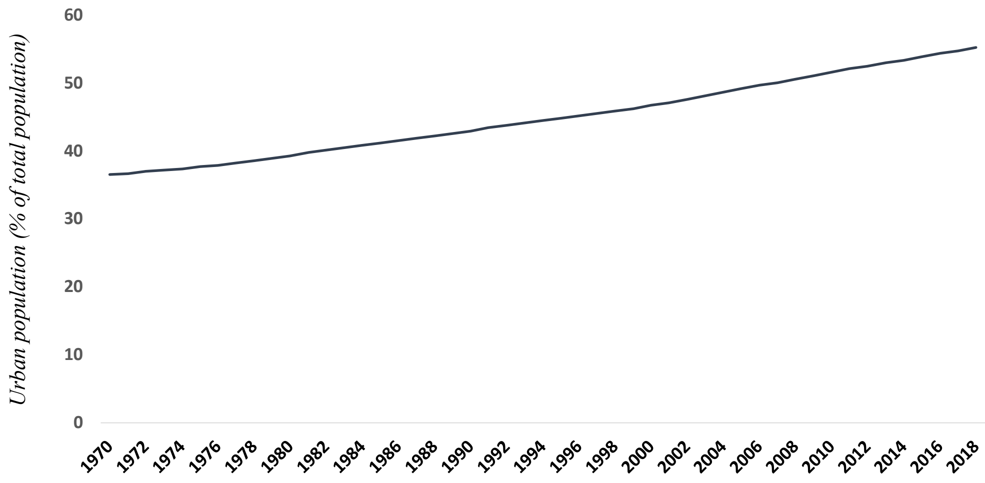


Figure 15. Percentage of urban population on total population, from 1970 to 2018 (data collected from (World Bank, 2020)*)*

The reduction of occupied environment represents one of the main targets for smart working applications, helping to preserve unneeded space for further future uses. From a broader perspective, the benefits from the adoption of occupancy sensors and their optimal placing are not bounded to buildings only, as several applications emerged for challenging other issues of future urban spaces (Willingmann, Turbek and Goldsberry, 2018; Navigant Research, 2019). One prominent example is related to car traffic congestion and, in particular, to the shortage of parking spaces. Using sensors to pinpoint vehicles entering and leaving each parking sector, a smart parking system collects and analyses occupancy data and communicates real-time availability through digital displays, guiding drivers to free spaces and reducing congestion (Willingmann, Turbek and Goldsberry, 2018). However, the advancement of smart and sustainable buildings may help to solve other major issues related to increasing urbanization, one of which represented by *energy scarcity* (Bansal, Shrivastava and Singh, 2015). Indeed, with the connectivity potential of IoT, improved distributed energy generation, HVAC and lightning applications, buildings raise energy efficiency efforts. Moreover, the adoption of platform solutions may generally bring to higher savings and experience economies, optimizing energy consumption and reducing grid stress (Navigant Research, 2019)

1.3.2 'Millennial' Workforce

The working environment has undoubtably been affected by the new wave of technology introduced in recent years, in a way that has brought managers to completely reimagine how offices and facilities should be designed and which services should be delivered to employees. Moreover, the mobile technology has amplified such effects, by extending this reach beyond the boundaries of built spaces (Condeco, 2019). What drove the change toward a new model of working space was the emergence of a new generation of employees, the 'Millennials' (born between the early 80s and the early 2000s), with new – and, in a sense, disruptive – traits, requirements, and objectives. In this regard, they represent a more demanding category of workers, potentially being on the way to become the most diverse, influential and world changing generation in history. As reported by Deloitte in a recent survey, in which they interviewed 13,416 millennials (born between 1983 and 1994) across 42 countries or territories, 49% of respondents declared that they ought to quit their current jobs in the following two years, representing a challenge for companies aiming to consolidate positions across their organizational structure (Deloitte, 2019). Such tendency is also confirmed by the growing average of companies changed by workers during their first five years after graduation, which is between 2.5 and 3.0 for workers graduated between 2006 and 2010 (Kurian, 2017).

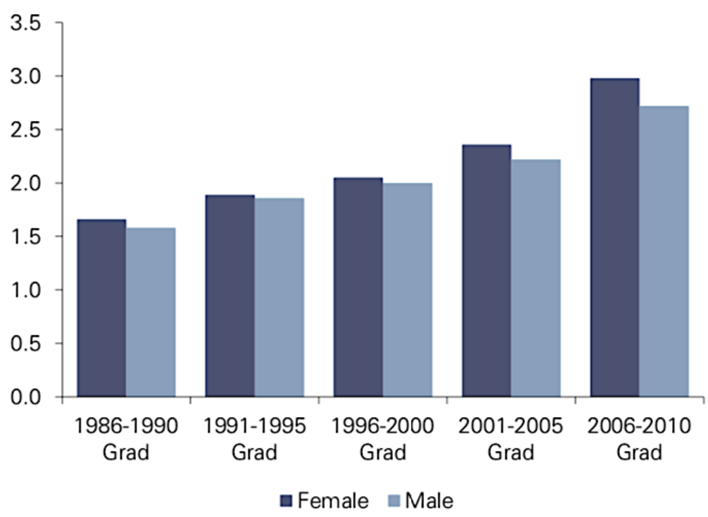


Figure 16. Average number of companies within first five years after graduation (Kurian, 2017)

In the report it is also emphasized that a structural change must occur in order for corporations to attract and motivate millennial talents, that is to move from profitability-only oriented decisions to a mindset that coincide more with what younger generations seek (Deloitte, 2019). Among the top priorities of a millennial workforce is the need for higher level of workplace connectivity, mobility, flexibility (in line with the prominent emergence of smart working as a real practice, not an abstract utopia anymore) and occupant choice in built environments (Locatee and Memoori, 2019). Derrick Feldmann, founder of 'Millennial Impact Project', confirms how "millennials have been able to unite around their passions in large numbers, thanks to social media and a digital landscape that's growing at lightning speed. Fluent in digital technology before graduating from high school, most have rarely known a day without high levels of digital interaction. While companies and causes struggle to keep up, millennials are adapting to new technologies as quickly as they become available – and using them to force attention onto the issues that matter to them" (Condeco, 2019; Feldmann *et al.*, 2019). From the above lines, the most important takeaway is represented by the strong interaction between millennials and technology, in a way that strongly affects as well as redefines working patterns and boundaries. This argument is gaining more and more importance, as estimates show how the number of millennials expected to occupy working positions will be around 50% by 2020 (Locatee and Memoori, 2019). Moreover, the effects of changing forces of Industry 4.0 have drastically impacted the working environment: according to Deloitte, "as the marriage of physical and digital assets proliferates, the impact on workers will multiply" (Deloitte, 2019). To sum up all of the previous considerations, smart buildings seem to represent one of the most peculiar solutions to meet the future challenges addressed by a millennial workforce, by offering the levels of connectivity, flexibility, diversity – more in general, experience – that workers increasingly keep demanding.

2 Smart Building: Definition and Scope

The previous section of the literature review has verted around the analysis of the main macrotrends that affected the shift of real estate companies and property owners toward a new, disruptive model of building, called *smart* (or *intelligent*) *building*, for which a proper definition has not been provided yet. In this section, by going through an accurate evaluation of some of the most relevant papers and reports in regard, a comprehensive definition of the term smart building will be presented. After a historical digression on the evolution of the term and its associated definitions, the final interpretation of the concept of smart building is established, followed by a related in-depth analysis which is structured according to a two-steps process:

- In the first part of the analysis, the Big Picture of the smart building definition is illustrated, also evaluating the relation between its main functions and each category of stakeholders (Energy&Strategy, 2020);

- In the second part of the analysis, the definition is fragmented into its more essential components, which are (Energy&Strategy, 2020):

    - *'Building devices and solutions'*, divided among energy generation, energy efficiency, safety&security and occupant satisfaction and well-being;

    - *'Automation technologies'*, which comprehends the hardware infrastructure enabling the intelligent functioning of the building, such as sensors and actuators;

    - *'Building Management Platform'*, which contains the software involved in the collection, elaboration and analysis of data generated by hardware components;

    - *'Connectivity'*, which determines the communication infrastructure, classified into either wired or wireless, that has been adopted in order to allow every other component to properly communicate.

After having formalized a suitable definition of smart building, a scope analysis of its theoretical 'infrastructure' is conducted, by following an investment logic aimed at identifying the most important advantages associated to its adoption. It is important to mention how not all the benefits of a smart building investment are ascribable to clear economic (thus, numerical) outputs, despite the evidence of correlation with a company's financial performances (Singh, 2018). The classification of a smart building by means of its revenue generation opportunities represents the foundation supporting the last chapter of the research, which focuses on the evaluation of company's case studies for assessing the economic implications of an investment into intelligent buildings. The last part of the section is dedicated to a qualitative illustration of a prominent smart building business case in the European context.

2.1 Definition of 'Smart Building'

2.1.1 Brief History

The first discussions around the concept of smart buildings refer to the early 80s, as in 1984 a New York Times article openly mentioned the idea of 'buildings able to think for themselves', also denominated 'intelligent buildings' (Sinopoli, 2010). The conceptual model around smart building became relevant in the early 80s as the consequence of major trends (one of which was the creation of the personal computer industry) simultaneously influencing different markets, breaking boundaries and connecting industries that seemed somewhat separated and unrelated, as happened between real estate and technology systems (Sinopoli, 2010). At first, telecommunications systems had been part of the innovative business model, originally called 'shared tenant services', which verted around the creation of a large telecommunications system and the leasing of telecommunication services to tenants. Although the idea had been eventually abandoned by real estate companies (as the needed know-how was still inadequate), 'shared tenant services' represented one of the first trials of incorporating major technology systems in buildings. In the following decade, technological advancements in buildings have been modest, as confirmed by the strict dependence of commercial real estate on incremental advancements in interior and exterior design, construction methods, and energy savings (this last aspect has been particularly deepened in the last two decades or so). Until recent years, however, the pace of technological advancement in the vast majority of industries was considerably faster if compared to the case of real estate and construction (Sinopoli, 2010; Fletcher, Santhanam and Varanasi, 2018). Indeed, technological improvements within buildings have been addressed only later, as the consequence of an increasing need for optimization of building expenses, mostly ascribable to energy generation and efficiency. Yet, each wave of technological change did not address the issue of interaction between individuals and buildings, as communication with occupants usually assessed around mechanical actions such as button pressing for elevators call or light switching (Fletcher, Santhanam and Varanasi, 2018). The great step through which the concept of smart building may be truly comprehended is related to the acceptance of technology systems as enablers, a means to an end for enabling efficiency, supporting security and nurturing occupants' health and well-being. It has been only in the most recent years that a step forward has been made concerning the understanding of the relations that exist between buildings and users and the way occupants may benefit from stated relations. By means of a wave of technological breakthroughs – comprehensively collected into the term 'industry 4.0' – that enabled and disclosed several new opportunities for building owners and tenants, the existing boundaries between human and machine comprehending are rapidly fading in favor of a systemic and integrated approach, aimed at supporting increased communication and services. (Kejriwal and Mahajan, 2016; Fletcher, Santhanam and Varanasi, 2018; Wellener *et al.*, 2018). As the first models behind this new vision of integrated and connected buildings are emerging, the value potential that still needs to be unlocked is massive, therefore opening the opportunity for companies and property owners to create sustainable advantage over time. This revolution leads to define a positive trend of adoptions that may open the market to a new era in which barriers and boundaries are blurring, leaving space for innovative business opportunities (Kejriwal and Mahajan, 2016; Pieper *et al.*, 2018). To conclude, the concept of smart building should not be unfolded by relying only on its technological side, or, more generally, from a single perspective. Instead, all of its 'components' should be equally addressed, as the result of a multi-perspective (hence, multi-stakeholder) and systemic approach.

2.1.2 Smart Building Definition: State of the Art

The enhanced interest towards smart building and its impact to the marketplace has growingly inspired the research of scholars as well as reporting and consultancy initiatives, who started questioning about its peculiar traits and economic potential opportunities. As soon as the topic became prominent subject material for studies and reports, there has manifested a growing need to provide a univocally acknowledged definition of the term 'smart building' or 'intelligent building'. This has been an ongoing debate in many articles and presentations over the years (Tomlinson, 2019). Nevertheless, technology and related solutions evolved over time, research initiatives offered diverse perspectives of the same argument, moreover definitions of a smart building may vary across building types, industries and owners/tenants, therefore proposing a complex and diverse environment in which the aim is to highlight common features shared among each case. Seeing as all of the aforementioned reasons implicitly generated uncertainty among academics, it is quite evident that the terminology has eventually been (and still is) subject to changes and interpretations, therefore lacking consensus about its essential meaning (Locatee and Memoori, 2019; Shivakumar, 2019).

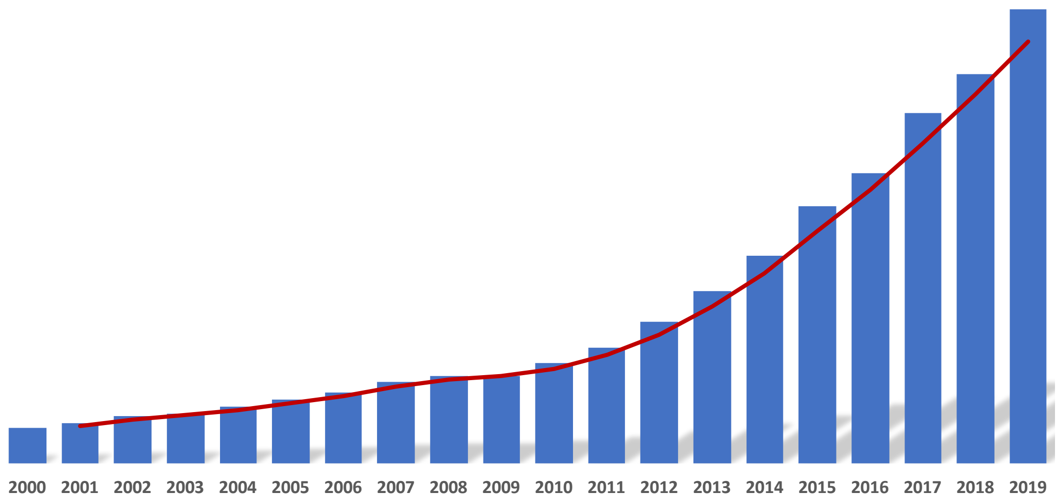


Figure 17. Number of publications that expressively reported the term 'smart building', from 2000 to 2019 (ScienceDirect, 2020)

Currently, the European Union is evaluating the possibility of creating a certification program to address the lack of a formal definition, in order to raise awareness about the potential value-added opportunities behind its investment (Sullivan, 2019).

2.1.2.1 'Smart building' or 'Intelligent building': a first distinction

Preliminary to every review and analysis of literature studies concerning the identification of a suitable smart building definition, a first contextual distinction between smart and intelligent building is provided. By evaluating the contribution of the literature, both the terms 'smart building' and 'intelligent building' have been used to describe a new paradigm of building, suited with innovative technologies, that enables to achieve precise objectives. Frequently, the two terms are used interchangeably to illustrate the same concept of building, bringing to the conclusion that there is not a clear existing distinction between them. As Buckman, Mayfield, and Beck noted, "there is a clear confusion as to the differentiation between smart and intelligent buildings." (Buckman, Mayfield and Beck, 2014; Hoy, 2016). As proposed by Hoy, the two terms may indeed share some common aspects, nevertheless referring to two different states of advancement of building technology, as the last two outputs of the building transformation process through history, from 'primitive', to 'simple', to 'automated, to 'intelligent', to 'smart'. "(..) The intelligent building combines the best of both simple and automated buildings: systems are still controlled automatically, but sensors allow the building to adjust to user needs in real time. Smart buildings take it a step further, beyond simply turning things on and off. Smart buildings also collect data about how and when a building is being used and provide a real-time picture of the status of a building. Using networks of sensors and cameras, smart buildings can count the number of occupants in a building at any given time and track that data over time. (..) Using the data from these sensors, building managers can see current and past use and predict future use. They can also adjust traffic flows as needed to reduce congestion and plan staffing levels to meet demand." (Hoy, 2016). Therefore, it can be affirmed how the two concepts have some aspects in common, which only partially justifies their interchanging usage within literature and reporting studies. Indeed, a more appropriate application may be that of mentioning the two concepts by adopting a time-related perspective, in order to illustrate the evolution of building technology through history.

2.1.2.2 Technology-oriented smart building definitions

As the concept of smart building still lacks any sort of formal recognition, the literature has provided several interpretations, as the purpose of each study varies according to the research objectives of each side aiming to deepen into the argument. Indeed, it is possible to identify two branches when referring to a potential smart building definition. On the one hand, a first branch defines smart buildings by leveraging on their *technological features and peculiarities*, addressing the importance of the most recent innovation waves that dramatically changed the building landscape and the way different building end devices interact and connect to each other. On the other hand, a second branch aims at depicting smart buildings by leveraging on the *benefits associated to their adoption* rather than the technological infrastructure upon which a smart building lays its foundation, providing a less technical but 'visionary' overview of what newer buildings may potentially be able to provide to owners and end users . As a result of the opposing perspectives that arise by reviewing some of the main publications on smart buildings, two main classifications of smart building definitions arise, being them either *technology-oriented* or *goal-oriented*. It is to note that, as two major interpretations of the concept emerge, there are some definitions that may not be completely referred to any of the two branches, therefore assuming an intermediate position.

This subsection deepens the discourse about *technology-oriented definitions*, for which a first argumentation is provided by Sinopoli in 2011, giving a systemic perspective of building founded on the importance of information, managed infrastructure and building systems: "A smart building involves the installation and use of advanced and integrated building technology systems. These systems include building automation, life safety, telecommunications, user systems, and facility management systems. Smart buildings recognize and reflect the technological advancements and convergence of building systems, the common elements of the systems and the additional functionality that integrated systems provide. Smart buildings provide actionable information about a building or space within a building to allow the building owner or occupant to manage the building or space. Smart buildings provide the most cost-effective approach to the design and the deployment of building technology systems." (Sinopoli, 2010). As this definition specifically verts around the concept of 'integrated building technology systems' as the suite of systems that are managed through smart buildings, the importance of communication between different automated end devices is critical, for which the use of open and standard communication networks become necessary. Sinopoli also provides a further understanding of system integration within buildings: "system integration involves bringing the building systems together both physically and functionally. The physical dimension obviously refers to the cabling, space, cable pathways, power, environmental controls, and infrastructure support. It also touches on common use of open protocols by the systems. The functional dimension refers to an interoperational capability, this means integrated systems provide functionality that cannot be provided by any single system, the whole is greater than the sum of the parts" (Sinopoli, 2010).

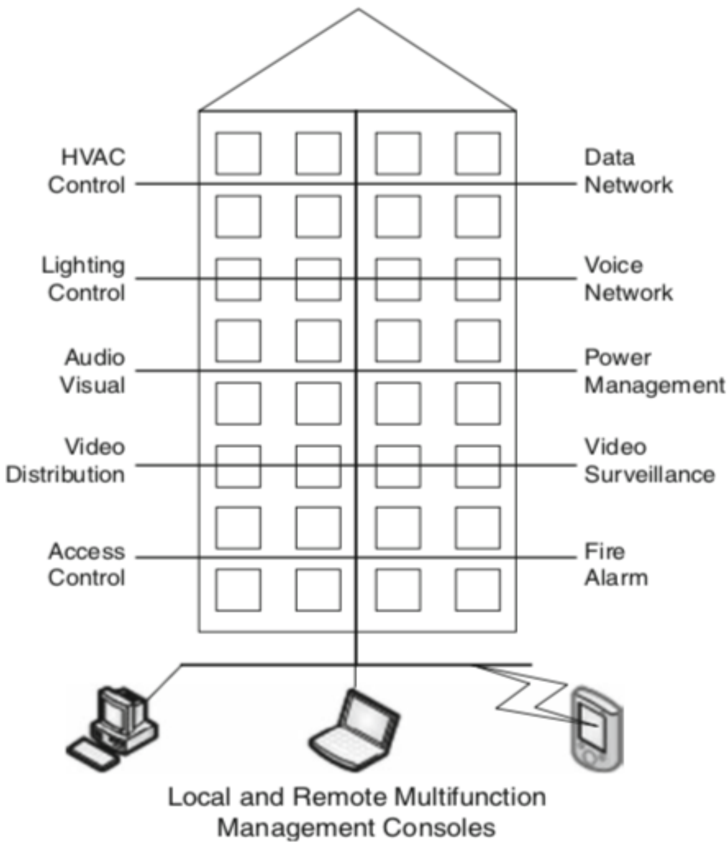


Figure 18. Integrated Building Systems (Sinopoli, 2010)

The same pattern is present in the definition provided by the Digital Transformation Monitor: "The concept of Smart Building could be defined as a set of communication technologies enabling different objects, sensors and functions within a building to communicate and interact with each other and also to be managed, controlled and automated in a remote way. Indeed, technologies help to connect a variety of subsystems that originally operated independently. Automated processes allow the control of the building's operations including HVAC (Heating, Ventilation, Air Conditioning), lighting, security and other systems." (Digital Transformation Monitor, 2017). Again, the concept of communication technologies is central to the discussion, as one of the main peculiarities behind smart buildings is related to the integration of different systems to seek for efficiency and additional benefits. As a last example adopting the same logic in drafting a smart building definition, Berawi *et al.* propose the following: "The smart building integrates the complex system in certain coordination to manage resources efficiently. The key to smart building concept lies on the integrated system called smart building system that uses automation in its operational stage. The system mostly installed on heating, ventilation and air conditioning (HVAC) to provide energy efficiency, security protection, telecommunication interface, and vertical transportation." (Berawi *et al.*, 2017). From this definition, as for the others mentioned, integration is the core concept to which smart buildings are commonly associated. As also suggested by Herrenkohl, "it may come as a surprise to those who envision a collection of technologies automatically switching off lights in unused rooms, or turning on air-conditioning as another room fills with people, that none of these capabilities alone make a building smart" (Herrenkohl, 2017). Another fundamental, worth mentioning aspect of these definitions is related to the mutual agreement about the importance of remote monitoring, meaning that buildings would be able to operate smartly even without human control: the integrated work of physical devices (sensors) with digital ones (usually a building management platform) enable data collection, analytics and processing functionalities (Kejriwal and Mahajan, 2016; Wellener *et al.*, 2018). With IoT and the 4th Industrial Revolution gradually beginning to produce worthy and profound results, buildings are rapidly transforming into sensor-rich environments as companies keep investing more and more into data-collection and data-analytics projects (Kejriwal and Mahajan, 2016; Brick and Memoori, 2019). Indeed, as also suggested by Shivakumar, "the main difference between traditional and smart technology is that smart technology is predicated on the creation, collection, transmission, use, and analysis of data, driven by physical devices" (Shivakumar, 2019).

2.1.2.3 Goal-oriented smart building definitions

This subsection provides an overview of the branch of literature that defines smart buildings according to the set of advantages and benefits achievable, rather than depicting their overall technological infrastructure and properties. As affirmed by Herrenkohl, “technology is changing more rapidly these days than ever, and what might be cutting-edge tomorrow is likely to be obsolete next year. One way to view a truly smart building is as a reflection not solely of a particular piece of technology but also on the goals that stakeholders need to achieve” (Herrenkohl, 2017). Therefore, the common belief of this branch of the literature is that – despite the fundamental role technology has in delineating a building properties and ‘capabilities – it is not sufficient to build a definition by leveraging only on technological features, as it would easily be subject to future reinterpretations in line with the newest developments and advancements. Instead, a building smartness may be founded on the level of performance it provides to its stakeholders, in different circumstances and according to the diverse needs of people (Tomlinson, 2019).

Several interpretations have delineated by analyzing research and reporting research initiatives. According to King, “smart buildings are those in which different technology systems work together to reduce the costs of operations and enhance the experience of occupants. Smart buildings are more efficient, flexible and adaptive, making them more attractive and desirable places to work. In contrast to earlier notions of the ‘intelligent building’ that arose in the 1980s and focused on narrow concepts of operations, today’s smart buildings deliver far greater benefits and a complete concept of operations for developers, landlords and occupiers of commercial real estate” (King, 2016). This definition particularly focuses on two major sources of advantage enabled by smart building technology: the reduction of operational cost and the enhancement of users and occupants experience. While the first sought benefit has long determined the nature of several facility investments, the latter has gained more consensus only in recent years, as a step change has been made towards “user-centric features that evolve the ways in which occupants benefit from their surroundings” (Fletcher, Santhanam and Varanasi, 2018). Such step forward constitutes a cardinal element of analysis for Tomlinson, who states that “while smart buildings have been traditionally associated with technology such as building automation or IoT, the focus is now shifting from technology to user experience.

Putting the user experience at the center of the design process and using technology as a "means to an end, not the end itself" will enable the industry to deliver buildings that are fit for purpose" (Tomlinson, 2019). Moreover, smart building platform provider Locatee and research and advisory firm Memoori affirm that "the fresh focus on user-centric buildings has meant we are reaching a tipping point in the evolution of the workplace. Building owners and operators are becoming far more interested in increasing occupant well-being and productivity, whereas, a short while ago, the main focus of technology in buildings was to optimize energy use" (Locatee and Memoori, 2019). Although it is well-acknowledged how managers' focus is rapidly moving towards the idea of a building capable to provide user-tailored services in order to raise the overall level of experience, a roadmap of smart building benefits should take into account the whole range of disclosed opportunities rather than only focusing on a specific application. In this perspective, Wellener *et al.* give a well-rounded and more comprehensive definition of smart building: "Smart buildings are digitally connected structures that combine optimized building and operational automation with intelligent space management to enhance the user experience, increase productivity, reduce costs, and mitigate physical and cybersecurity risks" (Wellener *et al.*, 2018).

Differently to the definitions previously exposed, other characterizations of the concept of smart building may provide a diverse structure, aiming at schematically listing its main features rather than trying to depict a comprehensive overview. The rationale behind such approach is related to the firm conviction that a unique definition cannot be established, as it will vary across building types and vertical markets. As explained by Herrenkohl, "if a smart building can be defined by the logic of the ecosystem and the strategy of the stakeholders' goals, it can also be seen as a highly tailored initiative. Cooling and lighting might be the priority for a portfolio of manufacturing facilities, whereas reducing overnight operational costs might be the priority in an office park" (Herrenkohl, 2017). As more and more cases are emerging, the result is an increasingly variegated landscape of smart solutions, creating a perception of complexity, unjustified considering the simplicity of the tasks technology is performing, but effectively real if considering the plateau of choices to be taken in order to create the 'ideal' building for each individual necessity (Locatee and Memoori, 2019). An example of such interpretation is provided by Tomlinson: "there are seven fundamental attributes or capabilities enabled by digitization, which can define a Smart Building". These attributes are: control, secure, optimize, conserve, find, communicate and personalize (Tomlinson, 2019). Each of the attributes would provide the foundation for a set of use cases, while also representing an initial framework upon which a smart building strategy may be created, aligned to the overall objectives of owners, tenants and operators. *Figure 19* shows a roadmap – from a use case perspective – for each possible declination of the seven attributes/capabilities, in order to provide a whole picture of the complex smart building landscape that facilitates investment assessment by companies.

Figure 19. The smart building use case picture for office buildings (Locatee and Memoori, 2019)

Another example of use case oriented framework aimed at making real estate companies and tenants aware of the benefits of smart buildings is the Activ8 model proposed by King, which details eight outcomes to assess a building's smartness (King, 2016):

- *Insightful*: smart buildings provide sensible information on how the building operates, by means of real-time monitoring and processing capabilities. The insights generated by smart buildings provide support to managers in decision making processes;

- *Sustainable*: smart buildings allow users to drive optimal levels of resource efficiency, therefore heavily enhancing sustainable practices if combined with green applications such as renewable energy production, space optimization and waste management initiatives;

- *Flexible*: thanks to monitoring and analytics capabilities, smart buildings enable the creation of highly flexible environments and re-configurable spaces, supporting emerging trends such as smart working and agile organizations;

- *Experiential*: users may particularly benefit from smart buildings' capability to provide higher customizable spaces, tailored to fit the most optimal comfort levels according to each person's preferences;

- *Healthy*: smart buildings enable the measurement and data collection of wellbeing parameters, helping in designing the most suitable environment to reduce the costs of sickness and absenteeism;

- *Productive*: a more efficient use of space and generally better working conditions enabled by smart buildings enable to pursue higher levels of occupants' productivity;

- *Collaborative*: smart buildings utilize advanced data measurements and analytics to foster interactions and knowledge sharing among occupants, according to precise algorithm that increase the chances of potential encounters of specific people;

- *Effective*: "smart buildings meet the needs of their stakeholders and transform a company's real estate into an enabler of business growth".

2.1.3 Definition of Smart Building

In light of the revision of literature contributions, which has been carried on in the previous section, this part aims at drafting a suitable definition of smart building, which shall be exhaustive and comprehensive of all its important characteristics and features. The selected definition addresses the main elements of a smart building, by adopting both a technology-oriented perspective and a goal-oriented one. By basing on such premises, the following definition of smart building has been adopted in the context of this research work (Energy&Strategy, 2020):

"The term Smart Building refers to an environment in which existing ***building devices and solutions*** *are managed intelligently and* ***automatically****, by means of the adoption of a* ***connected management & control platform****, with the aim of* ***optimizing resource use and consumption, occupant experience, wellness and security****, while also enabling the* ***integration with the electricity system*** *the building belongs to"*

This definition properly encompasses all of the main information that delineates the concept of smart building, by equally depicting aspects of both technology and benefits sought. Similarly to that proposed by Wellener *et al.*, this one provides a picture of the state of art of a smart building, in which the marriage between technology and objectives is strengthening in favor of a more human-centric vision of infrastructure. However, while the first seems to mainly focus on a precise category of building (i.e. office buildings and, more in general, working facilities), the latter may result more flexible and therefore applicable to a wider number of cases (Wellener *et al.*, 2018; Energy&Strategy, 2020). It is worth mentioning how the benefits reported in the definition are mostly ascribable to building owners (being either private investors, real estate companies or big companies) and users (owners or tenants). However, other parties may directly benefit from the shift towards smart technologies, such as O&M companies, who can take advantage of the set of data related to building state, therefore taking either predictive maintenance actions and granting higher interoperability between different systems (Energy&Strategy, 2020).

From the definition of smart building, four 'key' elements emerge, resulting in a schematic representation of the foundation infrastructure upon which the whole technology is structured (Energy&Strategy, 2020): *building devices and solutions*; *automation technologies*; *management and control platform*; *connectivity*. The following subsections deepen into each of these four elements, in order to further elaborate the technological structure of the building.

2.1.3.1 Building devices and solutions

The term 'building devices and solutions' refers to all the end elements of a building, constituting its functional capabilities that enable operations within the built environment. Such element comprehends several and diverse applications, for which three main categories may be identified (Energy&Strategy, 2020):

- *Energy*: it refers to all the applications related to energy generation, energy management and energy efficiency. It is can be as well distinguished between:
    - *Energy generation solutions*: it comprehends renewable energy production, cogeneration technology as well as energy storage systems;
    - *Energy efficiency solutions*: it comprehends heat pumps, condensing boilers, smart windows, etc.

- *Safety & Security*: it refers to all the plants needed in order to prevent and manage risks hindering occupants' safety and security. It distinguishes among:
    - *Safety systems*: it comprehends emergency lighting and fire alarm systems;
    - *Security systems*: it may as well be divided between *physical security systems* (video-surveillance, access control, alarm systems) and *cybersecurity systems*.

- *Wellness*: it refers to the plants and systems that improve the overall conditions within a built environment. The most relevant are HVAC, lighting, charging stations and internal mobility (elevator).

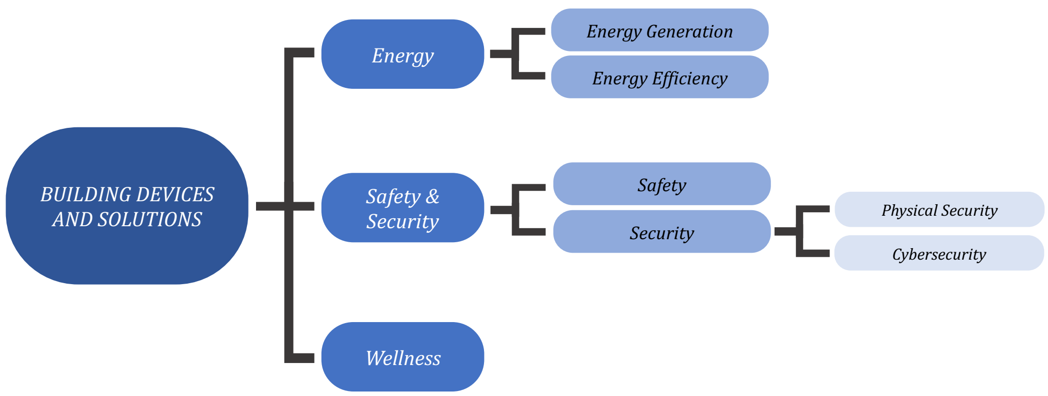


Figure 20. Building devices and solutions classification

2.1.3.2 Automation technologies

Automation technologies constitute the hardware component of the management & control infrastructure, enabling the mechanical functioning of building operating systems. Automation technologies can be divided into three typologies (Energy&Strategy, 2020):

- *Sensors*: devices that react to an external impulse, converting it into an input information to be delivered at the higher levels of the infrastructure. Some examples of commonly used sensors are: temperature, humidity, lighting, air quality, occupancy detection, proximity, smoking and smart meter;

- *Controllers*: devices that receive input data generated by sensors, elaborating and successively translating it into output messages to be delivered to actuators;

- *Actuators*: devices that receive output messages generated by controllers, then execute a specific command according to the content of the message, which is to either activate or disactivate specific building tools and components.

2.1.3.3 Management and control platforms (BMS)

A building management and control platform (also defined as Building Management System, BMS) constitutes the software component of the whole infrastructure, allowing to manage and supervise building systems, either in an integrated or individual way, on the basis of diverse communication procedures. Thanks to IoT and cloud-based services, BMS have rapidly transformed into data-rich smart environments that enable advanced communication and integration both intra-building and inter-building, allowing for unprecedented optimization and scalability (Kejriwal and Mahajan, 2016; Energy&Strategy, 2020). As IoT allows for higher peaks of excellence, three levels of BMS may be identified, as shown in *Figure 21*: individual BMS, partially integrated BMS and fully integrated IoT BMS.

Figure 21. Evolution of BMS as IoT enters the market
(Kejriwal and Mahajan, 2016)

2.1.3.4 Connectivity

Connectivity represents the essential element that enables communication between sensors, controllers, actuators and BMS. It comprehends the communication protocols, through which building systems and/or single devices interconnect to each other (Energy&Strategy, 2020). Two main categories of communication protocols are used in buildings (not considering hybrid applications):

- *Wired*: type of connection that uses a cabling system in order to allow for communication between devices;
- *Wireless*: type of connection that does not rely on the installation of a cabling system to enable communication between devices.

As to any pair of opposing solutions, a trade-off exists for the installation of either wired or wireless communication systems, as reported in *Figure 22*. Nevertheless, the adoption of one solution over the other depends on the necessity of each use case stakeholders.

Wired Connection

+ *Security*, difficult to be attacked or disturbed
+ *Distance*, communication between distant devices is easier
+ *Simplicity*, immediate connection to the network
+ *Reliability*, constant and solid connection
+ *Velocity*, velocity reaches up to 100 Gbps

- *Mobility*, difficult to modify system layout
- *Expansion*, difficult to expand network coverage
- *Cost*, more expensive than wireless systems
- *Complexity*, requires specialist intervention
- *Power*, requires to be connected to an energy source to operate, problems in case of low voltage

Wireless Connection

+ *Mobility*, easy to modify system layout
+ *Flexibility*, ideal solution for retrofitting interventions as it is easy to install and not invasive
+ *Scalability*, easy and inexpensive expansion
+ *Cost*, does not require specialist intervention

- *Security*, subject to signal interceptions
- *Disturbances*, hinder communication quality
- *Coverage*, unreliable as obstacles may reduce it
- *Velocity*, significantly lower compared to wired
- *Autonomy*, battery duration limits autonomy of wireless communication compared to wired

Figure 22. Wired and Wireless connection: advantages and disadvantages (adapted from (Energy&Strategy, 2020)*)*

2.2 *Smart Building: Scope of Analysis*

After having provided a suitable definition of smart building as well as a fragmentation into its most essential elements, this section aims at deepening into the understanding of smart building environments. As there are multiple ways of viewing a smart building – in line with the different interests of involved stakeholders as well as literature research bodies – there is not a commonly acknowledged set of principles which support a comprehensive analysis of its application scope (Herrenkohl, 2017; Brick and Memoori, 2019; Tomlinson, 2019). Some research papers and reports may nevertheless suggest a possible interpretation of the framework. As reported by Deloitte in a dedicated report, "Deloitte's smart building framework consists of the physical assets within the building, the digital assets that create a fabric throughout the connected space, and finally the use cases that are enabled by the marriage of physical and digital assets" (Wellener *et al.*, 2018). According to DTM, which provides a more 'case-specific' interpretation, the scope of a smart building is articulated into the following categories: energy, lighting, fire, monitoring, vehicle charging, water, HVAC, elevators, access and security (Digital Transformation Monitor, 2017)

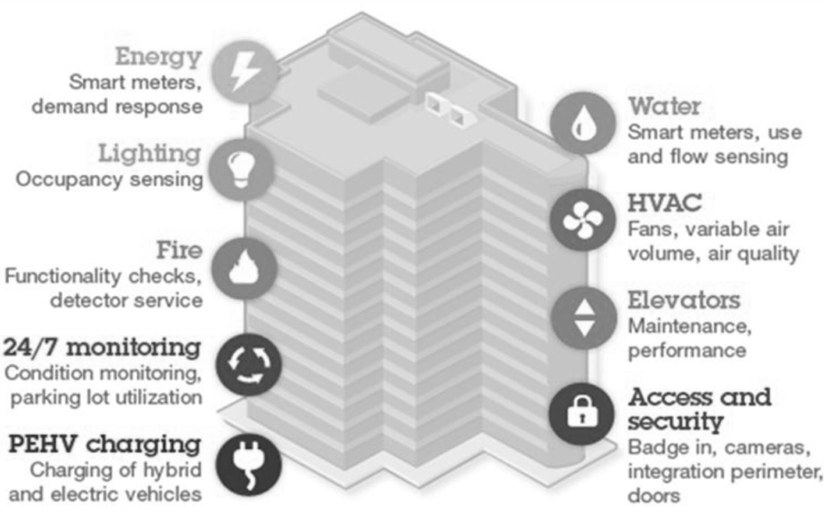


Figure 23. Scope of a smart building (Digital Transformation Monitor, 2017)

While each of the elements included in the framework is worth reporting as an important sphere enhanced by smart technology, the picture provided by DTM may not address all of the issues that are effectively targeted by a smart building, especially by looking at the most recent developments. As the main trend currently reshaping the way buildings are conceived and intended is related to the shift towards user centric design and management, this section aims at classifying buildings solutions by means of the benefits brought to users and, more in general, stakeholders (Herrenkohl, 2017; Brick and Memoori, 2019; Tomlinson, 2019). While not all the improvements achieved by adopting smart building technologies can be translated into economic results, there is evidence of their positive impact for companies, nonetheless. However, it is not immediate to assume a unique position in order to determine all of the main advantages enabled by investing into smart building technologies. Indeed, while owners and real estate companies may benefit from increased property value, higher rental fees, lower costs as well as enhanced scalability, tenants mainly benefit from optimized processes and operations, increased occupants' wellness, satisfaction and productivity, as well as decreased risks (King, 2016; Singh, 2018; Tomlinson, 2019). Moreover, as tenants usually ask for high independency in the designing of internal spaces, real estate firms initially create the infrastructure that would enable flexibility for successive customizations, which are made on the basis of future occupants' needs and interests. Hence, it is generally difficult to evaluate each party's investment contribution in the installation of smart systems within the building, and consequently revenues partition may result complicated. An example is related to the installation of a smartphone application for both occupants and managers, which would provide higher levels of interactions between humans and buildings, boosting productivity, integration and control while also reducing operating costs. While usually the app is installed by the tenant company, the surrounding infrastructure of sensors and systems is provided by the real estate company during the preliminary installations, therefore generating difficulties in determining each party's impact on performances (King, 2016). Nonetheless, by assuming the case of a simplified unique investment, in which owner and tenant roles coincide, a general structure may be delineated. Each of the following sections collects of all the solutions that address similar 'issues', in order to schematically represent the whole picture. To include the highest number of applications within the scope of smart buildings, the building typology selected for the analysis is that of *office buildings*, as they cover for most of the features that smart buildings help to enhance, while also being subject to keen economic evaluations.

2.2.1 Resource Efficiency and Optimization

Under this category lie all the interventions done with the purpose of addressing excessive resource consumption and usage, establishing it around optimal levels of efficiency. Several elements fall under the concept of *resource*, and several are the solutions and applications designed in order to enhance their efficiency. The following paragraphs aim at providing a broad overview of each subcategory, by distinguishing solutions according to the nature of the 'resource' considered.

2.2.1.1 Energy consumption

The reduction of energy consumption and use (and therefore its overall cost as well) has always been one of the driving objectives that pushed companies toward the adoption of smart building technology (Digital Transformation Monitor, 2017). The European Union, who seek to achieve economic as well as environmentally sustainable performances, has targeted buildings as one of the main contributors to energy consumption, being they responsible for around 40% of global usage as well as 36% of greenhouse gas emissions (Ramboll, 2019). Solutions used to monitor, manage, control and report on building energy performance in CRE (particularly true in the case of office buildings) range from building management systems, energy management software and services to IoT-driven platforms to monitor energy and operational efficiencies (Locatee and Memoori, 2019). As reported from Deloitte, those who invested into IoT-enabled sensors and smart devices have seen energy savings of up to 70% in three years, demonstrating the goodness behind the adoption of said technology (Wellener *et al.*, 2018). Indeed, on a general basis, "connected building technologies enable better coordination of energy audits, allowing providers to perform usage assessments that empower better energy procurement contracts, identify opportunities for reducing consumption, and suggest alternate energy sources, including renewables and micro-grids" (Wellener *et al.*, 2018). Two areas of intervention are particularly relevant while evaluating the impact of smart building solutions in the reduction of the overall energy consumption, although different is the perspective from which they address the same problem: energy efficiency and energy generation.

- *Energy efficiency*: in recent years, energy efficiency has become a sensible topic to for national and international policy discussions, as also suggested by its inclusion in the 20/20/20 package defined by the European Union as one of the set targets to be achieved, although not compulsorily in this specific case (Peña and Rodríguez, 2019). According to Alexandri *et al.*, “successive studies have shown that energy efficiency offers many of the most cost-effective options for meeting global emission targets. In many cases, energy efficiency measures have been shown to be ‘negative cost’, meaning that it would be economically advantageous to implement them” (Alexandri *et al.*, 2016). Smart buildings are highly energy efficient, and the adoption of IoT integrated with machine learning capabilities to intelligently manage energy consumption and use has brought companies to unexplored levels of resource optimization. Although the scope of energy efficiency applications which may benefit from the adoption of smart building technologies is sufficiently wide, two main categories are mostly responsible for the majority of in-building energy expenses (Digital Transformation Monitor, 2017):

    - “*Smart lighting* that adjusts the light levels according to times but also according to other smart elements like windows and HVAC system. Occupancy sensors also influence the required lighting when combined with space management”;
    - “*Smart HVAC systems* that are linked with different types of sensors and that have the ability to adjust quickly and automatically according to weather forecasts, occupancy, ineffective systems, etc.”.

  A research conducted by the American Council for an Energy Efficient Economy finds a cost saving of 24-32% when implementing smart HVAC and smart lighting solutions (Digital Transformation Monitor, 2017). It is relevant to denote how energy consumption reduction is heavily dependent on the knowledge about *space utilization* within a facility, as smart buildings may effectively reduce energy levels by implementing intelligent space management capabilities. By being able to collect and analyze data about daily room occupancy rates, information is provided to managers that would in turn adapt spaces on the basis of real necessities, therefore optimizing energy consumed (King, 2016; Digital Transformation Monitor, 2017; Locatee and Memoori, 2019).

- *Energy generation*: on-site energy production from renewable sources has been addressed at European level as one of the main responses to the raising issue of environmental sustainability, with the achieved result of an average 20% share of RES in the overall energy mix (King, 2016; European Commission, 2020a). Buildings have heavily contributed to the raise of renewables, also pushed by the favorable incentive schemes that some countries decided to adopt in order to reach the requested levels, as in the case of Italy. With the advent of smart building technology, production levels are collected and integrated to calculate the optimal amount of energy to be used to power building devices, the amount that should be stored into batteries, and the remaining amount to be injected into the smart grid, at a predetermined moment and considering trend analysis of past performances and data about future energy fluctuations. According to Navigant Research, "integrated renewables can help building owners and corporate leaseholders recognize new revenue streams and minimize uncertainty around energy costs and power reliability" (Talon and Strother, 2017b; Navigant Research, 2019). Locatee and Memoori state that "on-site energy generation and distributed energy storage to power Smart Buildings enables more reliable, economic and efficient use of both central and distributed energy resources" (Locatee and Memoori, 2019). Another current research topic that will have a relevant influence to decentralized energy production is related to 'energy harvesting', which is "the process in which a small amount of energy, that would otherwise be lost such as heat, light, sound, vibration, wind magnetic force or movement, is transformed into an electric current and stored for later usage" (European Commission, 2017).

2.2.1.2 Space utilization

Space utilization represents one of the most inefficient resources in most business landscapes, despite the considerable reduction of the average square footage per employee in the last decade (Wellener *et al.*, 2018). According to Deloitte, "industry reports have indicated that on average only 56 percent of work seats are utilized, while the remaining 44 percent remain vacant. Even at peak seasons and times, upward of 30 percent of seats remain empty the majority of the time" (Wellener *et al.*, 2018). Smart buildings facilitate better, more efficient use of space and environments that enable companies to reduce occupancy costs and plan future investments on the basis of effective space needs (King, 2016). Data captured by a range of smart IoT sensors can report the occupancy of workplaces in real time, measure how effectively the space is being used and enable better decision-making by heads of real estate and facilities managers: using analytics to identify office space usage and reducing office footprints to reflect actual occupancy can save considerable costs related to overhead, operations, and resource consumption (King, 2016; Wellener *et al.*, 2018). Moreover, the adoption of occupancy sensors allows for complete flexibility about the configuration of workplace organization. This translates in the adoption of emerging working models, such as 'smart working', 'Activity-Based Working' (ABW) and 'agile organization'. According to King, "models of workplace design based on non-assigned seating, such as ABW, allow companies to unlock significant space savings by freeing up under-occupied space while also providing office users a choice of settings from which to work. By overturning the idea that every employee 'owns' a desk, even when they are not in the office, firms are able to create highly efficient offices and better manage the costs of locating closer to the center of cities" (King, 2016). Such novel interpretation of the concept of workplace and office desk is particularly suitable for companies that have their employees often be outside of their buildings, such as consultancy firms. The same model is usually also extended to parking management, by using smart occupancy sensors to visualize which parking slots are empty in real-time, in order to minimize the space needed.

2.2.1.3 Human resource management

This branch examines the effects of smart technology to a building workers' productivity, either being a firms' employees or external service companies' ones. *Employee productivity* has long been addressed as one of the most innovative research topics when referring to smart buildings, despite the current difficulty of translating positive efficiency trends into effective economic results. However, new analytics techniques are being pioneered that can correlate data collected in working spaces with firms' business performance. The effectiveness of workplace design on individual performance, speed to market and sales growth has been demonstrated through the use of 'Social physics', the practice of using vast datasets from smartphones, wearables and workplace sensors to gauge how people interact and share ideas (King, 2016). As the costs of talent increase, it is even more important that firms create environments that maximize the output of their staff. One example of employee performance boost is the reduction in the number of ‘illness days’, by leveraging on better workplace parameters such as indoor air quality and lighting, as it will be further explained in its own dedicated section (King, 2016; Wellener *et al.*, 2018; Locatee and Memoori, 2019). Other similar applications relate to the reduction of waiting time of employees during work, as in the case of cafeteria and bathroom queues. Another example is related to enhanced solutions for real-time finding of available meeting rooms, workplaces, equipment and parking spaces, which would lower frustration and increase employee productivity by reducing the time spent trying to locate free spaces, tailored in dimension and number of seats (in case of meeting rooms) on the basis of each worker’s needs (Locatee and Memoori, 2019). As a side note, employee productivity may also be raised by having the possibility of recruiting a wider number of talents, and firms are growingly aware of the role their workplaces play in attracting and retaining the best talents. Therefore, the importance of smart workplaces is raising as the interest of occupants is moving towards higher interconnections (with people and spaces), better working conditions (customizable workspaces) and an overall enhanced level of experience (King, 2016). While uncertainty about numerical outputs of increased employee productivity is still an issue, it remains easier to convert enhanced performances of service companies (such as catering and cleaning) into clear economic results. The case of cleaning companies shows evidence of the tangible benefits brought by intelligently elaborate data and insights provided by smart buildings. Information of real-time utilization of spaces as well as the aggregated utilization time can be integrated into the IoT platform and translated into a list of work areas to be prioritized when planning cleaning activities. Such output may completely reshape the way contracts with cleaning companies are defined: instead of arranging payment on the basis of the time spent working, service companies are paid according to the space covered for cleaning. Moreover, work disturbance is mitigated, and time losses are reduced (Locatee and Memoori, 2019). The outcome of such process is a clear reduction of cleaning costs, and an overall better experience level for occupants inside the building. The case of cafeteria service is generally similar, with menu planning processes and personnel number based on daily building occupancy levels, smartphone apps that provide information on queue level and smart waste collection.

2.2.1.4 *Operations and Maintenance*

Another field of inefficiency within facilities is related to O&M activities: as maintenance involves up to 30% of a building total cost during operation, the interest towards intelligent and efficient maintenance has been one of the most important reasons that drove companies to invest into smart building. Indeed, according to Navigant Research, 19% of customers think that 'improvements in Operations and Maintenance' represent an important driver for investing into smart building technologies (Digital Transformation Monitor, 2017; Talon and Strother, 2017b). Smart buildings enable performances of each physical building device to be carefully monitored and controlled through an IoT-enabled BMS, which is able to draft prospective trends which in turn translate into insights on the optimal time when to schedule maintenance interventions. The benefits ascribable to intelligent performance monitoring are increasing business continuity and maximized asset value generation (King, 2016; Locatee and Memoori, 2019),

2.2.1.5 *Waste and water management*

This branch examined the impact of smart building technology to how waste and water management issues are addressed. Smart Building solutions for managing and disposal of waste leverage on the implementation of IoT sensors to collect data about the usage of objects such as garbage bins and paper towel dispensers: by basing on predictive data trend and analytics, smart buildings are able to alert facility management staff more efficiently, reacting to signals of fill sensors in order to schedule more efficient and reactive O&M activities, rather than relying on pre-determined routine operations (Wellener *et al.*, 2018; Locatee and Memoori, 2019). Robotic sorting may facilitate the identification of re-usable and re-cyclable materials. Such solution may help reducing both the time and energy required for waste management as well as the amount of waste created (Wellener *et al.*, 2018). Smart water management solutions can locate the sources of water wastage, detect leaks and notify staff accordingly, bringing to a substantial reduction of operational costs, especially in the case of CRE such as hotels, hospitals and stadiums (Locatee and Memoori, 2019).

2.2.2 Occupant Experience

Under this category lie all the interventions and solutions aimed at providing the ideal living conditions within a building, tailored on occupants' needs and preferences and boost the overall experience level. The benefits obtainable by such interventions are related to the level of occupants' satisfaction, which in turn may reflect on their productivity. Smart building solutions focused on enabling a personalized workplace experience which can be beneficial for all occupants (Locatee and Memoori, 2019). There is a wide range of solutions that focus on the enhancement of occupant's experience within buildings, for which two main branches are identified.

2.2.2.1 Occupant health and wellbeing

Physical as well as mental health and wellbeing have been given increased recognition by governments and companies, as the result of a number of trends that started creating awareness among business operators. As most of a person's activities are done within the working environment, its living conditions should be adequate to the parameters defined by each person. The introduction of IoT and cloud computing within buildings has provided managers with actionable insights about occupants' preferences and habitudes. Workplace sensors in a smart building measure companies' organizational health, while also giving office users greater control over their working environment. Data on indoor air quality, light and noise levels and levels of physical activity can all be assessed by smart building sensors (Deloitte Centre for health solutions, 2017; Locatee and Memoori, 2019). Moreover, "solutions for promoting the health and wellness of occupants in office buildings can involve ergonomic comfort, biophilic design, green walls and access to natural light" (Locatee and Memoori, 2019). The increased focus on employee wellbeing has led to the development of a WELL Building Standard, a certification that rates buildings on seven different criteria related to health and wellbeing, including indoor air quality, access to natural light and how much a building's design encourages physical activity (Deloitte Centre for health solutions, 2017; International WELL Building Institute, 2018). As wellness becomes more important to companies and institutions, WELL and similar other standards are likely to be incorporated into tenants' and occupiers' selection criteria for new sites.

2.2.2.2 Occupant interactions and collaborations

The increase in the level of interaction of building occupants with their surroundings, being them either people or devices, has been an emerging research topic to be addressed by managers. Connected digital workplaces enable companies to provide a unique and differentiated position, granting exceptional levels of employee experience and comforts, helping employers to attract and retain talents. Workplace apps become the key interface between users and smart buildings in which they work, allowing them to access a wide range of services. “Indoor wayfinding, digital signage, smart kiosks, wireless charging, and even concierge services can all be enabled through a connected workplace and set an employer apart” (King, 2016; Wellener *et al.*, 2018). As part of the whole concept of experience, also collaborations have been deeply analyzed by management teams: according to Deloitte, “ongoing research on workspaces has reported data that suggests creating ‘collisions’ – chance encounters and unplanned interactions among coworkers – improves performance”. Generally, the level of employee engagement increases when the workplace enforces interaction and communication. Applications such as video conferencing and virtual meeting walls can bring physically remote coworkers into an environment that can support more creative interactions. And, the ability of a connected workplace to sense and respond to the coworkers that are present is a peculiar feature of smart buildings (Wellener *et al.*, 2018). Layering in tools such as virtual digital assistants and wireless content sharing makes collaboration effortless. Activity Based Working, as a solution disclosed through smart building technology, allows for workers not to be tied to a desk, but make a transition between a number of different settings for work, on the basis of the tasks they are performing (King, 2016). As employees are not tied to any particular space in an ABW environment, there are more opportunities for occupants to interact and – possibly – generate profitable encounters. Occupant engagement solutions constitute an important element in motivating and retaining staff and attracting new talent (Locatee and Memoori, 2019). However, In order for user-oriented services to be effective, real-time location represents a key prerogative: data about occupant position and movements has to be constantly monitored and collected in order to tailor services on the basis of individual habits and preferences, raising concern about the way data on individual’s movements will be stored and used. Thus, ethical strategies and data access authorization protocols must also be adopted to avoid misuse of data and loss of user confidence or trust (HID Global and Meemoori Research AB, 2017).

2.2.3 Risk Mitigation

Under this category lie all the interventions aimed at reducing risks and enhancing security within a building. Difficulties arise in determining exact calculations of investment return from safety&security projects, as the benefits lie in the reduced number of threats, which in turn brings to reduced losses. Among the several applications referring to the concept of risk reduction, two main branches are distinguished.

2.2.3.1 Safety

Safety solutions include:

- *Access control and visitor management*: comprehend measures aimed at limiting access to buildings or a specific area for employees and/or guest occupants. It can reduce real and perceived threats as well as ensure business continuity, therefore raising employees' confidence of being secure within the facility (Locatee and Memoori, 2019);
- *Threat detection*: although they provide an effective safety measure, access control systems may still be vulnerable to threats coming from intruders or inanimate objects. Smart building systems, working alongside security personnel, may help to identify many different types of threats and raising an alarm (Locatee and Memoori, 2019).

2.2.3.2 Security

Security solutions include:

- *Physical security*: the concept of physical security embeds an array of solutions, aimed at specifically address both occupants and assets security against physical threats such a theft or fire. In this perspective, smart occupancy sensors enforce security within the building, by locating people/assets in real-time (Locatee and Memoori, 2019);

- *Cybersecurity*: cybersecurity emerges as an impellent necessity for companies aiming at implementing innovative smart building solutions, and more generally to all those companies embracing digitalization as a holistic approach to be pursuit when defining corporate, business and operational strategy. Indeed, as the process of data collection and analysis through IoT technology becomes fundamental for the achievement of optimal operational efficiency, increasing vulnerability raises as well, leaving room for potential cyberattacks. Therefore, while evaluating the benefits brought by shifting towards cybersecurity practices (it is a process, not a product), also negative effects of smart building technology adoption should be accounted (Boyes, 2013; Locatee and Memoori, 2019). Indeed, there are several risks an organization should address when dealing with potential cyberattacks in case poor cybersecurity practices have been implemented into smart buildings. As buildings become more and more connected in all their elements, cyber-criminals may have easy access to sensible areas of a facility by 'disturbing' the operations of some in-building devices. As an example provided by Barth "malicious actors could potentially take advantage, launching attacks that could, for instance, sabotage HVAC devices to overheat data centers or compromise physical access control systems in order to gain unauthorized entry to sensitive locations" (Barth, 2019; IoT Security Foundation, 2019).

2.3 A Case of European Excellence: 'The Edge'

Considered by many as the top reference for smart and sustainable buildings in the world, The Edge is a 40,000m² office building in the Zuidas business district in Amsterdam, headquarter of professional service and consultancy firm Deloitte, its main occupant. The project has been developed as an answer to Deloitte's objectives, two of which were clearly determined (Preziosa, 2019):

I. Unite all of its employees under a unique working environment, characterized by a strong identity and entirely representing the company's principles and values;
II. Show the commitment of the company in the transition towards the digital era, by creating one of the smartest and most sustainable buildings ever built.

With the world's highest BRE (Building Research Establishment) score awarded to an office building (98.3%) and a BREEAM certification of 'outstanding', it integrates several smart technologies to create adaptable and intelligent workspaces. The building is a prominent example of how the pursuit of a vibrant and collaborative working environment can be successfully combined with the achievement of the highest levels of sustainability (BREEAM, 2016). This section aims at illustrating the main technical characteristics of The Edge, while also reporting the main benefits and results achieved after its implementation.

2.3.1 Technological Features

There are over 28,000 sensors and actuators at The Edge, measuring everything from the occupancy of workstations to the cleanliness of bathrooms, providing a vast amount of data from which Deloitte is able to obtain sensible information on the way the building is run and how employees interact with it, ensuring operational savings and predictive planning. Super-efficient LoE (Light over Ethernet) LED panels built by Philips, for instance, are powered using Ethernet cables and packed with sensors that measure motion, light, temperature, humidity, and air quality. This provides an unprecedented level of control, as changes to the system can be implemented quickly and easily without opening suspended ceilings. SmartStruxure, an iBMS (intelligent Building Management System) built by Schneider Electric, analyses the data produced by the building's sensors, actuators and valves to optimize the operation of the building (King, 2016; Digital Transformation Monitor, 2017). The building's entire south facade is fitted with solar panels, providing the building with more energy than what actually consumed. If considering also the roof, 65.000 square ft of solar panels are located around the building, and remotely on the roofs of buildings of the University of Amsterdam – thereby making use of neighborhood level energy sourcing. To provide perfect monitoring of energy inflows and outflows, more than 180 energy meters have been installed around The Edge, with all the data fed back to the iBMS. A subterranean aquifer dug 130m beneath the building, storing warm water collected in the summer and releasing it when it is needed in the winter. To further enhance the sustainability level of the building, rain water is collected on the roof and used to flush toilets, and irrigate the green terraces in the atrium and other garden areas surrounding the building. (BREEAM, 2016; King, 2016). Every employee is connected to the building via an app installed on their smartphones, tablets and laptops. Using the app, they can: find parking spaces, free desks or other colleagues; report issues to the facilities team, or even navigate within the building; customize temperature and light levels anywhere they choose to work in the building via the mobile app. The app collects information about employees' preferences, memorizing and displaying them on the menu, and raise awareness of their energy use (BREEAM, 2016).

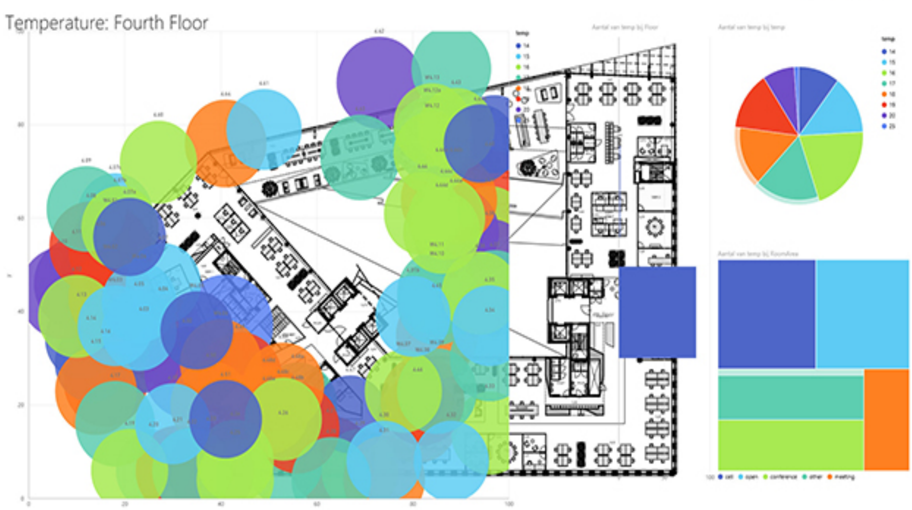


Figure 24. Sensors measuring floor temperature(s) at The Edge
(Preziosa, 2019)

2.3.2 The Edge: Benefits and Achievements

The Edge represents the ideal example of how a smart building should be designed at its best, and the benefits it should provide. Indeed, the potential behind smart buildings is still not fully disclosed, yet the level of excellence achieved in this scenario is evident. Some numbers and information about the advantages brought by smart building technologies installed at The Edge are here briefly proposed. As a first note, it is relevant to mention how the building was initially planned to be 100,000 m^2: by means of space management solutions, the space required was eventually reduced to less than half of the initial space, allowing for significant cost reduction (Digital Transformation Monitor, 2017). Concerning energy efficiency, the Philips LoE LED system was used in all office spaces to *reduce the energy requirement by around 50%* if compared to conventional TL-5 Lighting. The system also enables constant monitoring of daily building use. Data is fed to facility managers via the BMS, providing the following achievements (BREEAM, 2016):

- Anonymous insights on occupant presence in the building. Being heating, cooling, fresh air and lighting fully integrated and controlled per 200 square ft based on occupancy, therefore *ensuring next-to-zero energy use in case of no occupancy*;
- Predictions of occupancy at lunchtime based on real time historical data, traffic and weather information to *avoid food-waste*;
- Cleaning operations are scheduled on the basis of effective room usage, allowing for *significant time and cost reduction, less disturbance and smart contracts*;
- Predictive maintenance on lighting bulbs needing replacement, printers needing paper, and several other preventive measures, enabling to achieve the *highest levels of service continuity*.

As previously mentioned, users can find working spaces, reserve meeting rooms and locate their colleagues using the building's app. Other services, such as ordering food and beverages, checking the availability of car parking spaces, and scheduling classes in the building's gym, could also be available via app, thus improving everyday building life and *occupant's satisfaction*, which in turn brings to expected *raise in productivity* (BREEAM, 2016; King, 2016; Preziosa, 2019). Even security is carefully (and intelligently) managed at The Edge: the building hosts "knee-high robots that come out at night to autonomously patrol the office building. These machines can identify and challenge potential intruders, and are one example of the security benefits that smart buildings can offer to landlords and tenants" (King, 2016). In terms of waste management, the building collects rainwater to reuse in the sanitation system. Moreover, smart bins and robotic sorting, which can significantly increase the operational efficiency of the facility, are involved. Radio-frequency identification (RFID) tracking and fill sensors can detect fill levels and identify the materials that can be recycled and reused. Both the *time and energy required for waste management services*, as well as the *amount of waste created*, would be highly *reduced* (Wellener *et al.*, 2018). These and many other applications have been effectively implemented at The Edge. The building is able to ensure great performance levels, in terms of economic, social and environmental sustainability. In this regard, the following statement from OVG, the real estate company responsible of The Edge development, is reported: "Sustainability is about more than a great sustainability rating. It is also about a building's overall comfort and efficiency for its occupiers, so that they can operate with ease in a productive and healthy environment. Furthermore, an inspirational and healthy environment attracts talent and leads to higher employee satisfaction. An environment such as The Edge leads to lower energy and maintenance costs, reduced sickness leave and higher productivity which ultimately achieves a much better financial performance. Thanks to the BREEAM criteria the use of construction materials and costs per square meter was significantly reduced" (BREEAM, 2016).

Section II: Case Study Analysis

This section aims at illustrating some examples of smart building applications, by evaluating company use cases in the Italian market. After having deployed the purpose of the study as well as the research methodology, each business case is presented, contextualized and analysed. The last part of the section covers a comprehensive discussion of the economics of a smart building.

3 Purpose and Scope of the Study

The global smart building market has been consistently growing in the last years and is expected to grow even further: in the forecast period 2019-2026, the expected global CAGR is of 18.9%, with major peaks in the Asia-Pacific area as the fastest growing market, due to rapid infrastructural advancement and government initiatives in the region's developing countries (Straits Research, 2020). Currently, Europe holds the largest share of the smart building market, followed by North America. The diffusion of smart building solutions in the European area is (at least partially) due to the efforts made by governments in setting clear and mandatory objectives for the reduction of greenhouse gas emissions, with buildings representing one of the most targeted sectors. In 2018, European countries revised the Energy Performance of Buildings Directive (EBPD), which defines measures aimed at accelerating the pace of building renovation towards more energy efficient systems, strengthening energy performances by making them smarter. The mandatory requirement of implementing nZEB buildings (nearly zero energy buildings[5]) starting from 2021 (2019 in case of public buildings) has pushed countries in the direction of a great requalification of the sector, in order to achieve the

[5] A nZEB (nearly zero energy building) is defined as a building with excellent performances, which net energy consumption (very low or nearly inexistent) is mostly covered from on-site renewable energy production. The concept has been introduced in the EBPD of 2010. The main requirements for a building in order to be classified as nZEB vary according to each country's technical specifics (Hermelink *et al.*, 2016; Costanzo *et al.*, 2019).

restricting goals claimed by the European Union (Hermelink *et al.*, 2016; Energy&Strategy, 2020; Straits Research, 2020). Considering the strong step forward into the integration of digitalization within building design and implementation, given the actuality of smart building discussions in the European context, a necessary deepening has to be made about the viability of such solutions in said environment. *This study leverages the analysis of five use cases to have a general understanding* (although limited in its contents) *of the economic feasibility of a smart building investment. It is essential to assume how not all the benefits are quantifiable into clear economic results yet*, limiting the validity of a pure economic evaluation: thus, other criteria should be taken into account in order to depict a clear image of the state of affairs around smart buildings and identify all the reasons driving investors towards their adoption.

3.1 Segmentation by Market: the Italian Scenario

A first important restriction to the scope of research and analysis of smart building case studies is related to the identification of the reference area. For this study, *the Italian territory has been selected*, with several reasons justifying such choice. A first motivation is driven by the economic scenario around the Italian market of smart building, which has registered a significant growth, as confirmed by the amount of national investments assessed around 3.6 bln €, an already significant number (despite the relatively low impact on the overall share of building investments, assessed around 139 bln €) and expected to increase in the following five years (Energy&Strategy, 2020). The increasing interest (in terms of investments) towards smart buildings in Italy may find significant correlation to the raising necessity of reducing in-building energy consumption, one of the main advantages derived from smart solutions installation. According to the PNIEC (Piano Nazionale Integrato Energia e Clima), the building sector in Italy will be responsible for 5.7 out of 9.3 Mtoe of future energy consumption reductions in 2030, divided between residential (3.3 Mtoe) and commercial (2.4 Mtoe) markets (Energy&Strategy, 2020). Therefore, it is clear how smart buildings may represent a suitable solution for enhancing energy efficiency practices and managing energy production from renewables with the best performance levels, increasing the rate of adoption of nZEB buildings.

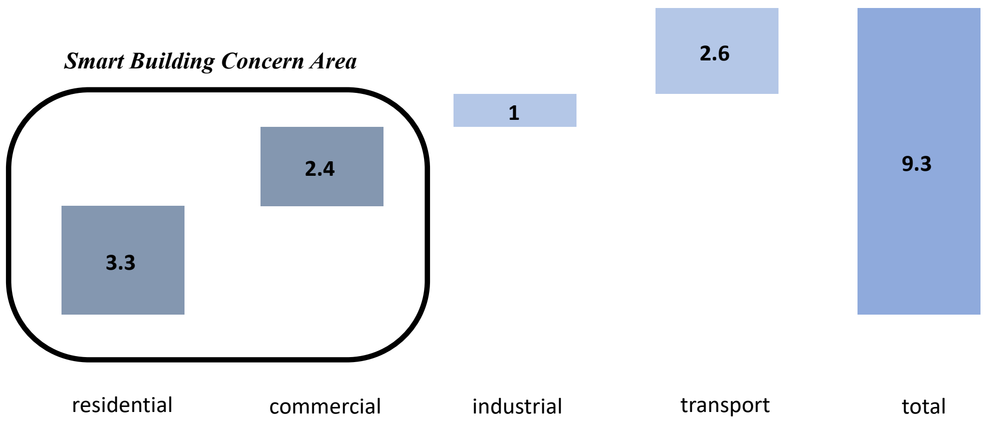


Figure 25. Energy reduction targets partition per sector, with evidence on those influenced by smart building adoption, as established in the PNIEC (Energy&Strategy, 2020)

Another determinant that contributes to generate concern around the Italian scenario for smart buildings is related to the lack of a clear and comprehensive regulatory structure. Despite the increasing interest towards the subject at national level, the market is characterized by great complexity, resulting also in an articulated yet fragmented set of norms, certificates and incentive systems, in which aspects and characteristics of the building are addressed singularly: therefore a holistic regulatory approach to building design, implementation and operation phases is still not present in Italy, giving rise to problematics in the identification of an optimal solution that formally accounts for all the specifics related to a smart building investment (Energy&Strategy, 2020). By contemplating the aforementioned thoughts and reasonings, awareness towards the current Italian situation is raising among regulatory and research bodies, as the advantages behind a smart building investment are becoming clearer to potential stakeholders. However, one of the main problems lies in the lack of an inclusive and definite understanding of the concept of smart building and its reference environment, which seems to reflect on the current fragmentation of the related legislative structure.

4 Research Methodology

The research methodology is articulated into two parts. A first subsection provides the steps adopted in order to search for, identify and target potential cases of smart buildings in Italy, alongside the actors that has contributed for the development and management of the targeted cases. A second subsection provides the procedure for which the structure of the questionnaire to be submitted to the targeted actors has been delineated. The final phase of the research focuses on gathering the information collected during the interviews in a comprehensive and structured way, in order to provide valuable insights for each business case. Five business cases are studied in this research work.

4.1 Categorization of Smart Building Investments

The identification phase of valuable smart building cases in the Italian territory has been carried out by prevalently relying on authors, contacts and web researches. In order to select case studies, the process used comprises keywords searches, screening and categorizations.

The *keywords searching* phase aims at finding potentially constructive cases by associating them to words commonly used in their representation. In regards, this investigation used the following terms: *'Smart Building', 'Intelligent Building', 'Energy Efficient Building', 'Sustainable Building', 'Automated Building', 'Intelligent Building Management', 'Smart Energy', 'Case', 'Example', 'Solution', 'Investment', 'Italy'* and *'Italian Territory'*.

The *screening* phase is structured according to a qualitative analysis that aims at carefully distinguishing proper smart buildings from inexact interpretations. Since a worldwide acknowledged assessment method for defining the level of smartness of a building is still missing, each case has been addressed singularly, on the basis of its unique set of assumptions and considerations, by evaluating whether its main features aligned with the prerequisites that generally constitute and characterize a smart building.

The *categorization* phase aims at collecting similar cases within the same group of analysis, likewise to the logics driving the evaluation process of smart buildings under the same category. The smart building ecosystem is a complex and articulated domain in which several factors and processes have to be included when performing a building investment assessment. Moreover, as several actors are involved in the building design, implementation and management processes, a straightforward cost and benefit analysis may result difficult to be carried out. For this and many other reasons, it is important to differentiate among potentially generic paths to be followed, in order to determine standard approaches when analyzing a business case. In doing so, this study provides a *segmentation by building category*, since cases within a specific class of buildings are commonly characterized by analogous processes, investment typologies and actors involved. In this perspective, *two different building categories are identified*:

- *Residential buildings;*
- *Commercial buildings.*

According to market studies from reporting companies, the commercial sector for smart buildings is projected to have the highest share in terms of investments made. The growth of the sector is mostly related to the need of tailor-made solutions for resource optimization, user-centric experience enhancing and security increase. The residential segment registered the highest CAGR, as the consequence of the growing demand for smart homes with advanced energy and security management solutions incorporated (MarketandMarkets, 2019; Fortune Business Insights, 2020). A segmentation according to building category (also defined as 'application' by some reporting companies) may also have a proper role in sharply remarking the diversity between buildings which apparently fall under the common definition of 'smart building'. In particular, differences emerge in terms of the benefits sought by investors, which vary according to the reference business environment. Once a segmentation by building category has been achieved, a further distinction has to be addressed between *new* or *existing buildings*. There are indeed several differences between the two typologies, particularly in terms of investment specifics, cost, project duration and feasibility. Moreover, the two categories also differ in terms of regulatory framework and incentive schemes, at least if considering the Italian scenario (Energy&Strategy, 2020).

4.2 Structure of the Questionnaire

In order to organize the set of information that has eventually been collected during the interviews, a questionnaire has been prepared and submitted to the targeted companies. The structure of the questionnaire has been organized in order for it to be indistinctively addressable for each building category, therefore covering for commercial as well as residential applications. The questionnaire is articulated into four sections, which are now briefly illustrated (the whole detailed questionnaire is available in the annex 1):

- *Preliminary Information*: this section proposes questions aimed at giving a brief overview of the smart building, by explaining the steps made in order to carry out the project, the actors involved as well as the reasons that drove investors to finance this solution, also specifying whether it is a new or renovated building;

- *Investment Analysis*: this section represents the core and soul of the questionnaire, in which the technical and – more prevalently – economical aspects of the investment are deepened. Six subsections are determined, each of the first five representing a potential revenue stream enabled by the smart building. They are respectively: *energy management* (divided among HVAC, lighting and other processes/applications); *space utilization*; *occupant management*; *security management* (divided between physical security and cybersecurity); *waste and water management*. The general configuration followed by the first five subsections comprehends: the description of the technology utilized for that application (among sensors, actuators as well as smart devices and systems); the overall capex and opex; the benefits expected (enhanced revenues, savings, or other sorts of improvements); the benefits effectively achieved. The distinction between benefits expected and achieved derives as a consequence of the lack of historical data of smart building performances for a sufficiently long time period, nevertheless necessary in order to provide prospective trends. Thus, in order to provide a solid The last subsection is left for other economics associated to the smart building investment which do not clearly refer to any of the previously mentioned subsections: in particular, the followings are to be highlighted: the advantages and disadvantages related to the use of an integrated and centralized building management platform; the benefits achieved by means of predictive maintenance; the efforts (economic and non) made in order to accelerate the transformation process to a smart building, in particular considering the eventual resilience to change of some of the occupants; the financial performance improvements through obtainment of incentive schemes and certificates achievements. Overall, this structure allows to clearly differentiate among use cases, by arranging a method that helps respondents to focus only on the areas covered for each specific building. It also provides a better understanding of the investment categories with the higher associated benefits in relation to the costs sustained. The final output, where possible, would be composed of a both quantitative and qualitative representation of the smart building investment scenario.

- *Company's investments and strategy in the smart building market*: this section verts around the interviewed companies' strategic perspective on the smart building market, by understanding their involvement in terms of projects and initiatives, the main barriers to be addressed in the development, implementation and processing phases of a smart building, and the future trends that could redefine the competitive landscape;

- *Regulations, incentives and certifications*: this section centers around the impact of regulation, incentive schemes and certifications into smart building investments, with a focus on the Italian scenario and the comparison with other countries' regulatory systems in the European market. The aim is to understand how the regulatory framework may change in the next years according to the evolution of the smart building market in Europe, and, more specifically, in Italy.

5 Case Study

This research work proposes five smart building case studies, in which the main characteristics of each project are highlighted and the whole picture of the intervention is provided. In order to analyze each case, both primary and secondary information is used. Primary information includes the following: (BNL, 2019; NOI Südtirol, 2019; Teicos Group, 2019; Carlo Ratti Associati, 2020). While the first concerns data and insights collected from direct sources, such as interview respondents, the second relates to information obtained and collected from indirect sources, such as web articles and reports.

5.1 Condominio Via Verro, Milan

The first case analyzed is that of a residential apartment building in Milan, built in the first half of 1970, with an original energy efficiency class of D[6] (Teicos Group, 2019). The building went through a massive energy retraining process, with the intervention being carried out by Teicos UE S.r.l (a partner of the ‘Sharing Cities’ project) and Future Energy S.r.l (responsible of the plant installation process). Other project partners are: Legambiente, Consorzio Poliedra, Politecnico di Milano and Comune di Milano. The intervention also saw the active participation of the apartment inhabitants, as co-creation ‘partners’ in the choice of the ideal energy efficiency measure to be adopted for the specific case (IlSole24Ore, 2018). The project has been mostly focused on the improvement of the building energy efficiency level, with multiple interventions: external and countertops insulation, a thermostatic valve instalment, LED bulbs lighting and smart windows. To further decrease energy consumption levels, a photovoltaic plant has been installed. Moreover, information about building performances are monitored through a smart energy management system – IoT enabled – that collects data on temperature, air humidity, pressure and lighting (measured every 15 minutes, both internally and externally), determines energy consumption at building and district level, and studies

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[6] EU Directive 92/75/EC first established an energy consumption labelling scheme, assigning to the application an energy efficiency class ranging from A to G (classes A+, A++ and A+++ have been introduced later), with A representing the most energy efficient (European Parliament and The Council Of The European Union, 2017).

possible future city-level interventions, following an energy optimization logic. The system uses a LoRaWan communication protocol to coordinate the interactions between the different smart elements within the building. The investment cost related to energy efficiency and photovoltaic plant has been of 452244 €, with additional 372264 € for building maintenance (which is excluded from smart building-related interventions, therefore not further accounted in the analysis). The intervention displayed some consistent results: the overall energy consumption dropped from 91,5 kWh/m^{2}y to 37 kWh/m^{2}y, with the energy class raising up to B level. The overall yearly savings due to reduction in energy consumption are of 52% (corresponding to total yearly savings of 50450 €), achieved if an optimal building usage is guaranteed by occupants (Teicos Group, 2017). Indeed, in order to achieve the expected performance levels, residents shall accept and embrace a new way of living within the building, adopting new behaving practices. The resilience of occupants towards changes, especially in case of older people, may represent one of the biggest challenges to overcome for the successful implementation of smart building systems and practices. Therefore, despite energy savings calculations assume a constant reduction output over the years, inhabitants' behavior heavily contributes in shaping the real yield curve of a smart building. By performing the investment feasibility assessment, the results obtained may need some considerations. In normal investment conditions, assuming the discount factor equal to a cost of capital of around 5%, without applying any incentive scheme, the NPV at year 10 results to be negative (with a value of -58870 €), while the pay-back time (PBT) is between 12 and 13 years.

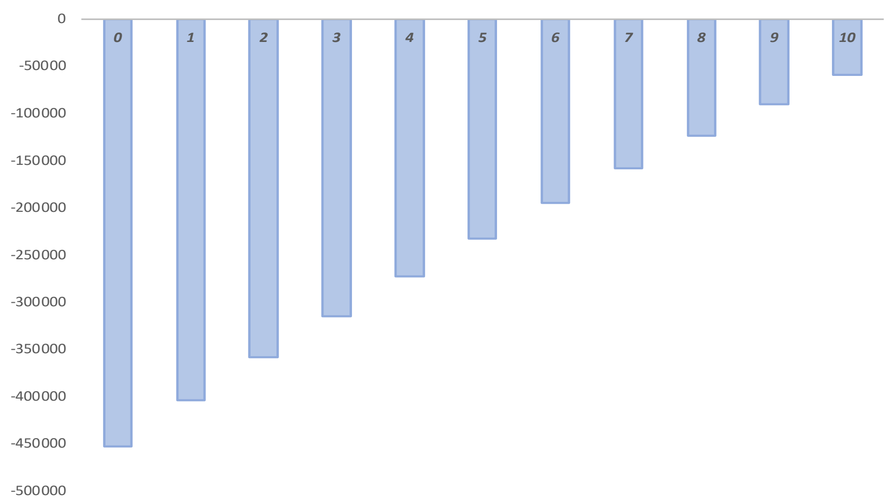

Figure 26. NPV in case no incentive scheme is applied

Under the current conditions, despite the long-term outcome is eventually going to be positive, the investment does not represent a valuable opportunity at the eyes of building occupants. Indeed, the extremely long PBT represents a considerable barrier at the eyes of investors, who mainly seek to achieve short term results, as in the case of most energy efficiency interventions (which do not usually represent an urgent priority). Thus, it seems difficult to separate investment-based economic results to the incentive mechanisms aimed at favoring the adoption of energy efficiency and smart building solutions. For residential interventions, a fundamental role in ensuring the project economic feasibility has been played by the so called '*Ecobonus*', in conjunction with the *deed of assignment of tax credit*[7] (Energy&Strategy, 2020). The combined action of the two mechanisms allows – in this particular case – to recover in advance up to 70% of the investment value (50% in the case of maintenance interventions), significantly reducing the PBT, which assesses around 3 years.

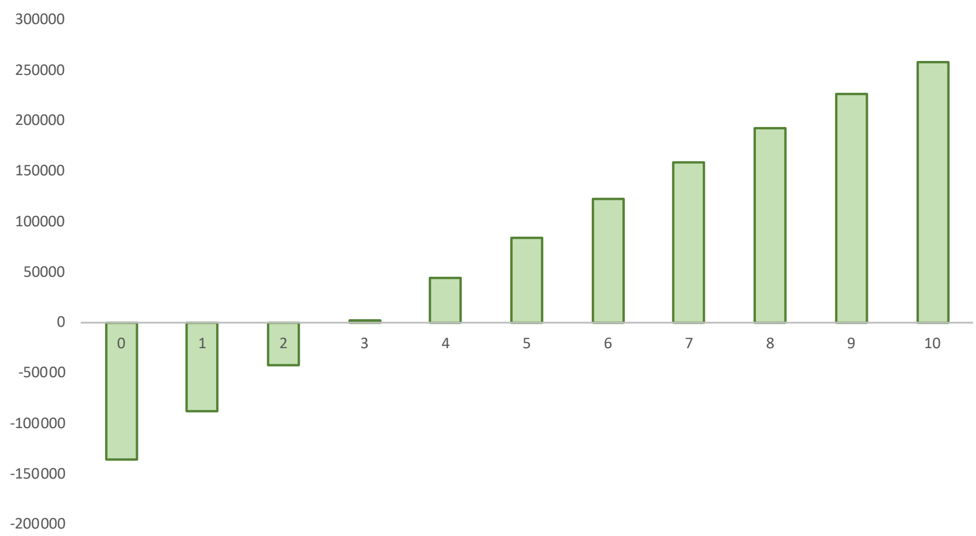

Figure 27. NPV in case of conjunct application of both 'Ecobonus' and deed of assignment of tax credit

[7] Ecobonus is an incentive mechanism, part of a wider package of procedures that aim at financing residential investments. The incentive provides coverage for a percentage of the intervention cost (depending on its typology), in the form of a tax deduction scheme distributed along a period of 10 years. The novel introduction of the deed of assignment of tax credit enables investors to refund the previously mentioned tax credit to the company responsible of the intervention, allowing for the immediate recovering of all the credit amount (Energy&Strategy, 2020).

Aside from energy savings related to energy efficiency and renewable energy production, other insights can be caught about the improvements granted by smart residential building interventions. A first important achievement is related to the improvement of occupants' wellness inside the building, as temperature range is massively reduced, from 23-33 °C to a nearly constant distribution, between 24 °C and 25 °C. Relative air humidity is substantially improved as well, with an overall range of 17% compared to a previous measure assessed around 31%.

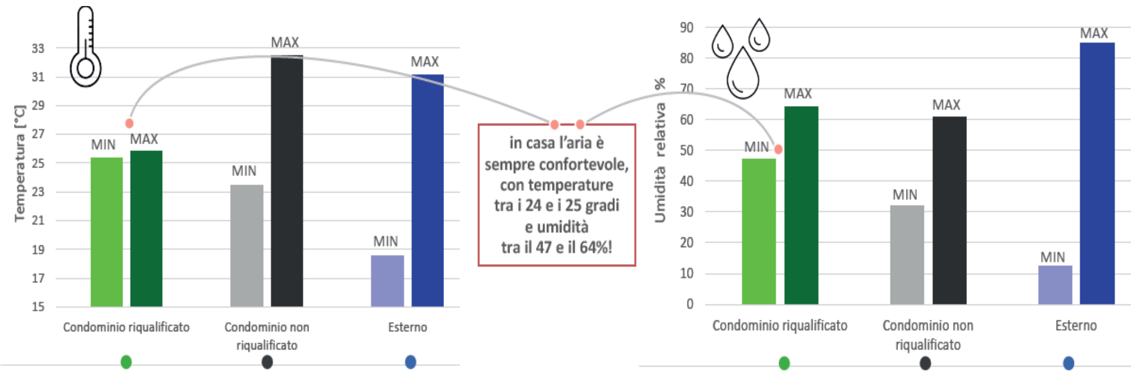

Figure 28. pre-intervention and post-intervention measures of internal temperature and relative air humidity (Teicos Group, 2017)

A second remarkable achievement consists in the increased value of occupants' apartments, as a consequence of the shift in energy class, from D to B. More specifically, according to this specific case, an average increment of 4% per class is applied, overall resulting in a raised building reselling value of 8% (Teicos Group, 2017).

A final consideration is related to the enhanced environmental performances of the building: indeed, through smart appliances, energy efficiency and generation technologies, 60% of energy consumption has been avoided, generating a positive reduction of CO_2 emissions amounting at 23500 Kg (estimated to have an effect equal to that of planting 870 trees in the city) (Teicos Group, 2017).

5.2 Corso Como Place, Milan[8]

This building, opened in 2020, is located in the area of Garibaldi/Porta Nuova in Milan, and it represents one of the most advanced case of smart buildings in the Italian territory, at the frontier for what concerns both energy efficiency and people's well-being. The building structure comprehends two different areas: a restructured 21 floor tower and an adjacent podium of new construction. Two main motives have been highlighted by the investing firm that led to the realization of a smart, digitally advanced structure:

- *Market 'intuition'*: as evidence of growing trends in the construction sector manifests abroad, especially in the US (pioneer market in the field of smart buildings), the company has assumed an early adopter position. In Italy, it has been the first real estate company that moved towards the adoption of IoT sensors and in-building smartphone app;
- *Increase of market competitiveness*: the cost of technology has considerably reduced, currently being economically sustainable in relation to the market segment in which the company operates (prime rent market). Two years before the building realization, the company has analyzed the reference target market in relation to the type of solution to implement, in order to find the best available technologies. At the time, the investment target was excessively innovative, despite little testing had already been done;

According to the company, 'a smart office building is at the same time intelligence and human-work interface. The gravity center is represented by people, with technology as a service enabler'. The steps followed for the building realization have been:

1. Understand the main market trends (worldwide and at EU level);
2. Determine the main competitive advantages of the smart building;
3. Evaluate the market of enabling technologies;
4. Calculate technology costs and rent value, understand solution competitiveness.

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[8] All sources inherently consulted for this building are not displayed for privacy reasons. Data and information have been provided by a referent of the real estate investment trust responsible of the project, with some case-specific secondary sources being consulted as well.

The most important berries encountered in the development of the solution have been:

- Difficulty in finding Italian benchmark business cases, given the early adopter position of the company. As no similar investment existed at the beginning of building development, it has also been difficult to find the level of expertise needed for this project realization;
- Tenant's reluctancy towards smart building's uncertain performance outputs: as a low number of benchmark cases were present, not all the potential tenants were ready to implement the innovative practices being possible thanks to smart IoT system implementation.

The set of corporate strategies and decisions brought to the realization of a product which embodies the principles and features of the most innovative smart buildings in the world. The whole structure surface (around 21000 m^2) is covered by a massive installation of smart IoT multi-sensors (one every 13 m^2). Each multi-sensor measures temperature, light, humidity, CO_2 and sound pressure; a DALI driver (digital addressable lighting interface) is comprehended, in order to directly connect to the lighting system; a Bluetooth beacon is installed in order to geo-localize elements in the building, including people (it is the only solution that enables indoor positioning without needing identity displaying). Sensors are connected – through a wireless communication system (Wi-Fi) – to a gateway, which communicates – through a switch – with the server, which enters the cloud and provides data availability to the API. Moreover, sensors directly connect to the cloud based BMS. The interception between occupant position and his/her identity is provided by the smartphone app, which the tenant develops, in order to protect employees' privacy. This case shows how the investing company is not generally involved in the development of the whole smart building system: it provides the technology infrastructure (the occupant-building interface) which enables to run specific operations at high performance levels, but the customization of building services and app configuration are decided by the tenant. Also parking spaces are equipped with IoT sensors, showing whether a box is free or occupied at a certain moment.

Before evaluating the contributions of specific features of the structure, some economics are highlighted about general improvements achieved from the study of this specific case. A first significant advantage for the real estate firm from investing into a smart building is related to the sharp increase of market performances. While on average office buildings in Grade A zones remain vacant for a certain period of time after opening (vacancy rate assessed around 6.0% for the PN BD district in 2016-2018 collection period), this building's spaces have been rented before the effective conclusion of construction works (early 2020), as proof of the high attention of tenants for innovation.

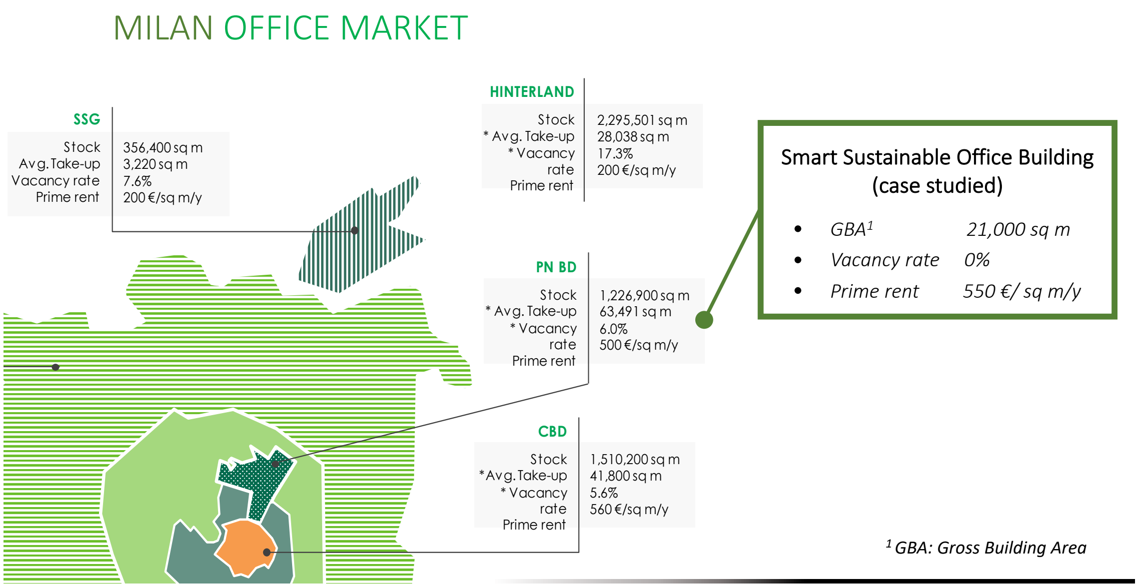

Figure 29. Building case vs average office market performances (Porta Nuova BD, Milan)

The positive economic impact is immediate: by making earlier revenues from rental activity, pay-back time is reduced proportionally to the vacancy time difference with a Grade A zone standard building. Moreover, the company is able to charge a higher differential rental price than comparable Grade A facilities, assessing around 10% of the standard prime rent. *Figure 29* provides a comparison between this business case and Porta Nuova BD reference standard performances. Finally, the real estate firm may benefit from a building resale value increase, consequently to the attainment of certificates such as LEED Gold and WELL Gold. According to a study published by CBRE, a commercial property resale price is assessed to increase of a value between 4% and 11%. On the tenant's side, the shift to smart buildings significantly improves brand performances: one example is the sharp increase in talent acquisition power. Basing on data about the company's main European reference benchmark (The Edge, Deloitte), a fully IoT enabled smart building can receive around 400% job applications compared to A-grade prime-rent standard offices. Although difficult to quantify, a similar result would represent an invaluable improvement to tenant's operational performances.

While the previous paragraph focuses on building market performances (both financial and non), this part deepens into the analysis of operational results, by carrying out an evaluation of this business case specific interventions. The estimated differential cost for implementing a smart building is around 1.5% - 2% of the structure value (which assesses around 1500 €/m^2). This percentage does not account for any BMS investment: according to the company, it alone does not guarantee the building 'smartness', as it is only able to automatically and simultaneously process input data, *reacting* to them by responding to raising issues. Thanks to data collection and storage capabilities provided by IoT and cloud computing technologies, the BMS, reimagined into a digitally connected structure, is able to act *predictively*, which brings to increased value generation. The peculiarity of a smart IoT system is its versatility in generating advantage through collection, elaboration and usage of data on different internal parameters. A first invoice is related to the reduction of building's operational expenses (opex). Among the several target achievements the company ought to reach, the followings are concerned:

- *20% reduction of energy costs*: it comprehends savings resulted from smart lighting and smart HVAC system optimization;

- *65% energy consumption from building renewables production*: as the building is capable of elaborating real-time and future data about energy price and grid congestion, the mix between self-consumption and grid injection is perfectly balanced. Therefore, an energy storage system is not present;

- *20% reduction of cleaning expenses*: this output results from optimal contract stipulation, arranged according to space cleaned rather than hours of operation;

- *10% reduction of maintenance costs*: achievable through predictive maintenance;

- *10% reduction of space needed*: achievable thanks to space optimization practices enabled by smart building indoor positioning and location systems.

- *5% - 15% increase in occupant productivity*: rough measure that tries to quantify expected occupant's performance increase as the consequence of an overall improved experience level within the building.

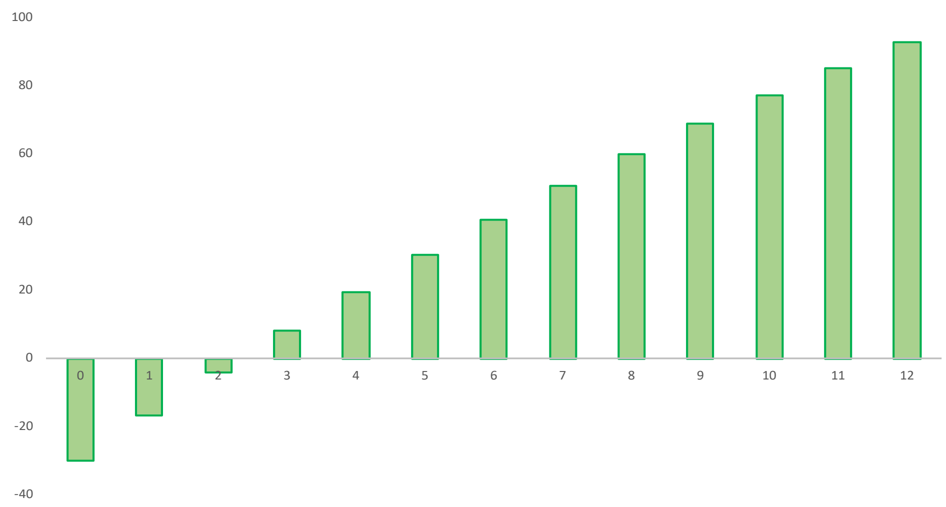

Figure 30. Differential NPV between a smart IoT enabled building (business case) and a standard sustainable building[9]

By estimating the impact of opex reduction only, in front of an initial differential investment of 2%, the resulting PBT is between three and four years. Another relevant achievement for tenants occupying smart building is represented by the increase of occupants' overall health and well-being. The company estimates a potential reduction in the number of sick days of 15%, and an occupant satisfaction increase of 20%[10].

The company also obtained incentives for the installation of an integrated photovoltaic system, with around 1000 modules used. Indeed, a volume bonus of 5% is applied in case renewable energy production exceeds a certain target, meaning that the company benefited from an extra 5% of construction area. Therefore, it is worth mentioning how an investment in solar panels should account for the potential building value increase (resulting from the extra 5% of volume assigned) as among the revenues achievable thanks to its adoption.

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[9] The NPV is estimated by considering a base case, in which the overall capex is approximately 1500 €/m^2 and opex assess around 40 €/m^2, and an investment case in which the additional capex is 2% of the initial one and opex are reduced to 25 €/m^2, as provided by the company's referent. The discount rate applied for this case NPV is 5.17%, corresponding to the cost of capital applied for the US Real Estate Operations and Services sector.

[10] Values are estimated by comparing future building performances to benchmark reference cases.

5.3 *Diamond Tower, Milan*

Financed by Coima, headquarters of BNP Paribas group in Italy, situated in the area of Garibaldi/Porta Nuova in Milan, Diamond Tower stands out as one of the most recent and iconic buildings in the city, being part of the great requalification project of the entire area, and particularly appreciated for its irregular structure which gives it the name. The building is almost entirely dedicated to office working, with BNP Paribas currently being the only tenant. Siemens has been the technological partner for every phase of the project – from building system configuration to internal design customization. Diamond Tower first opened in 2012 as a completely new structure, as part of the tenant's new vision, centered around the realization of smart and sustainable spaces. In this direction, the accomplishment of the LEED Gold certificate represents an important advantage at the eyes of investors, also considering the rental price increase dynamics that characterize its obtainment (BNL, 2012).

Diamond Tower constitutes a prominent case of smart building, due the presence of an integrated – IoT enabled – BMS, connecting the large number of internal devices and appliances and interrelating with them in an intelligent way. Thanks to the advanced level of interaction between occupants and applications, a first important output achieved lies at the early stages of the building design phase, as all the spaces have been projected in order to support smart working practices. Also referring to this work state-of-the-art, the actuation of flexible spaces and multi-purpose working environments brings to a reduction of the overall amount of space needed, assuming a constant number of occupants. In the case of BNP, this eventuality has allowed the company to successfully concentrate nine branches of the bank within a single building, vacating eleven facilities distributed in the city.

At energy optimization level, great effort has been put into smart energy efficiency applications:

- *Lighting*: the integration of both natural and artificial light performances constitutes an innovative element that characterize modern office buildings. In this case, the high penetration of natural light is due to the internal design of the facility – with a central core (for elevators and additional services) around which stand office spaces: this solution permits to maximize natural light penetration, also enhanced by the contribution of glass windows. Moreover, the instalment of a LED lighting system for almost all of the building floors contribute to sensibly reduce energy consumption levels. The IoT-enabled BMS collects data about daily light and coordinates the interaction between natural and artificial light on the basis of saving optimization and occupant wellness (which usually tend to be opposed);

- *HVAC*: heating and cooling systems within the building show high efficiency performances, with data about internal daily conditions being collected and processed by the BMS, in conjunction with other related parameters, in order to provide an integrated picture of building performances. As in the case of Diamond Tower, where glass windows are substantially locked, great attention has to be dedicated to parameters such as internal temperature and air quality. As an example, in order to grant occupant optimal wellness conditions (which in turn may bring to benefits in terms of productivity), air quality and temperature should be constantly monitored and maintained at a set level, with little oscillations: constant air quality requires a continuous air recycling process from within to outside the building (and vice versa), which in turn requires for external air to be heated up or cooled down (depending on the external environment conditions) in order to reach the set internal target of temperature, ultimately increasing energy consumption. Therefore, the establishment of optimal levels of both resource efficiency and people health and overall wellness may sometimes result in a trade-off.

Security represents another matter of great concern, even more in the case of a bank. In terms of physical security, attention is put on ensuring service continuity: in this perspective, wireless connection (i.e. Wi-Fi) does not generally fit the necessities of a banking system, due to the high signal disturbance probability. Concerning cybersecurity, the issue of excessive attack exposal by adopting IoT technology is partially mitigated by the choice of not running a cloud based BMS. Access to the BMS is significantly limited and enabled only by entering the company's browser, therefore hindering the possibility of future cyberattacks.

5.4 *NOI Tech Park, Bolzano*

NOI Tech Park is a public structure, also referred as a ‘technological park’, where local as well as international synergies emerge in favor of research and development activities (mostly in the green, food, digital and automotive & automation sectors). The whole park is a complex integration of new and restructured buildings (both at structural and technological level), hosting both office spaces and research laboratories. The realization of NOI Tech Park comprehended several successive steps. In 2006 the first project contest has been hosted: initially, the investment was planned to involve an urban-scale area (also awarded with the LEED Gold certification, for the integration between green areas, shared services, public and sustainable mobility), which had been gradually declined to a building-scale installation. Construction works started in 2015 and ended in 2017, with the implementation of the smart technological infrastructure only in 2018 (shared for each of the park’s five buildings). Main project partners for the implementation of the smart digital infrastructure have been Schneider Electric and EcoXpert Bettiol. Currently, the park comprehends five fully operating buildings, with a covered area of around 27000 m^2. NOI Tech Park offers an IoT enabled, intelligent, sustainable and dynamic environment, responding to clients’ needs in the most optimal way, favoring smart working initiatives.

The technological infrastructure of NOI Tech Park is characterized by strong complexity (also enforced by the presence of both new and existing building installations), hindering any attempt of an accurate and inclusive analysis of all its associated benefits. In order to frame the build on the basis of its main benefit-enhancing categories, two main areas of intervention have been distinguished for this specific case (according to the nature of the intervention), namely *energy optimization* and *building security*:

- For the build *energy system*, an innovative structure has been configured, with the implementation of different elements. All the activities of each element are monitored and coordinated by the EcoStruxure Building Operation and EcoStruxure Power platforms, which installation has brought to consistent results in terms of energy savings, environmental impact, optimal resource management and systems operations. Thanks to enhanced connectivity (granted in this case by a wired communication system), data and information are available in real-time for monitoring and analysis by dedicated personnel, opening opportunities for predictive maintenance practices (therefore ensuring process continuity). The constant monitoring of energy consumption profiles fuels continuous improvement practices, with respect of the diverse needs of building occupants. The main device categories considered for this application are, respectively, *lighting*, *HVAC* and *energy production*:

- *Lighting*: the overall structure is characterized by a centralized LED lighting system, together with an emergency lighting system Dali1, automatic dimming and predetermined use profiles. The overall energy profile for the lighting system amounts at 110 MWh/year;

- *HVAC*: several building solutions have been installed: two high-efficiency reversible heat pumps (overall power around 1200 kW) for heating and cooling purposes, linked with the adjacent steelworks in order to benefit from excess heat power. Furthermore, the build is connected to district heating for either demand peak management or primary system's maintenance activities, and residual thermal energy is collected (as some specific functions of the park necessitate constant cooling throughout the year). Temperature is automatically assessed, with occupants having the possibility to change default levels for a maximum of 3°C. The presence of a centralized and connected platform for monitoring and energy management activities allows for higher thermal efficiency, having the possibility of optimally exploiting a unique thermal system for all the buildings in the park;

- *Energy production*: a photovoltaic plant powers up the entire building system, allowing for positive results in terms of energy savings. In 2018, 185 MWh of electricity have been produced and simultaneously consumed. EcoStruxure Power platform assists the building energy distribution system and monitors data generated from smart energy metering activities.

- The build smart system includes several applications for ensuring the highest levels of internal security, with a specific focus on physical security practices. A first insight is represented by the instalment of an access control system, which differentiates access rights to certain areas of the park on the basis of the occupant's authorization level. Personal badges are distributed to occupants in order to provide further control at the access points. Moreover, each building includes: a fire and gas alarm system FXnet, emergency lighting, TVCC video-surveillance, and an anti-intrusion component. Data concerning the economic impact of increased security mechanisms has been calculated, although it is specified that all the interventions are necessary for this structure, in order to grant continuity of all its activities.

The numerical calculations related to the economic benefits of NOI Tech Park smart systems and applications have not been provided, given the aforementioned difficulties in determining exact results of a considerably complex structure. Therefore, a schematic representation of the main benefits achieved during the intervention is depicted, by leveraging on data and information supplied during the interview. No incentive retributions have been assigned for the realization of NOI tech Park.

NOI Tech Park benefits and achievements

- *Energy Savings*
- *Environmental Sustainability*
- *Occupant Wellness*
- *Productivity Optimization*
- *Remote Control and Management*

Figure 31. Main benefits resulting from smart building systems at NOI Tech Park

5.5 *Fondazione Agnelli, Turin*

Fondazione Agnelli represents one of the highest and most advanced Italian expressions of the smart building entire potential. Originally being a historical residence, since 1966 the structure became among the most prominent research centers in the field of social and human sciences. In 2017, the building has sustained profound renovation: architecture, design and engineering study Carlo Ratti Associati, partnered by Siemens, transformed Fondazione Agnelli ‘3.0’ into a 6500 m^2 hybrid space, with the aim of stimulating open innovation, technological development and free research, encouraging start-up creation and development in a dynamic, involving environment. The building is the manifest of a completely new conception of office work, understanding the needs and requirements of modern society, in order to provide a large coworking space which aims to foster interactions and partnerships in the name of innovation and creativity. The structure is currently managed by Talent Garden (the biggest European physical coworking platform for digital talent) as one of the main requalification project partners, in order to fuel ideas generation by converging several diverse actors, ranging from start-ups, innovators and venture capital investment funds to creative professional and professors. The key for the coexistence of different companies (and perspectives as well) is related to the high customization opportunities the building offers: in regards, it represents one of the most noteworthy Italian case of optimal integration between IoT technology (smart sensors, actuators and appliances) and an advanced BMS, granting – through the use of a smartphone building app – intelligent space management and single areas personalization. As Carlo Ratti states, Internet is drastically changing how much people value the importance of physical spaces, setting at the base of every initiative, either being at smart home, smart building or smart city level. The analysis of Fondazione Agnelli brings to some insightful results, from which the versatility of an IoT enabled platform is fully manifested. By leveraging on both primary and secondary information, the overall technological effort can be articulated into three intervention areas, namely: reduction of energy consumption; space optimization and adaptability; occupant experience and interactions.

- The great driver of enhanced energy efficiency within the building is the presence of an occupant indoor positioning system, developed through Siemens’s platform Desigo CC. The system is able to geo-localize people inside the structure, automatically activating application-based customized responses, on the basis of data collected by IoT sensors and showed through the smartphone app. Thanks to a number of countertop fan coil units, activated by the presence and movements of people, the smart building system is able to monitor occupants as they move within the facility, therefore creating an ‘individual thermal and light bubble’. As an example, once a person leaves a room, the environment automatically reconfigures itself to standby mode, providing a significant energy saving. The advantages brought by IoT in matter of energy efficiency are evident. As mentioned by Carlo Ratti, “nowadays, a lot of energy is lost because of heating or conditioning of empty buildings…by synchronizing energy use with human space occupancy we can create a more responsible and sustainable architecture, theoretically cutting down energy consumption by 40%” (Di Marzo, 2017);

- Given the primary nature of Fondazione Agnelli, which is that of a coworking space, the flexible reconfiguration of internal spaces is of fundamental importance. In order to leverage the total area of 3000 m^2 without neglecting privacy requirements, different solutions have been implemented within the structure: moving glass panels, curtains with reverberation absorption, and folding divisors (in wooden panels), each one with a set of neutral colors in order to maximize natural light penetration. Such solutions provide a vast range of possible space reconfigurations, on the basis of occupants’ changing needs. The adaptability and flexibility of building spaces represent an immediate contribution to internal spatial resource optimization, allowing to save considerable amounts of space which could be dedicated to further future interventions;

- To enhance occupant experience, not only the building enables configurations of internal environment parameters such as temperature and lighting, it also provides – by using the smartphone app – additional services. Indeed, people can book spaces in advance, and can pinpoint their position in order for the BMS to provide better interaction chances with colleagues of similar research purviews. The information provided by the BMS about occupants’ behavior and interactions will eventually be used in to understand how certain environment conditions may alter people creativity and performances.

Section III: Discussion and Conclusions

The last section of the thesis aims to collect and elaborate results and considerations from previous sections. The first chapter highlights the main insights of the study from a theoretical viewpoint, by leveraging on what achieved in the section of literature review. The second chapter discusses and elaborates on the findings of the thesis work, with a focus on the analysis of the empirical results brought from the case study. The third and last chapter provides the conclusions of the work.

6 Considerations from the Literature

This chapter proposes an understanding over the main theoretical results brought throughout this work's review of the extant literature, through a detailed summary of its outcomes. The argumentation is composed of two main branches: the first one explains the relevance and actuality of smart buildings to society transition into the digital era; the second one contributes to show an overview of the smart building landscape, by delineating the opportunities and challenges related to its acceptation.

6.1 Relevance of the Smart Building Topic

As smart buildings have achieved a valuable niche position in the current building sector, considering how the reference market is expected to grow in the following years, the relevance of this research topic is of straight actuality. Therefore, by leveraging on this thesis's literature study, the main impacts of smart buildings on current society and building ecosystem are highlighted. Significant insights might be deduced by looking at the approach adopted in order to structure this work literature review. Indeed, the first part of the study is aimed at mapping the main macro-trends that influenced and modelled the development of the smart building ecosystem, while the second one has the purpose of modelling a comprehensive definition of the term. In the circumstance, a *divergent-convergent* approach is applied, given how each trend has been initially addressed singularly, then successively merged into a unique outcome, namely the concept of smart building. By taking the inverse perspective, that is to unravel the concept of smart building in order to understand the trends it generates or directly contributes to reinforce, relevant outcomes can be found:

1) From a *technological perspective*, the smart building revolution is having a profound influence on the transition of people towards the digital era, which implies a completely reshaped interaction between human-side and technology-side. In this context, smart buildings represent an additional proof of how technology is slowly adapting and modelling around people's needs and ways of communicating, not vice versa. Such pattern may be found in the way buildings are now able to react and configure internal environment parameters according to the data collected about people's preferences and habits;

2) From a *macro-economic and environmental perspective*, smart buildings represent an ideal outcome of sustainable development, since they contribute to concurrently enhance the environmental, social and economic spheres of sustainability. More specifically, in most of its ambits, a smart building identifies and reflects into the principles that guide *circular economy* practices, given the heavy impact it has on resource reuse and resource conservation. Certainly, one of the main problems related to circular economy have always been represented by the difficulty of exhaustively mapping resource flows inside and outside a company's boundaries. Regarding, smart building enables high traceability through enhanced connectivity and monitoring, supporting efficient solutions in the reintegration of wastes and in the avoidance of unnecessary expenses, while also ensuring positive economical returns. Besides, the scalability potential of smart buildings, in light of the connection with both internal and external environments, may support rapid diffusion of best practices, contributing to the renovation of modern society;

3) From a *socio-demographic perspective*, smart buildings, if integrated into a broader smart city ecosystem, have the potential to successfully counter the issue of increasing urbanization, by simultaneously mitigating both space scarcity and grid congestion, in a way that also enforces the value of occupant experience and interaction with its surroundings. Inherently, smart buildings favour occupant intelligent relationships into digitally connected spaces. The objective is to maximize optimal chance encounters between people, either real or virtual, creating the conditions for a more homogeneously connected environment, regulated by people's decisions and aspirations.

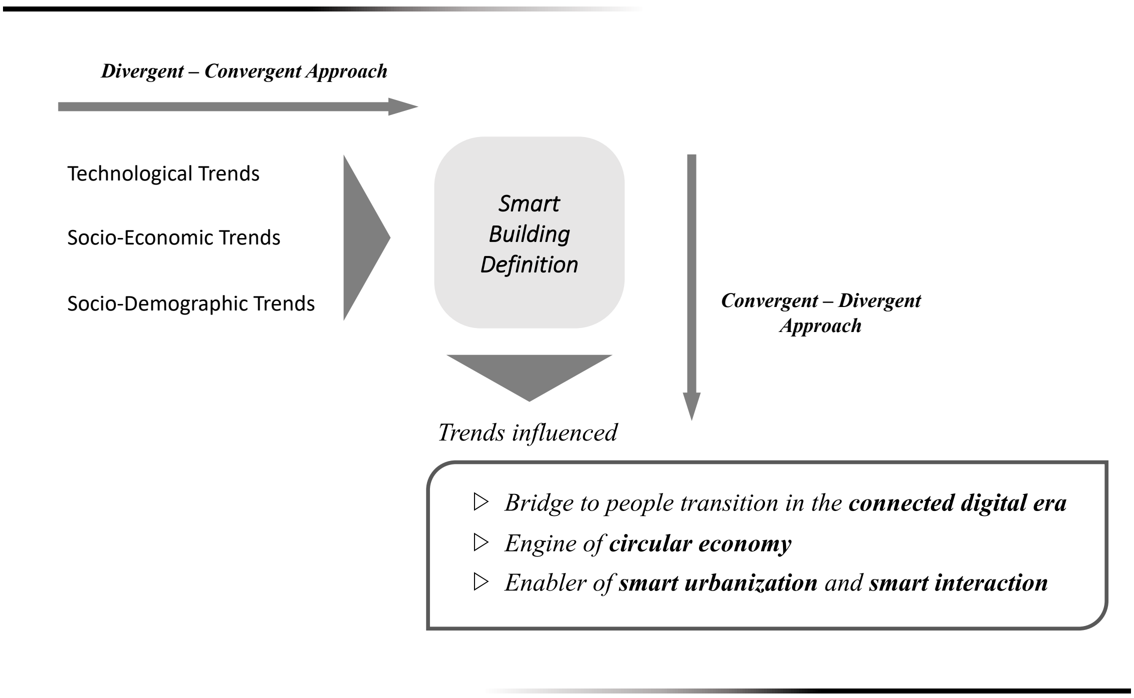

Figure 32. The influence of smart buildings on current society needs and trends

Basing on the aforementioned points, also summarized in *Figure 32*, smart buildings encompass different trends, fitting diverse models and frameworks, but also provide an innovative approach into the relation between humans and built environments, elevating their coordination at a completely different level. The renewed centrality of people in the process of technological transformation consolidates the importance and actuality of the theme, as one of the most discussed and referred outputs of the integration and simultaneous application of diverse branches of Industry 4.0.

6.2 *The Smart Building Landscape*

Smart buildings relevance and degree of novelty have been acknowledged by both research bodies and firms, which contributed to generate increasing interest over the topic. Yet, several aspects and attributes of smart buildings still have to be fully comprehended, as much as a reference inclusive market has not been identified. Therefore, by leveraging on the literature study provided in this work, this part focuses on understanding the main opportunities and challenges that lie ahead in the smart building landscape, synthetized into *Figure 33*. From the literature, it is evidenced how the smart building discussion is the result of the convergence of intersected trends and perspectives: while it is known that each individual change brings new challenges together with its degree of innovation, this wave of change as a whole offers unlimited possibilities for those embracing it. In the following paragraphs, the main outcomes, in the form of investment opportunities and challenges of the smart building market, are highlighted and briefly analyzed, providing a detailed yet not necessarily complete overview of its business potential.

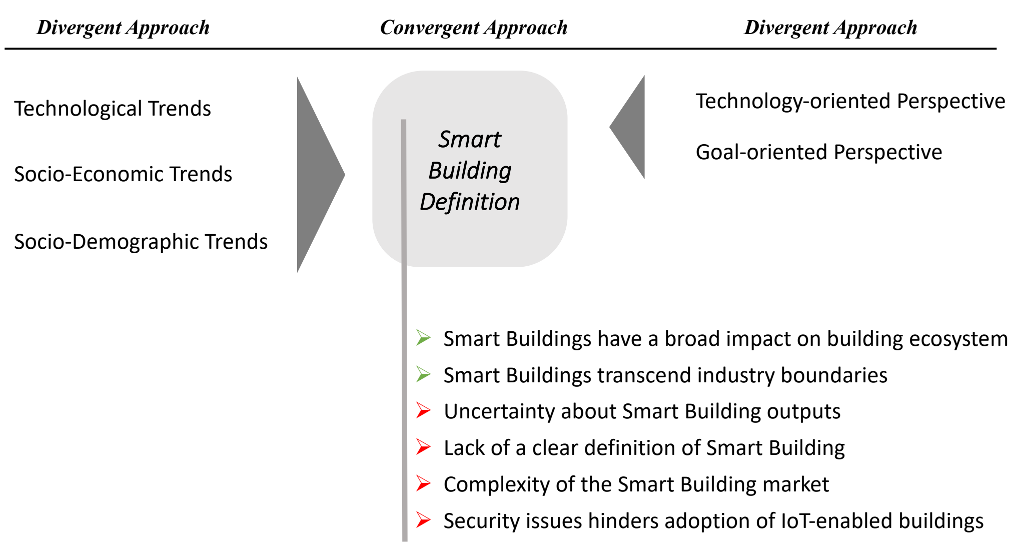

Figure 33. Main outcomes from the literature: opportunities and challenges

On the basis of what achieved in the literature section, two main opportunities are identified that fully express the potential behind smart buildings:

- *Smart buildings have a broad impact on a building ecosystem*. The relevance of smart building at the eyes of investors primarily lies in its versatility of application at different levels of the building, from energy efficiency and waste management to occupant wellness enhancement and space reconfiguration. The high number of possible smart technologies configurations within a building enables people to design internal spaces according to the exact set of attributes and features required. In a society where people needs and interests are central in a firm's corporate strategy, *flexibility of configuration and extreme customization* represent fundamental characteristics for companies that aim to intensify the overall customer experience, also considering the easiness of implementation for different building typologies, and on both new or already built spaces;

- *Smart buildings transcend industry boundaries*. Technology is enabling and facilitating cross-sectoral innovation, with smart buildings representing a renowned example. Through connectivity, data collection, storage and processing, buildings are now able to interrelate with several new 'counterparties', *augmenting efficiency practices and boosting collaboration at an unprecedented level*. Real estate markets, once independent to the developments of other industries and 'governed' by static variables (noteworthy is the case of location), are now aligned with the current pace of innovation of other markets. A notable case is constituted by the evolution of interactions between buildings and power grid. While initially buildings were only viewed as isolated, energy 'consumers', with the advent of renewable energy and distributed generation, their role has shifted to that of 'prosumers', as a reference to the increased contribution of buildings to the overall grid balance. As distributed (and, in a sense, unpredictable) generation became common practice among residential and commercial counterparties, grid congestion and complexity increased exponentially. In this perspective, the joint combination of smart building and smart grid investments has provided intelligent data exchange about distributed profiles and centralized grid requirements, therefore supporting the creation of a structured architecture in which operational efficiency is maximized.

Despite the great opportunity represented by the smart building wave of change, some barriers still emerge that prevent its diffusion:

- *Outputs generated through smart building technology might be uncertain*. In view of a certain degree of novelty around smart buildings, also considering how not all the related innovations have been directly appointed by any explicit demand raise, it can be assumed how technology might be evolving at a higher pace compared to that of the market, bringing to the presence of fewer cases of the smartest building expressions. As a consequence, in light of scarce statistical evidence of a smart building (positive) economic results, companies are diffident at investing into it. The case of residential markets might be different, given the generally higher number of cases on which to provide statistically solid results;

- *The smart building argument still lacks a proper definition*. Another factor that generates uncertainty around smart buildings is the lack of a clear path to follow in contextualizing associated investments, bringing to an increasing misuse of the term 'smart'. As a direct consequence, some 'rigid' applications, supporting only specific protocols and communication systems, might be classified as smart, while flexibility should be a key attribute of smart buildings. In this perspective, system interoperability is still far to be achieved, especially for big, commercial applications;

- *The smart building market is characterized by great and raising complexity*. Technology is acting as an engine that facilitates the continuous introduction of novel applications into the smart building ecosystem, augmenting the range of opportunities available to investors. This is resulting in an *increasingly complicated landscape of smart building solutions, which creates the perception of complexity*, leading to a degree of confusion over the multiple choices to be made in designing the appropriate space and selecting the most tailored solutions. Indeed, structural market complexity represents an indirect cost companies are facing when deciding to model smart environments.

- *Security issues hinder the adoption of IoT-enabled smart buildings*. Security and privacy concerns continue to act as the major barriers to market growth, especially considering the higher attack exposure brought by IoT solutions.

7 Discussion of Results

The empirical core of this study focuses on the investigation of results – quantitative and qualitative – attributable to any smart building investment, across building category and nature of intervention (either new or existing construction). Therefore, this chapter aims at deepening into the analysis of the dynamics that govern smart building investments. In the first part of the chapter, the investigation of the current smart building investments landscape is provided, by leveraging the information consulted and gathered in the previous sections. The second part collects the main results of the case study and proposes a both qualitative and quantitative analysis of its most relevant outcomes.

7.1 Smart Building Investments Outlook

Smart building market adoption is registering a positive growth (expected global smart building market CAGR is of 18.9%), being the technology as a whole riding the wave of industry 4.0 disruption, especially concerning IoT-enabled solutions. Despite the evidence of growing financial performances (which anyway represent an excessively aggregated form of measurement), an effective evaluation of the smart building current and future market evolution presents some degrees of complexity. Given the absence of a hypothetical threshold assessment (that would objectively distinguish between smart buildings and 'not-so-smart' variants), in regards of the lack of any definition or framework that could possibly determine its key fundamental elements, it is currently unrealistic to determine a country's number of 'certified' smart buildings. In spite of the evident limitations that hinder any attempt of a complete and accurate market study, some considerations might still be formulated by observing different, but significantly correlated, building performance perspectives, such as that of energy efficiency, environmental and social sustainability. In regards, the study of some of the main *certification programs* (recognized worldwide) might provide valuable insights, which (at least partially) can reflect the state of affair around the smart building market. This analysis proposes a take on two of the most relevant certification programs, namely

LEED[11] and *WELL*[12] certificates. Although there is not straight correlation between the achievement of either (or both) of the two certificates and a building's level of smartness, some common traits may be found, in the form of similar performance objectives, such as energy and resource efficiency, emissions reduction, human health and well-being.

- With reference to the Italian market, between 2006 and 2019, 286 buildings have achieved LEED certification, with a related CAGR of 32.81%. Certified buildings represent 40.45% of the total number of buildings registered in the programme (707). As energy efficiency and environmental constraints highlight among the top priorities for companies and government bodies, also considering the current availability of incentive schemes for nzeb building projects, the growth in the number of certifications is expected to rapidly increase. Such growth projection is in line with the development of the smart building market, which in Italy appears to be prevalently centred around energy applications.

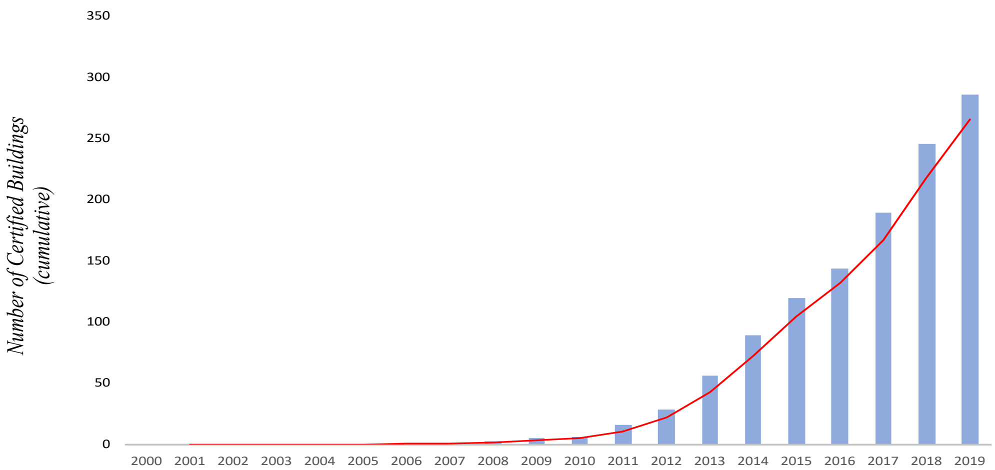

Figure 34. Number of buildings that received the LEED certification in the Italian territory (source: (U.S. Green Building Council, 2020)*)*

[11] LEED (Leadership in Energy and Environmental Design) certification is a class of certifications which aim is that of evaluating a building energy and environmental performances through a quantitative approach, setting for each building category a number of numerical targets to achieved (U.S. Green Building Council, 2018).

[12] WELL certification proposes a performance-based system for measuring, certifying, and monitoring features of the built environment that impact human health and well-being, through air, water, nourishment, light, fitness, comfort and mind (International WELL Building Institute, 2018).

- Given its early market introduction, WELL certificate is not currently aligned with the straight increase of LEED certified buildings, with only two structures that met the related requirements out of 45 registered. However, the increase in importance of the WELL certificate might represent proof of the augmented efforts towards building occupants' health and well-being. While energy efficiency practices are not necessarily reliant on smart technology in order to guarantee substantial performance improvements, enhanced results in favour of people's comfort, fitness and health are prevalently dependent on the adoption of smart IoT devices and applications that help collect data on occupants' preferences, in order to provide them uniquely-designed solutions.

The investigation of LEED and WELL certificate programmes offers a trend prospective characterized by a certain degree of connection with the smart building landscape. Moreover, by leveraging on the number of certified buildings, they also provide an indirect portray of the typology and relevance of technological interventions that currently affect and qualify the building market, according to the set of targets and principles displayed through their guidelines. On the basis of collected data and information, by relying on some of the contributions mentioned in the thesis previous sections, a panoramic of the rate of adoption of smart building applications is provided, together with an assessment of the impacts each application has on a building's performances. The output of the analysis is delivered in the form of two tables, both with a similar structure: a first segment reports some of the most diffused *applications* inherent to any smart building investment, while a second segment provides a categorization by *building investment typology*. A first analysis has been conducted to evaluate (for each building investment type) whether a certain solution sees use, distinguishing among three cases:

- *Current adoption*: the application is seeing use for the related building type;

- *Future adoption*: the application is not seeing use at the moment, or has not been designed for the related building typology yet, but there are possibilities that it will be adopted in the short-medium term;

- *No adoption*: the application is not seeing use at the moment or has not been designed for the related building typology, and it is not expected to see implementation in the short-medium term.

The first table aims at assessing the level of adoption of each application for each building typology, while the second table estimates the impact of applications on a building's economic performances. In providing the following figures, some estimations and approximations have been done, given the uncertain profile of several of the analysed invoices, both in terms of adoption rate and impact assessed. For each table, some of the most relevant outcomes are discussed, together with argumentations supporting the choices made in modelling each figure. In this regard, despite their increasing relevance at the eyes of investors (especially at commercial level), cybersecurity interventions have not been considered, given the high uncertainty about adoption rate and, in particular, impact assessed. Furthermore, rather than an addressable single investment, cybersecurity concerns the implementation of practices and internal procedures along time.

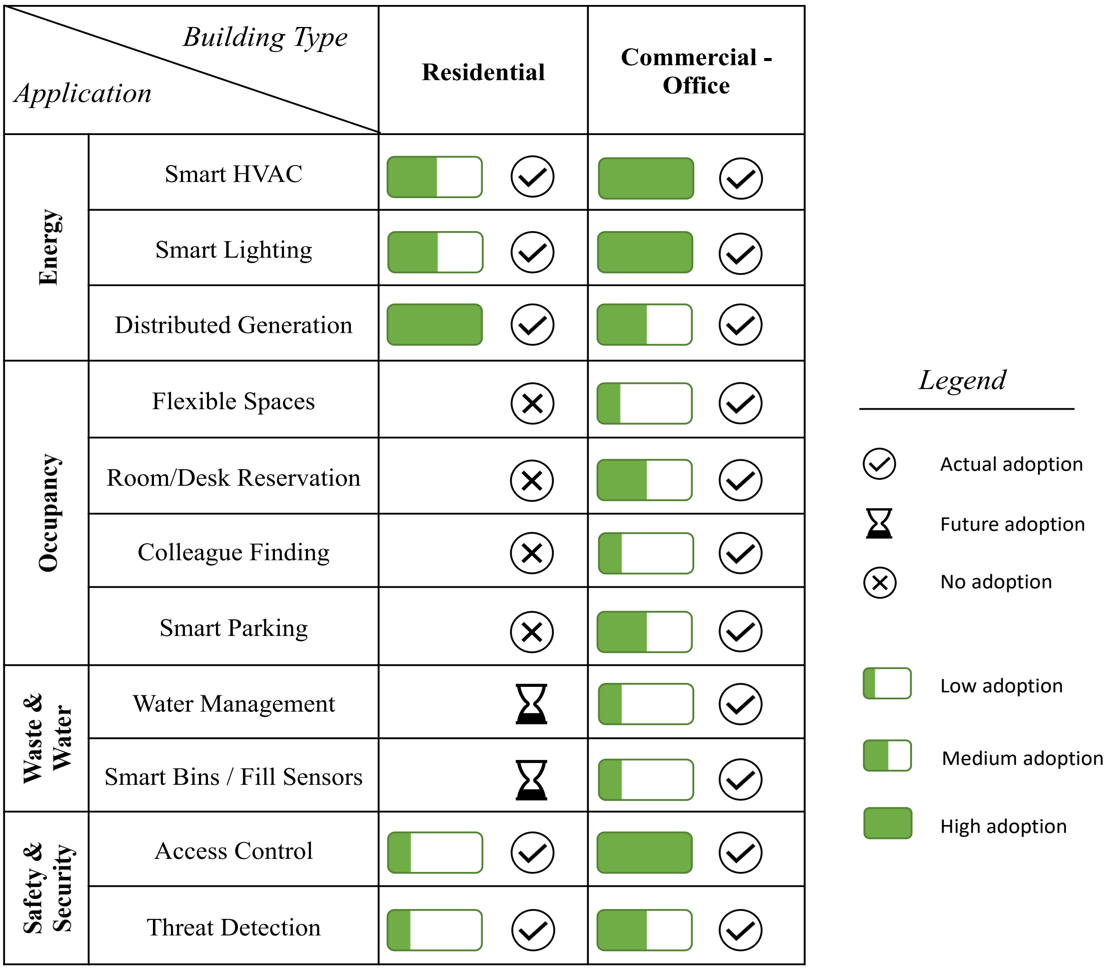

Figure 35. Matrix showing the rate of adoption of smart applications per building category

The main points highlighted from the analysis of implementations rates of smart building applications are the following:

- *Energy-related solutions* stand out as the most adopted across different smart building typologies. As also previously addressed, energy efficiency and generation applications appear to be the most desirable by managers, for they guarantee solid and mature performances while also reducing the amount of carbon emissions. Moreover, thanks to the adoption of an IoT-enabled BMS, it is possible to continuously monitor and collect real-time data on energy consumption, allowing for a more exact calculation of the economic impact of said technologies, with high output transparency, then resulting into broader adoption. Distributed generation (production from solar photovoltaic) might see a higher adoption in residential building projects than in every other building category, as a consequence of higher incentive accessibility and impact into the investment economic assessment. Smart HVAC and lighting find their best use in commercial buildings, in view of the higher scalability and permeability of the solutions, also helping in improving workers' level of comfort;

- *Occupancy-related applications* find their use especially in smart commercial buildings, where sensible results in terms of occupants' health and productivity are usually registered. However, not all the occupancy-related applications are seeing increasing adoption: the most addressed solutions are those linked to room/desk reservation and smart parking, as their economic impact is higher and easily quantifiable by determining the amount of saved space when implementing any building investment. Flexible spaces might represent a high-potential solution as well, although its impact is not clearly assessed. Any of the solutions are not suited for residential application, as they do not offer any tangible benefits for inhabitants;

- *Waste and water management solutions* do not find broad adoption at any building dimension: main motives lie in the lack of any clear procedure for assessing the economic gain behind the investment, as well as the overall limited impact on a building's total revenues;

- *Safety & security interventions* find little application at residential level, while investments at commercial level are not uncommon, especially those related to access control systems installations.

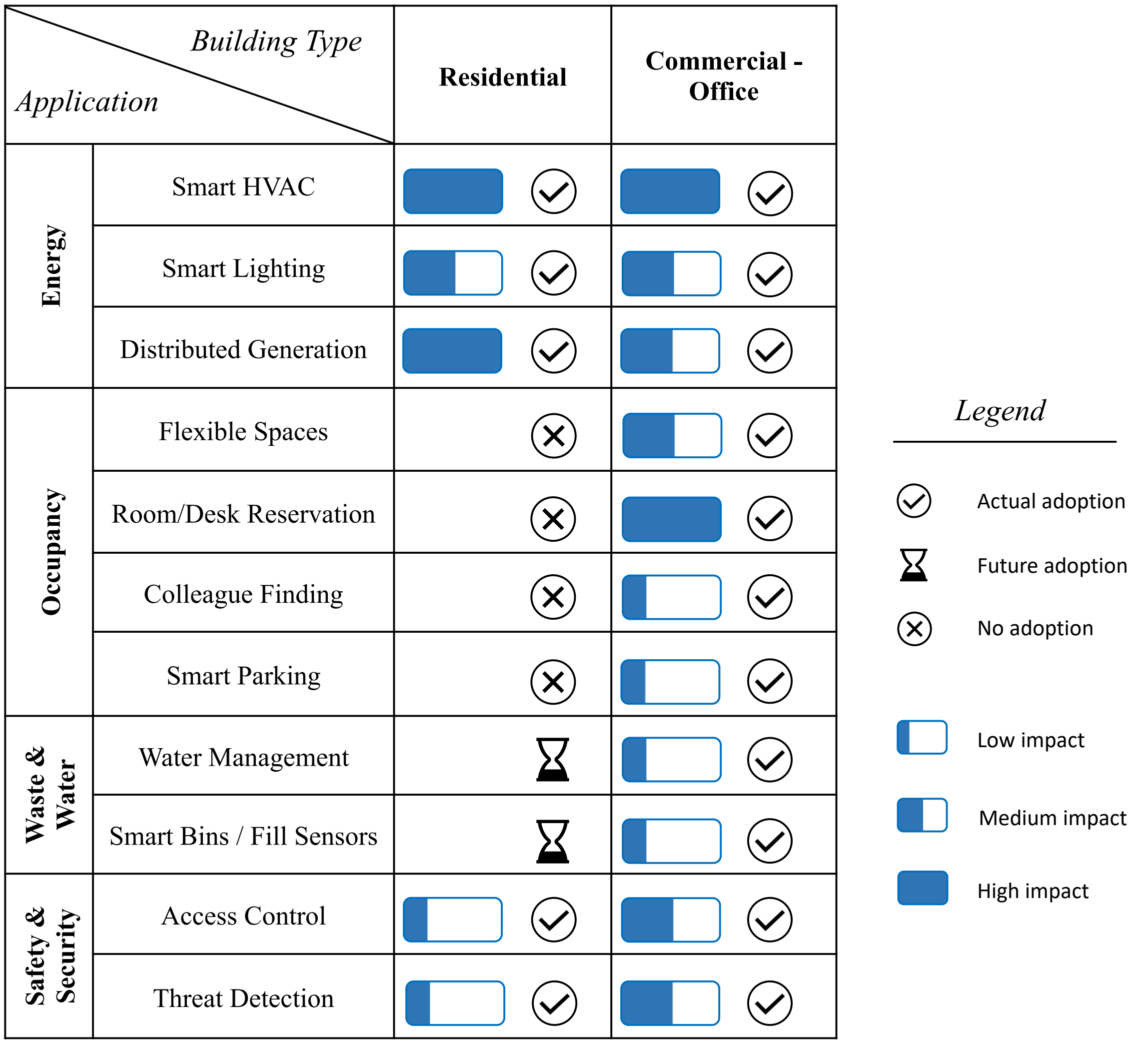

Figure 36. Matrix showing the impact levels of smart applications per building category

The main points highlighted from the impact assessment of smart building applications are the following:

- *Energy-related solutions* still manifest as the most important driver towards smart-building-oriented interventions, given the immediate and high impact on the structure's economic performances. HVAC-related energy consumption is between 40% and 50% of a building energy expenses, therefore potential savings account for a relevant share of total energy savings (at every building level). Regarding distributed generation from renewables, a higher positive impact at residential level is dependent on the integration with attractive incentive schemes, bringing to a considerable decrease of the investment PBT, as also presented in the analysis of Condominio Via Verro. The case of distributed generation at residential level has to carefully distinguish between single-home and multi-home apartments in the assessment of its economic performance. Given the current impossibility of sharing energy generated from renewables among private apartment owners (related to the restrictions imposed for the creation of energy communities), what produced is used for solving energy needs in the shared areas of the apartment, such as hall lighting, garden (irrigation system) and elevators: such limitation may hinder the optimal efficiency gain, since a lower self-consumption rate is likely to occur;

- *Occupancy-related applications* provide little to no economic implications at residential level, being them prevalently suited for office structures interventions. Flexible spaces implementation and room/desktop reservation appear as the most impactful applications in terms of occupancy rate improvements and people productivity increase, while colleague finding highlights an innovative feature with low associated costs and revenues (when able to be assessed, as it strictly depends on the improvement of occupants' performances);

- *Waste and water management solutions* do not provide enough contribution in terms of enhanced savings, justifying their limited adoption at every building dimension. Related future investments, with applications approaching their maturity phase, might represent a better opportunity for companies that want to further raise buildings operational outputs;

- *Safety & security interventions* have an important role at contributing to a building's overall performances, especially in case of larger structures. Indeed, threat prevention represents an invaluable source of savings, reducing inactivity time caused by physical damage, theft, system interruption, etc. Big shutdowns at commercial building level may lead to great losses from operational activities. Reducing the operational risk of a building is thus fundamental for a company in order to alleviate financial tensions. The impact assessed may profoundly vary according to the firm or tenant primary business.

7.2 Evidences from the Case Study

In light of the outcomes presented in the previous division of the chapter, this part provides some further evidences through a contextualized analysis of the business cases presented in section II. By examining the cases from an integrative perspective, a first important insight is related to the shared implementation of measures aimed at increasing each building's energy efficiency level, although relative dynamics and objectives pursued for each case differentiates from the others. In this prospect, some specificities are underlined.

- The case of the residential apartment in Milan (Condominio Via Verro) is emblematic, highlighting the *fundamental role of incentives support* to attract people towards smart building solutions that would have not otherwise been considered, despite the long-term benefits they bring. Indeed, by considering the total return generated from the intervention in ten years, the contribute of incentive schemes amounts at 315571 €, equivalent to 38.48% of total revenues: considering also how the invoice is entirely applied in the first accounting year of the investment, by means of the deed of assignment of tax credit, it is evident how necessary it appears to be at the eyes of investors. Allowing for *significant PBT reduction*, the application of incentive schemes represents a great flexibility increase for apartment owners, not locked anymore to any long-term investment. Such status generally applies to several efficiency interventions at residential level, with several similarities to distributed generation investments.

- The cases of Diamond Tower and Corso Como Place give proof of the *enhanced energy optimization capabilities* of commercial office buildings, as they are able to integrate a wider range of systems and devices that contribute to the achievement of higher performances, also considering how the presence of a IoT-enabled BMS provides massive coordination efforts. Moreover, best practices reported at one end point may be *scaled up to be implemented at other connected buildings*, in order to maximize a company's whole ecosystem outputs. At Fondazione Agnelli (a co-working space), efficiency is devoted to the attainment of occupants' ideal working conditions. It should be appointed how an important, yet indirect source of energy efficiency in advanced smart office buildings is represented by space optimization opportunities. Indeed, according to previously referred secondary sources, smart commercial buildings register (on average) an occupancy rate increase between 9% and 18%, thus avoiding energy losses for unused space.

Concerning occupancy-related solutions, no intervention has been applied for the space in Via Verro, confirming that residential buildings are not usually suited for optimally exploiting the potential of such applications. By consulting primary and secondary sources on the remaining four buildings, evidence exists of the inclusion of occupancy-related solutions among the set of implementations made.

Application \ *Building*		***Diamond Tower***	***Corso Como Place***	***Fondazione Agnelli***	***NOI Tech Park***
Occupancy	Flexible Spaces	✔	✔	✔	✔
	Room/Desk Reservation	✔	✔	✔	✘
	Colleague Finding	✘	✔ ✘	✔	✘
	Smart Parking	✘	✔	✘	✘

Figure 37. Smart commercial buildings: main applications adopted according to building

In this perspective, Corso Como Place stands out as the closest representation of what projected in the case of The Edge: at design phase, the hardware installations such as smart IoT sensors and devices enable several different configurations, on the basis of each tenant's requirements. The building has been projected to allow for every application usage, yet not all of them may be adopted by the tenant firm: in regards, hesitation might come from the use of person-based indoor positioning applications such as colleague finding, as it would require to display private data about occupants. In conclusion, Corso Como Place seems to be the only building actually offering smart parking as one of the services available in the building app. Fondazione Agnelli implements all of the aforementioned features, except for smart parking solutions. In particular, the structure is designed to greatly exploit flexible space management: as a co-working space, the capability of proactively adapting to diverse requirements with fixed resource availability represents an extremely relevant attribute of smart buildings.

Another fundamental aspect – common to the four commercial buildings analysed – is related to the *implementation of an IoT-based software BMS*, which has a completely different and broad impact on building performances compared to hardware installations. In regards, two main points are highlighted:

- IoT-based BMS has a considerably *lower economic impact on a building cost structure* if compared to hardware BMS. The comprehensive expense related IoT sensors installation and cloud-based software results to be approximately 10% (or even less) of the cost of hardware-based installations. Therefore, the current transition to IoT-enabled buildings may receive a considerable boost of installations in the near future, together with further cost decreases, especially considering how the technology has not reached maturity yet;

- IoT-based BMS provide *scalability opportunities thanks to enhanced connectivity*, enabling the 'smartization' of new buildings with hardly any extra costs incurred. Highly scalable smart buildings constitute a worthful business opportunity, especially for real estate companies, which could so create a connected and efficient building ecosystem.

Building / *Configuration*	***Diamond Tower***	***Corso Como Place***	***Fondazione Agnelli***	***NOI Tech Park***
BMS	IoT - based	IoT - based	IoT - based	IoT - based
Connectivity	Wired	Wireless	Wireless	Wired

Figure 38. Smart building configuration choices for the buildings analysed

As a last note, it may be worth pointing out some differences in the way connectivity systems have been configured for some of the buildings considered. As a matter of fact, configuration choices of a building communication protocol are mainly divided between wired and wireless systems, each one with its own set of affiliated advantages and disadvantages. The implementation of one category over the other is mostly dependent on the tenant/owner company profile. The case of Diamond Tower is emblematic to that effect: BNP Paribas, its only tenant, decided to implement a wired communication protocol, in order to exploit higher security, velocity, reliability and distance covered. The main focus of the firm is that of always guaranteeing service continuity and high connectivity performances, some fundamental requirements for ensuring optimal efficiency in a bank's operations and avoiding system collapses. For companies with lower standard requirements in terms of service continuity and velocity, wireless communication may be preferable, as it is less expensive and easily reconfigurable. Moreover, it better applies to retrofitting interventions on older buildings, such as in the case of Fondazione Agnelli, given its easiness of installation and the low invasiveness.

8 Conclusions

This chapter provides the conclusions of the study and comprehends two distinct parts. The first part aims at highlighting the innovative contribution brought by the thesis, while the second part reports the set of assumptions and limitations of the study, which are then leveraged in order to propose future developments.

8.1 Novelty of the study

The degree of novelty brought by the thesis derives from the attempt of analysing the impact of a smart building by considering all of the different outputs that can be generated from its investment. The thesis assumes a holistic perspective by targeting every process that smart buildings may affect (both positively and negatively, as in the case of increasing cybersecurity issues). Moreover, the thesis supports and applies the adopted perspective through the analysis of five use cases that provide evidence of some of the theorized outputs, both qualitatively and quantitatively. Besides, the thesis proposes a unique approach in delivering its own definition of the term 'smart building', by leveraging on the analysis of the main trends that characterized the diffusion of the concept, as well as on the two different perspectives – technology oriented or goal oriented – that could be assumed for determining its meaning.

8.2 Assumptions, Limitations and Future Developments

Assumptions and limitations of the research have to be found in the information gathering process for the design of suitable smart building business cases. In particular the following limitations are presented:

- *Limitation to the research area*: this study presents and analyses cases of buildings in the Italian territory, although valuable insights might come from cross-countries evaluations;

- *Limitation to the typology of building considered*: cases of facilities such as airports and hospitals have not been evaluated in this study, as the dynamics that govern their internal processes highly differ from those of conventional buildings, provided how any eventual quantitative and qualitative results could not be compared;

- *Main approximations in the investment analysis (where provided)*: in order to structure a fully comprehensive and detailed feasibility analysis of a smart building investment, plenty of information and data should be collected to cover for all the economic invoices and qualitative impacts addressed throughout the thesis. Therefore, information and data used for the case analysis are mostly presented in the form of aggregated invoices.

For what concerns possible future developments of the work, efforts should be concentrated into two directions, one dependent on the other:

- ♦ At business level, companies should try to optimally exploit the vast set of data gathered through monitoring processes. Currently, most of a firm's efforts are dedicated to the collection and processing of data on building energy performances, while the focus should be gradually extended also to other branches of the analysis, for which quantifiable results are not available yet;

- ♦ At both business and academic research level, efforts should be put in the realization of theoretical and empirical models aimed at mapping smart building performance outputs, following (as much as possible) generalized use cases classified according to the set of technologies implemented. Such approach would provide advance knowledge on the possible outcomes of a future specific investment. It might be concerned how models that reflect on real business applications have to be supported by a strong empirical activity, justifying the importance of the point previously explained.

Annex A: Questionario Smart Building Report

Il presente questionario ha l'obiettivo di raccogliere informazioni utili per esaminare l'impatto differenziale ottenuto in seguito all'adozione di soluzioni "smart" nella costruzione o riammodernamento di un edificio. L'impatto, ove possibile, viene generalmente misurato in termini di benefici economici ottenuti, partendo dai dati che è stato possibile raccogliere all'interno dell'edificio.

Il questionario è articolato in 4 sezioni: (1) Informazioni Generali, in cui vengono analizzate le caratteristiche dell'edificio e il processo cha ha portato alla sua costruzione/ammodernamento (2) Valutazione Investimento, in cui si cerca di valutare l'impatto economico differenziale in seguito all'implementazione di soluzioni "smart" per l'edificio. In particolare, sono state individuate cinque macro sezioni (a cui se ne aggiunge una facente riferimento a risultati "generici"), ciascuna rappresentante un'area dove poter generare valore aggiunto in seguito ad un investimento in una particolare tecnologia (3) Investimenti e Strategia, in cui vengono raccolte informazioni circa i vostri investimenti nel settore dello Smart Building e sulle opportunità e difficoltà del settore (4) Normativa, in cui vengono raccolte informazioni circa le principali norme, sistemi di incentivazione e di obbligo che stanno influenzando o promuovendo lo sviluppo del mercato dello Smart Building in Italia.

I dati raccolti verranno trattati in forma anonima e saranno aggregati per fornire indicazioni di tendenza e trend prospettici.

Le analisi effettuate su questi dati ed i principali risultati della ricerca saranno raccolti nello Smart Building Report (SBR) 2019, che verrà presentato ad inizio 2020 presso il Politecnico di Milano.

La definizione di Smart Building che viene adottata nello SBR 2019 è la seguente:

Smart building are digitally connected structures that combine optimized building and operational automation with intelligent space management to enhance the user experience, increase productivity, reduce (energy) costs, and mitigate physical and cybersecurity risks.

PARTE 1: INFORMAZIONI GENERALI

- Può brevemente illustrare il progetto? Quali sono stati i motivi che hanno spinto a realizzare un edificio "smart", e quali tra le parti coinvolte (sviluppatori, general contractor, investitori) erano orientate verso questo tipo di soluzione?
- Il progetto rappresenta un'opera di ristrutturazione oppure un edificio di nuova realizzazione?
- Può spiegare gli step fatti per la pianificazione e implementazione dell'edificio e/o delle tecnologie adottate al suo interno?

PARTE 2: VALUTAZIONE INVESTIMENTO

♦ **SEZIONE "RISPARMIO E MONITORAGGIO ENERGETICO"**

In questa sezione, si valuta l'utilizzo di tecnologie e soluzioni volte a favorire il monitoraggio dei livelli energetici all'interno dell'edificio, nonché la conseguente ottimizzazione degli stessi. In particolare, tre aree di intervento sono state individuate: **lighting**, **HVAC** (heating, ventilation, air conditioning) e **processes/appliances**. Si valuta inoltre il contributo legato all'utilizzo di fonti di energia rinnovabile, ed in particolare alla loro integrazione all'interno dell'edificio.

- LIGHTING
  - Tecnologia utilizzata (sensori, attuatori, impianti smart)?
  - Investimento (CAPEX e OPEX)?
  - Risparmi attesi (energia media consumata pre-intervento, energia media consumata post-intervento)?
  - Risparmi effettivi?

- HVAC
  - Tecnologia utilizzata (sensori, attuatori, impianti smart)?
  - Investimento (CAPEX e OPEX)?
  - Risparmi attesi (energia media consumata pre-intervento, energia media consumata post-intervento)?
  - Risparmi effettivi?

- PROCESSES/APPLIANCES

  La seguente sezione si riferisce al consumo di energia relativo alle varie attività di processo svolte all'interno dell'edificio (utilizzo delle apparecchiature informatiche, elettrodomestici, forze motrici):

  - Tecnologia utilizzata (sensori, attuatori, impianti smart)?
  - Investimento (CAPEX e OPEX)?
  - Risparmi attesi (energia media consumata pre-intervento, energia media consumata post-intervento)?
  - Risparmi effettivi?

- È stato sviluppato un software per la gestione integrata di tali applicazioni? Quali sono i vantaggi che ha fornito rispetto ad una gestione "isolata" in termini di risparmio energetico?
- Più in generale, come viene strutturata l'architettura del software di gestione?
- L'edificio è dotato di impianti per la generazione di energia da fonti rinnovabili? Se sì, come viene integrata la produzione di energia con le diverse applicazioni all'interno dell'edificio? Che risparmi sono stati ottenuti grazie alla gestione integrata di tali risorse?
- Per quanto riguarda l'infrastruttura per la trasmissione dati, che tipo di configurazione è stata utilizzata per il bus di collegamento? Wired (cablato) oppure wireless?

♦ **SEZIONE "OTTIMIZZAZIONE DELLO SPAZIO DI LAVORO"**

In questa sezione, si valuta l'utilizzo di tecnologie e soluzioni volte a favorire il monitoraggio e la gestione dello spazio di lavoro, al fine di poterne ottimizzare l'utilizzo in termini di tempo e capacità. Ne conseguirebbe un risparmio atteso in termini di costi sostenuti (gestione, manutenzione, consumo energetico).

- Che interventi sono stati fatti per il controllo/monitoraggio dello spazio di lavoro (sensori, attuatori)? Qual è stato il costo relativo a tale investimento (CAPEX e OPEX)?
- Che risultati sono stati conseguiti? Che tipologia di dati sono stati raccolti?
- (Caso di building già esistente) È stato possibile "liberare" alcuni spazi di lavoro per nuove applicazioni?
- Quali risultati/benefici sono attesi in futuro grazie a tale intervento?

- **SEZIONE “PEOPLE”**

In questa sezione, sono valutati gli interventi effettuati al fine di garantire un maggiore livello di benessere degli occupanti all’interno dell’edificio. Ciò porterebbe ad un incremento del rendimento atteso dei lavoratori all’interno dell’edificio, in modalità differenti: sia stimolando partecipazione e interazione, sia diminuendo il tempo di inattività atteso.

- Quali sono state le aree di applicazione valutate per migliorare il benessere interno all’edificio?
- Che tecnologia ha contributo alla raccolta e gestione dei dati relativi al benessere/produttivita delle persone internamente all’edificio (sensori, attuatori, impianti smart)?
- È stato possibile quantificare eventuali risultati in termini economici? Che tipo di analisi, assunzioni e considerazioni sono state fatte in tal senso?
- Il ritorno atteso può considerarsi positivo?

- **SEZIONE “SECURITY”**

In questa sezione, si valuta il contributo relativo ad investimenti atti ad aumentare il livello di sicurezza interna all’edificio, in termini di **“physical security”** e **“cybersecurity”**.

- PHYSICAL SECURITY

  Questa sezione valuta l’impatto di investimenti volti a diminuire la probabilità di danni causati da fonti esterne (furti, danni a strutture, rischio incendi, etc.), migliorando il sistema di sicurezza interno all’edificio.

  - Quali tecnologie sono state adottate (sensori, attuatori, impianti smart)?
  - È stato possibile quantificare i miglioramenti conseguiti (e conseguibili)? Attraverso quali analisi e assunzioni?

- CYBERSECURITY

  Questa sezione valuta l’impatto di investimenti volti a diminuire la probabilità di cyber-attacchi ad ogni livello dell’infrastruttura di supervisione e controllo (livello “field”, livello “automation” e livello “management”). Al fine di una corretta valutazione differenziale, l'analisi deve tenere conto del maggior rischio di cyber-attacchi dovuto all'adozione di tecnologia IoT e software di gestione centralizzati.

- Quali tecnologie sono state adottate?
- È stato possibile quantificare l'aumento di rischio e l'impatto atteso (in termini economici) dovuto a cyber-attacchi in caso di sensori wireless e software di gestione centralizzato?
- È stato possibile quantificare i miglioramenti conseguiti (e conseguibili)? Attraverso quali analisi e assunzioni?

♦ **SEZIONE "WASTE AND WATER MANAGEMENT"**

In questa sezione, si analizza l'impatto differenziale ottenibile attraverso l'adozione di soluzioni volte ad ottimizzare l'utilizzo, la gestione ed il controllo delle risorse (non energetiche) interne all'edificio (risorse idriche, rifiuti).

- Quali sono stati gli interventi effettuati (sensori, attuatori, impianti smart) e quali tipologie di dati sono state raccolte?
- È stato possibile quantificare eventuali risultati in termini economici? Che tipo di analisi, assunzioni e considerazioni sono state fatte in tal senso?
- Il ritorno atteso può considerarsi positivo?

♦ **SEZIONE "DATI GENERALI SULL'INVESTIMENTO"**

In questa sezione, si analizzano i risultati conseguiti attraverso l'investimento che non fanno riferimento ad una sezione in particolare. A tal proposito, si fa principalmente riferimento ai benefici ottenuti attraverso la manutenzione predittiva ed alla gestione centralizzata di tutte le attività di cui sopra (in questo ultimo caso, si valuta anche il contributo negativo dovuto ai possibili rischi di una tale gestione, in termini di privacy e continuità del servizio). Inoltre, si valutano possibili problemi riscontrati in termini di interazione con l'utenza (accettazione delle nuove tecnologie da parte dei residenti/lavoratori).

- Quali benefici sono stati riscontrati sfruttando la manutenzione predittiva (in caso fosse resa possibile dai sistemi di rilevazione)?

- Attraverso l'utilizzo di un software di gestione centralizzato, quali sono stati i benefici e i problemi riscontrati? (benefici: ottimizzazione del monitoraggio; problemi: privacy e service continuity)
- Sono emersi problemi per quanto riguarda l'accettazione del cambiamento da parte dei residenti/lavoratori? È stato eventualmente quantificato il costo degli interventi volti a favorire l'integrazione di tali persone con le nuove soluzioni nell'edificio?

PARTE 3: INVESTIMENTI E STRATEGIA

- Da quanto tempo siete attivi nel mercato degli Smart Building? A quanti progetti di realizzazione o ricostruzione in ottica Smart Building avete partecipato fino ad oggi?
- Ritenete che i benefici siano sempre superiori ai costi sostenuti? Oppure ci sono casi di investimento che ad oggi non sono redditizi?
- Quali sono a vostro giudizio le principali barriere allo sviluppo del mercato dello Smart Building in Italia? Più in particolare, quali barriere avete riscontrato nell'implementazione del progetto svolto?
- Quali nuove applicazioni smart verranno implementate in futuro all'interno degli edifici?

PARTE 4: NORMATIVA

- Quali obblighi/normative/incentivazioni/certificazioni hanno influenzato l'investimento?
- Quali sono a vostro giudizio le principali norme, sistemi di incentivazione e di obbligo che stanno influenzando o promuovendo lo sviluppo del mercato dello Smart Building in Italia?
- Quale ritenete che sia e che sarà nei prossimi 5 anni il loro impatto sul mercato in Italia?
- Quali sono i paesi internazionali che hanno a vostro giudizio un sistema di norme, sistemi di incentivazione e di obbligo più virtuosi che potrebbero favorire lo sviluppo del mercato dello Smart Building in Italia?

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