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Construction Engineering

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Rise, evolution and future opportunities of Smart Buildings

The definition of a framework to understand occupants' needs and expectations from smart technologies

Supervisor: Prof. Arch. Giuliana Iannaccone

Co-Supervisors: Ing. Francesca Grignani, Ing. Marco Merla

Student: Valentina Mori - 896824

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ABSTRACT

English

The Smart Buildings topic spread rapidly during the last years in the building field, generating curiosity both among the operators of this sector and less expert people.
Before reaching the Smart Building concept as it is intended nowadays (buildings aiming at satisfying in the best way possible the users' needs) several phases took place, presented in this research in Chapter 1.
The first step was the realization of Green Buildings, which objective was the reduction of CO2 emissions and consumptions optimisation.
Starting from the first years of XXI century, experts felt the need of new tools allowing to reach the same goals that were pushing towards the realization of green buildings. The tecnological evolution led to the recognition of modern technologies as possible allies for the realization of the first smart buildings. They are defined as Smart-Sustainable because of their primary purpose: to reduce the environmental impact of the building itself.
After 2010, the interest of building sector operators moved towards the user and his necessities. For this reason, the Smart Buildings realized in the last years are called "People-Oriented".
Also during this phase, technologies play a key role. Moreover, they are developed and differentiated according to the building typology they have to serve: offices, hospitals, museums, universities, shopping malls, airports and residential buildings are characterized by different smart systems because of the different users' needs.
To understand the direction towards which the smart technologies are moving, it has been developed a tool that aims at understanding needs and expectations of both who designs buildings and who lives inside them. A 15 questions survey has been written and shared thanks to the collaboration of Deerns, Urban Land Insitute and Politecico di Milano.
The conclusions are coherent with the fact that people-oriented design is becoming the key feature of a smart building: experts of building secotr would define a Smart Building as focused on user wellbeing and experience. However, while professional figures are aware about these topics, simple occupants still believe that the basic feature of a Smart Building is the high energy efficiency. The preferred technologies for each building typologies are identified, as the main advantages of a Smart Building. According to the 200 respondents the greatest advantage is the realisation of an healthier environment, thanks to the adoption of smart technologies.

ABSTRACT

Italiano

Gli edifici intelligenti (più comunemente noti come Smart Buildings) sono un argomento di discussione che negli ultimi anni si è velocemente diffuso nel mondo dell'edilizia, destando curiosità ed interesse sia tra gli operatori del settore che tra i meno esperti.

Prima di arrivare al concetto di Smart Building per come è inteso oggi, ovvero edifici volti a soddisfare al meglio le esigenze degli utenti, si è passati attraverso diverse fasi, presentate in questa ricerca nel Capitolo 1.

Il primo passo è stato quello degli edifici sostenibili (Green Buildings), il cui obiettivo era di ridurre le emissioni di CO2 ed ottimizzare i consumi. A partire dai primi anni del XXI secolo, gli esperti hanno iniziato a cercare nuovi sistemi ai fini di raggiungere gli stessi scopi che stavano spingendo verso la creazione di edifici green. L'evoluzione tecnologica ha portato ad individuare proprio nelle moderne tecnologie delle possibili alleate per la realizzazione dei primi edifici Smart, che vengono definiti come edifici intelligenti-sostenibili proprio in virtù del loro obiettivo principale: ridurre l'impatto ambientale dell'edificio stesso.

Dopo il 2010, l'interesse degli operatori del settore si sposta verso l'utente e le sue necessità. Per questa ragione, gli edifici intelligenti realizzati negli ultimi anni vengono definiti come People-Oriented buildings. Anche in questa fase, le tecnologie svolgono un ruolo chiave, si sviluppano e si differenziano a seconda della tipologia edilizia che vanno a servire: uffici, ospedali, musei, università, centri commericiali, aeroporti ed infine edifici residenziali sono caratterizati da sistemi intelligenti diversi in quanto, in ciascuna delle tipologie elencate, gli utenti hanno bisogni differenti a cui rispondere.

Per comprendere la direzione che le tecnologie smart prenderanno nei prossimi anni, è stato sviluppato uno strumento volto ad evidenziare le aspettative ed i bisogni sia di coloro che progettano, sia di chi abita gli edifici. Un questionario di 15 domande è stato redatto e successivamente diffuso grazie al supporto di Deerns, Urban Land Institute e del Politcenico di Milano.

Le conclusioni sono coerenti con il fatto che il People-Oriented Design sta diventando la caratteristica fondamentale degli edifici intelligenti: gli esperti del settore definirebbero uno Smart Building come un edificio orientato verso il benessere e l'esperienza dell'utente.

Tuttavia, mentre le figure professionali del settore sono a conoscenza di queste tematiche, i semplici occupanti immaginano uno Smart Building come un edificio ad alta efficienza energetica. Sensori capaci di monitorare la qualità dell'aria, sistemi di riscaldamento e raffrescamento automatici e Smart Bins sono tra le tecnologie che risultano più apprezzate. Inoltre, la realizzazione di spazi più salutari - derivante dall'utilizzo di tecnologie smart - è la caratteristica vincente di uno Smart Building, secondo gli intervistati.

Objectives and Methodologies

This thesis work has been developed starting from April 2019 in collaboration with Deerns, a consulting company that provides engineering services for the built environment.

The fundamental purpose of the research is to allow Deerns to have an overview of the Smart Buildings field: available technologies for the different building typologies, tendencies in terms of smart devices, possible problems related to the application of new technologies in buildings and ways through which it is possible to face these issues. In this way, the company has a tool through which orientate its design choices, market decisions and construction strategies.

Moreover, this research is inserted in the literature related to the Smart Buildings topic, which is trying, in the last five/ten years, to find an exhaustive definition of this emerging building typology. Many scientific papers and technical articles have been published, and some of them constitute also part of the bibliography of this thesis work. Under this point of view, the purpose of the research is to add a useful piece to the puzzle that is outlining definition and key aspects of Smart Buildings.

Since the Smart Building issue is an innovative aspect in the Buildings framework, it has been necessary to find tools able to help in the prediction of future perspective and possibilities. For this reason, together with the literature review, two other methodologies have been adopted along the research path. First, the analysis of existing innovative buildings, developed by Deerns and other companies, in which some smart devices have been implemented. Thanks to the study of buildings equipped with smart technologies it is possible to have a first overview of what already exists, how it works, and which are the possible problematic that may emerge in this innovative type of buildings. Moreover, the security systems are analyzed and investigated, in order to understand how they operate and if they are able to solve the basic issues rising from the adoption of Smart technologies.

The study of future perspectives of Smart Building Field is accomplished in this research through the use of the questionnaire methodology. In this way, it is possible to investigate the perception of both users and professional about smart technologies. The questionnaire has been diffused thanks to the collaboration with ULI, the oldest and largest network of cross-disciplinary real estate and land use experts in the world. An online platform, called Online Surveys, has been used for the survey diffusion and the answers collection.

After having collected all the answers, their elaboration has been performed by using Excel sheets. The key point is to understand the different perception of occupants and experts of building field, in relation to Smart technologies applied to different building typologies. These are the two filters

applied for the reading of the answers, but the whole answer sheets are provided in order to allow future researches to have a full overview about them.

This research is only a small part of all the studies that have been realized and that will be performed about such a complex and variable theme like the Smart Buildings one. The research aims to be not only a conclusion, useful to Deerns and other possibly interested engineering companies, but also a starting point for many other studies, which may exploit the questionnaire outcomes and the literature analysis here proposed to investigate more and more the Smart Buildings issue.

Introduction

This thesis work aims at providing a clear vision of the smart building field, from the basic definitions to the several technologies that characterize this new typology of building. After a preliminary analysis of the smart building concept, and the description of different building typologies where smart systems and devices can be successfully applied, the research will focus on people needs and expectations from a smart environment. Different actors of the building sector will be interviewed through a questionnaire, in order to understand which technologies can have room for future development in accordance with people requirements. The questionnaire will be submitted not only to the final users of the buildings, but also to the owners, the facility managers, the architects and the designers of all the technical aspects (envelope, systems, structure etc.) of the building. In this way, it is possible to trace a map of all the needs of the building sector's actors in order to discern which will be the smart technologies on whose development the companies should push more, and that will probably be the future of the smart building field.

The most diffuse definitions

Recent studies demonstrated that in the last 200 years people have changed radically their habits, especially in relation to the time spent indoor and outdoor. It has been estimates that inhabitants of industrialised countries spend almost 90% of their lives in closed spaces (YouGov 2018): the majority of the world population can be defined as the "Indoor generation", living inside the walls of houses, offices or other building typologies the majority of their time.

These dramatic numbers contributed to the growth of people's interest towards those buildings, rooms or spaces where the everyday life is facilitated and improved by using the so-called smart technologies. These considerations may explain the fact that the concept of smart building is spreading more and more in the common language. Books, magazines, scientific papers, articles: they all propose their own definition and vision of the concept of smart building, but what it actually is? Is it possible to find a complete and exhaustive definition of such a complex and contemporary topic?

Most of the time, instead of a real definition, the explanation of the intent of a smart building is presented: rather than assert what a smart building is, the focus is shifted on what a smart building does or should do. "*Smart Buildings today are aimed at providing safe, healthy, comfortable, affordable, and beautiful spaces in a carbon and energy-efficient way*" affirm Ruoxi Jia and his team

in the article "Design Automation for Smart Building Systems" (Jia, et al. 2017). From this perspective, the goal of a smart building should be to ensure a high level of indoor comfort and a health environment where people can live, work or spend time. Moreover, great importance is given to the way in which a smart building shall accomplish these purposes: in a carbon and energy efficient way. This definition emphasises a connection between Smart Buildings and energy efficient ones. However, is a smart building only a green building?

The energy efficiency issue, linked to the definition of smart building, is treated also by the BPIE (Buildings Performance Institute Europe) who comes up with three basic requirements that a Smart Building has to fulfil (BPIE 2016):

- It should drive a fast decarbonisation of the energy system through energy storage and demand flexibility;
- It should empower its users and occupants with control over the energy flows;
- It should recognise and react to users' and occupant' needs such as comfort, health and wellbeing, as well as operational performance.

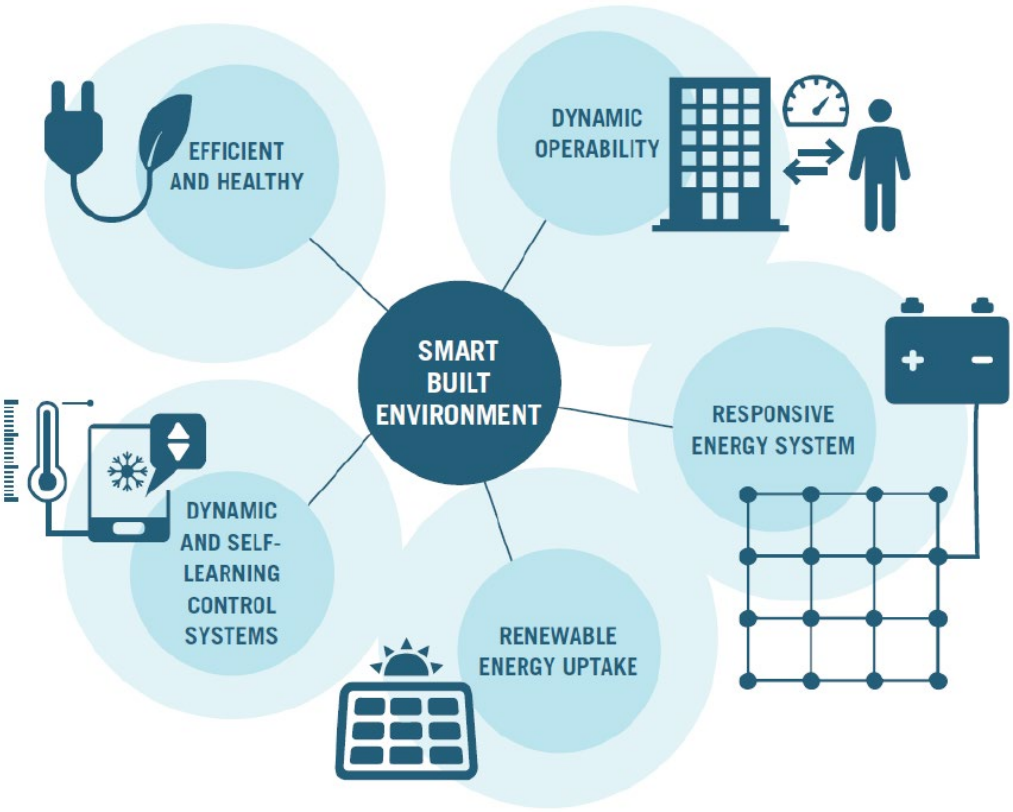


Figure 1 - Five pillars of a smart built environment (Source: Building Performance Institute Europe, "Smart Buildings in a decarbonised energy system")

The energetic performance of the building is the key point of four out of the five pillars of a smart building environment. The responsiveness of the building is related not only to the users' needs, but also on the environmental aspects such as energy consumption and renewable energy sources.

Shifting the focus on other "common" characteristics of Smart Buildings, an aspect that is often present in the definitions is the link with technologies. The European commission presents a Smart Building as a "*set of communication and IoT[1] 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*". Communication and automation are the two key words of this definition (Building Performance Institute Europe 2017): a building, to be smart, has to include automated technologies and sensors, which are able to interact one with the other so that they can operate in the best possible way. However, this kind of definition misses an element that is crucial when dealing with buildings: the users. This missing ingredient is included in C. Papatsimpa and J.P.M.G. Linnartz's description of Smart Buildings: *"A building is smart when it is responsive and to its inhabitants and it is able to adapt autonomously in sophisticated ways*" (Papatsimpa and Linnartz 2018). The inhabitants here are the focus, and the technologies are nothing but a mean to reach a better life quality inside the building itself.

These Smart Buildings definitions summarize in a proper way all the main features that are highlighted in the bibliography related to this issue. The energy efficiency, the presence of smart devices all connected in the IoT (Internet of Things) and the idea of improving and facilitate the everyday life of the users are the most discussed topics by experts and journalists when referring to a Smart Building Environment.

What is necessary to understand is if one of those features proposed in the different definitions is, or is going to be, the predominant one. The diffusion of the so called *"People Oriented Design"*, that will be deeply analysed in Chapter 2, suggests that the indoor comfort, and in particular the wellbeing and the health of buildings' users are going to become the focus of the Smart Buildings Design, and all the new developments and technologies shall be oriented towards this direction.

[1] The Internet of things (IoT) is the extension of Internet connectivity into physical devices and everyday objects. Embedded with electronics, Internet connectivity, and other forms of hardware (such as sensors), these devices can communicate and interact with others over the Internet, and they can be remotely monitored and controlled.

The historical Journey: from the past, to the present and towards the future

The analysis of the path of the smart building topic is crucial, in order to accomplish the purpose of this research work: identify the future of the smart technologies in accordance with people's necessities and what they expect from them. The only way to figure out what will happen in the future is to investigate the past: the study of the historical journey may be helpful to identify the milestones reached during the pathway from traditional buildings, passing through the green and sustainability issue, until the arise of the smart building topic.

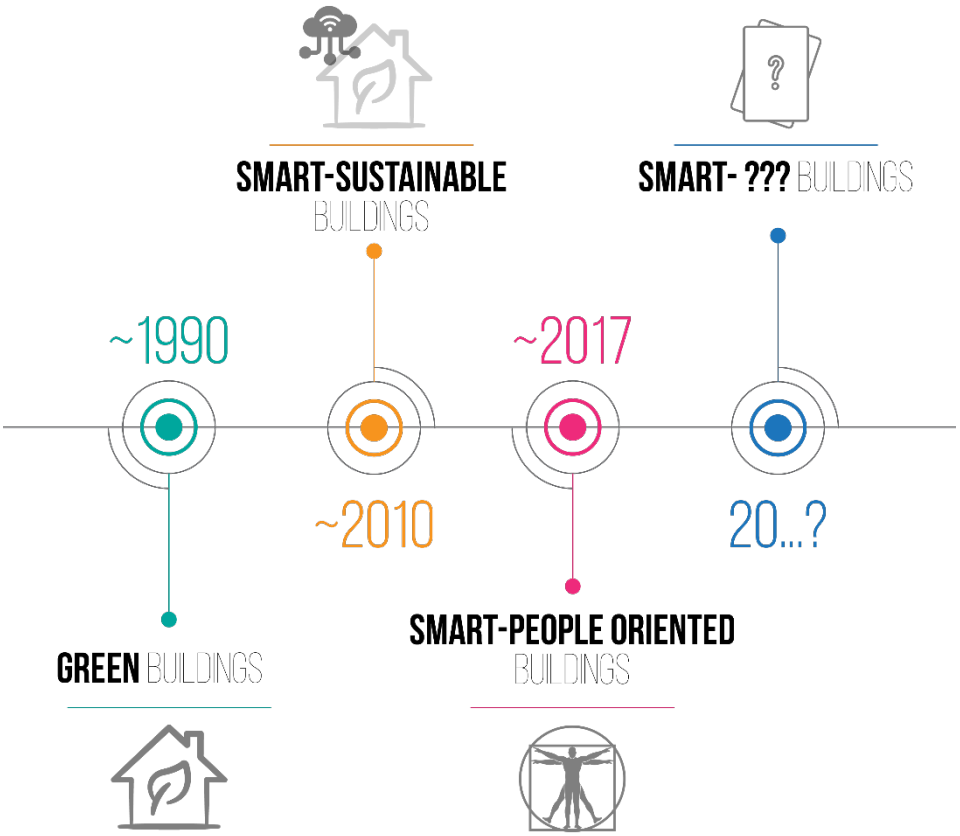


Figure 2: Diagram of the historical journey (Source: the author)

CHAPTER 1

The past: Smart Buildings oriented towards sustainability

The smart buildings can be seen as heirs of the green buildings, which in the past years have been the greatest innovation of the building sector. The analysis of these ancestors may be helpful in order to fully understand the pathway from the traditional buildings to the smart ones. Once the green buildings historical background is clear, it is important to point out that from 2010 the actors of the building field started to find new ways in order to realize green buildings. Technologies began to seem a good opportunity for the realization of sustainable buildings, and the experts decided to deeply explore them in order to answer to the increasing demand for a more sustainable approach in the construction sector. sustainabilityThe past: smart buildings oriented towards sustainability.

1.1 A step back: a revolution in the building sector

At the end of twentieth century, it started a revolution in the building sector, which has led to the implementation of green buildings. This step was crucial in the path started from the traditional building of the past towards the development of the modern smart building; for the first time, people started to feel the need to realize buildings able to respond to the changing needs of both people and environment.

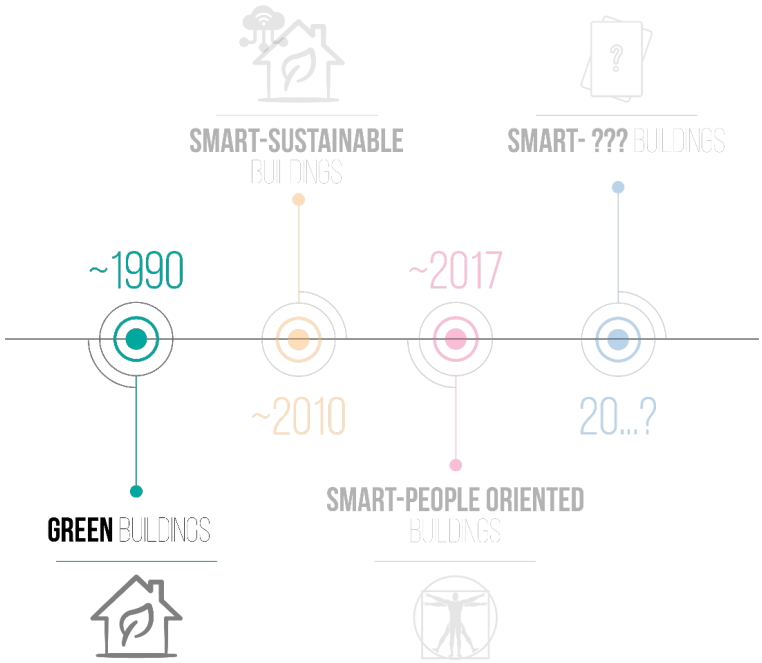


Figure 3 - Diagram of the historical journey, focus on the step back (Source: the author)

1.1.1 Historical framework: green buildings and the Passive Haus standard (1990-2010 ca.) (EESI 2017)

The key moment that pulled the trigger on a revolution in the building field was the climate change issue, which started to become a common concern at the end of the past century. During the first years of 1980s, there was a strong increase in global temperatures, and many experts point to 1988 as a watershed year, which placed global warming in the spotlight. NASA scientist James Hansen delivered testimony and presented models to a congress in June of 1988, saying he was "*99 percent sure that global warming was about to becoming a worldwide diffused concern*".

In 1989, the Intergovernmental Panel on Climate Change (IPCC)[2] was established under the United Nations, to provide a scientific view of climate change and its political and economic impacts. As global warming gained currency as a real phenomenon, researchers dug into possible ramifications of a warming climate. Among the predictions, there were warnings of severe heat waves, droughts and more powerful hurricanes, fuelled by rising sea surface temperatures. When these themes started to spread all around the world, government leaders began discussions to try to reduce the outflow of greenhouse gas emissions, in order to prevent the most terrible predicted outcomes. The first global agreement to reduce greenhouse gases, the Kyoto Protocol, was adopted in 1997: the protocol, signed by President Bill Clinton, called for reducing the emission of six greenhouse gases in 41 countries plus the European Union to 5.2% below 1990 levels during the target period of 2008 to 2012.

It has been proved (EESI 2017) that buildings and construction sectors combined are responsible for 36% of global final energy consumption and nearly 40% of total direct and indirect CO2 emissions. Once the Kyoto Protocol was emitted, the actors of the building sector recognized the necessity of a drastic change in the design approach, in order to reduce the environmental impact of buildings on the global warming. In accordance with these concerns, the green building field began to come together more formally in the 1990s.

Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life cycle, from siting to design, construction, operation, maintenance, renovation and deconstruction. Green building is also known as a sustainable or high-performance building.

In the first year of the green building movement, the passive strategies were at the basis of the high-performance buildings: renewable energy sources, optimal orientation and glazed surface positioning, insulation, good design for the natural ventilation were the fundamental elements that constituted the sustainable buildings (Passive House Alliance 2016).

By the late 1990s, a full passive house movement started spreading in North America, but the United States shifted its focus away from energy conservation, and Germany took the reins. German physicist Wolfgang Feist refined the passive house design to improve building efficiency and he

[2] The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. It was created in 1988 by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP), the objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies. IPCC reports are also a key input into international climate change negotiations.

developed a passive house with an annual heating demand of 15 kWh/m^2. This became a defining metric after Feist founded the Passivhaus Institute (PHI) and created the Passivhaus performance standard, commonly considered the most rigorous standard in energy efficiency until 2016 (Passive House Alliance 2016).

During this period, especially between 1990 and the first years of the twenty-first century, the most diffuse means for realizing green buildings were passive strategies, and the development of more advanced technologies in order to accomplish in an easier way the target of the high performance building started between 2005 and 2010 (Erickson, et al. 2009).

1.2 Historical Framework: IoT development and the first formulations of the smart building concept (2010-2017 ca.)
(Lilis, et al. 2016)

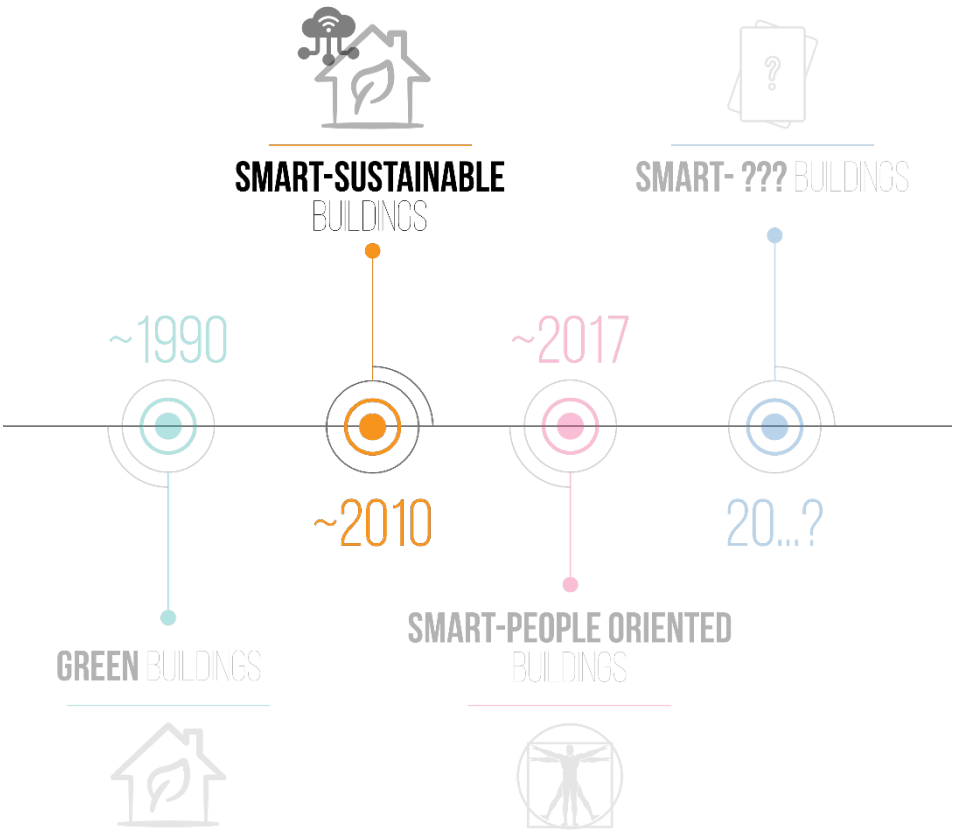


Figure 4 - Diagram of the historical journey, focus on the past (Source: the author)

In recent years, the idea of green and sustainable building started to cross the smart building concept, as the definition presented in the previous chapter demonstrate. Moreover, the diffusion of the IoT[3] pushed in the direction of a more technological approach in the building field.

The terms "Internet of Things" has been coined in 1999 by an American researcher, Kevin Ashton, who understood the great potential of internet and the importance that it will have had in every aspect of life in the future years. Almost five years later, the main American news organizations started to discuss about the IoT topic, and RFID[4] sensors began to be diffused on a large scale, inside many products in the US market. For what regards Europe, the IoT started to circulate between 2006 and 2008, and the first European IoT conference took place.

In 2008 a group of different societies launched the IPSO alliance (IP for Smart Objects alliance), in order to promote the diffusion and the development of the IoT technologies. Today this alliance counts more than 50 partners, including Bosh, Ericsson, Intel, Google and Fujitsu.

The key year for the IoT was 2008, during which it is possible to say that the IoT started to be not only an ideology, but also a real connection between Internet and the objects, and, as a consequence, between internet and people (Breghiroli 2016). The number of devices connected to Internet reached 12.5 billion, for a rate of 1,84 each person in the world. Finally, in 2009, the National Intelligence Council of USA inserted the IoT in the list of the six civil technologies more disruptive, recognising its potential and the impact that it may have had in the future years both in the United States and in the rest of the word.

For what regards specifically the building sector, in the first years of the 2010s, the energy efficiency of a building became one of the fundamental features that a building should have had in order to be defined smart. The difference between the green building and the smart- sustainable building is that the first one is concerned only of the environmental impact, while the second one introduced a new variable in the design: the user. The smart building in its first conception is a building that has to be energy efficient but at the same time has to ensure proper indoor conditions in terms of temperature and air quality to the occupants, by exploiting the possibilities and the technologies offered by the IoT.

[3] Internet of Things

[4] Radio-frequency identification (RFID) uses electromagnetic fields to identify automatically and track tags attached to objects. The tags contain electronically stored information. Passive tags collect energy from a nearby RFID reader's interrogating radio waves. Active tags have a local power source (such as a battery) and may operate hundreds of meters from the RFID reader. Unlike a barcode, the tag need not be within the line of sight of the reader, so it may be embedded in the tracked object. RFID is one method of automatic identification and data capture (AIDC).

The possibility for the user to control the main environmental parameters is the greatest innovation between 2010 and 2013, but it has the same importance as the energy optimisation issue. "*A smart built environment takes advantage of the full potential of ICT*[5] *and innovative systems to adapt its operation to the needs of the occupant, to improve its energy performance and to interact with the grid"* stated De Groote, Volt and Bean (De Groote, Volt e Bean 2013). "*Smart Buildings can play a leading role in transforming the EU energy market, by transforming it into a more decentralised, renewable-based, interconnected and variable system that maximises efficiency and ensures that all resources are used in an optimal way, while at the same time enabling a better living and working environment for the occupants".* It emerges that the smart building concept is still strictly related with the idea of the high-energy efficient building, coupled with the technologies offered by the IoT, but at the same time, new themes such as the idea of a better indoor environment, in terms of comfort for the user, are emerging.

Having clarified the historical step related to the period 2010-2017, it is important to describe how it is defined a smart building in this period, and which are the smart technologies and devices installed in it.

As the term "**Smart-Sustainable**" suggests, it emerges that the energy consumption and the buildings' emissions have a central role when dealing with Smart Buildings in the period between 2010 and 2017. With this in mind, it is necessary to understand which the "standard" technologies that characterize a Smart Building in its basic conception are, and that in almost all the articles and papers are presented.

A preliminary analysis of the main topics discussed in the bibliographic references displays that the Energy efficiency and sustainability issue, together with the smart HVAC systems that ensure an optimisation of consumptions, are the most diffused matters. They are flanked by the presentation of technologies like smart lighting or occupancy sensor, which allow managing in a smart way the comfort of people inside the building and the energy consumptions.

[5] Information and Communication technologies. ICT refers to technologies that provide access to information through telecommunications. It is similar to Information Technology (IT) but it focuses primarily on communication technologies. This includes the Internet, wireless networks, cell phones, and other communication mediums.

1.3 The technologies: smart - sustainable buildings

The literature related to the Smart Buildings topic reports some technologies and characteristics that are at the base of a Smart Building, intended as a smart-sustainable one. These systems can be divided in three categories: smart HVAC system with energy monitoring appliances, lighting management and smart windows

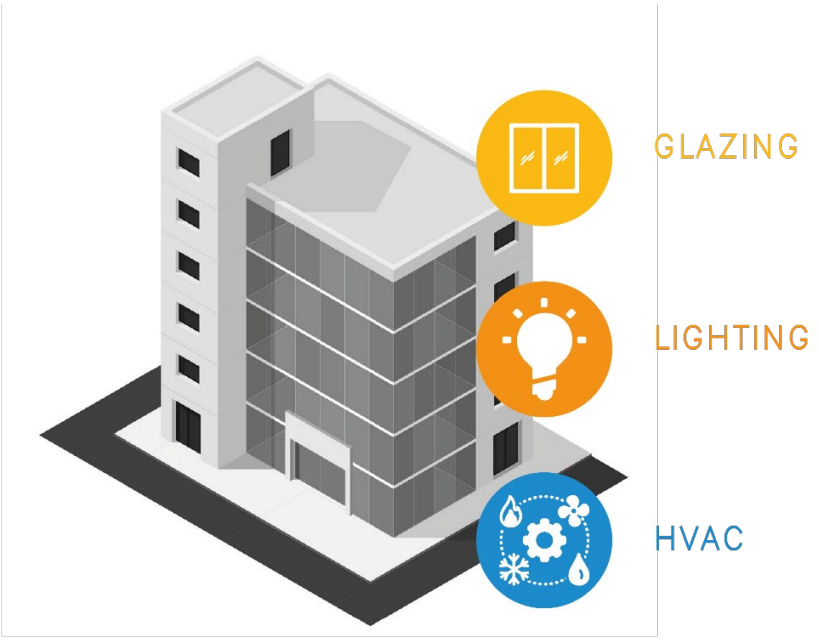


Figure 5 – Three main categories of technologies applied in Smart Buildings between 2010 and 2017 (Source: European Commission, "Smart Building: Energy efficiency application", October 2017)

1.3.1 The smart HVAC systems

The first most mentioned technology when discussing about Smart Buildings between 2010 and 2017 are the smart HVACs. The European commission presents them as systems which are linked with different types of sensors and that have the ability to adjust quickly and automatically according to weather forecasts, occupancy and ineffective systems.

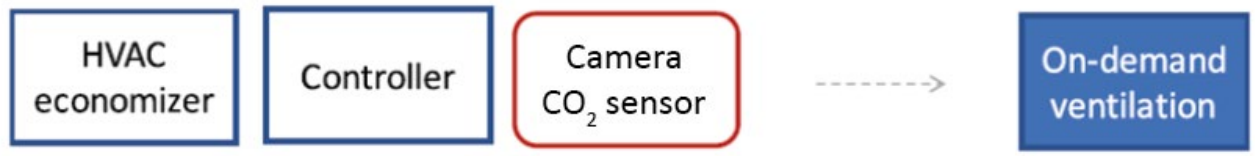


Figure 6 - Smart HVAC system basic components (Source: Ruoxi Jia, Baihong Jin, Ming Jin, Yuxun Zhou, Ioannis C. Kostantakopoulos, Han Zou, Joyce Kim, Dan Li, Weixi Gu, Reza Arghandeh, Pierluigi Nuozzo, Stefano Schiavon, Alberto L. Sangiovanni-Vicentelli, Costas J. Spanos, "Designing Automation for Smart Building Systems", 18/07/2018)

A demand control ventilation system must include an economizer (or air makeup unit) with modulating damper[6], a sensing device such as a camera that counts the number of people in the space, and a controller to communicate either directly with the economizer controller or with a central control system (Jia, et al. 2017).

The main characteristic of a smart HVAC system is to use dynamic temperature set points for heating and cooling equipment: this is useful in reducing the energy consumption up to 40% during the year (Rocha, Siddiquia and Stadlerc 2014). The "dynamism" of the set point temperatures regulating the HVAC system is a quite discussed topic: it has been demonstrated (Groissbock, et al. 2014) that energy consumed for meeting buildings' heating requirements may be reduced by over 10% by operating the equipment in a way that is more responsive to external conditions. They implemented a so-called dynamic temperature set point method, which allows the zonal temperature to fluctuate in a user-specified range, on one public building in Austria and another in Spain (Rocha, Siddiquia and Stadlerc 2014).

According to the model proposed by Paula Rocha, Afzal Siddiquia and Michael Stadlerc, the users express a preference in terms of desired temperature range. The smart HVAC system determines the flow rates of air and water in the cooling and heating systems that maintain the zone temperature

[6] A modulating actuator positions the damper (or valve) as commanded by the controller to achieve a desired position or flow, differently from an open/close, or on/off, control signal which produces a two-position response (0% open or 100% open) for the damper.

in the desired range, taking into account the external temperature, the solar gains, the building's shell, and the internal loads (Rocha, Siddiquia and Stadlerc 2014).

When discussing about smart HVAC systems it is important to consider also the users: what is relevant is the idea of thermal comfort, an important indicator of overall building performance. It is defined as "*that expression of mind which expresses satisfaction with the thermal environment*"[7]. Since thermal comfort is personally determined and differs substantially between people, it is not easy to quantify and analyse as a numerical value. Many researchers have investigated the parameters influencing thermal comfort in attempts to identify thermal comfort zones acceptable to the greatest number of people. An example of a model developed to "quantify" the thermal comfort is the Predicted Mean Vote (PMV) index. Fanger developed it in 1970s and nowadays it is the most well-known thermal comfort model. To determine thermal comfort, this model evaluates six parameters: indoor air temperature, mean radiant temperature, relative humidity, air velocity, clothing, and metabolic rate of the occupant. The thermal comfort index is obtained as follows:

Acronym	Meaning	Unit of measure
PMV	Predicted Mean Vote index	-
M	Metabolic Rate	W/m^2
W	Rate of Mechanical Work	W/m^2
P_a	Partial water vapour pressure	Pa
t_a	Indoor Air Temperature	°C
t_{cl}	Surface Temperature of Clothing	°C
t_r	Mean Radiant Temperature	°C
f_{cl}	Clothing Surface Area Factor	-
I_{cl}	Thermal Resistance of Clothing	m^2°C/W
h_c	Convective heat transfer coefficient	W/m^2°C
v_{ar}	Air Velocity	m/s
h_r	Relative Humidity	%

Table 1: Summary of the variables involved in the PMV definitions

$$\boldsymbol{PMV} = \left[0.303 \cdot e^{(-0.036 \cdot M)} + 0.028\right] \cdot L$$

[7] Definition given by the American Society of Heating, Refrigerating, and Air-Conditioning (ASHRAE).

$$\boldsymbol{L} = (M - W) - 3.5 \cdot 10^{-3} \cdot [5733 - 6.99 \cdot (M - W) - P_a] - 0.42 \cdot [(M - W) - 58.15] - 1.7 \cdot 10^{-5} \cdot M \cdot (5867 - P_a) - 0.0014 \cdot M \cdot (34 - t_a) - 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\overline{t_r + 273})^4\right] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a)$$

$$\boldsymbol{t_{cl}} = 35.7 - 0.028 \cdot (M - W) - I_{cl} \cdot 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\overline{t_r + 273})^4\right] - I_{cl} \cdot f_{cl} \cdot h_c \cdot (t_{cl} - t_a)$$

$$\boldsymbol{h_c} = \begin{cases} 2.38 \cdot |t_{cl} - t_a|^{0.25}, if\ 2.38 \cdot |t_{cl} - t_a|^{0.25} > 12.1\sqrt{v_{ar'}} \\ 12.1\sqrt{v_{ar'}}, if 2.38 \cdot |t_{cl} - t_a|^{0.25} \leq 12.1\sqrt{v_{ar'}} \end{cases}$$

$$\boldsymbol{f_{cl}} = \begin{cases} 1 + 1.29 \cdot I_{cl}, if\ I_{cl} \leq 0.078 \\ 1.05 + 0.654 \cdot I_{cl}, if\ I_{cl} > 0.078 \end{cases}$$

$$\boldsymbol{P_a} = h_r \cdot 6.1094 \cdot e^{\left[\frac{(17.625 \cdot t_a}{(t_a + 243.04)}\right]}$$

7 points represent the PMV index, from −3 to +3; the optimal temperature is achieved when PMV is zero, indicating thermally neutral sensation, during different human activity level.

Thermal condition of the indoor environment is determined by maintaining a PMV in the range of −0.2 to 0.2. For example, during winter season, a heating system operates. If the PMV value is less than −0.2, a command signal for a heating system is given as "1." Else, the command signal is given as "0." During summer season, a cooling system is used. If the PMV value is greater than 0.2, a command signal to operate the cooling system is given as "1." Otherwise, the command is "0."

Herie Park and Sang-Bong Rhee presented a model of smart HVAC system based on occupants' comfort conditions (Park and Rhee 2018). More in detail, they exploited the Predicted Mean Vote (PMV) to make smart the HVAC system and able to be responsive to users' requirements. The driving idea of this type of technology is that a PMV-based control is expected to make occupants more comfortable and satisfied than a temperature-based control (Park and Rhee 2018).

This concept of setting the HVAC systems on users' preferences and not only on energy optimisation is an indicator of the fact that the humans should be the focus of the smart building Design, and this idea will be the starting point of the new smart technologies developed starting from 2017.

In a practical way, this smart HVAC system operates by means of sensors installed in the building and wearable, which monitor the six parameters of PMV. When presence of people is detected by sensors, the PMV is evaluated according to the equation presented above and through an algorithm a signal is sent to the building systems, which is able to adapt its operation according to the input received.

The occupancy sensors

The occupancy sensors are the basis for many smart devices, in particular the ones dealing with the management of the indoor space (lighting, thermal, indoor air quality). The possibility to identify the level of occupancy of a room opens the gates to many smart technologies, because occupant presence and behaviour in buildings is considered a key element towards building intelligent and pervasive environments (Papatsimpa and Linnartz 2018). For example, the occupancy sensors are used to control and dynamically adjust energy-related appliances and all the building systems, both HVAC and lighting, in order to optimise the building consumptions and the users' comfort.

An example of occupancy sensor is a system that tracks user movement in building spaces using a camera network solution called SCOPES (Erickson, et al. 2009). More in detail, it consists of a wireless camera sensor network for gathering traces of human mobility patterns in buildings. Its driving idea is that the understanding of occupancy patterns makes possible to adopt an occupancy-based building energy management. The use of SCOPES sensors is designed for developing HVAC control strategies in those buildings that lack an occupancy-sensing infrastructure (Erickson, et al. 2009). From the researches carried out on these types of technologies, it emerges that they are able to reduce up to 20% the HVAC consumption, because they optimize the working scheduling of the systems on the basis of people presence and their habits in terms of mobility pattern.

Many times occupancy sensors are based on advanced modalities, such as cameras and wearable devices, which are expensive and may generate privacy concerns. In order to overcome these issues, different technologies have been proposed: for example, J. Lu, T. Sookoor, and V. Srinivasan present a Smart thermostat device that exploits data provided by an occupancy sensor in order to save energies in homes. The basic idea is to adopt a cheap and simple sensing technology to automatically sense occupancy and sleep patterns in a home, and to use these patterns to save energy by automatically turning off the home's HVAC system (Lu, et al. 2010).

The evidence driving the development of this technology comes from different studies, which have shown that 20-30% of the energy consumed in residential buildings could be saved, by turning off the HVAC system when residents are sleeping or away (Iowa Energy Center n.d.). However, these savings are often difficult to achieve: typical residents do not manually adjust the thermostat several times a day, and programmable thermostats are too difficult for most people to use effectively. In fact, recent studies have found that households with programmable thermostats have higher energy consumption on average than those with manual controls because users program them incorrectly (Lu, et al. 2010). The answer to this problem is the use of occupancy sensor to detect users' presence,

and the smart thermostat in order to adjust itself automatically and to minimize energy consumptions then uses these data. In this way, the building systems are activated only when it is needed, and for the rest of the time they are automatically turned off.

The technology that is used to determine occupancy presence is often based on PIR sensors, used to estimate the probability of home occupancy and automatically turn off the HVAC system when the occupants are away from home. The PIR technology is used also for smart lighting management, and it gives the possibility to integrate different functions in one unique device: installing a PIR system allows implementing a smart lighting as well as a smart HVAC system.

Another possibility of occupancy sensor that is less expensive, less intrusive and more privacy preserving, are CO2 sensors: a group of researchers at the University of California in Berkley have designed, in 2017, an algorithm that can detect the presence of people in a room by measuring the CO2 concentration inside it. The study is entitled "*Sensing by Proxy: Occupancy Detection Based on Indoor CO2 Concentration*", and it proposes the application of SenseAir's K-30 carbon dioxide sensor module for occupancy detection. This kind of occupancy sensor can be used to improve the efficiency of Demand-Controlled Ventilation systems (DCV) commonly in use: DCV is based on the principle that it is possible to save energy by heating, cooling or adding fresh air to a room only when it is needed. More in detail, the amount of fresh air that should be added to a room can be managed by a carbon dioxide level transmitter, according to which when CO2 levels go up, fresh air is added until the CO2 levels return to standard values (typically 10% or less of the background CO2 levels). In this way, the CO2 sensors are exploited not only to identify the occupancy level of a space, but also to monitor the indoor air quality and to constantly ensure an adequate CO2 concentration.

The detection of people presence through the measure of CO2 concentration of the room is useful especially in public buildings like offices or shopping malls, where it is not always positive to identify where people are by means of camera;, the adoption of a CO2 detection system provides the possibility to preserve the privacy of the users, and at the same time to achieve the same results offered by the smart thermostat.

Nonetheless, common sensing technologies still have limitations. More in detail, they do not allow to successfully detect a person that is sitting still, reading, typing, or watching a video, thus without making large movements with the arms or the body. Knowing not only where people are, but what they are doing offers the possibility to manage in a better way the environmental parameter and improve thermo-hygrometric comfort of the users (Papatsimpa and Linnartz 2018).

1.3.2 The smart lighting

The smart lighting is one of the three key features of a Smart Building (European Commission 2017), and it is described as a tool that is able to adjusts the light levels according to times but also according to other smart elements like windows and HVAC system.

The smart lighting system is often related also to the occupancy sensors (Jia, et al. 2017): light is turned on only when people are present, and then it is turned off when it is not needed. Another factor affecting the automation of the light system is the natural light: thanks to a daylight sensor the smart lighting is able to recognise if the natural light provides an adequate illuminance level for the execution of a specific activity; when the daylight sensor detects a proper level of illuminance, the artificial lights are switched off.

Figure 7 - Diagram of the functioning of an occupant responsive lighting. (Source: Ruoxi Jia, Baihong Jin, Ming Jin, Yuxun Zhou, Ioannis C. Kostantakopoulos, Han Zou, Joyce Kim, Dan Li, Weixi Gu, Reza Arghandeh, Pierluigi Nuozzo, Stefano Schiavon, Alberto L. Sangiovanni-Vicentelli, Costas J. Spanos, "Designing Automation for Smart Building Systems", 18/07/2018)

This scheme provided by R. Jia and his The scheme proposed in Figure 8 schematically explain the main components of an occupant responsive lighting device: the standard led lights are integrated with a daylight sensor and a PIR sensor[8]. In this way, the responsive lighting system is able to adapt its operation both in relation with natural light and with the presence of occupants.

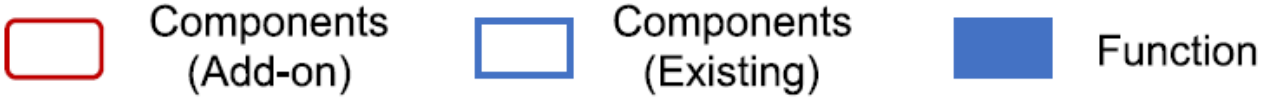


Figure 8 - Legend of the diagram. (Source: Ruoxi Jia, Baihong Jin, Ming Jin, Yuxun Zhou, Ioannis C. Kostantakopoulos, Han Zou, Joyce Kim, Dan Li, Weixi Gu, Reza Arghandeh, Pierluigi Nuozzo, Stefano Schiavon, Alberto L. Sangiovanni-Vicentelli, Costas J. Spanos, "Designing Automation for Smart Building Systems", 18/07/2018)

The legend related to the above-presented image express an interesting aspect of the responsive lighting system described by R. Jia: it can be implemented also in already-built structures, since the

[8] PIR stands for Passive InfraRed and is a device that measures infrared (IR) light radiating from objects in its field of view.

daylight and the PIR sensor are defined as add-on, so as devices that can be implemented in the already existing building's lighting system.

The goal of the presented system is to ensure a proper level of indoor visual comfort and, at the same time, optimise the energy consumptions so to reduce the impact of the building on the environment.

A similar point of view is declared by C. Papatsimpa and J.P.M.G. Linnartz in their scientific paper about sensors and smart building control (Papatsimpa and Linnartz 2018). The idea of the authors is that, besides the general goal to maximise the potential energy savings, user comfort is an essential success criterion that should remain a critical design aspect in building control. The reference to the energy matter is still present, but the focus is moving towards the user comfort, considered as the determinant able to determine the success or the failure of Smart Building Design. More in detail, the researchers affirm that in lighting control, two factors of major importance are energy savings and user comfort.

The adoption of a smart lighting system, with sensors detecting the presence of users, is able to achieve energy savings up to 30 % (Papatsimpa and Linnartz 2018). For what regards the users' visual comfort, the system is set in a way that lights in a zone provide 500 lux when the zone is occupied, reduce to 300 lux when only the neighbouring zones are occupied, and switch off automatically as soon as the occupancy sensor estimates absence in a zone after a fixed delay period.

1.3.3 Smart lighting management: smart windows and electrochromic glasses

Another aspect that can be analysed when considering the Smart Building's light management is the control of the natural light in the indoor space. The Smart Window technology allows controlling the solar flux entering the building through the glazing.

The windows considered consisted of a double pane-glazing unit in which a controllable absorbing layer is added on the interior surface of the exterior glass pane. This absorbing layer allows changing the optical properties of the window, resulting in a direct potential of control of the incident solar heat flux that enters inside (Dussautl, Gosselin and Galstian 2012).

This type of glass is called **electrochromic glazing**, and it can be defined as smart glass because it is able to adapt to some external conditions, in particular the amount of solar radiation hitting them. From an aesthetical point of view, the electrochromic glass is exactly equal to a standard glazing, appearing as a transparent pane.

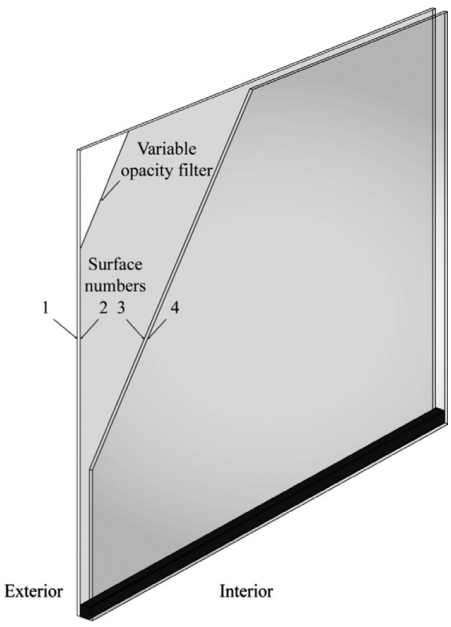


Figure 9 - Structure of the smart window presented in the paper. (Source: Jean-Michel Dussault, Louis Gosselin, Tigran Galstian, "Integration of smart windows into building design for reduction of yearly overall energy consumption and peak loads", 2012)

Saint Gobain offers different smart windows opportunities through their range of product called SageGlass; in general, the basic option SageGlass' electrochromic coating consists of five layers of ceramic material.

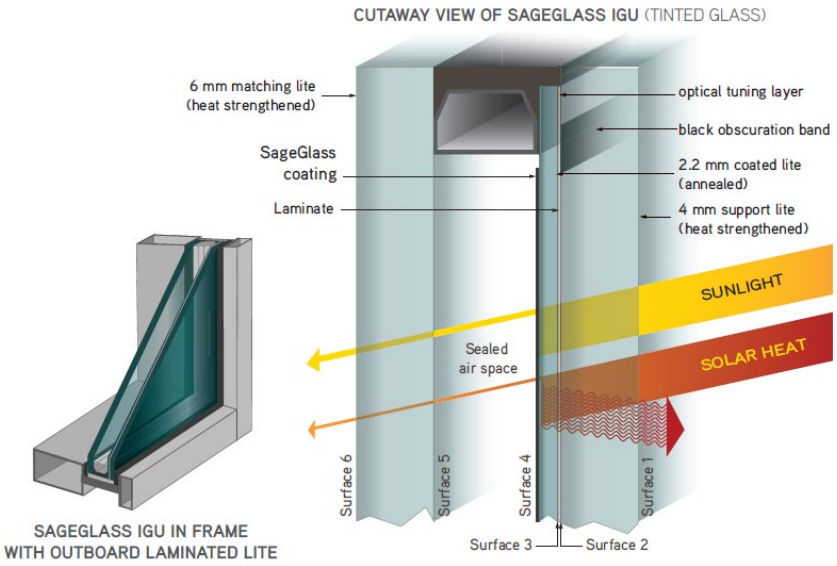


Figure 10 - SageGlass structure. (Source: SageGlass product guide).

The application of a low voltage of electricity darkens the coating, thanks to the lithium ions and electrons transfer from one electrochromic layer to another one. Reversing the voltage polarity causes the ions and electrons to return to their original layer, causing the glass to return to its clear state. This solid-state reaction is controlled through a very low voltage (less than 5V DC) power supply. A darkened state enables the glazed system to absorb and reradiate away the sun's unwanted heat and glare. A clear state allows maximizing daylight and solar energy (Snehashis e Subhasis 2013).

In terms of sustainability, the application of an electrochromic glazing offers the possibility to earn green labels such as LEED certification; in addition, it is able to block over 90% of solar heat in cooling seasons, or just 60% in heating seasons, by providing optimized energy efficiency all year. *"Windows should protect occupants from the elements such as wind, rain, cold, heat, and glare. Electrochromic glazings do that, exceeding ASHRAE standards. But they also let the users to control the level of sunlight and heat gain, reducing overall energy loads – heating, cooling, lighting – by up to 20 percent and peak energy demand up to 26 percent. Daylighting control also lowers operational costs by eliminating the need for additional blinds, shades or louvers."* (Lawrence Berkeley National Laboratory 2015)

The adoption of smart windows can reduce energy consumption for east, south and west oriented glazed facades, respectively, from 8% to 52%, 10% to 53% and 11% to 51%. On the other hand, north facade results have shown that this kind of technology does not improve building energy efficiency compared to the best passive low-E IGUs available in the market (Dussautl, Gosselin and Galstian 2012).

The advantage of a smart electrochromic glass, as SageGlass, is that it can be controlled and adjusted manually by the user, and it does not depend only on the solar radiation. For this reason, this type of technology can be considered as in between the past and the present phases. This is because, despite it has been developed and started to be diffused in the first years of 2010s, it has been able to offer new possibilities of integration with more recent technologies present in the new construction Smart Buildings. For example, some systems can be managed via mobile app to save predefined scene settings for specific lighting effects from anywhere in the building—wherever and whenever the user wants. Moreover, it can be integrated with voice control devices, like the Amazon Echo, providing occupants with additional flexibility so they can control the dynamic tinting of the glass via voice command (Sage Glass n.d.).

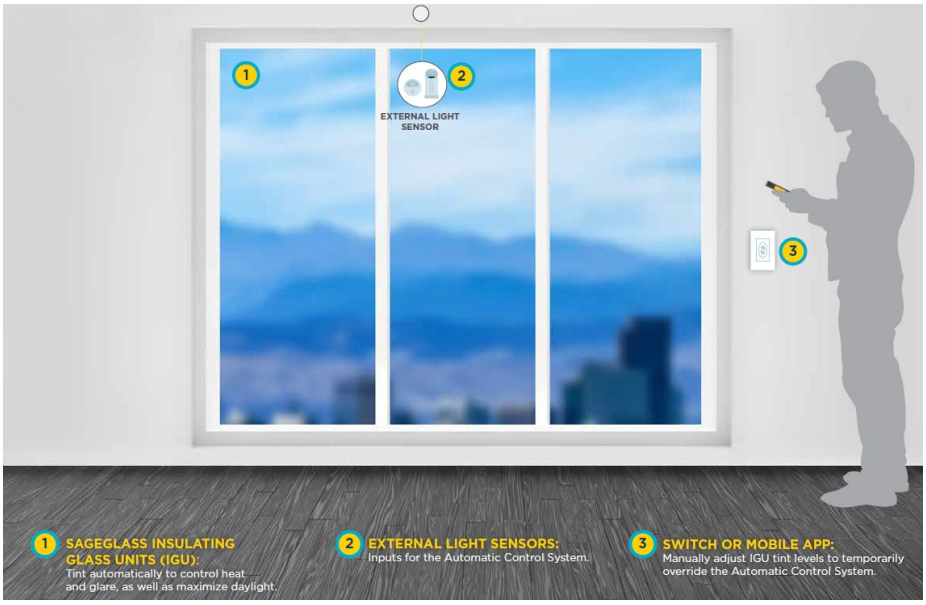


Figure 11 - SageGlass functioning and control. (Source: SageGlass product guide).

The researches dealing with this system have been published between five and eight years ago, meaning that this is not one of the most recent smart technologies; however, its importance relies in the possibility of managing not only the artificial light inside a building, but also the solar radiation coming from outside. For this reason, even if it is not a system developed in very recent years, it has the potential to be one of the technologies that will be included in the Smart Buildings of new construction.

What is necessary to analyse and understand is if it is possible to go a step further and move the attention to people comfort and health: how the people-oriented design deals with the light management? It is still a fundamental technology for Smart Buildings, or the users are more addressed towards different systems with other kinds of benefits?

CHAPTER 2

The present: Smart Buildings and People-Oriented Design

The smart buildings realized in the present years (between 2017 and 2019) are characterized by a particular attention towards the final users, both for what regard design strategies and technologies. For this reason, they are called people-oriented.
Different building typologies have different needs, and several types of smart devices have been developed to properly answer to them. Offices, hospitals, museums, universities, shopping malls, airport and houses are analysed in Chapter 2, and with them also many smart technologies present on the market, and the way in which they are linked to the people-oriented design issue.

2.1 Historical framework: people-oriented design and the present vision of the smart building (2017-present)

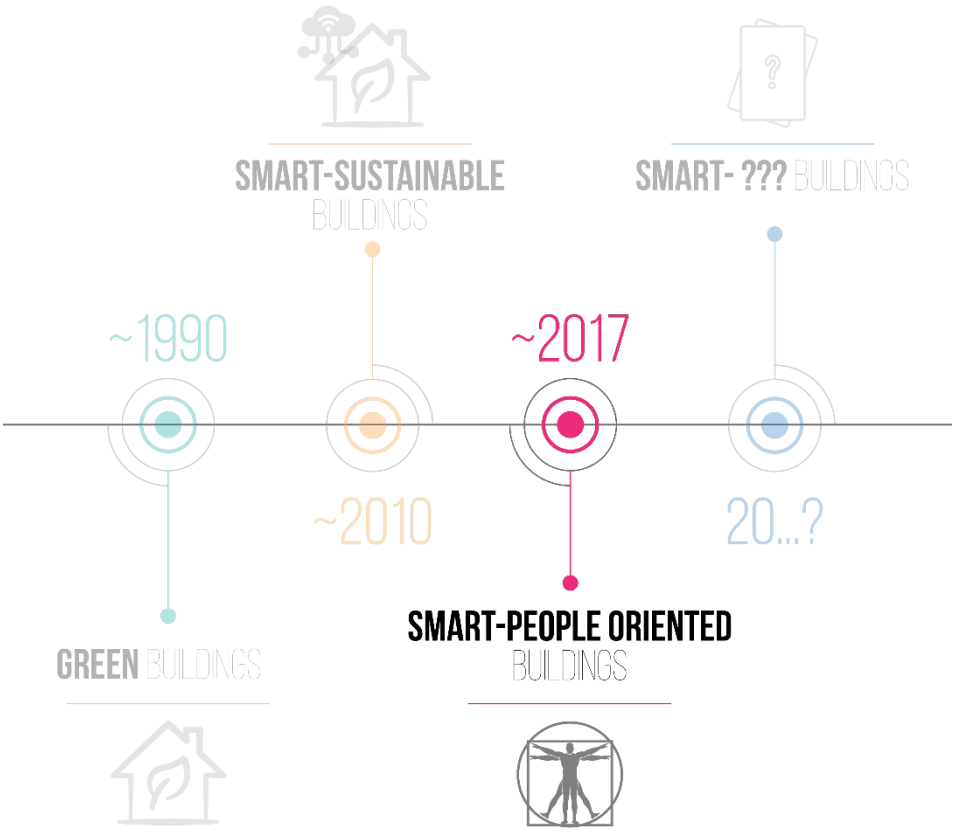


Figure 12 - Diagram of the historical journey, focus on the present (Source: the author)

During the last years of 2010s, a new vision started to spread in the building sector, according to which the focus of the smart building design should be the user, his comfort and wellbeing inside the indoor environment. For this reason, this kind of way of thinking has been named people-oriented design (British Land, Worktech Academy 2017) ,

The basic idea is that a building can be defined smart if it is able to facilitate the everyday life of people who live or operate inside it, with particular attention on their wellbeing and health conditions. The health issue comes together with the diffusion of the people-oriented design principles and becomes one of the essential characteristics of a smart environment.

The focus is not anymore on "*how much the building is consuming*" and "*which is the impact of the building on the environment*", but it has been moved to "*how the user feels inside the building*" and *"are the occupants staying in a healthy environment*" (Maryna and Anton, A Guide to Human-Centered Design Methodology 2016). After the smart building intended as a high efficiency

machine, aiming at optimising the consumption and give the users the possibility to interact with the main environmental parameters, between 2015 and 2017 the focus shifted towards a different purpose: people comfort and wellbeing in the indoor spaces (Maryna e Anton 2016).

Nowadays (D'Arjuzon 2019), many companies feel that they have achieved the maximum possible from the implementation of the green building and energy efficiency strategies (high performance building systems, use of LED lightings to reduce consumptions, etc.). For this reason, they are more oriented towards the optimization of the space management and the maximization of user's comfort inside the building.

Another evidence of the importance that is acquiring the image of the smart building as something that is oriented towards people and that is able to improve wellbeing and productivity of occupants is that the increase of comfort and productivity of building's users is at the top of many real estate executive's agendas (Clarke 2018). Sixty percent of the companies interviewed by Clarke stated that this issue is going to be at the top of their priorities in the next three years, and 52% declared that the occupants' wellbeing is one of the key issues of the next 12 months.

For these reasons, the Smart Buildings of the present years can be defined as people oriented.

2.2 Europe its readiness to the smart building revolution

Before to move from past to present Smart Buildings features and technologies, it is necessary to understand at which point is Europe in terms of smart readiness (Building Performance Institute Europe 2017). The European commission published in 2017 a paper entitled *"Is Europe ready for the Smart Building revolution?"* in which it is discussed about the presence of Smart Building in Europe, and the characteristics that a building should have to be defined smart.

This topic is discussed in between the past and present chapters because in this report by European commission the features of buildings defined smart are both belonging to the ones that have been classified as "past smart features" and to the ones that are going to be described in Chapter 2, dealing with the more recent characteristics of Smart Buildings.

This chapter aims also at answering to some basic questions about Europe situation in terms of Smart Buildings diffusion. Do they exist? Where they are mainly located? The European country are pushing towards the smart building development or it is just a theme that is discussed on paper without any acknowledgments in the reality?

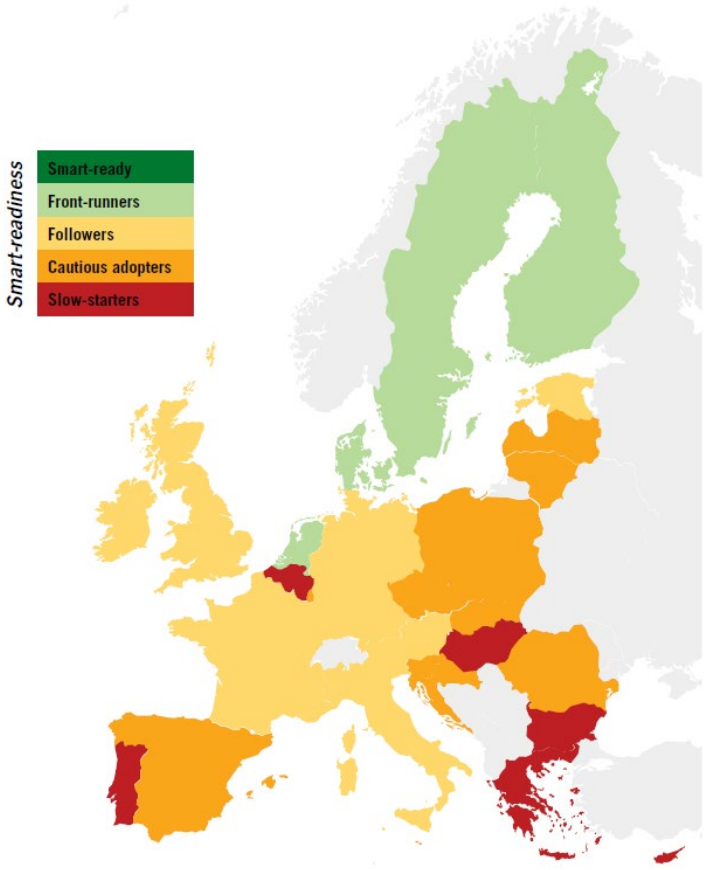


Figure 13 - The image presents the classification of the Smart readiness across Europe (Source: BPIE, "Is Europe finally ready for the smart building revolution?" February 2017)

The results of the research are summarized in the picture above, and it is visible how there is not a country that can be defined "Smart-Ready". The Northern countries like Sweden, Finland, Denmark and Netherlands are the most advanced in this field, and they are marked as front runners, but the majority of Europe is just a follower, and also the presence of the caution adopters is quite large, especially in the East-Europe.

The smart-readiness level is defined according to a factor that is defined as the Smart-Ready Built Environment Indicator (SBEI), which is numerically assessed by the use of this formula:

$$SBEI = \frac{\left(\left(\frac{BEP+FEC}{2}\right)+CMF+IAQ\right)+\left(SM+\frac{DP+FLX}{2}+CON\right)+(DR+BES+EV)+(RES+PV+\frac{HP+DH}{2}))}{12}$$

It takes into consideration a series of parameters that, according to the Building Performance Institute Europe (BPIE) are essential in order to call a building "Smart Building":

- BEP: Building Envelope Performance
- FEC: Final Energy Consumption
- CFM: Ability to keep adequately warm/cool
- IAQ: Healthy living and working environment
- RES: Renewable Energy Consumption
- PV: Photovoltaic
- HP: Heat Pumps
- DH: District heating
- SM: Smart Meter deployment
- DP: Dynamic Pricing
- FLX: Flexible market
- CON: Connectivity
- DR: Demand Response
- BES: Building Energy Storage
- EV: Electric Vehicles

More in detail, some of these parameters are defined and measured as follow.

- **BEP** = Building Envelope Performance

$$\frac{U\ value_{residential}}{\%\ residential}+\frac{U\ value_{non-residential}}{\%\ non-residential}$$

Well-designed and efficient buildings are able to maintain the desired indoor temperature better and over a longer period, which makes them more appropriate for pre-heating or pre-cooling. The smart-ready level is similar to nZEB regulations (W/mK = 0.29) (Building Performance Institute Europe 2015), while the lowest score is given to countries with an average U-value higher than 1.80, which is similar to a non-insulated wall built in the post-war period in Europe.

For what regards the building envelope performance, the value used to classify each country is referred to all the buildings present on the national soil that have been built after 1990.

Building Envelope	
Grade	U-Value
5	< 0.29
4	0.29 – 0.80
3	0.81 – 1.30
2	1.30 – 1.80
1	>1.80

As shown in Figure 14, apart from the northern countries, the scores are quite low, with some countries (including Italy) classified in the lower category, with a U value lower than 1.8 W/mK.

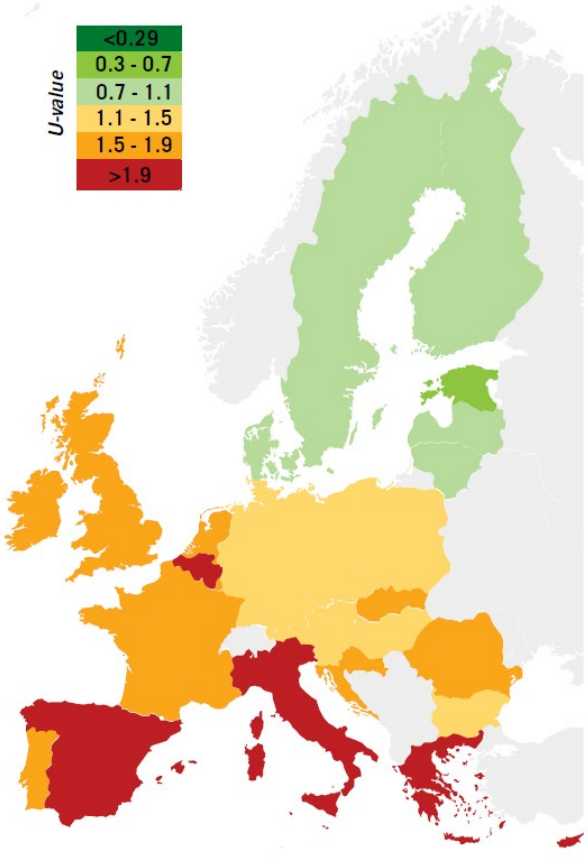


Figure 14 - Building envelope classification of European countries (Source: European Commission, EU Building Stock Observatory, [Online] Available: https://ec.europa.eu/energy/en/eubuildings, 2016.)

- **FEC** = Final Energy Consumption

$$\frac{Energy\ consumption_{residential}}{\%\ residential} + \frac{Energy\ consumption_{non-residential}}{\%\ non-residential}$$

Energy efficient buildings, smart controls and the behaviour of the occupant can all have significant effects on the final energy consumption. The score assigned to each category is reported in the following table, ant it is expressed in kWh/m^2:

Final Energy Consumption	
Grade	kWh/m^2
5	< 50
4	50 - 115
3	116 - 182
2	183 - 248
1	>248

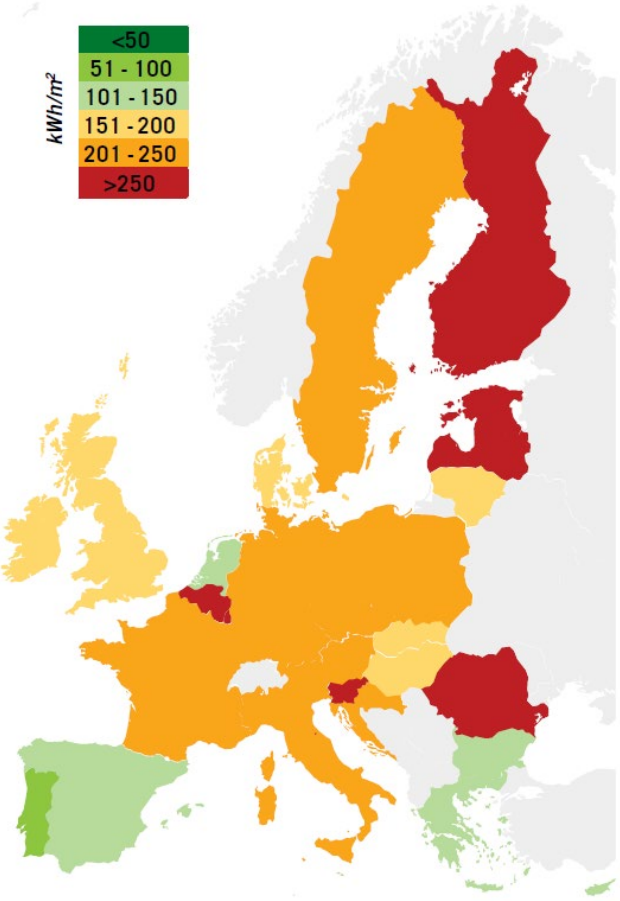


Figure 15 - Final energy consumption under normal climate conditions (kWh/m^2 for residential and non-residential buildings) (Source: European Commission, EU Building Stock Observatory, [Online] Available: https://ec.europa.eu/energy/en/eubuildings, 2016).

Looking at the score obtained by the different countries, it emerges that those ones that get a very high score for the building envelope, here are classified with a score equal to one and

two. On the other hand, Spain, Portugal, Greece and Netherlands are the countries with the higher scores.

- **CFM** = Ability to keep adequately cool

$$1 - \frac{\%\ of\ population\ incapable\ to\ keep\ home\ (warm + cool)}{2}$$

Energy poverty is one of the major problems for Europe, as between 50 and 125 million people are unable to afford a proper indoor thermal comfort43. Providing occupants with thermal comfort must be a central service that a smart building provides.

Ability to keep adequately warm/cool	
Grade	Share [%]
5	>99
4	92 -99
3	84 - 91
2	75 - 83
1	<75

- **IAQ** = Healthy living and working environment

$$1 - (\%\ of\ population\ living\ in\ a\ dwelling\ with\ a\ leaking\ roof, damp\ walls, floors\ or\ foundation, or\ rot\ in\ window\ frames\ or\ floor$$

The presence of a leaking roof, damp walls, floors or foundation, or rot in window frames or floors causes serious health problems for Europeans (Buildings Performance Institute Europe 2015). From this type of indicator, it emerges that the focus is not just on the energy consumption, but also the health issue has an impact on the smart readiness of a country in Europe.

Healthy living and working environment	
Grade	Share [%]
5	>99
4	92 -99
3	84 - 91
2	75 - 83
1	<75

- **RES** = Renewable Energy Consumption

$$\%\ of\ renewables\ in\ final\ energy\ consumption$$

The use of renewable energy sources has a fundamental importance in the assessment of the smartness of a building. When discussing about RES, it is referring to the share of renewable energy in gross final energy consumption. Renewable sources include solar thermal and photovoltaic energy, hydro (including tide, wave and ocean energy), wind, geothermal energy and all forms of biomass (including biological waste and liquid biofuels) However, in the last years the attention is shifting from the sustainability issue towards the people-oriented design, as it is described in paragraph 2.3.

Renewable Energy	
Grade	Share of gross energy consumption [%]
5	>50
4	38 - 50
3	24 - 37
2	10 - 23
1	<10

The Renewable energy sources, when referring to the single building or to a network of multiple buildings, result to be poorly used in Europe, since most of the countries get a score between one and three. Only Sweden, Finland and Latvia are able to be classified as Smart ready and Front runners. Italy, also in this category, receives a quite low score, and it is defined as a caution adopter of renewable energy sources.

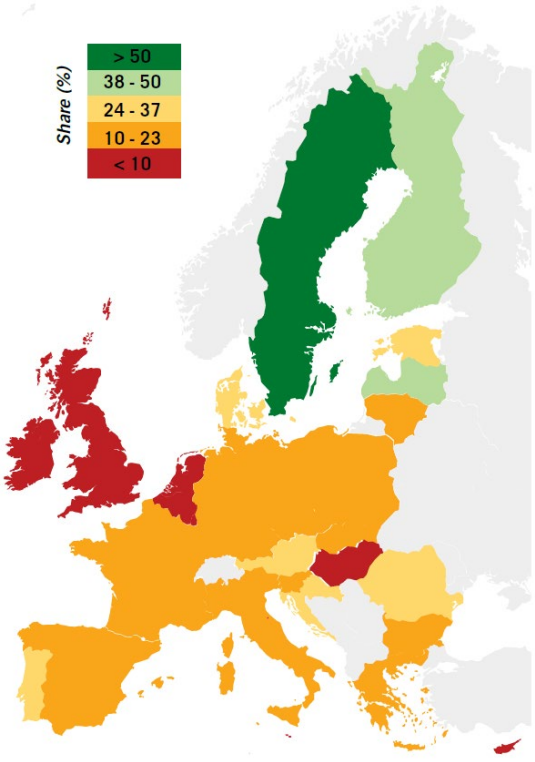


Figure 16 - Share of renewable energy in gross final energy consumption in 2014 (Source: Eurostat, "Share of energy from renewable sources", 2016.)

- **PV** = Photovoltaic

$$\frac{PV\ production}{population \cdot energy\ need\ per\ capita}$$

The PV system are the most diffuse renewable energy source, and they allow to balance the energy consumption of a building and to realize a Nerly Zero Energy Building, that is able to self-produce all the energy that it needs.

Renewable Energy	
Grade	Share of gross energy consumption [%]
5	>8
4	6 - 8
3	3 - 5
2	1 - 2
1	<1

- **HP** = Heat Pumps

$$\%\ of\ population\ with\ heat\ pumps$$

When using electricity and thermal energy from renewable sources, heat pump systems provide a 100%-renewable solution for heating and cooling of buildings.

Heat Pumps	
Grade	Share of primary energy consumption [%]
5	>6.5
4	4.01 – 6.50
3	1.51 – 4.00
2	0.10 – 1.50
1	<0.10

- **DH** = District Heating

$$Share\ of\ district\ heating\ in\ final\ energy\ consumption\ for\ heating$$

District heating (also known as heat networks or teleheating) is a system for distributing heat generated in a centralized location through a system of insulated pipes for residential and commercial heating requirements such as space heating and water heating. In a dynamic energy market, end-users connected to district heating could even sell their excess energy, cutting down the heat-load peak and allowing the district heating supplier to avoid running peak-load boilers, often fuelled by conventional energy sources.

District Heating	
Grade	Share of DH in final energy consumption for heating [%]
5	>50
4	34 – 50
3	18 – 33
2	1 – 17
1	<1

- **SM** = Smart Meter deployment

$$\%\ of\ dwellings\ with\ a\ smart\ meter$$

A smart meter is an electronic device that records consumption of electric energy and communicates the information to the electricity supplier for monitoring and billing. Smart meters typically record energy hourly or more frequently, and report at least daily; moreover, they can empower end-users by enabling them to have better understanding and control over their energy system. Accurate measurement of the energy consumption to provide real-time data on the energy used is a requirement to valorise demand response services.

Smart meter deployment	
Grade	Share [%]
5	>99
4	50 – 99
3	25 – 49
2	1 – 24
1	<1

The smart-ready level is set to be equal to a full deployment of smart meters on national scale. The lowest score is given to countries where the smart meter deployment had not started by 2015 (the year with the most recent data)[9]. For what regards Smart Meters deployment Italy is one of the leading countries in Europe, being classified with the maximum score, together with Sweden and Finland.

[9] Data from the Agency for the Cooperation of Energy Regulators (ACER).

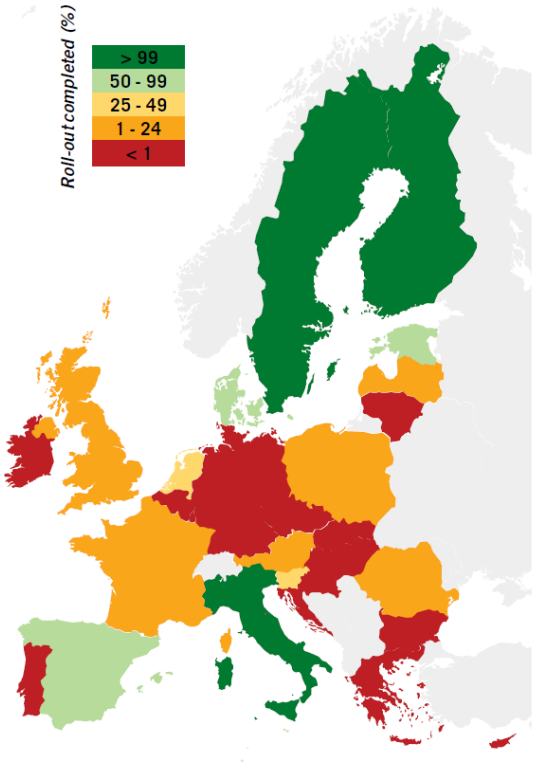


Figure 17 - Share of household customers equipped with smart meters for electricity in 2016 (Source: European Commission, EU Building Stock Observatory, [Online] Available: https://ec.europa.eu/energy/en/eubuildings, 2016; The Agency for the Cooperation of Energy Regulators, "ACER Market Monitoring Report 2015 - Electricity and Gas Retail Markets," [Online] Available: http://www.acer.europa.eu/officialdocuments/, 2016.).

- **DP** = Dynamic Pricing

% of stadard household consumers supplied under dynamic pricing for supply and network charges of electricity in EU MS

Dynamic pricing, also referred to as surge pricing, demand pricing, or time-based pricing is a pricing strategy in which businesses set flexible prices for products or service based on current market demands.

Thanks to technological advances, dynamic pricing is now a possible path to energy savings, leading to a smarter use of energy from the grid and easing of peak loads. The availability of dynamic price signals for commercial and residential consumers is a requirement for demand response.

Dynamic Pricing	
Grade	Evaluation of electricity market
5	Fully dynamic pricing
4	Hourly pricing (for majority of users)
3	Hourly pricing (for minority of users)
2	Static time of use pricing
1	Fixed pricing

- **FLX** = Flexible Market

$$Market\ share\ of\ the\ largest\ generator\ in\ the\ electricity\ market + switching\ rates\ (electricity)$$

A flexible electricity market fosters manoeuvrability for consumers and competition among utility companies. To assess both consumer flexibility and competition on the market, the Indicator looks at how many consumers are switching electricity providers per year (switching rates) as well as at the market share of all utility companies except the largest one. For example, if the switching rate in a country is 10% per year (i.e. 10% are changing electricity provider during the year) and the biggest utility company has 60% of the market, the score will be 50 = 10 + (100 - 60) (De Groote, Volt e Bean 2013).

Flexible market	
Grade	Share [%]
5	>90
4	75 -90
3	60 - 74
2	45 - 59
1	<45

- **CON** = Connectivity

$$\%\ households\ with\ internet\ connection$$

The number of households with a broadband connection measures levels of connectivity.

Connectivity	
Grade	Score [%]
5	>99
4	92 -99
3	84 - 91
2	75 - 83
1	<75

- **DR** = Demand Response

$$Evaluation\ (based\ on\ assesments\ made\ by\ JRC\ and\ SEDC)\ of\ the\ demand\ response\ market$$

Demand response is the ability to shift energy demand by reducing peak consumption and avoiding grid imbalance (De Groote, Volt e Bean 2013).

Demand Response	
Grade	Evaluation of DR market
5	Commercially open
4	Open for majority of actors
3	Open only for major industries/actors
2	Very low partecipation
1	Closed

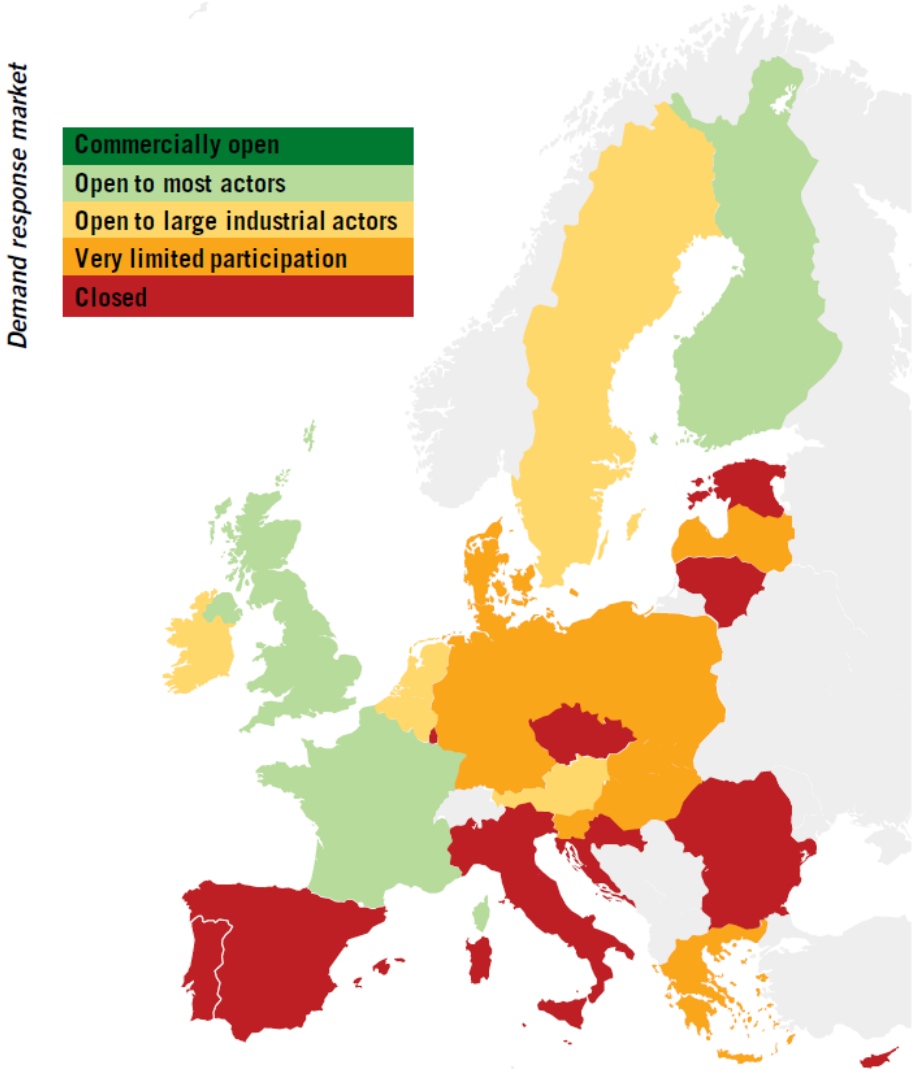


Figure 18 - Implicit demand response availability across the EU in 2015. The score is combining SEDC's and JRC's respective assessments (Source: Smart Energy Demand Coalition, "Mapping Demand Response in Europe Today 2015," [Online] Available: http://www. smartenergydemand.eu/?p=6533, 2015; Bertoldi, Paolo - Zancanella, Paolo & Boza-Kiss, Benigna, "Demand Response status in EU Member States," European Commission's JRC Science for Policy Report, [Online] Available: http://iet.jrc.ec.europa.eu/energyefficiency/node/9147).

The smart-ready level is equal to a framework, including both existing and new construction buildings, that is commercially open for demand response. The lowest score is given to countries with a closed market for demand response. The scores for the Demand Response category are low, with only three countries classified as front-runners.

- **BES** = Building Energy Storage

$$\%\ of\ buildings\ with\ energy\ storage$$

Battery-based projects are likely to be an important part of future building related storage, but other technology options, such as thermal and hydrogen storage, must also be considered.

Building Energy Storage	
Grade	Share of dwellings [%]
5	>1
4	1 - 3
3	0.1 – 0.99
2	0.001 – 0.099
1	<0.001

- **EV** = Electric Vehicles

$$The\ market\ share\ of\ EVs\ of\ total\ new\ car\ registrations$$

Intelligent solutions will manage supply and demand between cars and buildings and use their separate storage facilities in an optimal way. Combining flexible loads and decentralised storage potentials of both buildings and cars will maximise the local integration of renewable energy.

Electric vehicles	
Grade	Share of EVs from new car registrations [%]
5	>75
4	50 - 75
3	25 - 49
2	10 - 24
1	<10

As it has been showed in the image at the beginning of the chapter, Sweden, Finland, Denmark and the Netherlands are the leading countries, which is due to progressive policies such as smart meter rollout and investments in renewable energy. However, the score five is never reached by none in no category. Summarizing the scores obtained, the results are displayed in Figure 19.

It emerges that on one side, the aspects related to the efficiency and the health of the building, together with the dynamic operability indicators, have the maximum scores, while for what regards the energy issue, the scores are really low, with many countries reaching only one as score.

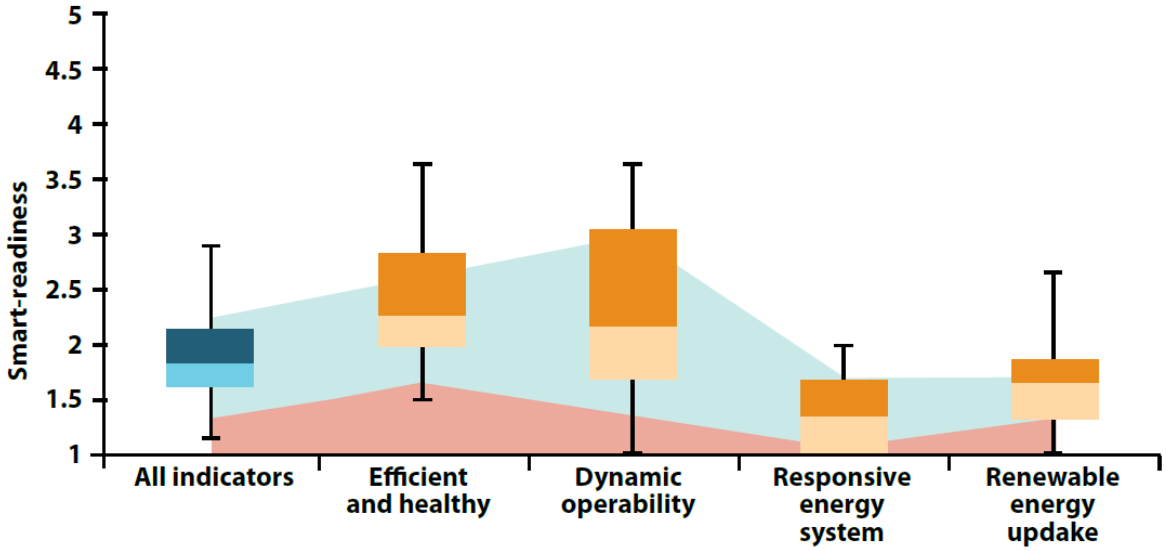


Figure 19 - Box plot showing distribution of average score for all countries (Source: BPIE, "Is Europe finally ready for the smart building revolution?" February 2017).

The overall low score can be partly explained by rigid regulatory frameworks, lack of investments, but also by the recent market penetration of some of the indicators, such as building energy storage, electric vehicles and demand response (Building Performance Institute Europe 2017). Building energy storage and electric vehicles are the two indicators with the lowest aggregate score. However, interest in these solutions is growing rapidly, marked by decreasing prices and an increase in service offers. In the case of electric vehicles, the Netherlands is in the lead with almost 10% of newly registered vehicles being electric, while Germany - through a building-energy-storage programme - succeeded to increase heavily the market share of smart and environmentally friendly alternatives (Building Performance Institute Europe 2017).

Finally, in Figure 20 are reported all the scores obtained by every country. Thanks to a specific focus on Italy's situation, it is possible to list some fields in which it has the lowest score and that should improve, in order to be considered as front-runner or even a smart ready country.

First, if considering the Building envelope performance indicator, Italy is classified with the lowest score, as a slow starter. This is due to the fact that the BEP calculations considers all the buildings built after 1990; in order to increase its own score, Italy should adjust and improve the envelope performance of buildings of not-new construction, and making them reaching an U-value of at least 0.8 W/m^2K.

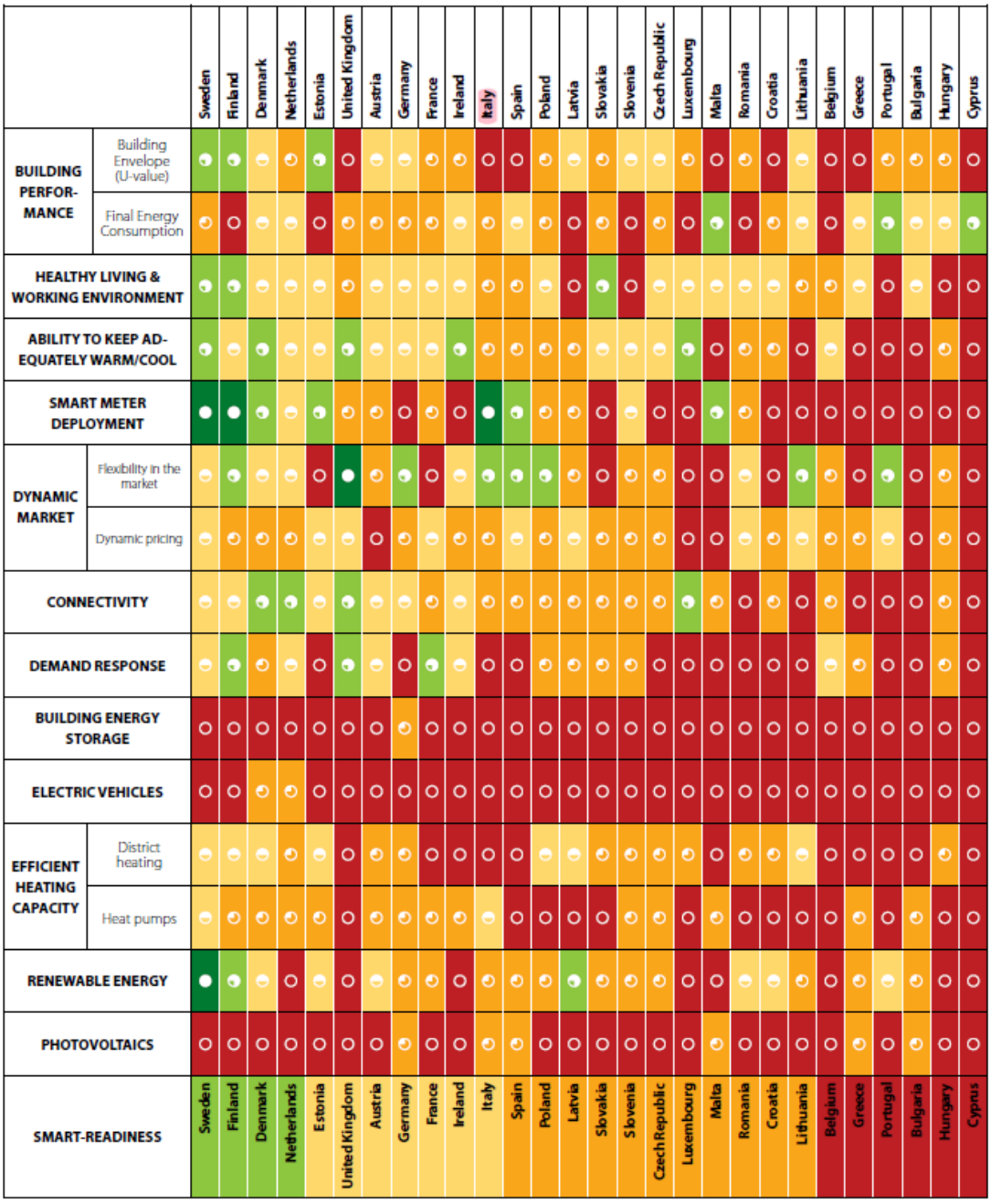


Figure 20 - Smart built environment results (Source: BPIE, "Is Europe finally ready for the smart building revolution?" February 2017).

Italy should push also towards the implementation of demand response system, as well as on the improvement of the building energy storage and on the diffusion of electric vehicles. When comparing the numbers about the diffusion of electric vehicles in Italy with the ones in Norway or Germany, it emerges the big gap: in 2017, in Italy 4827 electric cars have been sold, against the 62000 and 55000 of Norway and Germany (Politecnico di Milano, Energy & Strategy Group 2017). Finally, Italy needs to improve the usage of photovoltaic systems and of renewable energy sources, implementing them also in already existing buildings and not only in the ones of new construction.

2.3 People oriented design: a definition

In the last years, the attention is moving from the sustainability issue and the green buildings topic to the so-called People Oriented Design.

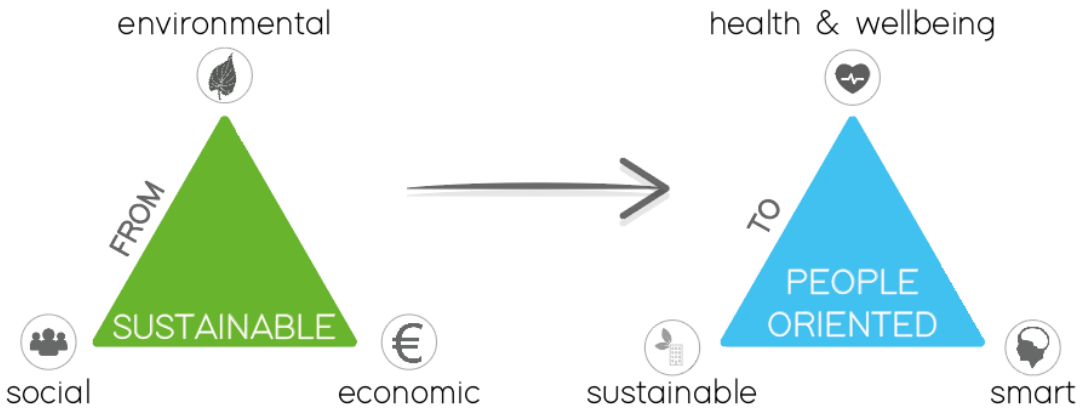


Figure 21 – Diagram of the transition from sustainable to people-oriented buildings (Source: the author)

In "Architect or Bee?" Mike Cooley coined the term "*human-centred systems*" (Cooley 1980), defining them as spaces where the aim is to "*preserve or enhance human skills, in both manual and office work, in environments in which technology tends to undermine the skills that people use in their work*". Even though the book by Cooley has been published in 1980, the theme that he introduced is more recent than ever; moreover, the new technologies that have been developed in the Smart Buildings field may be exploited towards this direction, aiming at facilitating the people's everyday activities.

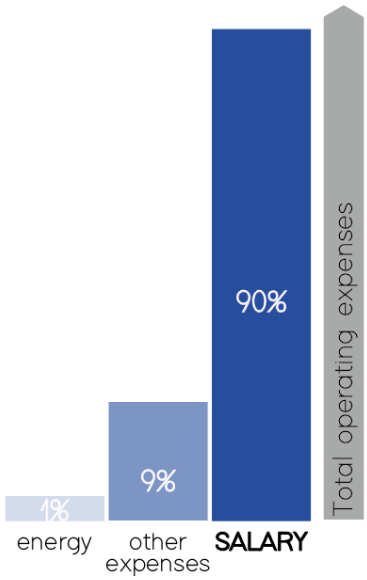


Figure 22 - Source: the author (Data coming from a research by Deerns)

One of the main reasons that are driving towards this new vision of cutting-edge buildings is the amount of operating expenses that a company has to face.

The reduction of the energy consumptions has been the main concern of building design in the last years but looking on the economic impact of the bills that a company has to pay, they correspond only to about 1% of their total expenditures. Of the remaining 99%, 9% is related to different type of costs, such as the rent of the spaces, and 90% correspond to the salaries for all the employers.

In order to have a return from the investment on people, a company should optimise what the employers do, so that the

incomes are maximised. The guiding principle is "*Invest in people for return on investment*" (Garton 2017): it is necessary to find a mechanism through which it is possible to increase employee productivity, lower the absenteeism and decrease the health insurance costs. In this way, all the money invested in workers' salaries, can get back to the company in the form of more incomes due to the higher amount of work by the employer themselves.

C. Tagliaro came up with similar results in her research (Tagliaro and Ciaramella 2016), demonstrating that the economic impact of the workplace is composed of the value created by spaces and by people. Over the lifecycle of a building, the company's cost is distributed between the following items:

- **82 %** is used for employee wages and other benefits;
- **3 %** is destined to operations and maintenance;
- **10 %** to technology;
- The last **5 %** is for facilities, including design and construction of the building.

This is evidence that any kind of intervention should be directed at enhancing employees' experience and maximizing the effectiveness of Human Resources. The Smart Buildings of the future, that are starting to be developed in the last years, will be more user-friendly, and they will prioritize users' comfort, in order to improve the wellbeing and work efficiency of occupants (Verdantix 2018). Since most of the expenses of a company are related to employers' salary, the goal of a company should be to maximize their productivity: even a small increase in the productivity will have a significant effect on the company's bottom line. A one percent increase in the productivity, for a medium-size company with about 50 workers, can offset the entire cost for the services provided at the office. A four percent increase means for the company to be able to cover almost entirely the rent cost (Coor n.d.).

Another driver of healthy buildings is that in many aspects of the everyday life there is a global trend towards healthy lifestyle. Wellness is now evolving and becoming a sort of new status symbol among consumers: according to Euromonitor research, "*the desire to be fit and healthier seems to be almost universal. Healthy living is becoming a status symbol, as more consumers opt to flaunt their passion for wellness through paying for boutique fitness sessions, "athleisure" clothing, food with health-giving properties and upscale health and wellness holidays*" (Euromonitor Research 2017). In accordance with this vision, it is reasonable to assess that a greater focus on health and wellbeing must be guaranteed also in buildings, where people spend almost 90% of their lives.

2.3.1 "Human centred design", a new design methodology

The definition of Human centred system, provided by Mike Cooley, has been the inspiration for the so-called "Human Centred design", a methodology for realizing successful design solutions. This design method has been applied by several professional figures, including the so-called UX designers [10]. According to this methodology, UX designers focus on end-users from the very beginning of product creation and they have users testing each iteration of a product. As a result, end-users get a product that satisfies their needs.

Human-centred design does not simply force the designer to consider the needs and desires of product-users first; the fundamental issue is how it is possible to satisfy those needs in both functional and emotionally meaningful ways. There are three general principles of human-centred design, that aim at accomplishing the purpose yet mentioned (Maryna and Anton 2016):

- **Collaboration**: great minds create great ideas when they work together.
- **Empathy**: it is not possible to create a product for people without deeply understanding their motivations.
- **Experimentation**: it is only through conversations, experiments (checking hypotheses), and learning that a great product is born.

Even if these three guiding principles are related to the design of a smaller scale product with respect to the building scale, they can be used as reference to understand if they are able to lead to the same result: a Smart Building that satisfies people needs in terms of health and wellbeing (Maryna e Anton 2016). The experimentation will be a key element in this research, and in particular, the aspect related to conversations with the buildings' users. The questionnaire methodology is going to be adopted (Chapter 3) in order to verify what are people's expectation from a people oriented Smart Building.

Despite the definition proposed by Maryna Z. and Anton S. is referred to the web design, the methodology which they present can be applied to any kind of product, including a building. Moreover, the goal of this design process perfectly matches with the economic issue related to the improvement of working conditions in order to make employees more productive.

The general approach to human-centred design is the same for any context, and can be reduced to three basic steps (Harte, et al. 2017):

[10] UX Design (UXD) is acronyms of *User Experience Design*; it is a set of processes that aim at enhancing the user's satisfaction, by improving the usability of a web page, its user-friendliness, its intuitiveness and the interaction.

- **Discover:** once the goal and the challenge have been set, first it is fundamental to discover ways in which they can be approached, and to find people to talk to about the matter.
- **Ideate**: once enough information to solve the problem have been collected, creativity shall be exploited to think up solutions.
- **Prototype**: turn the ideas (based on real feedback) into tangible designs.

The Discover phase is going to be the focus of this research about new possible Smart Buildings technologies. Every smart technology for different building typologies will be submitted to people's "judgment" through the questionnaire, presented in Chapter 3, in order to understand which the user's real requirements and necessities are.

The Prototype phase is not going to be considered in this research work, but the real feedbacks that are going to be collected might be the starting point of a future work to implement some of the proposed ideas.

2.4 The Smart Buildings and the health issue

It has been underlined the importance of a Building design that is people oriented, and which goal is to ensure the best possible environment to people, who will then improve the quality of their staying inside the building and of their work.

With this in mind, it is possible to state that a Building, in order to be smart, has to be also healthy: the vision that has been developed starting from the mid-10s has as one of its cornerstones the idea of ensure to the users a high level of wellbeing in the indoor spaces (Ministero della Salute n.d.). A people oriented Smart Building must be focused on user's wellbeing and on their health conditions, and all the design strategies and the technologies should be addressed mainly to improve occupants' health.

One evidence of the importance that the health conditions in buildings are acquiring a great importance is the introduction of specific parameters related to this issue in the main rating evaluations. An example is the "Health and Well-Being" module, quoted by the agency GRESB[11] in 2017 and recently integrated in GRESB Real Estate Assessment 2019. The indoor wellbeing is a requirement for buildings everyday more and more important, which is beyond the compliance with the standards (Santoro 2019). From the image of the Health and performance pyramid, it emerges that the level of indoor environmental quality of standard buildings, compliant with the traditional standards of comfort, it is a starting point and not the finish line.

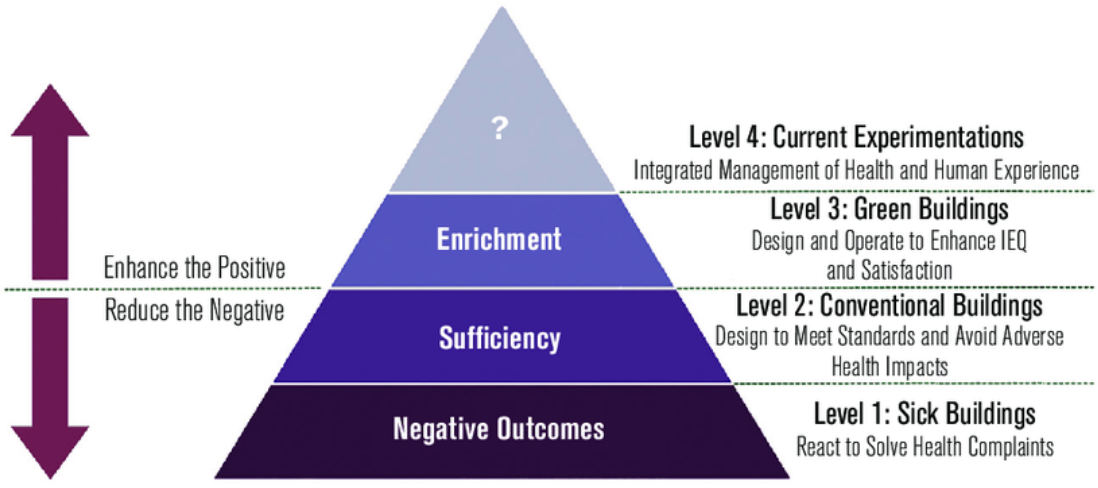


Figure 23 - The "Health and performance pyramid" (Source: Dusan Licina, "Occupant Health and Wellbeing in Green Buildings", ASHRAE Journal, 2019).

[11] GRESB is the environmental, social and governance (ESG) benchmark for real assets. Working in collaboration with the industry, GRESB defines the global standard for sustainability performance in real assets, providing standardized and validated ESG data to the capital markets.

The potential to support employee health and wellbeing has headed to the top of the occupier agenda, and smart building management systems have the ability to do that. Absence from work because of sickness is costly both for companies and for the economy: the numbers are around £14 billion a year in the UK (Meemori Research AB 2017). Again, the economical aspect appears to be the driving force pushing towards the development of a new smart building generation, focused on people and in particular on their health and wellbeing.

The importance of the design phase in the realization of a building that is actually a Smart and Healthy Building is highlighted by the World Green Building Council, in a research about Health, Wellbeing & Productivity in Offices: "*There is overwhelming evidence which demonstrates that the design of an office impacts the health, wellbeing and productivity of its occupants*". British Land and Worktech academy, in their report *"Smart offices: a 2017 Vision for the future"* discuss about a responsive approach to health and wellbeing. They refer to smart devices that are able to monitor and alter light and noise levels, in order to ensure to the user what they call a Smart Wellbeing (British Land, Worktech Academy 2017).

There are multiple aspects, described in the figure below, that are all connected to people wellbeing inside a space. These four categories have been developed by Deerns in order to classify Smart Technologies and sort them according to their purpose. One of the aims of this research is to apply this categorization to most of the systems present on the market, to see if these four groups are enough to categorize many different smart technologies.

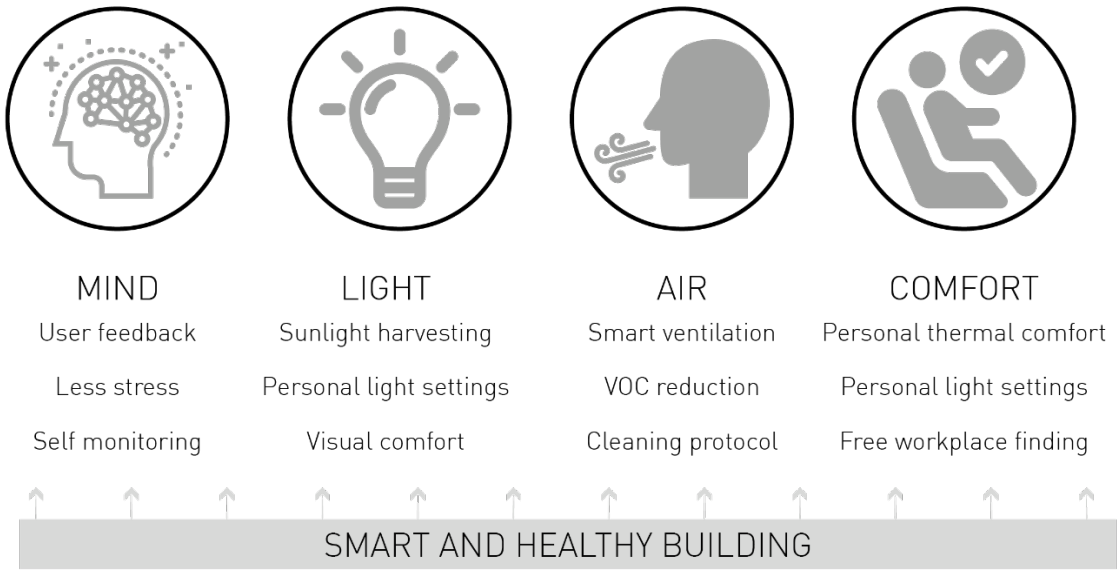
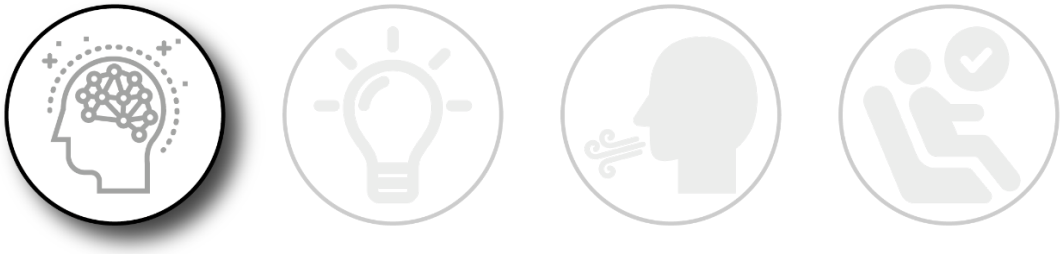


Figure 24 - Main topics related to the Smart and Healthy Building (Source: Deerns presentation)

2.4.1 "Mind"

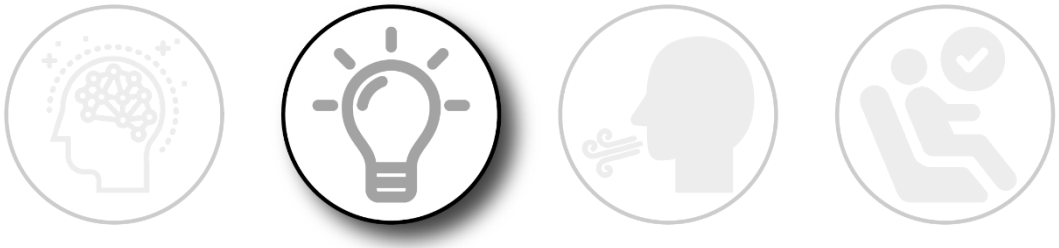


The "Mind" topic is linked with the idea of reducing stress levels and improve self-monitoring devices, in order to allow the occupants to acquire a greater awareness of themselves and their health conditions.

Some smart technologies related to the mind issue (reduction of stress and improvement of user's experience) are:

- Keyless entry technologies
- Parking booking
- Smart recycling
- Visitor management applications
- Wearables
- Automation of airport procedures
- Smart mirrors and Smart shelves
- Smart plugs
- Smart speakers

2.4.2 "Light"



The light issue has already been discussed in the previous chapter, when presenting the technologies of the smart-sustainable buildings; at this point of the research it is interesting to see how the same issue is treated in a different way, in accordance with the different purpose. In the past (2010-2017) the goal was to manage lighting devices in an optimal way to minimize energy consumption; nowadays the leading principle is to ensure a healthy environment, and the light plays a key role.

In recent years, there is a growing interest in the physiological effect of light on the human body (Besenecker and Appleman 2017). Many researches refer to the so-called human-centric lighting, biological lighting, or circadian lighting, reflecting the emerging understanding that light can have a profound effect not just on what people see around us but also upon humans' health. Light affects the daily rhythms of the body, including the sleep-wake cycle (Figuero 2013); it can impact obesity, energy and awareness (Figuero 2013), depression, and even, among patients with various forms of dementia, their agitation levels (Figuero 2012). Because of all these understandings, the lighting system of a building has major importance in the wellbeing of the users. A smart lighting system must be responsive to health issue and ensure the proper environmental conditions for people's wellbeing inside the building.

In some researches, the smart lighting is discussed together with the Circadian-effective lighting system. The Circadian rhythm is defined as the normal near-to-24-hour rhythm of people's body clock (Figuero 2013). The wavelength of the lights can affect the circadian rhythm of humans: lighting with wavelengths below 500 nm affects this rhythm, because photoreceptors in the periphery of the eyes sending signals to the parts of the brain involved in biological impact have their peak sensitivity around 480 nm.

The theme of the circadian artificial lighting has been presented by some companies already in the years '00s, which developed some lighting devices based on this concept, that have been called "biodynamics"; however they didn't diffuse much because the theme of the circadian lighting was seen with a certain diffidence by users and designers. However, in 2017 Jeffry C. Hall, Micheal Rosbash and Micheal W. Young won the Nobel prize for Medicine because of their discovers about genetic mechanisms demonstrating the existence of the circadian rhythm. This has reiterated the scientific basis underlying the science known as chronobiology and of circadian lighting and has re-aroused the interest of businesses and associations around this field. Moreover, a new impulse in this direction has been given by the new systems of management and control of LED lighting, that are connected in the IoT and integrated in the building automation systems (Rossi 2019).

The products that have been developed because of the Human Centric Light[12] concept are new LED lamps called Tunable White: they give the possibility to mix warm and cool white light and adjust light intensity so that it is possible to create energising, relaxing and productive lighting modes. This promotes feelings of well-being and productivity for people who spend big part of their day indoors in artificial light, e.g. office workers, school students, hospital patients, etc.

The smart lighting systems are based on the use of sensors, which can collect information about the light present in a certain environment, in terms of light type and colour. In this way, it is possible to adjust automatically the kind of light provided by the tuneable white LED lamps. These types of sensors work together with the occupancy sensors, in order to avoid keeping the light on even when the room is empty.

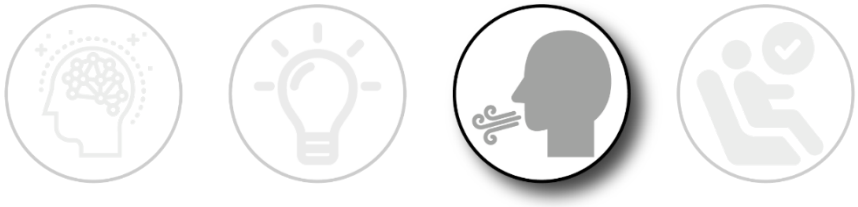
The topic of the Human Centred Lighting is affecting also the normative fields all around the word. In Europe there is not yet a precise normative about this issue, but on world level the International Commission on Illumination (CIE) published a technical report entitled "Research roadmap for healthful interior lighting applications" in which it proposes a research path in order to identify a healthy indoor illumination. The European commission, thanks to the reports by SCHENIR, Scientific Committee On Emerging And Newly Identified Health Risks, (Health effect of artificial light 2012) and SCHEER, Scientific Committee On Health, Environmental And Emerging Risks, (Opinion on potential risks to human health of Light Emitting Diodes LEDs 2018) committees, recognizes the importance of a proper indoor illumination for health and psychophysical wellbeing of people. Moreover, the building certification "WELL Building Standard", focused on psychophysical wellbeing of people inside buildings, recognises the circadian lighting as a positive element inside a building.

Some smart technologies related to the light issue are:

- Personalized setting of light parameters
- Customizable light conditions

[12] The concept of Human Centric Lighting is based on the variation of colour and intensity of white light and on the lighting design based on the final users' needs.

2.4.3 "Air"



The air quality monitoring is one of the fundamental aspects that must be present in a healthy building: people have to breathe an air that is not contaminated by too high level of CO2 and pollutants. The indoor pollutants are several, and they can be originated by different sources; they are classified in three main categories, chemical, biological and physical agents. Part of them come from the outdoor environment (atmospheric pollution), but many of them are originated inside the building. The main internal sources are the occupants (people and animals), dust, building materials and building systems. The following table summarizes the main sources and the corresponding produced pollutants (Ministero della Salute n.d.).

Sources	Pollutants
Gas and/or coal combustion processes for heating and/or cooking, fireplaces, flue gases of vehicles	Combustion products (CO, NOx, particulate matter)
Construction and insulating materials	Asbestos, artificial glass fibres, particulate matter, radon, biological agents (due to humidity and/or dust)
Finishing materials and moquette	Formaldehyde, acrylates and COV and biological agents (due to humidity and/or dust)
Furnitures	Formaldehyde, COV and biological agents (due to humidity and/or dust)
Cleaning products and liquids	Alcohols, Phenols, COV
Printers	Ozone (O3), toner dust, volatile hydrocarbons (COV)
Cigarette smoke	Polycyclic Hydrocarbons, COV formaldehyde, CO, particulate matter
Air conditioning systems	Co2 and COV (due to low amount of air changes per hour or recirculation excess); biological agents (due to lack of cleaning/maintenance)
Dust	Biological agents (indoor allergens: mites)
People	CO2 and biological agents (bacteria and virus)
Animals	Indoor allergens (hair etc.)

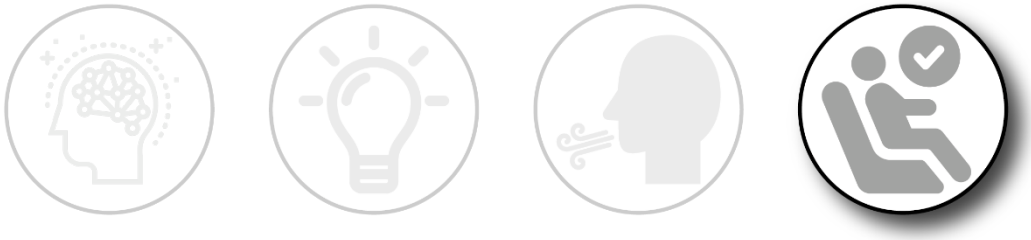
Table 2: Sources and Pollutants leading to problems in air quality

The presence of pollutants, even in very low concentration, may have an important effect on the health and wellbeing of the occupants, due to the long exposure to those particles. Indeed, the risk of health problems is more linked to the time of exposure than to the concentration of the pollutants themselves. Considering that most of the people spend 90% of the day inside the buildings, the time of exposure is quite long, and it is possible to recognize how this is a key aspect to take into consideration during the building design phase. The indoor air quality must be a design criterion, in order to ensure a proper level of comfort to the building's users (Ministero della Salute n.d.).

Some smart technologies linked to the air issue are:

- Air filtering houseplant
- Air quality monitoring devices
- Monitoring of environmental parameters

2.4.4 "Comfort"



The "comfort" inside a building can be related both to the thermal comfort (temperature, humidity, ventilation) and to the visual comfort (artificial and natural light settings), together with the idea of being able to find easily a place where to work (in an office), where to study (in a university) or where to sit and rest (for instance in a shopping mall).

Some smart technologies related to the comfort issue are:

- Sound masking devices
- Personalized setting of environmental parameters
- Indoor Positioning
- Room booking
- Personalized notifications

2.5 The technologies: new visions for different building typologies

There are many building types where the Smart technologies can really determine a revolution in how those spaces are used. In all the cases, the centrality of the user has to be the driving force of all the Smart features that are included in the building: the goal is to improve the user experience and his/her wellbeing in the space he/she is experiencing. Deerns is focusing the attention on those building functions: offices, hospitals, shopping malls, universities, museums, airports and houses.

Figure 25 - Scheme of the main building typologies that will be analysed (Source: the author)

In terms of smart technologies, there are some of them suitable for all these functions, while some others are specific for a particular function. For this reason, each building type will be presented and analysed separately, by investigating which are the main actors (users, owners, etc.) and which are their needs, in order to provide them technologies properly answering their requirements. In the second phase of the research, presented in Chapter 3, the abovementioned actors are interviewed to see if the smart technologies proposed are what they expect from a smart building.

SMART OFFICES

2.5.1 Smart offices

The smart offices are nothing but a subset of the Smart Buildings; it is important to give them a particular attention because a working person spends almost 40% of his day inside a working place, commonly an office (Capoferro 2018).

As for the Smart Buildings, a definition of a Smart Office is essential in order to better understand its main features and characteristics. *"In essence, the smart office is one that uses cutting-edge, internet-enabled technology to gather data and bring all its key operating systems and services under central control, so that a whole range of different elements work in tandem to create a better, people-centric workplace"* (British Land, Worktech Academy 2017). In this definition, the centrality of the users is strongly underlined, in accordance with the concept of people-oriented buildings. The basic idea of the modern vision of the Smart Office is that it is not just tech-smart, it is people-smart: the smartness of an office building must be oriented towards the improvement of the user's experience, who will feel more comfortable inside the office space and will then perform better. A Smart Office should create an enhanced user experience that helps to increase productivity, attract and retain talent, support wellbeing and promote corporate brand values (Clarke 2018).

During present years, the Smart office must embrace the new standards of a more agile and interconnected workforce (Coor n.d.). Nowadays people are more agile and interconnected than ever before; the key to success for a Smart Office is to exploit this situation and to combine people's new needs with innovative thinking and new technology to support and release the full potential of the workforce. The modern worker needs new stimuli to express fully his creativity and potential and he needs a space where it is possible to adopt this kind of behaviour. Because of this shifting in the way of working, the vision of the standard office space is undergoing a drastic transformation as well, based on the new requirements of the offices' final users, the workers.

2.5.1.1 The new approach to work: smart working

As well as the offices developed in the last period are defined Smart Office, because of the new technological advancements that are included in them, also the new way in which people work has been called "Smart Working". Before to analyse the connection between Smart Office and Smart Working, it is important to understand what the latter is. According to the research work developed by the Osservatorio del Politecnico di Milano, the smart working is a new manager philosophy based on the restitution to people of flexibility and autonomy in the choice of the working spaces, of the timetable and of the instruments to be used, aiming at a major accountability of the work results (Madini 2015). The Smart Working is a management model that regulates the relation between the worker and his company. It is based on a "smart re-thinking" of the working modes inside the office spaces, removing constrains like the fixed working station, the open space and the single office, all concepts that are in contrast with the principles of customization, flexibility and versatility (Capoferro 2018).

This new way of working allows a better balance between the life quality of the employee and his productivity, and it is strongly connected with the conscious use of the digital innovation, a perfect support for enhancing collaboration between people and companies. The Smart Working is fully linked with the concept of Digital Transformation, because it allows innovation, improvement of the everyday activities and the productivity of workers.

"The working cannot become smart without a re-thinking of the organisation of work, spaces and technologies" (Vota 2019). Smart Working and Smart Office are strongly connected, and one cannot exist without the other. On one side, the transformation of the working place is affecting the way in which people work inside it, but at the same time, the transformation itself is driven by a new approach to the way of work, strongly affected by the emerging communication technologies (Tagliaro and Ciaramella 2016). Mobility, working remotely, differentiation of activities are the main trends affecting today's way of working, and these are the main factors that are leading to a completely re-thinking of the office space: the overall tendency in the new construction offices is the downsizing, i.e. the propensity to reduce the total floor are dedicated to the working activities. In the traditional work set-up, each employee has a desk, and if an employee were absent because of various reasons, then space would end up not being used. This does not happen in a Smart Office, which is designed exactly for the Smart Workers, who may be working remotely in a different place. Following these principles, many companies (particularly ones where people often work at home or travel a lot) moved some of their business units, or all of them, to the so-called "hoteling" or "hot-desking" models, that means providing workstations on an "as needed" basis. The difference

between the two models is that the "hoteling" allows the employees to book their desk in advance, while the "hot-desking" works on a first come-first-served basis. These models, conveniently combined with teleworking[13], can save at least 15/18% of space requirements (Madini 2015), with an estimated 25% increase in productivity (O'Mara 1999). This can be advantageous not only in terms of economic return for the company itself (fewer square meters occupied correspond to fewer costs), but also to increase environmental sustainability, benefitting cities (reduction of land consumption), and human involvement from the worker's perspective (better satisfaction, well-being and quality of life).

According to a survey conducted on 500 office users in North America by Memoori, in which the respondents occupied several typologies of office layout types (39.6% open plan, 34.6% cellular and 25.8% somewhere in between), in open plan offices 71.4% of the workers feel that this layout improved productivity, compared to 44.2% who worked in cellular office cubicles. Conversely, only 12.2% feel that open plan hindered productivity, compared to 30% of cubicle-dwellers.

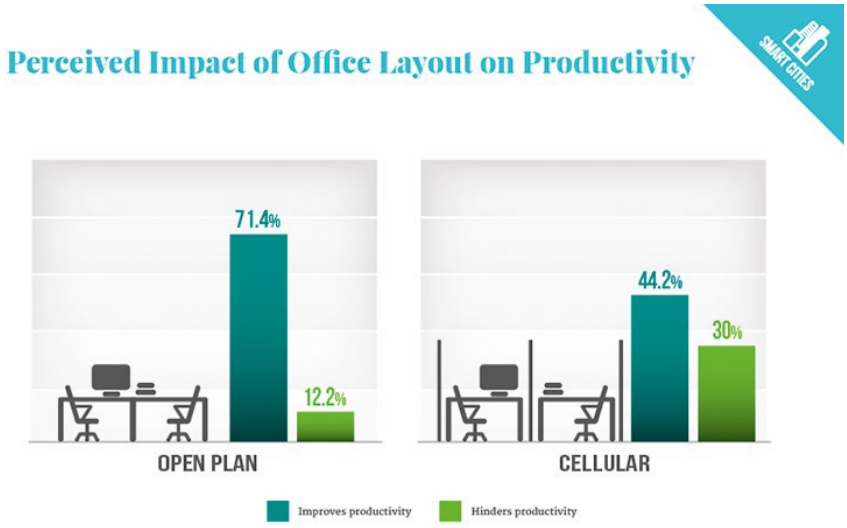


Figure 26 - The graphs describe the perceived impact of office layout on productivity (Source: Meemoori Research AB, "The Future Workplace: Smart Office Design in the Internet of Things Era", 2017)

These results support the increasing trend for companies preferring open plan to cellular, but they also suggest that the optimal solution for most businesses is probably some sort of multi-space layout (McLellan 2018). It follows that a complete open-plan office is not the answer to the Smart Working. Even if there are no assigned workstation, in the office there must be different "functional area", where employees are able to accomplish all their activities in a proper way (Meemori Research AB 2017).

[13] Working from home using virtual technology.

2.5.1.2 Design strategies for realizing a smart office space

The smart office cannot be just an open plan space, and it is necessary to find some key features that the office designer should include in their projects of new Smart Offices. Thanks to researches conducted by the "Osservatorio Smart Working" at Politecnico di Milano, it has been possible to defined six basic design strategies that must be the basis for the design of a Smart Office. One of these is the **Multifunctionality**, which appears to be the perfect answer to what people are looking for, the so-called Activity based Working. Every single activity must have the ideal space in which it is possible to complete it in the best way possible. The model of Activity Based Working proposed by Jeremy Myerson identifies six main working space typologies (Myerson e Bichard 2010):

1. **Concentration**: silent spaces, far from noise and sources of distraction (ex. Concentration rooms). In these spaces, employers can focus on individual activities, that do not require teamwork, and for which a well acoustic insulated space is necessary.

Figure 27 - Example of a concentration room (Source: https://www.estel.com/it/categoria/smart-office/)

2. **Collaboration**: areas with enough space to share materials and ideas (formal and informal meeting rooms). The key point of a meeting room inside a smart office is the presence of a technological equipment that allows communicating with people who are not physically present in an easy way. In a typical conference, the use of a Centralized Control System eliminates the need of numerous remote controls for the various equipment and enabling endless possibilities such as "One-Touch" settings for presentation or conferencing to enhance the User Experience.

Figure 28 - Example of a conference room inside a smart office (Source: https://komstadt.com/smart-conference-room/)

3. **Communication**: spaces that are able to ensure a proper level of acoustic insulation and a good level of privacy, dedicated to those activities that deal with confidential topics. They can be the same type of space explained in the first point, related to concentration. In this case, the acoustic issue has greater importance.

4. **Contemplation**: zones where the worker can find silence in order to have individual creative thinking and to relax.

Figure 29 - Example of a contemplation and relax area inside a smart office (Source: https://www.architonic.com/en/collection/estel-group-smart-office-comfort-and-relax/3101469/3012205/1)

Going on considering the design aspects that aim at realizing a smart office in terms of space layout and workers wellbeing, two more strategies have to be mentioned and described: together with the multifunctionality, the **flexibility** is a key feature for a Smart Office Design. Besides the spaces variety, also their ability to adapt to both short and long period situations must be considered: the

structural elements like the walls should be designed in a way that they can be easily moved and reconfigured, also to allow the same space to be used for different purposes and people requirements. The third key feature (Madini 2015) is the **focus on the wellness service**, so that the employees can find a comfortable working space where to develop new ideas. It is fundamental to provide the workers with spaces intended for wellness activities and relax.

Great importance is given to the realization of a healthy space, that is able to improve life quality and to increase the productivity (Meemori Research AB 2017). During the design phase it is essential to enhance the correct relation between natural and artificial light, choose materials that are not harmful for people's health, ensure a proper ventilation and acoustically insulate the environments in order to prevent stress conditions.

In an office space that is becoming more and more open and transparent, it is essential to provide the so-called private corners, that ensure privacy and places where to find concentration. The phone booths are example of private corners (Capoferro 2018): they are the evolution of the traditional phone booths placed along the streets, and they are spaces acoustically insulated where employees can find privacy, silence and concentration.

Figure 30 - Example of phone boots inside a smart office (Source – left image: https://www.urban-office.com/office/pods/hush-space-pod.html, Source – right image: https://officesnapshots.com/products/phone-booth/)

Together with the Phone booths, the social hubs are another typology of space that did not exist in the traditional offices, but which accordingly to the experts, has a great importance. In order to encourage the creativity of the working teams, hybrid spaces are created, where people can meet and share ideas. Work together and have moments of relax is of basic importance to increase the workers satisfaction and productivity (Politecnico di Milano 2018). For this reason, real HUBs are

built inside the office space, where it is possible to experiment, learn, share project an information inside the company.

Figure 31 - Examples of social hub (Source: Orange group, "The Social Hub, a new digital space with a window on the world", 05/03/2018)

Another tendency that is spreading out in the building sector is the Office branding (Politecnico di Milano 2018). Through the correct use of color, the companies have a way to express their own philosophy. The psychology of color acquires a fundamental role in the Smart Office Design, because the chromatic choices influence the perception of the space, the feeling of the time passing and the workers productivity. In general, the use of shades and textures to create customized environments affect positively the employee's state of mind. More in detail, the meeting areas and the relax zones should be characterized with specific colors and textures in order to diffuse the values of the company.

Technology during the design phase: The Generative Design

Until now, the basic design strategies to realize a Smart Office have been described, without any reference to technology. However, in the XXI century it is not reasonable to describe something smart with no mention of technological devices: is it possible to make smart not only the office, but also the way in which it is designed? Thanks to some advanced software, nowadays it is possible: this type of design process is called Generative Design. Generative design (GD) is the process of defining high-level goals and constraints and using the power of computation to automatically explore a wide design space and identify the best design options. While generative design applied for manufacturing is gaining more and more attention, its use for architectural space planning has been explored (Villaggi and Nagy 2018). The generative design is an optimization tool that allows optimizing the internal layout of a space in function of some constrains selected by the designer.

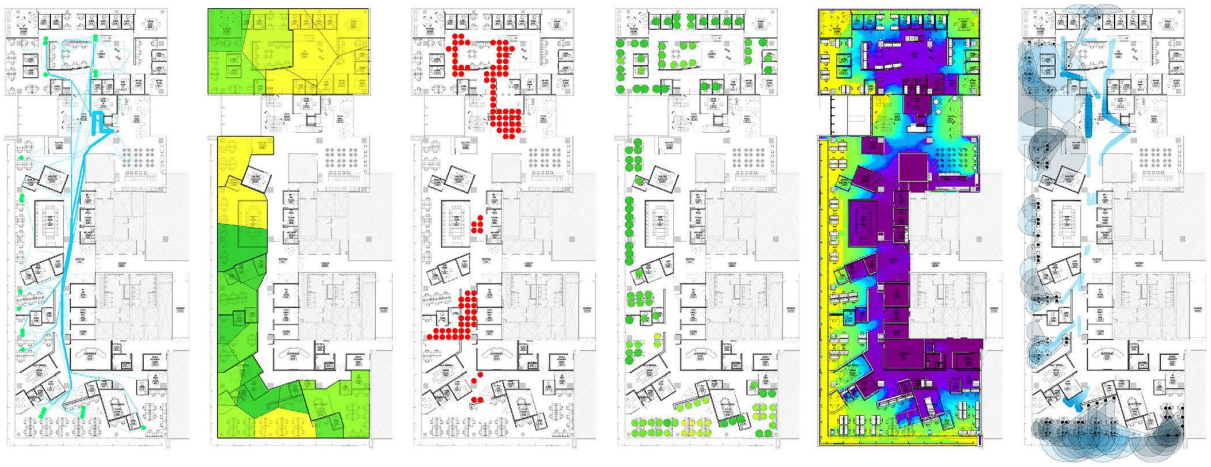


Figure 32 - Possible design metrics used as inputs for the generative design process. From left to right: adjacency preference, work style preference, buzz, productivity, daylight and views to the outside (Source: Danil Nagy, Damon Lau, John Locke, Jim Stoddart, Lorenzo Villaggi, Ray Wang, Dale Zhao, David Benjamin, "An application of generative design for architectural space planning", May 2017)

In a traditional design process, design decisions are developed through what are typically called 'rules of thumb' and human design intuition. For example, it is proved by the experience that at Milan latitude, the placement of an external overhang is the best way to ensure proper solar gain in winter and to avoid summer overheating. Borrowing the terminology from computer science, this type of approach to problem solving is called 'heuristics': simple strategies for problem solving that have proven to be somewhat successful in the past. Although this approach is efficient, when applied to complex problems they generally do not yield to the best overall solutions. For this reason, computer scientists have introduced 'metaheuristics,' a set of optimization techniques that for a given complex problem they can find a set of overall best solutions by iteratively sampling solutions and using performance criteria to generate better and better outcomes. Through the application of generative design, it is now possible to move away from traditional layouts and rule of thumb decision making and discover new layout solutions that are both novel and high performing accordingly to some specified design goals (Nagy, et al. 2017).

A premise is necessary about the origin of the generative design, and it is important in order not to make confusion between generative design and parametric design. The parametric design has been developed in the last decade, and it is a great tool to define geometrical solution and to describe the entire system behind how a design is generated. The parametric approach makes it easy to create variations and custom adaptations of a design: instead of manually creating multiple versions for different applications, the designer can expose the critical parameters that drive different variations and automatically generate different versions by changing those parameters (Nagy, et al. 2017).

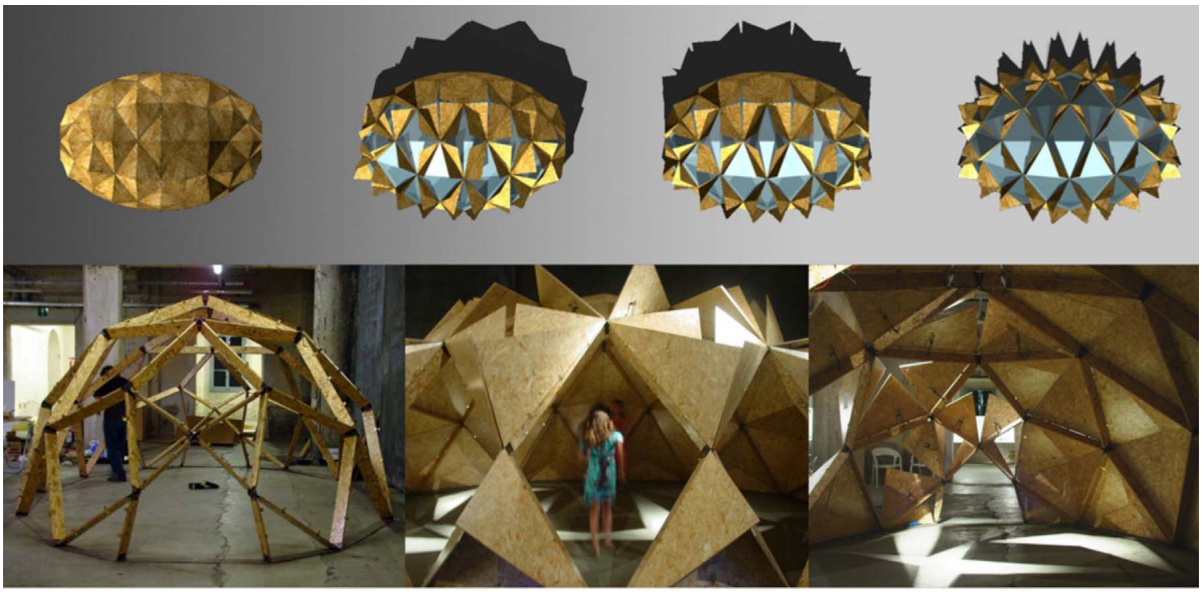


Figure 33 - Example of a design for a pavilion controlled parametrically. Thanks to a Grasshopper script, it has been possible to model and study all the possible configuration of the envelope. (Source: Ahmad Eltaweel, Yuehong SU, "Parametric design and daylighting: A literature review", 2017)

Most importantly, the parametric approach allows the designer to think through design solutions in a more dynamic way with respect to what it is possible to do with traditional methods. In a standard approach, the designer studies the issue, internalizes all of its constraints and objectives, and then use their skill and experience to define a solution. With the parametric approach, the constraints and goals of the design problem can be directly embedded within the parametric model, which can then be used to automatically generate a variety of solutions. Instead of designing a single solution, the designer can now think of designing a multi-dimensional 'space' of design. While the parametric approach has broadened the possibilities of design and pushed the boundaries of human-computer interaction in the design process, the exploration of the design of the internal space is still limited by the abilities of the human designer. Although some parameters may be set by some constraints found explicitly in the design problem, for the most part of the design process the human designer must investigate different options by manually varying individual parameters and evaluating each option using their own criteria and intuition in a way not much different from traditional design methods. The concept of generative design, as described in this paper, addresses this limitation by tasking a computer with exploring the design space semi-autonomously, and then reporting to the designer which options it considers promising for further analysis. Because a computer can process information in a quicker way than a human can, such a system allows a much deeper exploration of complex design spaces.

There is a way to move from parametric design towards generative space design: to take advantage of the possibilities of generative design, the basic parametric model must be extended in two ways.

First, the model must include real metrics by which each design option can be evaluated. Since the computer does not have any self-intuition about design, the human must explicitly describe to the computer how to determine which designs perform better than others do. Second, the model needs to be connected to a search algorithm that can control the input parameters of the model, get feedback from the metrics, and intelligently tune the parameters to find high performing designs while also exploring the full possibilities of the design space (Nagy, et al. 2017). Of course, not all design problems require generative design workflows to be adopted. The ones that are complex enough that a human alone is not able to solve are the appropriate type of problems that generative design should tackle. Generative design integrates artificial intelligence into the design process by using algorithms to discover novel and high-performing results within a given design system. Its framework is dependent on three main components:

- a generative geometry model that defines a 'design space' of possible design solutions;
- a series of measures or metrics that describe the objectives or goals of the design problem;
- a metaheuristic search algorithm such as a genetic algorithm which can search through the design space to find a variety of high-performing design options based on the stated objectives.

After having clarified what is necessary to operate a generative design process, now it is necessary to describe which are the fundamental phases of this process, that can be summarized in pre-gd, gd and post-gd (Autodesk research group 2017).

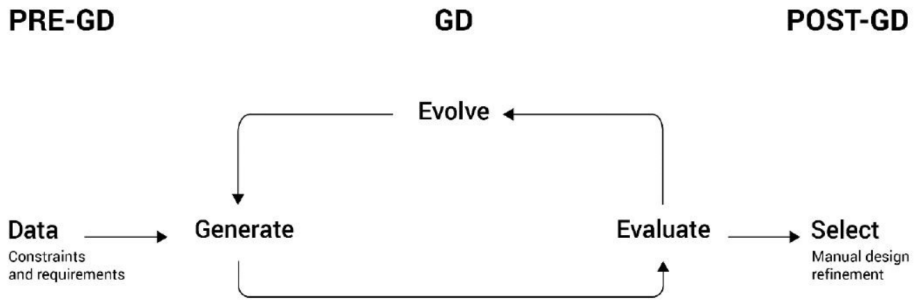


Figure 34 - Diagram summarizing the main phases of the Generative Design process. (Source: Autodesk research group, "Generative Design Applied on Buildings", 06/09/2017)

The **pre-GD phase** involves working closely with the stakeholders and gather unique and critical data about the project that can inform the generative model and the evaluative component. More in detail, the first step is data gathering: it is necessary to collect information about all the requirements and constrains imposed by the client and the normative. The second step of the pre-gd phase is the goals formulation that has to be assessed together with the stakeholders and the project committer.

For what regards the **GD phase**, it is constituted by three main components, that have been mentioned before and that will be now described more in detail. The phase related to the generation of the geometry is the one in which the "shell" to be filled in is defined, and the main elements of the internal subdivision are set (main corridors, atrium...). Of course, different possibilities will emerge, and for this reason, the second phase (Evaluation) has great relevance: through the automated evaluative components, each design is scored along the established metrics. Such numerical values are used by the metaheuristic search algorithm to evolve high-performing designs and learn over time. Finally, in the evolve phase the high-performing designs are recognized: the solutions are presented in a Kiviat diagram (better known as a "spider diagram") to learn more about the different components and their obtained scores in relation to the input metrics that have been established at the beginning of the process.

In the **post-GD phase**, the human component becomes critical. Aided by design space navigation tools, the human designer can explore the high-performing designs, navigate metric trade-offs and qualitatively judge design options. By directly inspecting a subset of high-performing designs, the designer together with the main stakeholders can focus on a small set of candidate designs to be manually refined. As final action, manual refinement takes place in order to further develop the design and ensure that constraints and requirements are met. Examples of software that can support a generative space planning process are Grasshopper and Dynamo: they give the possibility to cycle through thousands—or even millions—of design choices, test configurations and learn from each iteration what works and what does not.

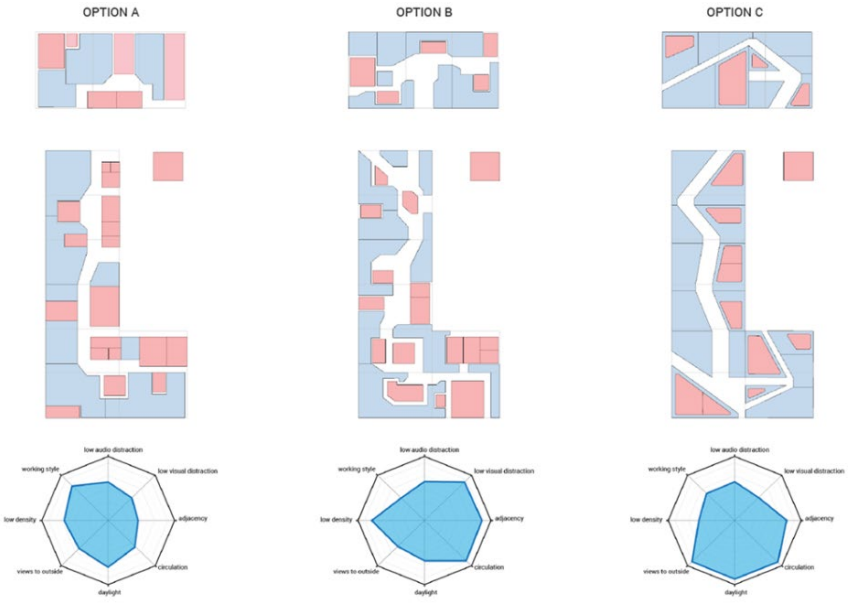


Figure 35 - This image is an example of an evolve phase, during which the best options are presented and evaluated through a spider diagram. The best solution is the one with the greater blue area in the diagram itself. (Source: Autodesk research group, "Generative Design Applied on Buildings", 06/09/2017)

2.5.1.3 The new technologies for the Smart Office

The Smart Office does not deal only with design strategies and space layout, which are of course very important aspects, but there is much more, linked to the development of new Smart technologies aiming and improving the life quality inside the office itself.

The presence of technology in the new offices is in general appreciated by both workers and supervisors: British Land and Worktech Academy surveyed 1.063 office workers in London in 2017, including 291 with decision-making involvement in their organization's location, as part of a study entitled "*Smart Offices: A 2017 Vision for the Future*". Ninety percent of decision-makers saw a business reason for working in a smart office and a similar number (87%) would require smart office tech in their next relocation. Benefits are expected in several areas: productivity, wellbeing, appeal to new talent and employee loyalty (McLellan 2018).

The big companies are the ones who are more interested in the benefits that the technology may offer to them; an example is Microsoft, who published in 2018 a report entitled "Digital Culture: Your competitive advantage". The basic issue, which is discussed in their research, is if, and how, the digital culture can have a positive effect on the office productivity and on the wellbeing of the employees. To help businesses understand how best to empower their employees, Microsoft commissioned research on over 20.000 employees across 21 countries examining the interaction of technology and people in the workplace. The output of the report is that the digitalization of the office space is able to offer benefits both to the workers and to the company: the research revealed the importance of a digital culture in the path towards the digital transformation.

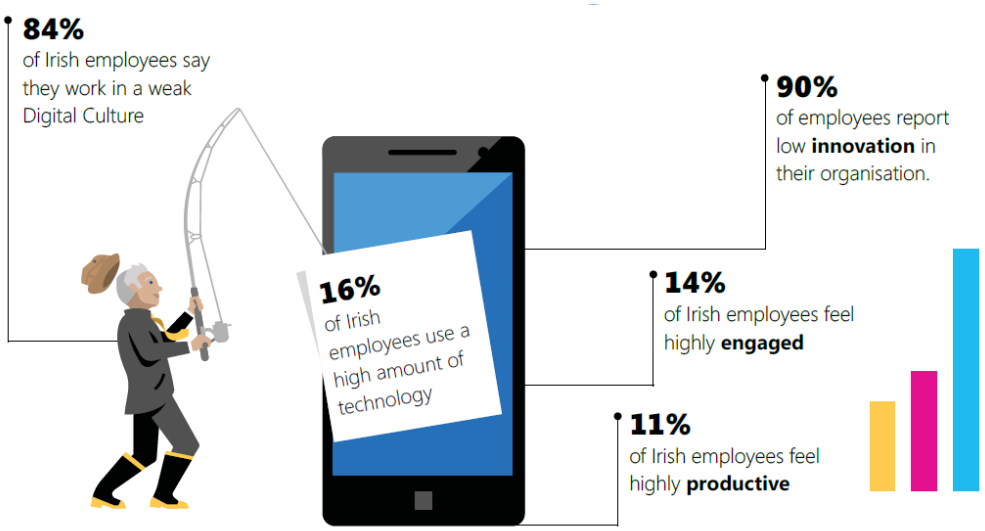


Figure 36 - Summary of the results obtained by interviewing employees about their perception of the digital culture. (Source: Microsoft research group, "Digital Culture: Your competitive advantage", 2018)

First, it is necessary to understand what it means "digital culture": a digital culture is the environment in which workers feel inspired by their leaders and managers about the potential of technology to help them in their jobs and help grow the business. In terms of numbers, the research by Microsoft displayed that 84% of the interviewed employees believe they have a weak digital culture, and close to 90% feel unproductive at work because they feel disconnected.

Moreover, Microsoft demonstrates that businesses with a strong digital culture are more likely to have twice as many employees who feel productive (Microsoft research group 2018).

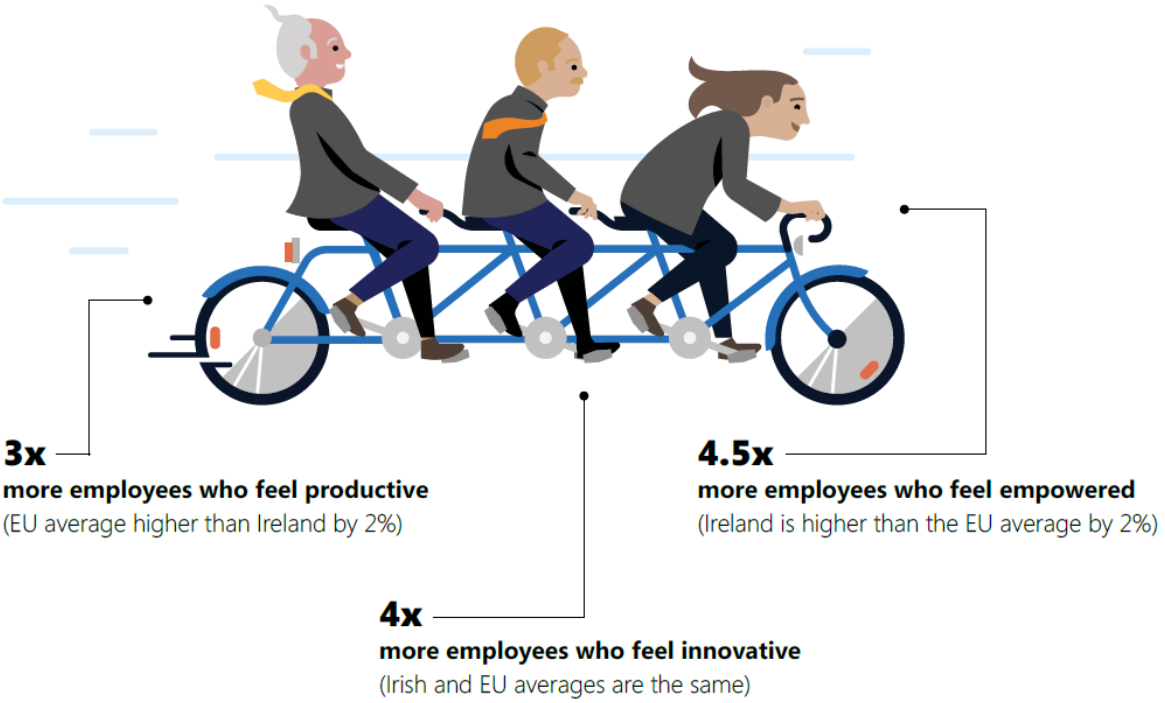


Figure 37 - Effects of digital culture on workers. (Source: Microsoft research group, "Digital Culture: Your competitive advantage", 2018)

It emerges that people are feeling the necessity of a transformation in their approach to work activities, and the re-thinking of the office space in terms of internal layout it is not enough.

In an era in which technology is all around everyone every day, also the working place must be aligned with this tendency and offer a digital experience able to help people performing better and easily. In this regard, Harvard University demonstrated that 80% of today's CEOs believe digital disruption is imminent, and almost half think their business model will be obsolete by 2020 (Harvard Business Review 2017). Modern workers have an abundance of technology readily available, but this availability does not necessarily translate into impact: to ensure technology truly empowers people to unlock growth, every company needs a strong digital culture.

However, what does mean for a company to have a strong digital culture? It is just a matter of having abundance of technological devices or there is more? Basic ingredients are training, access to information, manager promotion of tech adoption, and a clear strategic vision from leaders regarding technology's transformative potential. When all these elements are in place, a company can be said to have a strong digital culture. When a company has a strong digital culture, the impact on key performance indicators is substantial (Microsoft 2018).

The following graph (Politecnico di Milano 2018) shows the relation between the level of digital culture in the companies object of a study and the consequent feeling of productivity of the workers. In general, the predominant answer in all the three conditions (Weak, average and strong digital culture) is of a sense of average productivity of the workers; however, the high productivity feeling in the case of a strong digital culture is 14% and 12% higher with respect to the weak and average digitalization, respectively. Moreover, also the sense of low productivity almost disappears in conditions of strong digitalized companies.

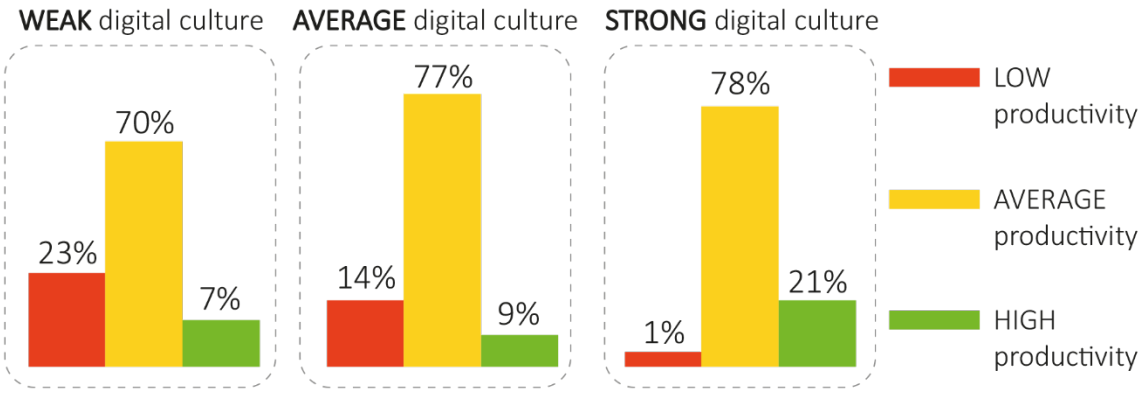


Figure 38 - The graph underline how when in a company the level of digital culture is higher, also the productivity of workers increases. (Source: Microsoft research group, "Digital Culture: Your competitive advantage", 2018)

Another aspect that is underlined in several researches about the digitalization of the working environment (Microsoft 2018), (Steelcase 2018) is the engagement, or flow. It can be defined as the ability for workers to focus on the task and deliver a better result more efficiently. Overall, just 20% of respondents felt highly engaged at work, but there was a fourfold difference between engagement levels in businesses with strong versus weak digital cultures. In addition, adding more technology to the mix increased engagement in strong digital cultures, but not in weak ones (Microsoft research group 2018).

The Steelcase Global Report uncovers five key findings about the factors that influence workplace satisfaction and engagement (Steelcase 2018):

- **Employee engagement correlates with workplace satisfaction**: employees who are most satisfied with their workplace are also the most engaged. These are "people who come to work energized, ready to generate new ideas, create new strategies and make meaningful progress each day," as the report by Steelcase states.

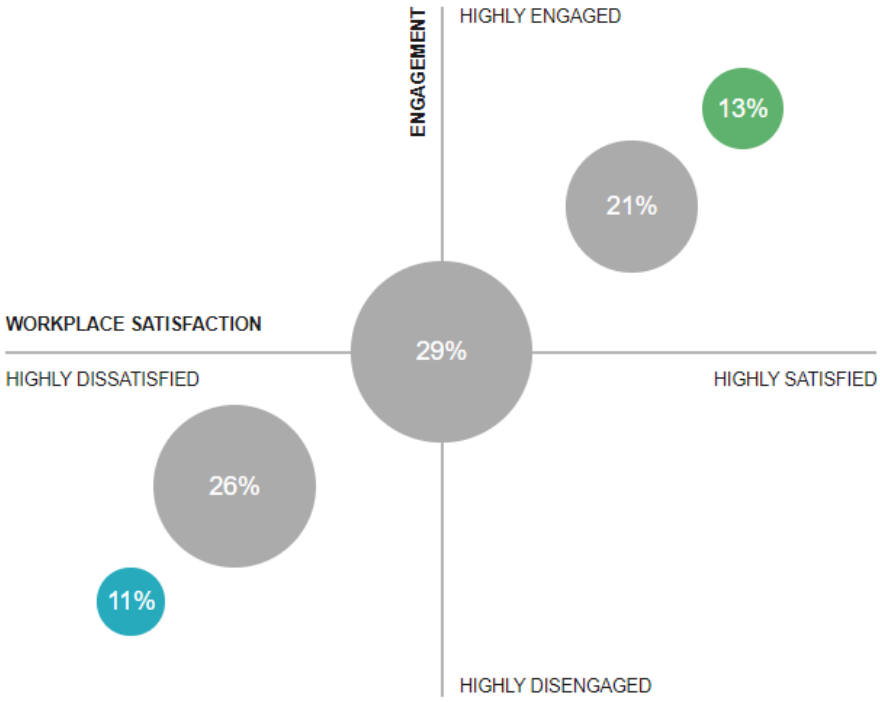


Figure 39 - The data presented in the graph reveal high workplace satisfaction positively correlates with high employee engagement. 11 % of global workers are highly dissatisfied with their offices and are highly disengaged. This means that they are not able to stay focus and to accomplish the final goal in a good and fast way. On the other hand, 13 percent of global workers are highly engaged and highly satisfied with their workplace. (Source: Steelcase global report, "Engagement and the Global Workplace: Key findings to amplify the performance of people, teams and organizations", 2018)

- **Engaged employees have more control over their experiences at work**: flexibility is a key component of engagement, with 88 % of highly engaged employees reporting the ability to choose where they work depending on the task. Moreover, Steelcase also found that employees who could choose their office furniture were more likely to be satisfied with other workspace attributes such as room temperature, ambient noise levels, ventilation and technology equipment. It emerges that flexibility over desk choice seems to be a proxy for a progressive management culture.

- **Fixed technology exceeds mobile by 2:1**: Despite the high global adoption of mobile devices for personal use, the vast majority of study participants report that their organizations provide twice the amount of fixed technology than mobile options for work.

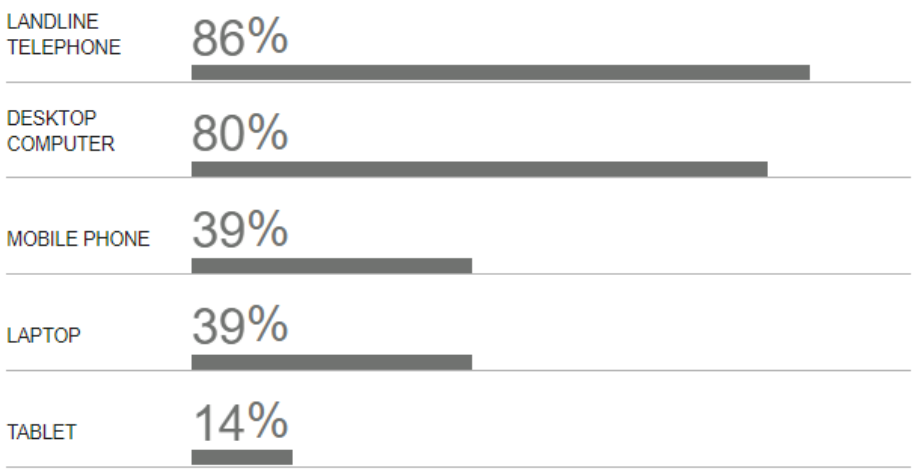


Figure 40 - Most workers use fixed technology at work, as the graph shows. (Source: Steelcase global report, "Engagement and the Global Workplace: Key findings to amplify the performance of people, teams and organizations", 2018).

- **Traditional workstyles persist**: although global collaborative work has become a rising trend, nearly two-thirds of employees say they work either in individual offices or shared private offices. To the question "*What type of workspace do you want to work in*", the answers are (Steelcase 2018):

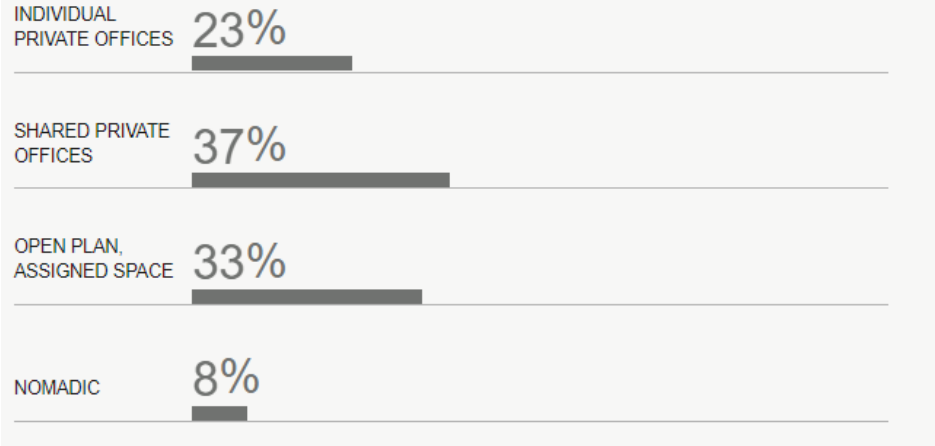


Figure 41 - Nearly two-thirds of employees who have been interviewed by Steelcase stated that they work in either individual or shared private offices. (Source: Steelcase global report, "Engagement and the Global Workplace: Key findings to amplify the performance of people, teams and organizations", 2018).

- **Cultural context influences engagement levels**: the survey revealed wide variation in employee engagement and satisfaction levels by country. India was way out in front with 53 percent engaged/satisfied and 20 percent disengaged/dissatisfied, while at the other end of the scale France reported almost the mirror image: 20 percent engaged/satisfied and 54 percent disengaged/dissatisfied. The general pattern was one of positive attitudes in emerging economies versus low engagement and satisfaction in established economies (Steelcase 2018).

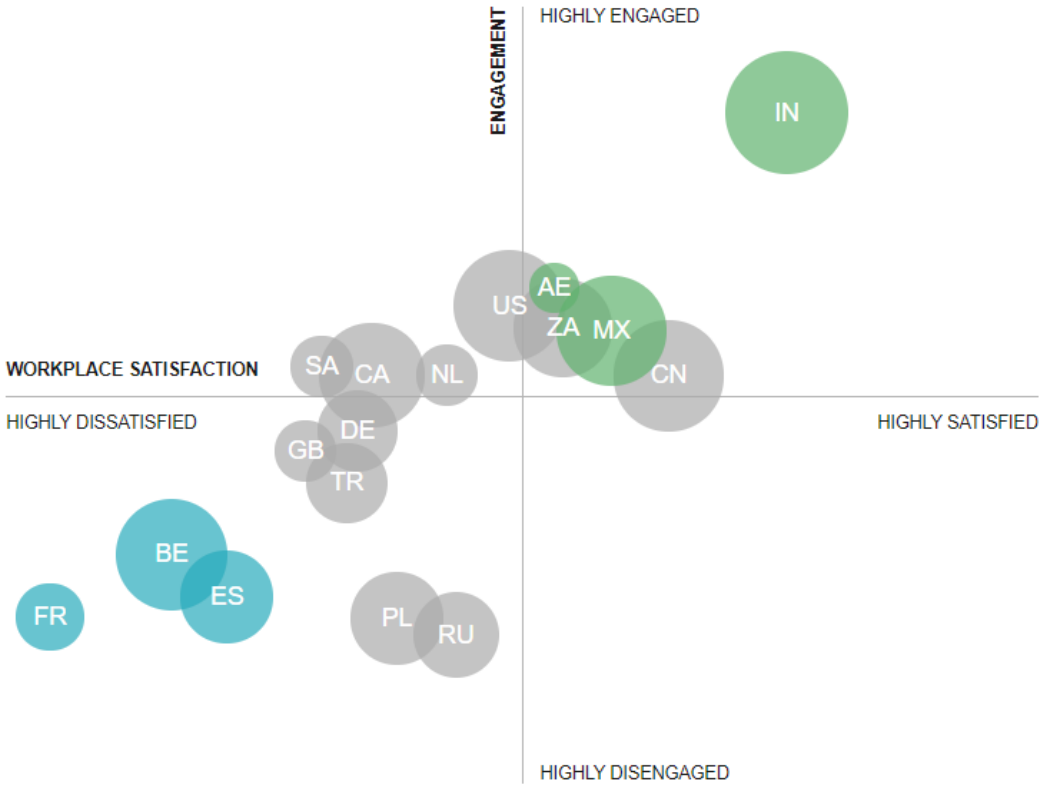


Figure 42 - The results of the research show that the cultural context can have a strong influence on engagement and workplace satisfaction. Countries that result to be highly Disengaged and highly Dissatisfied are France, Spain and Belgium. On the other side of the graph, the countries highly engaged and highly satisfied are India, Mexico and United Arab Emirates. (Source: Steelcase global report, "Engagement and the Global Workplace: Key findings to amplify the performance of people, teams and organizations", 2018).

Results from surveys carried out by researches are useful to have a first idea about which are the most popular smart office features among the respondents. British Land and Worktech Academy surveyed 1,063 office workers in London in 2017, including 291 with decision-making involvement in their organisation's location. The most popular smart office features across all respondents were self-adjusting lighting and window shades; personalised heat and light settings that follow you around the building; circadian lighting systems that mimic natural daylight and heating/lighting systems that adjust automatically according to weather and occupancy. Decision makers were also interested in an app for booking desks and meeting rooms, meeting rooms where screens work seamlessly with personal devices and desk or room sensors that track usage for efficiency monitoring.

In the following chapters, the most diffused and innovative smart office technologies will be presented and described, with specific reference to already existing products and to their possible evolution.

Smart recycling and E-Bins

One of the most innovative technologies in the smart office design are the E-Bins for a better and smart recycling: for a more environmentally friendly smart office, automated recycling tools can help sort trash when employees do not have time. The eBins can sort, compress, and of course, save money. An available product on the market is called "BinE", a smart waste bin helping in sorting the different materials for a smart recycling system.

Figure 43 - Scheme of the functioning of BinE (Source: http://bine.world/howitworks/).

This kind of technology offers many possibilities: for example, the smart recycling e-Bin can be programmed to communicate relevant information with both the user and the recycling company. The e-Bin may be able to tell the user if it is full and suggest the location of the next nearest e-Bin, whilst informing the recycling company to come and empty its contents. It is also able to tell the user if their item is not suitable for recycling.

The great advantage of such a technology is the possibility of implementing it almost everywhere: not only in offices, but also in hospital, museums, universities, houses and even in the open areas of the cities, in order to ensure a correct recycling procedure everywhere.

Keyless entry technologies

Another smart technology that catching on in the building sector are the keyless entering systems: they make entering and exiting the building in a secure and easy way. There are two ways to realize a keyless entrance system: first, if the employees use ID cards, it is possible to replace those cards with Card Beacons. These can interact with the cloud via a Gateway installed at entrances. Once the Card Beacon[14] is in a given vicinity the Gateway, the door can be automatically unlocked. This works best in scenarios where managers want to track employee movements or create a complete connect system around their office. The second, simpler option uses one beacon at an entrance working with an app present on users' mobiles: the employees' phones can act as the key to automate entry.

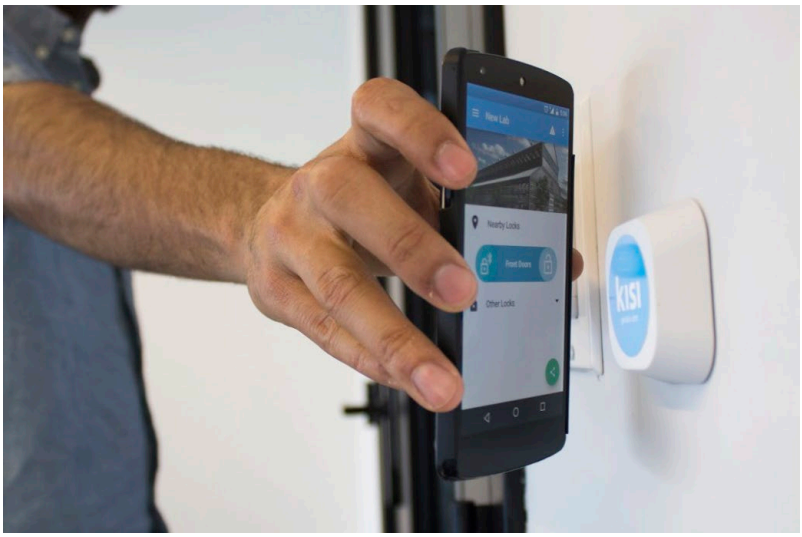


Figure 44 - Example of a keyless entrance method which uses an app installed on the smartphone to guarantee the access to the building (Source: https://www.getkisi.com/).

This type of technology is becoming standard, as the world is moving beyond traditional keys and into the world of keyless entry systems. There are big benefits with the implementation of these types of technologies: enhanced security, better data, and better access control (Pawlowski 2018).

There are different types of keyless entrance systems, and the best option depends on the building type and location.

[14] Beacons are small computers, roughly the size of a standard Wi-Fi router. As part of indoor positioning systems, beacons use proximity technology to detect human presence nearby and trigger pre-set actions to deliver informational, contextual, and personalised experiences. When a user walks past an area where an indoor positioning system is set up, a beacon sends a code with a message to their mobile device. Here app solutions come forth: this coded message, which is shown in a form of a notification, can only be viewed with a mobile app (third party or brand mobile app).

First, there are the Key Fobs or cards, quite similar to the beacon cards presented in the previous paragraph. Key-fob-based systems are some of the most common keyless entry systems available on the market. They follow the same principle of the opening of a car that has been made within the last fifteen years: the key fob allows unlocking the car when the user is in proximity of the receiver using an encrypted radio signal. Commercial key fobs work generally the same way and can be active (meaning that data is transmitted, and doors are unlocked upon push of a button) or passive (meaning that data is transmitted consistently, and doors are unlocked when the fob is held to the reader). Card-based systems function similarly, although there is potential for different methodology. Cards can transmit data via radio signal (in which case they function exactly as key fobs), or via magnetic stripe. These types of system have both positive and negative aspects. For what regards the advantages (Pawlowski 2018):

- They're relatively inexpensive compared to other keyless entry systems;
- They can be activated for different access points;
- They can be remotely deactivated.

On the other hand, some possible drawbacks are:

- Like keys, these physical tokens are still losable;
- There are limited in real-time monitoring capabilities;
- They are generally lower-security – these systems tend to be easily hacked.

Another possibility in terms of keyless systems is the biometric access control. The logic to biometric keyless entry systems is easy to be understood: individuals' biological identifiers (like facial structure or fingerprints) are used to grant access into and out of buildings. This, in theory, makes security tighter and removes the danger or lost tokens. Fingerprint scanners, for example, can be configured at entry and exit points. Individuals who have registered access with the system are then able to scan their fingerprint and enter a location. Facial recognition systems work in much the same way, although today's machine camera technology can take things to the next level by automatically granting access on sight of a person – so, doors can be unlocked without any real action by recognized users. The benefits of biometric access control are (Pawlowski 2018):

- It provides increased security, as it's harder to fake identity than to replicate a token;
- It is relatively simple to maintain (no replacement card costs, for example);
- There are no physical devices to lose.

Biometric access is not without its drawbacks, too:

- It is not convenient with a frequently changing user list;
- Systems tend to be more expensive compared to other keyless entry solutions;
- There are occasionally identification issues (failure to recognize a face or fingerprint) that can lockout users.

Finally, app-based access control is another type of keyless entry system, already mentioned in the previous paragraphs. As mentioned in the name, these systems are based on user control through mobile apps to manage entry and access. The methods for doing this can vary; for instance, some systems function by allowing users to control access-granted locks through the app. Other app-based systems function more similarly to key fobs: they use proximity technology such as beacons to open doors when users are near, or, alternatively, open when a phone is pressed to an access point. These systems can be customized to fit a range of contexts, because they are generally less hardware dependent and can often be tailored easily via the admin-side of the application (Pawlowski 2018). However, they also have drawbacks in addition to benefits. The benefits of app-based access control systems are:

- They tend to be easily customizable in terms of access levels and user control;
- They enable remote access control.
- There are also in this case some negative aspects that need to be presented and discussed:
- They rely on user-controlled smartphones, meaning greater potential for user error;
- If they rely on connectivity, phones without data can face lockouts.

The building owner can choose among a wide range of opportunities for what regard keyless entrance systems, and all of them offer the possibility to simplify the entrance/exit procedure and improve the experience of the building itself.

	PRO	CONS
CARD access	- Cheap - Multiple access points - Remotely switchable	- Losable - No real-time monitoring - Low security
BIOMETRIC access	- High security - Simple to maintain - Not losable	- Not suitable for visitors - Expensive - Possible failures in recognitions
APP-BASED access	- Customizable - Low hardware involved - Remote control	- Subject to users' errors - Cybersecurity concerns - Relay on connectivity of smartphone (they must have data active)

Table 3: Summary of the different types of keyless entry technologies and their pro and cons.

An example of App-based keyless entry technology is Doordeck, which does not require additional hardware and it can be implemented in already existing buildings. This is the main difference of Doordeck system with respect to the keyless entry devices based on the use of cards or on Bluetooth sensors to be connected with the smartphone. Both these two latter technologies require the installation of a new hardware, meaning installation costs and time losses. Doordeck requires the installation of a software on the same server that is already in use by the building to manage the access control. The second step is to mount a tile next to the door opening system, which is the main component of Doordeck, and then the keyless entry technology is ready to operate, by simply using the QR code reader of Doordeck app on the smartphone.

Figure 45 - The three images show how Doordeck system works: the QR code tile is installed on the door, and then it has to be selected on the smartphone or on the smartwatch that is the door to be opened (Source: Doordeck brochure).

Room booking

Both in big and smaller companies' buildings, employees in offices with activity-based workspaces are used to experience scheduling issues, related to the lack of a room booking system (McLellan 2018). For this reason, the room booking technology is one of the most appreciated and diffused (Politecnico di Milano 2018) in the modern Smart offices, because it allows to avoid all that waste of time related to the need of finding a place where to work. Moreover, both in big and small offices, often happens that employees complain about the lack of meeting rooms, but in the end the majority of them remain empty (Madini 2015). Keeping in mind that the future of the office space is to become flexible and agile, with the removing of the fixed working positions (Tagliaro and Ciaramella 2016), the room booking technology appears to be essential in such a working environment and considering the issue presented in the previous paragraph. IoT solution providers are finding numerous ways to make room and desk booking easy and effective. Offices are turning to apps and online platforms to actively book or review bookings for a given space: when a person book a meeting room, this information will be displayed on the digital time log at the room entrance, so that everyone is able to recognize that that room is occupied. Some solution providers are even automating the process with beacons: a Bluetooth beacon can tell the app exactly which room the user is in in or automatically mark a room as "in use" (Fischer & Kerrn n.d.).

Durante, an Italian company, developed a system called "Space Booking" which includes all the features described above. The starting points for the realization of the system were the issues related to the space management in the office. It has been observed that it is often difficult to book a meeting room or to recognize if it is booked or not. This leads to the risk of overbooking or, on the opposite, of underused of spaces.

Figure 46 - Main elements of the Space-Booking system proposed by Durante (Source: https://www.durante.it/soluzioni/space-booking/).

Therefore, the technology developed by Durante allows to book the rooms via app on the smartphone or though the tablet placed outside each room, and to manage the multimedia systems of the room itself with a unique graphic interface.

The booking system offers to the attendants or to the chairman of a conference to simply book a room adequate to the type of meeting, and at the same time he can send an invitation to all the participants, also in videoconference, and to ask for specific devices, accessories or advanced services like a translator or a catering service.

The tablet on the tables placed inside the meeting rooms allows a smart management of the room automation scenarios. For example, it is possible to organise a videoconference with a simple touch of the screen, or to adjust the light settings in the same way.

The tablet outside the doors allow everyone to visualise the status of booking of a room. In case of availability, it is possible to operate the instant room booking, necessary in order to access the room. The system shares the information on all the office devices in order to avoid superpositions.

The system transfers simultaneously to the technical staff and to the management staff the room booking requirements. Through a system of morning check of meeting rooms and devices inside them, it is ensured the proper functioning of all the environment, and all this data and information are transmitted to the users and managed through the technical wallboards.

The room status monitor gives the possibility to verify the occupation status of a specific room or space, facilitating the research of the closest free room.

The acoustic issue: sound masking

In the office space there is another aspect that need to be addressed: the acoustic issue. A correct sound insulation between different spaces in essential to ensure a proper level of privacy and to allow workers to focus on the activity they are doing without being distracted. The question now, is to understand how acoustic insulation will work in the new Smart offices, where the idea is to have open spaces and workstations that are no more fixed. The Sound Masking offers a great possibility: Sound masking is the process of adding background sound to reduce noise distractions, protect speech privacy and increase office comfort (Cambridge sound n.d.). The Sound Masking in the modern Smart offices has a fundamental importance, for three main reasons (Cambridge Sound 2018): first, it aims at reducing sources of distraction of the employees. In a recent study presented to the International Congress of Noise as a Public Health Problem, researchers found that, on average, employees wasted 21.5 minutes per day due to conversational distractions, making lack of speech privacy the number one cause of reduced productivity. An additional 2014 Steelcase/Ipsos study found that employees lost as much as 86 minutes per day due to noise distractions. Talking about money, this loss of productivity leads to big monetary losses for companies: 21.5 minutes daily is roughly 4% of an average employee's workday (based on an 8-hour day). Through simple calculations, it is possible to demonstrate that that a company with 100 employees and an average employee salary cost of $50,000 is losing $200,000 a year in lost productivity. An additional advantage offered by the sound masking is that it ensures the privacy of private speeches: workers are allowed to speak more freely knowing people won't overhear their conversations across the room or in adjacent private offices. Finally, the sound masking improves the workplace acoustic.

The basic idea of the sound masking technology is that by adding sound to a space makes that space seem quieter: even if it sounds counter-intuitive, actually it is true. This is because the added sound reduces the understand ability of human speech, and the image below shows a very simple example of that from the everyday life. Sound masking is often misunderstood as white noise (Page 2017). White noise is irritating when it is amplified, because it sounds similar to a loud AM radio static. Differently, sound masking has a band limited to only overlap with the frequencies of human speech.

By matching these frequencies, sound masking is envisioned specifically to mask conversations for greater speech privacy and productivity. On the other hand, white noise includes all frequencies at equal energy and can be distracting and annoying; therefore, sound masking is more comfortable acoustically, as only the frequency spectrum needed to increase privacy and minimize distraction are produced.

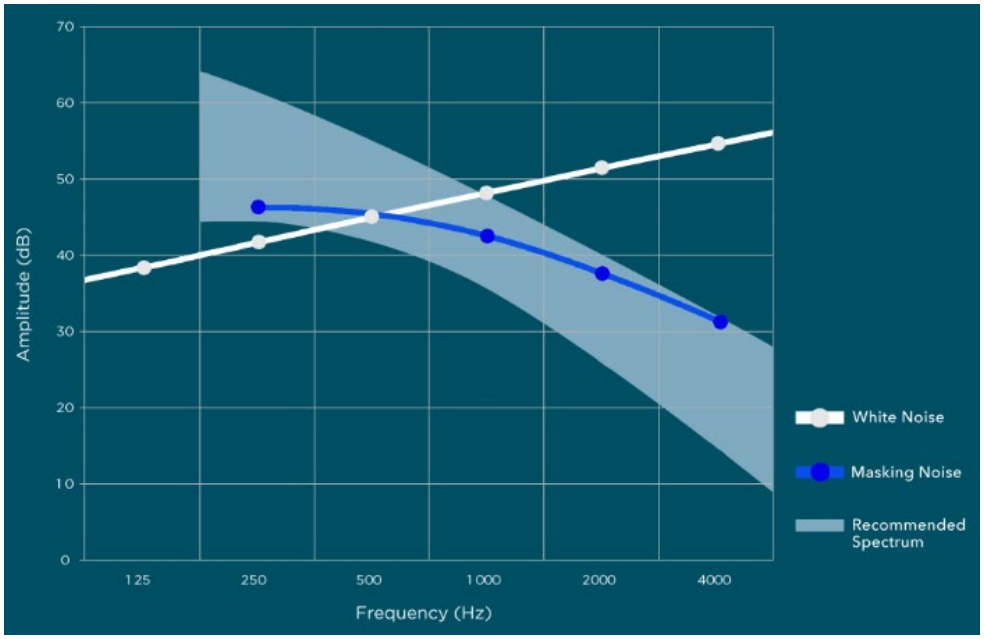


Figure 47 - By looking at this graph, it is possible to understand why white noise is disturbing and sound masking is effective. This is due to the fact that sound basking's frequencies are inside the recommended spectrum, and they do not create acoustic discomfort. (Source: Jon Page, "White Noise vs Sound Masking", 11/09/2017).

When a person is not able to understand what someone is saying, these words are less distracting, and probably that person does not even notice them. Sound masking is an ambient sound, like the sound of airflow, which is specifically addressed to the frequency of human speech. Sound masking does not delete sound or eliminate all speech noise in an environment; it simply reduces how far away conversations can be heard and understood by others, which it is called the radius of distraction.

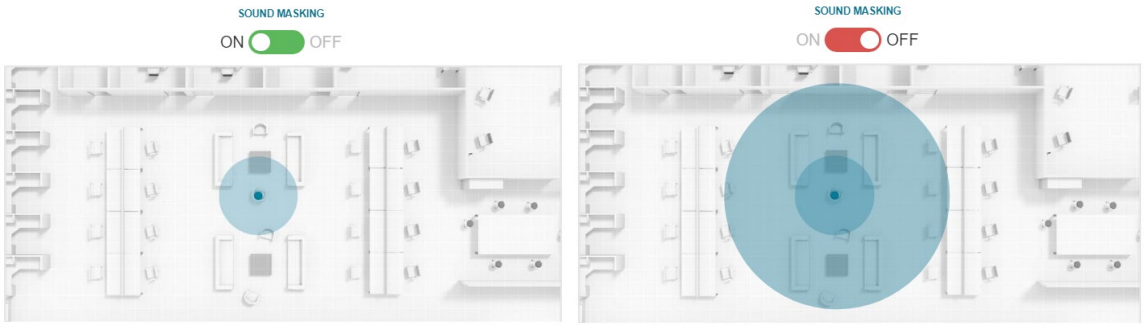


Figure 48 - The image on the left shows the radius of distraction when sound masking is on, and it is compared to the radius of distraction with sound masking off, which is considerably bigger, as the image on the right shows (Source: Cambridge Sound Management, "Sound Masking 101 technical brochure".)

Once masking is added, it becomes more challenging to understand conversations from across the room, and thus makes it less likely that conversations will distract workers. It is proved that the Sound Masking technology increases workers' satisfaction and this has been proved through a survey by U.S General Services Administration Study. Approximately 24,000 office workers in private

offices, shared offices, cubicles, and open offices were asked to rate their satisfaction with their noise and speech privacy levels. Those with private offices were the only ones satisfied with their speech privacy, and even they only rated them a .55 out of 2 on average. Moreover, the image shows that cubicle and open office employees were notably dissatisfied with their office's levels of speech privacy (U.S. General Services Administration Study 2019).

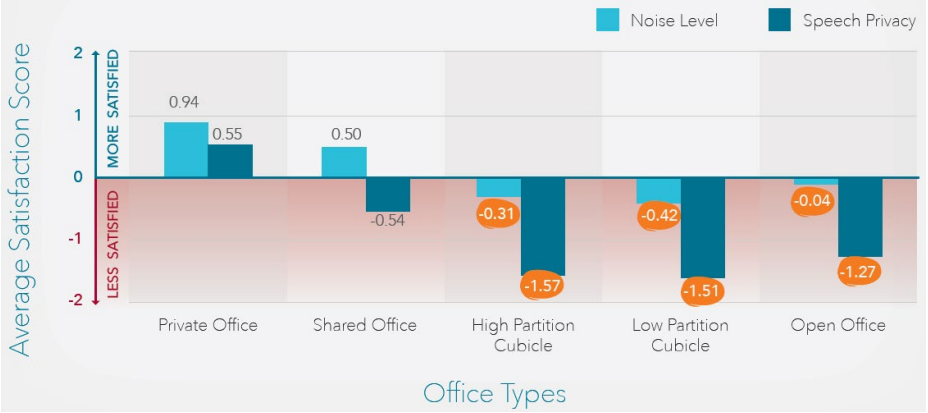


Figure 49 - Average satisfaction of users of different office type about the noise level and the speech privacy (Source: U.S. General Services Administration Study)

Another factor that stress the importance of a correct sound insulation in the offices is the fact that the speech privacy is the primary concern of workers, as it has been demonstrated by a survey conducted by the Centre for the Built Environment in Berkeley, California. They surveyed more than 25,000 workers in more than 2,000 buildings to determine what the key environmental issues were for workers. Of all of the factors workers encountered in their environment, speech privacy was by far the factor they were the most dissatisfied with (Cambridge Sound 2018).

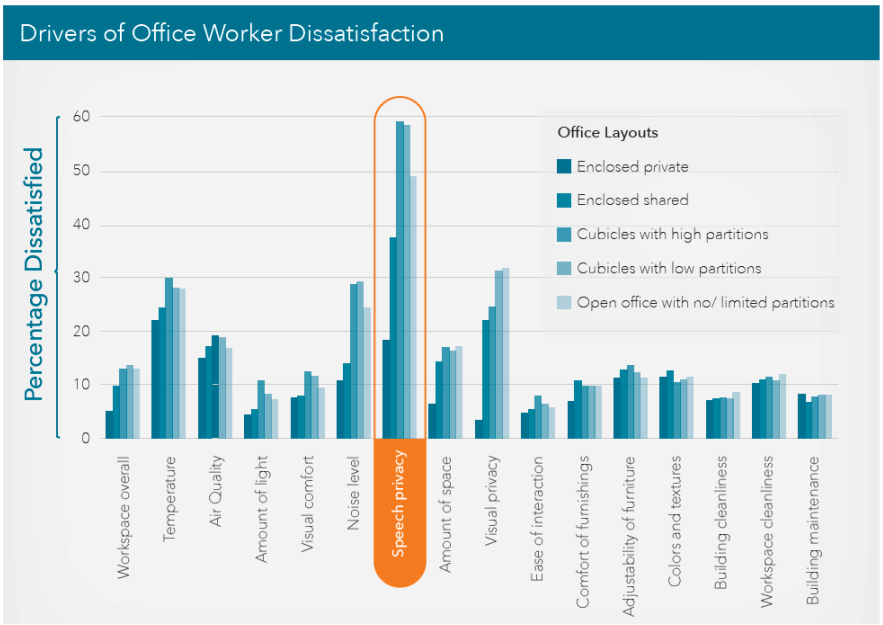


Figure 50 - Drivers of worker dissatisfaction (Source: Analysis of data from the Centre for the Built Environment by Jungsoo Kim and Richard de Dear, University of Sydney)

Personalised setting of environmental parameters

For what regards the lighting issue, before to discuss about smart lighting system, it is important to say that the correct type of illumination is already a very good starting point for people wellbeing inside the building (Figuero 2013). Office lighting does not just let the worker see what he/she is doing; it can have significant effects on the human circadian system, on employee wellbeing and on productivity. Considering 1000 people working in an office, two-thirds (65%) reports no perceived effect of lighting on their ability to concentrate, but when the issue is moved to specific types of lighting, a clear pattern emerges. Less than one in ten (9.7%) of workers in offices with halogen/fluorescent lighting say it increased their concentration, compared to 40.2 percent working in 'abundant natural light', followed by LED (32.1%), energy-saving bulbs (25.9%) and incandescent bulbs (21.3%) (Meemori Research AB 2017).

The crucial aspect of a smart lighting system is its ability to adapt in a fast way to what a person needs in that precise moment, according to the type of activity that he is doing or to the illumination level that he wants. Everything in the IoT era is possible, and this is valid also for the lighting devices: they all can be controlled via app, and with a simple touch of the screen it is possible to regulate the colour and light intensity, as well as the positioning of the light source (Rossi 2019).

Figure 51 - Possibilities offered by Casambi app in the light management (Source: https://casambi.com/)

An example of a smart lighting solution is offered by Casambi[15] lighting control solution provides for all the control options that are expected from a full featured professional lighting control solution.

The image presents all the options offered by this smart lighting system. First, through the grouping feature, it is possible to operate as for grouping apps in a smart device. After grouping, all the luminaires in the group can be controlled all together or the group can be opened for individual control. Thanks to the scene mode, different lighting situations for different occasions can be created. Moreover, it is possible to control multiple luminaires with a single tap on the app in order to create a suitable ambience for different needs. The diagram describing the possibilities offered by this light management system includes also animations: they are dynamic scenes, where it is possible for the lighting to fade from one scene to another scene.

The gallery feature allows users to take photos of a space, or upload a floor plan to the app, and mark the positions of the luminaires. The images then appear in a gallery in the app, with luminaires shown, and users simply tap the one they want to control.

A luminaire manufacturer can define the limits of the light device's colour range beforehand and then the user can change the colour from the app and also save his/her favourite colours in a colour palette. Together with the possibility to choose the light colour, the user can also change the colour temperature for each luminaire.

Through the light sensors there is an automatic dimming of artificial lighting when daylight is available for achieving maximum lighting quality and reduced energy consumption. Daylight sensors measure the illuminance and report the lux values to the network (sensors may be standalone or integrated into luminaires). Moreover, movement sensors are included, that can be used to save energy and to have lighting on when it is actually needed.

With the calendar and timer functionality, scenes and animations can be turned on and off based on a convenient time, date or certain weekdays to fit users' needs, seasons and different activities.

The smart lighting units are aware of the location in which they are placed, and they are able to calculate the local sunrise and sunset times. When the location is requested the application is temporarily using GPS to retrieve the current location of the mobile device. With the gateway

[15] Casambi is the one of the leaders in modern wireless lighting control solutions based on Bluetooth Low Energy. Key aspects of the Casambi solution are great user experience, high performance and scalability from basic individual fixture controls to industrial scale solutions with cloud based remote control, monitoring and data logging.

functionality a Casambi network can be accessed remotely: it is possible to control luminaires remotely.

Apart from the lighting issue, one feature which people expect from a Smart office (British Land, Worktech Academy 2017) is related to the heat and cooling setting, that have to be customizable in every moment by everyone so that all the people inside the building are in perfect comfort conditions.

One of the smart technologies that is spreading nowadays is the thermal bubble, proposed by Carlo Ratti in his project for an office building in Turin. In his project for the renovation of Fondazione Agnelli Building, Carlo Ratti proposes what he calls "Office 3.0", a set of advanced technologies all linked to an IoT system. One of them is the personalised thermal bubble: every person, through an app on the smartphone, is able to act on the Building Management System of the building, selecting his or her preferences about the temperature and humidity levels. Thanks to a series of fan coils inside the false ceiling, activated by people presence and movement, the system is able to follow the occupants when they are moving inside the building, creating in this way the individual thermal bubble. Once a person leaves a room, the environment goes back by itself in the standard mode, in order to save energy (Consoli 2016). This concept is based on the idea that each person inside a space has the possibility to adjust the main environmental parameters though an app, and then this sort of personalized bubble follows you all around the building, thanks to the presence of specialized sensors detecting each person's positioning inside the building.

However, the idea of leaving to the user a complete control on the environmental parameters is not always positive, as it is discussed by the European commission in its paper about Smart Buildings and energy efficiency (European Commission 2017). If all the users of the building have the possibility to choose their own thermal settings, there may be overloads of the HVAC systems, generated by peaks of too high demand, which determine a loss in efficiency, and an increase of the consumptions. Moreover, it is possible that personal conflicts between people with different needs in terms of environmental settings will arise.

Indoor positioning

Indoor positioning and indoor navigation can make the management of large offices a lot easier. Visitors and invitation management, workplace management and access control systems, among other features, can lead to simplified internal processes and reduced costs (InSoft 2018). The adoption of an indoor positioning system offers many advantages both to companies and to the employers. For what regards the companies' advantages, the use of an indoor positioning system can create benefit for staff and visitors: visitors can be routed directly to their respective contacts (process that is called "invitation management"). In addition, a location memory function for cars ("car finder") and the integration of public transport facilitate the arrival. In order to help visitors and new employees orientate themselves inside the building, the map offers the possibility of a turn-by-turn navigation, showing the fastest path to the user-defined destination. The indoor positioning device allows having a comprehensive overview of the staff's location and can therefore delegate tasks more efficiently: available staff near a location can directly be assigned tasks using push notifications. On the other hand, this system provides numerous advantages also for office workers. Within an indoor navigation app, users can search for the offices of individual employees or unoccupied meeting rooms, which can be booked and navigated to. Using the "Colleague Finder" function, employees can share their location with each other and thus better coordinate their work. Finally, company news, messaging, canteen plans and a parking space finder are other useful features (Streich, Location-based Employee services 2018).

Figure 52 - The position is determined via a network of Bluetooth Low Energy (BLE) beacons. They emit signals which the app on the user's smartphone uses to calculate the position. The user is guided to his destination via turn-by-turn navigation. The "Colleague Finder" function enables sharing employees' position. (Source: Katja Streich, "Location-Based Employee Services", 23/02/2018)

Visitor management application

Another innovative smart technology that is spreading (Carvelli 2019) in the offices is the one related to the management of visitors entering/exiting the office. Sometimes the check in procedures to enter inside an office as a guest are long. It is necessary to be registered, to give the own personal information and to receive a badge before to enter, and if the guest is in a hurry because the meeting to which he has to take part is about to start all this process can be a problem.

For this reason, some companies are developing the so-called Visitor Management Applications, which are apps downloadable on the smartphone that simplify the procedures of check in when a guest arrives in a new office. An example is the app developed by Digi While[16], called Easy Visit. It includes several functions, all of them aiming at speeding-up the check in procedure of a visitor when he or she arrives in an office. The application enables to:

- Register guests' data and policy documents in digital format for the full length of the visit.;
- Send a notification to the internal responsible of the imminent arrival of the guest;
- Distribution of company benefits like WIFI passwords to guests for the whole length of their stay: when the visitor complete the automatic check in procedure, the app send on his/her phone all the relevant information, like the password of WiFi, useful for his/her staying inside the office;
- Real Time Monitoring of the list of guests that are in the premises, their company referent and the number of meeting room allocated in case of emergency.

One great advantage of Visitor management application like Easy Visit is the Fast check in, allowing to avoid long lines at the reception. The guest has the possibility to operate a pre-registration via app, which then will send them an email with all the relevant information about time and place of the meeting. In this way all the data of the visitor are already in the database of the company, and the formal registration at the moment of the guest arrival is not necessary.

Another useful feature of Easy Visit is the Emergency list. Easy Visit offers the possibility to have a real time dashboard with all guests in the building and reference of why they came (meeting, interview, etc.). This is useful especially in case of emergency, because all people, both workers and guests, inside the building are registered and appear inside the list provided by Easy Visit.

[16] Digiwihile is a digital factory that develops smart solutions for smart workplaces, and it is a branch of the Durante group, based in Milan.

Air filtering houseplants

A possibility to improve the quality of the indoor air is to integrate greenery inside the building: the plants are able to act as a filter for different pollutants, constantly purifying the air. The NASA, during the '80s, developed a research (McCarthy 2017) in which demonstrated which are the plant species able to purify indoor air. During this research, different types of plants have been exposed to volatile organic compounds (VOCs) like formaldehyde and benzene, and it emerged that some species of plants are capable of improving the indoor air quality, by acting as a filter against the VOCs. After having pointed out which are the main pollutants present in the air and their effect on humans, NASA moved to research which species of houseplants are able to filter these harmful components and protect the occupants.

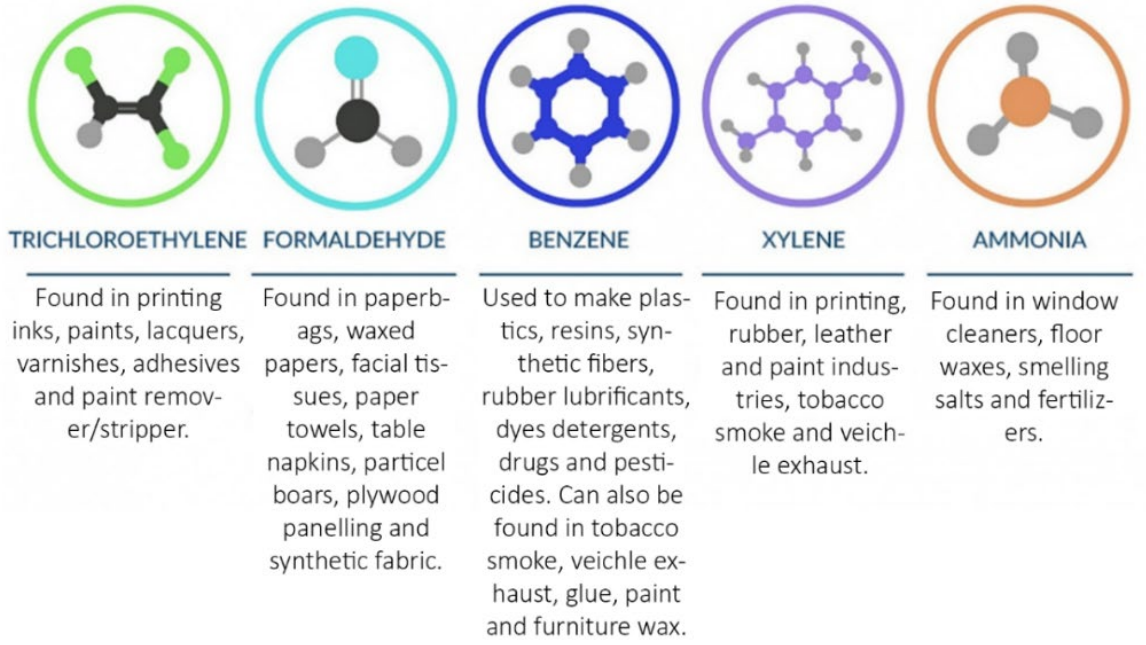


Figure 53 - Diagram of the main indoor pollutants (Source: Patrick Mccarthy, "The NASA guide to air filtering plants", 05/06/2017)

Like most chemical compounds, the adverse effect on humans' health depend on several factors, including the amount to which a person is exposed, the way he or she is exposed, the duration of exposure and the form of chemical. In the following table, the main effects (McCarthy 2017) related to the different indoor pollutants are presented.

There are many houseplants that are able to help reducing these effects of the pollutants on humans' health, and most of them are common and easy to treat.

Figure 54 - The main houseplants able to act as a filter against pollutants (Source: Patrick Mccarthy, "The NASA guide to air filtering plants", 05/06/2017)

The most diffuse houseplants presented in NASA research are:

- **Aloe Vera** is a very good filter against formaldehyde and benzene;
- **Spider plant** is a great solution against formaldehyde coming from cleaning and personal hygiene products;
- Draceaenea fragrans "Massangeana" (**Tronchetto della felicità**) is one of the best solutions for removing xylene, trichloroethylene and formaldehyde, coming from lacquers and paints;
- **Devil's ivy** helps in filtering formaldehyde, benzene and xylene, and it is able to grow u even with poor natural light;
- **Lilyturf** acts against trichloroethylene, ammonia and xylene.

IAQ smart management systems

The management of the IAQ can be entrusted to a smart ventilation system, a process that continuously adjust it in time to provide the desired IAQ benefits (Air Infiltration and Ventilation Centre n.d.). This system adjusts ventilation rates in time or by location in a building to be responsive to occupancy, outdoor thermal and air quality conditions, electricity grid needs or direct sensing of contaminants. More in detail, being responsive to occupancy means that a smart ventilation system adjusts its operation depending on external factors, such as reducing ventilation if the building is unoccupied.

The fundamental element of a smart ventilation system are the Smart Building sensors, that can detect changes in indoor air quality – which can adversely affect performance and wellbeing – and then autonomously fix the issue. Moreover, it is able to collect information about the air quality level and provide them to the building owners or to the occupants, together with data related to the need of maintenance or repair (Air Infiltration and Ventilation Centre n.d.).

On the market, it is possible to find many smart ventilation products that can be installed in order to improve the life quality inside a building. An example is the Snap 'Air Quality Balancer, produced by Elica[17]. Three sensors that constantly monitor the air quality, humidity and temperature characterize it. It can be activated manually or automatically, and it is able to regenerate the air of a 25m^2 room in 30 minutes. The goal of this device is to free the indoor environment from bad smells, pollutants, moisture excess, bacteria and moulds. It monitors the temperature and regulates the exiting air flow consequently, in order to avoid wastefulness and sudden changes in temperature (Elica n.d.). From the first time in which Snap is activated, it works in "reception phase", during which it become familiar with the environment in which it has been placed thanks to continuous sensing. Once it knows the environment, it is able to calibrate its interventions on an "ideal situation" specific for each room and moment of the day.

[17] Italian company which produces technologies for the air treatment, located in Fabriano (AN)

NUVAP: IoT solution for environmental parameters monitoring

An innovative tool for the constant monitoring of environmental parameters, including of course also the air quality, is Nuvap[18], which provides its customers with an accessible and reliable platform for monitoring indoor pollutants (Nuvap n.d.). Nuvap is a device that is able to monitor up to 26 environmental parameters: from the most "traditional" ones, like temperature and humidity, to the air quality, CO2 content, electromagnetic field and Radon gas. In this way, it enables an easy risk assessment in the field of health and safety at work, and it ensures a high level of protection in workplaces.

The components of Nuvap system are the My.Nuvap platform and the Nx Series Devices, a range of ultra-compact multi-sensor devices, which collect data about the abovementioned parameters and send them to the My.Nuvap platform, where they can be easily monitored. Devices are connected to company's Wi-Fi and once they are connected, they begin to monitor the environment sending feedbacks on the Nuvap platform. Each device has a coverage of approximately 80 m^2.

Figure 55 - The image shows the Nuvap NX series devices on the left and the 26 parameters that can be monitored on the right. (Source: Nuvap Pro System brochure).

The output of the constant monitoring of the 26 environmental parameters can be red in real time by the user, and it is possible to activate the notification system when critical values are detected. The first signal that is sent is the alert, meaning that a certain parameter is about to reach a critical value and it is necessary to intervene. The second type of notification is the alarm, when the critical value has already been reached[19]. The basic output that is given on the Nuvap APP is a score of the indoor environment subject to the monitoring from 1 (bad conditions) to 10 (optimal conditions).

[18] The Nuvap engineering laboratories are in Pisa and the sales offices in Milan.
[19] Nuvap Pro System brochure.

SMART HOSPITALS

2.5.2 Smart hospitals

The concept of Smart Hospital and Smart healthcare is spreading out quickly in this fourth industrial revolution era, during which technology is affecting all the aspects of people's everyday life. The last few years have seen an exponential increase in the capacity and capability of new health technologies, making possible to think about a very different model of healthcare.

Connected medical devices are already transforming the way the healthcare industry works, and it is reasonable to think that by 2020 the widespread adoption of technology-enabled care will ensure that the concept of the "Smart Hospital" becomes a reality (Taylor 2017).

2.5.2.1 The new technologies for the Smart Hospitals

First, it is necessary to understand what it means to talk about smart healthcare and Smart Hospitals, which are their main features and what factors are pushing towards their development and diffusion all around the world.

The smart healthcare has to answer to some fundamental issue: first, it has to be based on the idea to provide the adequate healthcare in right place and moment, and to exploit technology to make diagnosis, treatments and cures in the best way possible (Deloitte 2019). Moreover, the data of all the patients should be centralised, easily accessible by doctors and by the patients themselves but at the same time protected in the right way. In this new smart healthcare vision, patients must have an active role, always aware about the treatments that they will undergo and with a constant monitoring of their health conditions.

According to this idea of the smart healthcare, it is possible to derive and present the definition of a smart hospital. The objective of the smart-hospital vision is to build a facility that uniquely balances three key aspects: excellence in clinical outcome, efficiency in the supply chain and enhancement of the patient experience (DXC Technology 2018). Conventional healthcare delivery models have often

been based on a belief that ideal health-service delivery requires finding an optimal balance between the three. However, more recently, healthcare institutions around the world have started to drive these three elements, conventionally considered contradictory to each other, simultaneously.

There is growing experience and illustrations among hospitals in different markets that show how all three dimensions of patient experience, clinical outcome and supply-chain efficiencies can be driven concurrently and, in many ways, complement each other. A fundamental component of becoming a smart hospital is embracing IoT technology throughout the entire facility to increase efficiency and patient satisfaction (Archer Software n.d.). This includes all medical devices and smart sensors that are connected to the network, including Wi-Fi, and enable machine-to-machine communication and an infinite abundance of useful data. The possibilities of this technology are endless. Some of them are:

- Smart device into hospital beds which monitors moisture and movement to alert healthcare staff of an infection or a wound, or automatically adjusts the bed to proactively prevent sores;
- A vital sign monitoring system that transfers and analyses high volumes of data in real-time in the hospital's EHR system, saving nurses up to 30% of time transcribing to spend with patients
- Patients being able to control their own environment with ease, including lighting, entertainment systems, heating, food selection, HVAC, and more at their fingertips.

Having understood the importance of technological device in the Smart Hospital framework, it is now relevant to present the main smart technologies that are applied in a Smart Hospital. Some of them have already been mentioned, as the RFDI tag for an easy finding of medical items, or Bluetooth devices allowing communication between hospital and patient.

Object-finding technology

According to the survey by Nursing Times (Nursing Time n.d.), nurses and doctors spend at least an hour looking for necessary items during an average hospital shift. In order to minimize these time wastes, it is possible to implement in the hospitals the radio frequency identification of the objects: with RFID and IoT, it becomes possible to track and visualize assets' locations and movements in real time reducing equipment search time. Thanks to the IoT technologies the items finding is fast, and it can help also reducing the waiting times.

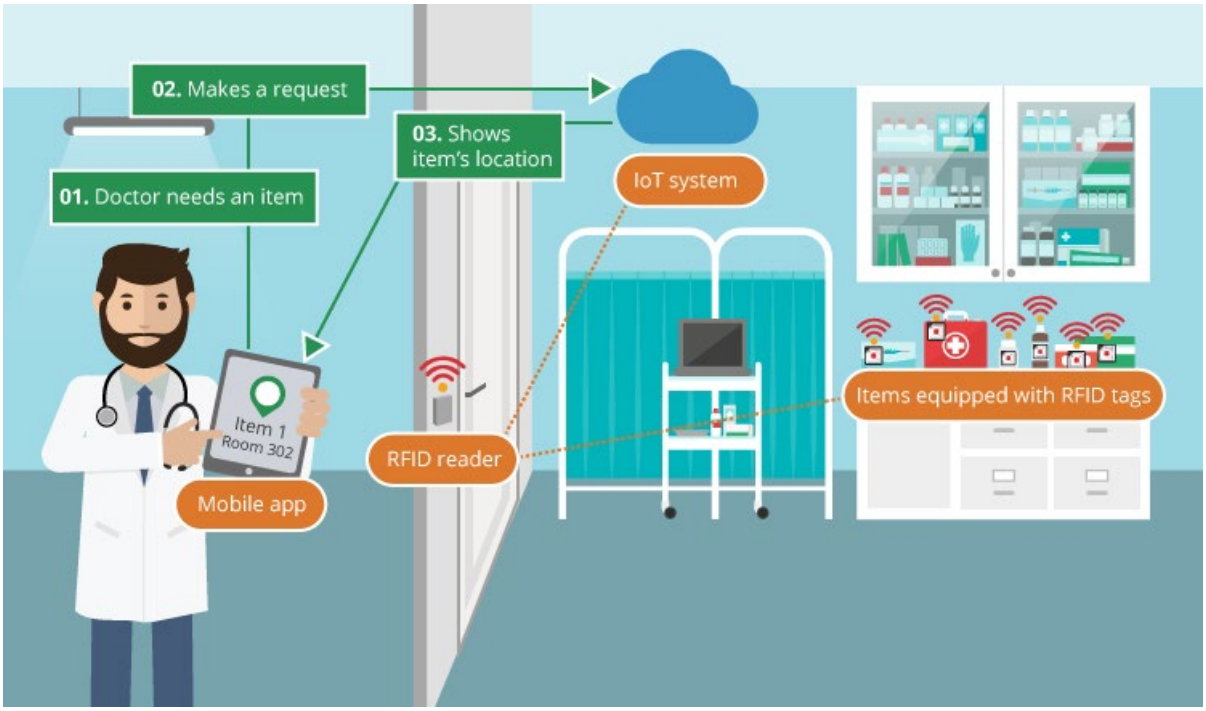


Figure 56 – Diagram of the functioning of the RDIF technology (Source: Science Soft "RFID and IoT, a smart symbiosis for hospital asset tracking and management" 09/10/2018)

The way in which this "object-finding" technology works (Shiklo 2018) can be explained in an easy way. Hospital items are equipped with tags. The list of these items may include single-use items (gloves, plastic vials, gauze), linen, bottles and boxes with medication, medical tools and equipment (surgical tools, pumps, monitors) etc. Tags can be attached to the assets or embedded into them (e.g., in surgical tools). Readers located in the hospital rooms and corridors (e.g., on the walls, by the doors) send the info about the location of each object. Personnel can track movable assets with a mobile or web app featuring the map of a hospital. When a certain item is needed, a doctor or a nurse makes a request, then an IoT system finds the nearest available item (or items) and informs the user who needs it about its precise location.

Boris Shiklo explains also the utility of this type of smart technology, which may seem cumbersome and not so useful. The RFID of objects inside the hospital can lead to several benefits, including the automation of the routine activities, the discovery of bottlenecks in internal hospital processes, the prevention of loss and theft of movable assets, the optimisation of investments in inventory and equipment and the possible forecasting of items demand.

The automation of the routine helps to overcome the drawbacks and limitations of manual asset tracking (for example the low speed, the possible human error and the quantity of paperwork necessary). By implementing an RFID system of all the equipment it is possible to improve the way in which all these objects, both drugs and technical devices, are supplied: when a hospital is nearly out of a certain item, the IoT system to which the radio frequency identification is connected can automatically order a new batch. Moreover, the collection of data about the hospital equipment utilization is able to report how the different departments use hospital items, and it allows to identify lacking or underused assets.

Another advantage that is related to the removal of the manual assent tracking is that hospital personnel gets the opportunity to focus directly on healthcare services. Doctors and nurses do not get distracted from the working process and their job functions and they do not have to prepare numerous reports on using items and equipment and spend precious time to find needed assets sterilized and ready to use.

In a hospital where the RDIF of items is implemented, it is easier to manage in a better way the logistic processes. For example, if a certain amount of surgery tools is waiting in front of autoclaves, an IoT system generates a corresponding warning. If such a situation happens systematically, it may indicate that sterilization is established in a very ineffective way, and the hospital needs to take specific measures in order to avoid this problem (for example, installing additional sterilizers may help increasing the speed of sterilizing surgical tools).

Finally, thanks to the continuous monitoring of hospital items and of their usage, it is possible to predict which assets should be included in the following purchase procedure (Shiklo 2018).

An example of the application of this technology is the Milton Keynes University Hospital in the UK, which is using RFID tags to track the location of 1,800 mobile medical devices from May 2012. "*Just being able to tell wards where the equipment was last detected makes a big difference and really cuts down on the time nurses spend looking for a particular device*" says Victoria Errington, the Medical Equipment Library Manager (NHS Foundation Trust 2019). Moreover, she explains that the adoption of the RFID technology is having several benefits inside the hospital, confirming the

ones that have been presented by Shiklo. First, one of the main benefits experienced by Milton Keynes Hospital is the time saved when looking for medical devices, and this means more time is available to look after patients. Another positive aspect described by V. Errington is that, being all specialist bariatric equipment in Milton Keynes Hospital tagged, the Moving and Manual Handling Advisor can access the database to locate suitable equipment including wheelchairs, hoists and commodes. "*Trying to find a bariatric armchair used to be like looking for a needle in a haystack. Being able to interrogate the RFID system for location of equipment is a massive improvement for our Moving and Manual Handling Advisor and improves patient care*" says Victoria.

It emerges that the difference between a traditional hospital and a Smart Hospital is the use of smart technologies as the basis of the organization system. The Smart Hospitals are places where patients, staff, laboratories and medical instruments are all interconnected and the information move in real time in a way that all the services offered by the hospitals are speeded up and the therapies are improved. The primary goal of a Smart Hospital is to ensure a high level of patient care through the use of technology.

Moreover, thanks to the use of connected devices it is possible to extend the boundaries of the hospitals and offer medical support remotely.

Wayfinding and indoor Google technologies

The way finding is an emerging technology that is diffusing in many typologies of Smart Buildings, including smart hospitals. When a visitor enters inside a hospital, one of the most triggering things is to orientate inside it, and find the right place where to go, for example the room of the patient to visit.

It has been demonstrated that almost 30% of the visitors when entering for the first time in an hospital get lost. Moreover, the concern of where to go increases the level of stress of both a patient and a visitor when arriving at the hospital (MapsPeople 2018). Studies have shown that when the human brain is stressed, it is significantly less likely to take in new information, such as directions. Confusing signage, unclear maps, and complicated nomenclature only add that stress. According to healthcare provider Kaiser Permanente, which has more than 30 hospitals around the U.S., patients' first wayfinding concern is getting from home to hospital, and then finding the right building and entrance (Landro 2014).

The wayfinding issue is not related only to visitors and patients who do not know where to go, but also to all hospital employees who work in large hospitals. Nearly half of doctors, experience incidences of getting lost on the way to an emergency call. It has been demonstrated (Brown, et al. 2015) that even when a person knows where to go, he/she often do not take the fastest route; indoor navigation allows to optimise the workflow inside the hospital and to secure efficient route planning for all staff members. The wayfinding, as the name suggest, is the cognitive and corporeal process and experience of locating, following or discovering a route through and to a given space (Symonds, Brow and Lo Iacono 2017). Inside a hospital, it acquires a wider meaning, and it is envisioned as a form of holistic care[20]. With this in mind, it is possible to identify some key benefits (MapsPeople 2018) of the wayfinding technology inside hospitals:

- Improve the overall patient and visitor experience inside the hospital;
- Control who should have access to where – visitors do not require access to the same parts of the hospital as doctors and nurses do;
- Reduce interruptions of medical staff being asked for directions;
- Patients, visitors and staff will always be offered the most optimal route to their location.

[20] Mapspeople, "Improving the Modern Hospital: utilizing indoor wayfinding as a form of holistic care for better patient outcomes", 2018.

In view of smart issue, a smartphone app can be the solution to indicate people where to go inside the hospital. A patient going to a medical visit, thanks to the wayfinding app, can easily discover where is the room where to go in the faster way possible: messaging and wayfinding features can provide turn-by-turn directions and arrival time instructions to make the navigation in large hospitals simpler and less stressful for visitors.

There are many apps on the market that integrate the technology offered by Google maps in the indoor spaces, offering the users the possibility to have precise indications about where to go even when they are inside a building. An example is MapsIndoor, offered by MapsPeople, and indoor navigation system built on Google Maps (MapsPeople n.d.). This makes the transition from outdoor navigation to indoor navigation seamless: All the known functionality and design of Google Maps is brought inside, and the user can get directions from any point of the indoor location where he or she is.

One of the great advantages that these types of wayfinding system offer is that they help hospital management optimise the use of resources; in fact, on average, in a standard hospital, nurses and doctors spend around 850 hours annually showing patients and visitors where to go, especially in big hospitals (Michelle Jeppesen 2019).

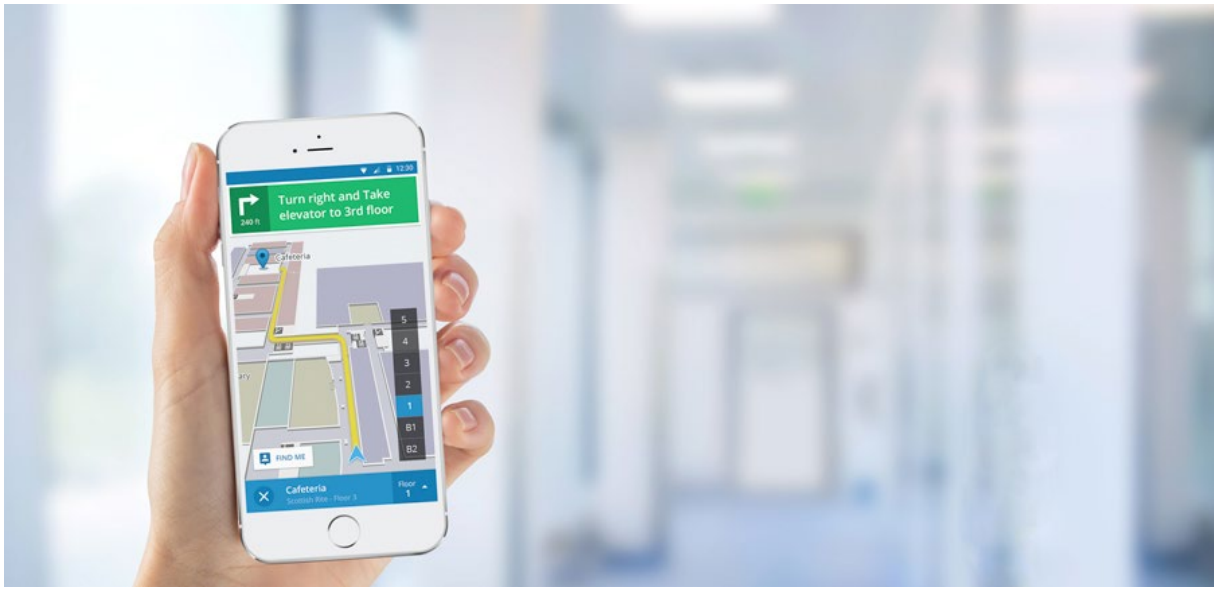


Figure 57: Example of a wayfinding app inside a smart hospital (Source: https://www.modernhealthcare.com)

Cloud platform for medical reports 

Another issue for hospital patient is that sometimes there can be a lack of communication from the medical staff about the health condition and the treatments to which the patient has to undergo.

In a smart hospital, it is possible to exploit the possibilities offered by the IoT to avoid this gap between the patient and the doctors. Each bed can be equipped with a tablet where the person staying in the hospital can be involved in the care process and know more about his/her treatment progress and health condition. While staying at the hospital, patients can view their health records and test results and get to know daily treatment schedules. Every time doctors or nurses visit the patient, they have to update all their actions, comments and notes to the cloud system, to which the patient can have access and constantly monitor the situation.

This system works also in the opposite way: when the patient feels pain, has the possibility to immediately communicate in a fast way what is the problem, so that doctor already has an idea of which kind of treatments may be necessary. The constant update of the patient's health condition can be combined with the medicines organization: once the doctor completes the visit, if a specific medicine is needed he has to update this information to the cloud system. A notification is sent to the pharmacy that is in-charged of supplying drugs to the hospital, and in this way the pharmacy knows precisely which the medicines to be delivered are.

Moreover, all the drugs can be tagged and, always via app, the nurse is able to read which medicine has to be administer to who and with which quantity and frequency. In this way, the possibilities of mistakes are reduced (Archer Software n.d.).

Wearables as a way of monitoring patients' conditions

The monitoring of patients, both if they are at home and in the hospital, is another issue that is really important in the modern Smart Hospitals. It can be facilitated and improved though the use of wearables, constantly sending information about the person's vital parameters to the doctors. Moreover, when person is staying in the hospital, his bed can be equipped with specific sensors, inspired to the wearable devices, sending signals if some vital parameters are compromised, so that the intervention of the doctor can be immediate with the possibility to solve the problem in the faster way possible.

An example of a wearable device used in hospitals is the Zephyr Anywhere's BioPatch (Venture Beat 2014) a small, unobtrusive item of sophisticated electronics which is attached to a patient's chest to collect all vital signs and transmit them to a nurses' station for general ward monitoring.

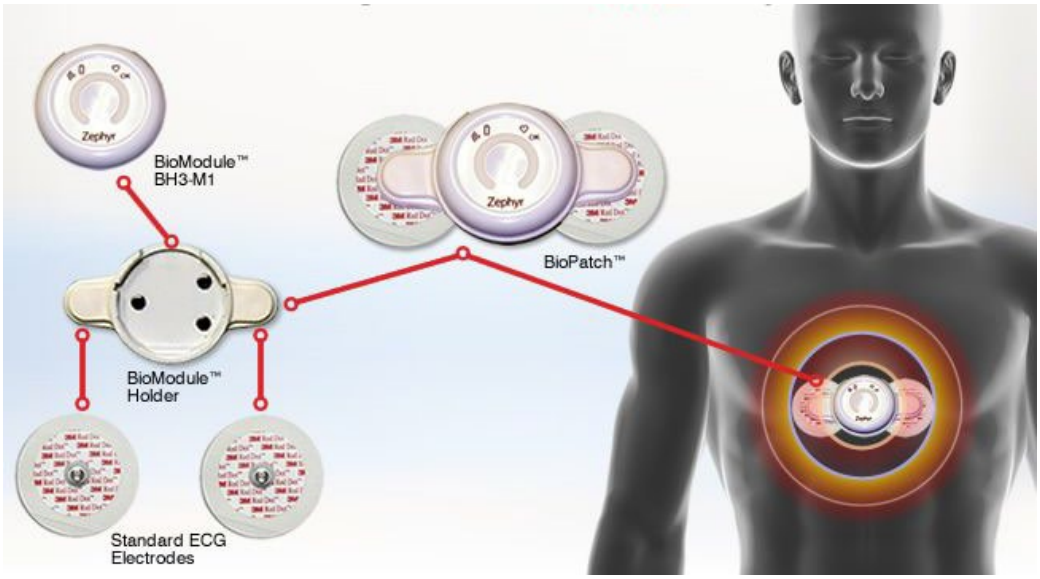


Figure 58 - The image shows the correct positioning of Zephyr Anywhere's BioPatch and its main components. (Source: https://venturebeat.com/)

This device is not a standard fitness wearable, it has been conceived and designed for the healthcare sector, and it is an FDA[21] approved device.

The BioPatch is used in combination with its software platform (ZephrLife), which uses a color-coded alarm system to notify nurses that patients are in acute need. In addition, the platform can

[21] The Food and Drug Administration (FDA) is responsible for protecting the public health in the United States by assuring the safety, efficacy, and security of human and veterinary drugs, biological products and medical devices.

also notify nurses directly via a cellular device, so that if they are not in proximity of a control room, they can still receive notifications about critical conditions of patients.

Besides the obvious benefit of 24-hour monitoring, the patient's hospital experience is also greatly enhanced. By the application of such a small device, it is possible to avoid the use of complex and uncomfortable monitoring equipment, so that patients can be more mobile. Moreover, they also do not need to be woken up regularly for vital-sign checks, since the wearable device provides all the information needed by the medical staff at every hour of the day.

The BioPatch, as well other wearable devices of this kind, is useful also when patients are at home. The device continues to monitor patients with serious medical conditions after discharge and transmitting data back to care teams via smartphones. The system has the possibility to identify patients who are at risk for readmission and it immediately enable care teams to intervene before it gets that far. A great advantage for the patient, when using a wearable device, is that it prevents the stress of returning to the hospital and reducing unnecessary hospital admissions saves the systems lots of money.

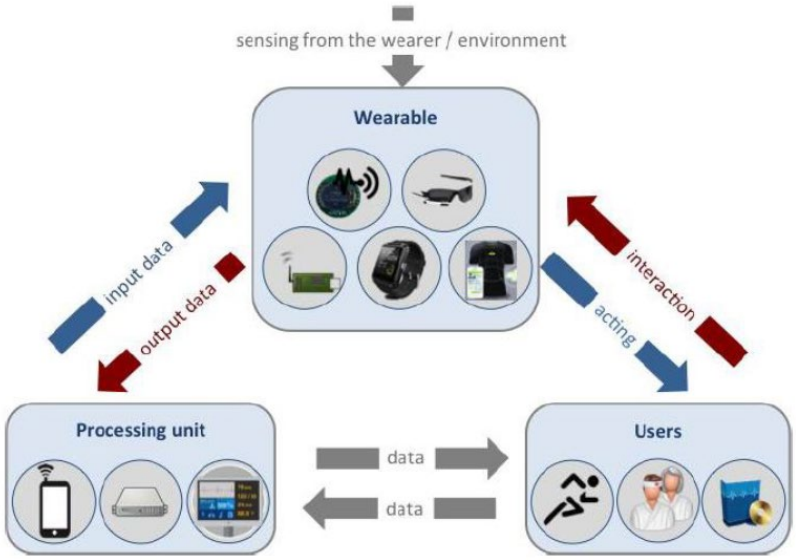


Figure 59 - Scheme of the wearable devices functioning (Source: European Commission, "Smart Wearables: Reflection and Orientation Paper", 28/11/2016)

The wearable is able to measures a great number of body parameters such as vital signs (ECG, pulse, blood oxygen saturation, respiration, skin temperature, blood pressure, C02), body kinematics as well as sensorial, emotional and cognitive reactivity such as EMG, posture, fall, movement, speed, acceleration and pressure (Lymberis 2003) also when the patient is at home, with a very high precision.

Wearables are extremely useful in the field of self-monitoring, and they can be exploited also outside the hospitals: by collecting and analysing biometric data from wearable fitness devices, any kind of smart building may respond directly to the state of health of its occupants. In an era of demographic change in which the workforce is ageing and there will be more older people remaining at work for longer, this smart sensitivity to wellbeing is especially important (British Land, Worktech Academy 2017). The great potential offered by the wearables is that they can be integrated easily with any Building Management System, and they provide information about the building user to the central system that can then adjust its settings in order to provide the users the best environment possible, in accordance with their physical condition.

Additional smart technologies for hospitals

The no-show rates cost the US healthcare system $150b each year (Ministero della Salute n.d.). The Smart Hospital can avoid this problem, through notifications generated by the hospital IoT software that can be sent to patients, in their preferred language, informing them about the time of their appointment and exact office number. Such smart hospital systems can also push updates telling the patients if the appointment location or time has changed.

Not only patient and medical staff are present in the hospitals, but also patients' relatives that most of the time wait the doctor to receive information about his or her relative's state of health. In the smart hospital, this process is facilitated trough and app system that is able to provide constant update about a visit or a surgical intervention. Careggi[22] Smart Hospital presented a new app that allows following in real time interventions, via smartphone or tablet. First, the patient has to approve this type of communication system, and then the relatives have the possibility to follow the conditions of the patient even without being physically present in the hospital.

Another process that can be simplified thanks to the Smart technologies is the meal selection of the patient. Instead of writing on a piece of paper which is the selected menu for breakfast, lunch and dinner, which has then need to be delivered in the kitchen by the in-charged person, the patient can select on the app his or her choices, and then a signal is sent directly to the kitchen. This system can be integrated by specific indications by the doctor about what a patient can or cannot eat; in this way, the patient will see, at the moment of the meal selection, only suitable choices for his health status, in order to prevent collateral effect due to allergy or incompatibility with medicines.

[22] Hospital in Florence

SMART MUSEUMS

2.5.3 Smart museums

The smart building revolution is spreading also in the spaces of culture like museums. Even if it may appear strange and useless to introduce smart technologies and devices in spaces where people usually go to walk through and admire works of art, actually the introduction of new systems powered by the IoT is able to enrich the museum experience and make it smarter (Solima 2016).

2.5.3.1 The new technologies for Smart Museums

There are many opportunities in terms of smart technologies that may be applied to the museums sector. The first chance that the IoT era offers to the museum field is the so called "Audience development": thanks to specific digital platform, the museum is able to reach not only the users that physically go to the museum, but also the "digital" ones, with whom the museum should establish a new way of relation and interaction deeply different from the past. Moreover, focusing on the people who actually go and visit the museum, the IoT technologies offer the possibility to overturn the way in which they relate to the works of art present in the museum.

There are also technologies that are applied in other building typologies, that can be adapted and installed also in exposition areas, offering the possibility to improve the user experience during the visit of the museum.

Indoor localisation apps

The geo-localization allows to acquire additional information when the visitor is in front a certain masterpiece, even without asking for them (Opzione Cultura 2019). This technology, based on the use of a smartphone that is connected to the museum smart network, is able to work thanks

to the presence of beacons[23] in the proximity of the work of art, which communicate via Bluetooth with the smartphones of the users, sending them all the multimedia data about the masterpiece they are observing.

Figure 60 - The image is an example of interactive indoor navigation App for museums visitors. Thanks to the beacon-enabled app, related content shows up on the visitors' smartphones once they approach an exhibit. Moreover, visitors can use the app to navigate to any chosen destination on the map (Source: Katja Streich, "Indoor Navigation and Interactive Tour in a Museum", 19/12/2017)

The use of this kind of technology gives the opportunity to substitute the old audio-guides (Streich 2017), which consumes valuable resources of the museum. In addition, these devices must be repaired, charged and kept clean, and the staff is required to be sure that the audio guides are returned at the end of the tour.

Bluetooth Low Energy (BLE) beacons are deployed throughout the building and in proximity to the exhibits. Beacons are cost-effective and can be installed with minimal effort, since they are operated with batteries. The position detected by the beacons can be used for providing specific data (text, images, audio or video recordings) about the works of art in proximity of them. The ability of the museum to identify the presence of visitors and they preferred pathways has multiple advantages: first, the museum staff would have the possibility to have access to the timing and tracking of their visitors. This information is useful in order to understand how the space inside the museum is used, if there are some areas which are subjected to overcrowding and, on the opposite, if some spots of the exposition area are marginally frequented by users (Solima 2016).

[23] Beacons are small radio transmitters that broadcast signals using Bluetooth Low Energy (Bluetooth Smart) in a radius of up to 70 meters. These signals are detected by a mobile device (e.g. smartphone) in a client-based approach or by a specific hardware in a server-based approach.

Wayfinding

The indoor positioning app gives the user the possibility not only of receiving particular information about the masterpiece they are looking at, but also to acquire turn-by-turn navigation inside the museum (InSoft 2018). Thanks to this feature of the indoor positioning apps, the visitors can be guided towards some museum's exhibits that they would like to see, or towards services as toilets, museum shop or restaurant/cafeteria.

There are two main technologies allowing the wayfinding system to be implemented in the museum or in other building typologies: the indoor navigation with Wi-Fi or with beacons. The Wi-Fi based technology has an accuracy of 5-15 meters. The available Wi-Fi infrastructure can be used (e.g. customer hotspots, Wi-Fi-capable point of sale systems, routers), and the user only has to activate Wi-Fi on his/her smartphone. The second option is the use of beacons, which are able to offer a higher accuracy (1-3 meters). Moreover, if they are installed for all the purposes that have been described in the previous chapter, it is not required the implementation of an auxiliary system to have the wayfinding active inside the museum. A beacon should be placed every 7-10 meters depending on the desired accuracy. Beacons are the most popular hardware for indoor positioning due to their high level of flexibility and accuracy.

Figure 61 - Playhouse Peoria is a children museum located in Peoria (Illinois, USA), where a fun and kid-friendly wayfinding app has been implemented. It provides a map of the building by level and it serves as a guide to each exhibit: a list of activities to be completed at each exhibit is given by the app, when entering in each exhibit area. (Source: https://www.behance.net/gallery/33896686/Childrens-Museum-Wayfinding-App)

2.5.4 Smart universities

University campus are a particular typology of building, since most of the time they are a sort of neighbourhood, including many buildings separated one from the other. Moreover, inside a campus there are many different actors, with different ages, necessities and role. A smart university should be able to answer to all these needs in a proper way, and to make the life inside the campus easier and less stressful (Stracke, Shanks and Tveiten 2017).

The definitions of Smart Campus that can be found in the literature are quite similar to the ones of Smart Buildings, since universities are nothing else that a subsystem of the buildings set. One of the possible definitions is that "*what makes a Campus Smart is its ability to link devices, applications, and people, and to enable new experiences or services and improve operational efficiency"* (Nedwich 2018). When all the people, devices and applications present inside a campus share a common technology infrastructure, they can interact with each other to enable experiences and efficiencies that are completely new with respect to what was possible at the beginning of the 21th century.

Furthermore, when dealing with Smart University, the centrality of the human is a key aspect. "*The Smart Campus actively learns from and adapts to the needs of its people and place, unlocking the potential of e-technology and enabling world-changing learning and research*", stated Chris Pearce[24], when presenting the proposal for the realization of a new area of the Glasgow university in 2016. All the devices designed for universities must be conceived for people who live the university.

The peculiarity of a Smart Campus is that it can be seen as the intersections between properties typical of Smart Homes and of Smart cities (Kumar Kar and Gupta 2015). Not only the single buildings composing the University are becoming smarter, but also the way in which they are connected is experiencing the introduction of new technologies enhancing the experience of moving from a place to another inside the Campus itself.

[24] Dean of Research, College of Science & Engineering Professor of Computational Mechanics in Glasgow University.

2.5.4.1 The new technologies for Smart Universities

In 2015, professor Fulvio Corno proposed to his students at Politecnico di Torino to think and design a smart technology in order to transform their university into a Smart campus. All the presented projects start from basic needs of students during their everyday life inside the university: how they can find a free and silent space where to study, avoid being late at lectures, find the cleanest and nearest bathroom etc. All these projects are good hints for smart technologies inside universities, because they are based on the idea of improving the life quality of students inside the campus. They are people oriented, in the sense that they are conceived with the student (or the user of the campus) at the centre of the design process. The technologies presented are based on tools that are applied also to other building typologies, and in this case are adapted to the university's framework.

Marco Poli: interactive map of the campus

The winning project is called "Marco Poli" and it consists of an app that is able to identify on a map of the campus the available and free spaces, indicating for each of them the level of lighting, temperature, noise and crowding.

Figure 62 - Example of the app functions on the left, and of the app layout on the smartphone on the right. (Source: http://ami-2015.github.io/MarcoPoli/).

The Marco Poli app[25] offers the possibility to include preferences in terms of space setting (a desired level of temperature, noise, crowding and light level) so that the app offers to the user a series of recommended spaces, which are able to satisfy his or her requirement in that specific moment.

[25] The authors of the winning project are Riccardo Cappuzzo, Roberto Marturano e Luca Mezzatesta, all students of Computer Engineering at Politecnico di Torino in 2015.

Moreover, when something is happening in the campus, on the map appears a coloured dot, which can be red (in case of situations generating high noise level), green (when it is referred to a particular lecture or event fitting with the preferences that have been set on the ap) or orange (indicating a lecture or event which does not correspond with the user's preferences). The app offers also the possibility to insert the personal timetable and receive notifications about when a lecture is about to start or if it is delayed or moved to another classroom, always with the possibility to receive turn by turn indications in order to reach it easily.

The app works thanks to the presence of sensors, called "Stations" all around the campus, both inside rooms, study spaces and in external common areas, sending information about their conditions in terms of temperature, lighting, crowding and noise level to a central server. Then, the server sends all the info that receives to the app, from where the users can easily read them.

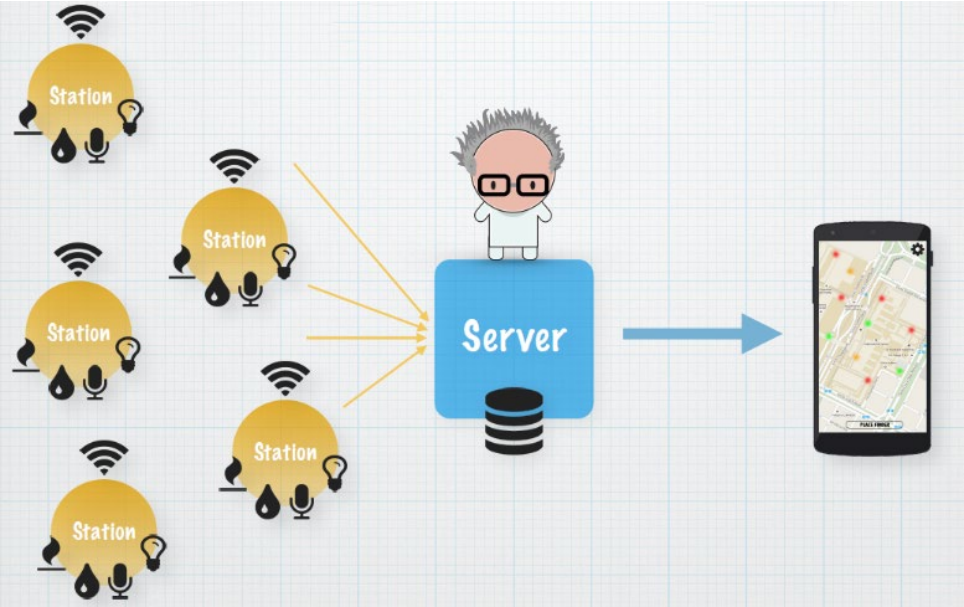


Figure 63 - How the Marco Poli app works. (Source: http://ami-2015.github.io/MarcoPoli/).

This type of Smart technology is able to provide great advantages, first to the students: their life inside the campus is strongly simplified and they can spend all the time that they would spend in searching the perfect place where to study in actually studying or participating to events in which they are interested.

The advantages exist also for the university: it has the possibility to collect data about how the spaces are used, if there are some of them underused and some others that are often overcrowded, and to adopt measures against congestion of spaces. Moreover, the app can be exploited also by other actors, such as sellers, bars, shops inside the campus, which can create events and make them visible by all the students via Marco Poli app.

Well Cleaned: monitoring of bathrooms' conditions.

The second classified project is called Well Cleaned[26], and it consists of a system that allows monitoring and verifying the cleaning conditions of all the bathrooms of the campus, according to three parameters: presence or lacking of toilet paper, of soap and level of filling of trashcans.

Well Cleaned works through an app that can be installed both on smartphones and on tablets. It consists of a very simple map of the university, showing where all the bathrooms are located, and specifying if they are men-only, women-only or both men-women ones. The bathroom icon on the map uses an intuitive colour system, indicating whether that place is in a "fine condition" or not, differentiating, in the latter case, the gravity of the situation (e.g. green: fine, yellow: not so fine, red: critical situation).

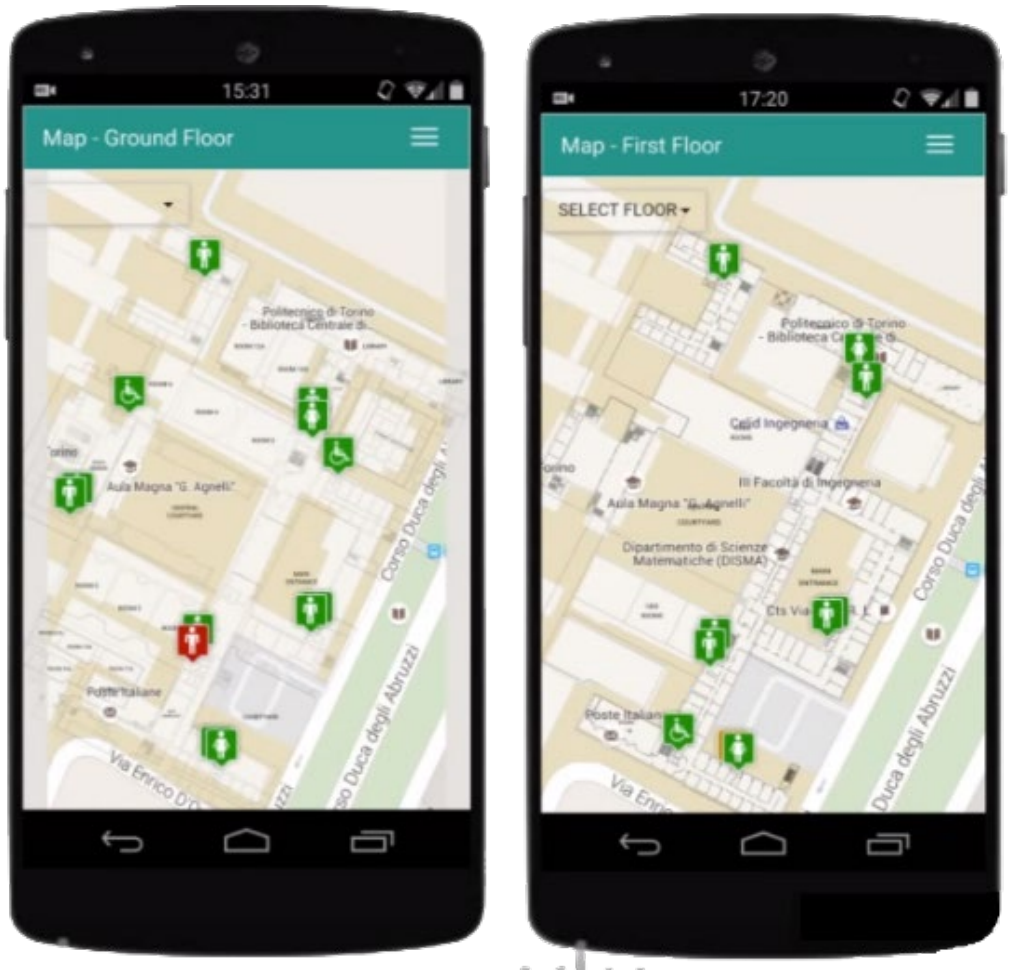


Figure 64 - Example of bathroom localization on a map of the campus. (Source: http://ami-2015.github.io/well-cleaned/index.html).

[26] The authors are students of Computer engineering at Politecnico di Torino: Federico Fallace, Alessandro Gaballo, Christian Palmiero, Eugenia Spano.

Well Cleaned app includes a notification system, which can be always enabled/disabled; if enabled, users can specify which bathrooms they would like to be notified about, and what time (range of time) they would prefer to receive notifications.

If disabled, users will not obviously be notified, but they can always check a particular bathroom status by tapping on its icon: this will show, using the same colour pattern described before, the status of each one of the three items, and also the time when this data was last collected. Another innovative function of Well Cleaned app is that each toilet is capable of learning when to increase/decrease the automatic checking frequency, depending on the usage of a specific item, ensuring the best service possible.

This type of app for a university may be very helpful both to students and to the members of the cleaning staff: how many times does a student wonder if the bathroom he/she is waiting in line for provides toilet paper? How many times does the student approach the sink, ready to wash his hands, only to find out there is no more soap? Well Cleaned offers the solution to these problems: when the user taps on the icon of the bathroom he/she is about to go to, the app shows all the relevant info about that toilet, so that it is easy to understand if the bathroom is in good conditions and if there is line outside it.

The app is very useful also for the members of the cleaning staff, who have the opportunity to know exactly where their services are more urgent. If the bathroom is in critical conditions, the staff receives a communication about it, with info related to what is missing (e.g. toilet paper or soap) so that they perfectly know where to go and what to bring to solve the problem.

When their shift is over, they just need to disable notifications (or schedule the notification system to be disabled at a specific time, so that the app does it automatically), so that they can go on with using their smartphone without caring about the conditions of bathrooms inside the university.

It's Your Turn: smart management of meetings with professors.

ItsYourTurn[27] is a system that is able to help students and Professors to get in touch more easily and efficiently. It understands, in real time, whether the Professor is in his office or not and if he is available according to his agenda and his commitments, showing it to students.

Moreover, the app allows for booking meetings and gives information about the probability of finding the Professor in his office in the future.

It's Your Turn app is based on two main interfaces, one for the professor and the other one for the student. The professor interface offers the following possibilities:

- The Professor is able to select his state from his office;
- The system shows the name (registration number) of students who have booked an appointment and the main reason for which they need a meeting (this is asked to the student at the moment of the reservation of the appointment);
- Every reservation is deleted according to any changes on the Professor's Google Calendar account (he is able to delete a reservation only by adding a new schedule);
- The Professor is able to see any changes of the queue;
- The Professor has the opportunity to set preferences about his week office schedule (when available or not, most suitable hours to see him) from Google Calendar.

On the other hand, the interface related to the students allow them to:

- See the list of professors and their states;
- Book a meeting with a Professor;
- Remove a previous booking;
- See general information about every Professor like email, phone number, location of the office;
- See the weekly and daily commitments of every Professor;
- Receive a notification if a meeting is deleted;
- See the probability of finding the professor in his office.

[27] The authors of this app are all students of Computer Engineering at Politcenico di Torino: Andrea Andreoli, Samuele Aicardi, Simone Regis, Antonio Risoli.

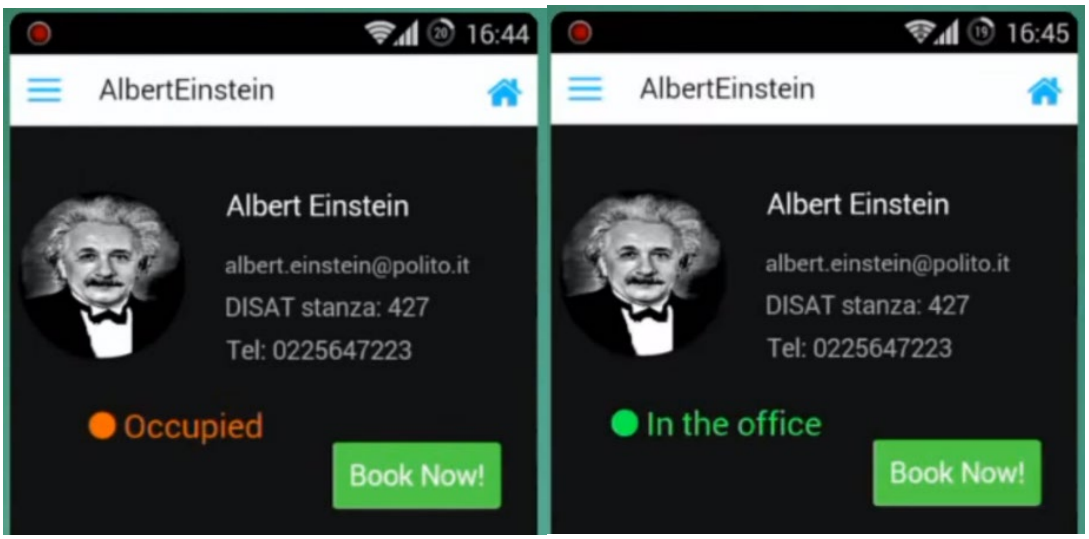


Figure 65 - Views of the app on a student's smartphone (Source: http://ami-2015.github.io/MyBP/index.html)

The app is based on a simple interface, showing the students if the professor is in the office and if he is available or not for an appointment. The student may book an immediate meeting with him/her or, by looking at professor's timetable on the app, book the meeting for a specific date and time.

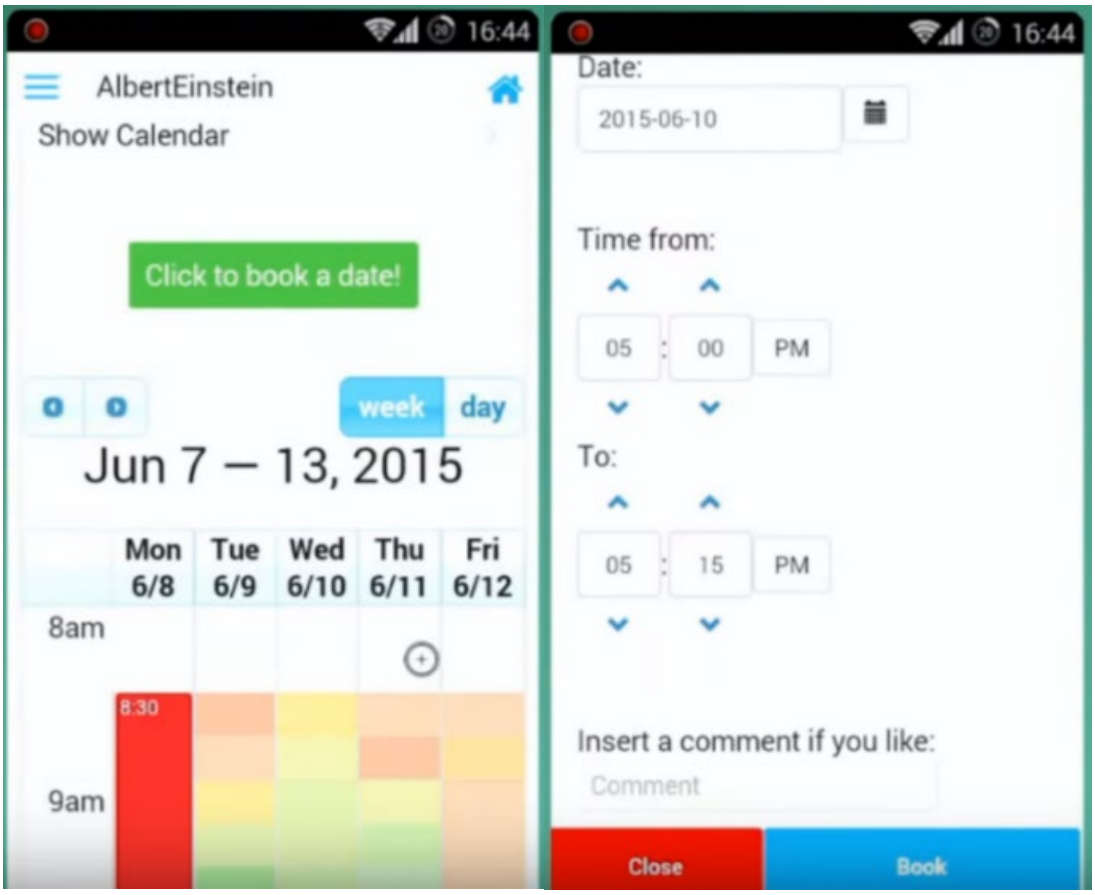


Figure 66 - Views of the way in which it is possible to book an appointment with a professor (Source: http://ami-2015.github.io/MyBP/index.html).

ClassAid: room booking inside the campus. 

Another major issue for students is to find a free place where to study. Most of the time, a student has to go in front of a classroom and read (if it is present and updated) the scheduling for the class in a certain date. However, a much more complex situation occurs during exams period: it is even harder to know in advance is a certain room will be occupied by an exam during the day.

ClassAid app offers the opportunity to solve these problems, to save time and to know exactly what is happening inside a room in each moment of the day. The main features of this app are (Politecnico di Torino n.d.):

- At the entrance of every classroom of the campus there is a screen with which students can interact, by asking and receiving information about that classrooms;
- It fulfils the function of the old static schedule, by publicly displaying the timetable, which is automatically updated from university's databases, without the need for the environmental waste of printed paper and having people to manually replace the static schedule;
- Around the screen some LED strips are located, which are used to indicate the availability status of the rooms. This allows the students to immediately understand if a class is free or not from a distance, by just checking the intuitive colour of the frame of the screen, which indicates whether there is an exam or a lecture in the class or whether it is free. A user walking into the hallway will immediately see if there is a 'green light' (indicating a free room) outside of one of the classes, without directly interacting with the system.
- It provides more reliability than the static schedule, when indicating availability by crossing the schedule information with sensed information, like the effective presence of the professor inside the class;
- It solves the problem of students interrupting classes by constantly opening doors to check if the class is empty, avoiding distractions for both students and teachers;

The app works also on the smartphone, by proposing to the student which is the shortest route to the classroom of their next lecture, improving navigation in the campus and preventing users wasting time when looking for a classroom, especially in the case of first year and international students.

SMART AIRPORTS

2.5.5 Smart airports

Airport as a building typology is complex, sensitive and different from all the others. The airport is the gateway to the country, state or city, and it creates the first impression for visitors. The peculiarity of the airport, if compared to other building typologies like offices, museums, universities or shopping malls, is that it is a business that operates 24 hours every day of the year. Therefore, it has to be resilient and ready to adapt to ever-changing customer demands while being cost-effective (Upadhya and Rawat 2018).

One of the reasons of the rapid development of airport during the last years is due to the continuous growth of the total number of passengers processed per year (the worldwide passenger traffic increased by 64% between 2009 and 2016) (Wavestone 2017).

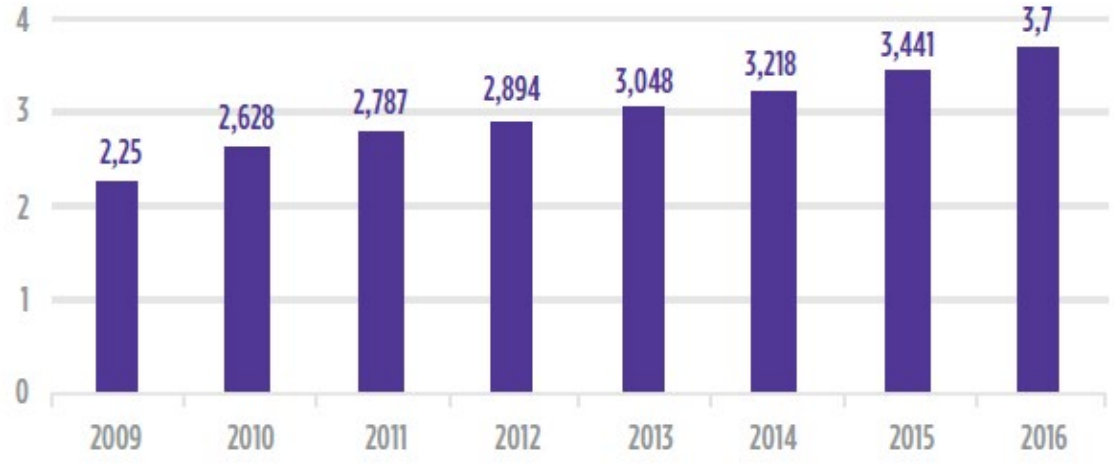


Figure 67 - Number of passengers transported per year in airports all over the world (Source: International Civil Aviation Organization (ICAO))

The air transport volume in terms of passenger traffic is expected to explode with an annual cumulative growth rate of 4.9% until 2040 (Wavestone 2017). However, this boom will be mainly driven by four leading markets: Asia-Pacific, Middle East, Africa and South America.

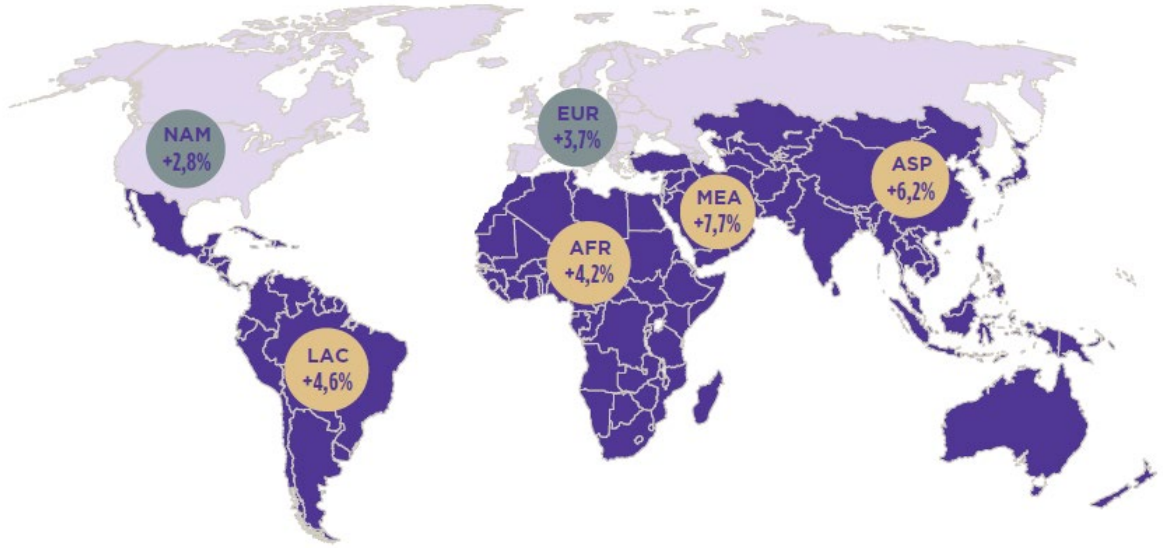


Figure 68 - Contribution of the different regions to the growth of the Airport sector. (Source: Airport Council International (ACI)).

This rapid growth of the industry has put airport operators in conditions of facing important challenges such as increasing their capacity, optimizing their processes, diversifying their revenues, being part of the passenger global experience and, of course, providing top security and cybersecurity measures. In this context, digital and smart solutions give airports the unique opportunity to solve these problems and optimize their activities. The digital transformation in the airport field started at the beginning of the 1990s and led each airport to move onto different levels of "digital maturity", where each level is characterized by the set of technologies adopted.

Being the digitalisation the key in order to answer to the growth of passengers, the need of an airport became to adapt itself to the technological evolution of the society. This is reflected in the rapid growth of this building typology, which in the last three decades has completely transform itself. The process of change of the airport building typology can be summarized in three main steps (Fattah, et al. 2009):

- **Airport 1.0: Basic Airport Operations**. During this first phase, airports focused on capabilities necessary for safe and efficient management of landings, departures, and other aircraft operations. They offered basic passenger services (check-in, boarding, security, and baggage pick-up), moderate retail and food and beverage services. Airports 1.0 exhibited highly evolved operational efficiencies, but they were paying insufficient attention to passenger experience. These types of airports normally run a B2B[28] business without any

[28] Business to Business: it refers to sales the airport makes to other businesses rather than to individual consumers. In this case, the airport is serving the airlines and the ground handlers.

service marketed directly to the passenger. Operations, systems, and business units were likely to be highly independent one from the other, making it difficult for different entities to collaborate across business boundaries.

- **Airport 2.0: Agile Airports.** The term "agile airports" is related to the fact that airports became able to adapt well to a changing environment. Airports 2.0 are adopters of partial self-service, limited just to check-in process and Wi-Fi technology being deployed in these airports.

- **Airport 3.0: Evolved Airports**. During this phase of development, self-service is deployed across the passenger journey at all levels. Operations management is automated and predictive and mobility solutions are largely used on terminal side and airside (particularly in apron areas[29]).

- **Airport 4.0: Smart Airports**. The third phase of development is defined "smart airports" that fully exploit the power of emerging and maturing technologies, which are affecting also many other building sectors. Systems are built around a "digital grid": a single, converged, often carrier-class IP network that enables high-speed broadband traffic throughout the entire ecosystem. The digital grid is the airport's nervous system, touching and managing every point of interaction. By enabling the exchange of real-time information and airport-wide process integration, smart airports significantly improve operational efficiencies, passenger services, and advanced security capabilities. They also take passenger experience to new heights by delivering a range of personalized services enabled by seamless exchange of passenger data to anticipate needed services. During this phase, airports clearly sees its business shifting from B2B to B2C[30].

In order to go ahead with digital transformation, and to be as close as possible to the third phase of development explained above, airports decided to invest massively in technology over the last decade. These investments doubled between 2011 and 2016, increasing from USD 4.42 billion to USD 9.07 billion (Wavestone 2017).

[29] Area of an airport where aircraft are parked, unloaded or loaded, refuelled or boarded.
[30] Business to Consumer refers to the process of selling products and services directly to consumers who are the end-users of products or services.

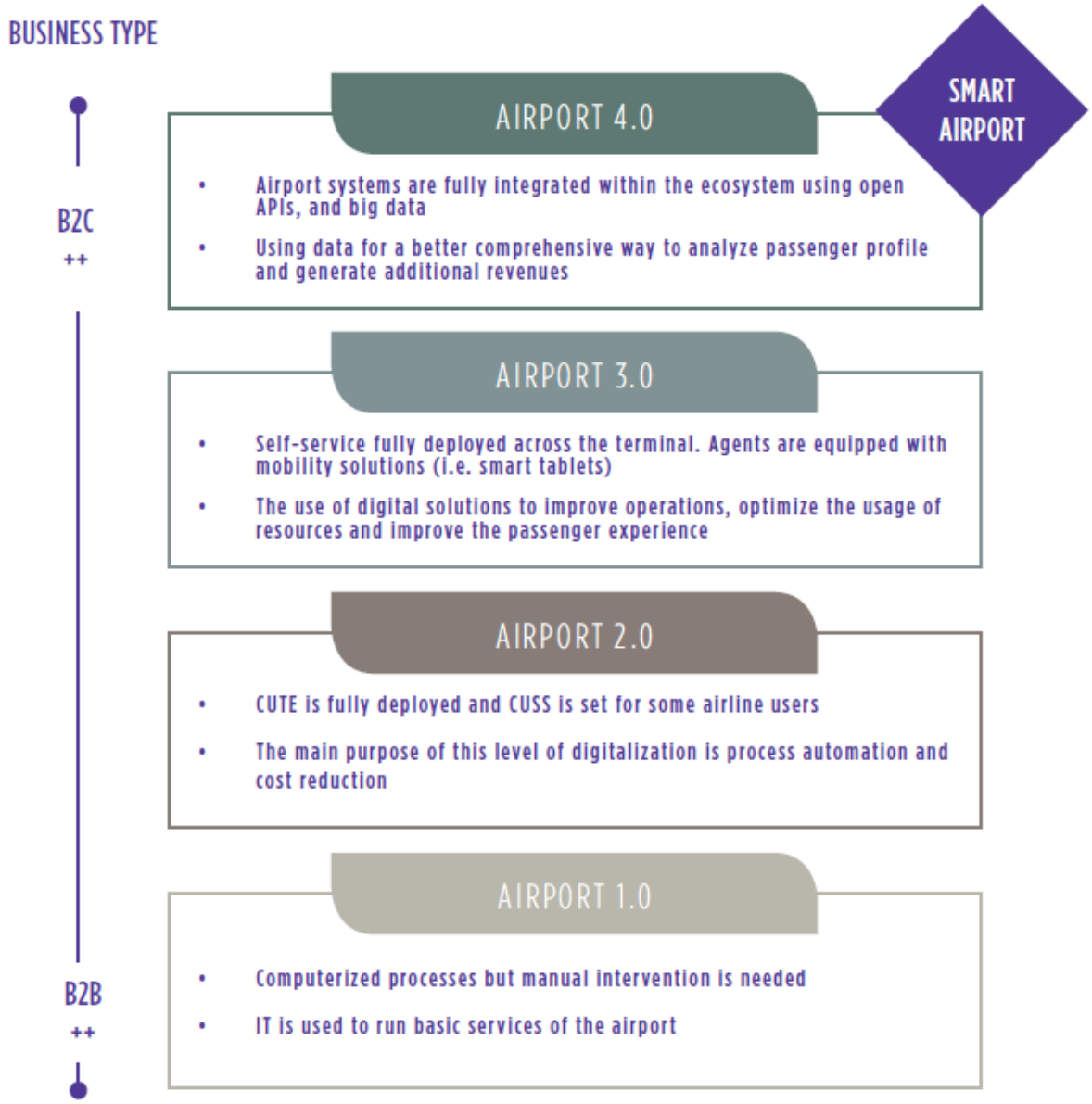


Figure 69 - Scheme of the four phases of airports development[31]. (Source: Nau Jean-Baptiste, Benoit Franck, "Smart Airport: how technology is shaping the future of airports", 2017).

The key feature of Smart Airports developed in the last years is common to the other building typologies described in the previous chapters: the enhancement of user's experience. This is linked also to the fact that the average time spent at the airport counts for more than 60% of the overall time spent during the travel in certain cases. Airports, airlines, and partners should start to use smart technologies like sensors, processors, and always-on communications to produce a new framework, enabling real-time sense-analyse-respond capabilities. The result is supposed to be a pervasive and

[31] **CUTE** stands for Common Use Terminal Equipment and applies to the sharing of traditional check-in desks and the software platform to generate the bag tags. **CUSS** stands for Common Use Self Service, for the sharing of check in self-service kiosks. They enable airport operators to take space that has previously been exclusive to a single airline and make it available for use by multiple airlines and their passengers.

persistent connection to the passenger who will be enabled to have continuous, real-time communications anytime, anywhere (Fattah, et al. 2009). The goal is to provide the passenger a better control over the airport experience, by providing real-time flight details, queue info and notifications in a graphical manner to facilitate the flow of activities starting from outside of airport to onboard. Moreover, in the last years, the value proposition of an airport or a terminal to attract additional flight connections, is no longer exclusively linked to the minimum connection time (MCT) (historically, airlines used to choose an airport as a hub or connection, based on the accessibility and transfer time between each flights), but it is also linked to the quality of the in-terminal experience that the airport is able to provide (Wavestone 2017). In these terms, the user experience become one of the fundamental aspects that an airport should address in order to be competitive on the market, under the eye not only of the passengers, but also of airlines.

The peculiarity of the Airports is that they are conceived as a sort of assembly line; there is a strong dependence among all the actions that a passenger, but also the staff of the airport itself, has to do. In such an environment, if a step of the chain is subjected to issue which generate a delay, this delay is transferred to the rest of the chain and the passenger is almost in all cases dissatisfied and stressed. Because of this strong dependence between the activities performed inside an airport, the smart technologies should be part of an integrated system, able to assist and improve the experience not only of the client (the passenger) but also of the workers. The smart airport conceived in this way becomes people oriented not only towards the passenger, but also for airport staff, retailers, airlines, government systems and airport security (Upadhya and Rawat 2018).

2.5.5.1 The new technologies for Smart Airports

The development of new technologies in the Airports is driven by many factors, and one of them is the enhancement of user experience. Being the passenger the focus of the smart technologies, it is necessary to understand who the passenger spending time inside an airport is, and what he or she expect in terms of Smart technologies.

Passengers' needs are changing under the global connectivity boost: according to the airport IT provider SITA, 83% of passengers carry a smartphone today. This over-connectivity caused the traveller to change his attitude and expectation during his travel; nowadays the passenger is looking for a connected travel journey and is asking for a personalized experience: in this technological landscape, an airport must adapt his merchandizing strategy and propose the right service for the right passenger at the right moment. These three conditions should all meet in order to maximize the value created by a passenger (Wavestone 2017):

- **Mobile over connectivity**: despite the reason for which passengers are travelling (business or leisure); they are all looking for internet connectivity "everywhere". Of course, for the airport, this become a cost, but it can also be seen as an opportunity: the airport has the possibility to make revenues out of this ancillary service.
- **Personalized service**: what passengers expect are services that answer to their specific needs and preferences.
- **Seamless experience**: the expectation of passengers is that the airport experience, made of a series of steps equal in all the airports of the world, is as seamless as possible.

Self-check-in kiosks and Self Bag Drop

One of the biggest issues for the passenger inside the airport are the long lines for the check-in and the bag drop. In recent period, the online check-in procedure has become quite widespread, but there is the possibility, offered by smart technologies, of improving this phase of the journey also inside the airport.

The first self-service check-in kiosk appeared around the beginning of the 2000s, when it was considered as a revolution for passenger experience. This technology provided great improvements for the delay spent checking-in, and important cost reduction opportunities, especially in countries where the labour cost is high. Another factor that is driving towards the development of self-check-

in kiosk is the diffusion of low-cost airlines in most of the airports. The profitability of low-cost airlines indeed is directly linked to the ground handling costs, in particular the ones related to the check-in procedures.

The self-service airport kiosk can be dedicated to a specific airline or shared as common use by multiple airlines. The kiosk can be used for several self-service processes, including booking, changing a reservation and check-in (SITA n.d.).

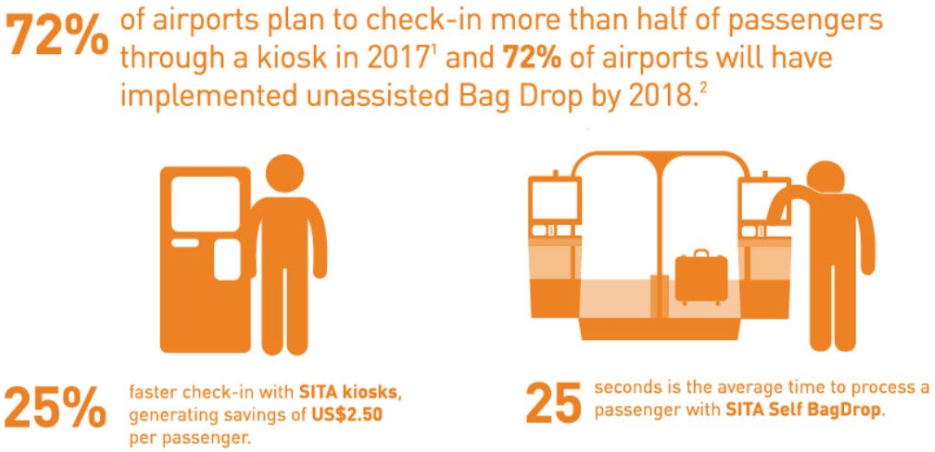


Figure 70 - Results of a study performed by SITA, about the development of self-check-in kiosks and self-Bag Drops. (Source: https://www.sita.aero/)

The numbers coming from a study performed by SITA[32] displays that it was expected for 2017 a 72% of airports using kiosk for the check-in procedures in order to make them faster and less expensive in terms of labour costs. A saving of USD $ 2.50 per passenger was expected, together with a fastening of the procedure of 25%, if compared to the standard check-in procedure.

However, this type of technology presents also several problems, first the one related with its user-friendliness. *"It all depends upon the passenger profile,"* says IT support manager at Newcastle International, Darren Kelly. *"Business passengers and frequent flyers seem to be a lot more open to the use of kiosks but once-a-year vacation flyers and those flying with a lot of luggage and large families will be more wary"*. Sometimes it may happen that, despite the presence of a self-check-in kiosks, a long line is still present because of a passenger that has troubles in using that type of device.

Another issue that may be a deterrent for the adoption of these kiosks inside an airport is the transformation that is going on for what regards travel habits. The rise of low-cost airlines, who limit

[32] SITA is the world's leading specialist in air transport communications and information technology.

the number of checked luggage by making it an ancillary paying service, has pushed travellers to change deeply their behaviour. The number of passengers carrying checked luggage on medium or short haul flights is getting lower; in addition, the average length of vacation is being shortened, especially for young travellers who prefer short breaks to long holidays. This change in traveller behaviour has limited the actions to be done at the airport to passenger check-in. Moreover, the mobile and online technologies have made it possible to perform all operations from reservation to on-board service purchase. This technological improvement, associated to the traveller behaviour change, has made the usage of in-terminal automated check- in kiosks very limited.

The self-baggage drop is another opportunity for improving airport efficiency and for optimizing the passenger experience. SITA has demonstrated that the use of a self-Bag Drop brings to an increase of the terminal capacity by 60% (SITA 2016). For this reason, it was expected that by 2018 almost 70% of airports would have provided a self-Bag Drop system.

The self-Bag Drop technology addresses three main issue, very common in all the airports worldwide (SITA 2017):

- **Dissatisfied passengers**: even though many passengers check in online at home, once they arrive at an airport, they may still have to wait in a long queue for a ground agent to check in their bags.
- **Limited terminal capacity**: with continually rising passenger numbers, airports have to expand their existing terminal space in order to avoid long queues and dissatisfied passengers.
- **High operational costs**: the increasing number of travellers leads to a need for more ground agents. This in turn results in higher recruitment and staff costs.

The application of this technology generates benefits both for the users and for the airport, by solving the three basic problems presented above. On one side, queues are shorter, and passengers are less stressed; moreover, for the airport there is a 40% reduction of the operational cost, considering that a single agent can manage up to six bag-drop units.

The general procedure of a self-bag drop station is simple and fast, requiring 60 seconds to be performed by the passenger. Every step is guided by a video-tutorial on a screen. First, the passenger selects the language with a simple touch on the screen, and then he has to place the boarding pass under the reader. The system recognizes the passenger, the flight and the destination, and it is required to place the luggage on the conveyor belt. The system emits the label that the passenger

has to place on the luggage, and once the stat button is pressed, the luggage enters the sorting system.

The self-service bag drop technology has been recently deployed for Easy Jet at Gatwick North Terminal. The driving idea was that departing passengers have the possibility to spend less time landside, with the focus of passenger experience shifting towards the airside departures lounge.

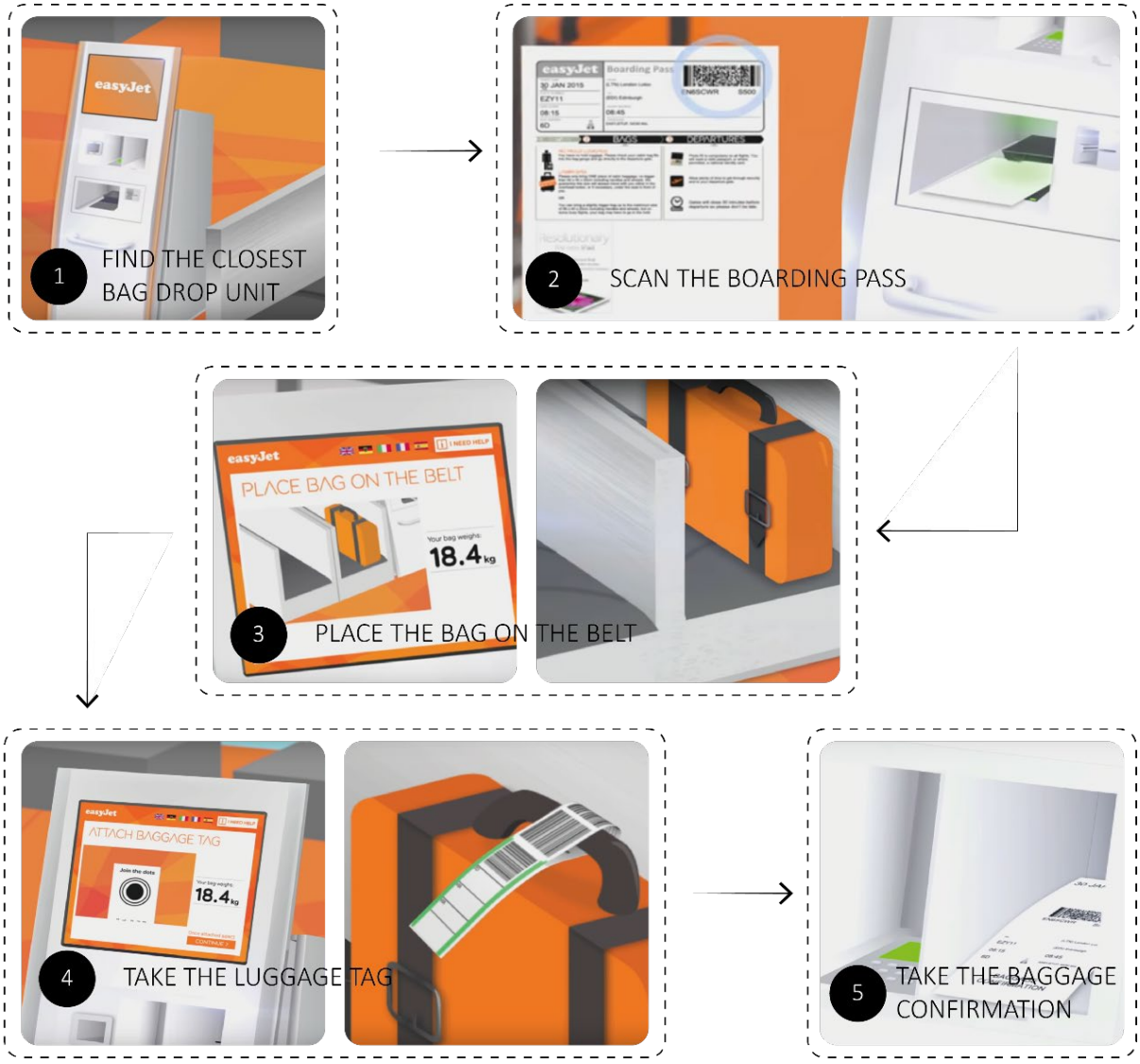


Figure 71 - Diagram of the self-Bag Drop process offered by EasyJet at Gatwick North and South terminal (Source: the author)

At Gatwick airport the introduction of the self-bag drop technology has brought several advantages. Queue times have been reduced by half, and more than 90% of Easy Jet passengers wait less than 5 minutes at the bag drop area.

Network-based services

Any business or customer-oriented IT solution requires an efficient network to support its performance and evolution. Airports follow this principle, and telecommunications and networks are the backbones of the airport IT. The presence of Wi-Fi connection is crucial, and it is still one of the main requirements of the passengers: according to a survey by SITA, 70% of travellers want internet connection from when they enter the airport to the moment in which they exit the gate and get on the plane.

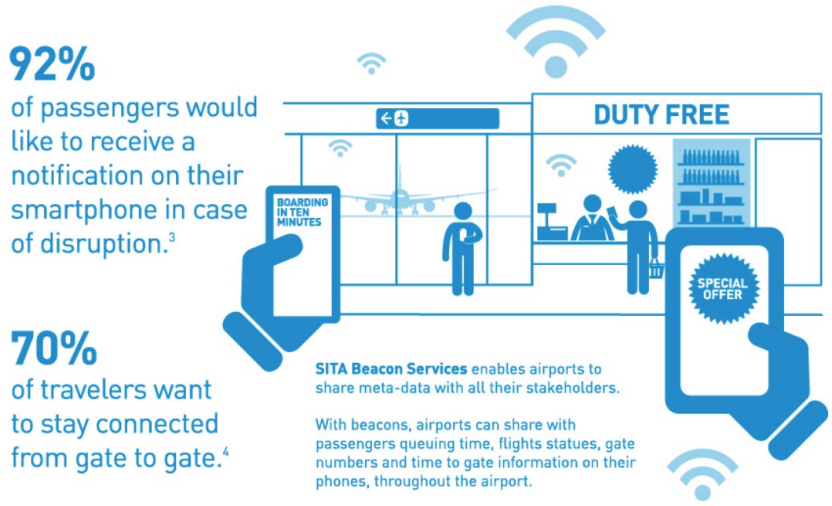


Figure 72 - Results of a study performed by SITA, about the airport network and use of beacons. (Source: https://www.sita.aero/)

Moreover, airports should consider the fact that the smartphone, for instance, is the second most used channel after the website for retrieving flight information, or buying additional services (Wavestone 2017). *"Smartphone are the backbone of the passenger experience,"* said Jean Baptiste Nau, Senior Manager of Wavestone and expert in the air transport industry; airports that understood the importance of being in touch with passengers though their smartphone and social media and started to implement a mobile application are generally the bigger and digitally mature ones.

Referring to the classification of the airports according to their maturity in terms of technology (from Airport 1.0 to Airpot 4.0), it emerges that the real smart airport is the one able to fully exploit the possibilities offered by a smartphone coupled with an internet connection, better if offered by the airport itself. On one side, the traveller can find all the information he needs about flight status, possible queues, and special offers from the shops present inside the airport. On the other side, is the airport itself that has the possibility to propose these offers, since it knows where the traveller is, his basic information like gender and age, required at the moment of the log-in inside the airport's Wi-Fi network, and his flight purpose (business, recreation, tourism, etc.) or destination (Fattah, et

al. 2009) . The retail concessions are the largest source of non-aeronautical revenue for airports (30.2% of the total) (ACI 2019); for this reason, airports should attract retailers by ensuring that travellers will take advantage of the services they will offer.

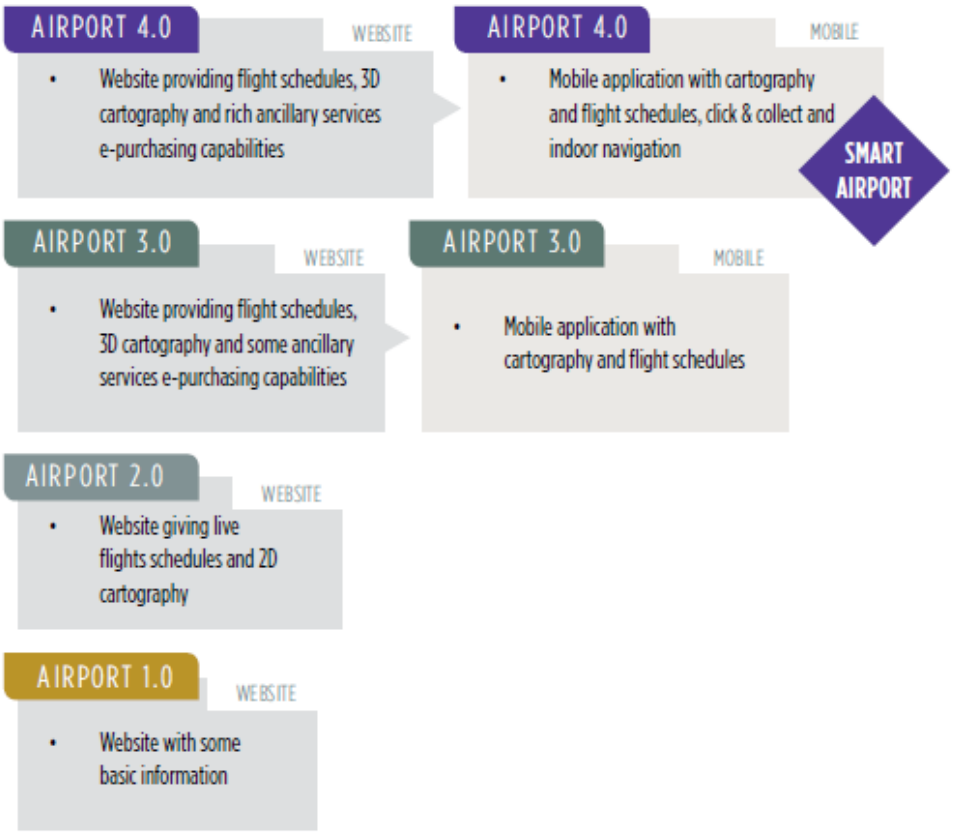


Figure 73 - the level of digital maturity of the airport characterizes the type of information it provides to the passenger and through which channel. (Source: Nau Jean-Baptiste, Benoit Franck, "Smart Airport: how technology is shaping the future of airports", 2017)

Together with the economical aspect, the use of the smartphone as main channel of communication between the airport and the passengers must be related also to the practical information about the flight. Keeping passengers constantly informed is one of the key factors in smart airport concept. This type of communication can be very useful also before the passenger reaches the airport; real-time travel services keep passengers informed of any travel problems and offer premium services, such as valet parking or route switching, if the passenger is at risk of being late.

Once the passenger is inside the airport, the wayfinding is one of the most required and useful technologies: passengers receive real-time indications about the fastest way to reach a determined location, as the gate or the closest toilet. In this way, it is possible to reduce stress, minimizes queues, and increases retail sales: if the passenger is not worried about where to go or of being late, he is more relax and wishful of looking at the shop windows and of buying something (Fattah, et al. 2009).

Self-Boarding gates

The self-service principle inside the airport can be applied not only at the arrival, with self-check-in and bag drop, but also during the boarding phase. Before boarding, there are always long lines in correspondence of the gates, but the situation can improve with the adoption of self-boarding gates. The main issues during the boarding procedure are (SITA 2017):

- **Managing boarding time**: the formation of a long line before the boarding procedure causes congestion around gates and potential delays in take-off.
- **Disruption management and flight delays**: when inbound flights are delayed, the airport need to reduce the knock-on effect they have on other outbound flights.
- **Improving customer satisfaction**: the boarding gate staff should focus on complex issues such as dealing with excessive hand luggage and delivering excellent customer service rather than working on repetitive tasks.
- **Managing passenger expectation**: passengers are increasingly choosing the self-service option to take ownership of their journey and be in control.

The adoption of a self-boarding system allows to avoid the presence of boarding agents; moreover, the installation of multiple systems for a single gate offers the possibility for reducing lines and fastening the boarding procedure (it is foreseen a reduction of 50% in boarding time with the use of self-boarding technology) (SITA 2017).

Figure 74 - Results of a study performed by SITA, about the development of self-boarding gates. (Source: https://www.sita.aero/)

The survey performed by SITA in 2017 shows that 63% of passengers would prefer a self-boarding gate rather than the standard procedure applied nowadays in airports. This technology, similarly to the self-bag drop, allows reducing the staff working at the gate during boarding phase: it is enough one operator managing until three self-boarding gates. This means that there will be more operators free for other activities, like the assistance to the passengers or for solving specific issues.

Another useful data is given by IATA (International Air Transport Association): through a survey performed on 10,675 travellers from around the globe, it emerged that 72% of them would prefer a self-boarding procedure, with an increase of 2% with respect to the results obtained in 2016 (IATA 2017).

In the field of self-boarding, there is a new possibility that is spreading, by bringing the self-boarding gates to a next level: the biometric control. A survey conducted by VISA on a sample of 1000 people, demonstrates that over 65% of consumers are already familiar with biometrics and 86% are interested in using biometrics to verify identity or to make payments (AYTM market research 2017).

Moving to the airport sector, IATA discovered that four out of five travellers would like to be able to use a "digital passport" on their smartphones for as many travel activities as possible, from booking flights to passing through the airport. "*Passengers want technology to give them more control over their travel experience*", said Nick Careen, IATA's Senior Vice President for Airport, Passenger, Cargo and Security (IATA 2017). On the side of airports and airlines, SITA's 2017 IT Trends Insights reveals that around three out of five airports (63%) and two out of five airlines (43%) plan to invest in biometric ID management solutions in the next three years: these numbers display a desire across the industry to exploit new technologies to improve experiences and processes.

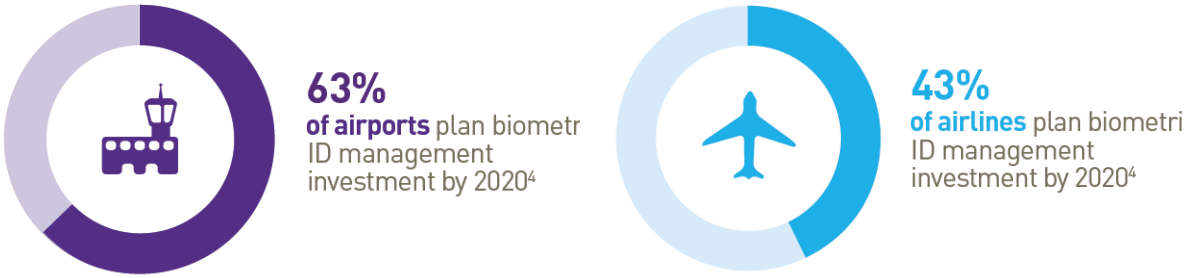


Figure 75 - Results of the survey published by SITA about the desire of airports and airlines to invest in biometric identification. (Source: SITA's 2017 IT Trends Insights)

Not only numbers coming from surveys, but also real examples are able to show the success of biometric identification applied at boarding phase.

In 2017, Southern India's Bangalore International Airport Limited (BIAL) implemented an e-boarding process at Kempegowda International Airport in Bengaluru. It was based on real-time biometric identification of passengers using their Aadhaar ID5[33]. In the first phase of the program, passengers boarding domestic flights at Bengaluru, completed all airport processes (including check-in and boarding) using a contactless fingerprint scanner. As well as reducing queues and giving passengers a less stressful experience, the airlines gained advantages like improved on-time performance. Moreover, benefits were gained by the airport also in terms of security, operational efficiency and optimize use of resources.

Also in Europe, it is possible to find airports that are investing in biometric technologies. British Airways, in early March 2018, announced that they were working in collaboration with Greater Orlando Aviation Authority, the US Customs and Border Protection (CBP) and SITA to realize and install self-service biometric boarding gates using facial recognition, in order to provide passenger with a fast and smart procedure. The project follows a similar one at Los Angeles International Airport in 2017 and adds technology already in use by BA on its domestic flights from London's Heathrow's Terminal 5 – checking customers' biometric data at the gate when they scan their boarding pass. What is interesting about this case study is the time needed for the boarding: the boarding of international flights for almost 240 passengers takes more or less 15 minutes (Farrel 2019).

In June 2017, JetBlue[34] collaborated with the CBP and SITA to trial the world's first biometric boarding system using facial scanning, integrating checks with government systems, to board passengers while completing the US Customs and border exit checks. The initiative also allowed JetBlue to move its crew member from behind the counter to interact with customers and assist them throughout the process.

After some airports all around the world decided to implement biometric technologies, SITA in the SITA's 2017 Passenger IT Trends report, performed a survey in order to understand the satisfaction of passengers about the use of this type of smart solution. The answer was positive: 37% of passengers used automated ID control (passport scanning or biometrics) on their last flight and 57% of respondents declared to be satisfied about all the procedures in which biometric identification was required. Being the passenger experience the core of the development of smart airport, this

[33] The Indian government's Aadhaar program assigns a unique 12-digit ID number to all residents of India, based on secure registration of their biometric data.
[34] Low cost Airline Company based in USA.

result should be a starting point for a deeper implementation of self-procedures flanked by biometric systems.

There is an emerging desire of both airports and airlines to adopt self-boarding gates by 2021 (Wavestone 2017). This willing is pushed first by the need of passengers, who want faster and simpler procedure than the ones applied nowadays in the majority of airports. Secondly, having seen the results in terms of performance of the pilot airports in which biometric systems have been applied, more and more airports realized the great efficiency of self-boarding gates and want to implement them.

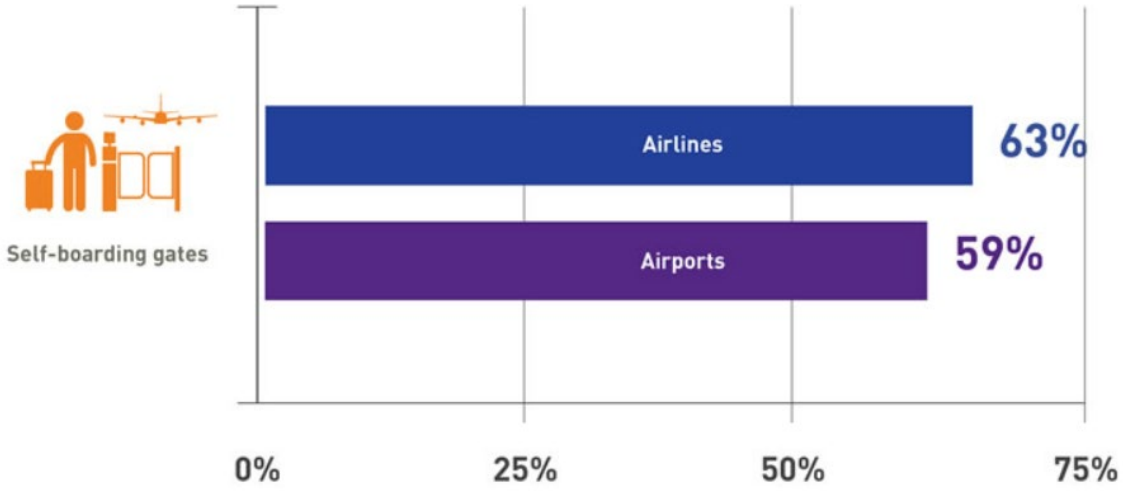


Figure 76 - % of airlines and airports using or planning self-boarding gates using biometric and travel documents by 2021. (Source: Sherry Stein, "Biometric self-service - taking the next steps", 08/11/2018)

An example of a real product that airports may decide to install is offered by Vision-Box[35] and it is called Seamless ABC Gate.

The Seamless Gateway is a contactless face biometrics passenger identification gateway. It consists of a self-service solution that enables travellers to experiment a seamless on-the-move identification experience, without having to show their travel documents at any point of the airport journey. Whether at check-in, border control, security checkpoint, boarding or even accessing the lounge, a proper level of security is met, simply by walking through. The innovation offered by this system is that the passenger does not have to stop in order to be recognized. When he or she is walking through, the scanner checks the passenger's face and compare it with the picture present on the

[35] Vision-Box is a multinational technology company headquartered in Lisbon, Portugal, dedicated to improving the quality, convenience, efficiency and security in government services, travel, border control and all smart facilities. It is a leading partner of the most prestigious airports, airlines, governments and private entities with critical security and identification challenges, supporting them to optimize the identification and flow of travellers.

passport, that the passenger had to upload at the moment of the online check in or at the arrival to the airport.

Figure 77 - Seamless ABC Gate, example inside an airport. (Source: https://www.vision-box.com/products/seamless-abc-gate)

Nowadays, the greatest limit of the biometric identification is that, for privacy reasons, it is limited to one single travel. The biometric identity gathered and verified is largely impermanent and is re-confirmed on every new trip (Garcia 2018). Every time a passenger travels, he has to provide his picture, in order to be able to use facial recognition for all the self-procedures. However, both airports and airlines are working to overcome this limit, and to ensure by the next 5 years biometric identification systems that are "permanent", without the need of repeating the picture procedure every travel.

Automation of border control procedure: iBorders

A delicate aspect of the travel, both for passengers and for airports, are the border control procedure. When dealing with international flight, it is fundamental to check carefully the identity of all the travellers, and this procedure often generates long lines and dissatisfaction among passengers.

As a proof of this sentiment, a survey realized by SITA in 2017 displays that almost 70% of the respondents would like an improvement in border control procedures, especially in terms of fastening of the procedure itself.

Figure 78 - Results of a study performed by SITA, about the border control procedure. (Source: https://www.sita.aero/)

When dealing with border control procedures, there are some issues that need to be addressed, and for which Smart Airport have to provide proper solutions:

- **Passenger processing**: the growing international traveller numbers, coupled with peak demand of careful control around major events (like terrorism on particular threats for a country), are great challenges for border management and security.
- **Resource efficiency**: with the increased complexity of immigration risks and the difficulty of managing border, border staff needs the flexibility to focus their resources on the most complex and demanding cases.
- **Security threats**: Identity fraud, smuggling, terrorist threats and illegal immigration are on the rise, as is the use of fraudulent identities for illegal migration and for committing trans-border crime.

An effective Smart solution must address all these problems in an efficient way. A possible solution may be the automation of border control, or a part of it, for most travellers who represent little or no risk, thus enabling skilled resources to focus on higher risk passengers. SITA proposes two systems able to respond to these issues, leading to the same benefits: iBorders BorderAutomation ABCGates and iBorders BorderAutomation ABCKiosks. First, they both give the possibility to governments to verify the identity of large numbers of passengers in record time and speed up the arrival and departure process, ensuring an enhanced travel experience thanks to the reduction of waiting times. Moreover, both the solutions offer a secure self-service alternative to traditional manual border controls for travellers holding biometric travel documents. As for self-check in and self-bag drop, the adoption of these smart systems for management of border operation allows operators to control more than one person at the time, and they have the possibility to focus on the most delicate situations.

Baggage real time location

One of the major issues of the airport experience is related to the baggage. The use of self-bag drop is not enough to avoid stressful situations for passengers, who are worried about the possible loss of their luggage: one of the major sources of frustration for travellers is linked to lost or delayed baggage (SITA 2019). For this reason, airports who want to be smart should move towards this direction and find solutions to this problem in order to properly answer to traveller's needs.

Figure 79 -Results of a study performed by SITA, about the luggage management. (Source: https://www.sita.aero/)

Over the past year, a growing number of airlines have introduced baggage tracking at key points in the journey – check-in, loading onto the aircraft, transfers and arrival – in response to passengers needs about the baggage issue (SITA 2019). This investment in tracking is already having a positive impact. The analysis of baggage records reveals that in those cases where bags are tracked at check in and at the moment of the loading onto the aircraft, the rate of improvement ranged between 38% and 66%, depending on the level of tracking introduced.

The investment in baggage tracking was also pushed by a new rule imposed by IATA, called IATA Resolution 753. This rule is intended to encourage airlines to further reduce mishandling by implementing cross-industry tracking for every baggage journey. Resolution 753 became effective on 1st June 2018; it was initially requested by airline members and approved by the Joint Passenger Services Conference (JPSC) in 2013 allowing enough time for implementation (IATA n.d.). The three fundamental objectives of this rule are to reduce global baggage mishandling, to increase efficiency in baggage operations and to ensure a better passenger experience.

Delayed bags accounted for over three quarters of all mishandled bags in 2018 (77% of the total). Considering these data, the focus of airlines and airports is to invest in technologies that will avoid this problem before it happens. The tracking of luggage is, of course, the main strategy that may help in reducing these numbers, and a great step forward has been possible thanks to IATA Resolution 753. However, every airport, according to its digital maturity, is dealing with the tracking in a different way, and this is reflected in the fact that the rate of improvement after the application of the new tracking rule by IATA ranged between 38% and 66%, according to the way in which the airport managed the tracking itself.

Apart from the airport handling of baggage, another essential issue to be considered is the passenger experience in relation to baggage. The use of smart technologies increases passenger satisfaction with bag services (SITA 2019); it has been studied that waiting at the baggage carousel can be a stressful point in the passenger's journey. However, the ability to receive real-time notifications increases satisfaction levels. Moreover, those travellers who receive notification about the baggage location and status via app have a satisfaction level 8.6% higher than those relying on screen or public announcements (SITA 2016).

While the primary objective for Resolution 753 is to improve airline and airport baggage operations, airlines feel the need to find opportunities to enhance passengers' satisfaction. An example is providing them with information on their mobile devices about what is happening to their bags.

This is perfectly in accordance with what people expect: when questioned about the mobile services they would like to have inside the airport, two thirds of passengers say that they would definitely track their bags on mobile apps, use bag collection information at arrivals and use their mobiles to report mishandled bags. For this reason, real-time bag tracking information via mobile apps is on the self-service investment agenda for most airlines over the next three years. They plan to offer bag location status updates and missing bag communications to passengers.

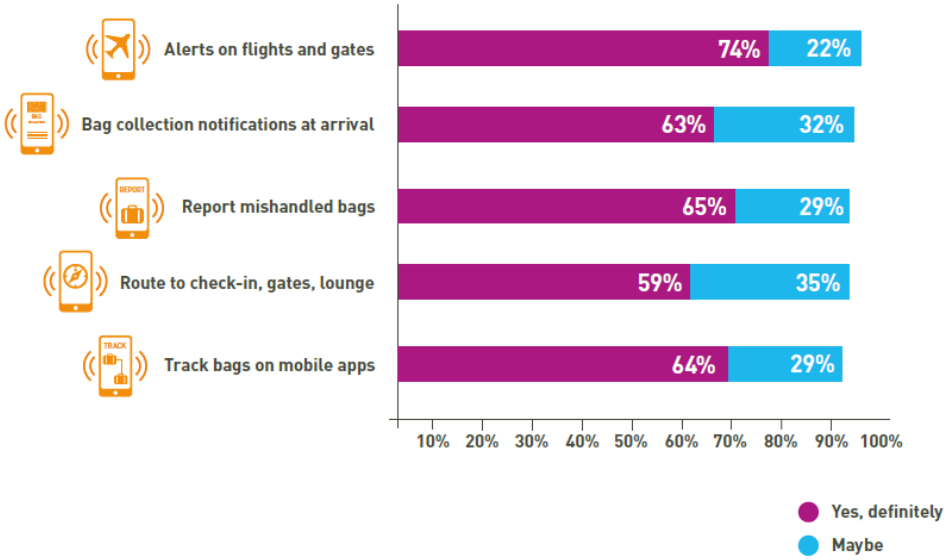


Figure 80 - % of passengers willing to use new mobile services in 2018. (Source: SITA 2019 Baggage IT Insights)

Practical examples about baggage management can be found in applications by both airlines and airports.

"The 33% improvement in baggage mishandling in 2018 came from our ability to efficiently plan and prioritize the loading and off-loading sequence of baggage into our Abu Dhabi hub. Our baggage management system (BMS) tracks all luggage across our network and links to the baggage reconciliation system (BRS) at originating stations and baggage handling system in Abu Dhabi. If a local BRS is not available, we deploy our own e-ULD scanners to scan manual bingo cards. Our BMS helps track global compliance for baggage loading and hub planning for transfer prioritization. Baggage tracking testing was completed and implemented in Q1 2019. We also launched the online baggage tracking system via the Etihad Airways guest mobile app in Q1. This year, our focus will be on improving baggage tracking tools, loading procedures and compliance and developing a Baggage Support Unit for the network." Says Paul Smith, General Manager, Ground Operations, Etihad Aviation Group.

Aegean Airlines offer another example: in 2018, they mapped and tried to improve factors that cause failures in a bag's journey. The company analysed delay codes to better understand the cause of

mishandling, and then they and targeted areas where they could influence and eliminate the delay. They also introduced a centralized baggage performance-reporting tool within their business intelligence platform, which has great digging capabilities that further enhanced monitoring of their performance. *"We are actively working towards making baggage tracking available to passengers through our mobile app, which will be using the Star Alliance Digital Services Platform to cover not only Aegean and Olympic flights but also flights operated by our Star Alliance partners. This will roll out in 2019"* says Timos Korosis, DCS Administrator, Aegean Airlines.

The effects of these actions are stimulating: the company evaluated a decrease of 32% in mishandled bags caused by internally controlled factors. Moreover, thanks to the tracking procedure, it is possible for the airline to solve problems of mishandled bags within the first 24 hours, with greater satisfaction of passengers. In terms of technologies for the tracking of baggage, Andrew Price, Head, Global Baggage Operations for International Air Transport Association says that the industry is looking at RFID as a low-cost tracking solution. However, airlines will require the support of airports if they add RFID inlays to baggage labels, and for this reason, it is fundamental to understand how airports want to deal with this issue (SITA 2019). According to the research performed by SITA, airports seem to be ready to implement RFID for baggage tracking, which will provide them a rich data set for operational analysis and planning.

For what regards airports in which a system for tracking baggage has been implemented, Abu Dhabi international airport may be a good example. "*In 2018, we installed automated tag readers (ATRs) across the arrival belts in Terminals 1 and 3, and we provided a platform for all airlines to comply with IATA Resolution 753 for automated arrival baggage scanning and tracking. We also introduced handheld scanners to scan and track terminating out of gauge (OOG) bags and provided ground handlers with barcodes to track and reconcile arrival OOG bags in SITA Bag Manager. The BHS (Baggage Handling System) for Terminal 3 and Transfers were modified so that bags are auto sorted to destination-planned carrousels, which has enhanced efficiency, baggage connectivity time and, ultimately, passenger satisfaction. For 2019, our goals include a BHS availability 99.5%; an ATR read rate of 95% for originating tags and 80% for inbound tags and a baggage delivery satisfaction target score of 4.32 out of 5.0, based on ACI best practice"* says Mohamed Nasser Al Otaiba, General Manager of Operations for Abu Dhabi International Airport.

The performances of the baggage management system in Abu Dhabi International airport are good, and better than the average of the airports all over the world. In terms of average delivery time, Abu Dhabi International airport has a time of 16 minutes for the first bag, two minutes faster with respect to the airport's target of 18 minutes, and of 31 minutes for the last one.

SMART SHOPPING MALLS

2.5.6 Smart shopping malls

The spread of the digital age is affecting the whole building sector, including shopping malls. Many global trends, like the diffusion of different types of technologies, are changing the role of shopping malls: nowadays they are not only a place where people go shopping, but they are spaces where consumers are looking for experiences that go beyond the traditional way of buying things (Fantoni, Hoefel and Mazzarolo 2014).

The trends driving this change include many aspects of people's lives. First, the change in demographics (aging population and increased urbanization) which means a greater number of people living in smaller spaces, and a greater need for public spaces for socialization and interaction. In this environment, malls offer a welcoming space, especially in cities where other public spaces are not safe; this concept is valid especially for American and Asian cities, where the shopping malls is often the real city centre. In European cities, the tradition of the main piazza as the central point for meeting and socialisation is still valid.

Sustainability concerns are causing some consumers to prefer to go shopping in a place where it is possible to find many different types opportunities, like to buy clothing, home furniture and food, instead of having to get into a car and drive from a shop to another one. Also in this case, this concept is referring more to American cities, since in the European ones shops that are not inside a shopping malls are usually along one or two main streets of the city.

The growing middle classes in Latin America and Asia maintain a strong association between consumption and pleasure, driving the need for more engaging shopping experiences. Moreover, the e-commerce revolution and the rise of digital technologies are reshaping consumer expectations and shifting the function of stores toward useful and entertaining customer experiences.

2.5.6.1 Design strategies for realizing a smart shopping mall

As for offices, also shopping malls have the possibility to modernize themselves and to answer to new people's need without recurring to technology (of course, only in a first step). The goal, both of non-tech and tech solutions, is to provide costumers an experience and a reason for going to the shopping malls. Because of the diffusion of e-commerce, people have the possibility to buy all what they need directly from their couch, and for this reason sometimes they have not a motivation for going to a shopping mall. Malls will never be able to compete with the endless product selection, price comparisons and always-on nature of online. Instead, shopping malls need to move in a different direction, away from commoditized shopping experiences and toward a proposition of experiences for consumers (Fantoni, Hoefel and Mazzarolo 2014).

Innovative malls are incorporating value-added elements that attempt to present the mall as the new downtown, including concerts, arts centres, spas, fitness clubs, and farmer's markets. These services provide a level of leisure and entertainment that cannot be satisfied via e-commerce. From an economical point of view, it has been demonstrated by a study performed by Cambridge University in 2017, revenue coming into malls from these offerings grew 41 % in 2017 compared to 2016.

Another non-technological opportunity or shopping malls to become more attractive against online shopping is the introduction of Pop-up stores.

Pop up Stores are temporary and flexible spaces that can accommodate different retailers over time, with a change between one retailer and the other that is quite fast. In this way, the shopping mall is able to provide customers with a sense of the unexpected and give them a reason to come back to the mall to see the innovations.

Nowadays malls are overcoming the challenge against e-commerce and the fact that people prefer to buy things by staying at home, by focusing on specific consumer segments and/or creating specific zones within the mall that allow consumers to find an area that interests them. In the Dubai Mall, for instance, the so-called "Fashion Avenue" is an area dedicated to luxury brands and services realized for the upscale customer, including a separate outside entrance and parking area. Another example is the 7-story Central World mall in Bangkok, where home décor is on the fifth level, technology on the fourth, and fashion apparel on 1-3. This approach also represents a way for malls to ensure that customers do not get lost inside the ever-increasing square footage of malls.

2.5.6.2 The new technologies for Smart Shopping malls

Even though shopping malls have the possibility to face some of the challenges of the digitalised age without recurring to technology, it is clear that the biggest advancements and innovations are possible though the use of Smart solutions. This is a common feeling of retailers all over the world: 77% of retailers believe that smart technologies are one of the most powerful opportunities to improve customer experience inside the store. Moreover, 89% of interviewed retailers, states to be able to increase his knowledge about clients' preferences and behaviours thanks to sensors and connected objects (Verizon 2017). Moreover, many retailers are planning in investing in technology for the next years (Zebra 2017).

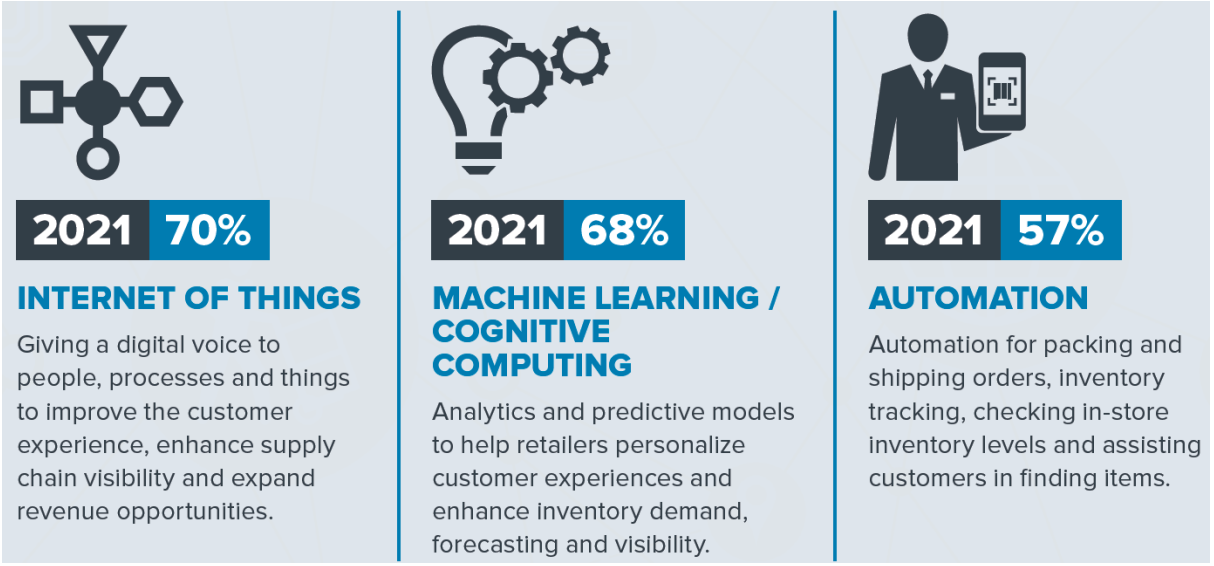


Figure 81 - Percentage of respondents planning investments by 2021. (Source: Zebra, "Reinventing retail: 2017 Retail vision study", 2017)

70% of retailer plans to invest in IoT technologies, 68% in machine learning and cognitive computing, and 57% in automation, in order to increase the efficiency of the store chain. More specifically, the numbers related to the IoT development indicate that stores are really interested and focused in this type of revolution: nearly 70% of retail decision makers are ready to make changes required to adopt IoT. Already 21% percent of respondents have implemented IoT and another 27% are planning to deploy within a year (Zebra 2017).

Of course, the investment in technologies must have a purpose, and coherently with the overall trend of Smart Buildings that in the recent years are people oriented, also shopping malls are focused on the user experience as the driving force for smart devices development.

Figure 82 - The importance of the focus on consumer experience is validate by these data. (Source: Deloitte, 2018 and Bain & Company, 2019)

According to recent studies, it emerges that half of the consumers pay attention to the overall experience when they have to decide if to buy a product or not (Deloitte, 2018). Moreover, form an economical point of view, if a retailer invests in order to enhance customer experience, he may expect a 4-8% extra revenue growth (Bain & Company, 2019).

There are other factors that are driving the shopping mall sector towards the implementation of smart technologies: generate revenue, reduce operating costs, keep pace with competition and improve inventory management (Zebra 2017).

Being the customer experience the top priority for the development of smart shopping malls, it is fundamental to understand which are shoppers' expectations for their ideal shopping experience (Brown and Roth 2018).

- **Convenience, efficiency and speed**: for most shoppers, the number one priority is becoming the speed. Retailers should address this need by delivering products and services in the fastest way it is possible for them. Moreover, another important aspect to be considered is the efficiency; customers enjoy choice, but not so much choice that selection

becomes confusing. The preferred retailers nowadays are the ones who help clients understanding their options by simplifying the choosing process.

- **Experience**: in the last years, people want shopping to be an experience and not just be a speedy acquisition. They seek the pure joy of shopping as an activity unto itself, regardless of their need to buy. Retailers should offer new and particular experiences inside their stores, in order to encourage people to visit them. The goal of retailers should be, for the next years, to develop technologies that make shopping more social and help people to choose, in order to provide clients memorable experiences that increase the relation with the brand.
- **Transparency**: recent studies demonstrated that consumers want to understand the company, its manufacturing policies, how its products are made, and how seriously it takes corporate social responsibility before they decide to buy something (Brown and Roth 2018). Retailers will need to consider proactively increasing the transparency of their operations. This might include being able to provide present and future clients details on the origin of their products, labour practices, and even political donations.
- **Personalized/customized experience**: Shoppers are increasingly looking for products and experiences that have been customized to meet their individual requirements. This is particularly true of Millennials, and in a survey by The Cassandra Report, 80% of US Millennials said they would prefer to have a customized product.
- **Ownership to access and associations**: led by Millennials, shoppers of the future are becoming less interested in owning things. Nowadays many consumers prefer simply having access to products and services when they need them, without owning them.

Smart stores and heat maps

One of the greatest opportunities for retailers is to know the preferred path of visitors, where they stop, what they look at, in order to optimize the merchandise strategies and to have higher revenues. The basic idea driving the development of this technology is that the owners of shops nowadays are not just interested in what clients buy, but they also want to know how they shop (Griswold 2014). Stores previously had to perform surveys on customers in order to get any data, but now they can use customer-mapping technology to gain valuable insights into how consumers interact with their stores (Clickatell 2018).

These "smart stores" use heat maps to map where and how customers find objects in their store. Thanks to the data obtained by this system, retailers can use these insights to better position items for sale, adjust the store layout to eliminate empty spaces, and record shopping trends. Knowing where customers move is extremely useful for retailers. It allows them to optimize their store layout and strategize about where to place popular vs. unpopular and expensive vs. cheap merchandise (Griswold 2014). Heat mapping technology uses security camera images to generate a heat map of the store interior and translates this data onto a dashboard for managers to easily use. It emerges that one of the greatest advantages is that this technology is based on elements that are already present inside the stores, so the investment for implementing this type of system is reduced. One of the leading firms in this arena is Prism Skylabs Inc., a software company that provides shopping analytics to more than 80 retailers. The technology provided by Prism works by taking real-time video footage from the cameras in stores and analysing the movements of customers to see two main things: where the customers walk, and what items they stop to touch and pick up.

Figure 83 - Heat map that Prism Skylabs to show where customers walk. (Source: https://www.businessinsider.com/)

Figure 85 shows an example of heat map: the colours on the floor correspond to foot traffic in a particular moment. Red areas are the ones where many people walked in, while green spots have lower traffic. The small blue spot in the centre suggests that almost anyone went there.

Figure 84 - Heat map coming from the system created for STORY, an apparel store in New York. (Source: https://www.businessinsider.com/how-retailers-track-shoppers-in-heat-maps-2014-1?IR=T)

In this other heat map of Figure 86, there is a lot of blue space, meaning barely anyone is bothering to walk in that areas. That suggests the store should rethink its layout of that section to increase traffic flow. There is another kind of heat map that Prism creates, and it looks at what people touch. This is important because studies have shown that touching items increases the chance of consumers making a purchase (Griswold 2014). The data obtained by this type of map can also help retailers in identifying pricing problems. For example, if many people are touching an item but few are actually buying it that suggests that object is too expensive.

Figure 85 - Heat map for Betabrand focuses on the merchandise instead of the floor patterns. (Source: https://www.businessinsider.com/how-retailers-track-shoppers-in-heat-maps-2014-1?IR=T)

Also in this case, red indicates a high level of interaction (in this case, lots of people touching an item), while blue represents low interest. A retailer might look at this and realize the single blue item really is not selling, so should be relegated to a less prominent location.

Cliff Crosbie, senior vice president of managed services for Prism Skylabs, says that a technology like the one of heat map is going to revolutionize retail: *"You're able to highlight fixtures, tables, anything in your retail space and get a very clear read of what products people are picking up and what they're not,*" he explains. *"If you look at the whole floor, you can see exactly where people have walked and where they haven't, and that gives you a good idea of what's working and what's not."*

Prism Skylabs has not yet quantified the effect of heat map technology on sales, but Crosbie guesses that it's "significant." He adds that retailers have spent ages doing manually what Prism is now doing with cameras and computer software.

Personalized notifications

The use of Smart technologies offer the possibility of providing the customers with a personalized shopping experience: by 2021, 70% of retailers will be able to customize the shopping experience inside the store for the clients, thanks to the fact that they actually are inside the store (IQUII 2018).

Also retailers are considering of exploiting smart technologies to provide clients with a customized shopping experience. It is expected that by 2021, 75% of stores will not only know when specific customers are in the store, but will also be able to customize the store visit for them (Zebra 2017).

Figure 86 - Preferred opportunities of the localization of costumers. (Source: Zebra, "Reinventing retail: 2017 Retail vision study", 2017)

The application of technologies like beacons offers many possibility; the most appreciated ones by retailers are to customize the visit inside the store, for example through personalized notifications with special offers, to know which are the favourite times in which consumers visit the shop, to receive notifications about when a client needs assistance and to know where the client is.

The beacons are sensors useful for the retailer in order to obtain profit from the gathered data. The goal of using this type of technology is to generate concrete, actionable insights on customer shopping habits and recognize patterns by tracking customers' movements throughout a store and

note where people tend to stop. Retailers can exploit this behaviour data to make smarter merchandising and marketing decisions, like boosting inventory levels of hot-selling products. When sensors detect a poorly trafficked area in a store, for example, that real-time data insight alerts associate to merchandising issues.

An example of technology offering a personalized shopping experience is the geotargeted SMS campaigns. Basically, this technology deliver content directly to a consumer's mobile device by using their specific geographic location (Clickatell 2018). The consumer's geographical location can provide to retailers meaningful information about what clients are interested in and what they are looking for.

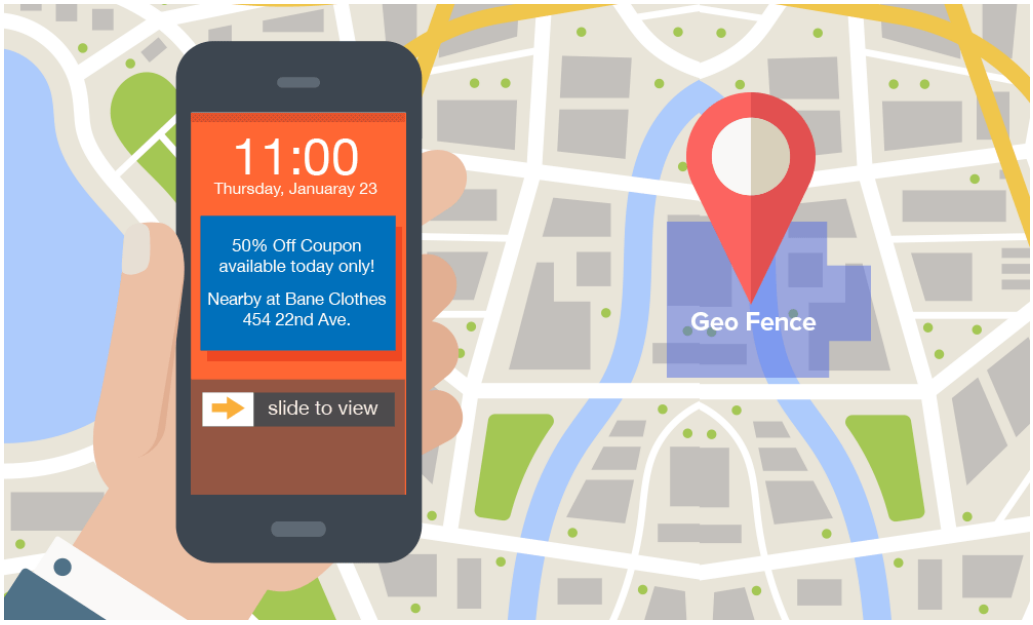


Figure 87 - Example of a message a client may recieve, with spiecial offers from a nearby shop. (Source: https://www.propellant.media/geofencing-marketing-company-providers/)

In order for a customer to receive a geo-targeted SMS, they need to sign up on a retailer's website and register to receive SMS updates. The geographic location allows retailers to send promotions and special offers for the consumer's area. Once clients signed up for this type of service, it gives the store the permission it needs to start sending contents to them when they are nearby. When that customer is near a certain shop, the system is notified, and an automatic text message is sent to their mobile phone. The SMS may contain a discount code, deal or coupon that aims at attracting costumers inside the store.

One brand that has seen geo-targeted SMS success is Timberland, as they use it to send dynamic advertisements to customers based on their location and lifestyle. This campaign increased store visits by 6%, with one out of five of these visits taking place within 24 hours of customers receiving the adverts (Tan 2017).

Smart Mirrors

Another big innovation in the field of smart shopping malls, related to the personalization and enhancement of the shopping experience, are the Smart mirrors, introduced for the first time in Rebecca Minkoff[36]'s store in New York. The technology is based on RFID tags, present on each item of the shop, which are recognized by the mirror inside the fitting rooms. The mirror works as a screen through which it is possible to have an internet connection and simulate possible combinations with other items, check the availability of other colours or sizes, and even ask the staff to bring inside the fitting room something else to try on.

According to Uri Minkoff, the brand's CEO and co-founder, the enhanced fitting rooms have both increased customers' time spent in stores and boosted clothing sales since the store opened. *"We are predominantly known for our handbags,"* said Minkoff. *"Since opening the store, we've seen a huge sales boost in clothing. We've made triple the amount of clothing sales than we thought we would."* Minkoff added that 30 % of customers who try things on request, via the fitting room's touch screen, additional items to be brought in by a member of the staff of the store. *"That's substantial,"* said Minkoff; *"Trying something on signifies intent, and the customer may not have been thinking about buying a dress, but they see it suggested on the screen and know to ask for it."* (Milnes 2015).

Figure 88 - Example of how a smart mirror works in Rebeca Minkoff store. (Source: Hilary Milnes, "How tech in Rebecca Minkoff's fitting rooms tripled expected clothing sales", 23/09/2015)

[36] A fashion label based in New York City.

Another brand who adopted smart mirror is Neiman Marcus[37]. Their system has been named *"MemoryMirror"*, and its goal is to reduce the long process of trying and retrying on clothes. The MemoryMirror shows the client a 360-degree view of himself with the outfit on and allows him to compare outfits side-by-side (Sandalo 2018).

An additional feature of these smart mirrors is the possibility they record an eight-second video, protected with a password, which can be e-mailed to some contacts selected by the client, allowing shoppers to instantly share and solve any shopping situation with the help of friends and family.

Figure 89 - Example of how MemoryMirror works. (Source: Euronews, "Memory mirror does away with changing room hassles", 2015)

[37] Neiman Marcus is an American chain of luxury department stores owned by the Neiman Marcus Group, headquartered in Dallas, Texas.

Smart Shelves

The Smart shelves are a smart technology in which many retailers are interested in because of the opportunities it offers. It can change the shelf's role within the selling process. Until now the shelf has played a passive role in this process, but a smart shelf can fulfil a much more active role where it understands shopper needs, understands the product or products it is showcasing, and it has enhanced capabilities to participate in a dynamic way in the selling process (Brown and Roth 2018).

The two-fundamental characteristic of the smart shelf are the capability of making the shopping experience easier and at the same time more exciting, two aspect that are part of what modern shopper expect from their shopping experience.

It offers advantages also for retailers: the smart shelf can create data-led sales and marketing opportunities and it helps manufacturers in better understanding who is buying their products, and who is not. It can also maximize profit for the retailer by optimizing pricing dynamically, Moreover, another great advantage is that the technology of the smart shelf is conceived for being extremely flexible, in order to answer to needs of different typologies of stores, from a supermarket to a clothing shop.

Different types of shelf can be based on different levels of technology: simple shelves may have only proximity sensors, while more advanced ones might include the ability to see, smell, feel, understand, and sense the world around them. These shelves will not only know what products they have loaded on them (this can be done by using cameras, RFID readers or weight sensors), but also understand and interact with the person stood in front of them. This particular action requires a combination of sensors (3D cameras, microphones, proximity, touch) and computing capability. The main concern in this case wold be the privacy, but there are ways in which this issue can be overcome. For example, the shelf should process all shopper image data locally and not transmit any images to the cloud for privacy reasons. Once the shelf is able to understand the feelings of who is standing in front of it, it can really become a real shop assistant, by providing the most suitable suggestions in accordance with the conditions of the shopper.

A great opportunity for the future, even if it can be considered quite extreme, is to connect together many shelves in a single network. A shelf network would include shelves (Brown and Roth 2018):

- In the home, both in the fridge and in the pantry;
- In the local neighbourhood convenience store;

- In big box stores;
- In distribution centres and warehouses (these could be distribution centres that feed physical stores or pure play online stores).

A smart recipe system connected into this network of shelves could suggest menus optimized around the ingredients available in the home, but also point out the availability of other useful ingredients in other locations, including neighbour's homes.

The opportunities offered by a smart shelf are many, and they can be adapted to the type of store in which the shelf is installed. One of the most simple but effective function a smart shelf offers is the implementation of electronic labels, ideal inside a supermarket. Electronic labels give the opportunity to eliminate all the paper, and they make it easier to change the prices in an entire store within minutes (Bandoim 2018). Kroger[38] has already started to use EDGE, a cloud-based display solution for shelves. Kroger EDGE displays prices, advertisements, nutritional data, coupons and videos. A person who is standing in front of a milk display can read nutritional information among different brands and he can get a flashing coupon that he scans with the smartphone.

Figure 90 - Example of a smart shelf with electronic labels in a Kroger store. (Source: Bill Briggs, "Kroger's smart shelves ditch the paper, drop the lights and delight the shoppers", 25/06/2018)

[38] Kroger is the United States' largest supermarket chain by revenue, the second-largest general retailer and the seventeenth largest company in the United States.

Smart shelves can be used also for providing a personalized shopping experience, thanks to their interaction via apps with the customer's smartphone. Sensors installed in the shelves can tell when someone is approaching them, so they can show him a deal on the same bread he bought last week. Additionally, if a client uses a store's app to create a shopping list, the smart shelves can interact with the list and display where to find the items that the customer put in the list. These features lead to privacy and data collection concerns, but despite that, there are people who may decide to share their personal information and purchase history to obtain special offers and experiment a smarter shopping experience.

An example of a product present on the market is WiseShelf, a technology offering the following features (WiseShelf n.d.):

- **Real time alerts**: WiseShelf system prevents 'out of stock' situations by alerting when stock level gets low or critical;
- **Visual Planogram presentation**: a row of LED lights on the front of the shelf creates a visual on-shelf presentation of the planogram (electronic labels);
- **Analytics and insights**: the system analyses the data that has been collected from the shelves and produces business insights, useful for the retailer;
- **WiseShelf app**: the smart app associated with the shelves provides both real time status information and analytic data;
- **On-shelf position control**: sensors on the shelves detect the location of products to avoid bad positioning;
- **Hot product alert**: this feature helps prepare to replenish the stock of products that have high demand.

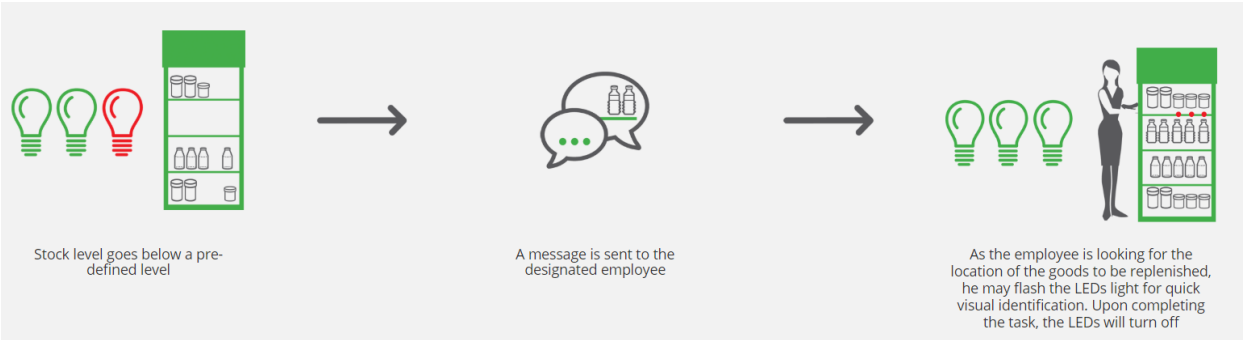


Figure 91 - Example of a stock replenishment scenario. (Source: https://www.wiseshelf.com/)

The implementation of this system offers several benefits:

- **Increase revenues per meter**: the retailer does not have to wonder whether a product is running out, because WiseShelf keeps him constantly updated;
- **Save on manpower**: the use of this technology allows to achieve perfect efficiency in products replenishment;
- **Increase Customers' satisfaction**;
- **Better planning**: both retailers and suppliers can use the system's insights to perfectly plan ahead;
- **Improving the business**: the data collected from the shelves can be used by anyone in the organization who may use this accurate information for their needs

The smart shelves offer the opportunity to make smart the management of the inventory, which is a phase of the supply chain that costs a lot and requires time and work force.

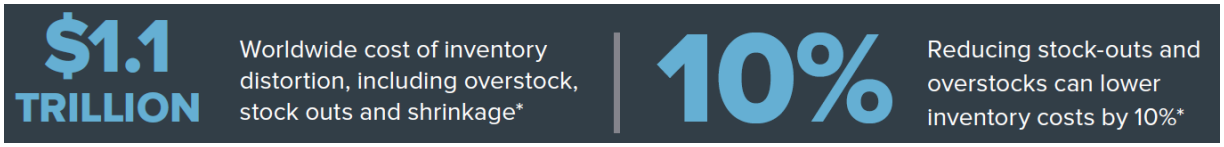


Figure 92 - The costs of inventory. (Source: Zebra, "Reinventing retail: 2017 Retail vision study", 2017)

Merchants surveyed by Zebra for their report are investing heavily in reinventing the supply chain, with a focus on tracking the status of inventory for sale. The most diffuse technologies in which retailers plan to invest by 2021 are alert of stock outs, video monitoring of inventory, product locators, item-level RFID sensors, automated inventory verification and sensors on shelves.

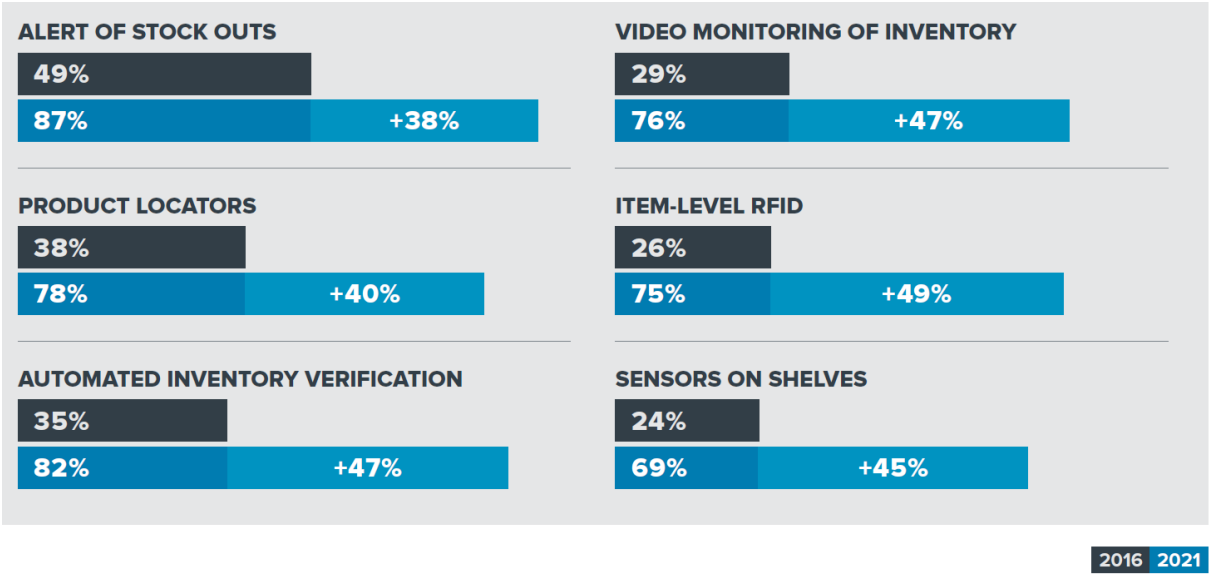


Figure 93 - Plans of retailer for the automation of the inventory process. (Source: Zebra, "Reinventing retail: 2017 Retail vision study", 2017)

2.5.7 Smart residential buildings

In 2015, the worldwide market for smart home services was estimated at $25.38 billion (Markets and Markets 2016). In the last years, it is growing in a very fast way, and it is predicted to expand to $56.18 billion in 2020 with a 17.2% compound annual growth rate from 2015 to 2020.

Because of this exponential growth of the market, it is necessary to focus on what a Smart Home is, and which are the drivers that are leading towards the diffusion of smart technologies inside residential buildings.

From the literature related to this topic, it is possible to find several definitions of a Smart Home, each one addressing a different theme. As for the Smart Building definitions, there is not a right definition, nor a wrong one; it is important to present many of them in order to clarify which are the main topic proposed by researchers, and to have a clear and wide vision of such a delicate and complex issue.

"The smart home is a residential-based platform that uses IoT, computer technology, control technology, image display technology and communication technology to connect various facilities through the network to meet the automation requirements of the entire system and provide more convenient control and management" (Li, et al. 2018). The first relevant feature to address is the one related to the technology; a home is defined smart when it includes technology on which automated systems are based. The goal of this use of technology is an easier and smarter management of different elements inside the house. Another topic to be considered is the one of the network: many Smart Home definitions include the idea of an interconnected system that offers the possibility of controlling all the smart devices present in the house.

"Smart homes are residential buildings, which are equipped with intelligent sensors, lights, heaters and electronic devices based on the anticipated needs of its residents to increase the comfort, entertainment and security" (Hoffman and Novak 2016). The three main themes addressed in the definition proposed by Hoffman and Novak are comfort, entertainment and security of users; also

in the Smart Home field, the centrality of people and their needs is one of the predominant issue, and many technologies are designed in order to provide a better experience to who is living inside the house. *"Smart home services are a set of technologies that provide human-oriented networking environments for connecting equipment and applications in the house"* (Park, et al. 2017): this definition incudes the two fundamental concept of the human-oriented technologies and the connection among the smart devices of the house.

Another recurrent topic when dealing with Smart Home features is the automation: "*The Home becomes "intelligent" when it offers a wide array of new applications from home automation (home security, comfort and entertainment), home cloud (management of content, productivity, sensors data used or produced at home), and e-Health services*" (Levy, et al. 2012). Home automation refers to the centralization on a unique user interface of the main home systems: home security, home energy and utility management, home motorization (remote control of devices such as alarm systems or thermostats), lighting and entertainment. Arthur D. Little forecasts a 6% annual growth rate for the services linked to home automation by 2020 (Levy, et al. 2012).

The last widespread issue when dealing with characterization of a Smart Home is the one related with energy efficiency: *"Smart homes are seen as an integral part of a future energy efficient system, helping to reduce overall demand as well as alleviating supply constraints during periods of peak load"* (Wilson, Hargreaves and Hauxwell-Baldwin 2017). As for all the other building typologies, the sustainability was the focus between 2010 and 2017, and it is still an issue that must be addressed when designing a building, including a residential one.

For what regards the drivers of the market growth, Arthur D Little[39] published in 2012 a report entitled "Catching the smart home opportunity", in which they analysed the Smart Home field, the main actors, trends and opportunities. The report underlines how has changed the way in which people live starting from the beginning of the twenty-first century, because of three main trends:

- **Societal trends**: society is ageing, and in 2020 a fifth of the European population will be over 65 years old; moreover, single parent families are expected to represent 21 % of total families. These factors are increasing demand for new services in the home.
- **Digital addiction**: in January 2019, 4.4 billion people were active internet users and 3.5 billion were social media users (Trifonova 2019) . This development is a strong enabler for Smart Home applications as portable devices (like smartphone and tablet) are the perfect controllers for smart applications in the home.

[39] Arthur D Little is an international management-consulting firm originally headquartered in Boston (USA).

- **Strong push by large players positioning homes at the centre of the digital ecosystem**: a wide range of leading players is entering the Smart Home market, including top players such as Google and Microsoft, offering applications and operating systems. With them, also other actors are becoming interested in the Smart Home field: telecom and utility service providers (such as Telefonica, E.ON and GDF Suez) and appliance manufacturers (such as Philips, and LG with the LG Homnet) providing Smart Home devices.

In Europe, energy, cost savings, security and convenience are some of the major drivers of the smart home market; moreover, insurance company are pushing towards the adoption of smart technologies inside the houses. They are thinking to provide advantages to people who decide to install smart home services like leakage detection and humidity sensing, because water leak is one of the biggest costs for insurance companies (Neale, et al. 2018).

Being the residential sector so particular, because of the high impact on the personal desires and needs, it is useful to analyse which are the factors affecting in a positive way the adoption of smart technologies and which are the main perceived risk. A research developed by Herie Park and Sang-Bong Rhee in 2018 demonstrated that the perceived compatibility, connectedness, control, system reliability, and enjoyment of smart home services are positively related to the users' intention to implement the services inside their home, whereas there is a negative association between the perceived cost and usage intention (Park and Rhee 2018).

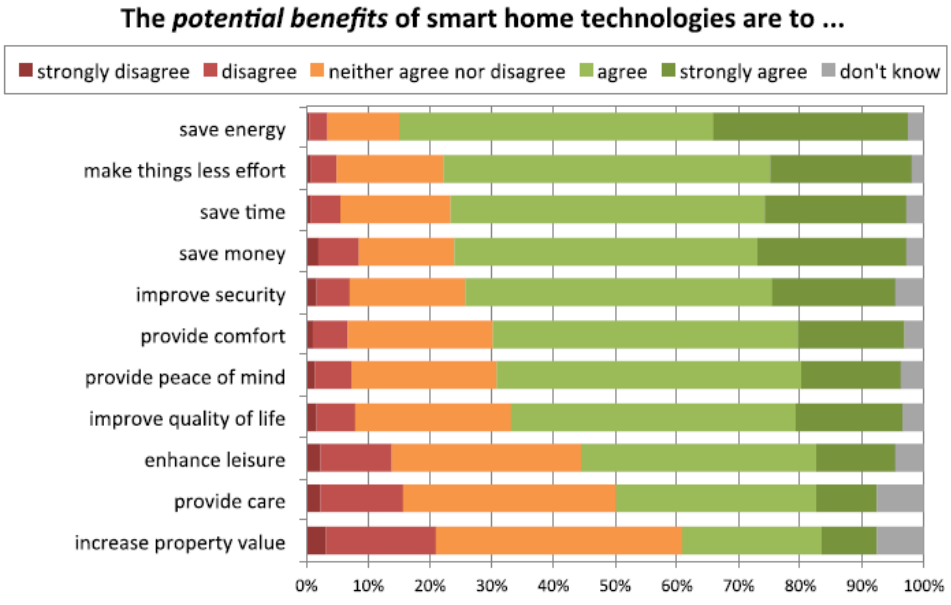


Figure 94 - Users' perception of the potential benefits of Smart Home technologies. (Source: Charlie Wilson, Tom Hargreaves, Richard Hauxwell-Baldwin, "Benefits and risks of smart home technologies", 2017)

When investigating in the literature related to the Smart Home issue, it emerges that the most cited benefits are savings in energy, effort, time, and money. This is in accordance with the results

obtained by Charlie Wilson, Tom Hargreaves and Richard Hauxwell-Baldwin in theirs research "Benefits and risks of smart home technologies": the graph shows that energy, time and money saving , together with a lower effort, are the most appreciated benefits offered by Smart Home technologies.

The adoption decision may not only be influenced by the usefulness of the technology, but customers may also perceive the technology to be particularly risky (Hubert, et al. 2018).

One big concern for people, which dis-encourage the implementation of new technologies, inside houses are the risk associated with privacy loss. Users are worries about losing control over personal information when using smart homes and about illegal access by third parties to the system. Moreover, people are often worried that the new systems do not work the way they are supposed to.

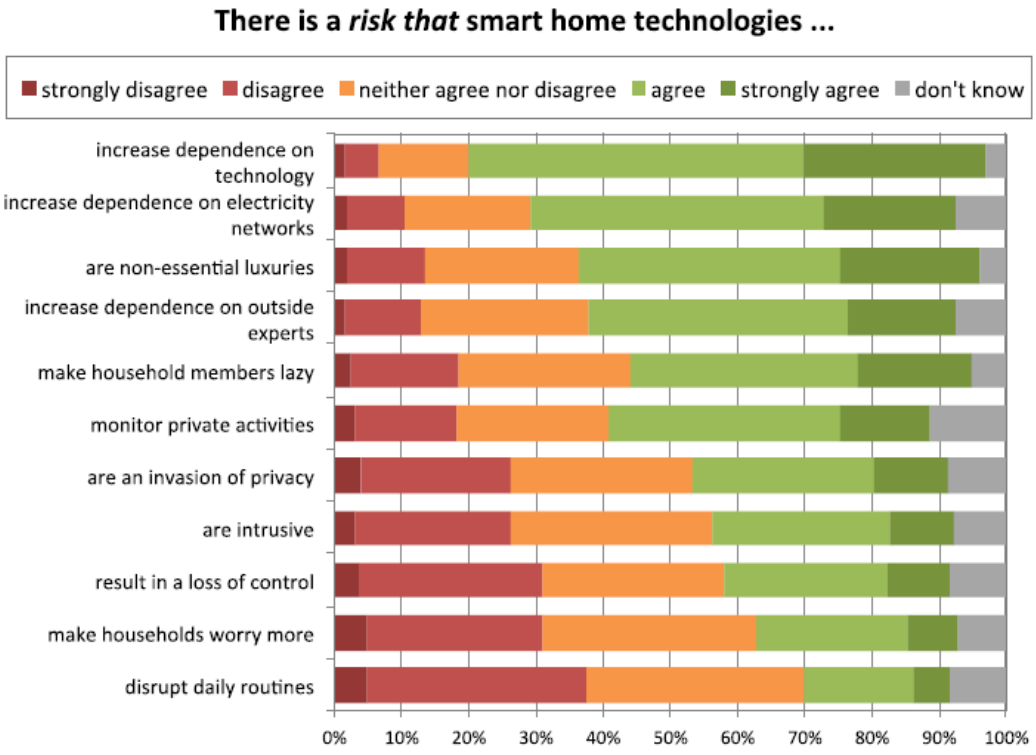


Figure 95 - Users' perception of the potential risks of Smart Home technologies. (Source: Charlie Wilson, Tom Hargreaves, Richard Hauxwell-Baldwin, "Benefits and risks of smart home technologies", 2017)

Another factor that may dis-encourage people in the adoption of smart devices for their home is the increased dependence on technology that they imply. In addition, the dependency to the electricity network is a disincentive according to users. The privacy issue and the intrusiveness of the new technologies is a perceived risk, but at the same time, almost an equal percentage of respondent

feels that this is not one of the main issue for which to be aware. 35% of interviewed people says that the invasion of privacy is a problem, but at the same time, 30% of them feels that it is not.

All the possible risks associated to the use of smart technologies can be summarized in three categories:

1) **Security risk**: it refers to the possibility of losing control of personal information (this also includes potential illegal system access from third parties that would cause to fraudulent or criminal activities in and around the house) (Yang, Lee and Zo 2017).
2) **Performance-based risk**: it refers to the possibility that the system is does not work the way it is supposed to and therefore does not provide the originally promised advantages (Featherman and Pavlou 2003).
3) **Time risk**: it refers to time loss caused by considerable effort in the decision to purchase, install or repair the system (Hubert, et al. 2018).

In terms of function, people expect that smart technologies enable them to better control their home and have information about the systems' operations. For what regards the way in which the smart devices operate, there are people who expect them to be always active, and who prefer to use devices that operate only when activated. Finally, it is preferable for users that Smart Home technologies blend into the background and are not easily noticeable (Wilson, Hargreaves and Hauxwell-Baldwin 2017)

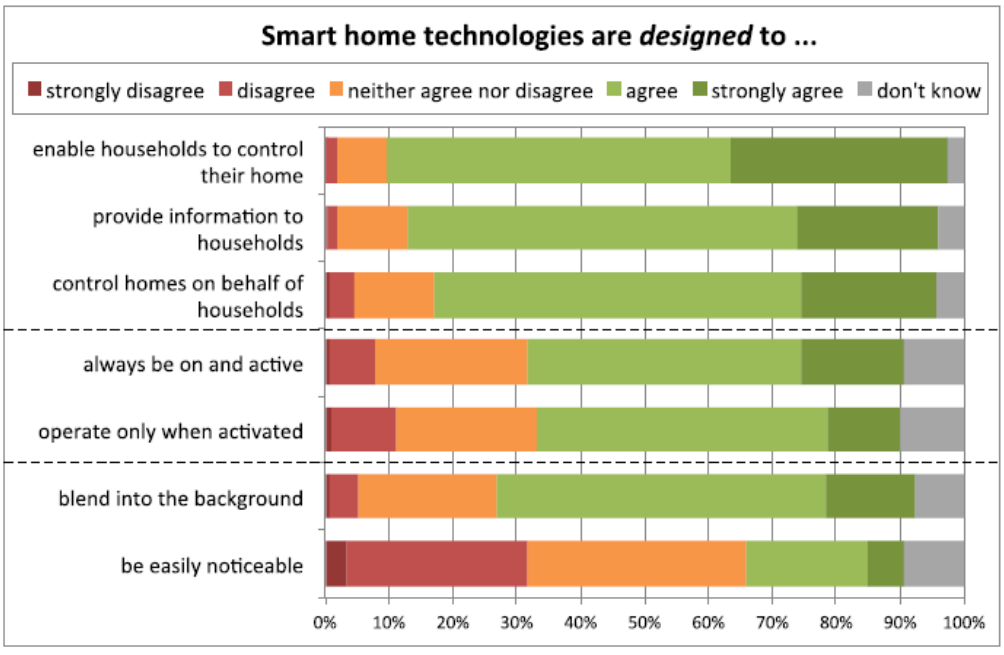


Figure 96 - Users' perception about how Smart Home technologies should work. (Source: Charlie Wilson, Tom Hargreaves, Richard Hauxwell-Baldwin, "Benefits and risks of smart home technologies", 2017)

2.5.7.1 The new technologies for the Smart Home

The new technologies that is possible to implement inside a Smart Home are compliant with the Smart Home definitions, people expectations and fears. The peculiarity of Smart Homes, with respect with the other building typologies, is that the majority of the new technologies are devices inserted inside the living space, and not systems implemented in the building in itself. Moreover, people who nowadays are interested of a smart office, or in the services offered by a smart hospital, are still reticent in introducing inside their homes any kind of smart devices. This is because new technologies for homes are perceived slightly intrusive and privacy-compromising.

The other side of the coin is represented by the several possibilities offered by smart devices inside homes. Reduction of energy consumptions and of electricity bills, simplification of everyday activity, enhancement of comfort and improvement of health conditions.

The determinant for the Smart Homes field will be represented by the position that users will take in the next years: if they will decide to fully embrace the opportunities offered by smart devices, Smart Homes will become the new place where to live; otherwise, people will continue to stay in traditional houses away from new technologies.

One major benefit of smart products is the potential to support energy reductions, and this can help in delivering cost savings on energy bills. The technologies related to the energy optimisation are named Home Energy Management (HEM) technologies, and they are defined as "*those that enable households to more actively manage their energy consumption by providing information about how they use energy in the home or to prompt them to modify their consumption, and/or providing the household (or third parties) the ability to control energy consuming processes in the home*" (Karlin, et al. 2015).

Load Monitors and In-Home displays

Load monitors are hardware only devices and they do not have a corresponding cloud-based platform or web-based energy portal. Users plug an appliance into the load monitor's outlet, which measures and displays several information under numerical format: power, energy, cost, carbon emission, current and voltage (Ford, et al. 2017).

Through the provision of energy feedback information, load monitors support users in learning about the energy demands of individual appliances. Moreover, since they are portable objects, users can

move the load monitor from appliance to appliance and be aware about the single impact of all the appliances on final consumption and electricity bills.

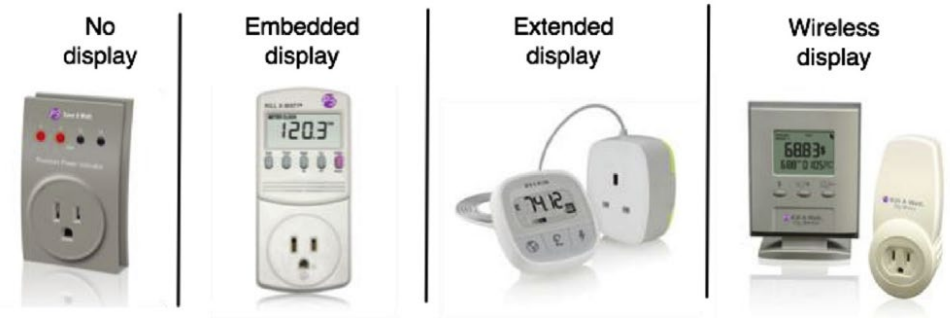


Figure 97 - Differences between load monitor hardware. (Source: Ford, et al. "Categories and functionality of smart home technology for energy management, 2017)

There are many types of load monitors: without display, with an extended embedded display and with a wireless display. Of course, the wireless solution is the most practical one, though which is extremely easy to connect the load monitor from an appliance to another.

More advanced systems offer the possibility to be simultaneously connected to several appliances, and to send directly on the smartphone all the data related to the single objects. An example is Sense, a load monitor designed to be simple to use and to install.

Figure 98 - Interface of Sense app on the smartphone. (Source: https://sense.com/)

Sense offers the possibility of tracking energy use over time, set a goal in terms of consumption and monitor the progress through the month, in order to be sure to stay under the limit that has been imposed. It is possible also to identify sources of energy waste and to set device level notifications, to be always informed about which appliances are working and for how long.

Smart thermostat

Smart thermostats are based on the principle of programmable thermostats, which incorporate on-board schedules whereby users can set time instant of activation/deactivation together with different set point temperatures, enabling energy savings by reducing heating and cooling loads at times of the day when it is not needed. Smart thermostats go beyond this, using a communications protocol so that users can view and adjust their settings remotely via a compatible smartphone app or website (Ford, et al. 2017). Another characteristic of smart thermostats is the presence of sensors, monitoring not only temperature, which is typical of all thermostats, but also humidity, occupancy, light level and outdoor weather.

The presence of additional sensors, like the one detecting the presence of people, can provoke a reaction in the thermostat; for instance, when the house is unoccupied the thermostat can revert to "away" mode, using energy-savings set points.

The main benefits from smart thermostats is the ability to remotely control temperature set points and modes (heat, cool, auto, off) via app or website. Moreover, smart thermostats enable users to set what is called a rule based control: the thermostat is set in a way that changing if rooms become unoccupied, if energy costs increase, if the weather forecast changes, or if people are coming home, the temperature set point is changed and adjusted according to the different situations.

Figure 99 - EcoBee smart thermostat. (Source: https://www.ecobee.com/en-us/smart-thermostat-voice/)

Many market analyses published in the first half of 2019 identified EcoBee smart thermostat as the best one for 2019. A great innovation is the integration of other smart technologies like the ones enabled by voice control within the thermostat itself. With Alexa and the latest in far-field voice

technology built-in, users can change the temperature, call friends, play music, and control other smart devices only with their voice.

The system includes the possibility of adding up to 32 sensors in different rooms, in order to optimize the functionality of the thermostat. These sensors, with the element in Figure 103, detect temperature level and people presence.

Another feature offered by EcoBee, but that is present in many other smart thermostats, is the possibility to choose among different operational modes:

- **Smart Home/Away**: when occupancy sensor detects the presence of people in the house, temperature is adjusted automatically for comfort, and vice versa for energy saving when none is at home.
- **Follow Me mode**: the occupancy sensors of smart thermostat detect which rooms are in use and adjust the home temperature accordingly for comfort in those rooms. Over time, Ecobee learns family's occupancy habits and automatically adjusts the temperature for smarter comfort and further savings.
- **Smart recovery**: with this feature enabled, the thermostat uses local weather information, occupancy habits, and an ongoing analysis of the HVAC system's heating and cooling patterns so that it's always the right temperature at the right time, without unnecessary consumptions.
- **Thermal protect**: thanks to this mode, it is possible to keep home comfortable and prevent HVAC system from excessive runtime. With it enabled, Ecobee thermostat will ignore a sensor when its readings diverge from those of other sensors beyond a certain customizable limit. (This can sometimes happen when a sensor is placed in a room that tends to get hotter (e.g. attic) or cooler (e.g. the basement) than the rest of the home.)

Advanced smart thermostats provide report about consumptions and, by monitoring heating and cooling equipment operations, let the user know when they need maintenance. Thanks to all the above-mentioned features, a smart thermostat like EcoBee allows to save up to 23% in annual energy cost (Ecobee 2018).

Smart Plugs 

Smart plugs operate in a way that is similar to the one of Load monitors: if connected to any appliance of the house, they allow to control it remotely and to monitor its consumptions and operations. There are many different models on the market, with all some common features:

- **Wi-Fi connected**: all smart plugs are connected to the Wi-Fi system of the house, so that they can be remotely controlled via smartphone.
- **Physical button**: they also have a button through which they can be turned on or off.
- **Programmable**: smart plugs, and with them the connected appliances, can be programmed by using the app on the smartphone.
- **Monitoring**: the devices connected to the smart plugs can be monitored in terms of consumptions, and it is possible to obtain information about eventual energy savings.
- **IFTTT[40] support**: with this technology is possible to give orders to a smart plug to do a certain action as a consequence of another action. For example, the app recognises the smartphone localization, and it is possible to program the turning-on or off of a certain device in accordance with the position of the smartphone (and so of the user).
- **Smart Home Hub**: smart plugs can work together with other smart systems like Google Home, Amazon Echo, Samsung SmartThing and so on. It is possible, in this way, to exploit smart plugs by using vocal command.

They can be used for different items present in the house: for the lighting system, by setting then turn on and off all the lights; for the household appliances, that can be turned on or off also when none is at home, and for the systems, which operations can be regulated remotely if they are connected to a smart plug.

An example of smart plug is Kasa Smart Plug Mini, considered one of the best smart home devices for 2019 (R. Brown 2019). This smart plug by Kasa allow controlling all the devices connected to it from anywhere, by using the Kasa Smart App. It works in integration with devices like Amazon Echo or Google home, thanks to the voice control, through which it is possible to turn on and off the appliances. Another advantage is that smart plugs like Kasa Smat Plug Mini work with a secured 2.4GHz wireless network, without the need for a separate hub. The use the Grouping feature on the Kasa Smart app allow to combine several devices together for unified control, with a tap on the

[40] If This Then That, also known as IFTTT is a free web-based service to create chains of simple conditional statements, called applets. In addition to the web-based application, the service runs on iOS and Android.

smartphone. For example, living room bulbs, plugs and light may be combined and switched together, for an easier way to turn them on or off when it is necessary.

Figure 100 - Examples of how Kasa Smart Plug Mini works. (Source: https://www.kasasmart.com/us/products/smart-plugs/kasa-smart-wifi-plug-mini)

The evidences about the benefits that the use of smart plugs generate can be found in real situations. If the microwave or the oven are connected to a smart plug, before going to work the user can insert what he wants to eat for dinner and then, once he finished to work, it is enough to activate the appliance so that the meal will be ready when he gets home. Another useful application is for regulating the on and off of TV and consoles for children: to avoid that they stay for a too long-time watching TV or playing a videogame, it is enough to manage the activity of these devices remotely from the smartphone. When devices are connected to a smart plug, their battery-charge can be controlled remotely, so that when the user arrives at home after work, everything is ready to be used.

Smart Speaker

The greatest innovation in the world of technologies for the Smart Home are the Smart Speaker. A smart speaker is a type of wireless speaker and voice command device with an integrated virtual assistant that offers interactive actions and hands-free activation with the help of voice command. Some smart speakers are integrated with other systems and they utilizes Wi-Fi, Bluetooth and other wireless protocol standards to control home automation devices.

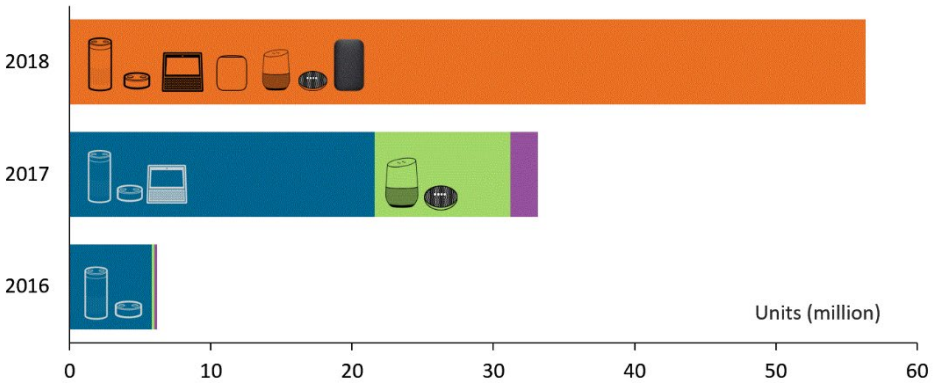


Figure 101 - Forecast for Smart Speakers' market in 2018. (Source: Canalys estimates and forecasts, "Smart Speaker Analysis", December 2017)

According to a research developed by Canalys[41] in 2018, Smart Speakers are the electronic device with the fastest growth in the last couple of years. They expected that in 2018 there would have been 56.3 million of smart speakers sold (in 2017 35 millions of items have been sold and, in 2016, "only" 5 millions) (Canalys 2018).

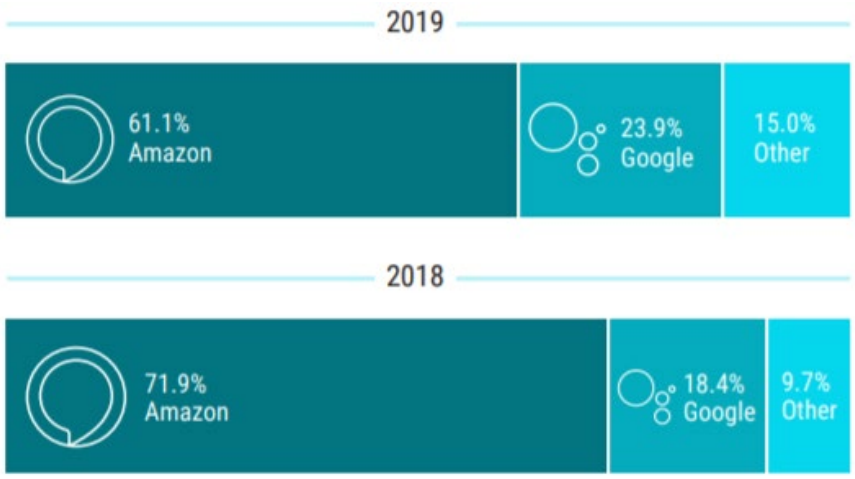


Figure 102: U.S. Smart Speaker Market Share by Brand January 2018 & 2019. (Source: Voicebot, "Smart Speaker Consumer Adoption Report", January 2019)

[41] Canalys is a research institution founded in 1998. Nowadays, it has headquarters in USA, UK, India, Singapore and China.

As Figure 104 shows, Amazon is the leader of this sector, controlling 61.1% of the worldwide 2019 market, with 41.7 million of speakers Echo delivered in 2019. The second place is occupied by Google, with 24% of the market controlled and 11.5 million of devices that have been sold (Licata 2019) (Kinsella and Mutchler 2019). Nowadays, researches have demonstrated that in more than 60 million of houses all over the world, it is present at least one smart speaker device.

What is encouraging when looking at the statistics related to the smart speaker market is that when someone own a smart speaker, he is fostered at buying another one, to be placed somewhere else in the house.

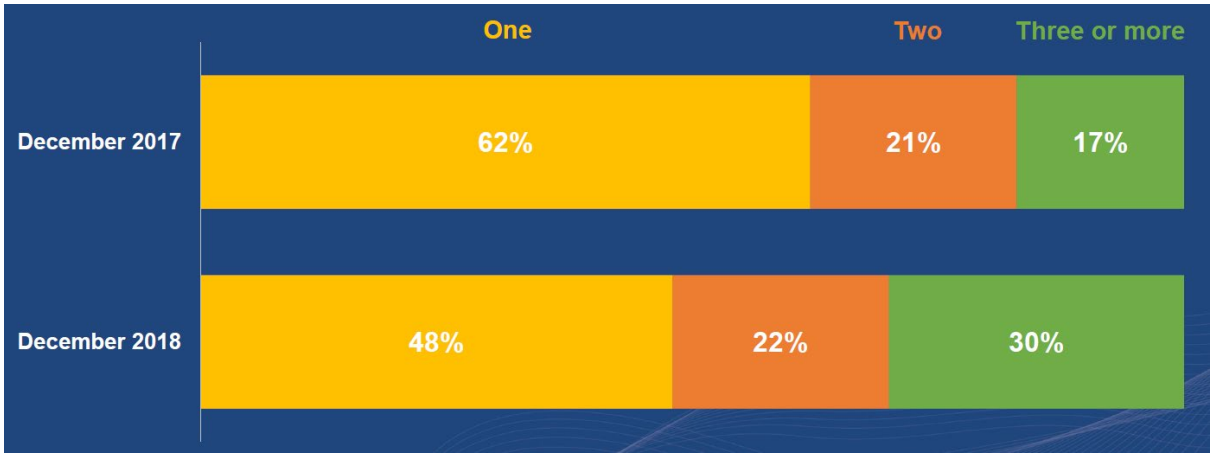


Figure 103 - Answers to the question "How many smart speakers do you own". (Source: NPR, Edison research, "The smart audio report", 2019)

Moreover, also the rate of growth of this technology is incredibly fast: if it was expected for 2018 to sell 56.3 million of devices, the actual number of smart speaker delivered in that year was 118.5 million, with an increase of 78% with respect to 2017 (National Public media 2019).

The main function of a smart speaker is to carry out a certain action after a vocal command performed by the user. For example, they can call someone whose number is present in the list of contacts, they can read emails and the results of a web research, and they can play music and interact with other smart devices present in the home if they are connected one with the other. For example, is a smart lighting system is present, it is enough to say to the smart speaker "turn on/off the lights" that the command is immediately performed.

Many of these functions can be performed everywhere, not only at home (having a Wi-Fi connection available); 64% of smart speaker owners are interested in having Smart Speaker technology in their car (National Public Media 2017).

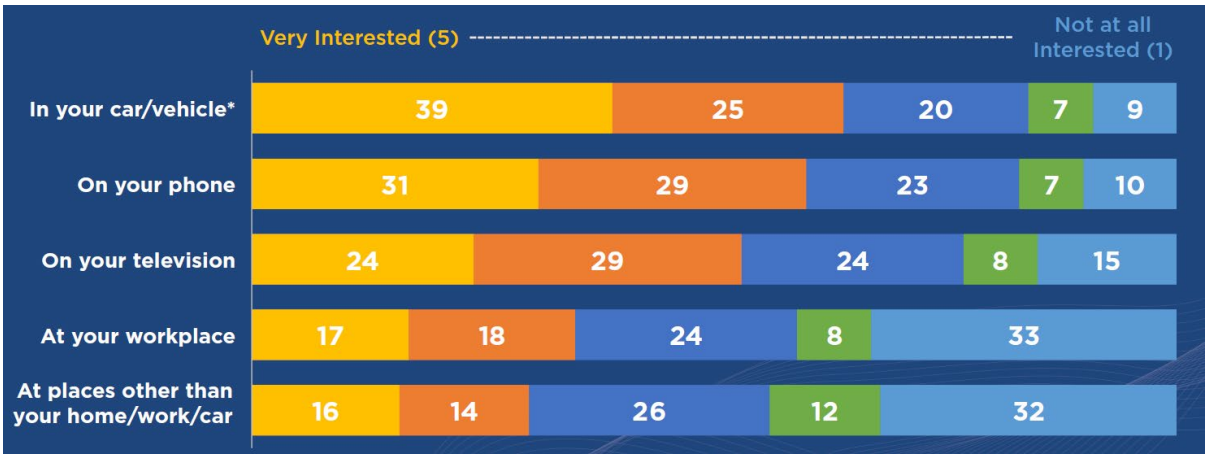


Figure 104 - Answers to the question "How interested would you be in having the Smart speaker technology…". (Source: NPR, Edison research, "The smart audio report", 2019)

There are functions not yet implemented, but that people would like to have in the new smart speakers. Among the respondents to the survey performed by National Public Media, 55% expressed interest in having a feature that would allow their smart speaker to call 911 if multiple smoke alarms went off in the home. Moreover, 24% expressed interest in having a smart speaker feature that would recommend mental health resources if it detects they are feeling depressed (National Public media 2019).

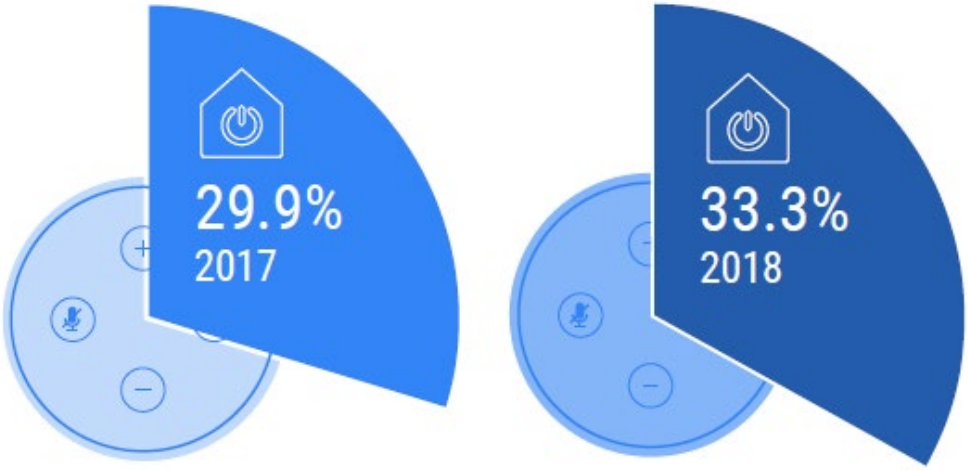


Figure 105: Monthly Active U.S. Smart Home Users on Smart Speakers. (Source: Voicebot, "Smart Speaker Consumer Adoption Report", January 2019)

One of the use cases of a smart speaker is for controlling Smart Home devices. Smart home use cases increased considerably between 2018 and 2019. In 2018, it was the fourteenth most common use case and it rose to ninth in 2019. Over 45% of smart speaker owners have used them to control smart home devices up from only 38% in 2018. More than 55% of smart speaker owners say they have at least one smart home device that they control by voice, and the most diffused devices are Smart TV (33.3%), smart lights (21.2%), Smart media controller, game console or cable box

(14.4%), Smart Thermostat (12.4%), Video doorbell (12.5%) and Smart cameras (6.2%) (Kinsella and Mutchler 2019).

Together with benefits, the use of these smart devices may generate problems. The most perceived issue by the user, and the main cause of not buying a smart speaker, is the privacy concern. Because of the presence of a microphone, people feel controlled by the object itself, and prefer not to use it. Moreover, many customers worry that hackers could be using their smart speaker to get access to their home or personal information. Companies are trying to answer to these people concerns, by ensuring them that smart speakers are actually safe and privacy preserving. Among interviewed people by National Public Media, 54% trust the companies that produce smart speakers to keep their personal information secure (National Public media 2019).

More detailed numbers are provided in the report about smart speakers by Voicebot[42] and Vocify[43]: according to their results, fears related to privacy do not seem to be undermining adoption, but it emerged that two-thirds of consumers express at least some privacy concerns and 26% are very concerned.

An interesting result from Voicebot survey is that the privacy concerns for the owners of a smart speaker and those that do not own one are nearly identical: only 27.7% of consumers without smart speakers said they were very concerned about privacy issues compared to 21.9% of device owners. This means that consumers with privacy concerns decided to buy smart speakers, despite their fears. However, the privacy issue remains the main deterrent for those who do not own a smart speaker.

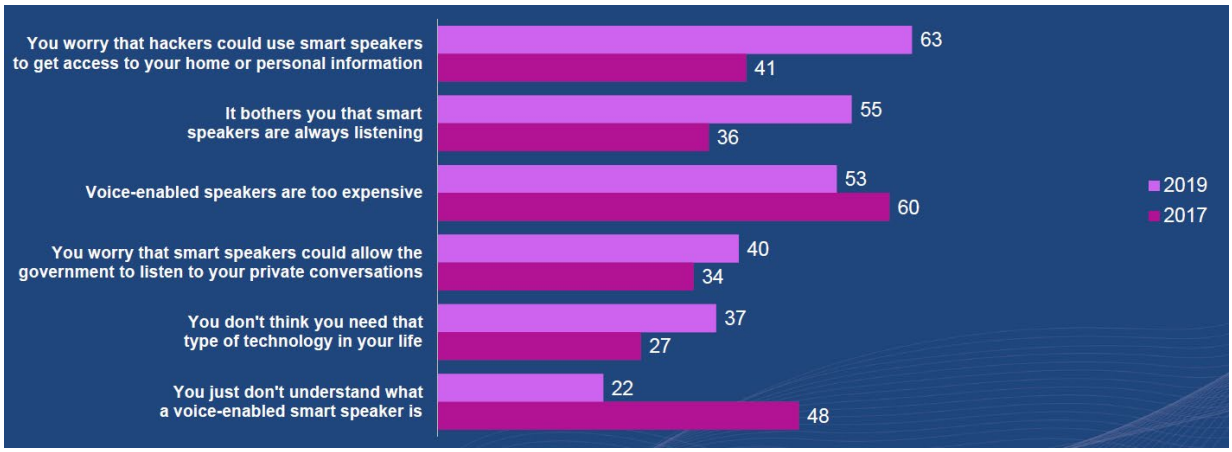


Figure 106 - Answer to the question: "Is this reason why you do not currently own a smart speaker?". (Source: NPR, Edison research, "The smart audio report", 2019)

[42] Research Company whose goal is to gather in one place the most important news, commentary, research and analysis of voice technology.

[43] The Voicify Conversation Experience Platform provides brands and organizations with the ability to create engaging convesation-based applications to be used with Amazon Alexa, Google Assistant, Microsoft Cortana, chatbots, and other devices.

From a social perspective, it has been demonstrated that a smart speaker is often used also when guests are presents; 66% of smart speaker owners use it to entertain friends and family (National Public Media 2017). The most required function when other people are present is to play music, followed by answering at general questions and listen to the weather forecasts.

For what regards products present on the market, the two most sold and appreciated are Amazon Echo and Google home. Their functions almost the same, already described in previous paragraph.

Figure 107 - Amazon Echo Dot and Google Home. (Source: Google Image search)

Smart Display

A smart speaker with a touchscreen is known as a smart display. They are similar to tablet computers, but smart displays differ in their emphasis on a hands-free user interface and virtual assistant features.

Consumers are attracted by the combination audio-video that they offer, and they represented 10% of the smart home devices demand at the end of 2018 (Licata 2019).

Voicebot survey data indicate about 2.8% of smart speaker owners also had a smart display in January 2018. By late May that figure had risen to about 5.9% and it rose again to 7.1% in early September. In the last trimester of 2018, smart displays were owned by 13.2% of smart speaker owners, a 558% growth rate in total installed base, from about 1.3 million in 2017 to 8.7 million in 2018 (Kinsella and Mutchler 2019). Multiple factors are behind this growth: in the first months of 2018, Amazon frequently offered heavy discounts on its smart displays, before the launch of a second generation display in September and because they were expecting the arrival on the market of competitive products. In fact, Google Assistant enabled smart displays have been announced in July and August.

In terms of functions, they are almost identical to the ones of smart speakers: like smart speakers, the user can speak to a smart display, which is powered by one of the common voice assistants (Amazon Alexa or Google Assistant). He can ask it to play music, read a receipt or information about weather forecast. As smart speaker, also smart displays can be connected to other smart devices of the house that are then controlled with vocal commands.

Figure 108 - Amazon Echo 2nd generation and Google Nest Hub (Source: https://mashable.com/review/amazon-echo-show-second-generation/ and https://mobilesyrup.com/2019/08/02/google-nest-hub-cast/)

2.6 The potential issues of Smart Buildings technologies

Until this point, the attention was on all the positive aspects and advantages of the Smart Building technologies. It emerged that for different functions, there are different smart devices that improve the quality of the everyday life and actions of the users, and thanks to that, the Smart Buildings are becoming more and more attractive on the market. However, "*The more Smart Buildings rely on new technologies, the greater the associated risks"* (Aon (The One Brief) 2017).

Many researches are demonstrating that the tendency of the building sector is to have every day a greater number of buildings defined smart. One of the proofs is that the smart building market is projected to grow from USD 5.71 Billion in 2016 to USD 31.74 Billion by 2022, at a Compound Annual Growth Rate (CAGR) of 33.7% during the period 2017–2022 (Markets and Markets 2017). A recent Deloitte Center for Financial Services study examined connectivity in commercial real estate and the researchers found that sensor deployment in the sector is likely to grow at a compound annual growth rate of 78.8 % from 2015 to 2020, reaching nearly 1.3 billion sensors (Kejriwal and Mahajan 2016). However, this diffusion of sensors and connected elements has its drawbacks: *"As buildings become ever more interconnected, the number of entry points for would-be hackers is only set to increase"* said Stefan Toi, Senior Broker at Aon[44]. The technology that is bringing great benefits to building owners and occupants also provides points of entry to hackers, and this is an aspect that must be considered during the design and the use of a Smart Building.

If, on one side, the smart systems installed in a building make it more attractive on the market, at the same time the fact that it may be exposed to cyber-attack is one of the factors reducing its value. In the same way that security breaches of customer information in banking or retail can affect sales and profits, cyber-attacks on vulnerable buildings could (in theory) reduce property values (Aon (The One Brief) 2017).

The greatest challenge of the risk management system of a Smart building is to keep it updated: "*The rapid development of smart building technology coupled with the ever-evolving nature of cyber threats makes it difficult to maintain a responsive and relevant risk management framework,"* said Andrew Mahony, Regional Director of Asia region, Aon. Smart technologies are developing in a very fast way, and for this reason, the way in which buildings are protected must be aligned with this transformation. As reliance on automation and connectivity grows, building owners and managers should consider more frequent cyber risk reviews.

[44] Aon is a leading global professional services firm providing a broad range of risk, retirement and health solutions.

Research and experience have shown that when things are connected to the Internet, they become a target for malicious hackers. As a result, it is imperative that smart building operators make security a priority (Phillips 2019).

Security does not mean only the development of a security systems able to keep all the relevant data of a smart building protected from attacks; another fundamental aspect to be addressed is to train staff on the security threats and teach them about the dangers of email phishing campaigns, including how to recognise malicious emails and attachments. Negligent employees represent the most common and maybe most unexpected cyber security breach. Careless, uninformed employees contributed to 46% of cyber security incidents in the past year (Kaspersky Lab and B2B International 2017). The proper training of employees against cyber-attacks allow saving a lot of money - up to 20% of a company's total revenue (Cisco 2017).

Figure 109 – The potential threat actors and the consequences of a cyber-attack (Source: Memoori, "Cyber Security in Smart Commercial Buildings 2017 to 2021", 2017).

Memoori published a research entitled *"Cyber Security in Smart Commercial Buildings 2017 to 2021"* in which they make an objective assessment of the market for cyber security software, services and hardware in Smart Commercial Buildings. Figure 111 displays some of the results, in particular the ones related to the main attackers who may perform a cyber-attack and the consequences of it on the building and its users (Meemori research AB 2017). In most of the cases, the attackers are

competitors, activists or criminals, whose purpose is to collect precious data that are contained in the building network.

A possible goal of the attackers is to generate a disease to the building owner; an example happened in 2017, in the Austrian hotel *Romantik Seehotel Jaegerwirt* that was hit by a ransomware attack, with hackers disabling the hotel's keyless entry system and locking guests out of their rooms (Aon (The One Brief) 2017). Moreover, the cyber attackers demanded a ransom of EUR 1.500 in Bitcoin from hotel management. In this case, the attack did not provoke a loss of compromising data or of the privacy of the users, but it is a good example of all the possibilities that an external hacker may have.

Another big attack was suffered by some hotels in the United States (Intercontinental Hotels Group) which have been victims of a three-month cyber-attack that sought to steal customer payment card data.

In 2013, Target Corporation[45] fell victim to a major breach of stolen customer data. Target POS systems were compromised by a computer from Target's HVAC vendor. The stolen credentials of the HVAC vendor enabled access to Target's application dedicated to vendors. Through a series of hacking activities, the breach resulted in 40 million shopper credit and debit cards being compromised.

Considering these examples, and many others situation of the same kinds, it emerges that the incorporation of cyber security design frameworks and risk based analysis tools for building services needs to become part of the building industry professional's toolkit (Mihalic 2018). The consequence is that the cyber security industry is establishing a presence within the building sector because of the cyber-security design concerns.

For what regards the consequences of a cyber-attack, the main issue is the loss of confidential data, and other "minor" impacts may be the failure of the building systems, loss of commercial data, brand and reputational damages, loss in productivity and of customer trust (Meemori research AB 2017).

From a practical point of view, the hacker gain access to the system he wants to attack by a so-called Attack Vector: *"An attack vector is a path or means by which a hacker can gain access to a computer or network server in order to deliver a malicious outcome. Attack vectors enable hackers to exploit system vulnerabilities."* (Mihalic 2018). Attack vectors include viruses, e-mail attachments,

[45] Target Corporation is the eighth-largest retailer in the United States.

Web pages, pop-up windows, instant messages, chat rooms, and deception. There are many ways to protect against these attack vectors, but in accordance with what has been explained in this paragraph (2.6), all the defence methods must be kept updated as much as possible in order to be effective. To some extent, firewalls and anti-virus software can block attack vectors, but no protection method is totally attack-proof: a defence method that is effective today may not remain so for long.

Some key considerations about cyber security and risks related to the use of smart technologies, coming from a survey performed by CSX in 2019, are (CSX 2019):

- **Consistency reigns across threat actors and attack vectors**. Top threat actors and attack vectors remain largely consistent year over year. The top three threat actors include cybercriminals, hackers and non-malicious insiders (Figure 112).

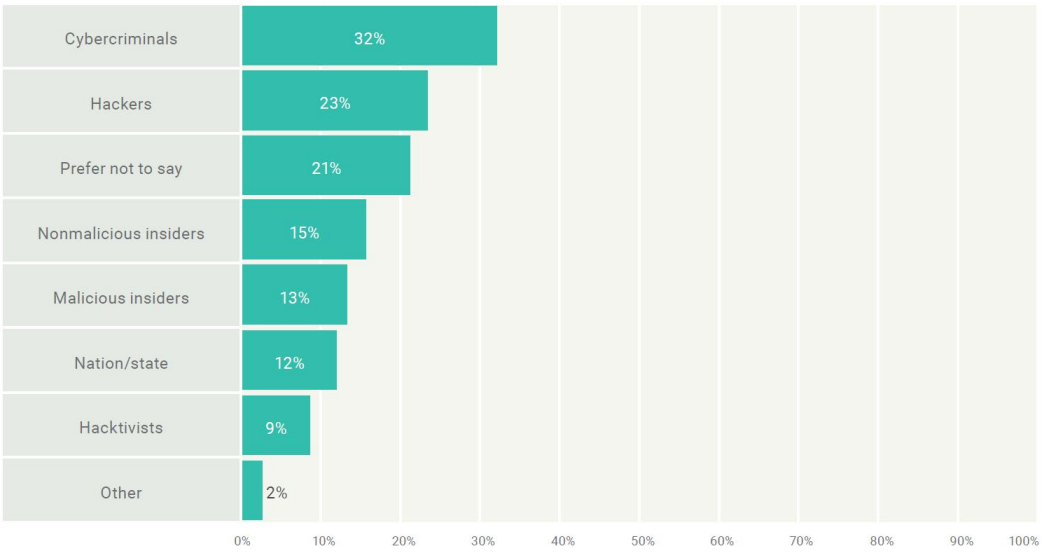


Figure 110 - Results about the threat actors who operate violations according to the interviewed companies. (Source: CSX, "State of Cyber security 2019, Part 2: Current Trends in Attacks, Awareness and Governance", 2019)

Respondents generally expect attacks to increase quantitatively in 2019; phishing[46], malware and social engineering[47] continue to top the list of prevalent attack types for the third year in a row (2017, 2018 and 2019).

[46] Phishing is the fraudulent attempt to obtain sensitive information such as usernames, passwords and credit card details by disguising oneself as a trustworthy entity in an electronic communication. Typically carried out by email spoofing or instant messaging, it often directs users to enter personal information at a fake website that matches the look and feel of the legitimate site.

[47] Social engineering is the term used for a broad range of malicious activities accomplished through human interactions. It uses psychological manipulation to trick users into making security mistakes or giving away sensitive information.

- **Expansion of attacks may be stabilizing**. While almost half of the respondents indicate that they are experiencing an increase in attacks relative to last year, a slight levelling did occur. When compared to 2018 analysis, the percentage of respondents indicating that their enterprises are experiencing more attacks decreases by four percentage points (50% in 2018, 46% in 2019), indicating that quantitative expansion of attacks may decrease.

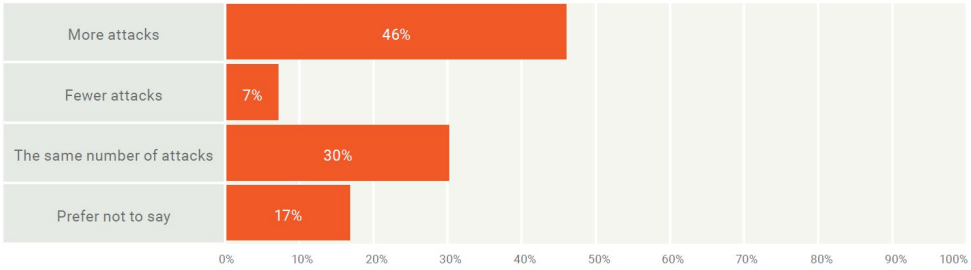


Figure 111 - Experience of respondents about the amount of attacks they have been subjected to in the last year. (Source: CSX, "State of Cyber security 2019, Part 2: Current Trends in Attacks, Awareness and Governance", 2019)

Furthermore, the percentage of respondents who indicate that they are experiencing fewer attacks compared to the prior year is up by one percentage point over 2018 results (6% in 2018, 7% in 2019). Although relatively small, these changes in the results underline that expansion in number of attacks may be stabilizing.

Despite these considerations, it is fundamental to point out that respondents' perceptions in 2018 and expectations for 2019 do not lead to conclude that the threat of cyber-attacks is diminishing.

Overall, 46 % of 2019 respondents indicate that they experienced more attacks year over year; moreover, 60 % of respondents indicate that it is either likely (26 %) or very likely (34 %) that their enterprises will experience a cyber-attack in 2020.

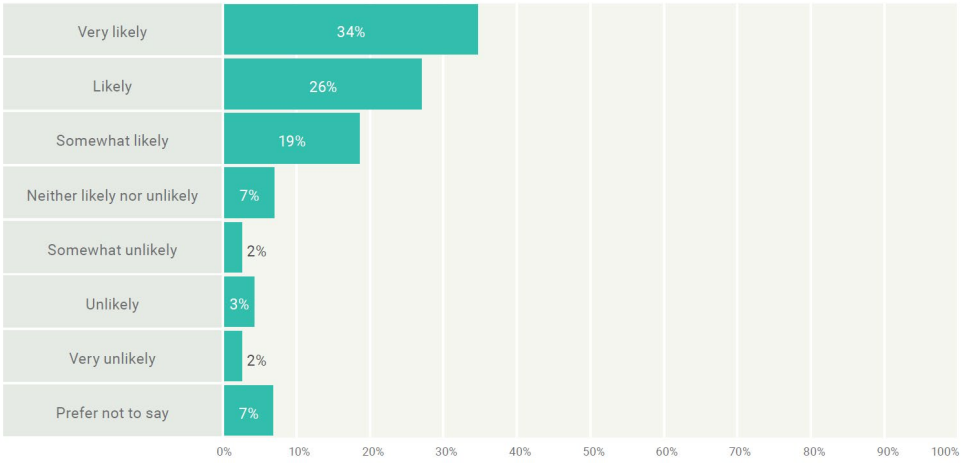


Figure 112 - Expectations of respondents about the possibility of a cyber-attack in the next year. (Source: CSX, "State of Cyber security 2019, Part 2: Current Trends in Attacks, Awareness and Governance", 2019)

- **Cybercrime may be significantly underreported**. Cybercrime is perceived as significantly underreported by survey respondents. Most respondents believe that cybercrime is consistently underreported, despite legal or regulatory requirements obligating enterprises to report such instances.

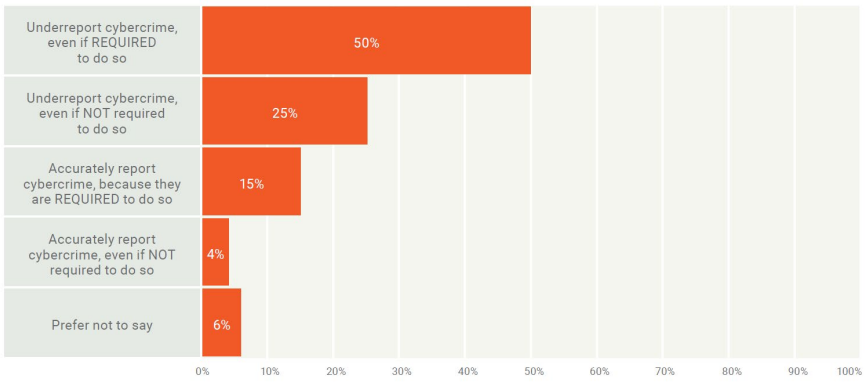


Figure 113 - According to the interviewed companies, when it comes to reporting cybercrime, most enterprises... (Source: CSX, "State of Cyber security 2019, Part 2: Current Trends in Attacks, Awareness and Governance", 2019)

- **Measuring effectiveness of security awareness programs does not drive confidence in threat mitigation**. An assessment of an anti-phishing program's effectiveness increases the confidence in the program itself, but not in the enterprise's capability to combat cyber security threats.

  Most enterprises promote awareness through internal training programs, without external input; however, while application of cyber security awareness programs is important, measuring the effectiveness of awareness programs is also key to building organizational resilience. Therefore, enterprises want to know whether their application of protective mechanisms are effective.

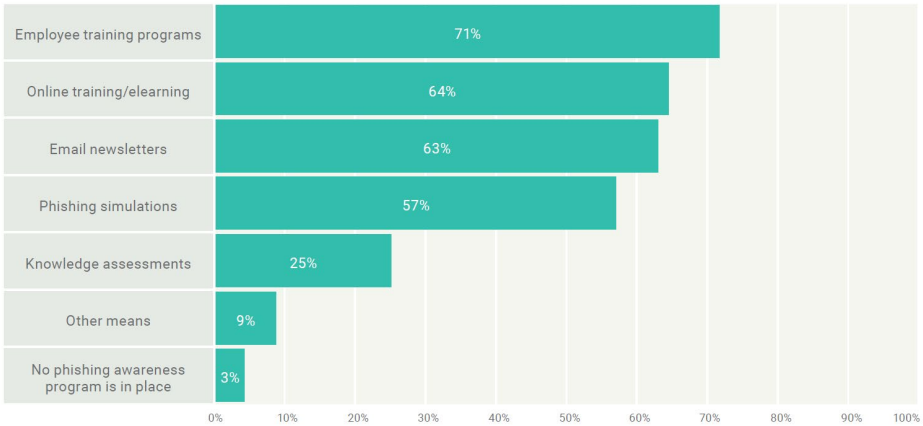


Figure 114 - Main methods used by the companies to promote phishing awareness and mitigate phishing threats. (Source: CSX, "State of Cyber security 2019, Part 2: Current Trends in Attacks, Awareness and Governance", 2019)

Even though 71% of the respondents assess that in their companies there is a training program against phishing, only 12% of them is completely confident in the fact that these programs are effective and enable employees to be able to act against cyber threats.

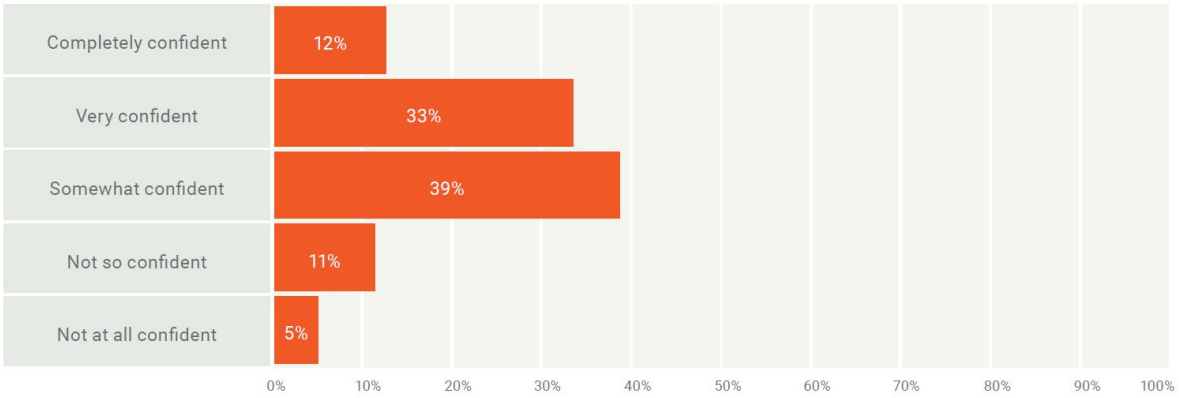


Figure 115 - Confidence level of respondents in the effectiveness of the training programs offered by the companies. (Source: CSX, "State of Cyber security 2019, Part 2: Current Trends in Attacks, Awareness and Governance", 2019)

- **Governance dictates confidence level**. A crucial aspect of the security field is the reporting structure of the cyber security organization within an enterprise; the top three executives to whom cyber security organizations reports include the CISO[48] (43 % of respondents), the CIO[49] (27 %) and the CEO[50] (13 %).

  Respondents indicate greatest confidence in a cyber-security team's capability to detect attacks and respond effectively when the cyber security teams report to the chief information security officer (CISO). Of the top three reporting structures, the chief information officer (CIO) inspires the least confidence:

  1) CISO reporting path: 79% of respondents in enterprises whose cyber security team reports to the CISO indicate that they are at least somewhat confident in their cyber security team's abilities to detect and respond to threats;

[48] Chief Information Security Officer: is the senior-level executive within an organization responsible for establishing and maintaining the enterprise vision, strategy, and program to ensure information assets and technologies are adequately protected. The CISO directs staff in identifying, developing, implementing, and maintaining processes across the enterprise to reduce information and information technology (IT) risks. They respond to incidents, establish appropriate standards and controls, manage security technologies, and direct the establishment and implementation of policies and procedures.

[49] Chief Information Officer: the most senior executive in an enterprise who works for the traditional information technology, and computer systems that support enterprise goals.

[50] Chief Executive Officer: the most senior corporate, executive, or administrative officer in charge of managing an organization. The CEO of a corporation or company typically reports to the board of directors and is charged with maximizing the value of the entity, which may include maximizing the share price, market share, revenues or another element.

2) CEO reporting path: 74% of respondents in enterprises whose cyber security team reports to the CEO indicate that they are at least somewhat confident in the cyber security team's threat detection and mitigation abilities, even though only 13% of survey respondents report to the CEO.
3) CIO reporting path: 68% of respondents in enterprises whose cyber security team reports to the CIO indicate that they are at least somewhat confident in their cyber security team's abilities to detect and respond to threats.

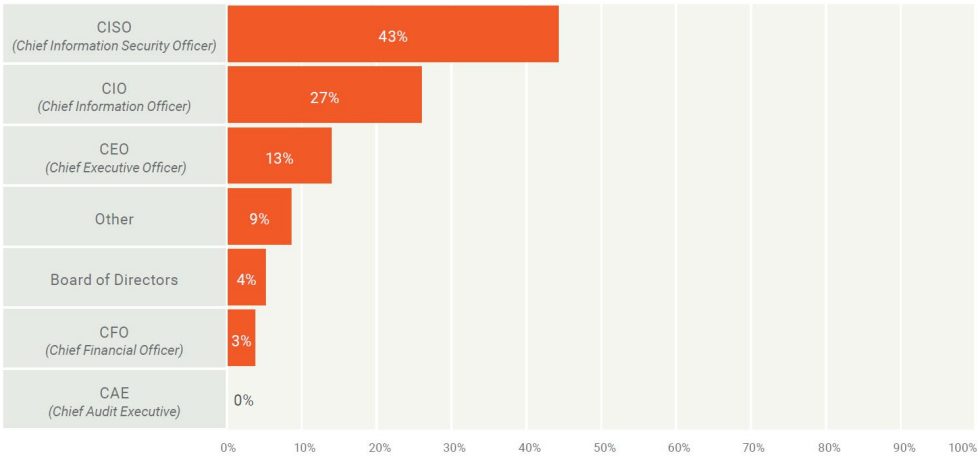


Figure 116 - Figures to whom cyber security staff reports problems and issues in the interviewed companies. (Source: CSX, "State of Cyber security 2019, Part 2: Current Trends in Attacks, Awareness and Governance", 2019)

It emerges from Memoori research that there is a positive trend of the market related to the cyber security, with an expected growth of 15.2% from 2016 to 2021. This increase is interconnected with the development of the smart technologies, which require a constant advancement of the security systems. What is essential to determine are what Memoori defines the *"Best Practice for cyber threat mitigation*"; in other words, companies should have in mind some good behaviour that would minimize the risk of cyber-attacks and loss of sensible data.

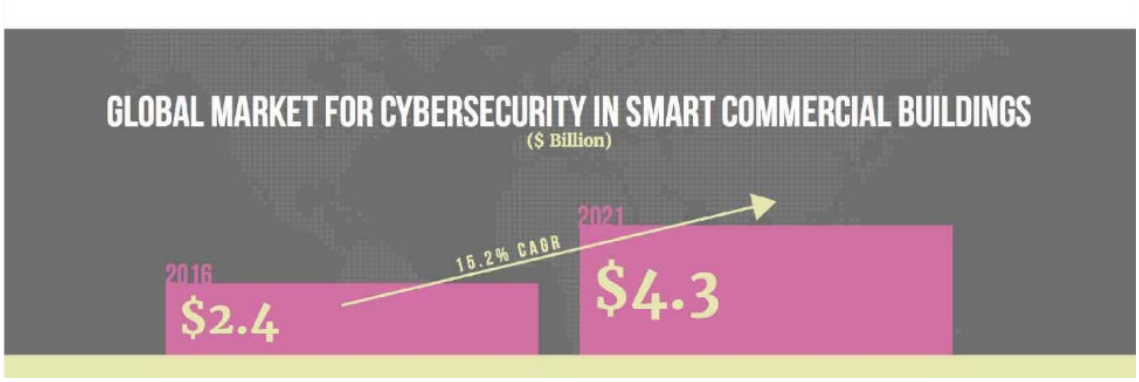


Figure 117 – The predicted growth for the market for cyber security on global scale. (Source: Memoori, "Cyber Security in Smart Commercial Buildings 2017 to 2021", 2017).

In conclusion, considering all the problems related to the security issue deriving from the use of smart technologies, it is possible to summarize four guidelines that may be useful for companies to prevent cyber-attacks (Meemori research AB 2017):

- **Perform risk assessment and security audits**: because of the continuous development of the smart technologies, there is a growth also of the threats that they are subjected to. It is essential to keep updated the security systems, by installing the proper updates, so that is is able to face the more recent and advanced cyber threats.
- **Develop safeguards, standards and corporate policies for cybersecurity across the company**: specific rules about how to deal with risks connected to the use of smart technologies has a great importance in the nowadays scenario. Everyone working in a company has to know how to operate safely, and the presence of a specialized staff dealing with this issue is of great help to maintain a proper level of safety.
- **Promote security awareness and collective responsibility across the company**: as it has been described, one of the main causes of cyber-attacks is the wrong behaviour of workers, who walk into the traps realized by the hackers. It is essential to train employees about the risks and the main types of attacks that they may face during their working activity, in order to avoid useless risks.

- **Adopt a layered security approach** with security embedded all the way from the device to the perimeter: because potential Internet security risks can occur at a variety of levels, it is a good choice to set up security measures that provide multiple layers of defence against these risks. The use of a layered approach when dealing with Internet security strategy ensures that an attacker who penetrates one layer of defence will be stopped by a subsequent layer (IBM knowledge center 2018).

2.7 Conclusions

The last five years have been crucial for the definition of the Smart Buildings issue. The focus is definitively moved from the green/energy efficient buildings to the development of technologies aiming at improving user wellbeing and experience inside several building typologies.

This fact is strongly connected with a new way of living that is becoming everyday more popular and one of the primary concern of people. The interest is moving towards a healthier lifestyle, with particular attention of the quality of the spaces where people spend the majority of their time. Building occupants want to live and work in spaces that are able to reduce their stress level and simplify their common activities, and for this reason smart technologies are finding breeding ground to grow up and be developed.

The tendency towards a new way of living involves also the working life, and the Smart Working philosophy is at the top of the agendas of many companies, especially the biggest ones. The basis of the smart working theory is that the way in which people work must be aligned with the new way of living that is spreading in the last years: flexibility and connectivity must be the two fundamental principles, regulating all the decisions of managers for improving the wellbeing of workers in order to increase their productivity.

This concept is practically translated in the design of working spaces that are flexible, varied and adaptable to different requirements and situations. Technology is another key element that fits perfectly in this framework: IoT offers the possibility to increase flexibility of working activity and, at the same time, simplify them. Wayfinding, Smart building systems, Easy Visit, Smart Bins are just some of the several options that exist nowadays to improve user wellbeing inside the working place.

User wellbeing and experience may be enhanced also in many others building typologies: universities, shopping malls, hospitals and also residential buildings. Many smart devices are perfectly suitable for all of them, while there are some specific user needs that, to be satisfied, have the necessity of a technology useful only in that building typology. RDIF localisation of objects for the hospitals, luggage tracking for the airports, smart mirrors for the shopping malls are examples of smart systems applicable only in a specific type of building.

The analysis of the present situation, for what concerns the Smart Buildings field, allow to realize that there are infinite possibilities, thanks to the technological and scientific progress, that may simplify everyday activities and improve life quality in the indoor spaces. The crucial point is now to understand which one of these possibilities are really what occupants expect and require.

CHAPTER 3

The future: what people need, and which are the technologies that will spread in the next years

When considering a topic like the one of smart buildings, which is constantly in transformation, it is essential to investigate its future opportunities and how it will change in the next years.
For this reason, it has been developed a tool that is able to help in the prediction of what is going to happen in the smart building field. Chapter 3 present the survey, key element of this research, that aims at investigating people's needs and expectation from smart technologies.
The development of this questionnaire is a very useful tool in order to understand the direction towards which Smart Building are moving. The 15 questions address all the aspects that have been investigated in previous chapters: smart building definition and general features, smart technologies, discouraging aspects, sustainability certification, privacy and security issues. The analysis of the answers is performed by distinguishing between simple occupants and operators of the building field. Moreover, the different building typologies are considered separately, in accordance with the method followed in Chapter 2.

3.1 Premise

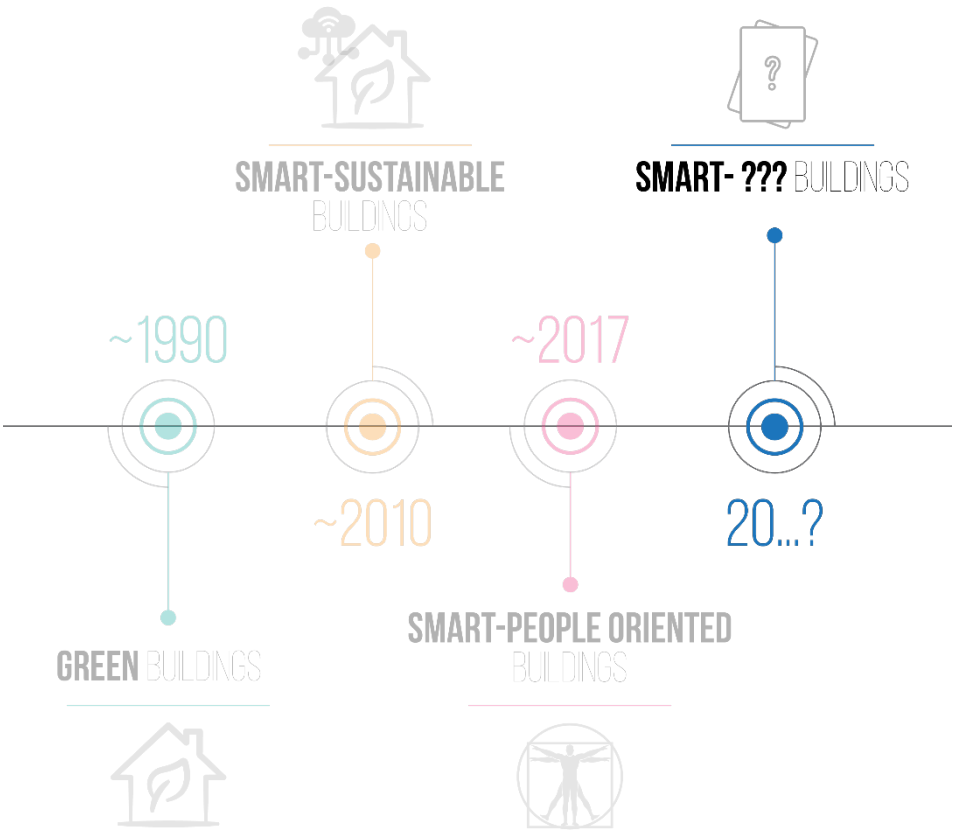


Figure 118 - Diagram of the historical journey, focus on the future (Source: the author)

After having presented and analysed many smart technologies present nowadays on the market, it is fundamental to understand in which direction the Smart Buildings field is going, in accordance with people needs and expectations.

For a company that is investing in the building innovation is essential to be aware about not only the main technologies and devices that are present on the market, but also which of all these possibilities are the most appreciated and required by the final users of the building.

Across the smart building ecosystem, there are several visions about how technology will be organized in the Smart Buildings of the future. It is reasonable to group these visions into two main groups: the first one includes all the ideas based on the technological integration, and proposes a highly integrated Smart Buildings based on a single IoT platform; the second group of visions intends Smart Buildings as integrated through multiple asset-specific IoT platforms (Verdantix 2018). The organisation of smart technologies inside a building that belongs to the first group is strongly different from what happens in a building of the second group.

Highly Integrated Smart Buildings will have a single cloud based IoT platform, with other key characteristics (Verdantix 2018):

1) **Majority of building and related data aggregated through a single cloud based IoT platform**. An essential element for a highly integrated smart building is the existence of a single platform to centralize, store and analyse data from all building assets, systems and devices based on technology. This vision of a single IoT platform already exists for small sites or in case of buildings equipped with standard building systems. However, it is considerably more complex to develop a single IoT layer for complex facilities, such as airports or hospitals, containing thousands of systems and critical operations. For this reason, the second vision is more suitable for these building typologies.
2) **Many devices and systems being connected to an IP network**. The vision of centralizing all building data on a single cloud-based platform is integrated with the idea of using, as mean of connection, the building IP network, rather than BMS protocols. Sensors and other small devices will connect locally using low-power networks such as Bluetooth or LoRaWAN[51]. This vision is supported by the trend of equipment manufacturers developing devices that are internet ready. For example, HVAC manufacturer Daikin offers a range of 'smart' devices (rooftop units, fan arrays, chillers and heat pumps) that contain preinstalled Intel-based gateways and sensors so that they can be connected to the internet.
3) **Majority of data analysis delivered through a host of apps sitting on top of the IoT layer**. It is expected that for buildings with a single centralized platform, data will be extracted and then analysed remotely in the cloud, through the use of a host of software applications staying on top of the IoT platform.
4) **Additional user engagement and reporting apps**. In some cases, there could be additional software layers implemented on top of the analytical apps, in order to provide an enhanced user interface.

The vision of highly integrated Smart Buildings is not always possible; there are clear limitations to that model when more complex building typologies and situations are considered. For this reason, it emerges the need for an alternative approach for organising Smart Buildings based on multiple IoT platforms. The key features of this vision are:

1) **Multiple IoT platforms for aggregating and managing data.** There are several possibilities for realising Smart Buildings in which data are managed and stored in multiple

[51] Long Range Wide Area Network, is a protocol developed by LoRa Alliance. Its main characteristic is the efficiency: very low battery consumption and a wide communication range, able to reach until 15 km in an open field.

data integration platforms. One opportunity is to build IoT platforms around specific asset groups such as lighting, security or heating. These asset-specific IoT platforms are the preferred vision by actors of the building sector because they open up the possibility for data integration platforms that are built around the needs of specific asset groups.

2) **Many vendors delivering analytics and services around asset specific IoT platforms.** Equipment manufacturers that have invested in embedded intelligence and IoT platforms want to monetize these investments by offering customers ongoing services and analytics, especially to support maintenance and asset optimization. This may result in many services agreements to manage buildings equipment and systems, such as a separate services agreement for elevators, lighting, lifts, security systems and HVAC.

These two visions are considered possible according to the expert of smart building sector, but it does not imply that they are the only options. The Smart Building field is complex and in continuous evolution, and what appears to be the best option today, may not remain so in a year.

Together with a deep analysis of past and present tendencies of the market, it is essential to investigate people requirements and expectation in terms of Smart technologies.

3.2 The questionnaire

The focus of the research is the development of a questionnaire, aiming at identifying the perception of building users and designers about the smart technologies issue.

3.2.1 The questionnaire methodology

The methodology of the questionnaire may be a good opportunity of interviewing people about their thoughts and concerns when dealing with the Smart Buildings issue.

The survey been developed on an online platform (*Sondaggio Online*[52]) and it has been diffused thanks to the collaboration of Deerns, Urban Land Institute[53] and Politecnico di Milano. The language in which the questionnaire has been written is Italian.

The survey consists of a series of questions, in this case all related to the Smart Buildings topics presented in Chapters 1 and 2, for which the recipients have to select one or more among the multiple answers that are proposed. In some case, it is asked also to rank different building features in order of importance or to give a score to several items proposed in a list. The goal is to collect information about people's expectations from the new technologies for different building typologies, in order to have a sort of ranking of the most appreciated features and to know the ones that are not considered of primary importance by the users.

There are many examples of surveys that have been useful for clarifying some aspects of a complex topic like the one of Smart Buildings, and some of them have already been discussed in Chapters 1 and 2.

For example, Microsoft published a paper entitled *"Digital Culture: your competitive advantage"* where are reported the results of a questionnaire performed on 20.476 workers in large (250+ employees) and small (50-250 employees) businesses across 21 European countries. Through this survey, the company examined productivity, innovation and empowerment in businesses, that then have been classified as having 'weak', 'average' and 'strong' digital cultures (Microsoft 2018).

Another report about the result of a questionnaire is "*Engagement and the global workplace*", by Steelcase. The answers are based on an online survey of 12.480 office workers from 17 countries in

[52] *https://www.sondaggio-online.com/*
[53] ULI is a network of cross-disciplinary real estate and land use experts in the world.

four continents, and the goal was to measure employee engagement and workplace satisfaction to examine "worker and organisational wellbeing" (Steelcase 2018).

A further example of how a questionnaire has been useful to understand the possibility of the office buildings in terms of innovation and technologies have been published by Memoori, a Stockholm-based consultancy company providing independent market research, business intelligence and advice on smart building technologies. They published a report (Meemori Research AB 2017) for which 500 office users in North America were asked about the level of technology in their workplaces and how they felt this affected their ability to work productively. The questions proposed to the employees are related to office layout, lighting, temperature and technology.

The effect of Artificial Intelligent and robotics on workplace culture was the subject of another study by Pega and Marketforce (Pega, Marketforce 2017), and it is in the form of questionnaire as well. The survey covered 845 senior executives in 11 industry sectors worldwide (financial services, insurance, manufacturing, telecoms & media, technology, public sector, healthcare & life sciences, energy & utilities, travel, transport & logistics and retail). The results provide an overview about people feelings about the introduction of Artificial Intelligence in their everyday working life.

Re results collected by these survey have been exploited as a strong basis for publications and scientific researches, and this is an evidence of how a questionnaire is a good way of collecting data that provide a base for scientific assessments. This is the basic idea of the survey that is going to be presented in this chapter, which primary goal is to give a definition of a Smart Building and identify the technologies more required by the users, on which companies should invest more.

3.2.2 Recipients and topics

Once having clarified what the methodology of the questionnaire is, it is necessary to explain who the recipients are. In order to have a clear overview of the opinions of different figures acting in the building field, the survey has been submitted both to buildings' owners and tenants, to architects, plant designers, engineers, facility managers, and of course to the final users. In this way it has been possible to collect data coming from different point of views, but still all belonging to the building field.

The questionnaire have been spread thanks to the collaboration with Deerns and Urban Land Institute (ULI) and 203 people involved in different ways in the building sector answered. Considering the operators of the building sector, some of them inserted the name of the society where they work:

D2U – Design To Users, Morgan Stanley, Tetris Design and Build, Cundall, Logical Soft, BNP Paribas RE, World Capital Real Estate, Telemotor, ISS, Lapis srl are the names of these societies.

Together with figures operating in the building field, the survey has been submitted also to the occupants of all the building typologies that have been investigated in Chapter 2. In this way, it is possible to have a complete overview about the perceptions of Smart Buildings both by experts and by simple occupants.

For what regards the topics covered in the questionnaire, they are all related to what has been discussed in the Introduction and in Chapters 1 and 2. First, there are questions dealing with the definition of Smart Buildings: in the Introduction it was discussed how delicate is this subject, because it is a theme in continuous transformation, and it is difficult to provide a precise and unique definition. Once different opinions coming from people involved in the building field under different point of view are collected, it is possible to present and discuss the most diffused definitions among those who will answer.

The second set of questions is related to main features a smart building should have in people's imaginary: management and monitoring of energy consumptions, enhancement of users' comfort and wellbeing, reduction of stress sources in the everyday activities, simplification of those procedures that are complex and require long waiting times, etc.

After having discussed about general characteristics of the Smart Building, the third set of questions deals with specific technologies that have been previously described in this research, in order to figure out if, according to all the actors involved in the building sector, they are considered useful and important or not.

Then a set of questions related to negative aspects of Smart Buildings are proposed. First, the matter of the economic investment that is necessary to sustain to implement smart technologies inside a building, both of new construction and already existing. Then also the privacy issue is discussed, in order to understand if according to the interviewed people, the loss of privacy that some smart technologies involve, is acceptable in relation to the benefits that they are able to provide or not.

3.2.3 The questions

Before to start with the main questions of the survey, a couple of preliminary questions are necessary in order to understand who is answering. First, it may be useful to know which the society for which the respondents work is and the range of age to which they belong. This is relevant because it could help in understanding if the Smart Building Issue is more diffuse among young or older people, and because people of different ages may have different needs and may expect different services from a Smart Building.

"Age:"

- Less than 30
- Between 31 and 40
- Between 41 and 50
- Between 51 and 60
- More than 61

The second question deals with the role the person who is answring has in the building sector.

"Which is your role in the building field (it is possible to select more than one answer):"

- Owner
- Developer
- Builder / Construction company
- Designer / Architect
- Facility manager
- Student
- User
- Other (specify)

Another relevant information that has to be gather is the sector of the building field in which the recipient operates.

"In which sector (building typology) do you operate (it is possible to select more than one answer):"

- Office buildings
- Hospitals and healthcare
- Museums

- Educational centres (schools, universities)
- Infrastructures (Airport, train stations)
- Commercial buildings (shopping malls)
- Tourist accommodation
- Industry / Pharmaceutical sector
- Data centre
- Residential
- Other (specify)

Before to proceed with more specific questions about the smart building topic, it is interesting to know if who is answering is aware of this topic or if it is the first time he or she hears about it.

"Have you ever taken part to the design of a Smart Building, or are you thinking of implementing a project with smart technologies?"

- Yes
- I am thinking about that
- No

The following set of questions deals with the definition of Smart Building, according to the different actors of the building sector and the main features that, in their opinion, are essential in order to define a building smart.

These questions are important because they give the possibility to understand which are the macro areas perceived more important than others, and that require higher investments and research by the companies of the building sector, in order to provide the users a Smart Building compliant with their needs and expectations. If a company involved in the production of smart technologies for the building sector knows in advance what people want, this would save time and money because they can directly focus in the production of devices and systems for which they are sure that people are interested in.

"Which one of these definitions describe better a Smart Building?"

- Building with HIGH ENERGY EFFICIENCY: A building that is able to optimise its own consumptions according to an advanced real-time monitoring of the boundary conditions (occupancy, temperature, etc.) in order to reduce costs and emissions.

- Building which IS FOCUSED ON USER WELLBEING: the user can set his own preferences in terms of environmental parameters (light, temperature, air quality) and the building adapts to them automatically.
- Building dedicated to the USER EXPERIENCE: Presence of technologies that simplify and speed up tall the every-day activities (ex. Wayfinding, room booking, smart working)
- DIGITAL TWIN: a digital copy of the building that is used for management and maintenance

All the proposed options reflect some of the aspects that well define a Smart Building; even if the energy efficiency topic is considered in this research as the "past" of the smart building, since nowadays it is a fundamental aspect of the buildings of new construction, it is one of the options. This is because it is useful to understand if the main concern of building sector actors is still the reduction of consumptions and emissions or if the attention is really moving towards the people oriented designed, as the literature states.

The next question is related to all the possibilities offered by a Smart Building. The goal is to figure out which are the opportunities in which people are interested the most and which they consider of primary importance. In this case, who is answering is required to give a score to all the characteristics proposed about their importance: from one (not important) to five (very important).

"Give a score of the importance of the following advantages offered by Smart Building, from 1 (not important) to 5 (very important):"

- Energy efficiency;
- Users' comfort;
- User experience;
- Smart management of people, object and data.

This question introduced, in a generic way, some possible features of a Smart Building. The next set of questions aims at adding more details and presenting to the respondents some specific technologies of the Smart Building Field. Also in this case, the request is to give a score from 1 to 5 to each one of the choices. It has been decided to keep the same formulation of question number 7 ("Give a score of the importance of the following characteristics inside a Smart Building, from 1 (not important) to 5 (very important)), and each set of answer is related to one of the fields proposed in question 6.

- Real time monitoring of the consumptions, with notifications when they exceed a certain limit;

- Real time monitoring of building systems, with notifications when there is something that needs maintenance;
- Automatic HVAC systems, regulated by diffused sensors;
- Automatic lighting, regulated by sensors of presence and sensors measuring the level of natural light inside a space;
- Automatic shading devices (curtains, smart glasses, etc.).

The second set of answer is referred to these technologies affecting users' wellbeing. Also in this case, who is answering has to give a score of importance from 1 (not important) to 5 (very important).

- Personalized setting of temperature;
- Personalized setting of lighting level according to the activity one is doing;
- Personalized setting of furniture according to the activity one is doing;
- Sensors monitoring the acoustic comfort and sound masking devices;
- Sensors monitoring air quality and the level of pollutants.

The third set of answers relates to the user experience and those technologies aiming at improving it.

- Wayfinding/People finding: indoor guide for reaching the required destination or person;
- Parking finding/booking: map showing the closest free parking;
- Room booking: possibility to book in advance a desk or a meeting room via app;
- Sound masking devices in order to have spaces with a higher acoustic comfort;
- Keyless entry technology: access to the building without the need of key or badge;
- Personalized advertisements on smartphone or on wearable: sending of push notifications (coming bus, advertisement, discounts, etc.) through the use of beacons;
- Easy visit: faster and easier management of check-in operations inside a building.

The last set of answer is referred to the management operations of the building.

- Smart cleaning: optimisation of cleaning activities only in the areas that have been effectively used;
- Smart bins: automatic differentiation, tracking, etc.;
- 3D archive of the administrative documentation of the building;
- Building website, used by everyone as a hub of collection and sharing of information;
- Direct communication between users and facility management.

These questions have a great importance because people have the possibility to express their opinion directly about the smart technologies present on the market. Something that a producer defines useful and well performing may not be what the final users want or expect. The answers deriving from these questions will give the possibility to summarize which the most and the less appreciated technologies are.

Finally, a question about the advantages offered by a smart building is proposed:

"Give a score from 1 (not important) to 5 (very important) to the following advantages offered by a smart building"

- Smaller and more optimised spaces;
- Spaces that are easier to be used;
- More inclusive spaces (user experience);
- Healthier environment;
- Many data available to optimise management and services.

The next couple of questions are related to the perception of users of Smart Buildings:

"Which one of the following functions may contribute to the definition of a Smart Building?"

- Outdoor public spaces;
- Restaurants;
- Shops or temporary shops;
- Kindergarten;
- Services (laundry, delivery points of packages/ grocery shopping)
- Areas for sport activities;
- Relax spaces.

"In your opinion, a Smart Building is a building that achieved a sustainability certification? In case of affirmative answer, which one?"

- LEED
- WELL
- BREEAM
- Wiredscore
- Cradle2Cradle

- ITACA
- No, any certification
- Other (specify)

Until now, all the questions of the survey were dealing with positive aspects of a Smart Building, involving all the features that aim at improving the everyday life of the users. However, the IoT technologies applied in the Smart Building field have also a negative aspect that cannot be neglected. Once objects and people are connected in the Interned of Things, they become extremely vulnerable to external attack on the network of the building (Manfredini 2019).

Of course, as the technology of the IoT is developing, as the one related to the protection and security of people and data is evolving with it. However, it is important to understand first, if people are aware of this type of problems and second, if these concerns about hacker attacks and compromising of important data act as deterrent against the adoption of smart technologies.

"How much scare you possible leaks in the security systems, with consequent accesses by external people to your personal data or to the control systems of your IoT devices?"

- A lot, and for this reason I am reticent in the adoption of Smart technologies inside my building;
- Quite a lot, but I trust in the security systems and I prefer to take advantage of what smart technologies are able to offer;
- Not at all.

Another issue that must be addressed when dealing with smart technologies is the privacy: when objects and especially people are constantly monitored under the action of many sensors or cameras, the privacy decreases consistently. For example, if, on one side, the people finding allow to reduce all the time losses related to looking for someone without finding him, on the other side, to avoid this problem, all the users are constantly monitored and localised.

"How much scare you the theme of privacy reduction deriving from the use of smart technologies?"

- A lot, and for this reason I am reticent in the adoption of these technologies inside my building;
- Quite a lot, but I care more of the advantages that these technologies offer;
- Not at all.

In addition to the security and the privacy matters, also the economic investment that is necessary in order to implement Smart Building technologies may be a deterrent for people when they have to decide if to realize/move in a smart building or not.

"How much do you think it may increment the cost of the building the implementation of smart technologies with respect to traditional systems?"

- 1-5%
- 5-10%
- 10-20%
- More than 20%

Moreover, another big concern that may be perceived as a disadvantage of Smart Building technologies is the difficulty for the users to learn how to use them. In some occasions, the new smart devices may be seen as an obstacle rather than something able to facilitate the everyday life.

It is interesting to compare all these issues with the others previously mentioned, to understand which the main problem against the implementation of Smart devices is.

"What do you think is the main aspect that discourage the use of smart technologies? Put in order the following options from the first one (very critic) to the last one (not so much critic)":

- Initial investment;
- Management and maintenance costs;
- Loss of privacy of the users;
- Possible leaks in the systems leading to the loss of relevant data;
- Difficulties for the users to learn how to use all the smart devices;
- Difficulties in personal data management;
- Low interest in the offered services.

For what regards this question, a clarification it is necessary. The questionnaire has been submitted to simple occupants and to experts of the building sector, by using two different platforms: Google Drive in the first case and Sondaggi-Online in the second one. Because via Google drive it was not possible to select as question typology the one where respondents have to put in order a list of option, they were required to assign a score of importance (from 1 to 5) as it was for question n°7.

3.3 The questionnaire: outcomes

Among the 203 people who answered the survey, 78 are directly involved in the building field (architects, engineers, facility managers, etc), while 125 are occupants, operating in all the building typologies that have been analysed (offices, hospitals, shopping malls, airports, houses, museums).

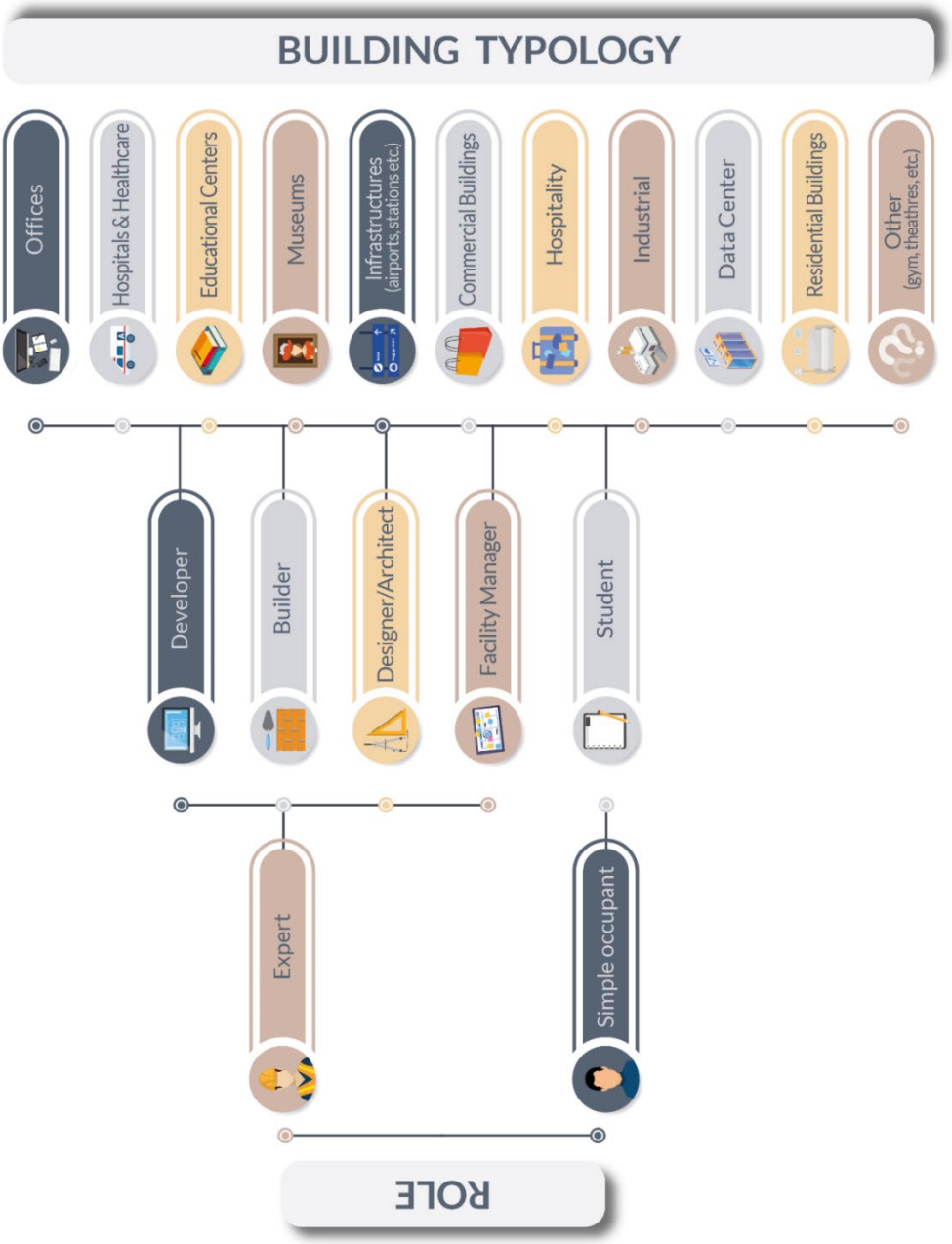


Figure 119: Diagram about the reading of the answers. (Source: the author)

The guiding principle of data analysis has been to identify opinions about the Smart Building topic according to some key factors:

- The **role** in the building sector;
- The **building typology** in which who is answering operates;

This subdivision in the answers analysis allows identifying precisely needs, expectations, perceptions and thoughts of the different personalities acting in all the building sectors.

Since it was possible to select more than one building typologies in question four, every time that an answer was referred to more than one typology, it has been considered two times (one for a typology, and one for another). For example, if who is answering is an architect who design offices and hospitals, his answer has been considered one time when analysing office spaces and another one when considering hospitals.

According to the methodology that has been followed for reading and interpreting the results, paragraph 3.3 has two sub-paragraphs: one for the answers of occupants (3.3.1) and another one for building sector operators results (3.3.2). Each one of these paragraphs is divided in sub-paragraph related to one specific building typology: Educational Centres, Offices, Residential Buildings, Hospitals and Industrial buildings for occupants and Educational Centres, Offices, Residential Buildings, Hospitals and Shopping Malls for experts of building sector.

Another methodological note regards the minimum number of answers related to each building typology: in case a certain building typology received less than 10 answers, the data related to it have not been reported.

3.3.1 The answers - Occupants

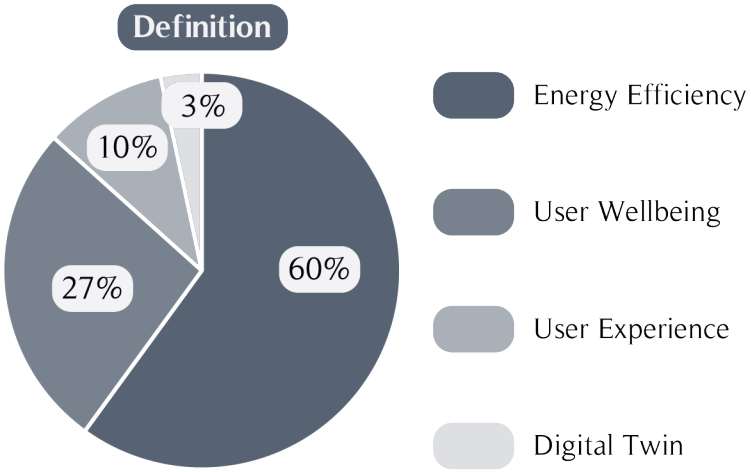
The roles in the building sector that it was possible to select in question number 3 are Owner, Developer, Builder/Construction Company, Designer/Architect, Facility manager, Student and Final User. Occupants and experts of sector have different perception of how a Smart Building should be. For this reason, their answers are considered separately, in order to clarify each single point of view.

A fundamental premise necessary for reading in the proper way the answers given by students (and by occupants) is that these two categories are not directly involved in the building design or construction phases. The perception that they have of the building is radically different from the one that an architect or an engineer may have, as the level of technical knowledge. For this reason, answers to question number 10 have not been considered in case of students and final users.

Educational Centres

30 students answered to the survey, indicating as building typology in which they mainly operate the Educational Centres.

Question number 6 deals with the possible definition of a Smart Building. In case of students, more than the half (60%) intend a Smart Building as an Energy Efficient one. This may seem in contrast with the tendency of this market, going towards the Users' Wellbeing-focused technologies, but it is fundamental to point out that this is such a new and emerging topic that is not surprising that a person who is not directly involved in the building sector is not aware about that.

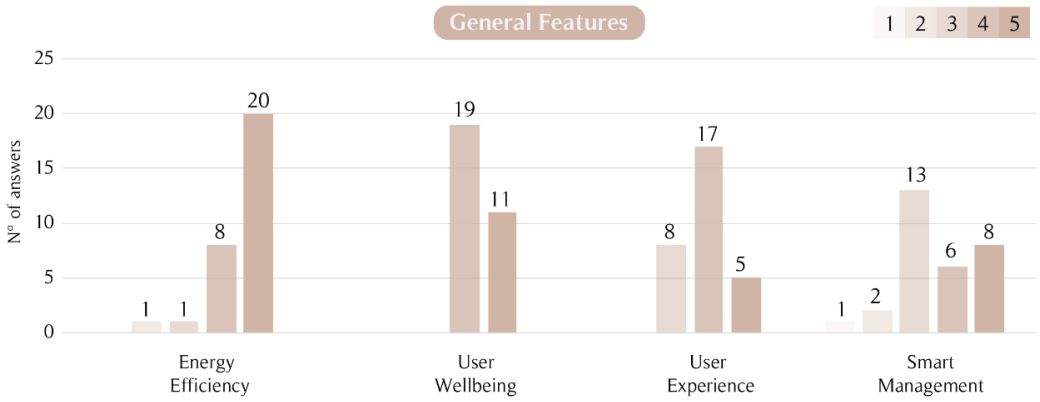


Graph 1: Answers to question n° 6 by Students about Educational Centres. (Source: the author)

The User-Focused definitions (User Wellbeing and Experience) collected almost 40% of the preferences, indicating that non-experts of the building sector feel that this topic has a great importance.

For what regards the set of questions in which people had to assign a score to different technologies of a Smart Building, the ones related to the User received, on average, the highest scores.

The Energy Efficiency is considered as very important by 20 respondents; however, it received also scores equal to 2 and 3 (both by only one person). The User Wellbeing as advantage of a Smart Building has been rated with only 4 and 5 points by everyone. This means that, despite when considering the definition there is a diffused idea of a Smart Building as an High Energy Efficiency one, the User Wellbeing is perceived as one of the greatest advantages a Smart Building is able to offer.

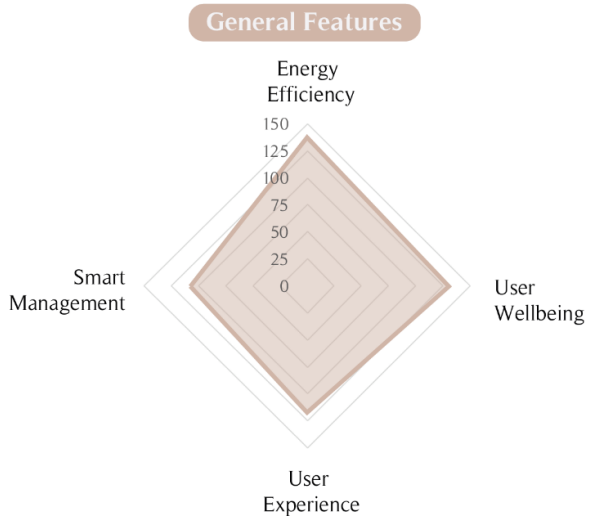


Graph 2: Answers to question n°7a (General Features of Smart Buildings) by Students about Educational Centres. (Source: the author)

To understand which one of the general features proposed received the highest scores, the Graph n° 2 is useful. All the four possibilities (Energy Efficiency, User Wellbeing, User Experience and Smart Management of people and data) are perceived as quite important, with an average score equal to 4,1. More in detail, 62.6% of respondents assigned a score to each option equal to 4 and 5. Only 2,7% decide to rate the proposed general features of a Smart Building with a score equal to 1 or 2.

To understand which one of the general features proposed received the highest scores, the Graph n° 3 is useful. The Feature that received the highest score is the Energy efficiency, with 137 points on 150 However, the User Wellbeing is really close (131/150), despite what it was reasonable to expect considering the results reported in Graph 1. User Experience and Smart Management have

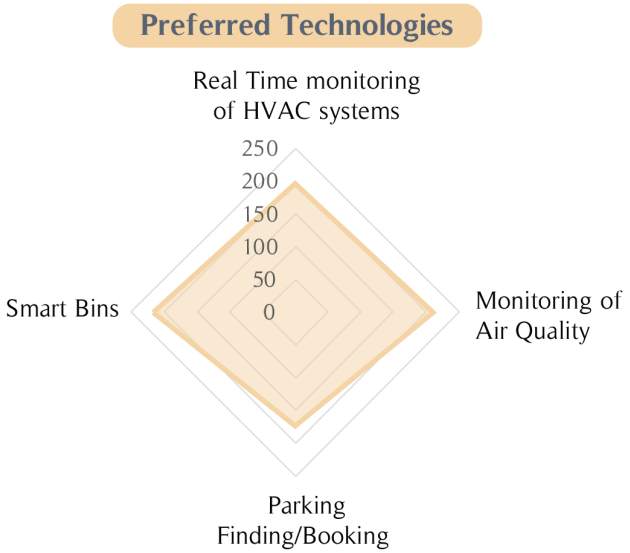
been considered as the less important characteristics for a Smart Building, but they received only scores from 3 to 5.



Smart Technologies	Score Tot.
Energy Efficiency	**137**/150
User Wellbeing	**131**/150
User Experience	**117**/150
Smart Management	**108**/150

Graph 3: Radar Chart and Total scores of question n° 7a (General Features of Smart Buildings). (Source: the author)

After the results related to the general characteristics of Smart Buildings, the perception of users about technologies to be introduced in schools and university is presented. The questionnaire proposes a series of possible smart technologies affecting energy efficiency, user wellbeing, user experience and smart management of people and data. The preferred technology for each set of answers (from 7b to 7e) is selected, and the four resulting technologies are compared in Graph 4.



Smart Technologies	Score Tot.
Real Time Monitoring of HVAC systems	**117**/150
Monitoring of Air Quality	**115**/150
Parking Finding/Booking	**98**/150
Smart Bins	**125**/150

Graph 4: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

The scores assigned to the smart technologies related to the energy efficiency (**7b**) of the building are quite fragmented. All the options received at least one answer to the score equal to one, and scores 2 and 3 have been selected several times. More in detail, scores 1, 2 and 3 have been selected by 35.4% of respondents, meaning that, despite the energy efficiency concept is perceived as the fundamental feature of a Smart Buildings, the single technologies are not always considered so important. All the 5 options related to energy efficiency received homogeneous scores, between 109 and 117. The real time monitoring of HVAC systems is the technology that registers more points (117/150), followed by the Real Time monitoring of consumptions (110/150) and the automatic shading devices (110/150).

The second set of smart solutions (**7c**) analysed are the ones related to the user wellbeing. Also in this case, some people assigned low scores (1 and 2) to the proposed technologies. Moreover, the 5 points have been selected by only 18% of the users. This is in contrast with the answers displayed in Graph 2, where it is visible that the User Wellbeing is rated only with 4 and 5 points. On average, respondents assigned to this set of technologies a score equal to 3.36; this result is close to the one registered by the options related to energy efficiency (3.74 on average). The preferred technology among the ones presented in this set are the Sensors monitoring the air quality. This confirm the tendency towards a healthier lifetime that has been presented in Chapter 2. Good result also for personalized setting of temperature and lighting level, registering a score, respectively, equal to 105/150 and 104/150.

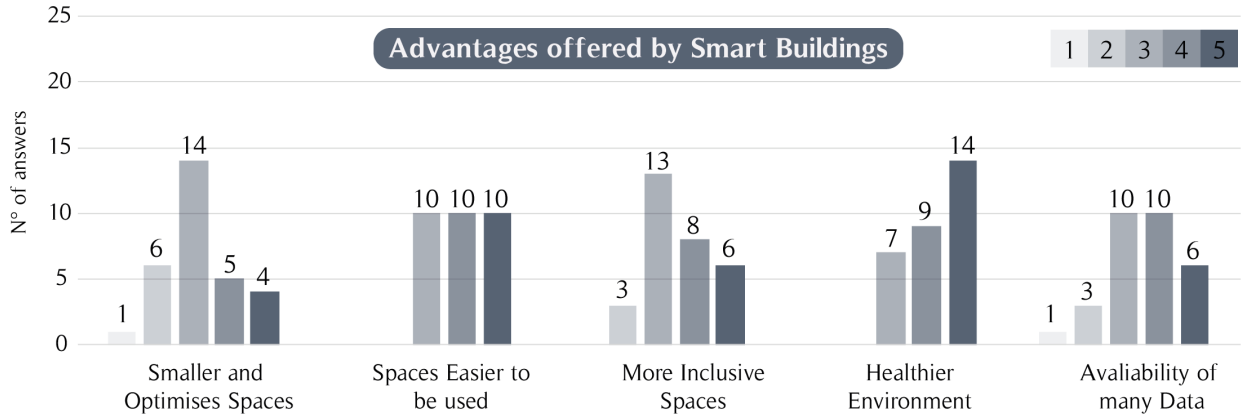
The User experience as general characteristic of a Smart Building has obtained the third score, considering all the options of Graph 3. Now specific technologies related to this topic are analysed (**7d**). The average score obtained by this set of technologies is slightly smaller with respect to the previous two sets – 7b and 7c - (2.97); this is coherent with the fact that, both considering the questions 6 and 7a, User experience has not been considered as the fundamental aspect of a Smart Building. Most respondents assigned a score equal to 3 (38%), and only 12.7% selected the 5 points option, that is even less of the percentage of people who chose a score equal to 1 (16.7%)

The overall scores obtained by the technologies related to the user experience are pretty low. Wayfinding and People finding register the lowest score of all the technologies of the entire questionnaire, with 71/150; this is curious considering that, when studying the literature related to this topic, the wayfinding is one of the most mentioned and analysed technology. On the other side, the Parking finding is perceived as the most useful options among the ones considered in this set of technologies, with a score of 98/150 and 3.3 points received on average.

The fifth set of options (**7e**) is linked to the Smart management of people and data. Even though the Smart Management of People and Data has been considered the less important feature in a Smart Building (Graph 3), the average score obtained of this set of technologies is high: 3.6 points. 55.3% of respondents assigned 4 and 5 points, and only 0.7% of them chose the option of 1 point. The greatest contribution to the 3.6 points on average is given by the Smart Bins, which collected 4.2 points on average and 125/150 in total. This is the highest score obtained among all the technologies presented in the questionnaire when considering Educational centre and respondents who are not experts of the building sectors.

Concluding, looking at Graph 4 it emerges that the scores obtained by the preferred options of each set of answers are similar, except from the User Experience related systems. The Smart Bins are, in absolute, the technology rated with the highest score. This is slightly in contrast with the fact that the smart management of people and data as general feature of a smart building obtained the lowest score (Graph 3). This means that the smart building issue and all the related topics are not completely known by users: for example, when they are told about "Smart Management of people and data" they do not comprehend the potentiality of this type of feature. But when possible technologies are presented, they are appreciated.

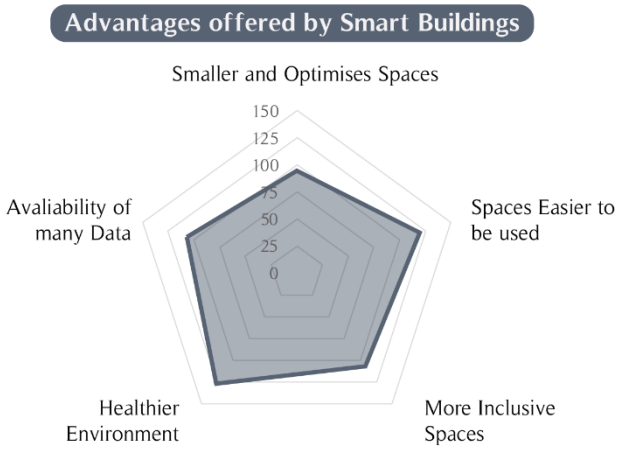
Question n° 8 deals with the advantages offered by a Smart Building.



Graph 5: Answers to question n°8 (Advantages) by Students about Educational Centres. (Source: the author)

All the proposals received good scores (3.7 on average), and the 54.7% selected 4 or 5 points. Moreover, only 1.3% decided to assign 1 point. The prevailing score that has been chosen are the 3 points, with a percentage of 36%.

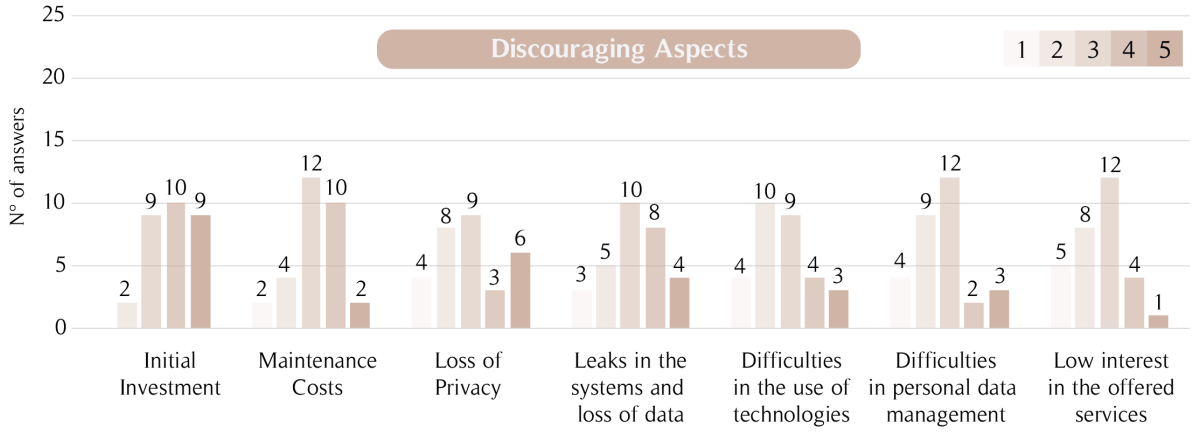
In accordance with the high score registered by the sensors monitoring air quality (Graph 4), the Healthier Environment is rated as the greatest advantage offered by a Smart Building (127/150).



Advantages	Score Tot.
Smaller and Optimises Spaces	**95**/150
Spaces Easier to be used	**120**/150
More Inclusive Spaces	**107**/150
Healthier Environment	**127**/150
Avaliability of many Data	**107**/150

Graph 6: Radar Chart and Total scores of question n° 8 (Advantages). (Source: the author)

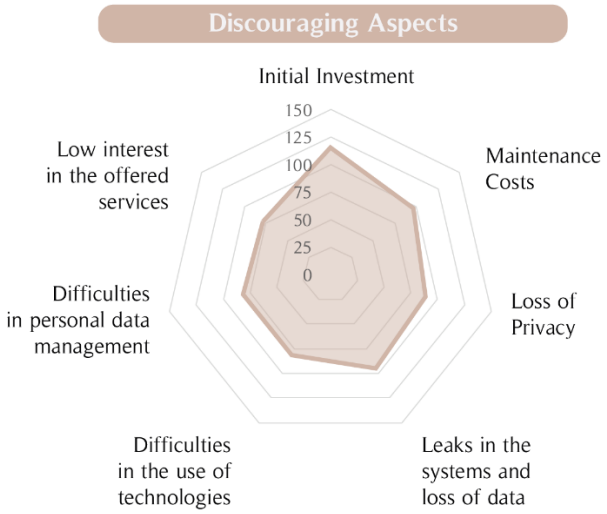
Going on with negative aspects of Smart Buildings, respondents had to assign a score from 1 to 5 to some side effect of smart features. Graph 7 reports the results.



Graph 7: Answers to question n° 12 by Students about Educational Centres. (Source: the author)

In general, the score that obtained the highest percentage of answers are the 3 points (48.7%), followed by 2 points (30.7%) and 4 points (27.3%). This means that the proposed negative aspects of Smart Buildings are perceived in a quite neutral way by the users. The option 5 points has been selected more times than the 1 point one, meaning that some of the options are perceived more discouraging that the ones that are seen as non-problematic.

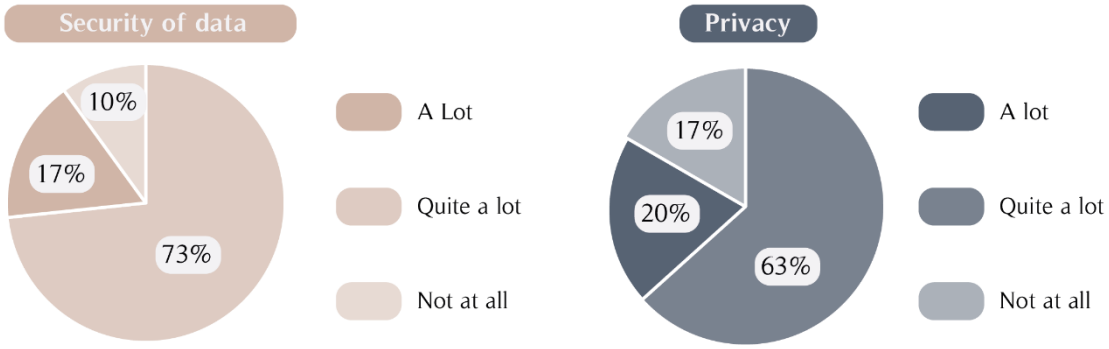
Considering the overall scores obtained by the different options, the one that discourage the most the adoption of smart technologies is the initial investment (116/150), and this is coherent with the results of question n°12, displayed in Graph 8. Being the cost increment, according to respondents, higher than 10%, it follows that almost everyone assigned to this option a score equal to 4 or 5.



Discouraging Aspects	Score Tot.
Initial Investment	**116**/150
Maintenance Costs	**96**/150
Loss of Privacy	**89**/150
Leaks in the systems and loss of data	**95**/150
Difficulties in the use of technologies	**82**/150
Difficulties in personal data management	**81**/150
Low interest in the offered services	**78**/150

Graph 8: Radar Chart and Total scores of question n° 12. (Source: the author)

Finally, security and privacy issue are analysed.



Graph 9: Answers to question n° 13 and 14 by Students about Educational Centres. (Source: the author)

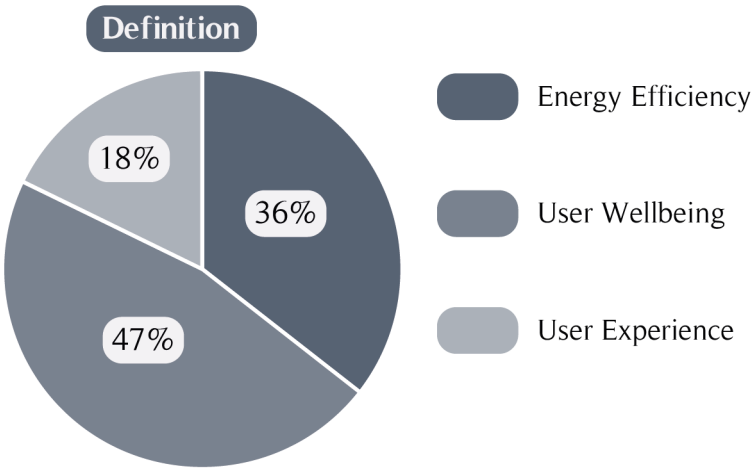
A good result for what regards the perception of users towards smart technologies is registered, when considering occupants and educational centres. Both for what regards Security and Privacy, more than half of respondents (73% and 63%, respectively) trust in in the security systems and prefer to exploit advantages offered by smart technologies rather than not using them at all.

Summarizing, users of educational centres would define a Smart Building as a high-energy efficiency one and think that the user wellbeing is its most important feature. The preferred technologies are the smart bins (followed by real time monitoring of systems and air quality monitoring) and the ones perceived as less useful are the personalized setting of furniture and the wayfinding / People finding. Cost increment related to smart technology is more than 10% and it is the main element discouraging the implementation of smart systems. This category of respondents is not completely scared by security and privacy issues, and they believe in modern protection systems.

Offices

Among the 125 respondents, 45 selected offices as building typology in which they mainly operate. The analysis of these answers displays some differences with respect to what emerged from the Educational centres' occupants.

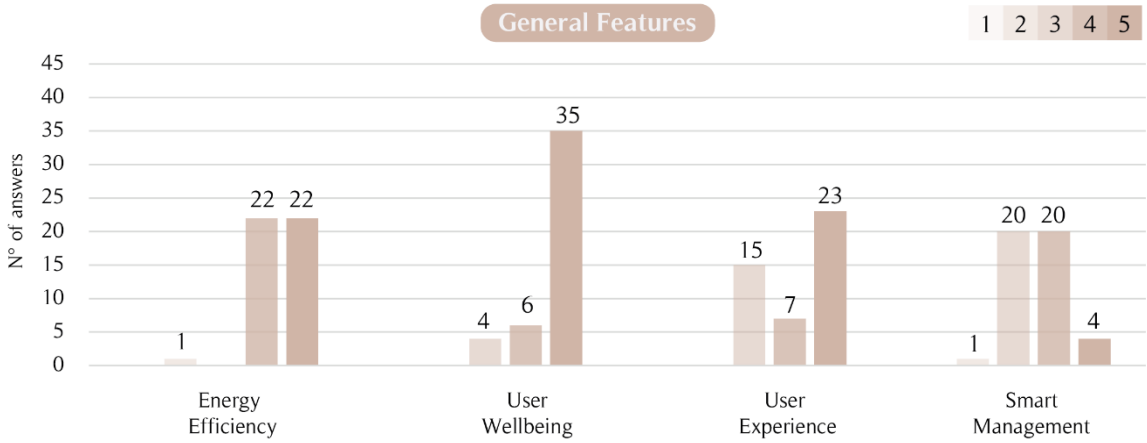
The first major difference appears when considering the definition of a Smart Building, given by users of office spaces.



Graph 10: Answers to question n° 6 by Occupants about Offices. (Source: the author)

Almost half of people working in an office perceives a Smart Building as something focused on the User Wellbeing. Energy Efficiency maintains a good percentage (36%), but it is not the preferred definition as it is in case of Educational Centers.

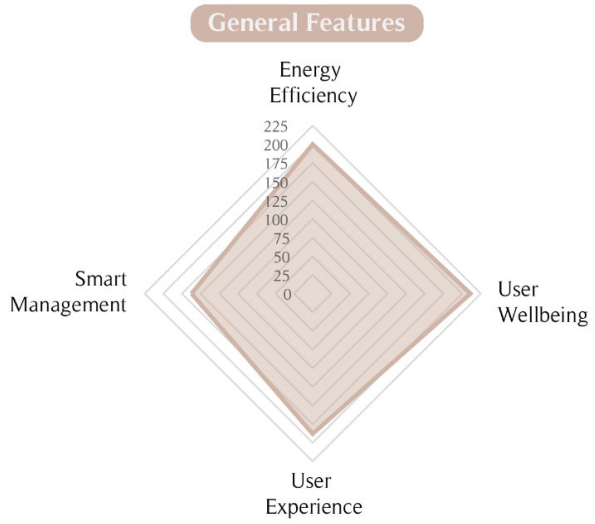
These results are confirmed in answers of question n°7a, as displayed in Graph 11.



Graph 11: Answers to question n° 7a (General Features) by Occupants about Offices. (Source: the author)

The user Wellbeing is rated mainly with 5 points, meaning that this is a very important and essential topic when dealing with Smart Buildings, according to users of offices. In general, 30% of respondents assigned a score equal to 5, 36,7% preferred the 4 points and only 1,3%decided to select the 2 points, with none choosing 1 point. This means that the proposed features are considered as pretty important inside a building to be defined smart.

User Wellbeing and Energy Efficiency received the highest scores (211/225 and 200/225, respectively) as Graph 12 shows. The Smart management registers the lowest score, but 162/225 can be still considered as a good result.



Smart Technologies	Score Tot.
Energy Efficiency	**200**/225
User Wellbeing	**211**/225
User Experience	**188**/225
Smart Management	**162**/225

Graph 12: Radar Chart and Total scores of question n° 7a. (Source: the author)

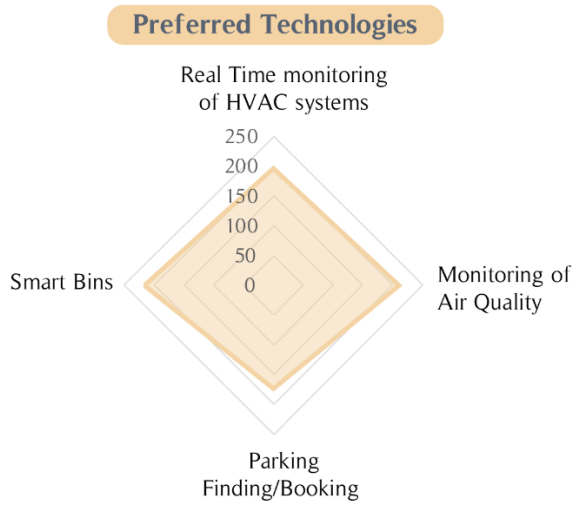
Question **7b** is the first one focused on Smart Technologies, linked to the Energy Efficiency feature. For this set of answers, 0% of respondents assigned 1 as score for the proposed technologies and almost 70% of interviewed people selected 4 or 5 points. The Real time monitoring of HVAC systems is the option that received the highest number of 5-points answers, followed by the automatic lighting and the automatic HVAC systems. The automatic HVAC system is the technology that collected the highest number of answers equal to 5 points, and it is also the most rated option, with a score of 196/225. All the other proposed systems obtained a result that is very close to the best one, and this means that according to offices occupants, all these smart technologies related to energy efficiency are important inside a smart building.

The sensors monitoring the Air quality are the most rated smart technology for what concerns the User Wellbeing (**7c**). They received 34 times a score equal to 5 points. Considering the overall results, in this set of answers 2% of respondents selected one point, differently from answers to questions 7a and 7b, where the one-point option was never chosen. At the same time, 76.5% of

respondents assigned a score equal to 4 or 5. In accordance with the results presented in Graph 13, the sensors monitoring the air quality are the options that received the highest overall score, equal to 210/225. Almost everyone assigned it 5 points, meaning that the Health conditions inside the office are perceived as a very important element to be considered in a Smart Building.

Even though the User experience is not the feature that received the highest number of preferences for what regards the definition of a Smart Building, some of the technologies related to this topic are perceived as quite important inside a Smart Office (**7d**). More in detail, Easy Visit (a system able to simplify check-in procedures) received 36 times a 4-points score. The most assigned score are the three points, chose by 35.9% of respondents. Also for this set of answers, 2% of people selected the one-point option, and only 18% of them assigned 5 points to the proposed option (more or less the half of respondents with respect to questions 7a, b and c. The set of technologies connected to the User Experience topic is the one that received the overall lowest scores. The parking finding/booking is the preferred feature of office users (174/225), followed by the Room Booking, Easy Visit and Keyless Entry Technology.

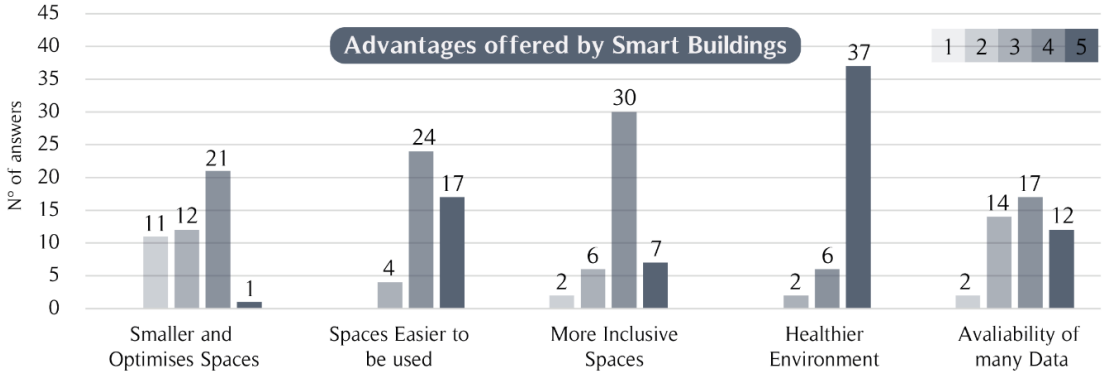
The answers related to the smart management (**7e**) given by office occupants are similar to the one of students in schools: Smart Bins received a very high number of 5-points answers, meaning that the issue of sustainability and environmental impact is considered important. 0% of respondents assigned one points to the proposed options, and 67% selected 4 or 5 points option. The smart Bins obtained a score even higher of the one registered for the air monitoring sensors (216/225 and 210/225, respectively). All the others smart technologies connected with the smart management of objects and data are far from this result, with a minimum score equal to 135/225 for the building website.



Smart Technologies	Score Tot.
Real Time Monitoring of HVAC systems	**196**/225
Monitoring of Air Quality	**210**/225
Parking Finding/Booking	**174**/225
Smart Bins	**216**/225

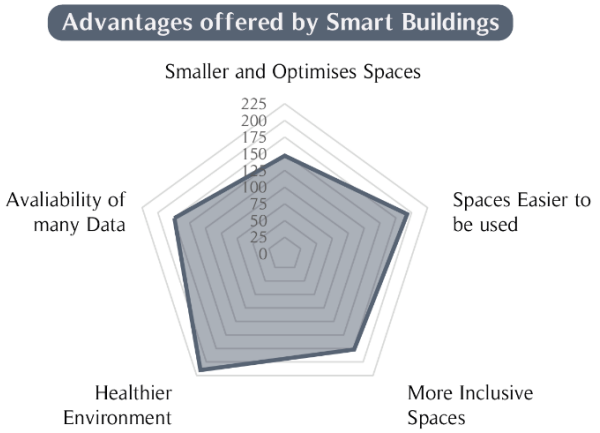
Graph 13: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

Graph 13 summarizes and compares the preferred technologies inside a smart office. As for schools, also in this case the Smart Bins lead the ranking; however, the sensors monitoring the air quality are very close, meaning that office occupants feel that health conditions have a great importance inside their working space. Differently from results presented in Graph 4, referring to educational centres, the real time monitoring of HVAC systems received the third highest score, being overcame by the monitoring of air quality system. The health issue is perceived as a fundamental aspect of the development of Smart Offices. This is confirmed in the answers to question n°8, and it is visible in Graph 14. The Healthier Environment option collected 37 preferences to the 5-points score. In general, all the proposed options are positively seen by respondents, who rated them with 4 and 5 points with a percentage 76.5% of the answers.



Graph 14: Answers to question n° 8 (Advantages) by Occupants about Offices. (Source: the author)

The greatest advantage of a Smart Building is, accordingly to office users, to have a healthier environment. This is coherent with the fact that they believe also that User Wellbeing is the essential feature of a building to be defined smart. Moreover, this result is compliant to the ones displayed in Graphs 10, 11 and 12.

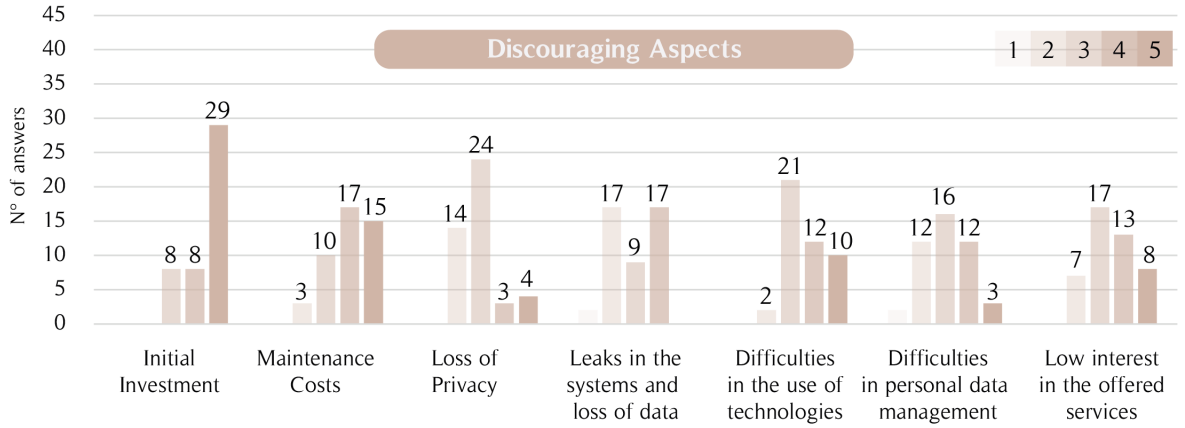


Advantages	Score Tot.
Smaller and Optimises Spaces	**147**/225
Spaces Easier to be used	**193**/225
More Inclusive Spaces	**177**/225
Healthier Environment	**215**/225
Avaliability of many Data	**174**/225

Graph 15: Radar Chart and Total scores of question n°8. (Source: the author)

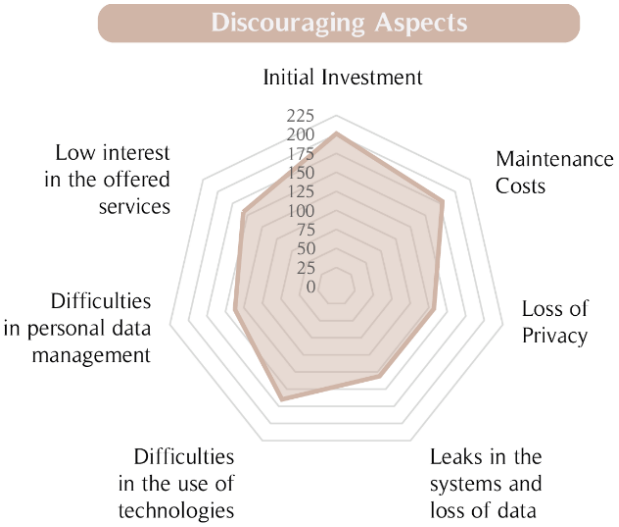
Question n° 12 deals with those aspects related to Smart Buildings that people perceive as discouraging from the implementation of Smart systems.

A low percentage of respondents assigned to the proposed options 5 points (22%). This means that, in general, they are not insuperable obstacles for the realization of a Smart Building. The most selected score are the three points (33.3%), followed by the 4 points (26.%).



Graph 16: Answers to question n° 12 (Discouraging Aspects) by Occupants about Offices. (Source: the author)

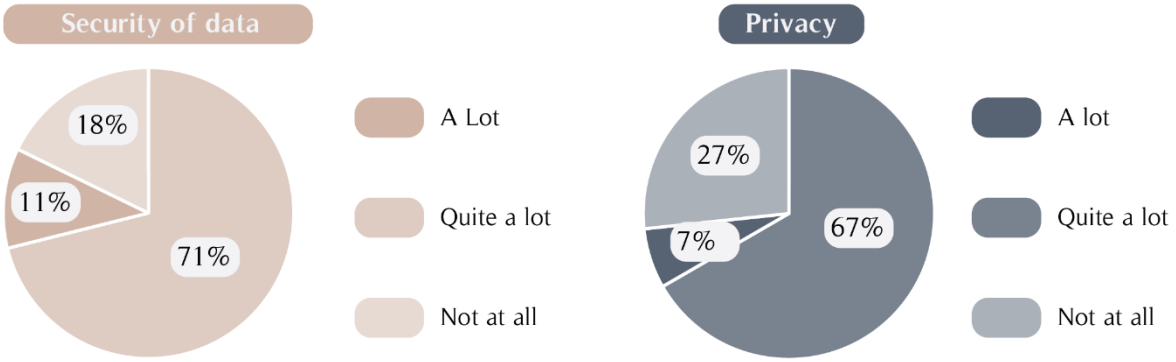
A for the Educational Centres, also in the case of offices the initial investment is the discouraging aspect that received more points (201/225). The scores assigned to the different options are homogenous, meaning that there is no an issue (apart from the initial investment) that scares the users more than another one.



Discouraging Aspects	Score Tot.
Initial Investment	**201**/225
Maintenance Costs	**179**/225
Loss of Privacy	**132**/225
Leaks in the systems and loss of data	**131**/225
Difficulties in the use of technologies	**165**/225
Difficulties in personal data management	**137**/225
Low interest in the offered services	**157**/225

Graph 17: Radar Chart and Total scores of question n°12. (Source: the author)

Privacy and security topics register the lowest scores (132/225 and 131/225, respectively) and this is compliant with the fact that the majority of respondents declare to be aware of the possible problems but they trust the security systems and they prefer to take advantage of the Smart Technologies in, more or less, 70% of cases (Graph 18).



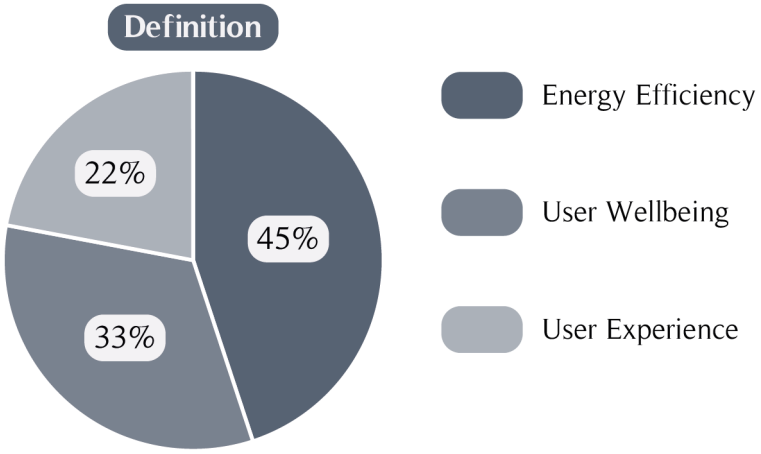
Graph 18: Answers to question n° 13 and 14 by Occupants about Offices. (Source: the author)

Summarizing, occupants of offices would define a Smart Building as foscused on User Wellbeing and think that this topic is its most important feature. For what regards technologies, the preferred one are the smart bins (followed by air quality monitoring and by automatic HVAC systems) and the ones perceived as less useful are the wayfinding / People finding and the personalised notifications on smartphones and wearables.

Cost increment related to smart technology is envisioned to be between 5% and 10, and this is the main element discouraging the implementation of smart systems. This category of respondents is not completely scared by security and privacy issues, and they believe in modern protection systems.

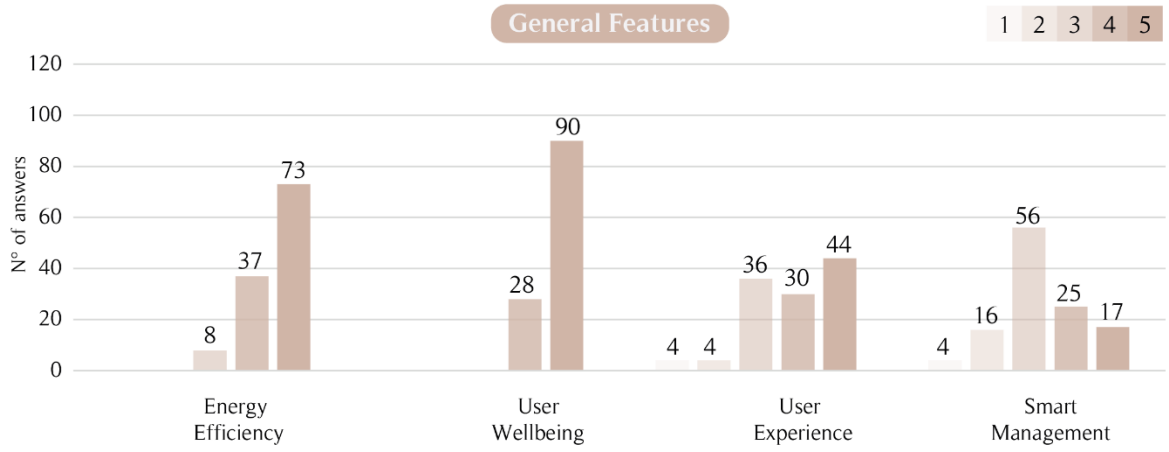
Residential Buildings

Almost all the respondents selected the residential buildings as one of the building typologies in which they spend most of their time. 118 answers for houses have been collected, and they are presented in the following graphs.



Graph 19: Answers to question n° 6 by Occupants about Residential Buildings. (Source: the author)

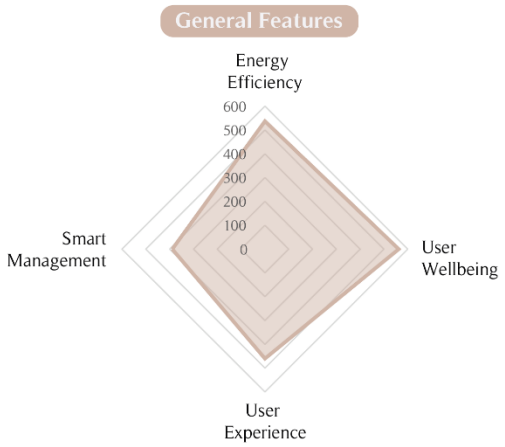
The answers about the definition are quite homogeneous, with 45% of the preferences for the Energy efficiency and 33% for the User Wellbeing. The digital Twin option has never been selected when considering residential buildings. The results (Graph 19) display a preference for the energy efficiency but the user wellbeing obtained a good amount of answers.



Graph 20: Answers to question n° 7a (General Features) by Occupants about Residential Buildings. (Source: the author)

Almost 50% of the respondents assigned 5 points to the proposed options. This means that they are all perceived as relevant features inside a smart residential building. Considering the same question

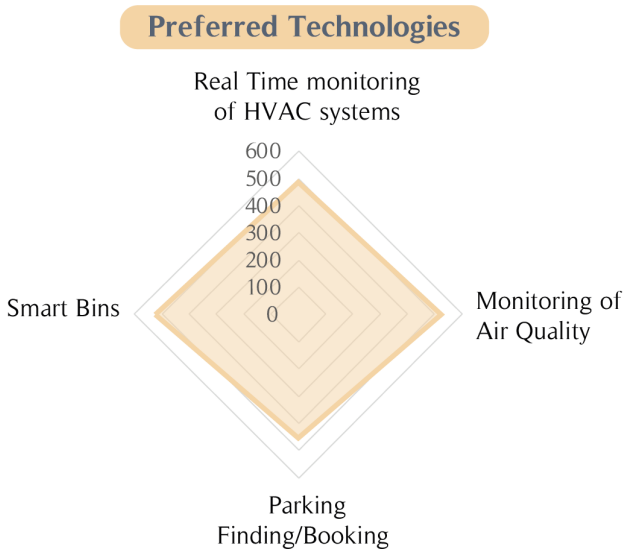
(n°7a) for the others building typologies, the residential buildings are the ones receiving the highest percentage of answers with 5 points. Moreover, only 1% of respondents assigned 1 point to the proposed features.



Smart Technologies	Score Tot.
Energy Efficiency	**537**/590
User Wellbeing	**562**/590
User Experience	**460**/590
Smart Management	**389**/590

Graph 21: Radar Chart and Total scores of question n°7a. (Source: the author)

Graph 21 displays the scores obtained by the different general features: the user wellbeing is the option registering the highest score with 562 points, followed by energy efficiency and user experience. Smart Management collected the lowest score, with 173 points less than the 562 obtained by the user wellbeing. Differently from the other typologies analysed until this point, in the case of residential buildings the answers to question 7a are in contrast with the ones of question 6: in the first one the user wellbeing appears to be the preferred general features of a smart home, while when considering the definition, the energy efficiency concept predominates.



Smart Technologies	Score Tot.
Real Time Monitoring of HVAC systems	**486**/590
Monitoring of Air Quality	**526**/590
Parking Finding/Booking	**453**/590
Smart Bins	**524**/590

Graph 22: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

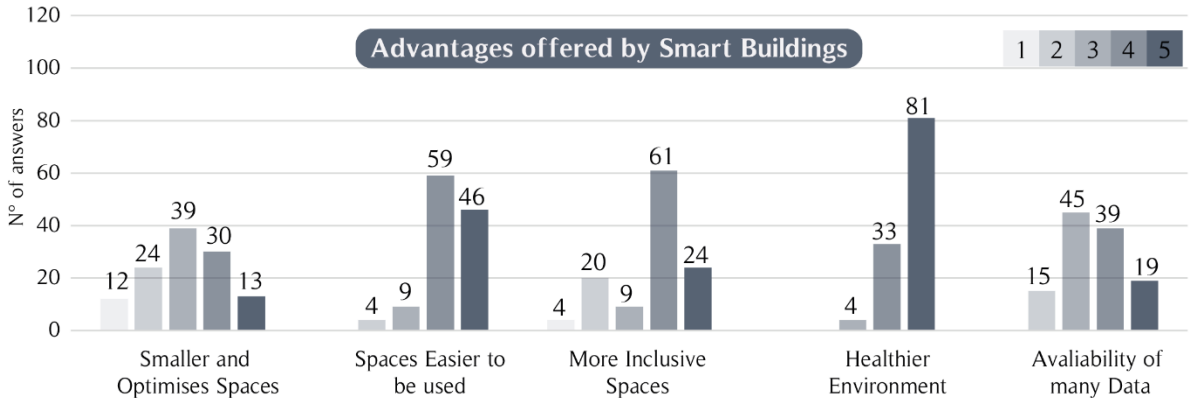
The results of question n° **7b**, about energy efficiency, shows that there is not a strong predominance of one technology on the others. 3, 4 and 5 points registered more or less the same percentage of preferences (25%, 35% and 32%, respectively). The average score assigned to the energy efficiency related technology is equal to 3,9 points. Two of the five proposed technologies obtained the same score: real time monitoring of HVAC systems and the automatic systems regulated by sensors (486 points on 590). It follows the automatic lighting (454/590), real time monitoring of consumptions (444/590) and automatic shading systems (432/590).

Question **7c** is related to user wellbeing. According to the results of answers to question n°21, this is the preferred feature to occupants of residential buildings. The average score obtained by this set of answers does not confirm this result: they registered 3,8 points, following the result of energy efficiency related technologies (3,9 points). Moreover, 3% of respondents assigned a score equal to one, while for the set of answers to question 7b only 0,2% of interviewed people selected this option. The preferred technology dealing with user wellbeing are the sensors monitoring the air quality, which obtained a score much higher than the other options. It follows the sensors monitoring the acoustic comfort (483/590) and the personalized setting of lighting level (462/590)

3,3 points is the average registered by the technologies related to user experience (**7d**). Much more respondents assigned one point to the proposed options, if considering the other typologies of systems: 8% is the percentage of users assigning 1 point, and only 29,8% of them preferred to give 5 points to the user experience related technologies. The parking finding/booking leads the ranking of this set of options, registering 453/590 points. The second classified is the keyless entry technology (420/590) while the less appreciated option are the personalized notifications (348 points).

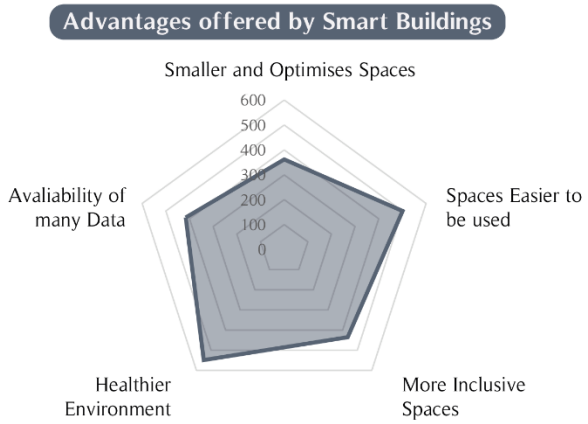
Finally, the last set of technologies deals with the smart management of people and data (**7e)**. 3,5 points is the average score and most assigned score to this systems are 4 points (30,3%). The preferred option are the smart bins, similarly to the results for educational centres and offices, with a very high score equal to 525 points. With almost 100 points less, it follows the smart cleaning (440/590).

Graph 23 displays the answers to question n°8, related to the advantages offered by a Smart Building. The healthier environment is he option registering the highest quantity of 5 points (81), and it is also the option with the higest total score (549/590). In general, all the mentioned advantages are percieved important, and 68,6% of respondents assigned a score equal to 4 or 5 points.



Graph 23: Answers to question n°8 (Advantages) by Occupants about Residential Buildings. (Source: the author)

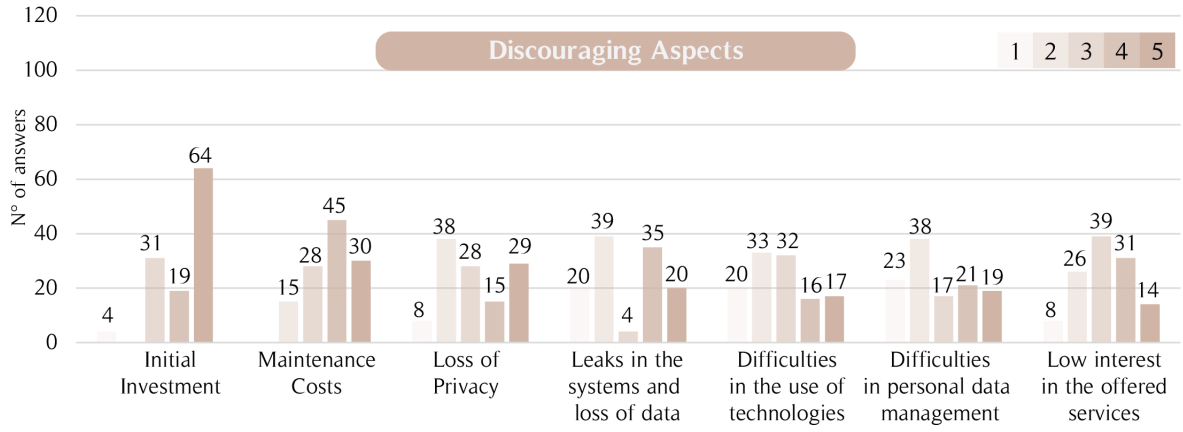
The spaces easier to be used registers the second highest score, equal to 501/590 points, followed by more inclusive spaces and the availability of many data.



Advantages	Score Tot.
Smaller and Optimises Spaces	**362**/590
Spaces Easier to be used	**501**/590
More Inclusive Spaces	**435**/590
Healthier Environment	**549**/590
Avaliability of many Data	**416**/590

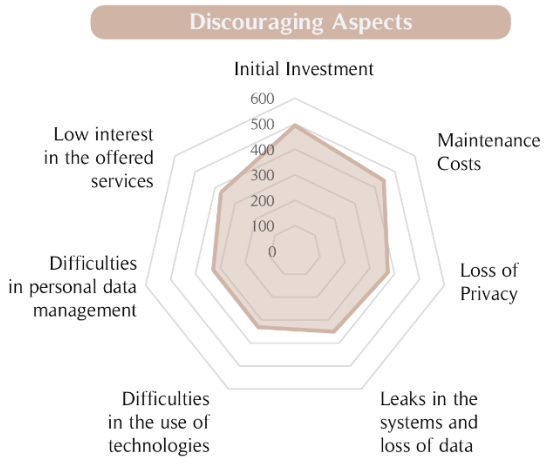
Graph 24: Radar Chart and Total scores of question n°8. (Source: the author)

On the other side, also the negative aspects are considered, and the answers to question n° 12 are displayed in Graph 25.



Graph 25: Answers to question n° 12 (Discouraging Aspects) by Occupants about Residential Buildings. (Source: the author)

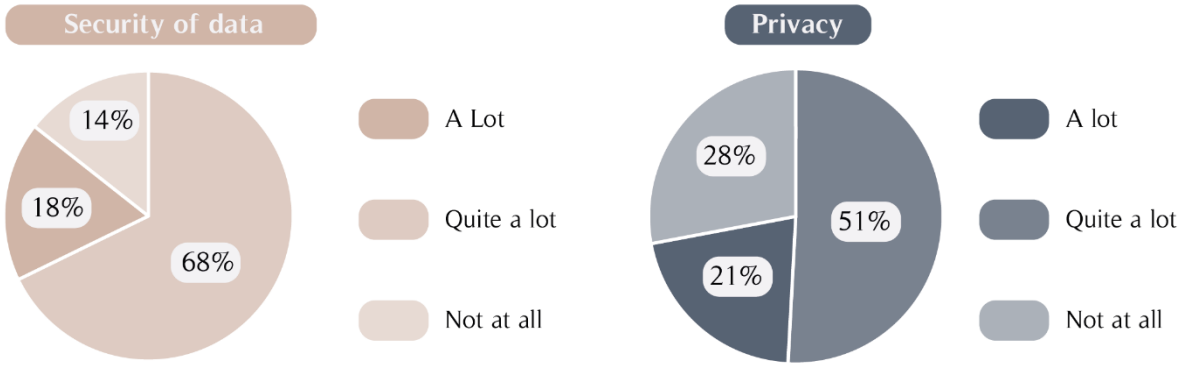
The average score obtained by the different discouraging aspects proposed as options is 3,0 points, meaning that occupants of residential building are not too much scared by the possible problems related to the implementation of smart tecnologies. What scares the most is the initial investment, registering 493 points, and followed by the maintenance costs and the loss of privacy (Graph 26).



Discouraging Aspects	Score Tot.
Initial Investment	**493**/590
Maintenance Costs	**444**/590
Loss of Privacy	**373**/590
Leaks in the systems and loss of data	**350**/590
Difficulties in the use of technologies	**331**/590
Difficulties in personal data management	**329**/590
Low interest in the offered services	**371**/590

Graph 26: Radar Chart and Total scores of question n°12. (Source: the author)

For what regards security of data and privacy issues, users are aware about these problems, but in general they trust the security systems which the smart buildings are equipped with. Respectiverly, only 14% and 28% of respondents are not aware at all about security and privacy issues.

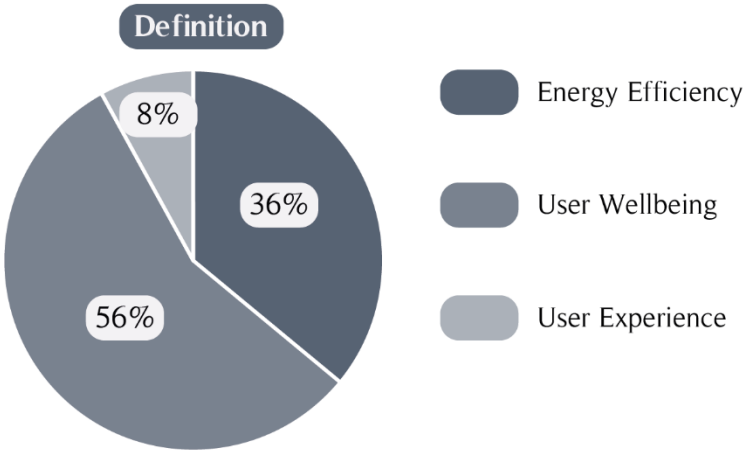


Graph 27: Answers to question n° 13 and 14 by Occupants about Residential Buildings. (Source: the author)

In conclusion, occupants of residential buildings would define a Smart Building as focused on energy efficiency and think that the user wellbeing topic is its most important feature. For what regards technologies, the preferred one are the smart bins (followed by air quality monitoring and by automatic HVAC systems) and the ones perceived as less useful are the wayfinding / People finding and the personalised notifications on smartphones and wearables.

Hospitals

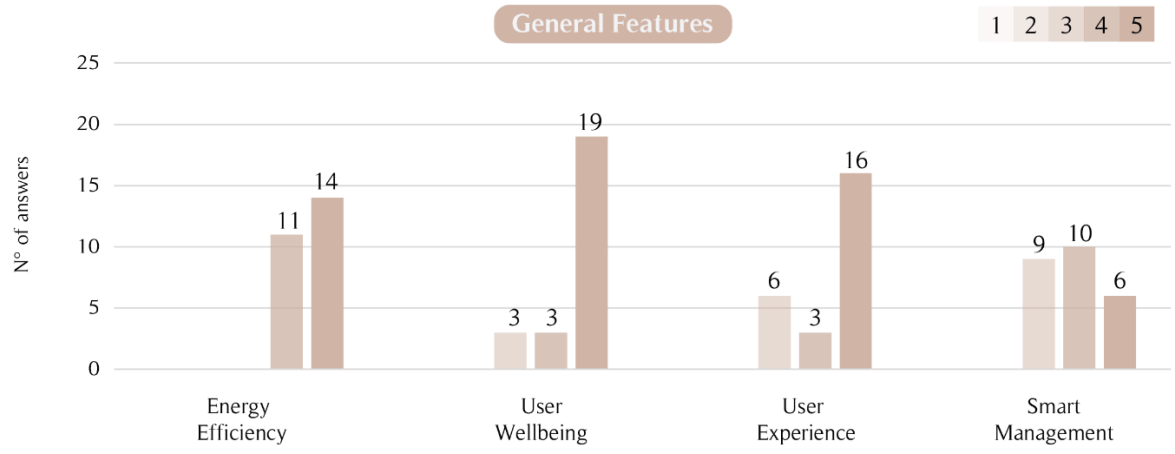
25 respondents, considering building occupants, selected the hospitals as the building typology in which they mainly operate.



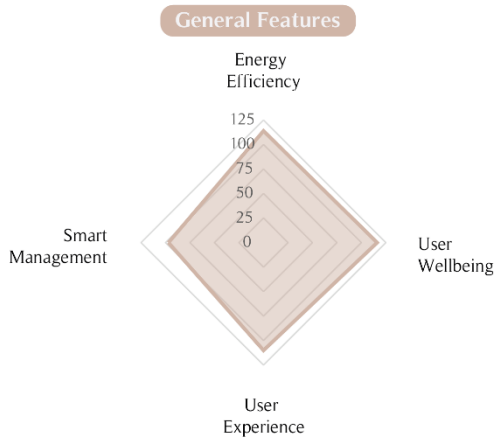
Graph 28: Answers to question n° 6 by Occupants about Hospitals. (Source: the author)

Differently from the results obtained for educational centres and residential buildings, more than half of the hospitals users define a Smart Building as people oriented, a place where the user wellbeing is the crucial element. The energy efficiency concept has been selected by only 36% of people, and 8% would define a Smart hospital as focused on the user experience.

What emerges from Graph 29 is that scores 1 and 2 have never been selected for any of the option. Moreover, the one receiving more 5 points is the User Wellbeing one, as it was reasonable to expect from the answers to question n°6, 55% of respondents assigned a score equal to 5 points, and the average score registered by the options related to the general features of a smart building is 4,37 points. This means that all the proposed features are perceived as important for a Smart hospital.



Graph 29: Answers to question n° 7a (General Features) by Occupants about Hospitals. (Source: the author)



Smart Technologies	Score Tot.
Energy Efficiency	**114**/125
User Wellbeing	**116**/125
User Experience	**110**/125
Smart Management	**97**/125

Graph 30: Radar Chart and Total scores of question n°7a. (Source: the author)

The results presented in Graph 28 are confirmed in the answers to question n° 7a in the order of preferences but not in the obtained scores. If, when considering the definition, there is a clear difference among the percentage that each option registers, in the case of question n° 7a this difference is not so pronounced. User wellbeing has been rated with 116 points, followed by energy efficiency (114/125) and user experience (110/125). It emerges that these three features are almost on the same level, according to users, and the difference between them is certainly less strong than it is if considering the definition (Graph 28).

For what regards the different technologies available for a Smart Buildings, they are investigated from question n°7b to n° 7d, and divided in thematic areas (energy efficiency, user wellbeing, user experience and smart management of people and data).

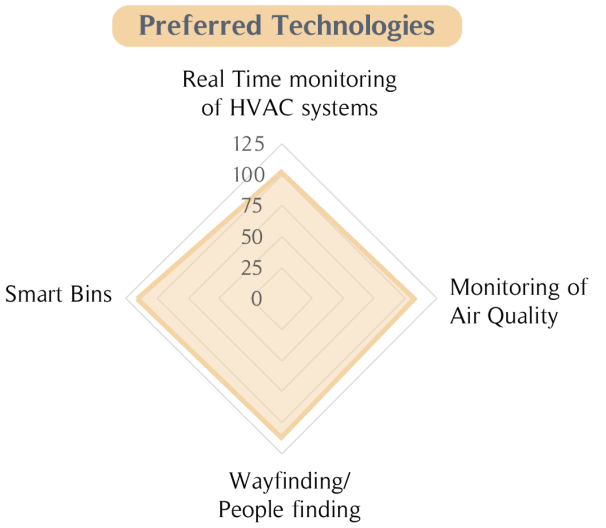
The options of question n° **7b** – technologies related to energy efficiency – registered an average score equal to 3,9. At the same time, almost 5% of respondents assigned 1 point to the proposed options (this is a quite high number if compared to all the other set of options analysed until now, also for the other building typologies). This is balanced by the fact that 41,6% of interviewed people decided to choose the 5 points option. This fact is index of a fragmentation of opinions related to this set of technologies. The preferred one is the real time monitoring of HVAC systems (102/125), followed, with a close score, by the automatic systems regulated by sensors (101/125).

Question n° **7c** deals with user wellbeing issue. The average score obtained by these technologies is, again, 3,9 points, meaning that they are perceived as useful inside a Smart Hospital. Also in this case, the fragmentation of opinions is strong, because 7,2% of respondents selected 1 point, while 37,6% and 37,6% decided to assign 4 and 5 points.

The air quality monitoring is the option registering the highest score (107/125), followed by the Lighting intensity regulation (103/125) and the personalized setting of temperature (99/125).

For what regards the technologies related to the User experience (question n°**7d**), they registered the lowest average score (3,6 points), in accordance with what emerged from question n°6 – displayed in Graph 27. 4 and 5 points obtained almost the same amount of preferences (28,7% and 3,7%, respectively), and the one-point option has been chosen by only 2% of respondents. The preferred technology of this set is, differently from the other building typologies, the Wayfinding – People finding. This is coherent with what emerged in Chapter 2: in places like hospitals, which in general are big and people go there occasionally, one of the main concern is to know where to go in the shortest time possible.

The smart management of object and data is the theme of question n°**7e**. The average score of these options is aligned with all the others (3,7 points), with 0% of respondents assigning one point. 34,4% and 30,4% of the answers have been, respectively, registered for the four and five points options. The most rated option are the Smart Bins (116/125).

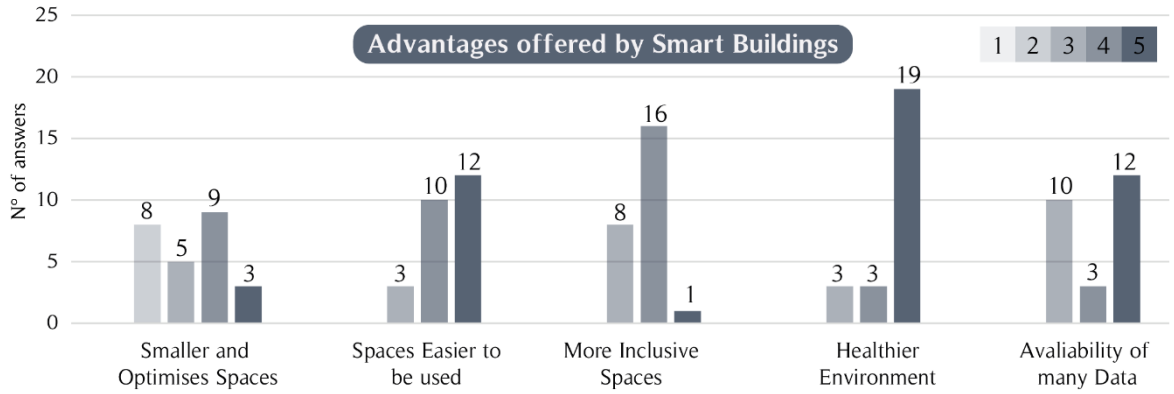


Smart Technologies	Score Tot.
Real Time Monitoring of HVAC systems	**102**/125
Monitoring of Air Quality	**107**/125
Wayfinding / People finding	**112**/125
Smart Bins	**116**/125

Graph 31: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

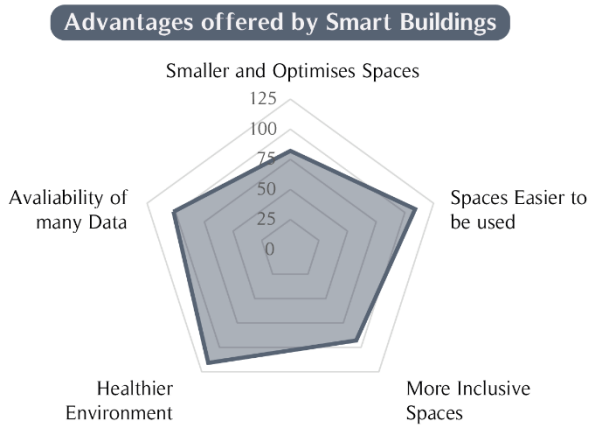
Considering the preferred technologies for thematic area, the one registering the highest score are the smart bins. This is an expectable result, considering the increasing concern for environmental issues such as the one related to wastes that are spreading in recent years. It is important to point out that also all the others preferred technologies (in order, wayfinding, monitoring of air quality and real time monitoring of HVAC system) received very similar and high scores.

Graph 32 reports the results of question n°8, related to the advantages offered by smart buildings. The average score is the highest registered among the ones considered until this point: 4,0 points. This indicates that hospitals' occupants feel that Smart technologies offer many advantages: spaces that are smaller, optimised, easier to be used, more inclusive and healthier. Almost 40% of respondents assigned a score equal 5 points and none decided to choose the one-point option.



Graph 32: Answers to question n°8 (Advantages) by Occupants about Hospitals. (Source: the author)

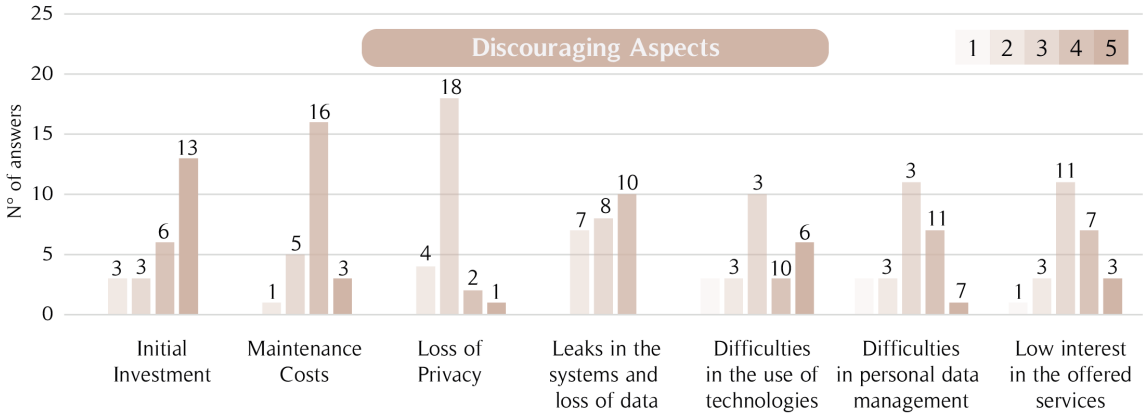
Also for hospitals, the healthier environment is the characteristic more appreciated of a Smart building, followed by spaces easier to be used and availability of many data.



Advantages	Score Tot.
Smaller and Optimises Spaces	**82**/125
Spaces Easier to be used	**109**/125
More Inclusive Spaces	**93**/125
Healthier Environment	**116**/125
Avaliability of many Data	**102**/125

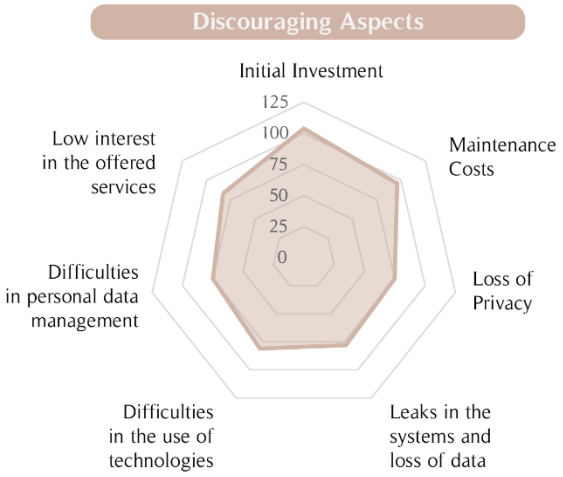
Graph 33: Radar Chart and Total scores of question n°8. (Source: the author)

For what regards the discouraging aspects, they registered, on average, a score equal to 3,2. Users' perception is that the advantages offered by a Smart Hospital are more relevant that the negative aspect related to its implementation. Confirming this, only 15,4% of respondents assigned 5 points to the propose discouraging aspect.



Graph 34: Answers to question n° 12 (Discouraging Aspects) by Occupants about Hospitals. (Source: the author)

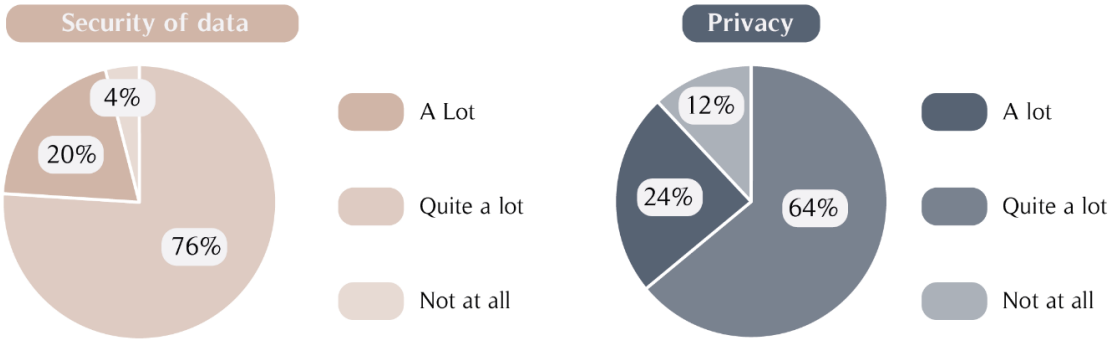
Initial investment and maintenance cost are the aspects perceived as more discouraging, among the ones proposed, registering, respectively, 104 and 96 points on a total of 125.



Discouraging Aspects	Score Tot.
Initial Investment	**104**/125
Maintenance Costs	**96**/125
Loss of Privacy	**75**/125
Leaks in the systems and loss of data	**78**/125
Difficulties in the use of technologies	**81**/125
Difficulties in personal data management	**75**/125
Low interest in the offered services	**83**/125

Graph 35: Radar Chart and Total scores of question n°12. (Source: the author)

The loss of privacy is the option to which respondents assigned the lowest score, and this is confirmed in Graph 36, where it emerges that, according to 76% of hospitals users, security issue would not prevent them for exploiting smart technologies.



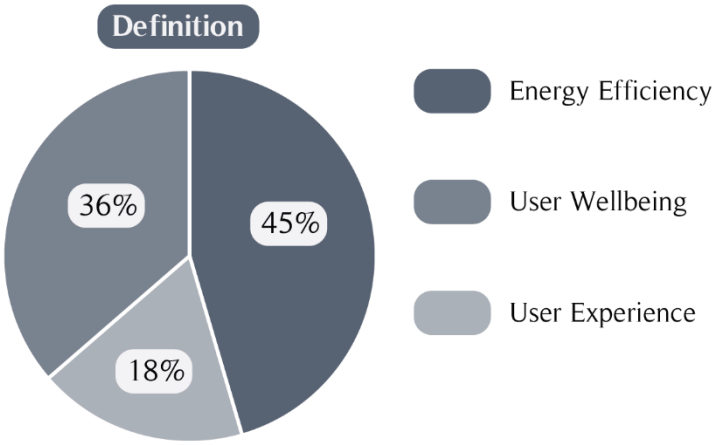
Graph 36: Answers to question n° 13 and 14 by Occupants about Hospitals. (Source: the author)

Privacy is perceived as a strong problem by 24% among interviewed who affirm to be highly scared by the fact that smart technologies lead to privacy reduction.

Considering all the answers, occupants of hospitals would define a Smart Building as foscused on user wellbeing and think that this topic is also its most important feature. For what regards technologies, the preferred one are the smart bins (followed by wayfinding and by monitoring of air quality) and the ones perceived as less useful are the communication with the facility manager and the personalised notifications on smartphones and wearables. Cost increment related to smart technology is envisioned to be between 10% and 20%, and this is the main element discouraging the implementation of smart systems. This category of respondents is not completely scared by security and privacy issues, and they believe in modern protection systems.

Industrial Buildings

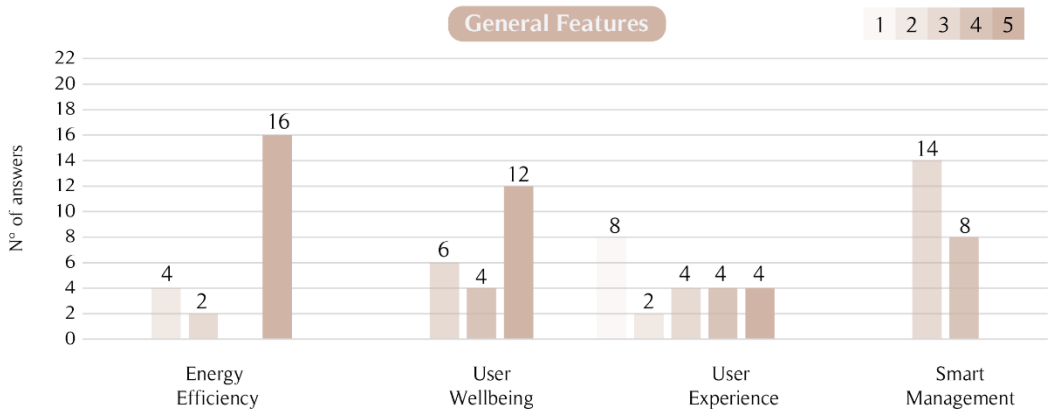
Among the 125 occupants answering the questionnaire, 22 of them selected, in question n°4, Industrial building as the typology in which they mainly operate.



Graph 37: Answers to question n° 6 by Occupants about Industrial buildings. (Source: the author)

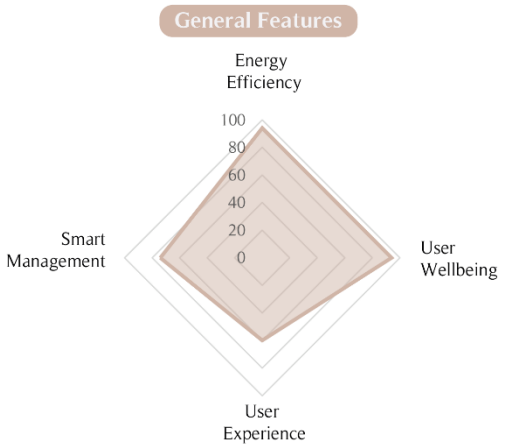
Energy efficiency and user wellbeing register almost the same amount of preferences when dealing with industrial buildings. Respectively, they obtained 45% and 36% of choices. The digital twin option, as for others building typologies, has never been selected.

4 points is the average score registered by the proposed general features in question n°7a. User wellbeing is the option collecting more 5 points (19), but energy efficiency received only 4 and 5 points, meaning that it is perceived as really important by users of industrial buildings. In general, 43,6% of respondents assigned 5 points to the proposed options, and only 3,6% chose the one-point score.



Graph 38: Answers to question n° 7a (General Features) by Occupants about Industrial buildings. (Source: the author)

Coherently with what emerged in Graph 37, Graph 39 displays that the User wellbeing and energy efficiency general feature are considered equally important inside a smart industrial building. User experience is pretty close to the highest score obtained by the overmentioned features, even if the latter one was selected only by 18% of interviewed people when questioned about the Smart Building definition.



Smart Technologies	Score Tot.
Energy Efficiency	**94**/110
User Wellbeing	**94**/110
User Experience	**60**/110
Smart Management	**74**/110

Graph 39: Radar Chart and Total scores of question n°7a. (Source: the author)

For what regards the different technologies available for a Smart Buildings, they are investigated from question n°7b to n° 7d, and divided in thematic areas (energy efficiency, user wellbeing, user experience and smart management of people and data).

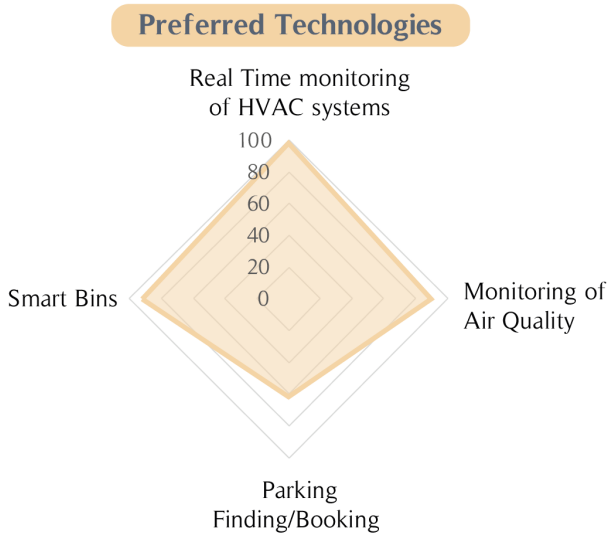
The options of question n° **7b** – technologies related to energy efficiency – registered an average score equal to 4,0. 3,6% of respondents assigned 1 point to the proposed options and a very high percentage (43,6%) of interviewed people decided to choose the 5 points option. This means that all the general features proposed are perceived as important by industrial buildings users. The preferred technology is the real time monitoring of HVAC systems (98/110), followed, with a close score, by real time monitoring of consumptions (92/110).

Question n° **7c** deals with user wellbeing issue. The average score obtained by these technologies is 3,0 points, pretty low if compared to the other building typologies. This is in contrast with results showed in Graphs 37, 38 and 39. Moreover, differently from all the other answers analysed until now, the score that registered the highest amount of preferences is the one-point option: 29,1% against the 27,3% received by the 5 points. The air quality monitoring is the option registering the highest score (90/110), followed by the acoustic comfort monitoring (86/110) and the personalized setting of temperature (62/110).

For what regards the technologies related to the User experience (question n°**7d**), they registered the lowest average score (2,5 points), in accordance with what emerged from question n°6 – displayed in Graph 37. 4 and 5 points obtained a low amount of preferences (12,1% and 6,1%, respectively), and the one-point option has been chosen by many respondents: 39,4%. The preferred technology of this set is, even if with a very low score, the parking finding/booking.

The smart management of object and data is the theme of question n°**7e**. The average score of these options is second only to the one registered by the energy efficiency related technologies (3,5 points), with 11,8% of respondents assigning one point. 21,2% and 24,2% of the answers have been, respectively, registered for the four and five points options. The most rated option are the Smart Bins (92/110).

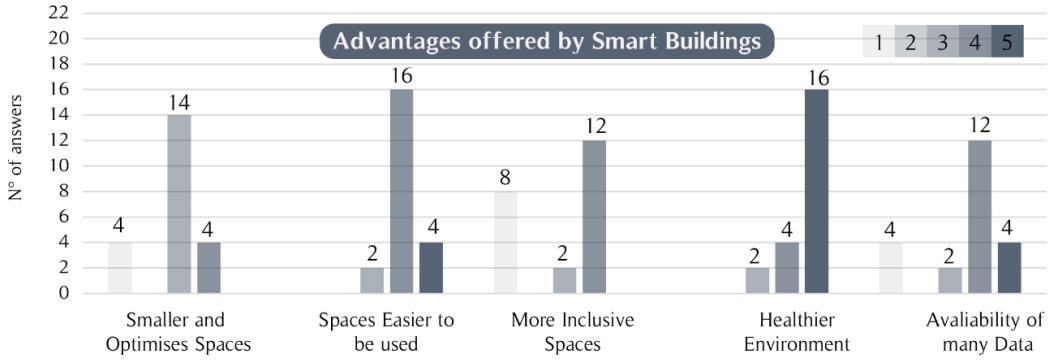
Considering the preferred technologies for thematic area, the one registering the highest score are the real time monitoring of HVAC systems. This is an expectable result, considering the fact that the energy efficiency is evaluated as the possible definition of a Smart Building. It is important to point out that parking finding/booking is the technology receiving only 62 points, very far from the 90/110 registered by the monitoring of air quality.



Smart Technologies	Score Tot.
Real Time Monitoring of HVAC systems	**98**/110
Monitoring of Air Quality	**90**/110
Parking Finding/Booking	**62**/110
Smart Bins	**92**/110

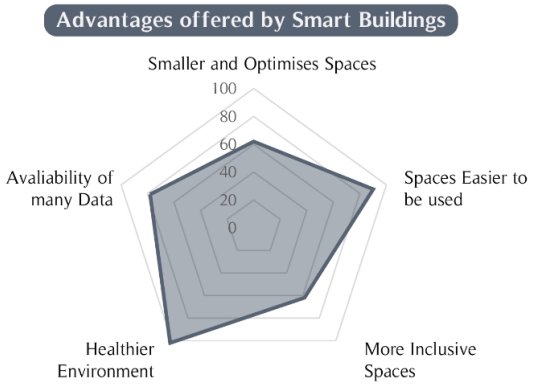
Graph 40: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

Graph 41 reports the results of question n°8, related to the advantages offered by smart buildings. The average score is 3,6 points., indicating that industrial buildings' occupants feel that Smart technologies offer many advantages: spaces that are smaller, optimised, easier to be used, more inclusive and healthier. 43,6% of respondents assigned a score equal 4 points and none decided to choose the two-points option.



Graph 41: Answers to question n°8 (Advantages) by Occupants about Industrial buildings. (Source: the author)

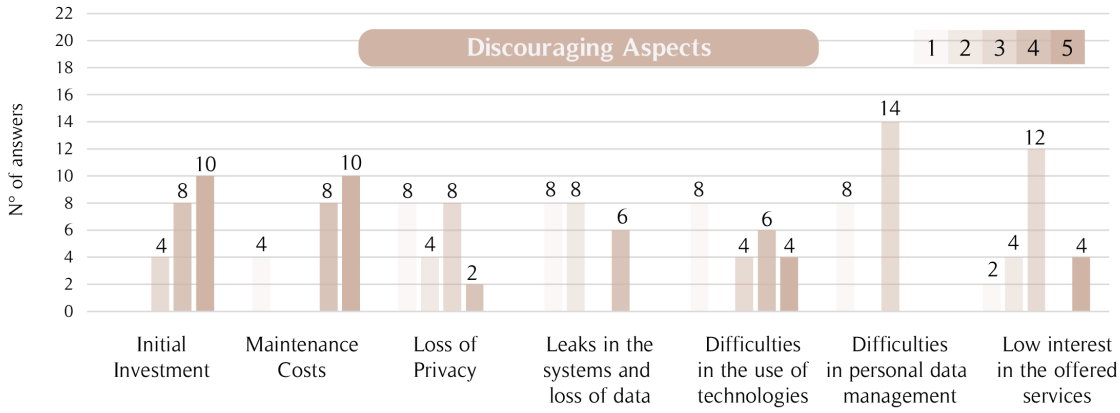
Also for industrial buildings, the healthier environment is the characteristic more appreciated of a Smart building, followed by spaces easier to be used and availability of many data.



Advantages	Score Tot.
Smaller and Optimises Spaces	**62**/110
Spaces Easier to be used	**90**/110
More Inclusive Spaces	**62**/110
Healthier Environment	**102**/110
Avaliability of many Data	**78**/110

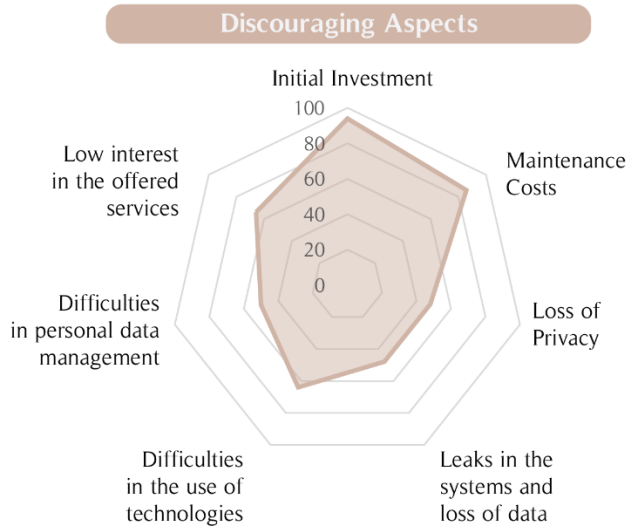
Graph 42: Radar Chart and Total scores of question n°8. (Source: the author)

For what regards the discouraging aspects, they registered, on average, a score equal to 2,9. Users' perception is that the advantages offered by a Smart Industrial building are more relevant that the negative aspect related to its implementation. Confirming this, only 18,2% of respondents assigned 5 points to the propose discouraging aspect.



Graph 43: Answers to question n° 12 by Occupants about Industrial Buildings. (Source: the author)

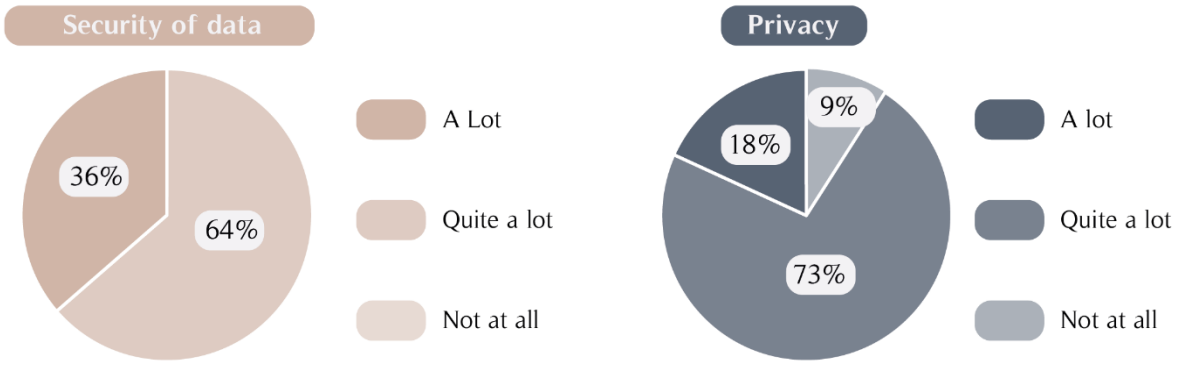
Initial investment and maintenance cost are the aspects perceived as more discouraging, among the ones proposed, registering, respectively, 94 and 86 points on a total of 110. The loss of privacy is the option to which respondents assigned the lowest score, and this is confirmed in Graph 45, where it emerges that, according to 73% of hospitals users, security issue would not prevent them for exploiting smart technologies.



Discouraging Aspects	Score Tot.
Initial Investment	**94**/110
Maintenance Costs	**86**/110
Loss of Privacy	**48**/110
Leaks in the systems and loss of data	**48**/110
Difficulties in the use of technologies	**64**/110
Difficulties in personal data management	**50**/110
Low interest in the offered services	**66**/110

Graph 44: Radar Chart and Total scores of question n°12. (Source: the author)

As said, privacy is not perceived as a strong problem: only 18% among interviewed people affirm to be highly scared by the fact that smart technologies lead to privacy reduction.



Graph 45: Answers to question n° 13 and 14 by Occupants about Industrial Buildings. (Source: the author)

Considering all the answers, occupants of industrial buildings would define a Smart Building as focused on energy efficiency and think that this topic is also its most important feature, together with user wellbeing. For what regards technologies, the preferred one is the real time monitoring of HVAC systems (followed by smart bins and by monitoring of air quality) and the ones perceived as less useful are the wayfinding / people finding and the personalisation of furniture.

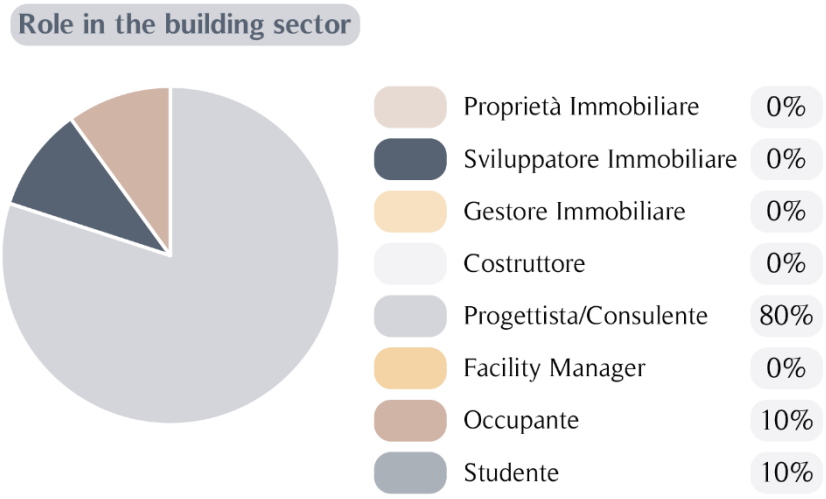
3.3.2 The answers – Operators of the building sector

78 Operators of the building sector answered the survey, and their answers are subdivided according to the building typology they refer to. As for answers of occupants, the results related to some of the building typologies are not presented because there is not a significant sample of respondents answering for that typology (the "significant sample" that it has been taken as limit are 10 people).

Educational Centres

10 Operators of the building sector answered to the survey, indicating as building typology in which they mainly operate the Educational Centres.

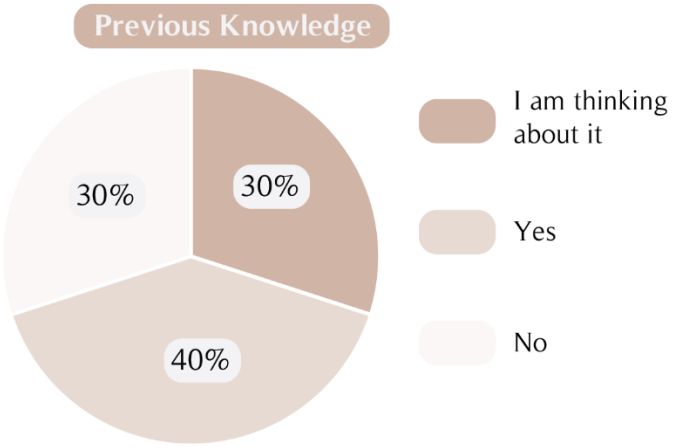
When analysing answers of field experts, question n°3 is considered, in order to point out which is the role of respondents. In case of educational centres, the results are reported in Graph 46. In case of these 10 respondents, 80% of them are designer or consultant, and the remaining 20% are occupants/students.



Graph 46: Answers to question n° 3 by Operators of the building sector about Educational Centres. (Source: the author)

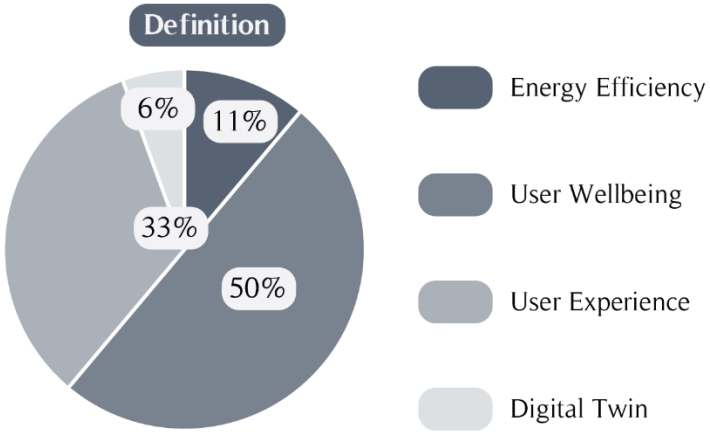
Another question that was not considered in case of occupants but that now it is interesting to look at, is the n° 5, dealing with a previous knowledge of the Smart Building topic: *"Have you ever taken part to the design of a Smart Building, or are you thinking of implementing a project with smart technologies?".* The answers to this question are useful because they allow to understand if the Smart building topic is a common issue among operator of building sector or if it is something that they do not know at all.

For what regard educational centres, the answers to question n°5 are homogeneous: 40% of respondents declare they already implemented smart technologies in their projects, 30% affirm to have never used these new systems and the remaining 30% is thinking about doing that. This means that at least 70% of them know what a Smart Building is an some of the technologies involved in its design and construction.



Graph 47: Answers to question n° 5 by Operators of the building sector about Educational Centres. (Source: the author)

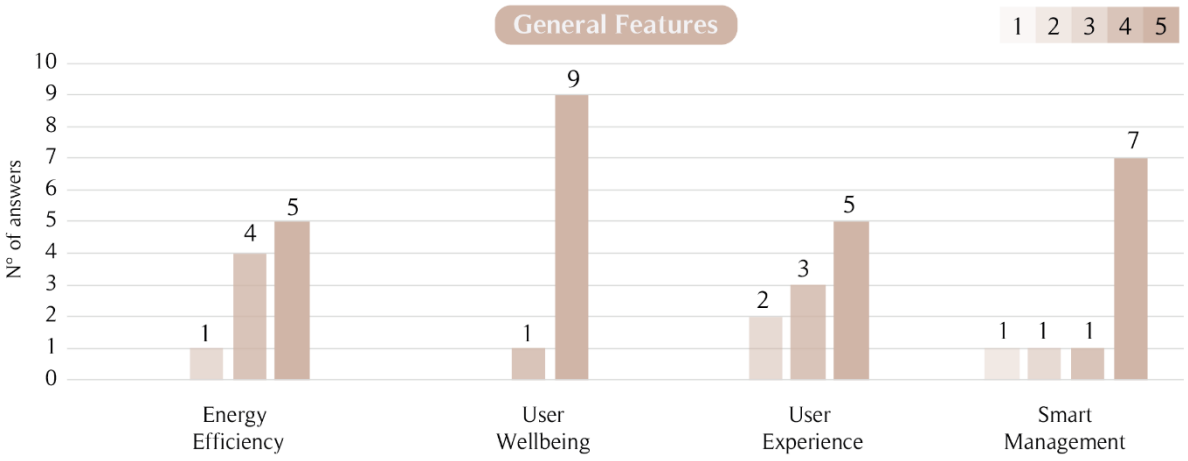
Question number 6 deals with the possible definition of a Smart Building. In case of **Operators of the building sector**, half (50%) intend a Smart Building as an Energy Efficient one. This may seem in contrast with the tendency of this market, going towards the Users' Wellbeing-focused technologies, but it is fundamental to point out that this is such a new and emerging topic that is not surprising that who operates in this sector for a long time is still focused on what he has done for a long time (70% of these 10 respondents is over 30 years old, meaning he has quite a long experience in his work).



Graph 48: Answers to question n° 6 by Operators of the building sector about Educational Centres. (Source: the author)

However, the remaining half of answers is related to present issues, like user wellbeing (33%), User experience (11%) and digital twin (6%).

For what regards the set of questions in which people had to assign a score to different technologies of a Smart Building, the ones related to the User Wellbeing received, on average, the highest scores.



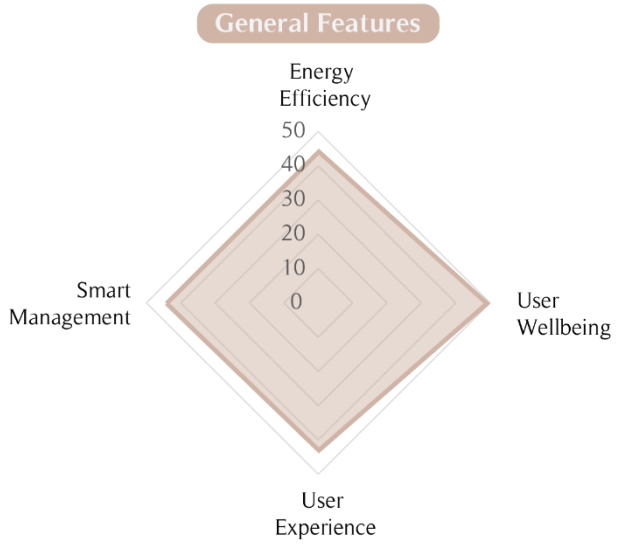
Graph 49: Answers to question n°7a (General Features of Smart Buildings) by Operators of the building sector about Educational Centres. (Source: the author)

The Energy Efficiency is considered as very important by 10 respondents; however, it received also a score equal to 1 (given by only one person). The User Wellbeing as advantage of a Smart Building has been rated with 5 by all respondents except for a single 4 points. This means that, despite when considering the definition there is a diffused idea of a Smart Building as a High Energy Efficiency one, the User Wellbeing is perceived as one of the greatest advantages a Smart Building is able to offer.

To understand which one of the general features proposed received the highest scores, the Graph n° 50 is useful. All the four possibilities (Energy Efficiency, User Wellbeing, User Experience and Smart Management of people and data) are perceived as quite important, with an average score equal to 4,5. More in detail, 65.0% of respondents assigned a score to each option equal to 5, while the 22.5% assigned a value of 4 points to the answer. Only 12,5% decided to rate the proposed general features of a Smart Building with a score equal to 3 or less.

As it can be observed on the Graph n° 50, the Feature that received the highest score is the User Wellbeing, with 49 points out of 50. However, the Energy efficiency and the Smart Management are really close (44/50 for both), coherently with the results reported in Graph 48.

Also the User Experience had been considered as an important characteristics for a Smart Building, in fact it obtained a total score of 43/50, only one point short from the User Wellbeing and Energy efficiency characteristics. These results are slightly different from the ones of the same question given by occupants. In that case, User experience and smart management of object and data received almost 30 points less than the other wo options. This is because simple occupants are less aware of how smart management and user experience technologies may be important in a Smart Building.



General Features	Score Tot.
Energy Efficiency	**44**/50
User Wellbeing	**49**/50
User Experience	**43**/50
Smart Management	**44**/50

Graph 50: Radar Chart and Total scores of question n° 7a (General Features of Smart Buildings). (Source: the author)

After the results related to the general characteristics of Smart Buildings, the perception of users about technologies to be introduced in schools and university is presented. The questionnaire proposes a series of possible smart technologies affecting energy efficiency, user wellbeing, user experience and smart management of people and data.

The preferred technology for each set of answers (from 7b to 7e) is selected, and the four resulting technologies are compared in Graph 51.

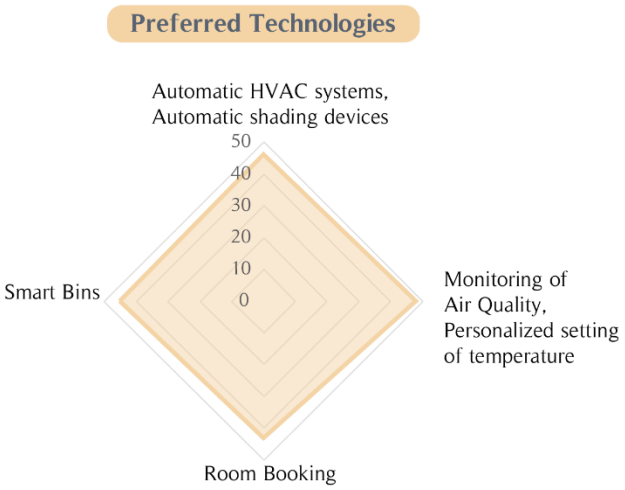
The scores assigned to the smart technologies related to the energy efficiency (**7b**) of the building are significant. Options 1, 2 and 3 points received only 20% of preferences in total. On the other hand, the 5 points option has been selected by 58% of respondents, meaning that all the technologies related to energy efficiency are perceived as important. All the 5 options related to energy efficiency received homogeneous scores, between 36 and 46 on a total of 50 points. The automatic HVAC systems together with automatic shading devices are the most rated technologies (46/50), followed by automated lighting (45/50) and real time monitoring of consumption (41/50)

The second set of smart solutions (**7c**) analysed are the ones related to the user wellbeing. Also in this case, few people assigned low scores (1 and 2) to the proposed technologies. Moreover, the 5 points have been selected by 50% of the users. This is aligned with the answers displayed in Graph 49, where it is visible that the User Wellbeing is rated only with 4 and 5 points. On average, respondents assigned to this set of technologies a score equal to 4.22; this result is close to the one registered by the options related to energy efficiency (4.28 on average). The preferred technology among the ones presented in this set are the Sensors monitoring the air quality. This confirm the tendency towards a healthier lifetime that has been presented in Chapter 2. Good result also for personalized setting of temperature and lighting level, registering a score, respectively, equal to 48/50 and 46/50. Personalized setting of furniture is the option registering the lowest score: only 28/50.

The User experience as general characteristic of a Smart Building has obtained the fourth score, considering all the options of Graph 50. Now specific technologies related to this topic are analysed (**7d**). The average score obtained by this set of technologies is slightly smaller with respect to the previous two sets – 7b and 7c - (3.5); this is coherent with the fact that, both considering the questions 6 and 7a, User experience has not been considered as the fundamental aspect of a Smart Building. Most respondents assigned a score equal to 4 (30%), and only 21.7% selected the 5 points option, that is even less of the percentage of people who chose a score equal to 3 (28.3%) The overall scores obtained by the technologies related to the user experience are pretty low. Keyless entry technologies and personalized advertisements on smartphone or wearables register the lowest score of all the technologies of the entire questionnaire, with 26/50. On the other side, the room booking is perceived as the most useful options among the ones considered in this set of technologies, with a score of 43/550 and 4.3 points received on average.

The fifth set of options (**7e**) is linked to the Smart management of people and data. The average score obtained of this set of technologies is the lowest one: 3.2 points. Only 20% of respondents assigned 5 points, and 24% of them chose the option of 1 point. The greatest contribution to the 3.2 points on average is given by the Smart Bins, which collected 4.5 points on average and 45/50 in total.

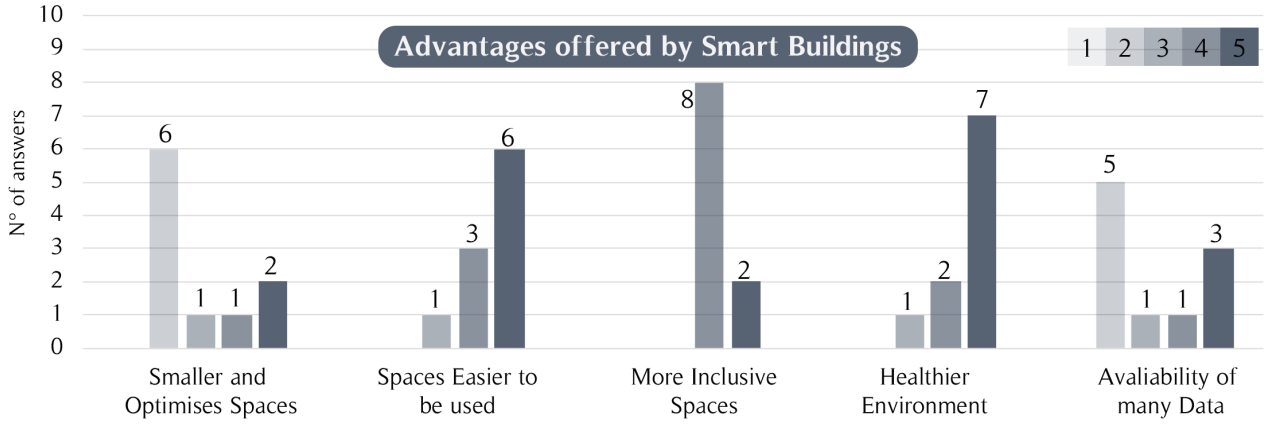
Concluding, looking at Graph 51 it emerges that the scores obtained by the preferred options of each set of answers are similar. The monitoring of air quality and the personalized setting of temperature are, in absolute, the technology rated with the highest score. This is coherent with the fact that the user wellbeing as general feature of a smart building obtained the highest score (Graph 50).



Smart Technologies	Score Tot.
Automatic HVAC systems, Automatic shading devices	**46**/50
Monitoring of Air Quality, personalized setting of Temp.	**48**/50
RoomBooking	**43**/50
Smart Bins	**45**/50

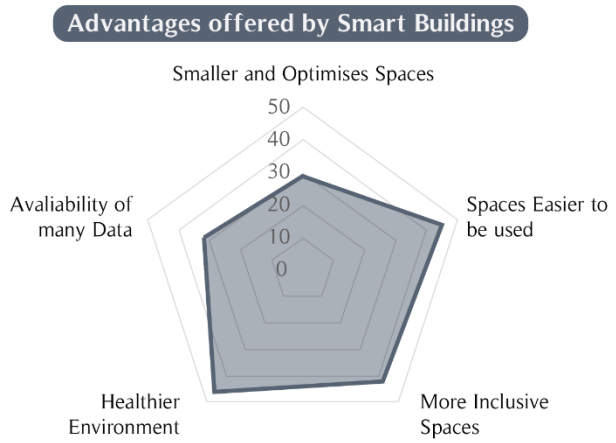
Graph 51: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

Question n° 8 deals with the advantages offered by a Smart Building.



Graph 52: Answers to question n°8 (Advantages) by Operators of the building sector about Educational Centres. (Source: the author)

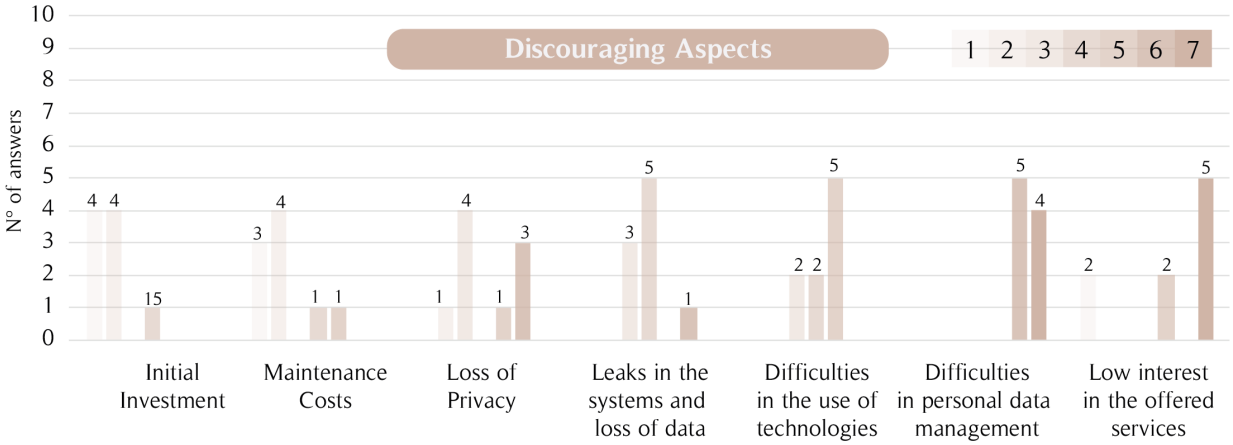
All the proposals received good scores (3.9 on average), and the 70.0% selected 4 or 5 points. The remaining 30% instead, assigned a score of either a 3 or a 2. In accordance with the high score registered by the sensors monitoring air quality (Graph 51), the Healthier Environment is rated as the greatest advantage offered by a Smart Building (46/50), together with a Space Easier to be used (45/50), as it can be perceived by the Graph n°53.



Advantages	Score Tot.
Smaller and Optimises Spaces	**29**/50
Spaces Easier to be used	**45**/50
More Inclusive Spaces	**42**/50
Healthier Environment	**46**/50
Avaliability of many Data	**32**/50

Graph 53: Radar Chart and Total scores of question n° 8 (Advantages). (Source: the author)

Going on with negative aspects of Smart Buildings, respondents had to put in order from 1 to 7 the negative aspects proposed as options. Graph 54 display the results. When reading this graph it is important to consider that if an option receives smaller points (1, 2 or 3) means that it is considered the first, second or third discouraging aspect preventing the implementation of smart systems.

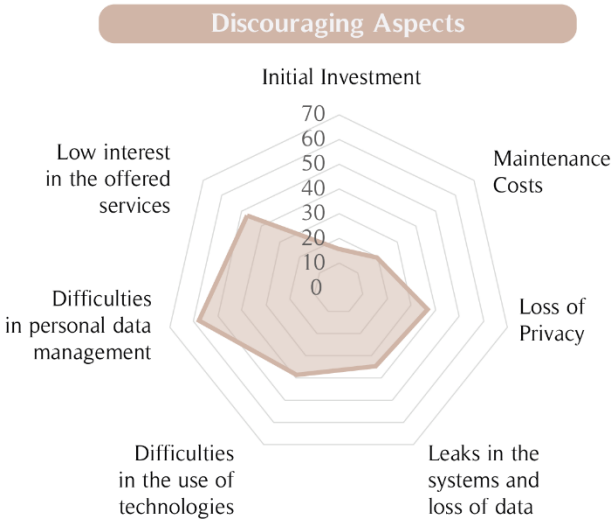


Graph 54: Answers to question n° 12 by Operators of the building sector about Educational Centres. (Source: the author)

It emerges from Graph 54 that Initial investment, maintenance costs and leaks in the systems are the negative aspects perceived as more problematic by operators of building sector when considering educational centres.

This is visible also in Graph 55, where the total scores of each option is clarified. The maximum points it was possible to achieve are 70 (10 respondents times 7 points maximum), and the options registering the lowest scores are, according to this category of respondents, the more problematic.

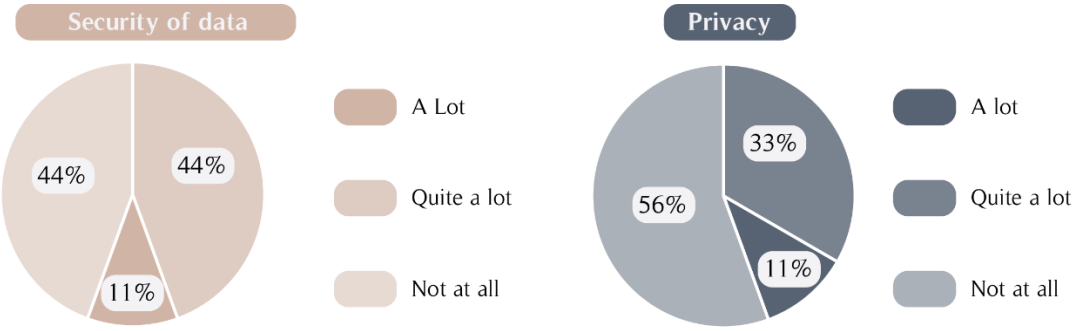
Initial investment is, in absolute, the greatest disadvantage, with a score equal to 16/70. It is followed by maintenance costs (20/70) and leaks in the systems and loss of data (35/70). On the other hand, Difficulties in personal data management and low interest in the offered services are not perceived as relevant issue when deciding of implementing smart technologies.



Discouraging Aspects	Score Tot.
Initial Investment	**16**/70
Maintenance Costs	**20**/70
Loss of Privacy	**37**/70
Leaks in the systems and loss of data	**35**/70
Difficulties in the use of technologies	**39**/70
Difficulties in personal data management	**58**/70
Low interest in the offered services	**47**/70

Graph 55: Radar Chart and Total scores of question n° 12. (Source: the author)

Finally, security and privacy issue are analysed.



Graph 56: Answers to question n° 13 and 14 by Operators of the building sector about Educational Centres. (Source: the author)

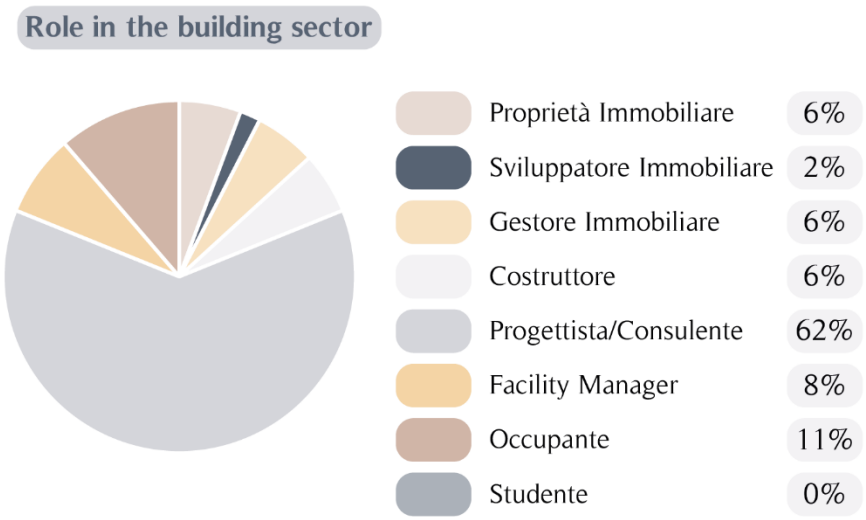
A good result for what regards the perception of users towards smart technologies is registered, when considering occupants and educational centres. For what regards Security, almost all of respondents (88%) trust in in the security systems and prefer to exploit advantages offered by smart technologies rather than not using them at all, while referring to the Privacy topic, more than half of the answers (56%) instead have shown an opposite behaviour, preferring to keep the privacy instead of having different benefits.

Summarizing, users of educational centres would define a Smart Building as a high-energy efficiency one and think that the user wellbeing is its most important feature. For what regards technologies, the preferred one are the monitoring of air quality and the personalized setting of temperature (followed by automatic HVAC systems and smart bins) and the ones perceived as less useful are the keyless entry technologies and the personalized advertisement on smartphone or wearable.

Cost increment related to smart technology is between 5 and 10% and it is the main element discouraging the implementation of smart systems. This category of respondents is not completely scared by security and privacy issues, and they believe in modern protection systems.

Offices

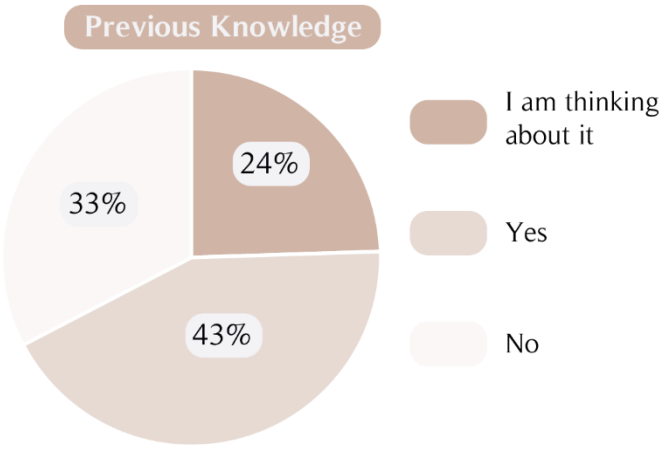
Among the 78 respondents, 49 selected offices as building typology in which they mainly operate. The analysis of these answers displays some differences with respect to what emerged from the Educational centres' experts.



Graph 57: Answers to question n° 3 by Operators of the building sector about Offices. (Source: the author)

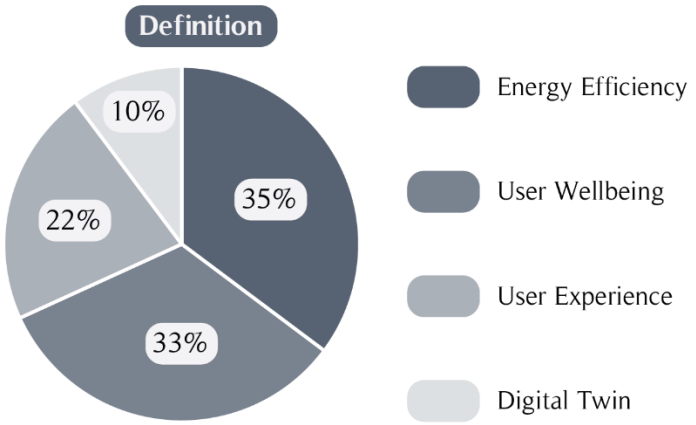
For what regards the role in the building sector of respondents, they are mainly designer/consultants (62%), with few builders, facility managers and building managers.

For what regard offices, the answers to question n°5 are homogeneous: 43% of respondents declare they already implemented smart technologies in their projects, 33% affirm to have never used these new systems and the remaining 24% is thinking about doing that. This means that at least 67% of them know what a Smart Building is an some of the technologies involved in its design and construction.



Graph 58: Answers to question n° 5 by Operators of the building sector about Offices. (Source: the author)

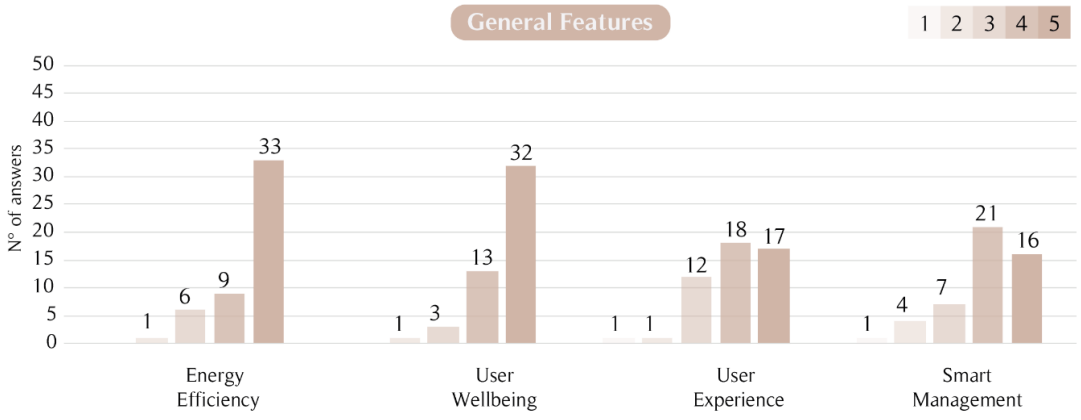
The first major difference appears when considering the definition of a Smart Building. While in case of educational centres the energy efficiency topic was selected by half of respondents, in this case only 35% of them would define a smart building as a high energy efficiency one. On the other side, 55% believes that a smart building is connected to the User (his wellbeing and experience).



Graph 59: Answers to question n° 6 by Operators of the building sector about Offices. (Source: the author)

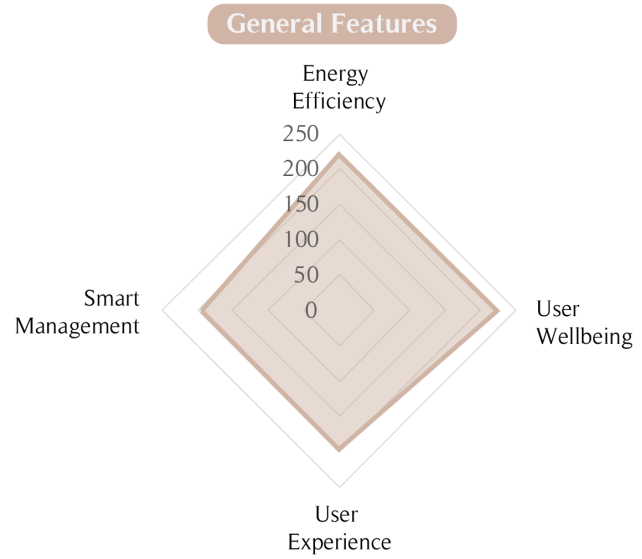
Almost half of people operating in office buildings perceives a Smart Building as something focused on the User. Energy Efficiency maintains a good percentage (35%), but it is not the preferred definition as it is in case of Educational Centres. These results are confirmed by the answers of question n°7a, as displayed in Graph 60.

The user Wellbeing is rated mainly with 5 points, meaning that this is a very important and essential topic when dealing with Smart Buildings, according to users of offices. In general, 50% of respondents assigned a score equal to 5, 31,1% preferred the 4 points and only 1,0% decided to select the 1 point option. This means that the proposed features are considered as pretty important inside a building to be defined smart.



Graph 60: Answers to question n° 7a (General Features) by Operators of the building sector about Offices. (Source: the author)

User Wellbeing and Energy Efficiency received the highest scores (223/245 and 221/245, respectively) as Graph 61 shows. The Smart management registers the lowest score, but 194/245 can be still considered as a good result.



General Features	Score Tot.
Energy Efficiency	**221**/245
User Wellbeing	**223**/245
User Experience	**196**/245
Smart Management	**194**/245

Graph 61: Radar Chart and Total scores of question n° 7a. (Source: the author)

Question **7b** is the first one focused on Smart Technologies, linked to the Energy Efficiency feature.

For this set of answers, 0% of respondents assigned 1 as score for the proposed technologies and 81,2% of interviewed people selected 4 or 5 points. The Real time monitoring of HVAC systems is the option that received the highest number of 5-points answers, followed by the real time monitoring of consumptions and the automatic lighting.

The real time monitoring of HVAC system is the most rated option, with a score of 222/245. All the other proposed systems obtained a result that is very close to the best one, and this means that according to offices occupants, all these smart technologies related to energy efficiency are important inside a smart building.

The sensors monitoring the Air quality are the most rated smart technology for what concerns the User Wellbeing (**7c**). They received 29 times a score equal to 5 points. Considering the overall results, in this set of answers 2% of respondents selected one point. At the same time, 69.4% of respondents assigned a score equal to 4 or 5.

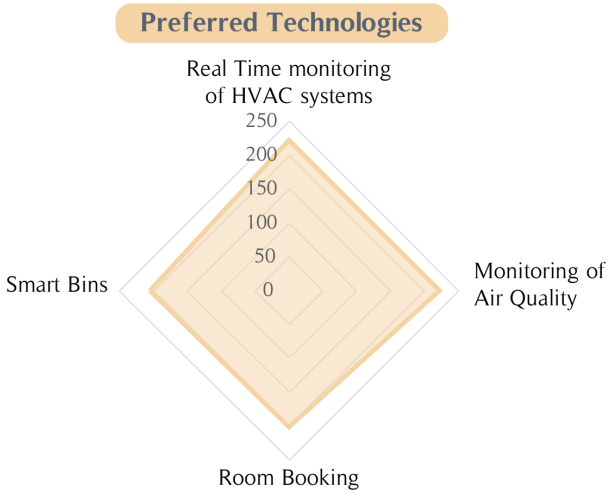
In accordance with the results presented in Graph 62, the sensors monitoring the air quality are the options that received the highest overall score, equal to 222/245. Almost everyone assigned it 5 or

4 points, meaning that the Health conditions inside the office are perceived as a very important element to be considered in a Smart Building.

Even though the User experience is not the feature that received the highest number of preferences for what regards the definition of a Smart Building, some of the technologies related to this topic are perceived as quite important inside a Smart Office (**7d**). More in detail, room booking received 39 times a score equal to 4 or 5 points. The most assigned score are the four points, chose by 38.4% of respondents. 3.1% of people selected the one-point option, and only 18.7% of them assigned 5 points to the proposed option (more or less the half of respondents with respect to questions 7a, b and c.

The set of technologies connected to the User Experience topic is the one that received the overall lowest scores. The room booking is the preferred feature (202/245), followed by Easy Visit and wayfinding. These results are slightly different from what has been noted when dealing with office occupants: their preferred technology is the parking finding/booking, that in the case of operators of building sector received the second lowest score (171/245).

The answers related to the smart management (**7e**) given by office occupants are similar to the one of students in schools: Smart Bins received a very high number of 5-points answers, meaning that the issue of sustainability and environmental impact is considered important. 0,8% of respondents assigned one points to the proposed options, and 64,5% selected 4 or 5 points option. The smart Bins obtained the highest score of this set of options (206/245 and 210/225). All the others smart technologies connected with the smart management of objects and data are far from this result, with a minimum score equal to 169/245 for the 3D archive or administrative documentation.

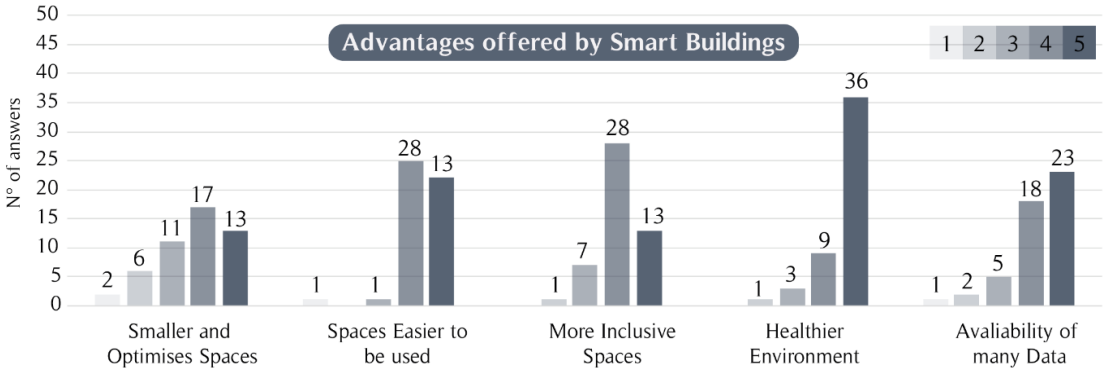


Smart Technologies	Score Tot.
Real Time Monitoring of HVAC systems	**222**/245
Monitoring of Air Quality	**222**/245
RoomBooking	**202**/245
Smart Bins	**206**/245

Graph 62: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

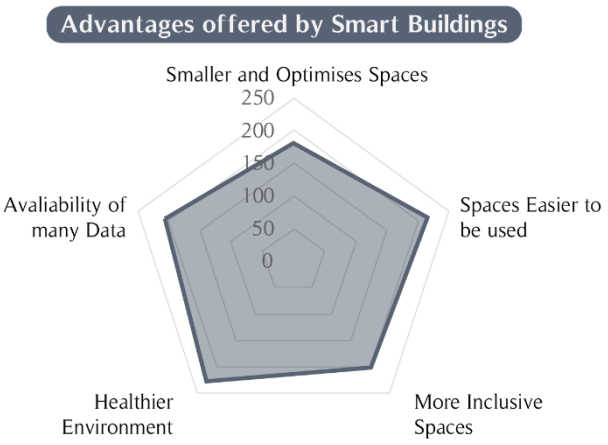
Graph 62 summarizes and compares the preferred technologies inside a smart office. The monitoring of air quality and real time monitoring of HVAC systems lead the ranking. Room booking and smart bins register a good score, higher than 200 points (202 and 206 points, respectively). These results are different from what emerged from answers given by office occupants. According to them, smart bins are the preferred technology, followed by monitoring of air quality and real time monitoring of HVAC systems. The health issue is perceived as a fundamental aspect of the development of Smart Offices. This is confirmed in the answers to question n°8, and it is visible in Graph. 63. The Healthier Environment option collected 36 preferences to the 5-points score.

In general, all the proposed options are positively seen by respondents, who rated them with 4 and 5 points with a percentage 83.3% of the answers.



Graph 63: Answers to question n° 8 (Advantages) by Operators of the building sector about Offices. (Source: the author)

The greatest advantage of a Smart Building is, accordingly to experts dealing with office buildings, to have a healthier. This is coherent with the fact that they believe also that User Wellbeing is the essential feature of a building to be defined smart. Moreover, this result is compliant to the ones displayed in Graphs 59, 60 and 61.

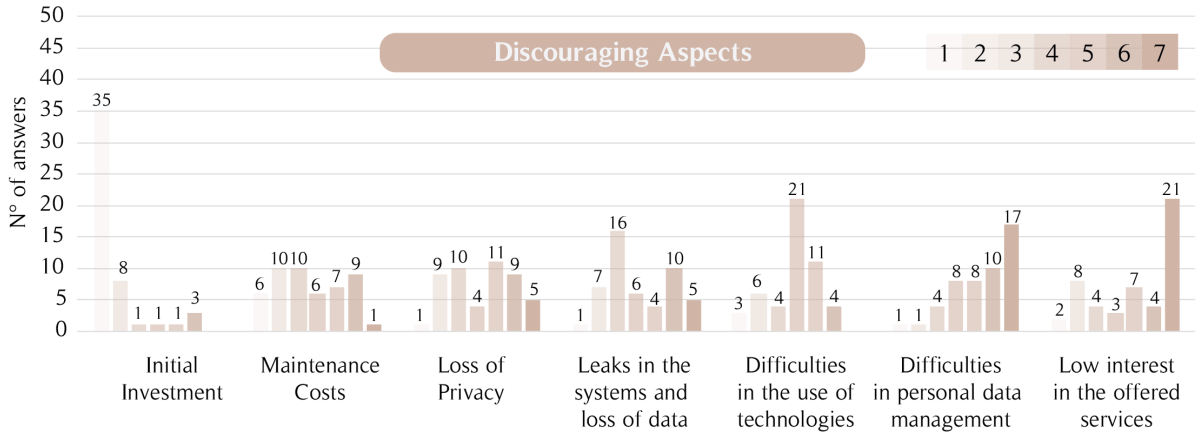


Advantages	Score Tot.
Smaller and Optimises Spaces	**180** /245
Spaces Easier to be used	**214** /245
More Inclusive Spaces	**200** /245
Healthier Environment	**227** /245
Avaliability of many Data	**207** /245

Graph 64: Radar Chart and Total scores of question n°8. (Source: the author)

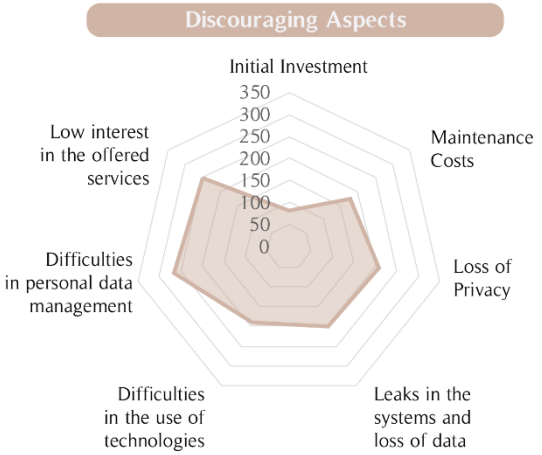
The smart buildings offer the possibility, according to this class of respondents, to have spaces that are easier to be used (214/245) and to have many data available for further improvement in building operations (207/245). These aspects are not rated so positively by simple occupants of buildings, because they are not aware of their importance from a technical point of view.

Question n° 12 deals with those aspects related to Smart Buildings that people perceive as discouraging from the implementation of Smart systems. As for educational centres, also for what regard office buildings the initial investment is considered as the greatest negative aspect derived from smart technologies implementation.



Graph 65: Answers to question n° 12 (Discouraging Aspects) by Operators of the building sector about Offices. (Source: the author)

Initial investment has been selected as first discouraging aspect by 35 respondents, followed by maintenance costs with only 6 people putting it on first place. This is an interesting indicator of the fact that promoter of smart technologies should focus the attention on the future return that smart systems are able to offer.

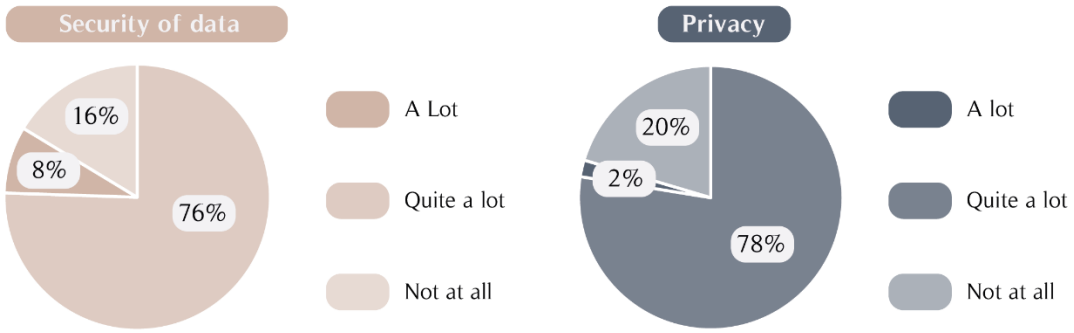


Discouraging Aspects	Score Tot.
Initial Investment	**81**/343
Maintenance Costs	**176**/343
Loss of Privacy	**209**/343
Leaks in the systems and loss of data	**202**/343
Difficulties in the use of technologies	**190**/343
Difficulties in personal data management	**266**/343
Low interest in the offered services	**248**/343

Graph 66: Radar Chart and Total scores of question n°12. (Source: the author)

Low interest in the offered services registers the highest scores (248/343 and 131/225) meaning that the smart technologies are appealing to the majority of building sector operators.

Security and privacy are not perceived an insurmountable problem, and the majority of respondents (92% and 98% respectively) prefer to exploit advantages offered by smart technologies

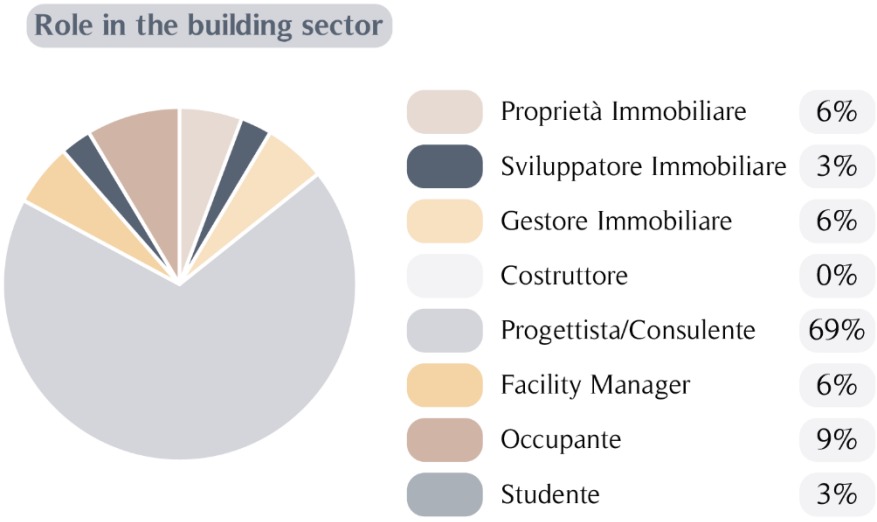


Graph 67: Answers to question n° 13 and 14 by Operators of the building sector about Offices. (Source: the author)

In conclusion, occupants of offices would define a Smart Building as focused on User Wellbeing and experience and think that wellbeing is its most important feature. The preferred technologies are monitoring of air quality and real time monitoring of HVAC systems and the ones perceived as less useful are the keyless entry technologies and the 3D archive of administrative documentation. Cost increment related to smart technology is envisioned to be between 10% and 20%, and this is the main element discouraging the implementation of smart systems. This category of respondents is not scared at all by security and privacy issues, and they believe in modern protection systems.

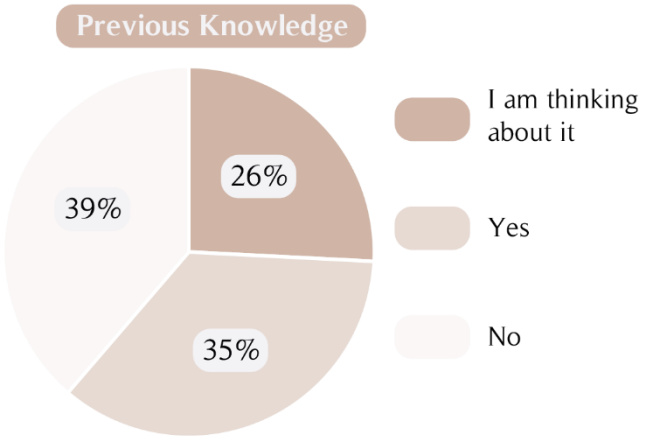
Residential Buildings

30 respondents selected the residential buildings as one of the building typologies in which they mainly operate. For what regards the role in the building sector, as for the other categories of respondents, the majority of them are designer/consultants (69%)



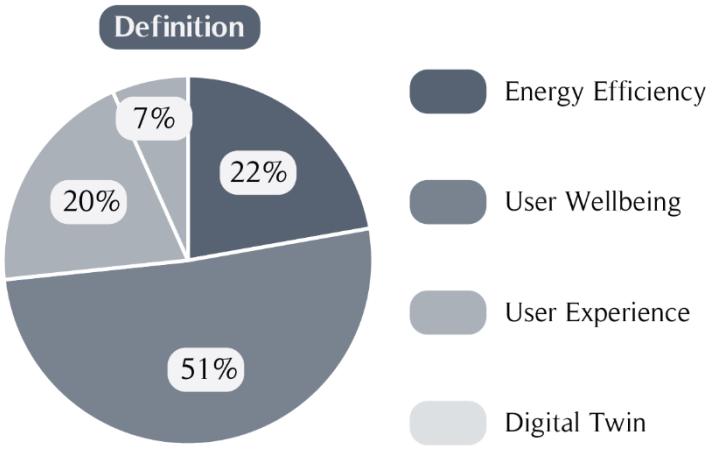
Graph 68: Answers to question n° 3 by Operators of the building sector about Residential Buildings. (Source: the author)

As for educational centres and offices, also in residential buildings the answers to question n°5 are homogeneous: 35% of respondents declare they already implemented smart technologies in their projects, 39% affirm to have never used these new systems and the remaining 26% is thinking about doing that. This means that at least 61% of them know what a Smart Building is an some of the technologies involved in its design and construction.



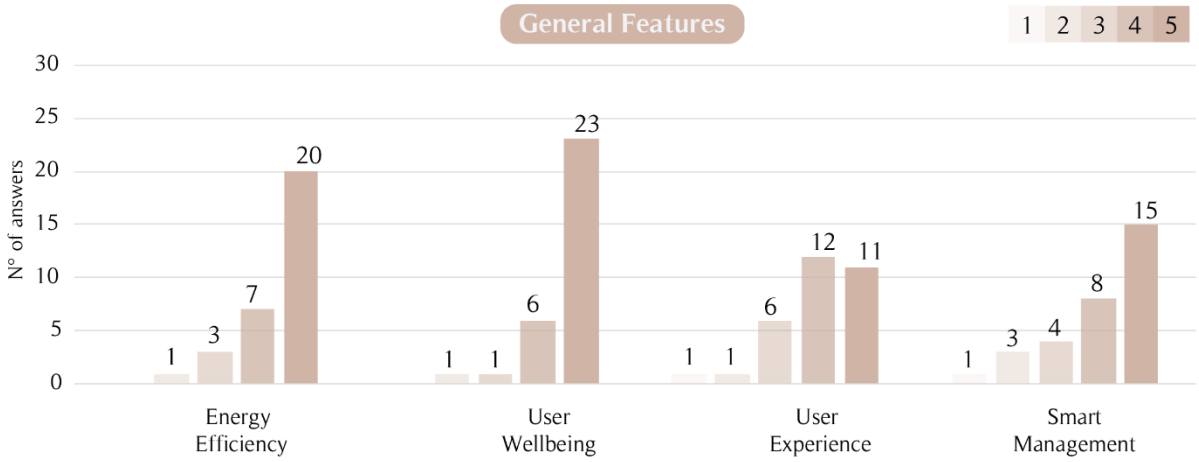
Graph 69: Answers to question n° 5 by Operators of the building sector about Residential Buildings. (Source: the author)

Completely in contrast with Occupants' answers (45% of them selected energy efficiency as definition of a Smart Building), in case of building sector operators the majority (55%) think that a smart building is focused on user wellbeing. Energy efficiency registered only 22% of choices, followed by user experience (20%) and digital twin (7%).



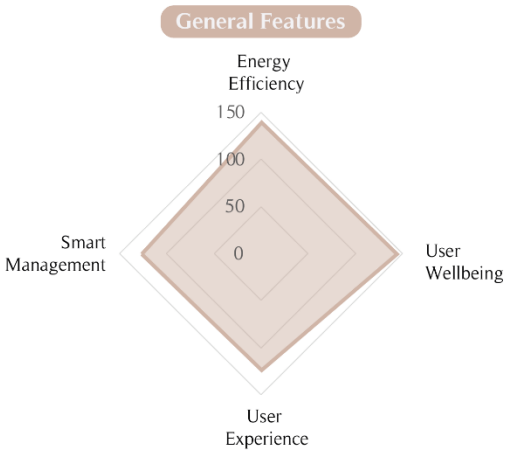
Graph 70: Answers to question n° 6 by Operators of the building sector about Residential Buildings. (Source: the author)

These numbers are confirmed in the answers to question n°7a (Graph 71): 23 respondents assigned 5 points to the user wellbeing. The average score obtained by the general features is 4.3, meaning that all of the options are perceived as fundamental characteristic of a smart building. Moreover, 82.2% of respondents assigned 4 and 5 points to the proposed options.



Graph 71: Answers to question n° 7a (General Features) by Operators of the building sector about Residential

Considering the same question (n°6) for occupants of residential buildings, the answers registered for experts of the building sector are similar. Also in case of occupants, the user wellbeing is the general feature registering the highest amount of respondents assigning it 5 points.



General Features	Score Tot.
Energy Efficiency	**139**/150
User Wellbeing	**144**/150
User Experience	**124**/150
Smart Management	**126**/150

Graph 72: Radar Chart and Total scores of question n°7a. (Source: the author)

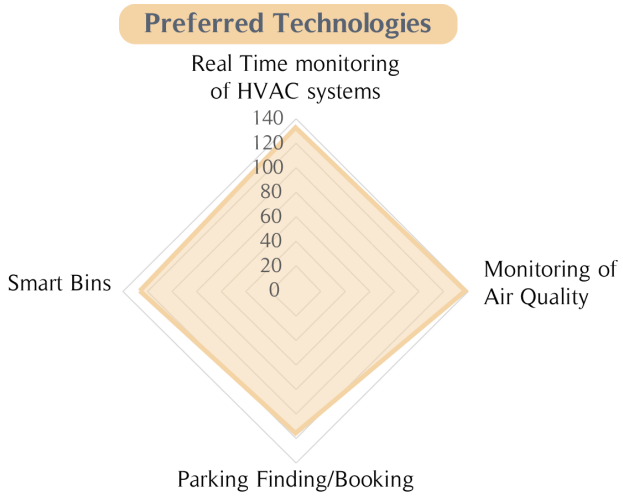
Graph 72 displays the scores obtained by the different general features: the user wellbeing is the option registering the highest score with 144 points, followed by energy efficiency (139) and smart management of object and data (124). User experience collected the lowest score, with only 18 points less than the 144 obtained by the user wellbeing.

The results of question n° **7b**, about energy efficiency, shows that there is not a strong predominance of one technology on the others. 4 and 5 points registered more or less the same percentage of preferences (32.3% and 44.5%, respectively). The average score assigned to the energy efficiency related technology is equal to 4.1 points. Two of the five proposed technologies obtained almost the same score: real time monitoring of HVAC systems and real time monitoring of consumptions (133 and 132 points, respectively). It follows the automatic HVAC systems (130/150), automatic lighting (128/150) and automatic shading systems (121/150).

Question **7c** is related to user wellbeing. The average score obtained by this set of answers is 3.9 points, slightly lower than what has been obtained by energy efficiency related technologies (4.1 points). This is in contrast with answers to question n°6 displayed in Graph 70. The preferred technology dealing with user wellbeing are, again, the sensors monitoring the air quality, which obtained a score much higher than the other options. It follows personalized setting of temperature (126/150) and the personalized setting of lighting level (124/150)

3.5 points is the average registered by the technologies related to user experience (**7d**). Much more respondents assigned one point to the proposed options, if considering the other typologies of systems: 3.8% is the percentage of users assigning 1 point, and only 20,4% of them preferred to give 5 points to the user experience related technologies. The parking finding/booking leads the ranking of this set of options, registering 116/150 points. The second classified is Easy Visit (111/150) while the less appreciated option are the keyless entry systems (97 points).

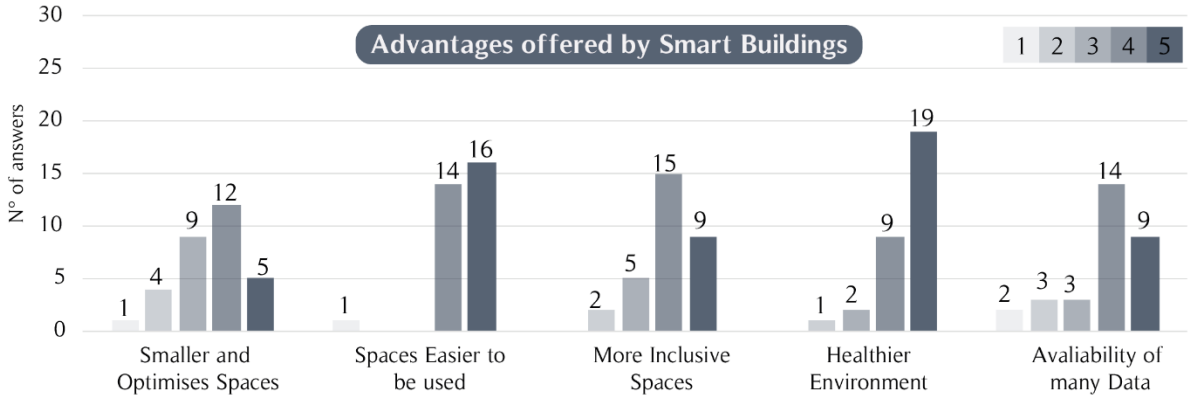
Finally, the last set of technologies deals with the smart management of object and data (**7e)**. 3.8 points is the average score and most assigned score to this systems are 4 points (38.1%). The preferred option are the smart bins, similarly to the results for educational centres and offices, with a score equal to 126 points. With only 5 points less, it follows the smart cleaning (121/150).



Smart Technologies	Score Tot.
Real Time Monitoring of HVAC systems	**133**/150
Monitoring of Air Quality	**138**/150
Parking Finding/Booking	**166**/150
Smart Bins	**126**/150

Graph 73: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

The preferred technologies for each gathegory are summarized in Graph 73. Despite the fact that user experience registered the lowest score as general feature of a Smart Building (Graph 72), the parking finding/booking is the technology that received the highest score, followed by monitoring of air quality and real time monitoring of HVAC systems

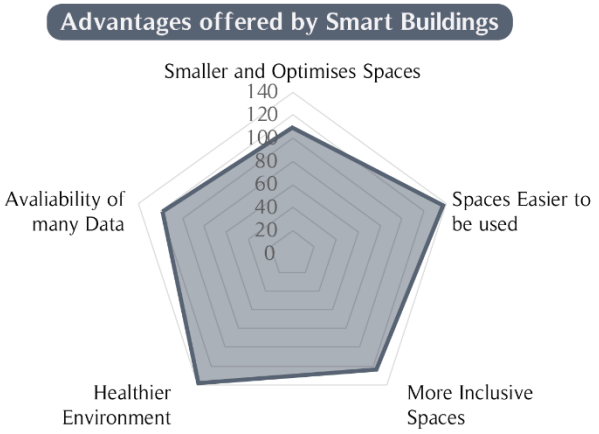


Graph 74: Answers to question n°8 (Advantages)) by Operators of the building sector about Residential Buildings. (Source: the author)

Graph 74 displays the answers to question n°8, related to the advantages offered by a Smart Building. The healthier environment is he option registering the highest quantity of 5 points (19), and it is also the option with the higest total score (139/150). In general, all the mentioned

advantages are percieved important, and 78.7% of respondents assigned a score equal to 4 or 5 points.

The spaces easier to be used registers the second highest score, equal to 137/150 points, followed by more inclusive spaces and the availability of many data. This ranking is exactly the same obtained by the advantages when considering occupant of residential buildings.

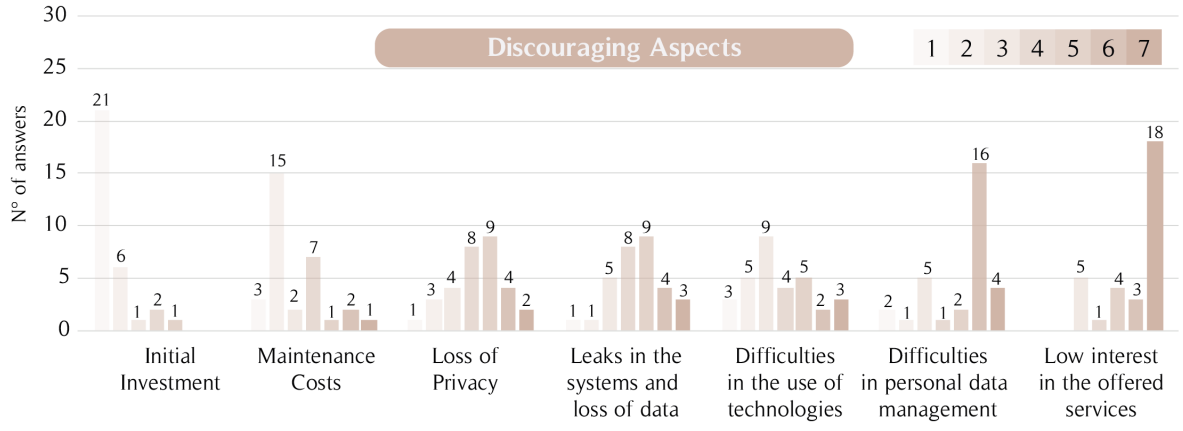


Advantages	Score Tot.
Smaller and Optimises Spaces	**109**/155
Spaces Easier to be used	**137**/155
More Inclusive Spaces	**124**/155
Healthier Environment	**139**/155
Avaliability of many Data	**118**/155

Graph 75: Radar Chart and Total scores of question n°8. (Source: the author)

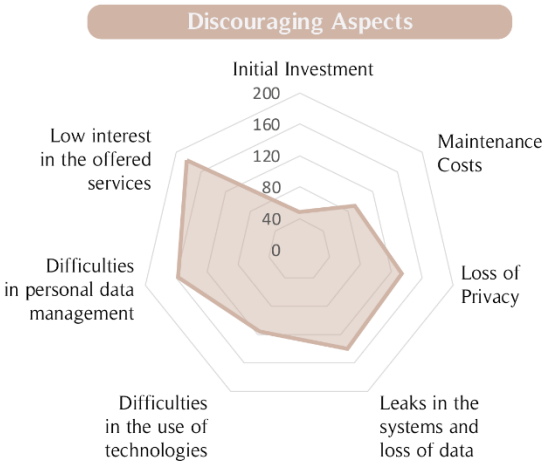
On the other side, also the negative aspects are considered, and the answers to question n° 12 are displayed in Graph 76.

Similarly to what has been displayed for Educational Centres and Offices, also in this case the Initial investemnt is the option that has been selected by most of respondents (21) as the first discouraging aspect of a smart building.



Graph 76: Answers to question n° 12 (Discouraging Aspects) by Operators of the building sector about Residential Buildings. (Source: the author)

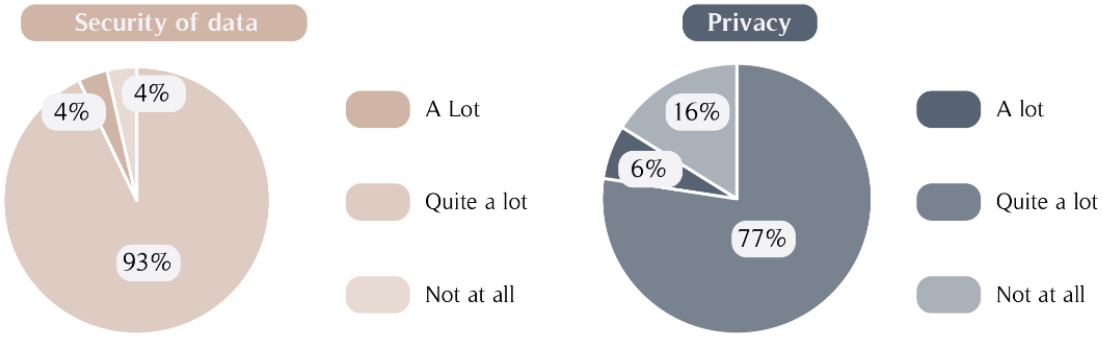
The initial investment, registering 49 points, is followed by the maintenance costs and the difficulty in the use of smart technologies (Graph 77).



Discouraging Aspects	Score Tot.
Initial Investment	**49**/217
Maintenance Costs	**91**/217
Loss of Privacy	**134**/217
Leaks in the systems and loss of data	**140**/217
Difficulties in the use of technologies	**114**/217
Difficulties in personal data management	**157**/217
Low interest in the offered services	**183**/217

Graph 77: Radar Chart and Total scores of question n°12. (Source: the author)

Also in case of residential building, the low interest in the offered services is not perceived as discouraging aspect, meaning that there is an actual interest towards smart technologies.



Graph 78: Answers to question n° 13 and 14 by Operators of the building sector about Residential Buildings. (Source: the author)

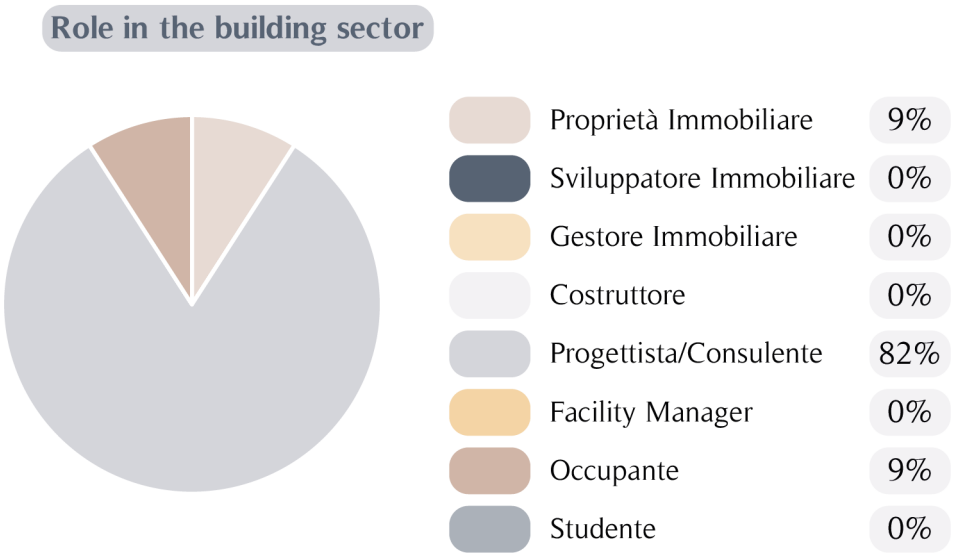
For what regards security of data and privacy issues, users are aware about these problems, but in general they trust the security systems which the smart buildings are equipped with. Respectiverly, only 4% and 6% of respondents are strongly scared by security and privacy issues.

In conclusion, occupants of residential buildings would define a Smart Building as focused on user wellbeing and think it is also its most important feature. For what regards technologies, the preferred one are the parking finding, while smart bins register, surprisingly, the lowest score among the preferred technologies.

Cost increment related to smart technology is envisioned to be between 10% and 20%, and this is the main element discouraging the implementation of smart systems. This category of respondents trust the modern protection systems and it is not completely scared by security and privacy issues.

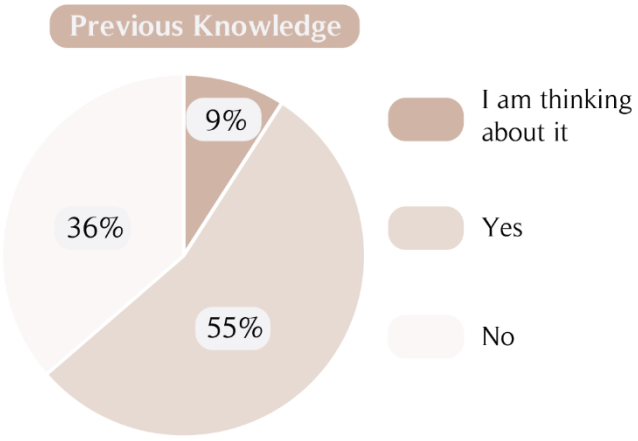
Hospitals

12 respondents, considering experts of building sector, selected the hospitals as the building typology in which they mainly operate. They are mainly designer/consultant as it is showed in Graph 79.



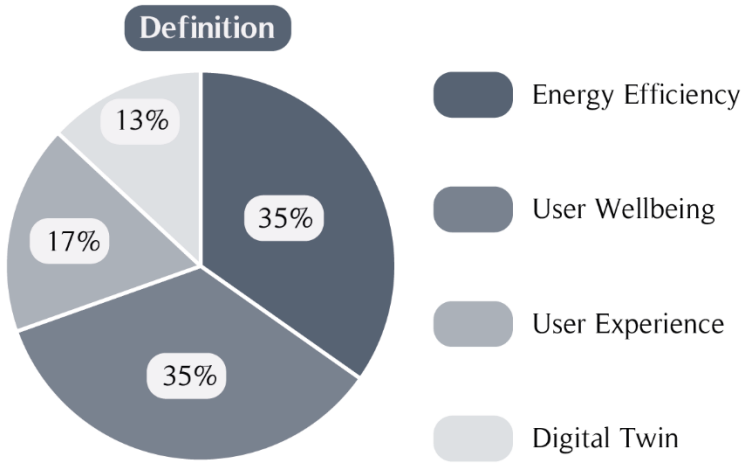
Graph 79: Answers to question n° 3 by Operators of the building sector about Hospitals. (Source: the author)

The answers to question n°5 given by operators dealing with healthcare buildings are different from the ones obtained by who operates in educational centres, offices and residential building. As Graph 80 shows, half of respondents (55%) already used smart technologies in their projects, and only 36% of them never did it yet.



Graph 80: Answers to question n° 5 by Operators of the building sector about Hospitals. (Source: the author)

Differently from the building typologies analysed until this point in this chapter (3.3.2), the answers to question 6 are homogeneous, and there is not a single option prevailing on the other. More in detail, energy efficiency and user wellbeing register the same amount of preferences (35%), followed by user experience and digital twin, close one to the other.



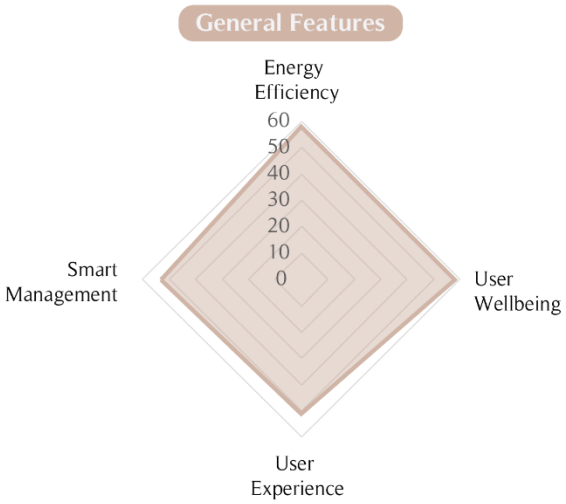
Graph 81: Answers to question n° 6 by Operators of the building sector about Hospitals. (Source: the author)

What emerges from Graph 82 is that scores 1 and 2 have never been selected for any of the option. Moreover, both energy efficiency and user wellbeing register the same amount of 5 points, as it was reasonable to expect from the answers to question n°6. 64.6% of respondents assigned a score equal to 5 points, and the average score registered by the options related to the general features of a smart building is 4,58 points. This means that all the proposed features are perceived as important for a Smart hospital.

Graph 82: Answers to question n° 7a (General Features) by Operators of the building sector about Hospitals. (Source: the author)

The results presented in Graph 81 are confirmed in the answers to question n° 7a: User wellbeing and energy efficiency registered the same score (58/60), followed by user experience and smart

management with a difference equal to 7 and 5 points, respectively. It emerges that the proposed features are almost on the same level, according to operators of the building field (Graph 83).



General Features	Score Tot.
Energy Efficiency	**58**/60
User Wellbeing	**58**/60
User Experience	**51**/60
Smart Management	**53**/60

Graph 83: Radar Chart and Total scores of question n°7a. (Source: the author)

For what regards the different technologies available for a Smart Buildings, they are investigated from question n°7b to n° 7d, and divided in thematic areas (energy efficiency, user wellbeing, user experience and smart management of people and data).

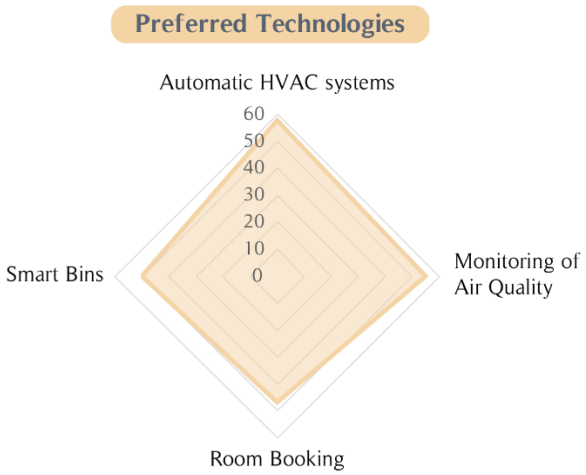
The options of question n° **7b** – technologies related to energy efficiency – registered an average score equal to 4.4. 0% of respondents assigned 1 point to the proposed options and 58,3% of interviewed people decided to choose the 5 points option. The preferred technology are the automatic HVAC systems (58/60), followed, with a close score, by the automatic lighting (54/60).

Question n° **7c** deals with user wellbeing issue. The average score obtained by these technologies is 4.0 points, meaning that they are perceived as useful inside a Smart Hospital. There is a slight fragmentation of opinions because the percentage registered by the different scores are similar: 13.3% for 2 and 3 points, 31.7% and 41.7% for 4 and 5 points. The air quality monitoring is the option registering the highest score (55/60), followed by the personalized setting of temperature (51/60).

For what regards the technologies related to the User experience (question n°**7d**), they registered the lowest average score (3.2 points), in accordance with what emerged from question n°6 – displayed in Graph 81. Differently from all the others set of technologies, in this case only 9.7% of respondents assigned a score equal to 5 points. The preferred technology of this set is the room booking. Moreover, wayfinding registered a good total score – 40/60. This is coherent with what

emerged in Chapter 2 and with he answers given by occupants for what regards hospitals: in places like hospitals, which in general are big and people go there occasionally, one of the main concern is to know where to go in the shortest time possible.

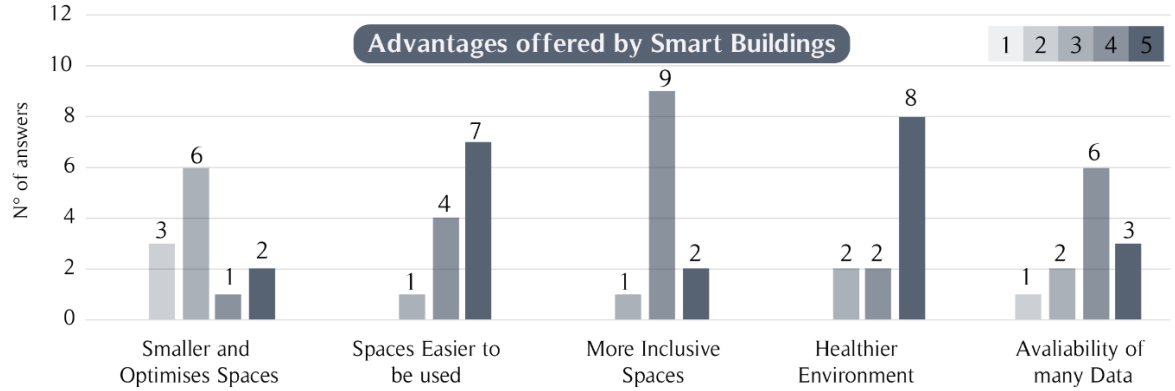
The smart management of object and data is the theme of question n°**7e**. The average score of these options is similar to the one obtained by user experience related technologies (3.3 points), with 6.7% of respondents assigning one point. Only 25% and 15% of the answers have been, respectively, registered for the four and five points options. The most rated option is the Smart Bins (50/60). Considering the preferred technologies for thematic area, the one registering the highest score are the automatic HVAC systems. This is an expectable result, considering what emerged in Graph 81 about the definition for a smart building according to experts operating with healthcare buildings. It is important to point out that also all the others preferred technologies (in order, monitoring of air quality, smart bins and room booking) received very similar and high scores.



Smart Technologies	Score Tot.
Automatic HVAC systems	**58**/60
Monitoring of Air Quality	**55**/60
RoomBooking	**47**/60
Smart Bins	**50**/60

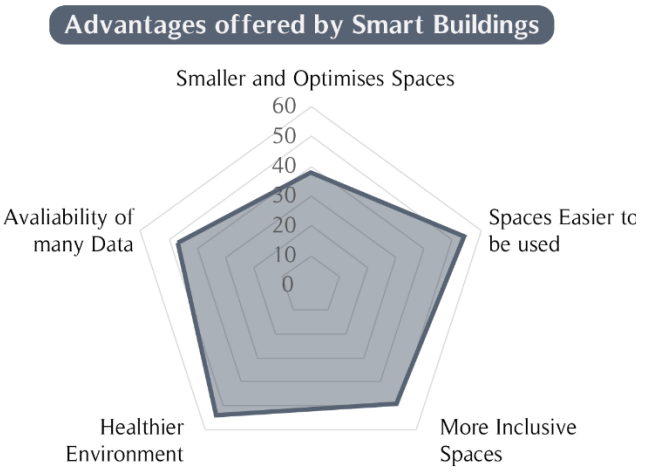
Graph 84: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

Graph 84 reports the results of question n°8, related to the advantages offered by smart buildings.



Graph 85: Answers to question n°8 by Operators of the building sector about Hospitals. (Source: the author)

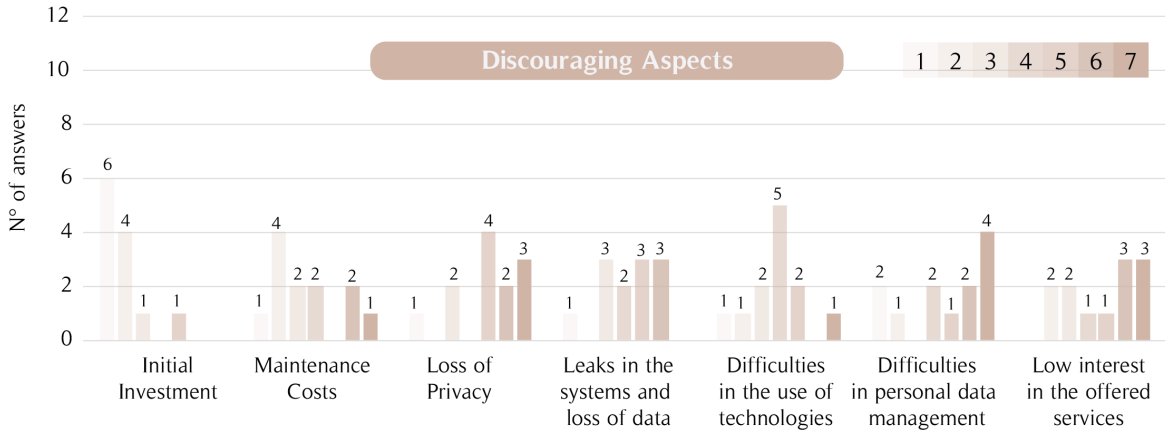
The average score is 4,0 points, indicating this category of respondents feels that Smart technologies offer many advantages: spaces that are smaller, optimised, easier to be used, more inclusive and healthier. 36.7% of respondents assigned a score equal 5 points and none decided to choose the one-point option. Also for hospitals, the healthier environment is the characteristic more appreciated of a Smart building, together with spaces that are easier to be used. The smaller and optimised paces is the option that received the lowest score – only 38 points on a total of 60.



Advantages	Score Tot.
Smaller and Optimises Spaces	**38**/60
Spaces Easier to be used	**54**/60
More Inclusive Spaces	**49**/60
Healthier Environment	**54**/60
Avaliability of many Data	**47**/60

Graph 86: Radar Chart and Total scores of question n°8. (Source: the author)

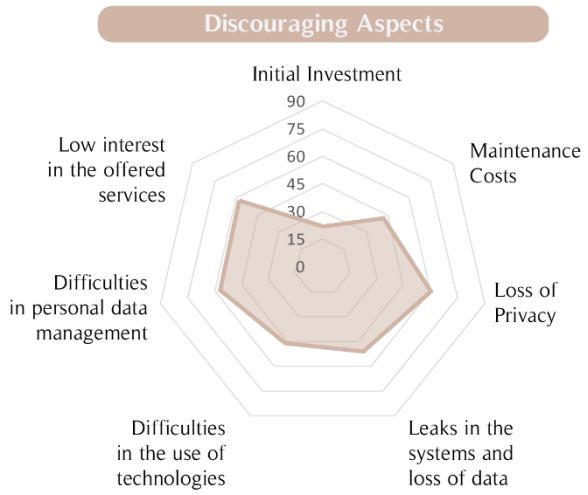
The initial investment is perceived as the most problematic aspect of smart technologies implementation also in case of hospitals.



Graph 87: Answers to question n° 12 (Discouraging Aspects) by Operators of the building sector about Hospitals. (Source: the author)

6 people put it in first position when deciding the order of all the proposed options For this reason, it is the discouraging aspect registering the lowest score (22/84), followed by maintenance cost and difficulties in the use of technologies. The low interest in the offered services is the option with the

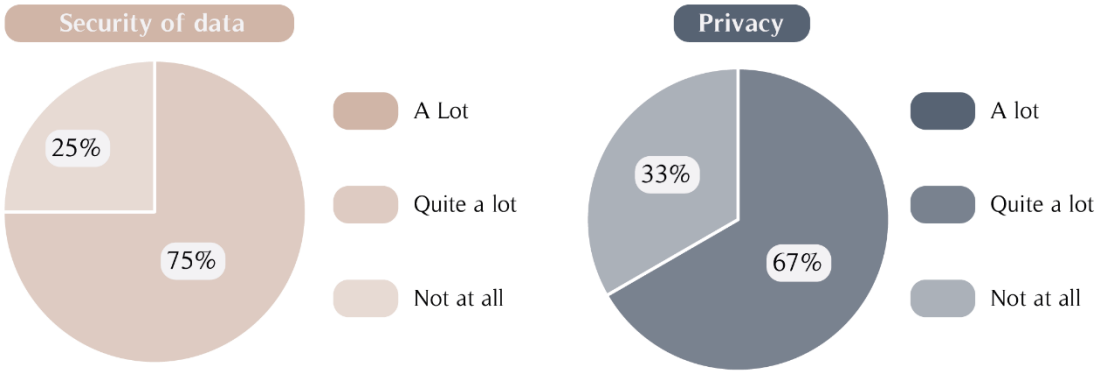
highest score, meaning that it is considered the less problematic for what regards smart technologies inside hospitals.



Discouraging Aspects	Score Tot.
Initial Investment	**22**/84
Maintenance Costs	**42**/84
Loss of Privacy	**60**/84
Leaks in the systems and loss of data	**51**/84
Difficulties in the use of technologies	**46**/84
Difficulties in personal data management	**57**/84
Low interest in the offered services	**58**/84

Graph 88: Radar Chart and Total scores of question n°12. (Source: the author)

Security of data is never perceived as a strong problem: 75% of respondents affirms to be scared by the fact that smart technologies lead to security problems, but they tryst in the protection systems and prefer to take advantages of smart technologies. Similar results have been obtained when considering privacy issue, as Graph 88 displays.

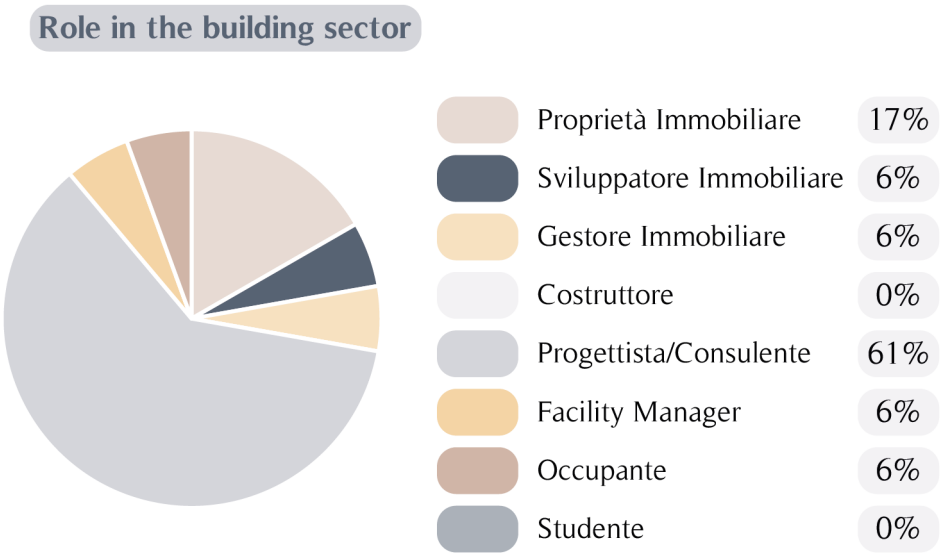


Graph 89: Answers to question n° 13 and 14 by Operators of the building sector about Hospitals. (Source: the author)

Considering all the answers, experts of building sector operating with hospitals would define a Smart Building as focused on user wellbeing and on energy efficiency. For what regards technologies, the preferred one are the automatic HVAC systems. Cost increment related to smart technology is envisioned to be between 5% and 10%, and this is the main element discouraging the implementation of smart systems. This category of respondents is not completely scared by security and privacy issues, and they believe in modern protection systems.

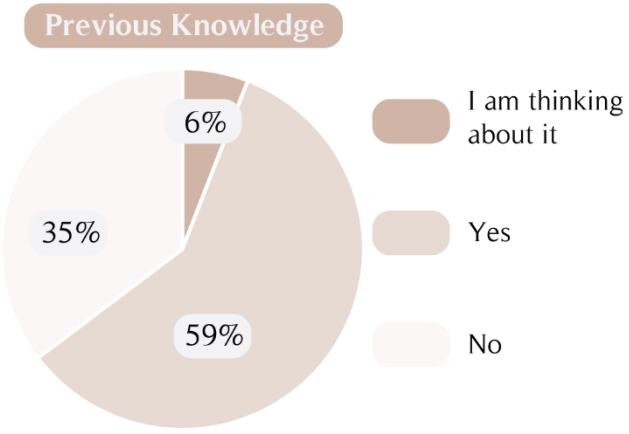
Shopping malls

Among the 78 experts answering the questionnaire, 17 of them selected, in question n°4, Shopping Malls as the typology in which they mainly operate. Also in this case, the majority of them are designer or consultants.



Graph 90: Answers to question n° 3 by Operators of the building sector about Shopping Malls. (Source: the author)

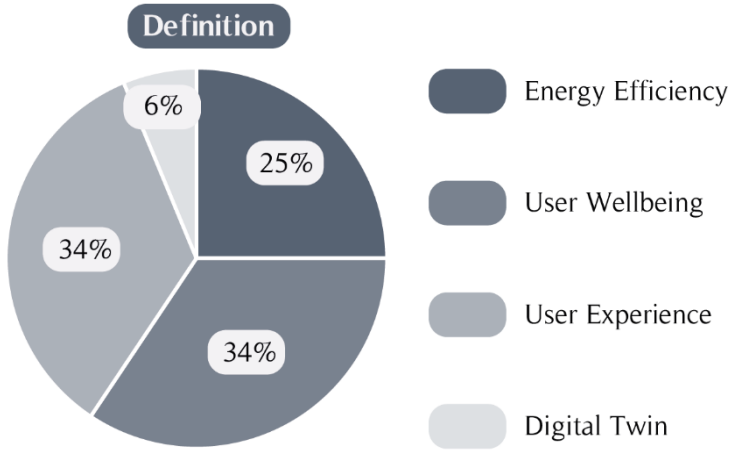
The answers to question n°5 given by operators dealing with shopping malls are similar to what emerged from hospitals. More than half of respondents declare to have already implemented smart technologies in their projects.



Graph 91: Answers to question n° 5 by Operators of the building sector about Shopping malls. (Source: the author)

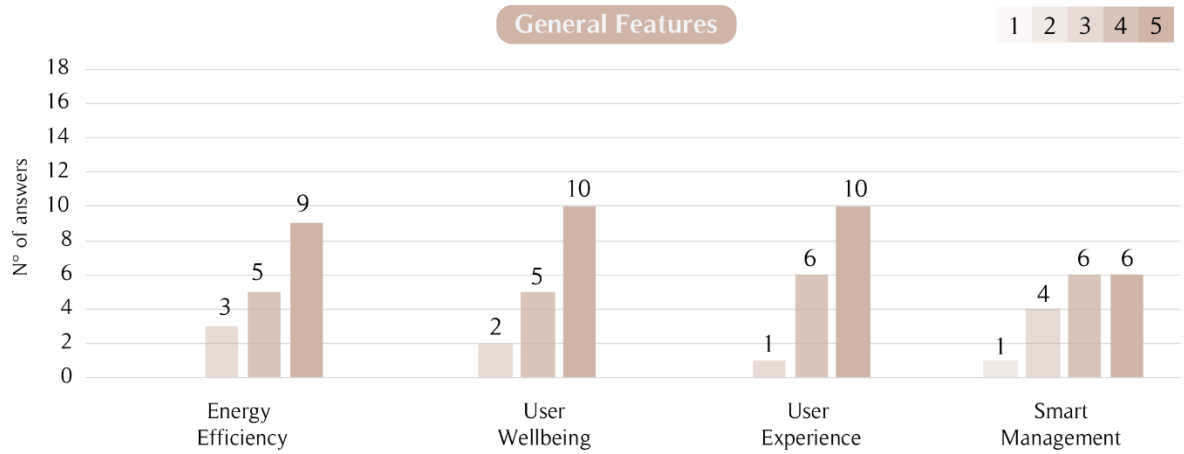
The Smart Buildings are, according to this category of respondents, user oriented: wellbeing and experience are the two key elements that may define a shopping mall equipped with smart

technologies. This is compliant with what have been described in Chapter 2 when treating the shopping malls: nowadays the experience is more important than what it is possible to buy inside them.



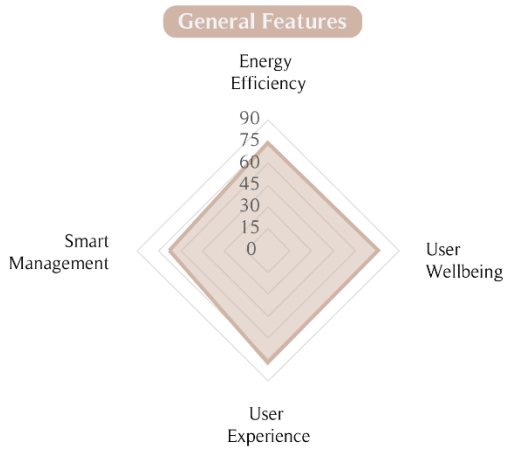
Graph 92: Answers to question n° 6 by Operators of the building sector about Shopping malls. (Source: the author)

4.3 points is the average score registered by the proposed general features in question n°7a. User wellbeing and experience are the options collecting more 5 points (10 and 10), but energy efficiency received only 3, 4 and 5 points, meaning that it is perceived as really important by users of industrial buildings. In general, 51.5% of respondents assigned 5 points to the proposed options, and 0% chose the one-point score.



Graph 93: Answers to question n° 7a (General Features) by Operators of the building sector about Shopping malls. (Source: the author)

Coherently with what it emerged in Graph 92, Graph 93 displays that the User wellbeing and user experience general feature are considered equally important inside a smart shopping mall. User experience registers highest score, equal to 77/85 points.



General Features	Score Tot.
Energy Efficiency	**74**/85
User Wellbeing	**76**/85
User Experience	**77**/85
Smart Management	**68**/85

Graph 94: Radar Chart and Total scores of question n°7a. (Source: the author)

For what regards the different technologies available for a Smart Buildings, they are investigated from question n°7b to n° 7d.

The options of question n° **7b** – technologies related to energy efficiency – registered an average score equal to 4.1. 0% of respondents assigned 1 point to the proposed options and a high percentage (43,6%) of interviewed people decided to choose the 5 points option. This means that all the general features proposed are perceived as important in a shopping mall. The preferred technology is the real time monitoring of HVAC systems (72/85), followed, with a close score, by automatic lighting and shading devices (69/85 each).

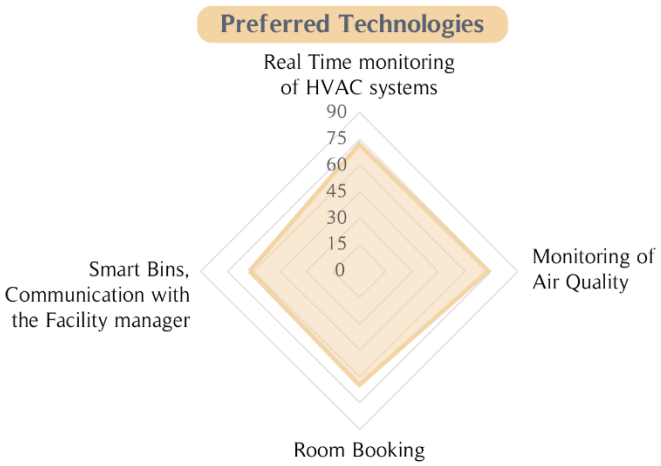
Question n° **7c** deals with user wellbeing issue. The average score obtained by these technologies is 3.9 points. The score that registered the highest amount of preferences is the four-points option: 40% against the 29.4% received by the 5 points. The air quality monitoring is the option registering the highest score (73/85), followed by the personalized setting of lighting (70/85) and the monitoring of acoustic comfort (68/85).

For what regards the technologies related to the User experience (question n°**7d**), they registered the lowest average score (3.4 points), in accordance with what emerged from question n°6 – displayed in Graph 92. 5 points obtained a low amount of preferences (11.8%), and the one-point option has been chosen by 2.9% of respondents. The preferred technology of this set is, even if with a not so high score, the room booking (65/85).

The smart management of object and data is the theme of question n°**7e**. The average score of these options is 3,5 points, with 1.2% of respondents assigning one point. 35.5% and 15.3% of the

answers have been, respectively, registered for the four and five points options. The most rated option are the Smart Bins and the direct communication with the facility manager (62/85).

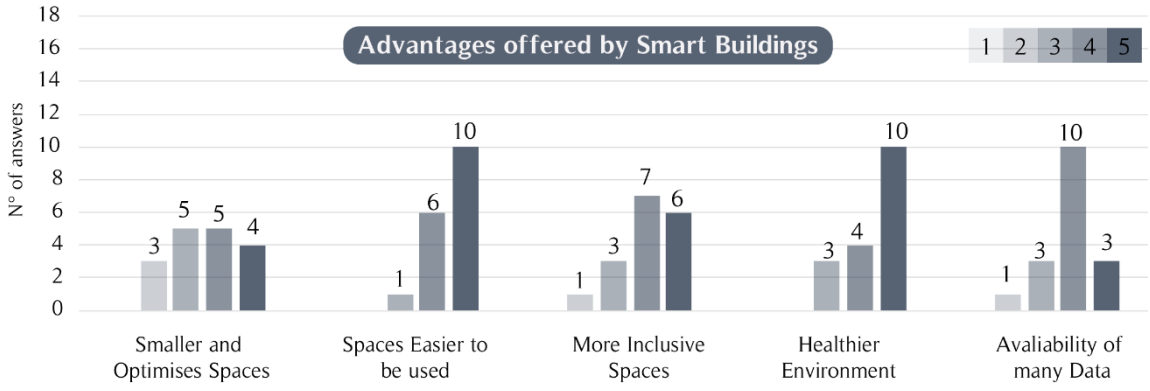
Considering the preferred technologies for thematic area, the one registering the highest score are the real time monitoring of HVAC systems. However, all the others preferred technology are close.



Smart Technologies	Score Tot.
Real Time Monitoring of HVAC systems	**58**/85
Monitoring of Air Quality	**55**/85
RoomBooking	**47**/85
Smart Bins, Communication with Facility Manager	**50**/85

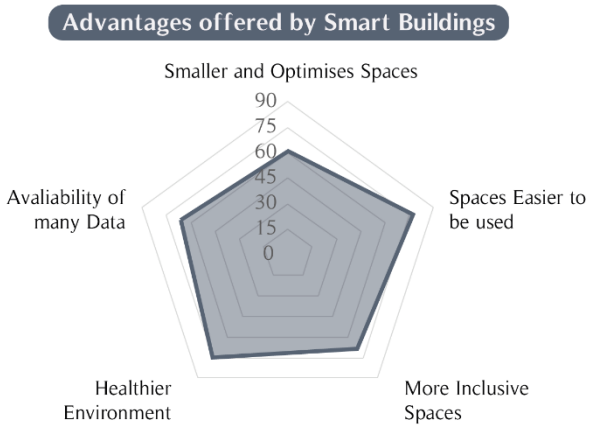
Graph 95: Radar Chart and Total scores of the preferred technologies (questions from 7b to 7e). (Source: the author)

Graph 96 reports the results of question n°8, related to the advantages offered by smart buildings. The average score is 4.1 points, indicating that this category of respondents feel that Smart technologies offer many advantages: spaces that are smaller, optimised, easier to be used, more inclusive and healthier. 76.4% of respondents assigned a score equal 4 or 5 points and none decided to choose the two-points option.



Graph 96: Answers to question n°8 (Advantages) by Operators of the building sector about Shopping malls. (Source: the author)

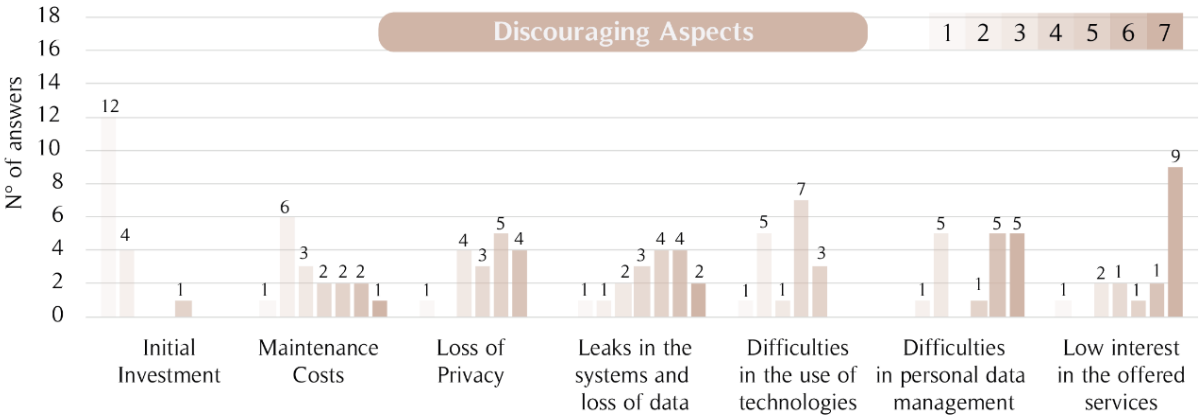
Differently from the other building typologies, where the healthier environment is the characteristic more appreciated of a Smart building, in this case are the spaces easier to be use leading the ranking, with 77/85 points.



Advantages	Score Tot.
Smaller and Optimises Spaces	**61**/85
Spaces Easier to be used	**77**/85
More Inclusive Spaces	**69**/85
Healthier Environment	**75**/85
Avaliability of many Data	**66**/85

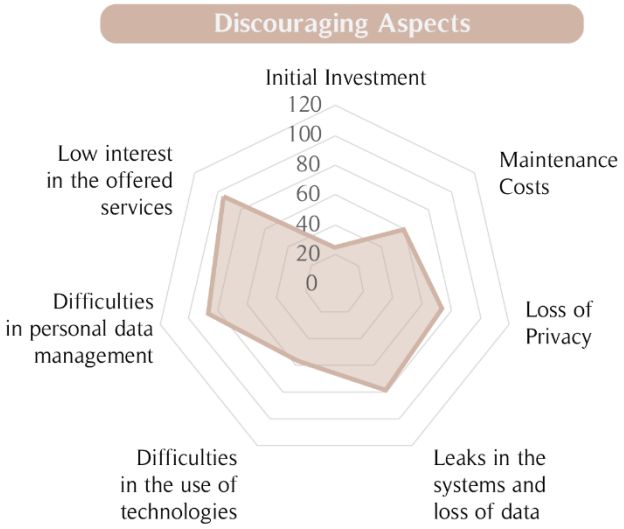
Graph 97: Radar Chart and Total scores of question n°8. (Source: the author)

The discouraging aspects had to be classified from 1 to 7 – from the one perceived as the more problematic to the less one.



Graph 98: Answers to question n° 12 (Discouraging Aspects) by Operators of the building sector about Shopping malls. (Source: the author)

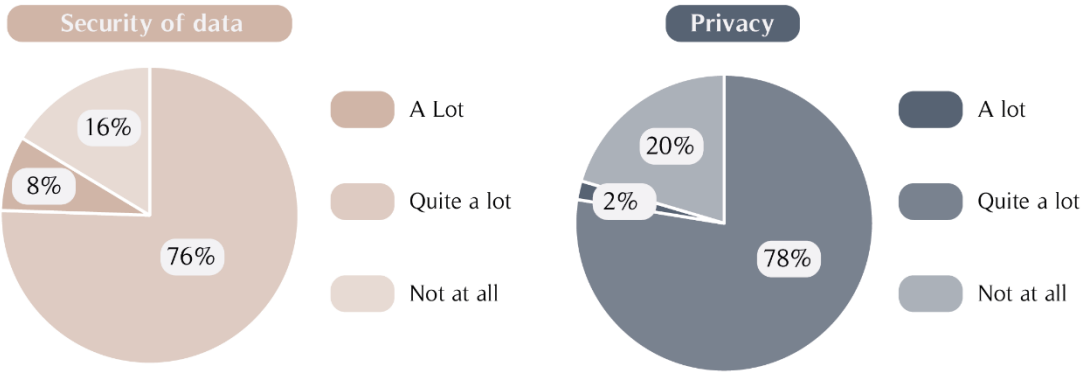
Initial investment and difficulties in the use of technologies are the aspects perceived as more discouraging, among the ones proposed, registering, respectively, 25 and 57 points on a total of 119. The low interest in the offered services is the option receiving the highest score, meaning that it is perceived the less problematic. This is encouraging because it means that users and professional figures are interested in smart technologies



Discouraging Aspects	Score Tot.
Initial Investment	**25**/119
Maintenance Costs	**59**/119
Loss of Privacy	**74**/119
Leaks in the systems and loss of data	**79**/119
Difficulties in the use of technologies	**57**/119
Difficulties in personal data management	**87**/119
Low interest in the offered services	**95**/119

Graph 99: Radar Chart and Total scores of question n°12. (Source: the author)

Also privacy is not perceived as a strong problem: only 2% among interviewed people affirm to be highly scared by the fact that smart technologies lead to privacy reduction.



Graph 100: Answers to question n° 13 and 14 by Operators of the building sector about Shopping malls. (Source: the author)

Considering all the answers, professional figures operating with shopping malls would define a Smart Building as focused on user wellbeing and experience. For what regards technologies, the preferred one is the real time monitoring of HVAC systems (followed by smart bins and by monitoring of air quality) and the ones perceived as less useful are the keyless entry technologies and the 3D archive of administrative documentation.

Cost increment related to smart technology is envisioned to be between 5% and 10%, and this is the main element discouraging the implementation of smart systems. This category of respondents is not scared by security and privacy issues, and they believe in modern protection systems.

3.4 Conclusions about the outcomes

The outcomes of the questionnaire are useful in order to verify and proof what has been presented in Chapter 2. Among all the different possibilities offered by the IoT in the buildings field, some of them have room for growth, if looking at people present needs, and some others do not have a fertile ground for new developments.

Of course, all the results exposed in Chapter 3 refer to the specific period during which the survey have been submitted to people's judgment. Its results do not prevent the possibility that in next years users' perception of smart technologies will completely change.

According the literature related to the Smart Building topic, the energy efficiency aspect is overcome, and the focus is moving towards all these technologies improving user's wellbeing and experience inside the building. However, the results of the survey display that this vision does not always represents the reality. In some cases (the residential and educational buildings according to their simple occupants are an example) the envisioned definition is exactly the one dealing with energy efficiency. In the case of educational centres, the energy efficiency is also the most rated general features, while for what concerns residential buildings the general feature registering the highest score is the user wellbeing. This fragmentation of opinion proofs what has been declared since the beginning of this thesis work: the smart building topic does not have yet a precise shape, but it is undergoing a continuous transformation. For this reason, the opinions about it are different one from the other, because a clear concept and definition do not exist yet.

The specific analysis of each building typology helps in differentiating which ones of them are more ready – according to users and experts of the building sector – to shift from the smart-green building concept to the human centred smart building. In general, it is possible to state that all of them are oriented ALSO towards the user wellbeing topic – never forgetting the centrality of sustainability issues – and what is still not felt as necessary by occupants is the user experience.

Not only this is the aspect registering the lowest score both when asking about the smart building definition and about the general features that a smart building should have, but also when the possible new technologies linked with user experience are listed, respondents assign them low score in comparison to the systems related to energy efficiency and user wellbeing.

The survey confirms the tendency towards a healthier lifestyle also when dealing with buildings. The air quality monitoring is a technology registering, for all the building typologies, really high scores, and it is always the preferred system among all the ones proposed about user wellbeing. On the

other hand, the fact that wayfinding and people finding is always the less-rated technology, is in contrast with the fact that it is frequently mentioned by literature related to the Smart Buildings topic. The availability of products and systems on the market does not find a positive answer in users' needs: respondent do not perceive the wayfinding technology as useful nor important inside a smart space.

For what regard security and privacy issue, the results obtained are aligned with what has been declared in chapter 2.6: according to the survey performed by CSX, it is expected that attacks will increase quantitatively in the next year. It has been demonstrated that users and experts of the building sector are aware about that, but in general they trust in the security systems and prefer to exploit the advantages offered by smart technologies rather than renounce to them for fear.

It is interesting to compare the results obtained when interviewing building occupants and expert of the sector. The major difference emerging from the analysis regards the definition of a smart building: if when considering occupants answers, digital twin was never selected as option and user experienced receives a low amount of preference, this does not happen when respondents are experts of building sector. Looking at results of paragraph 3.3.2, user experience receives, in general, the same amount of preferences as energy efficiency and user wellbeing. Moreover, the digital twin option registers, on average, between 7% and 10% of preferences.

Another great difference regards the energy efficiency topic. Both for occupants and experts, it is envisioned as an important feature of a smart building, but if in the first case it is considered as the basic element constituting a smart building, according to operators it is not more important than user wellbeing. This result is compliant with expectation, being the user focused issue quite new and not so diffused among simple occupants in their everyday life.

Similarities between the two categories of respondents can be found when dealing with advantages and disadvantages of smart buildings. The healthier environment is perceived as the greatest advantages by everyone, as the initial investment is perceived as the main disincentive for the implementation of smart technologies.

The security and privacy concerns are known both by occupants and by users, but none is so scared from them to decide not exploiting advantages offered by smart systems.

CHAPTER 4

Conclusions

The literature analysis and the survey results have been useful in order to discover which are the basic feature of a Smart Building and to provide it a synthetic definition. In general, the perception of building occupants is different from the one of experts of building field, because of their unbalanced level of knowlege about the Smart Building topic.

5. Conclusions

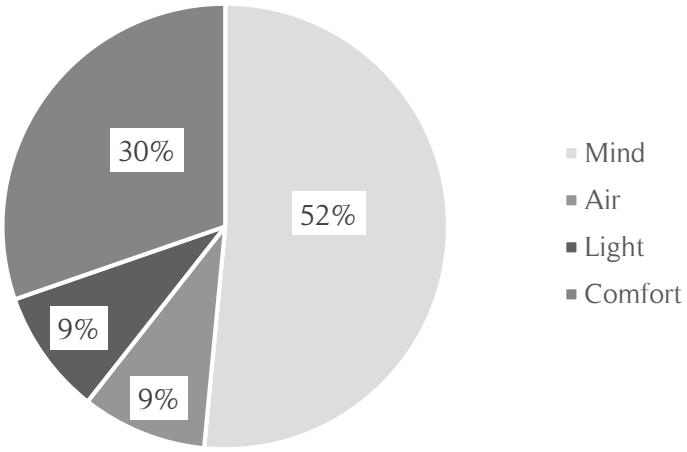
Smart Buildings are surely an interesting topic, which is becoming more and more well-known both by professionals operating the building sector and by occupants, who face often this issue in their everyday life. The value of this research is that it provides a complete overview about this complex and emerging topic: which are its origins, its present characteristics and its future opportunities. More in detail, many different building typologies have been analysed, and it emerged that for each of them the concept of Smart Building needs to be explicated in different ways. The common denominator of all the acceptation, from a theoretical point of view, is the centrality of the user, his needs and his wellbeing inside the building.

In order to reach this purpose, inside the different building typologies, several smart technologies have been developed and are continuously under transformation, in order to be improved and able to face the users' needs. The most diffused are indoor positioning systems enabling automatic HVAC systems, lighting and temperature setting, together with wayfinding and people finding. More innovative technologies are the sensors monitoring the air quality, the automatization of check in procedures and of all the airport operations (baggage tracking, boarding and border controls).

All the technologies that have been reported, have been classified according to four main parameters: light, air, comfort and mind. In this way it is possible to immediately recognize why a specific system may be useful and which is its basic purpose. The light-related technologies deals with environmental parameters such as light, temperature or noise. Air-related systems relate to the wellbeing issue and are able to improve and monitor the health conditions inside a space. Mind and comfort related systems are the most diffused ones, and both deals with user wellbeing and stress level. In the first case, the idea is to reduce stress levels and improve self-monitoring devices, in order to allow the occupants to acquire a greater awareness of themselves and their health conditions. For what regards the comfort issue, it is related both to the thermal comfort (temperature, humidity, ventilation) and to the visual comfort (artificial and natural light settings), together with the idea of being able to find easily a place where to work (in an office), where to study (in a university) or where to sit and rest (for instance in a shopping mall).

Thanks to this classification of technologies that have been performed, a company like Deerns can immediately recognize which smart devices to implement inside a new project in order to reach a certain purpose. Moreover, the results emerged from the survey are a fundamental tool for Deerns in order to know which is the direction that Smart Building are taking and where it is more useful to invest time and money.

33 technologies, related to different building typologies, have been investigated and classified according to the abovementioned categories. Graph 101 displays the results.



Graph 101: Technologies classification results (Source: the author)

The half of the smart systems reported in the research deals with "Mind" issues. This confirm the tendency toward a User Oriented Design. Moreover, the key features of technologies developed in present years is to increase user wellbeing inside the building and reduce his stress level, in order to put him in the conditions to be more productive.

The results of the survey are useful not only for Deerns and other companies interesting in investing in this field, but also to the literature related to this topic and to possible future researches. The knowledge of what are people needs and expectation when dealing with Smart Building is an interesting and useful tool in both cases. The key results emerged from the answers analysis are:

- There is a radical difference between occupants and experts of building sector perception about Smart Buildings: in the first case, the vision is still linked to the sustainability issue, as energy efficiency is intended to be the basic definition of a building to be defined smart. On the other side, according to building sector operators, the user wellbeing and experience are the key characteristics of Smart Buildings. This difference between the two visions is because the user-focused issue is an emerging topic and it is not yet diffuse in the common knowledge.
- Some technologies that are commonly present in the literature related to this issue are not perceived as useful by respondents. The most interesting evidence of that regards wayfinding and people finding systems; bibliographic sources mention these smart systems many times, indicating that as one of the key elements of a Smart Buildings. However, considering

answers of both occupants and building sector operators, this is the smart device perceived as less useful.

- Most professional figures already worked with smart technologies or they are thinking to implement them inside a project. This means that, among experts of this sector, this is a diffuse and known topic. Moreover, looking at the definition they would give to a smart building, they are already aware about user-focused design, meaning that the smart buildings they worked on or they will design may include this aspect.
- The initial investment is perceived to be, both by occupants and building field operator, the main negative aspect discouraging from the implementation of smart technologies.
- Everyone is aware about security and privacy issue related to the adoption of smart systems, but only a small percentage (smaller than 10%) of respondents declare to prefer not using at all smart devices because of security and privacy problems. The remaining 90% trust in modern security systems.

Both the literature review and the analysis of survey results allow to establish a possible definition of a Smart Building: *"A Smart Building is a place where user wellbeing and experience are the key aspects. The Smart Buildings of the future will be characterized by healthier spaces and a specific attention towards sustainability issues – both in terms of energy consumptions and environmental aspects."*

Bibliography

ACI. *Airport Economics Report: a comprehensive view of the indistry's financial performance.* Airports Council International, 2019.

Air Infiltration and Ventilation Centre. n.d. www.aivc.org (accessed Jun 04, 2019).

Aon (The One Brief). *Smart Building Technologies: Balancing Value And Risk.* 2017. https://theonebrief.com/smart-building-technologies-balancing-value-risk/ (accessed May 14, 2019).

Archer Software. *Smart hospital: what is it and how to build your own solution.* n.d. https://archer-soft.com/en/blog/smart-hospital-what-it-and-how-build-your-own-solution (accessed Jun 11, 2019).

Autodesk research group. *Generative design applied on Buildings.* 06 Sep 2017. https://autodesk.typepad.com/bimtoolbox/2017/06/generative-design-applied-on-buildings.html (accessed Jun 22, 2019).

AYTM market research. *Visa Survey Reveals Consumers Are Ready to Say Goodbye to Passwords.* 14 Dec 2017. https://www.businesswire.com/news/home/20171214005526/en/ (accessed Aug 03, 2019).

Bandoim, Lana. *How Smart Shelf Technology Will Change Your Supermarket.* Dec 23, 2018. https://www.forbes.com/sites/lanabandoim/2018/12/23/how-smart-shelf-technology-will-change-your-supermarket/ (accessed Aug 09, 2019).

Besenecker, Ute, and Ken Appleman. *Designing Lighting Systems Tuned to Circadian Rhythms.* Jun 2017. https://www.photonics.com/Articles/Designing_Lighting_Systems_Tuned_to_Circadian/a61980 (accessed Jul 18, 2019).

BPIE. "Smart Buildings in a decarbonised energy system." 2016.

Breghiroli, Eleonora. "Com'è nato l'Internet of Things? Le 15 date che hanno fatto la storia." May 05, 2016. http://www.kiteblue.it/come-nato-linternet-of-things-le-15-date-che-hanno-fatto-la-storia-2/ (accessed Apr 26, 2019).

British Land, Worktech Academy. *Smart offices: a 2017 vision for the future.* Annual Report, British Land, 2017.

Brown, Michael, Dominick Shaw, Ivan Le Jeune, and John Blakey. *A survey-based cross-sectional study of doctors' expectations and experiences of non-technical skills for Out of Hours work.* BMJ Journal, 2015.

Brown, Rich. *The best smart home devices for 2019.* 2019. https://www.cnet.com/news/the-best-smart-home-devices-of-2019-amazon-alexa-google-assistant-apple-homekit-smart-cameras/ (accessed Aug 11, 2019).

Brown, Steve, and David Roth. *The second era of digital retail. A vision for the future of shopping and the smart shelf.* Global Report, The Store WPP, 2018.

Building Performance Institute Europe. *A vision for smart buildings in Europe.* BPIE, 2017.

Building Performance Institute Europe. *Is Europe finally ready for the smart building revolution?* Report, BPIE, 2017.

Building Performance Institute Europe. *Nearly Zero-Energy Building Definitions Across Europe.* Factsheet, BPIE, 2015.

Buildings Performance Institute Europe. *Alleviating Fuel Poverty in the EU.* BPIE, 2015.

Cambridge sound. *Sound Masking 101.* n.d. https://cambridgesound.com/learn/sound-masking-101/ (accessed Jul 13, 2019).

Cambridge Sound. "Sound masking 101 technical brochure." Technical Brochure, 2018.

Canalys. *Smart speakers are the fastest-growing consumer tech: shipments to surpass 50 million in 2018.* 04 Feb 2018. https://www.canalys.com/newsroom/smart-speakers-are-fastest-growing-consumer-tech-shipments-surpass-50-million-2018 (accessed Aug 03, 2019).

Capoferro, Paola. *Smart Working: che cos'è, a cosa serve, perché è importante per il business.* Oct 25, 2018. https://www.digital4.biz/hr/smart-working/smart-working-che-cos-e-a-cosa-serve-e-perche-e-cosi-importante-per-il-business/ (accessed Apr 22, 2019).

Carvelli, Fabio. "L'efficacia dei meeting come chiave per l'innovazione." *Smart Building Conference.* Milano, 2019.

Cisco. *2017 Annual Cibersecurity Report.* Annual Report, Cisco, 2017.

Clarke, Derrek. *Global Survey: Smart Building Technology, Budgets, Priorities & Preferences.* Global Report, Verdantix, 2018.

Clickatell. *The future of the shopping mall: IoT applications in retail.* 2018. https://www.clickatell.com/articles/technology/iot-applications-retail/ (accessed Jun 07, 2019).

Consoli, Marco. "Carlo Ratti lancia l'ufficio 3.0." *Abitare*, Aug 08, 2016.

Cooley, Mike. *Architect or BEE?* 1980.

Coor. *Great business for a better future.* n.d. http://www.smartoffice.coor.com/areas/sustainability/ (accessed Apr 23, 2019).

CSX. *State of Cybersecurity 2019, Part 2: Current Trends in Attacks, Awareness and Governance.* Annual Report, ISACA, 2019.

D'Arjuzon, Rodolphe. *Market Overview: Identifying The Tangible Opportunities From The IoT In Buildings.* Market Overview Report, Verdantix, 2019.

De Groote, Maarten, Jonathan Volt, and Frances Bean. *Is Europe ready for the Smart Buildings revolution.* Report, BPIE, 2013.

Deloitte. *2019 Global health care outlook: shaping the future.* Annual Report, Deloitte, 2019.

Dussautl, Jean Michael, Louis Gosselin, and Tigran Galstian. "Integration of smart windows into building design for reduction of yearly overall energy consumption and peak loads." In *Solar Energy 86*, 3405–3416. Elsevier, 2012.

DXC Technology. "Emergence of the smart hospital and beyond: what's next for providers?" White Paper, 2018.

Ecobee. *The All-New smart thermostat.* 2018. https://www.ecobee.com/en-us/smart-thermostat-voice/ (accessed Jun 26, 2019).

EESI. *The History of Passive House: A Global Movement with North American Roots.* 23 Jun 2017. https://www.eesi.org/articles/view/the-history-of-passive-house-a-global-movement-with-north-american-roots (accessed Jun 12, 2019).

Elica. *SNAP: Air Quality Balancer.* n.d. http://snap.elica.com/it/ (accessed Jun 17, 2019).

Erickson, V. L., et al. "Energy efficient building environment control strategies using real-time occupancy measurements." *Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings.* Berkeley, California: ACM Digital Library, 2009. 19-24.

Euromonitor Research. *Wellness as Status Symbol: a top consumer trend for 2017.* Jan 16, 2017. https://blog.euromonitor.com/authenticity-wellness-status-symbol-among-top-10-global-consumer-trends-2017/ (accessed Apr 24, 2019).

European Commission. *Smart Building: Energy efficiency application.* Annual Report, European Commission, 2017.

Fantoni, Roberto , Fernanda Hoefel, and Marina Mazzarolo. *The future of the shopping mall.* Nov 2014. https://www.mckinsey.com/business-functions/marketing-and-sales/our-insights/the-future-of-the-shopping-mall (accessed Aug 12, 2019).

Farrel, Sean. *The changing face of travel in a post-digital age.* Jul 25, 2019. https://www.sita.aero/resources/blog/the-changing-face-of-travel-in-a-post-digital-age (accessed Aug 26, 2019).

Fattah, Amir , Howard Lock, William Buller, and Shaun Kirby. *Smart Airports: Transforming Passenger Experience To Thrive in the New Economy.* Report, Cisco Internet Business Solutions Group (IBSG), 2009.

Featherman, M.S., and P.A. Pavlou. "Predicting e-services adoption: a perceived risk facets perspective." In *International Journal of Human-Computer Studies*, 451-474. Elsevier, 2003.

Figuero, M. *An overview of the effects of light on human circadian rhythms: Implications for new light sources and lighting systems design.* Journal of Light & Visual Environment, 2013.

Figuero, M. *Effects of Light Exposure on Behavior of Alzheimer's Patients – A Pilot Study.* Journal of Light & Visual Environment, 2012.

Fischer & Kerrn. *Fischer & Kerrn: Meeting and Room Booking System.* n.d. https://fischerkerrn.co.uk/products/room-booking/ (accessed Jun 21, 2019).

Ford, Rebecca , Marco Pritoni, Angela Sanguinetti, and Beth Karlin. "Categories and functionality of smart home technology for energy management." *Building and Environment 123*, Jul 14, 2017: 543e554.

Garcia, Marisa . *Biometric Technology Is Taking Off As 77% Of Airports and 71% Of Airlines Review Digital ID Options.* Sep 29, 2018.

https://www.forbes.com/sites/marisagarcia/2018/09/29/biometric-technology-is-taking-off-as-77-of-airports-and-71-of-airlines-review-digital-id-options/#1cb3c6e4704d (accessed Aug 12, 2019).

Garton, Eric. *The Case for Investing More in People.* Report, Harvard Business review, 2017.

Griswold , Alison . *These Heat Maps Show How Retailers Track You As You Shop.* 28 Jan 2014. https://www.businessinsider.com.au/how-retailers-track-shoppers-in-heat-maps-2014-1 (accessed Jun 30, 2019).

Groissbock, M., S. Heydari, A. Mera, A. Siddiqui, E. Perea, and M. Stadler. *Optimizing building energy operations via dynamic zonal temperature settings.* Elsevier, 2014.

Harte, Richard, Liam Glynn, Alejandro Rodríguez-Molinero, Paul MA Baker, Leo R. Quinlan, and Gearóid ÓLaighin. "A Human-Centered Design Methodology to Enhance the Usability, Human Factors, and User Experience of Connected Health Systems: A Three-Phase Methodology." *JMIR human factors 2017*, 16 Mar 2017: 117-124.

Harvard Business Review. *Competing in 2020: Winners and Losers in the Digital Economy.* Analytic Services Report, Harvard Business School Publishing, 2017.

Hoffman, D.L., and T.P. Novak. "How to market the smart home: focus on emergent experience, not use cases." 15 Jan 2016: 29-38.

Hubert, Marco , Markus Blut, Christian Brock, Ruby Wenjiao Zhang, Vincent Koch, and René Riedl. "The influence of acceptance and adoption drivers on smart home usage." *European Journal of Marketing*, May 18, 2018: 1073-1098.

IATA. *Baggage Tracking.* n.d. https://www.iata.org/whatwedo/ops-infra/baggage/Pages/baggage-tracking.aspx (accessed Aug 12, 2019).

—. *Passengers want technology to give them more control over their travel experience.* 24 Oct 2017. https://www.iata.org/pressroom/pr/Pages/2017-10-24-02.aspx (accessed May 18, 2019).

IBM knowledge center. *The layered defense approach to security.* Annual Report, IBM, 2018.

InSoft. "Indoor positioning and services." White Paper, 2018.

Iowa Energy Center. "Lower energy bills with a set-back thermostat." n.d. http://www.energy.iastate.edu/news/pr/ (accessed Aug 24, 2019).

IQUII. *The future of retail: come IoT e Smart Retail costituiscono la shopping experience del futuro.* Jul 09, 2018. https://iquii.com/2018/07/09/iot-smart-retail/ (accessed Aug 16, 2019).

Jia, Ruoxy, et al. "Designing Automation for smart building systems." *Proceedings of the IEEE (Volume: 106 , Issue: 9)*, Sep 17, 2017: 1680 - 1699.

Karlin, Beth , et al. "Diffusion of feedback: perceptions and adoption of devices in the residential market." *DUXU 2015. Design, User Experience, and Usability: Interactive Experience Design.* 2015. 368-379.

Kaspersky Lab and B2B International. "Human Factor in IT Security: How Employees are Making Businesses Vulnerable from Within." Jul 10, 2017.

Kejriwal, Surabhi , and Saurabh Mahajan. *Smart Buildings: how IoT technology aims to add value for real estate companies.* Annual Report, Delottie University Press, 2016.

Kinsella, Bret, and Ava Mutchler. *Smart speaker consumer adoption report.* Annual Report, Voicebot, 2019.

Kumar Kar, Arpan , and M. P. Gupta. “How to make a Smart Campus: Smart Campus Programme in IIT Delhi.” 2015.

Landro, Laura. "A Cure for Hospital Design: strategies to Keep Patients and Their Visitors From Getting Lost." Feb 03, 2014.

Lawrence Berkeley National Laboratory. "The Energy-Savings Potential of Electrochromic Windows in the US Commercial Buildings Sector." *9th Nordic Symposium on Building Physics.* Tampere, 2015. Volume 3.

Levy, Didier , Omar Saadoun, Karim Taga, and Lars Riegel. *Catching the Smart Home opportunity.* Report, Arthur D. Little, 2012.

Li, Min, Wenbin Gu, Yeshen He, Yannian Wu, and Yiying Zhang. “Smart home: architecture, technologies and systems.” *8th International Congress of Information and Communication Technology (ICICT-2018).* Xiamen: Elsevier, 2018. 393–400.

Lilis, Georgios, Gilbert Conus, Nastaran Asadi, and Maher Kayal. "Towards the next generation of intelligent building: An assessment study of current automation and future IoT based systems with a proposal for transitional design." *Sustainable Cities and Society 28 (2017)*, Aug 18, 2016: 473–481.

Lu, Jiakang, et al. "The Smart Thermostat: Using Occupancy Sensors to Save Energy in Homes." 2010.

Lymberis, A. "Smart wearables for remote health monitoring, from prevention to rehabilitation: current r&d, future challenges." *4th Annual IEEE Conf on Information Technology Applications in Biomedicine.* UK: IEEE, 2003.

Madini, Emanuele. "Le sei leve progettuali per creare uno smart office." *Osservatorio del Politecnico di Milano*, Feb 06, 2015.

Manfredini, Alessandro. "“La sicurezza di beni e persone quando si parla (non solo) di edificio”." *Smart Building conference.* Milano, 2019.

MapsPeople. "Improving the Modern Hospital: utilizing indoor wayfinding as a form of holistic care for better patient outcomes." 2018.

—. *MapsIndoors – Indoor Navigation built with Google Maps.* n.d. https://www.mapspeople.com/mapsindoors/ (accessed Jun 27, 2019).

Markets and Markets. *Ambient assisted living and smart home market by product, services, assisted living, product (safety & security, communication, medical assistive, mobility, telemonitoring, compensatory impairment) and region-global trend & forecast to 2020.* Annual Report, Markets and Markets, 2016.

Markets and Markets. “Smart Building Market by Type (Building Automation Software, Services), Building Type (Intelligent Security System, Building Energy Management System,

Infrastructure Management, and Network Management System), and Region - Global Forecast to 2022.” 2017.

Maryna, Z., and S. Anton. "A Guide to Human-Centered Design Methodology." 03 2016.

—. *A Guide to Human-Centered Design Methodology.* 15 Mar 2016. https://rubygarage.org/blog/human-centered-design (accessed May 09, 2019).

McCarthy, Patrick. *The NASA guide to air filtering plants.* 05 Jun 2017. https://www.ecology.com/2016/03/31/nasa-guide-air-filtering-houseplants/ (accessed Jul 31, 2019).

McLellan, Charles. *Optimising the smart office: A marriage of technology and people.* 01 Mar 2018. https://www.zdnet.com/article/optimising-the-smart-office-a-marriage-of-technology-and-people/ (accessed May 27, 2019).

Meemori research AB. *Cyber Security in Smart Commercial Buildings 2017 to 2021.* Four-monthly Report, Meemori research AB, 2017.

Meemori Research AB. *The Future Workplace: Smart Office Design in the Internet of Things Era.* Annual Report, Meemori AB, 2017.

Michelle Jeppesen. *Top Benefits of Indoor Wayfinding for Hospitals.* 05 Apr 2019. https://blog.mapspeople.com/top-benefits-of-indoor-wayfinding-for-hospitals (accessed Jul 04, 2019).

Microsoft. *Digital Culture: Your competitive advantage.* E-Book, Microsoft, 2018.

Microsoft research group. *Digital Culture: Your competitive advantage.* Report, Microsoft, 2018.

Mihalic, Alan . *"Smart" Cities and Buildings: The Emergence of the Cyber Safe Building.* 2018. https://www.iotsecurityfoundation.org/smart_cities_the_emergence_of_the_cyber_safe_building/ (accessed Jul 21, 2019).

Milnes, Hilary. *How tech in Rebecca Minkoff’s fitting rooms tripled expected clothing sales.* Sep 23, 2015. https://digiday.com/marketing/rebecca-minkoff-digital-store/ (accessed Aug 10, 2019).

Ministero della Salute. n.d. http://www.salute.gov.it (accessed May 15, 2019).

Myerson, Jeremy, and Jo-Anne Bichard. *New demographics, New Workspace: Office design for changing workforce.* A Gower Book, 2010.

Nagy, Danil, et al. “Project Discover: An application of generative design for architectural space planning.” *Symposium on Simulation for Architecture and Urban Design*, May 2017.

National Public media. *The smart audio report.* Half Yearly Report, Edison Research, 2019.

National Public Media. *The smart audio report.* Half Yearly Report, Edison Research, 2017.

Neale, Hamish , Johan Pedersen, Matthias Wolff, and Adrian Obrist. *What’s trending in European smart home market.* 27 Jun 2018. https://www.asmag.com/showpost/26330.aspx (accessed Jul 02, 2019).

Nedwich, Rich. *Smart Campus – merging smart city and smart home in education for digital natives.* Feb 2018. https://www.dotmagazine.online/new-work-and-digital-education/ICT4D/smart-

campus-merging-smart-city-and-smart-home-in-education-for-digital-natives (accessed May 18, 2019).

NHS Foundation Trust. *Case Study: Medical device management with RFID.* Harland Simon, 2019.

Nursing Time. n.d. https://www.nursingtimes.net/ (accessed Jul 14, 2019).

Nuvap. *Nuvap Prosystem.* n.d. https://www.nuvap.com/en/company-profile/ (accessed Jul 15, 2019).

O'Mara, M. "Strategy and Place. Managing Corporate Real Estate and Facilities for competitive Advantage." *The Free Press, New York*, 1999.

Opzione Cultura. *Il museo multisensoriale.* 08 Jul 2019. https://opzionecultura.wordpress.com (accessed Jul 24, 2019).

Page, John. *White Noise vs Sound Masking.* 11 Sep 2017. https://cambridgesound.com/difference-between-white-noise-sound-masking/ (accessed Jun 16, 2019).

Papatsimpa, C., and J. P. M. G. Linnartz. "Propagating sensor uncertainty to better infer office occupancy in smart building control." In *Energy & Buildings 179 (2018)*, 73–82. Elsevier, 2018.

Park, Eunil , Kim Sunghyun , Kim YoungSeok , and Kwon Sang Jib . *Smart home services as the next mainstream of the ICT industry: determinants of the adoption of smart home services.* Long Paper, Berlin: Springer, 2017.

Park, Herie, and Sang - Bong Rhee. "IoT-Based Smart Building Environment Service for Occupants' Thermal Comfort." *Journal of Sensors*, 21 May 2018.

Passive House Alliance. *The history of Passive House and Passive Building.* 2016. https://www.phius.org/what-is-passive-building/the-history-of-passive-houses (accessed May 16, 2019).

Pawlowski, Mark. *What is the Best Keyless Entry System for a Commercial Building?* 05 Oct 2018. https://medlininc.com/what-is-the-best-keyless-entry-system-for-a-commercial-building/ (accessed May 06, 2019).

Pega, Marketforce. "The Future of Work." 2017.

Phillips, Jess . *Smart buildings: Understanding the security risks.* 22 May 2019. https://www.intelligentcio.com/eu/2019/05/22/smart-buildings-understanding-the-security-risks/ (accessed Aug 17, 2019).

Politecnico di Milano. "Office design: le tendenze per l'ufficio 4.0." *Osservatorio Smart Working - Politecnico di Milano*, 2018.

Politecnico di Milano, Energy & Strategy Group. *E-Mobility Report 2018: tutti i numeri dell'auto elettrica in Italia e nel mondo.* Annual Report, Politecnico di Milano, 2017.

Politecnico di Torino. *Class Aid.* n.d. http://ami-2015.github.io/ClassAID/vision.html (accessed May 13, 2019).

Rocha, Paula, Afzal Siddiquia, and Michael Stadlerc. "Improving energy efficiency via smart building energy management systems: A comparison with policy measures." In *Energy and Buildings 88 (2015)*, 203–213. Elsevier, 2014.

Rossi, Maurizio. "Tecnologie per Human Centric Lighting Design negli uffici." *Area*, 03 2019: 28-30.

Sage Glass. *Smart Glass for better buildings.* n.d. https://www.sageglass.com/en/products (accessed Jul 03, 2019).

Sandalo, Sabrina. *Smart mirrors transform retail.* 2018. https://antedote.com/smart-mirrors-transform-retail/ (accessed Jul 15, 2019).

Santoro, Antonella. "La Qualità ambientale indoor è un asset strategico." *Smart Building Conference.* Milano, 2019.

SCHEER. *Opinion on potential risks to human health of Light Emitting Diodes LEDs.* Final Opinion, Scientific Committees, 2018.

SHENIR. *Health effect of artificial light.* Final Opinion, European Commission, 2012.

Shiklo, Boris. *RFID and IoT: A smart symbiosis for hospital asset tracking and management.* 09 Oct 2018. https://www.scnsoft.com/blog/smart-hospital-asset-tracking (accessed Jun 18, 2019).

SITA. “2019 Baggage IT insights.” Annual Report, 2019.

—. *Airport self-service gate: Use Case.* 2017. https://www.sita.aero/solutions-and-services/products/airport-self-service-gates (accessed Aug 04, 2019).

—. *AirportConnect Kiosk: Next-gen kiosks for dedicated or common-use.* n.d. https://www.sita.aero/solutions-and-services/products/airportconnect-kiosk (accessed Aug 12, 2019).

—. “Drop&Fly: The compact, secure, new-fit bag drop unit.” 2017. https://www.sita.aero/solutions-and-services/products/dropfly (accessed Aug 11, 2019).

SITA. “SITA 2016 baggage report.” Annual Report, 2016.

Snehashis, Ghoshal, and Neogi Subhasis. "Advance Glazing System – Energy Efficiency Approach for Buildings a Review." *4th International Conference on Advances in Energy Research (ICAER 2013).* Elsevier, 2013. 352-358.

Solima, Ludovico. "Smart Museums. Sul prossimo avvento della Internet of Things e del dialogo tra gli oggetti nei luoghi della cultura." *Italian Journal of Management*, Mar 14, 2016.

Steelcase. *Engagement and the Global Workplace: Key findings to amplify the performance of people, teams and organizations.* Global Annual Report, Steelcase , 2018.

Stracke, Christian M., Michael Shanks, and Oddgeir Tveiten. “Smart Universities: Education's Digital Future.” 2017.

Streich, Katja. *Indoor Navigation and Interactive Tour in a Museum.* Dec 19, 2017. https://www.infsoft.com/use-cases/indoor-navigation-and-interactive-tour-in-a-museum (accessed May 23, 2019).

—. *Location-based Employee services.* 23 Feb 2018. https://www.infsoft.com/use-cases/location-based-employee-services (accessed Jun 11, 2019).

Symonds, Paul, David H. K. Brow, and Valeria Lo Iacono. “Exploring an Absent Presence: Wayfinding as an Embodied Sociocultural Experience.” *Sociological Research Online*, 28 Feb 2017: 50-62.

Tagliaro, Chiara, and Andrea Ciaramella. “Experiencing smart working: a case study on workplace change management in Italy.” *Journal of Corporate Real Estate Vol. 18 Iss 3*, 19 Mar 2016: 194 - 208.

Tan, Emily . *Timberland raised in-store visits by 6% using location-based targeting.* 11 Apr 2017. https://www.campaignlive.co.uk/article/timberland-raised-in-store-visits-6-using-location-based-targeting/1430187 (accessed Jul 17, 2019).

Taylor, Karen. *By 2020 the Smart Hospital will be a reality.* 13 Jun 2017. https://www.philips.com/a-w/about/news/archive/future-health-index/articles/20170613-by-2020-the-smart-hospital-will-be-a-reality.html (accessed Jun 23, 2019).

Trifonova, Viktoriya . *What Percentage of Internet Traffic Is Mobile?* 2019. https://hostingtribunal.com/blog/mobile-percentage-of-traffic/ (accessed Jul 18, 2019).

U.S. General Services Administration Study. *Research about acoustic and sound masking in workplaces.* Cambridge Sound Management, 2019.

Upadhya, Vasuki , and Deepak Singh Rawat. *Intelligent Airports - Your Runway to Success.* Nov 2018. https://www.wipro.com/engineering-and-construction/intelligent-airports---your-runway-to-success/ (accessed Aug 10, 2019).

Venture Beat. *How a smart wearable device is improving care and saving money for hospitals.* 20 Oct 2014. https://venturebeat.com/, (accessed May 10, 2019).

Verdantix. "The Future of Smart Buildings." Annual Report, 2018.

Verizon. *State of the market: Internet of Things 2017.* Annual Report, Verizon, 2017.

Villaggi, Lorenzo, and Danil Nagy. *Generative Design for Architectural Space Planning.* 10 Jan 2018. https://www.autodesk.com/autodesk-university/article/Generative-Design-Architectural-Space-Planning-2019 (accessed May 29, 2019).

Vota, Ruggero. "Costruire l'ufficio intelligente." *Office layout*, Mar 2019: 23-25.

Wavestone. *Smart Airport: how technology is shaping the future of airports.* 14 Dec 2017. https://www.wavestone.com/en/insight/smart-airport-technology-shaping-future-airport/ (accessed Jul 06, 2019).

Wilson, Charlie, Tom Hargreaves, and Richard Hauxwell-Baldwin. “Benefits and risks of smart home technologies.” In *Energy Policy 103 (2017)*, 72–83. Elsevier, 2017.

WiseShelf. *Transforming retail shelves to IoT.* n.d. https://www.wiseshelf.com/ (accessed Jul 29, 2019).

Yang, H., H. Lee, and H. Zo. “User acceptance of smart home services: an extension of the theory of planned behavior.” In *Industrial Management and Data Systems*, 68-89. Elsevier, 2017.

YouGov. "Survey for Velux." 2018.

Zebra. “Reinventing retail: 2017 Retail vision study.” Report, 2017.