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Historical building refurbishment and Smart Home: literature review and case study

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Summary

Introduction

In the last decades, the internet of things (IoT) evolution started to spread across every kind of object, with the creation of new connected environments and devices. The innovation hence streamed also over the house and its components, transforming it and evolving its devices and appliances, sometimes changing the way people communicate with its parts. The entrance in the market by tech giants such as Google and Amazon, providing newer and simpler solutions to unify the control of all the devices will – and already is – boost significantly the adoption of this technology by the users. The aim of this work is to investigate how this technology works, how it changes the relationship between the users and their house, assessing if it is possible to experience energetical improvements due to the innovation. Considering the existence of negative sides of the innovation, both from a user experience and from a privacy and security perspective, the work tries to understand if energetical savings can be reached thanks to the smart home instalment, which is its potential and which are its limits.

A relevant interest is dedicated to the literature regarding those buildings raised before the end of the World War II. Their distribution across Europe is not negligible, while emission regulations are constantly increasing their attention to the building sector, responsible of a high stake of the emission. Also, there is great difference in the emission generated by an efficient household and a low-efficiency building. With the European Directives 2010/31/EU and 2012/27/EC, increasing limits were defined also for the buildings with a recognized heritage value.

The historical and environmental value is therefore not anymore a justification not to meet the environmental legislation. This work reports the results of the scientific discussion about this matter and the solutions found in the literature in that sense, adding the analysis of a case study.

In fact, the refurbishment of an historical building - raised in 1922 and located in the Italian city of Turin – is analyzed and compared with the present literature, assessing the improvements that it is possible to achieve.

Energetical efficiency, capital expense, management savings and emission reduction are discussed, while considering if it is possible to save the historical and environmental value carried by the ancient, but low-efficient buildings.

Chapter One

Theme and context

1.1 Introduction to Smart Home concept

1.1.1 Smart Home market spreading and smart speakers

Smart home devices have been massively launched on the global market during last years, especially by suppliers which are well known in the technology field: Alphabet (Google's parent), Amazon, Apple, Alibaba and other two Chinese giants like Baidu and Xiaomi – which is the fourth worldwide smartphone vendor, despite it has been founded just in 2010 [9].

The success of those tools depends on their being bought, installed, combined and used by customers. As it happened with several other technologies, from the personal computer to the smartphone - which were transformed from powerful technical inventions to worldwide diffused innovations by Apple's and its competitors strategies, through fun, entertainment and fashion - also those new devices are entering human's life.

In January 2019, Amazon announced that 100 million devices with Amazon Alexa Assistant installed had been sold, on devices such as Amazon Echo model or on third-part OEMs. Focusing on smart speakers - which are the smart home devices most known by consumers - just in 2019 over 140 million units have been sold, in a market lead by Amazon, with a +70% on sales with respect to the previous year [71,71,72].

McKinsey analysts stated that "*With the technological advances in voice control and artificial intelligence, the intelligent assistant is now a viable control centre for the connected home. Tech giants and start-up attackers have developed solutions delivered through both existing devices and new, stand-alone products.*" [69].

If, on one hand, being the owner of a smart speaker does not make the consumer a smart home user, this new device can be one of the keys to finally transform the households in something completely new and intelligent.

Nevertheless, what is a smart home?

1.1.2 Smart home: the definition

Internet of things (IoT), since its definition - which took place in 1999 [73] - has been used as a technical term to describe systems of interrelated computing devices, able to transfer data over a network without the requirement of a human relation. In this framework, the word *smart* has emerged becoming the icon of innovative technology. As reported by Marikyan et al. (2019): "*The key attributes of a smart technology are the ability to acquire information from the surrounding environment and react accordingly*" [25].

In the wide space defined by IoT applications and smart technologies, part of it is taken up by smart home applications. A strict definition of **smart home applications**, however, seems to be more challenging. In the literature, the response to this matter comes in different ways, with a waterfall of references to previous papers suggestions.

Marikyan et al. (2019) found that three concepts were commonly included in the various definition: technologies, services and the ability to satisfy users' needs, with the core represented by the technology seen as hardware and software components (including sensors and home appliances). Smart home represents

smart devices and sensors, which are **integrated into an intelligent system** offering various services and, more generally, **benefits** to the user [25].

Among the documents published during last four to five years, the situation is described to have experienced some improvements: the various definitions continue to keep those three aspects, but they insist on the communication between the devices – and so, on the status of being a part of IoT – and the situation has been analysed under different perspectives. It appears clear that this skeleton for the definition has spread uniformly over the world.

Shin et al. (2018) define it as an intelligent environment able to acquire and apply knowledge about inhabitants, adapting in order to meet comfort and efficiency [5]. Nikou (2019) recognizes it as an application of IoT integrating technology and services for controlling network-connected home systems for a better quality of living [6].

To those European views, Li et al. (2018) – writing from different Chinese provinces – found that a smart home is an organic combination of various subsystems related to home life through advanced technologies with the main objective to provide an efficient and friendly home environment [50].

Meanwhile, Jacobsson et al. (2016) and Yassein et al. (2019) focus their definitions on the ability of the user to monitor, visualize and control the home features - not limited to the switching of devices on and off - and the automatic management handled by the automation system [34, 36].

Although the perspective has been moved from the home smartness to the user ability to manage it, the three pillars – technology, intelligent system and user benefits – are still present.

It may be possible to provide a definition which follows this lead, but it also needs to recall some characteristics.

"*A smart home occurs while an intelligent environment is established into a house, **involving devices** such as automation of lighting, heating, ventilation and air conditioning, cameras and monitoring sensors, home appliances – dryers,* *washers, ovens, refrigeration tools – all of which are connected to the internet, which allows to collect data and to control the devices by an* ***intelligent system.*** *This happens in order to reach some specific* ***goals****, such as comfort, control, security, safety, healthcare and energy efficiency, intended to transform home into a benefit provider to the users.*"

The ownership and utilization of a smart speaker is not necessary to the existence of a smart home. Accordingly to the provided definition, a smart home system is more complex and composed by more than an easy connection between the system and the user. In fact, many applications allow the user to control the smart home system through a computer or a smartphone. The key into the diffusion of smart speakers may be the change into behaviour of consumers, making them used to control the house with sentences like "Alexa, turn the lights off", and preferring that to the manual way, avoiding many of the resistances that will be discussed in the next chapters.

1.2 Smart Home applications

1.2.1 Worldwide situation

According to the data presented by Statista, during the first quarter of 2020 the smart home systems have reached 170 million units worldwide, experiencing a growth equal to the 30.5% YoY (year over year). The penetration is still lower than 10%, but it is anticipated to reach 19.3% before the end of 2024, evidencing the expectations of a constant growth [74].

Other estimations, computed during 2019, described a compound annual growth rate (CAGR) of 31% and expected smart homes to cover 35% of North American houses and 20% of European's before the end of 2020 [69,1].

Actual data confirm this trend and suppose a greater penetration than the first expected in the United States, as shown in *Figure 1* and reported in *Table 1*. It is clear that the technological diffusion is not uniform around the world: as visible into the map, Africa, Central and South America and Asia - with the Chinese, Japanese and South Korean exceptions - have penetrations inferior to 7.5% in each country. Actually, the region in which the market is strongly established are North America, Northern Europe and Oceania.

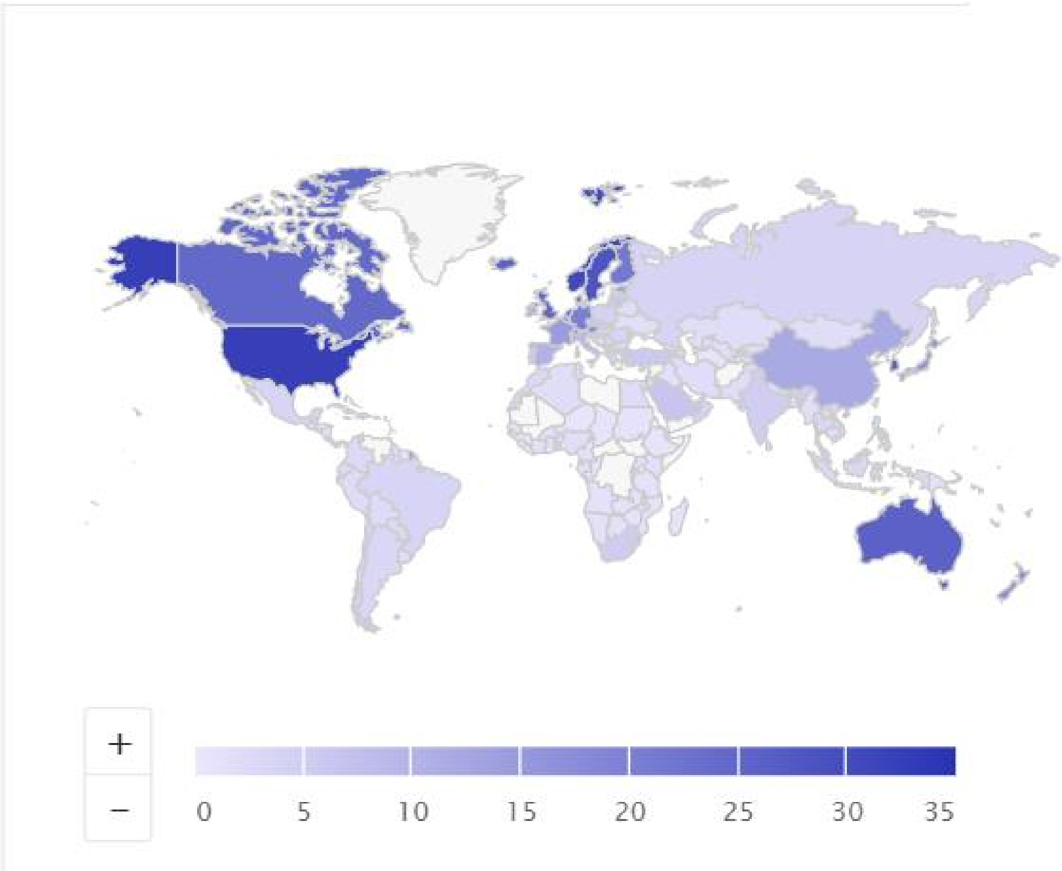

Figure 1: Global comparison of household penetration in September 2019. Source: Statista [74].

Country	Penetration (%)
United States	32.4
Norway	30.5
Sweden	28.5
South Korea	26.5
Australia	25.9
United Kingdom	25.0
Canada	24.4
Germany	20.1
New Zealand	17.8
Japan	16.2
France	14.5
China	11.9
Spain	10.3
Italy	9.5
Saudi Arabia	6.5
Turkey	5.9
India	5.1
Russia	3.8
South America	2.4
Central America	1.0

Table 1: Penetration data for some of the most important countries in September 2019. Source: Statista.

1.2.2 Main sectors interested by Smart Home applications

As it will be discussed later, the research and the technological development are focused toward the development of simple and efficient management applications, enabling an easy control over the system, and discussing methods to improve efficiency, in each aspect of the smart home.

Meanwhile, consumers' interest and vendors' attention are centred over smart appliances, security, control and connectivity and home entertainment. Revenues data, presented in *Figure 2*, are clear: lighting and energy management are still marginal.

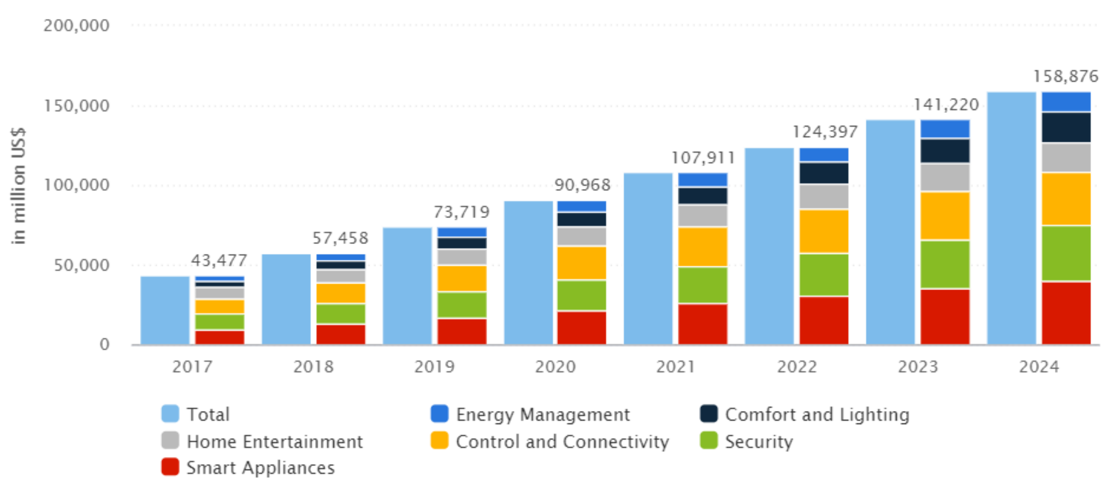

Figure 2: Revenues expectances for smart home different markets, updated to September 2019. Source: Statista

This may appear unlikely, since lighting and energy management are considered as the smart home applications that may effectively act over energetical – and, consequently, economical – expenditure. However, it must be considered the fact that each of the other applications is a technological evolution of something that is already present in most houses. With some examples that may be more understandable.

Smart appliances are introducing themselves through a smart fridge (*Figure 3*), substituting a classical refrigerator. A smart vent hood may substitute a classical one, just as a vacuum robot (*Figure 4*) can replace the vacuum cleaner, without asking consumers the effort of utilize it every time the floor needs to be cleaned up. The rose of all possible devices is extremely huge, reaching things like smart fork (to monitor eating habits) and intelligent frying pan (that notifies the user when the food needs to be flipped).

Figure 3: An example of smart fridge, called Samsung family hub refrigerator.
Source: Samsung.com

Figure 4: Xiaomi Mi Robot. Source: Xiaomi.com

Security systems recently welcomed Xiaomi Mi Home (*Figure 5*), a smart security camera, with a 360 degrees range and a Wi-Fi connectivity, compatible with Amazon Alexa. Another technological accessible technology for security is the doorbell sector, which integrates a camera into the house doorbell, taking a picture or recording some frame of the people that are ringing the bell, reporting it to the householders if there is no answer. Google Nest Hello is a good example of this kind of devices. One of the most disruptive devices is the one represented by the brand-new Ring family (*Figure 6)*, owned by Amazon.com, which owns an integrated artificial intelligence able to recognize who is ringing, and if a name is assigned to this person, that one will be recognized. Face recognition available to everyone is a great improvement from a technological point of view, but it is crucial to notice that legislation is still not ready to manage it.

Figure 5: Xiaomi Mi Home. Source: Amazon.com

Figure 6: One of the products of Amazon Ring family. Source: Amazon.com

This fact finds evidences in the arguments started in North America by senator Markey and repeated worldwide; stating that the existence and utilization of a system like Amazon Ring is a clear “*Open door for privacy and civil liberty violation”* [75].

Control and connectivity are recently dominated by the diffusion of smart speakers, but in general they are represented by smart home management applications available on every smartphone, and by technological assistants, like Amazon Alexa, Google Assistant and the historical Apple’s Siri.

Figure 7: Google Chromecast Ultra, a data receiver to be connected to the television.. Source: Google.com

Finally, home entertaining is well represented by Google Chromecast, which allows to connect devices like a smart TV, or to connect a classical TV through a device such as Google Chromecast Ultra (*Figure 7)*, to the internet. It enables the possibility to reproduce any kind of file on the television, transmitting it from a computer, smartphone or tablet, or reproducing it in streaming from the internet, transforming the television in a much more adaptive device.

Chapter Two

Literature Analysis and Taxonomy

2.1 Methodology

2.1.1 Database and documents selection

The first step in order to obtain reliable information about the state of the art on smart home applications is the scanning of databases of scientific literature through research engines.

The main selected database, with annex research engine, was ScienceDirect, which gives access also to Elsevier's publications. Not every document was taken into consideration: articles in journals, sections of larger scope books and scientific conferences papers were object of research.

A sequence of keywords has been used: **smart home, smart home research, smart home applications, smart building.** This selection, applied on a sample of documents aged from 2001 to 2020, allowed to reach the first works. Then, the focus has been moved to technical application, following the main themes discussed in the various works analysed.

Privacy, elder people, energy management, risk, issues, adoption, perception, environmental impact, heritage building, historical building, monitoring, control and **solutions** were utilized and combined, together and with the previous keywords, in order to find more relevant articles, always in the time frame between 2001 and 2020.

Among all the results found through keywords into the databases, a simple selection criteria was applied: the principal topic of the document had to be the smart home concept, under a general point of view, a specific application or the study of one or more of its features. This allowed to reduce the noise of information overload, due to citations to the matter in some shape, excluding non-specific and less reliable documents discussing the smart home topic just in an indirect and marginal way.

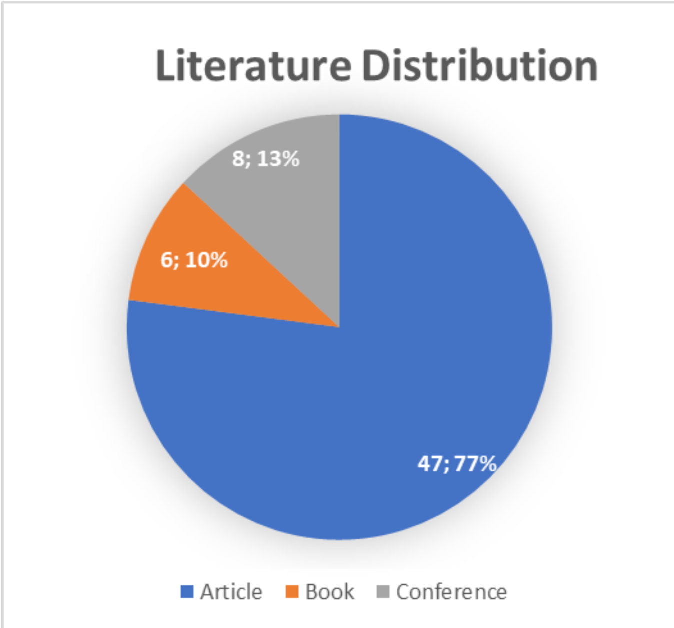

Figure 8: Literature distribution by source: article, book, conference.

With the aim of acquiring information about technologic and social development on this matter, articles from every year were accepted, but then a screening on the most recent literature has been performed. The literature included into the study happens to be aged between 2014 and the first months of 2020, decreasing the number of selected documents from 68 to 61, evidencing 47 articles, 6 book chapters and 8 conference papers.

2.1.2 Focus and Taxonomy

A taxonomy has been created in order to analyse the documents selected and to enlighten the topics discussed. Excel, from Microsoft Office suite, was then used in order to extract information, in form of tables and graphs, from the data collected into the taxonomy.

The taxonomy assigns some values to each paper. Those values may be names (as for country or university/ies of location of the writer/s), numbers (as the year in which the paper was published) or binomial values (0 or 1) indicating if a certain topic was discussed into the document.

The taxonomy target was to identify the main topics of interest found around the Smart Home theme among the sample of papers collected, allowing to get an overview of the State of the Art. A deeper discussion about each topic is reported into *Chapter Three.*

With the aim of identify the market, the trends, trying to reach a general overview of the worldwide situation, the future perspectives and the known issues related to the innovation diffusion, the first relevant topic considered is a *Consumer Analysis.* Then, the interest toward energetical consumption and the related costs was investigated under the *Energy Control and Management* topic. In order to understand not only the benefits, but also the "dark side" of the innovation, the topic *Risk and Security* was created, also considering the importance that the data have acquired during last decades, through the privacy-related issues raising due to the sensible environment in which the devices are placed and the data collected. The relationship with the single user - the home inhabitant - and the devices has been investigated under the *Display, Applications and User Interface* topic, with the aim to understand how the system can communicate and provide information to the user. Then, with the aim to understand which are the most important devices into a smart home, a *Main Devices* topic was created to collect this information and to keep track of the evolution of the Smart Home across the years. Eventually, in order to analyse the State of the Art around the requalification of an historical building through the creation of a Smart Home, such as the practical case considered into this work, the *Heritage Building* category was created.

2.2 Literature Review

2.2.1 Distribution over years

The analysed documents have a certain distribution among the years, evidenced into the *Figure 2,* where it is possible to notice an increasing interest into the matter. The spreading attention received is easily explained with the diffusion of the technology and the major request of efficiency by householders and legislations.

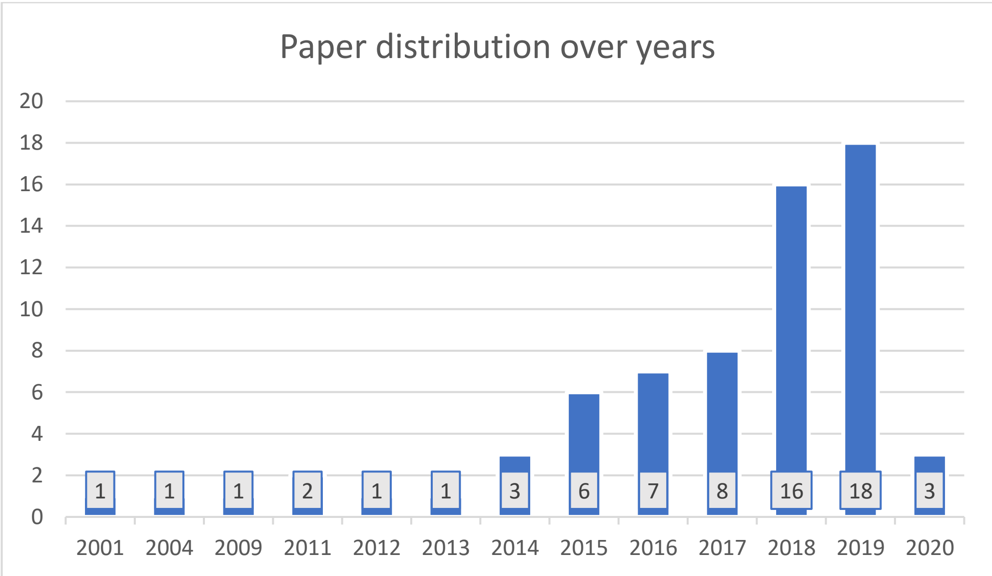

Figure 9: Paper distribution by year. All the 68 papers selected have been included with the aim to show the increasing of interest among a larger timeframe.

2.2.2 Distribution among the world and main clusters

The analysed documents are widely distributed among the nations, with a clear predominance of the "various" label, with 15 documents labelled in this way (please see *Graph 3*). This name has been chosen to indicate an international effort by members of two or more universities located into different countries.

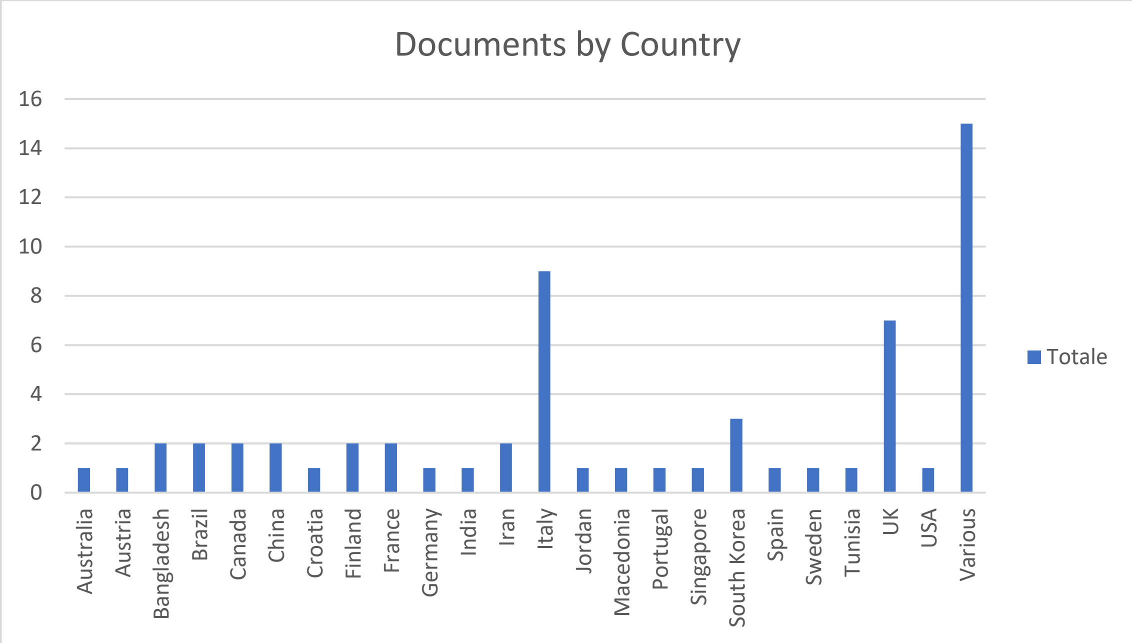

Figure 10: Documents distribution by country.

Another relevant cluster enlightened by an high relative number of publications is Italian's, where the 9 documents analysed are focused about the **historical/heritage building** topic, through the analysis, scanning and studying of the requalification of ancient building, especially under what concerns the energetical efficiency (heating and lightening) following the European environmental legislation.

The third relevant group is the one represented by the 7 documents produced in the United Kingdom. Those articles are mainly focused on the issues slowing the spreading of the technology: privacy issues, user perception and profiling of the expected consumers.

2.2.3 Main Topics

Among all the selected documents, an empirical focus is evidenced, with 12 articles directly based on surveys, accounting for the 19,67% of the documents, while 6 others are based on real case study, accounting for the 9,84% of the documents.

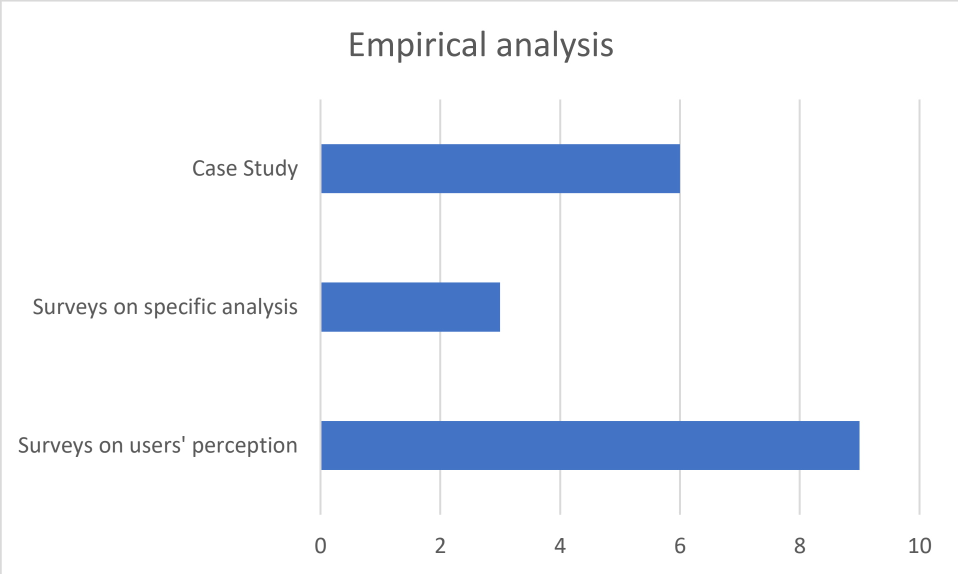

Figure 11: Occurrences of different kinds of empirical analysis into literature.

In 9 cases surveys were used to define users' perception of the technology, understand the drivers toward smart home adoption and to generate profiles of the consumers, following methods described in *Chapter Three,* discovering which benefits and risks of smart home technologies are actually perceived by customers. In all other cases survey were basis of specific analysis: an historical building energy consumption assessment, a survey on security solutions purposed by smart home technologies and a sequence of different data collections about historical building analysis. Case study are utilized as basis of technological evolution discussion of historical/heritage buildings.

The most important analysis that needs to be discussed among this created database is the one related to the most important – and then most researched about and most debated into papers – topics of interest.

Among the selected documents, the main focus seems to be over the energetical efficiency of households' technologies and the reduction of their consumption, through energy management and controlling discussions. This topic appears 22 times, with an incidence among the documents of 36%. One of the most discussed matters is the energy storage option, present in 6 documents, or in almost the 10% of the total. Another important factor is the wireless communication among different devices, which negligible energy expense may allow to reduce consumptions through a better management of the whole system.

The consumer analysis, which tries to identify the users, drivers and barriers to consumption, exploring the reasons for technological diffusion is the second most discussed topic, present in 14 documents (23% of the total).

Privacy and other security issues are discussed with attention respectively in 7 and 9 documents, leading to a total of 13 documents (21.3%), due to some overlap. This matter is probably one of the most challenging, since legislations are not only singularly complex, but also different among the several countries, for a bunch of products intended to be sold everywhere over the world.

Market forecasting, where researchers try to define actual and future trends for smart home market, for the whole industry or for single sectors, such as smart speakers or sensor for elders' health care, is present in 10 documents (16.4%).

Displays and applications, intended to communicate with the user - allowing him to manage the smart home system easily, and making him able to understand the various data about consumes and expenses, visualize which appliances are turned on or off and other management activities - are recalled in 7 documents (14.8%). Single sensors and applications, as smart thermostats, smart lights, smart switches and smart plugs, cameras for the tele-monitoring happen to be discussed each in some document, in a total of 7 documents (11.5%), not as the main topic but as an example or an application of technology.

The heritage building transformation into smart home has been researched with lower screening standards, due to the particular attention that this work aims to give to this matter, in order to reach the maximum amount of information possible, and considering especially Italian material, leading to 10 documents, into the selected time interval. The collaborations between different universities in this topic account to 4 documents over 10.

Various attempts of defining the smart home concept are present, as discussed in the *Chapter One,* into the selected documents. 8 documents (13.1%) clearly discuss this topic, while the others did not face the matter with attention.

Economical analysis of smart home applications appears in 5 documents (8%), mainly focusing among the return on the investment in smart home applications due to the energy saving.

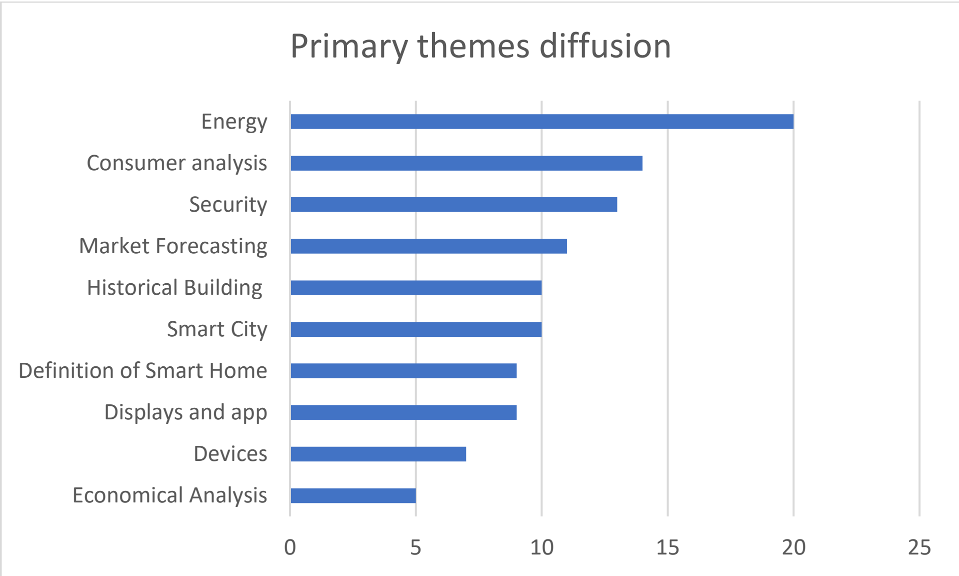

Figure 12: Occurrences of main themes discussed into literature.

Chapter Three

Literature Review and State of the Art

3.1 Targets

Among the considered papers, it is possible to distinguish among 9 different clusters of targets that lead the single document toward the discussion of one or many topics.

They can be described as it follows:

1. *Art Protection:* the target of the paper is to protect an historical building with respect to aging and needed refurbishments;
2. *Economy:* the target of the paper is to understand, from an economic perspective, the cost of the innovation and the payback period;
3. *Health:* the target of the study is to understand the benefits of the innovation over the health of the users;
4. *System development:* the target of the study is to develop a brand-new or an improved smart home system;
5. *Security:* the target of the study is assessing or developing the security of the innovation;
6. *Tech Advancement:* the target of the study is to assess and improve the technical State of the Art;

7. *Sustainability:* the target of the study is to improve the environmental sustainability of the building, also considering the refurbishment of historical structures, which are typically not environmental-friendly;
8. *Adoption:* the target of the study is to understand the consumers' behaviour and how it responds in front of the innovation;
9. *Energy:* the paper focuses on the energetical behaviour of the building in relation with the innovation and its features;

The results of the targets analysis are reported in *Figure 13,* where it is possible to notice the frequency of the target among the analysed literature.

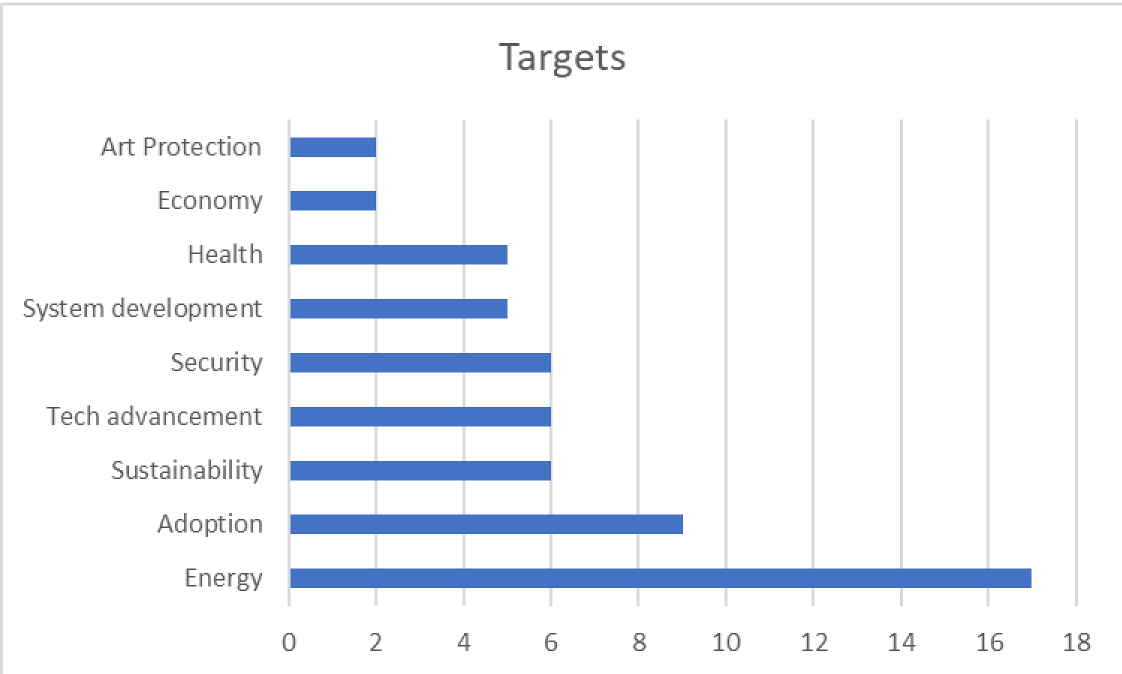

Figure 13: Target distribution across the considered literature.

3.2 Consumer analysis

3.2.1 Adoption factors

It exists a great difference between invention and innovation. Marketing experts work incessantly in order to find a way to make a product enter consumer life. Studies over habits and psychological mechanism that push people to buy and use a product or service, as every technological invention, are constantly published every year in order to better understand how human brain works or to find any information among what triggers needs and rewards feelings, pushing customers toward consumption.

As any market, also the one represented by smart home applications identifies specific needs and tries to purpose answers with physical products or services. A lot of drivers may influence the walk of an invention trough the development into innovation. Some factors can light the flame of desire toward the good, while others may act as barriers, avoiding the adoption of the technology by people, for many different reasons.

Factors may change during the different phases of the market development: different kind of customers – such as the typical consumers subdivision proposed by Rogers in 1962 into innovators, early adopters, earls subdivision into innovators, early adopters, early majority, late majority and laggards - and different needs may raise or disappear for many reasons, driving the market (and the technological development), towards different directions. The purpose of the first section of this chapter is to discuss the literature discoveries about drivers into smart home technologies adoption [80].

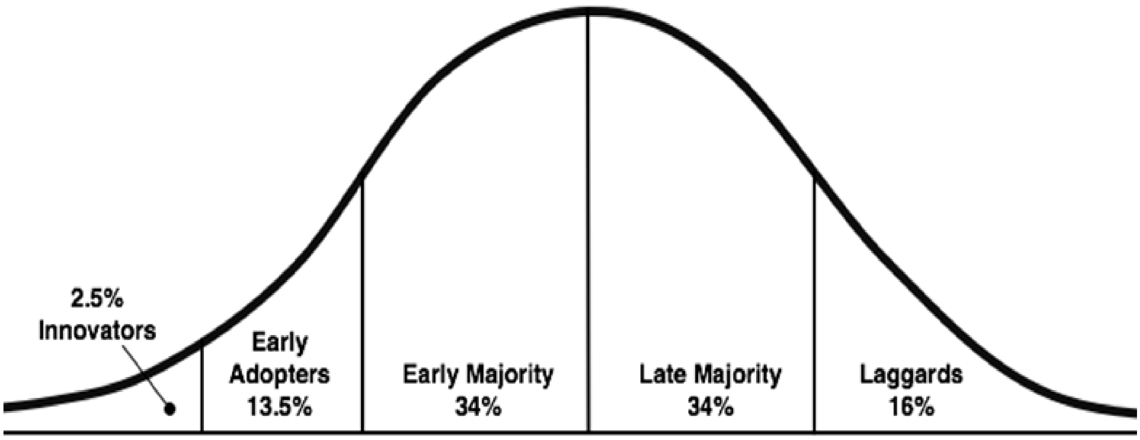

Figure 14: A graphical representation of Rodgers' Innovation adoption curve, presented in the book "Diffusion of Innovation" [80].

3.2.2 The basic: the TAM method

In 1989, almost a decade before the formal definition of a crucial concept such as the *Internet of Things,* Fred D. Davis analysed the results from two different studies about the technological diffusion of information technology with regression analysis and found correlations between *perceived ease of use* (PEoU), *perceived usefulness* (PU) and *utilization* [77].

From then to today, the consequences evidenced by this study became known as Technology Acceptance Model (TAM).

It has been changed in many ways, integrated with other approaches or extended with other studies following different developments in different contexts, but it has maintained his status as basis for many studies about the propensity of user to adopt a new technology to which he is not used to. Among many different technologies, also the adoption of smart home systems has been analysed by researchers using as a basis the Davis' TAM.

3.2.3 The user perspective: factors affecting the adoption

A certain current of thoughts developed, especially during last years, moving part of the research literature to the factors that make acquisition happen. A relevant increase of the interest into the matter has been experienced since 2016, with basis into TAM and other methods, applying them to the particular case of smart home systems, and verifying if the models were applicable to this particular sector. In this paragraph, the results obtained through the comparison of the most relevant articles will be reported and discussed, in order to identify the major adoption drivers of this technological innovation.

Shin, Park and Lee (2018) stated that most of the research on smart homes is based on technologies and their development, but few studies analysed the user perspective. Those studies are based on empirical observation of smart home services from the user's point of view. Shin, Park and Lee were the first that, following this flow, choose to analyse simultaneously both adoption and diffusion of the smart home systems. Starting form TAM, and accepting some extensions under the idea that every *internet connection technology* (ICT) has its own unique objective to user's eyes, this study allowed to demonstrate that in smart home appliances there are some crucial factors incurring into the adoption decision by users. Those key factors may affect the intention of buying a device, or the time in which this act may happen. Confirming the results obtained by the TAM, *perceived ease of use* (PEoU) is identified to be one of the most important factors, which affects the acquisition especially by people who are older and/or have access to an higher income, and who desire to give the burden of housework to technological devices.

Perceived usefulness (PU) and *intention to use* affect the intention to buy, while *compatibility* and *privacy* delay the intention of acquiring a device to the timeframe "within one year" or "within two years", neglecting "within six months", distancing the act of purchasing from the moment in which the survey is answered toward a future and less distinct instant [5].

S. Nikou (2019) added the *innovation diffusion theory,* also known as IDT (Rogers, 2003) to TAM. It considers five more key attributes: *relative advantages, compatibility, complexity, trialability* and *observability*. Complexity and PEoU (*perceived ease of use)* are very similar, while compatibility is a usual extension to the TAM model while referring to devices to be introduced in a system, and smart home system is one of them. S. Nikou adds also the *consumer perceived innovativeness* (CPI) to his study, following the footprints of Hong et al. (2017) [6].

As easily expectable, the results reported signalled a negative influence of perceived cost, and confirmed the influences between all the factors reported before and the adoption of a smart home device, proving positive influences between the various factors. For instance, compatibility increases both PU (*perceived usefulness)* and PEoU (*perceived ease of use)*, requiring less effort to the user [6].

Marikyan, Papagiannidis and Alamanos (2018) differentiated the factors influencing the users between benefits and barriers [25]. Barriers will be discussed in the next paragraph. During their analysis, Marikyan et al. (2018) found some new factors, described as benefits experienced by users. Those were: *health-related benefits, financial benefits* and *environmental benefits.* Health-related benefits occur when smart home technology can support ageing population, vulnerable people and users with chronic conditions. Health needs of a certain part of population makes necessary to monitor and control the health status and provide different form of health care. For those people, the adoption is obviously driven by a primary necessity: the health preservation. Financial benefits arise when the perspective of an investment in smart home applications moves to the long-term: energy efficient devices, coordinated by an energetic consumption efficient management may lead to consumption reduction, coping the initial capital expenditures with future economical savings in the bills, for some subsequent years. This effective benefit could be usually considered as one of the most important while talking of adoption of a technology, acting on consumers' pockets. However, consumer studies have difficulties to confirm the assumption that financial benefit is an important adoption driver: high-perceived maintenance costs and relatively low savings appear to make this factor negligible while the choice is taken. Both compatibility and improving of user experience outrank financial benefit during the choice. Environmental benefit appears to be a consistent factor since emerging threats such as climate change, global warming and volatility in energy prices increase the interest into smart systems. Smart home devices are efficient, and the direct consequence of their utilization is the reduction of consumption (and emissions).

Environmental issues importance between consumers' intentions to purchase smart home objects has been the focus of an investigation by M. Schill, D. Godefroit-Winkel, M.F. Diallo, C. Barbarossa (2019) toward a specific empirical analysis, again with the basis in TAM. Identifying as target of the intention a particular range of product among the market, represented by *eco-friendly smart home objects* (ESHO), this study found that environmental belief drives environmental concerns about the future of the planet. Then, this paper demonstrated that concerns have a significant importance over the intention to purchase a new product, and on the choice, that would fall on ESHO. Some limits of the environmental factor have however been evidenced: *materialism* decreases the perceived importance of environmental belief, where the distinction between a less efficient smart home application and an ESHO loses meaning in consumer's eyes, while an *environmental value-action gap* must be considered. Different studies noticed that the intentions declared about environmental matters are used to be decreased in the action phase by people's behaviours [14].

3.2.4 Barriers to adoption

Obviously, there are not only positive drivers influencing an adoption choice. Some negative factors must be considered and faced while trying to sell a new technology. Part of the literature refers to negative factors as barriers. This is an effective description: in many cases technology is stuck in a certain situation of diffusion and there is some external cause that stops the distribution spreading.

Marikyan et al. (2019) found that some barriers are the complexity of use and the lack of usefulness perceived by the consumers toward smart home technologies, as the obvious negative of their TAM method extension. Other attributes were also analysed, evidencing some new discoveries. The financial factor, as for initial expenditure (purchase and installation cost), repair and maintenance play a key role there, since interviewed people were not able to understand how a smart home system could make them saving money, instead of facing more expenses. The inability to understand triggers mistrust toward the invention and adds a new barrier. The privacy concern due to the fact of having devices collecting and sharing information among people's private life was another clear barrier to the adoption.

Some less expectable factors emerged as well, since psychological drivers appear to be effective too: smart home can change perception among socialization and isolation of the user, especially through the implementation of services as support and assistance into everyday activities. Self-perception may be negatively affected in terms of self-esteem – having technologies doing what people can do makes them feel weak – and of socialization-related issues, due to the fact that virtual relationships are not as satisfying as the ones that occur face-to-face [25].

A. Hong, C. Nam, S. Kim (2019) dedicated a whole article about the barriers to smart home adoption, adding to TAM some other methods as the *theory of planned behaviour* (TPB) and the *united theory of acceptance and use of technology* (UTAUT). This research noticed various psychological and personal barriers that put together might have an important influence into the spreading of smart home applications. TPB added to the analysis three considerations about human behaviour:

1. *Attitude toward behaviour:* degree of ability to put a behaviour in question;
2. *Subjective norms:* social pressure to do or not to do something;

3. *Perceived behavioural control:* people's perception of ease (or difficulty) of performing the behaviour.

The UTAUT model (*united theory of acceptance and use of technology)* tries to explain how expectancies and perceived conditions may affect behavioural intention.

Analysed barriers are, and leaded to:

1. *Perceived risk,* in the form of:
    a. *(perceived) performance risk*
    b. *(perceived) financial risk*
    c. *(perceived) privacy risk*
    d. *(perceived) psychological risk*

Differently from Marikyan et al. (2019), this research rejected the hypothesis of the financial risk as a barrier, since consumers is considered acknowledged of the fact that the devices are available at a wide range of prices.

All the other perceived risks were confirmed by the analysis.

2. *Technological uncertainty:* individual perceived inability to predict the future state of the environment, and the consequent inability to choose a response option and its consequences

3. *Service intangibility:* defined as difficulty of define or grasp mentally a service. The consumer experiences lacking in palpable or tactile quality of good. Here it is defined as the difficulty of users to define, describe or conceptualize smart homes

Both technological uncertainty and service intangibility were proven as correlated to the various perceived risks and detected as barriers to the adoption [19].

3.3 Energy: Control and Management

A huge interest is found among the literature about the energetical consumption of the smart home applications. The analysis is pursued from different points of view.

Basically, controlling and managing is performed in order to increase the energetical efficiency of the home automation system, where an infrastructure of connected devices is created allowing to a central unit to control the various applications.

There are some different ways in which a home automation system may be build and connected. As reported by Geraldo P.R. Filho et Al. (2019), these are conductible to three possible clusters of infrastructure for data communication and management, each with its limitations:

1. *Wired infrastructure*, expected to become impractical due to the cost, 50% to 90% higher than the others;
2. *Hybrid infrastructure,* integrating ZigBee, Bluetooth and Wi-Fi to the traditional infrastructure, which limits the compatibility of new devices after the system initial assembly;
3. *Wireless infrastructure,* the one that seems more promising, allowing adaptability and scalability. The major limit of wireless management is the dissipation of the residual energy; a problem usually coped through devices sleep mode, which reduces this effect [20].

Then, the decision-making step is performed by a central unit, connected with the user - and at least partially controlled by her (or him) - through an interface, such as a smartphone application (often referred as GUI or graphic user interface) and/or a virtual assistant artificial intelligence.

Taking the Amazon's range of devices and solutions for smart homes as an example, Amazon Echo's products are connected through the Wi-Fi to Amazon Alexa, which is the name of both the smartphone application (GUI) and the virtual assistant provided to the users to control the smart home system through the voice. As it will be described in the next chapters, both the solution called Amazon Alexa can enable the user to control every device through the extensions provided by the Alexa Skill suite.

Thereby, the literature is also interested into understanding if there is any energetical saving due to the shift from a traditional home to a smart home.

On one hand, it is clear that the number of energy-consuming devices distributed all around the building increases.

On the second hand the improvement in the ability of managing such devices is commonly expected to lead to an overall improvement in efficiency, reducing energy consumption and allowing advantages on costs and emissions.

Despite that, the reality appears to be less appealing than foreseen. According to Sergio Tirado Herrero et Al. (2018) the buildings sector represents one third of global final energy use and CO_2 energy-related emissions, leading residential sector representing 25% of global energy consumption and 17% of global carbon dioxide emissions. In this study is stated that, although smart home equipment manufacturers claim to reach up to 30% reduction in energetical consumption, the actual energy saving estimates account for a modest 10-12% in the United States, characterised by an increase of gas consumption in one third of the appliances, therefore evidencing an high variability [13].

Similarly, Rebecca Ford et al. (2017) noticed that the residential energy demand reduction has not been proved yet, with the expected energy saving not founded in actual applications. Ford's analysis is based on 308 HEM (home energy management) products, noticing that there is a "*split between those that are not focused on delivering energy-related information, and those that provide* *advanced control functionality, often with a focus on comfort, convenience and security rather than energy",* not expressing their efficiency potential.

Also, the load monitors communicating the consumptions are not programmed to collect historical feedbacks, preventing the users to learn about energetical demand [3]. Hence, it appears clear that there is a potential for further additional improvement, which has not been exploited yet.

On a larger perspective, trying to foresee the future developments, every single household is seen as inserted in a city, with others smart homes connected to smart grids, where the smart grids are source of energy supply also for Plug-in Electric Vehicles (PEVs), as claimed by Siwar Khemakhem et Al. (2019).

The fact that the mobility – at least the urban one - may shift its energetical demand from fuel stations to households appears as a possible great new challenge for the electrical power distribution and management, increasing the importance of the energetical efficiency goals [48].

Trying to reduce the consumptions while improving efficiency, some models are proposed, considering different options:

1. Simplifying the user approach through new user interfaces [18, 39], sometimes creating a new system architecture to simplify the management, with tools like Arduino [2, 11];
2. Suggesting simple but effective precautions in order to save energy such as appliances auto-play in low energy load moments [20] or controlling device consumptions while turned on and while in sleep mode [43];
3. Creating heuristics and decisional algorithm allowing the smart home system to control and reduce consumption and costs automatically [21, 22, 29], using batteries to store the energy available at lower cost during non-peak hours or establishing a communication with others smart homes to reduce consumption [23]; trading the energy between different homes [31].

3.4 Risk and Security

Although it might appear unlikely to find risk for a human being in a protected environment such as an home, in the reality there are some different risks that may rise into the domestic environment. Electronic devices can be used to cope such risks, increasing the security of the smart home, thereby exposing the users to new – and less known and investigated - risks, e.g. the privacy risk.

Jacobsson et al. (2014) explained this situation through a clear example having as the main characters the surveillance camera placed into a smart home. As it is obvious, they can effectively increase the security, from fire detection to childcare and elderly surveillance, but "[they] *cause serious privacy concerns, i.e. someone may monitor everyday life in the home environment*". Then, over every smart home application system, a risk analysis should be performed [34].

M. B. Yassein et al. (2019) performed a particular analysis, discussing about the IoT architecture supporting the smart home system, considering the main issues and the most common solutions adopted.

Three technical layers compose this architecture:

1. *Perception Layer:* responsible for data collection, using physical devices, such as sensors. The data collection requires accuracy and device authentication. Data confidentiality is the main issue, especially in case of cyber-attack. The device authentication, and a following encryption of data, can protect the user from the privacy concern.
2. *Network Layer:* collected data are transferred to the processing unit, through Wi-Fi, Bluetooth or other technologies. In that case, the raising problems affect the data management by the system, where authentication and authorization techniques can help the process.
3. *Application Layer*: software application able to manage data and devices take the decisions, following the user requests. This layer is the weakest

from a privacy perspective: user personal information can be stolen, as simply as using infected emails and links, allowing hackers to access to the data. Protection can be given with additional authentication measures, requiring more steps to be performed [36]. For instance, the access to the personal page can be performed in a two-steps authentication: the first one composed by the insertion of username (or email address) and password, while the second would require a temporary code sent to the email address or via SMS to the user. In this case the stealth of username and password is not enough to access to personal information, it becomes necessary also the knowledge of the combination of email and password or the physical ownership of the personal mobile phone (or smartphone).

Differently, R. Heartfield et al. (2018) pursue another perspective: after discussing the technicalities of various cyber-attacks, the paper considers the effects that a security break can have into the system. Burglary, performed by gaining access to the house – way simpler with the introduction of voice assistants such as Amazon Alexa and Google Echo - or accessing to the bank account exploiting authentication data leakage are some clear examples, as well as blackmailing after collection of private pictures collected by internal surveillance cameras, and then accessed by non-users [45].

As remembered by H. Mshali et al. (2018), the development of a wireless system requires consideration and efforts since the design phase. Encryption is required, but robust cryptography techniques need wide computation and resource, creating an unsatisfied need of effective defence with minimal resource usage [8].

Another of the targets of the smart home applications is to improve the quality of life of its habitants, and hence, to increase the security and reduce risks. Toward this direction some applications were developed, especially in what concerns the abnormality detection, attempting to protect the health preventing illnesses.

For instance, H. Sfar et al. (2018) investigated a causal association approach, while J. Ye et al. (2016) suggested a new technique based on statistical analysis of data collected by sensors, while H. Mshali et al. (2018) researched all the technologies available to pursue this scope [49, 52, 8].

As shown in *Figure 15,* it seems interesting that C. Wilson et al. (2017) were able to report a survey among the perception of the risks brought by the smart home technology, showing general indifference to the theme, with less than the half of the respondents agreeing with the sentence "*smart home technologies are an invasion of privacy*" [51].

A. Burrows et al. (2018) uncovered through various interviews, the need for mechanisms that allow people to interact more directly with the data, with consequences on the consent given to the use of such data [62].

The difference between those data is explainable by the fact that in the first case the interviewed are a sample of the population, while in the second paper they are selected among smart home technologies users.

In a research performed by J. E. Klobas et al. (2019), the respondents that were "*sufficiently familiar*" with this technology were just around a quarter over all the interviewed, and more than the half of this "*sufficiently familiar*" group was already a user of smart home technologies [9].

As discussed in 3.2.3, the perception of a privacy risk exists, and is able to dissuade consumers to purchase a smart home product [4].

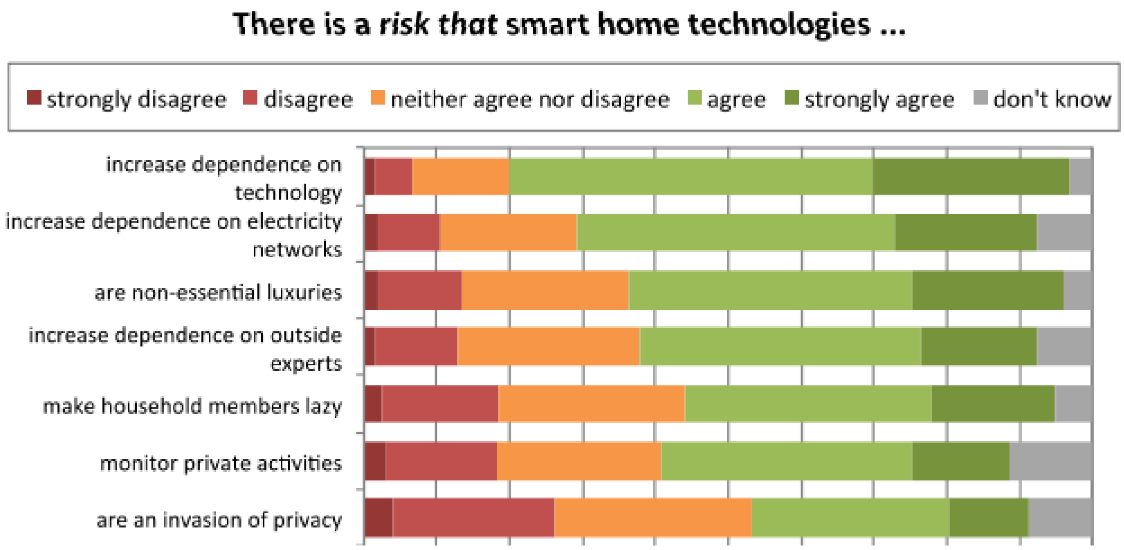

Figure 15: Part of the results obtained in the survey reported by C. Wilson et al. (2017) [51]

3.5 Display, applications and user interface

As anticipated in the previous chapters, a discussion about the communication between the technologies and the user is pursued as a secondary topic in some of the paper analysed.

As seen in 3.2, the consumer needs to communicate with the devices not only in order to turn them on and off, but also in order to understand the consumptions, their threads and distribution, and to manage them. This relationship is commonly seen as an important characteristic of the Smart Home. The active role of the user is then recognized as effective by different sources, underlining the importance of the increase in awareness [2, 53].

At first, the importance of the feedback is clear: Anders Nilsson et al. (2018) discuss about real-time feedbacks into smart home energy management systems. Noticing that many past models were assuming that the user is a rational agent, and considering that this is not always true, a research involving 154 households of new smart home adopters showed the importance of a developed user interface, with a mobile app mirroring the in-home control display.

Feeding the user with energy feedbacks, smart lightning control, smart plugs control and home/away switch (general switch) the overall trend showed important savings. Many users understood the impact of their actions and tried to manage them, while some others had an inferior control over the consumption, focused on enjoying the smart home features, and not on consumption [44].

If real-time feedback is able to increase the awareness, other data can be displayed: Rebecca Ford et al. (2017), analysing 19 in-home displays noticed how 17 of them allowed to access also to historical data and 6 provided predictive use. Expanding the time horizon from the present toward both past and future, a clear benefit is provided to the users' awareness [3].

From a smart home perspective, the data are collected from the devices by smart meters or through the conversion of the information from a traditional meter to an optic reader [3]. Then, the data are displayed together with an in-house display. Software have been developed in order to make the information more accessible by the users, exploiting PCs and smartphone diffusion through the people.

Shiu Kumar (2014) discussed the need of the development of a software app, applying Java and the Android Software Development Kit. In this way every Android-based smartphone allowed the authenticated user to access the information and the control over the devices. This control was enabled through the Graphic User Interface (GUI) displayed on the application, or with a vocal command to Google Assistant. The application also allowed the so-called *Automatic Mode:* maintain a temperature or switch the lights on and off with day and night, programming actions to be done and repeated [32].

The process to aggregate information and merge it with the (remote) control of the devices distributed across the home has been successfully pursued also by the tech giants, becoming a standard with Amazon and Google presenting their smartphone applications *Amazon Alexa* and *Google Home.* The process is quite simple for the user.

In Google Home, the user can create a virtual home, connecting the central software to the various devices through Bluetooth and Wi-Fi. Devices can be sorted in rooms and be controlled for single actions or programmed in routines to be executed and repeated.

Similarly, Amazon Alexa allows to manage the account and the devices, and offers some tools such as the creation of lists and message sending. In both cases - as anticipated in 1.1.1 – the control can be easily executed simply talking to the vocal assistants, accessible from the smartphone apps and from the smart speakers, activated with simple (and customizable) sentences such as “Ok, Google!” or “Alexa!”.

With these applications the user experience is made way simpler and more devices can be added to the system in different moments. The ease of control and the immediacy of the actions are the major interests of these solutions, which on the other side seem to leave on a second level the feedback over the consumptions, and its impact on users' awareness.

A further and completely different approach considering the relation between user and devices has been explored by Benjamin Eckstein et al. (2019), with software development and tests over 36 people. The scientists developed a system integrating smart home and virtual reality, creating the so-called Smart Substitutional Reality (SSR). The VR experience is hence exploited allowing the user to visualize an environment that can be either physical or digital, opening exterminate possibilities, also for game applications. Concerning smart homes, the VR technology is expected to allow the user to interact with the devices through virtual objects. For instance, an electric real-world fan can be turned on and off by "touching" a virtual collision shape. This model was realized and tested on 36 participants [12].

3.6 Main devices

Across the literature, there are some attempts to describe the main technologies composing a Smart Home System. In such case, comparing older articles - that are not accounted between the 61 selected through the method discussed in *Chapter Two* - with the most recent, it is possible to notice how more than a decade ago, many different applications were imagined and attempted to digitize the domestic environment. Then, over a great quantity of smart devices, just some applications survived in the research.

For instance, Li Jiang et al. (2004) listed a great quantity of smart appliances that would have been able to make users' life more comfortable. Some examples are a smart bed, able to wake the user up with combinations of preferred sounds and smells, a smart mat, that sensing the body weight and recognizing the footprint was able to recognize the user recording who is at home and who is not, while removing the dust and bad odours [46]. Recent literature does not discuss about applications like these, nor does the market.

Furthermore, Rebecca Ford et al (2017) noticed that some classification were purposed in the past, but the evolution of the market made them obsolete.

An example of this is the evolution of the in-home displays, formerly load monitors, which are experiencing a substitution by smartphone apps (see 3.4).

The appliances and the devices that gained more importance year over year are the ones perceived as most useful, the easiest to use, the easiest to install and hence, the most diffused.

Those are smart **thermostats**, smart **plugs/switches** and **smart lights**. They also gained major interest since they are compatible with many devices and their energetic consumption is easier to measure.

For a more detailed overview of those devices:

1. *Smart Thermostats:* one of the most successful smart home devices since its introduction into the market, its diffusion exploded at the beginning of the new century, due to the high impact of heaters in household consumptions (and costs). Smart thermostats collect data with sensors, from temperature to humidity and outdoor weather; allow programming of time points with set points temperatures, reducing heating when not needed. They also allow remote control from smartphones app and web platforms. "*Embedded sensors, actuation capabilities and communication make the thermostat smart*".
2. *Smart Plugs/Switches:* these products are able to sit between the electricity source and the appliance, providing information and control functionalities to non-smart appliances. Smart plugs and switches are hence controllable both physically and remotely, also through smartphone app and web applications, allowing the user to turn on and off the devices attached simply stopping the current flow, and to access to power use and instantaneous or historical consumption data.
3. *Smart Lights:* composed by sensors, microprocessors and remotely controllable switches, they can offer users remote or automated control functionality. Power consumption is usually not monitored, while advanced controlling options are offered, from switching on and off to colour and dim level management. Usually they exploit led lamps technology.

Other discussed devices are sensors – diffused in any smart device – micro-controllers, web-cams and the communication medium, connecting the smart devices to the wired or wireless control unit. [3, 16, 22, 15, 11, 45]

3.7 Heritage Buildings

3.7.1 Historical Buildings and Legislation Evolution

Across the literature, it is possible to determinate the presence of three main phases of building history.

The first one is composed by all those construction risen before 1945, the end of the World War II. In that era, the main materials were bricks and stones.

After the end of the Second World War, decades of post-war reconstruction, economic boom, technological advancement and growth in public support to the poorest classes led the industry to the mass choice of reinforced concrete and single-layered glass. This solution, which was very functional at the time, started to show its limits while approaching to the new millennium.

Between the end of the Eighties and the beginning of the Nineties, the governments started to look with increased attention to building carbon emissions. For instance, after the European directives, Italy regulated the issue with the Law 10/1991. For this reason in Italy, the third building phase starts in 1991, while in other countries the year can change by some units. In this last phase, the energetical efficiency reached better levels than in the past, accordingly to the new regulations.

An historical (or heritage) building is a construction belonging to the first of the three described phases. The historical relevance can be higher or lower depending on the antiquity or on the role of the building (i.e. a monastery or a castle), but an historical value is generally assigned to every structure raised before 1945.

As noted by Kristian Fabbri et al (2012), the legislation has always had a softer hand on building with an historical value. This pattern is easily recognizable also at the beginning of the new millennia, with the Directive 2002/91/EC (also known and referred to as *EPBD*), where the restriction on emission required by the European Union did not apply to buildings with heritage merit [64].

However, the impact of heritage building is not negligible at all. Giorgia Spigliantini et al. (2017) reported that the 14% of buildings in Europe was raised before 1920 and that in some areas, such as Bologna (Italy) City Centre the vast majority of the buildings – around the 80% - were belonging to the discussed first phase [56].

Luisa F. Cabeza et al. (2018) said that the building raised before 1945 compose at least the 30% of the European stock [58]. Acknowledged by that, at the end of the first decade of this century, the European Parliament intervened with stricter legislation, stating that the building sector was responsible of around 40% of total energy consumptions.

The Directive 2010/31/EU was signed, modifying the EPBD and its revisions accordingly to the spirit of the Kyoto Protocol (1998) aiming to reduce by 20% European greenhouse gas emissions (compared to 1990's) by 2020, to reduce human impact on climate change. Then new restrictions were then higher than in the past, expressing that *the buildings protected as part of an environment because of their architectural or historical merit* could not be affected by Member States alignment to the Directive, while reaching the energy performance requirements *would unacceptably alter their character or appearance.* So, the historical buildings were to be aligned to the others in terms of energetical efficiency, but they could avoid this regulation if meeting the target would have altered their character or appearance.

The new formulation was made stricter just two years later - with the request to Member States not to purchase non-efficient buildings - through the Directive 2012/27/EU, allowing to incentive the research toward energy efficiency [78, 79]. Reducing the demand also reduces the value of the buildings, pushing owners toward refurbishment efforts.

3.7.2 Technological Applications in Historical Buildings

With the increase of the interest in increase historical building efficiency, the literature developed many themes applying technology in order to intervene effectively on the heritage constructions.

The first identified theme is the protection of the historical value. This can happen during the management, as in the case purposed by Juan V Capella et al. (2011), where a set of low power sensors were installed to have an early detection of problems [59].

Otherwise, the conservative approach is important also during the restructuring phase: Antonio Costanzo et al. (2014) and Carlo Biagini et al. (2016) both exposed through a case study the importance of non-invasive analysis and non-destructive refurbishment techniques on historical buildings [60, 66], while age and techniques may expose the structures to unexpected failures. To minimize the impact is then important to perform an analysis through scanners such as laser, infrared and sensors in order to compose a 3D model of the building to be digitally analysed before the intervention, understanding how a specific part of the structure was raised, and its possible weakness.

Some other researches properly focused on the thermal efficiency, by far the most affecting the consumptions. An important solution was found into the insulation of the walls, with a coating applied in order to reduce the diffusion of the heat from the inner to the outer part of the rooms.

This is the case of Roberto De Lieto Vollaro et al. (2014) and Paola Boarin et al. (2014), analysing the thermal flows and their evolution with and without insulating windows and walls, showing important advancements made thanks to the technology [55, 61].

The effort to increase the thermal insulation lead in some cases to transform courtyard into atriums, hence reducing the difference between house indoor and outdoor temperature – reducing the heat flow. [58]

Also Giovanna Franco et al. (2015) confirmed the importance of the insulation, discussing about the smart management of historical buildings. They enhanced the fact that improving the thermal behaviour required taking improvements increasing the envelope of the building, as thermal insulation of ground, floor, walls, roofing, windows and rising damps elimination, obtaining efficiency values on thermal dispersion way better than before [65].

In parallel with the building thermal behaviour, the literature investigated the best choice regarding the heat-generation plant.

Both in HVAC (*Heat Ventilation and Air Conditioning*) and in DHW (*Domestic Hot Water*) production, the best choice falls on heat pumps, allowing the highest energy savings. In addition, it is compatible with the use of water as transfer mean, which usually requires little adjustments in the structure.

From an aesthetical perspective, the heat pumps are not pleasant to see and they can be loud, requiring to be hidden, especially in buildings with an architectural merit. A practical solution adopted is to place them in buildings upper parts, when that does not cause structural problems due to the weight of the device. To integrate renewable energy with this heat generators is usually complex, and the solution can involve, when possible, and in way not too invasive, the installation of solar or photovoltaic panels [54, 58].

Energetical efficiency is also a matter of user behaviour, as discussed previously. When the owner is not a resident of the house, the situation can raise some issues. Indeed, a great number of the historical buildings across the Europe are state-owned.

A Magrini et al. (2017) purposed a model to assess their energetical performance, understanding where and how the intervention needed priority.

Marijana Zekic-Susac et al. (2020) developed an IoT system aiming to manage and control the consumptions of Croatian state-owned buildings through acquisition and elaboration of historical data [57, 63].

Chapter Four

Case Study Analysis

4.1 The Case-Study Building

The analysis is executed on an historical building: a residential household located in Corso Giovanni Agnelli, in the city of Turin (Italy). The building is hence located in the Mirafiori district, in a residential square between two of the main streets of the city: Corso Agnelli and Corso Unione Sovietica. While the front door faces toward a secondary street connected to Corso Agnelli, the courtyard and the garden round the other three walls. Out of the enclosures, some other mono-familiar buildings and a multi-familiar structure separate the home from the two large streets, making the environment quieter.

Figure 16: A picture of the house exteriors before the refurbishment works begin. It is possible to notice the private courtyard and the proved aspect of wall and fixtures.

The building has a relevant historical value, specifically recognized as *historical-environmental value*. It was raised in 1922, and it is composed by an underground floor (the basement), a ground floor, a first floor and an attic, for a total of 190 m^2.

Regarding efficiencies and carbon emissions, the building original heat system accounted for an *energy performance index* before requalification equal to 271.06 kWh/m^2year, with *CO_2 emissions* before requalification equal to 82.42 kg/m^2year. These low-efficiency levels assigned the building to the lower European efficiency cluster: the G-Class.

Moreover, the level was way beyond the threshold, set at 175 kWh/m^{2}year.

4.2 The project

The building recovery plan was elaborated by ABSE Studio Srl. and composed by three steps to be performed:

1. Architectonical project and internal restructuring
2. Home automation system
3. Roofing restructuring and photovoltaic system installation

4.2.1 First Step: architectonical project and internal restructuring

The first step of the plan required many phases, as listed below:

- First floor slab consolidation
- Conditioning system refurbishment
- Insulation of external walls
- Electric system refurbishment
- Hydraulic system refurbishment
- Reduction of thermal dispersion due to fixtures

In the first phase, a structural weakness of the building was restructured, recovering the effects of time and allowing the access to the first floor. Here, a slab that was crucial in the support of the floor, needed to needed to be consolidated.

In the second phase, the conditioning system was thought – such as many other interventions – to increase the heat efficiency of the house, reducing energy waste. The first installation happened into the basements: the choice was a thermal system with energy generation based on a pellet stove. Then, for the rest of the house the selected solution was the installation of radiant panels on the ceilings of ground and first floor, allowing the heating of three floors with just two series of panels. The panels have been applied to the false ceiling (*Figure 16)*, for the protection of load-bearing structures. The false ceiling leaves 5 mm of blank space to the ceiling, and it is 27mm thick, supporting the 15 mm thick panels with a metal structure. The application of stucco and painting allowed the hiding of the panels to the residents' eyes (*Figure 17)*. The chosen thermic plant in charge to heat the panels is a reversible, air-condensed heat pump, which can be used to both condition and heat the panels of ground and first floors.

The panels heat generations is shown in *Figure 18.*

Figure 17: the radiator panels are installed on the false ceiling, enabling the heating of two floors with just one installation.

Figure 18: the radiator panels are hidden through the false ceiling completion with stucco and painting.

Figure 19: A thermography picture of the panels while working, obtained with a thermoscanner.

In the third phase, the key role was played by nanotechnology in order to obtain an energetical-efficient insulation of perimeter walls. The insulation, applied after an anti-mould treatment, was performed through a coating on the inner face of the walls. The coating material was composed by a fiberglass mesh with thermal skin coat constituted by lime, perlite, cocciopesto and hollow glass spheres (mainly composed by expanded silicates).

This solution is not only ecological – the materials are biocompatible – but also gives to the structure both mechanical resistance and high breathability, allowing humidity reduction, a typical issue in historical buildings.

The steam resistance is hence characterized by a factor $\mu < 8$. The thermal conductivity of cellular glass ranges between 0.040 and 0.050 W/mK. This value, associated with a thickness ranging between 4 and 5 mm, leads to a thermal resistance equal to 0.45 m^2K/W. The coating was then covered by a painting phase. A thermographic assessment of the walls showed improvements from an average value of 14°C before the treatment to an improved average of around 18°C. *Figure 19* and *Figure 20* report the thermography's pictures of the external wall temperature before and after the nanotechnology-based insulation.

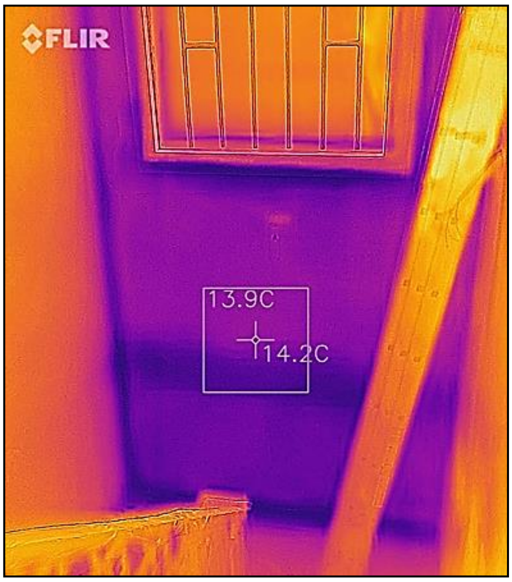

Figure 20: A thermography of an external wall before the nanotechnology-based insulation. The shown values range between 13.9°C and 14.2°C.

Figure 21: A thermography of an external wall after the nanotechnology-based insulation. The shown values range between 18.4°C and 18.5°C.

The fourth and the fifth phases were performed during the house refurbishment, through the elimination of the wall radiators and the creation of brand-new systems.

The electric system switchboard that will be supplied by the photovoltaic modules after the completion of the third step is connected with all the household plugs and appliances and the previously discussed heat pump.

The reversible heat pump generates the domestic hot water (DHW) used both in household utilities and in panel heating.

In the sixth phase, the windows and the other fixtures were replaced with newer – and most effective in insulation – solutions, maintaining the aesthetical historical shapes of the windows.

Figure 21 and *Figure 22* report a comparison of the window before and after the replacement. In the picture is also possible to notice the removal of the radiators adjacent to the windows, since the heating is now provided by the radiator panels.

Figure 22: An original window, with a single-layered glass, characterized by low thermal efficiency.

Figure 23: The new window maintains the aesthetical shape, providing a better insulation.

4.2.2 Second Step: home automation system

In order to allow the creation of a stable connection to the internet, the project determined the installation of an optic fibre connection.

A Mesh Wi-Fi network based on Netgear system was chosen, also due to the fact that it does not need reconnection while moving from an access point to the other. Besides, it is always effective in minimizing the peak load due to simultaneous connection of different devices. The system connection capacity is 550 Mbps.

The installed smart home system is based on Amazon Alexa and it is composed by different features.

For the house security improvement, surveillance cameras are placed across the house. The control of the smart home system is performed through the Alexa App and through the distribution of Amazon Echo devices (smart speaker) in different rooms. The user can control the domestic electric system through smart plugs and some smart applications. The integrated lighting system, which communication is based on Zigbee protocol, is controlled by Alexa Skills extension.

This is a simple update available on the Amazon Alexa smartphone app. Just selecting the app extension the user can improve its Alexa automation system with the so-called Skill, which similarly to a smartphone application or a personal computer program, allows the user to manage the desired device.

The house security relies on a system of surveillance cameras, model Arlo Pro (*Figure 24)*, provided by Arlo. One of their more interesting features is the fact that their control through the Arlo Alexa Skill, allows householders to access the surveillance cameras in any moment, managing them from the in-house speakers or from the smartphone application.

Figure 24: A picture of an Arlo Pro wireless surveillance camera.

4.2.3 Third Step

As anticipated, the last step of the project was the refurbishment of the roofing, together with the installation of a photovoltaic plant (*Figure 24)*.

The plant composition recalls 18 modules, for a generated nominal power of 6 kilowatt-peak (kW_p), with a production of 7780 kWh per year in an estimate condition of annual solar radiations equal to 1640 kWh/m^2. The roof acting as base for the photovoltaic modules has a slope of 35° for both the tilt and the orientation angles.

The photovoltaic modules generated power will then reach the inverter. Then the electric meter will provide information about the energy production. This generated energy will be exploited when possible, in substitution of the external energetical supply, both for the conditioning plant and the household utilities. Unused remains of energy will be entered into the electricity grid.

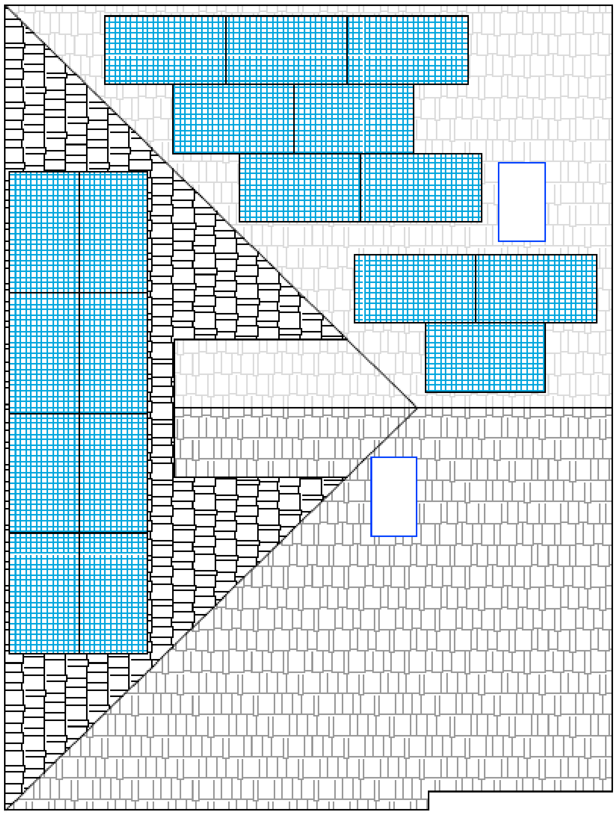

Figure 25: A drawing from the photovoltaic panels project and their placement on the roofing.

4.2.4 The refurbishment project in numbers

The refurbishment project will lead the house from the G-class to A1-class in the energetical ranking system, moving the *energy performance index* from 271.06 kWh/m^{2}year to 68.52 kWh/m^{2}year, hence reducing the value by 74.7%. Moreover, the *CO_2 emissions* after the requalification will account for 15.22 kg/m^{2}year, signing a reduction of 77.8%, also due to the utilization of the photovoltaic system.

The expectation is hence to reduce severely the household total consumption. The estimation performed by technicians assessed that such value was around 80,790 kWh/year before the refurbishment, distributed in thermal energy consumption equal to 73,190 kWh/year and electrical energy consumption at 7600 kWh/year.

The post-refurbishment scenario, despite its increase in electrical energy consumption due to the heat pump installation, sees a drastic reduction of the total value, down to around 32,280 kWh/year, with a split of 18,580 kWh/y on thermal energy and 13,700 kWh/h on electric energy.

Since the photovoltaic system will allow to produce the 54.8% of the electrical energy, the computed CO_2 total emission are lowered by the 87.9%: from 22,140 kg/year to 2,675 kg/year.

The major factor allowing this emission and consumption to take place is identified in the great efficiency of the new systems. On an economical perspective the project will reduce the household management costs from 5712 €/year to an estimation of 2500 €/year.

The project total costs accounted for 75,000 € of overall costs, corresponding to 394.74 €/m^2. The selected system applies technologies, which are more expensive than traditional ones, with an increase in costs of 27,690 €. Due to the improved efficiency savings, the payback horizon of this increased amount is just 4.31 years.

4.3 Case study comparison with literature

The analysed refurbishment of an historical building and its transformation into a smart home shows some similarities with the consulted literature.

The house, raised in 1922 - and so before 1945 - is considered as an historical building and its value needed to be protected.

As expected, its original energetical efficiency was low, causing its assignment to the lowest rank.

The refurbishment confirmed some of the trends evidenced by the literature: the most efficient way found to heat the house was a combination between insulation (of walls and windows) and the heat pump.

As mentioned in 3.7.2, it is commonly known that one of the best ways to grab the produced heat is to increase the capacity of the house of minimizing its flow toward the outer space through external wall and fixtures insulation, whilst the heat pump is the most efficient way to produce both DHW and HVAC.

The presence in the house of the basements allowed the hiding of the heat pump avoiding the issues arising with the instalment of the system and its weight at the roof layer.

The installation of the thermic plant for the basement heating, based on a pellet stove, since it is not an environmental-friendly solution, has not similarities with the literature. However, its environmental impact does not affect heavily the refurbished building emission performance, allowing the ranking into the best class, as reported before.

Accordingly with the literature, the combination between the heat pump installation and renewable energy has been performed with the placement of photovoltaic panels. They will not be able to provide all the needed energy, nevertheless this solution, combined to the attachment to the city electrical energy supply, provides a good compromise in sustainability and economical terms.

Other similarities can be found with the integration of the smart home system through Amazon Alexa’s Skills. The energy management system, which relies on Wi-Fi connection and ZigBee protocol, can hence be classified as a *wireless infrastructure* (see 3.3), in which the attempt to reduce consumption and improve efficiency follows two paths. At first, both the electric system and the heat generators - together with the lightning system and the surveillance cameras – are controllable by the Alexa Skills, providing in-app feedbacks and control flexibility.

Secondly, the energy generated by the photovoltaic panels is received and stored in a battery, allowing the system not to rely only on on-time generated energy and city’s electric supply.

As noticed in 3.5, this solution is more focused on controlling the home in a simple and more interacting way, whilst the consumption feedbacks are not one of the focus of this solution. However, Amazon’s system is one of the more advanced and open across the available on the market, allowing a holistic control over the devices installed in the house, with high ability to include future new devices to be purchased by the householders.

Secondly, if Amazon products are intended to entertain and simplify the human-to-machine relation, the various Skills, developed and provided by the device producers (Siemens, Philips, BTicino and Arlo), are able to provide data in a simple and user friendly way, without losing the most important details.

From a security perspective, the data protection is guaranteed by the ZigBee protocol. As described in 3.4, the major weakness is represented by phishing attempts, intended to steal the authentication data from the user. Amazon provides a practical solution to this problem: during the user authentication phase it generates a rechapta code (to avoid the access to bots) and asks for a second step of authentication with a two-passage code sent to the user personal e-mail or to the telephone number.

The main devices analysed by the literature, since they are key-devices for the smart home implementation, are all present. Smart lights, smart thermostats and smart plugs are connected to the system and distributed across the house.

In addition, smart speakers and surveillance cameras are integrated, allowing a connectivity between the users and the system which is not restricted to "smartphone-only" but allows to control every feature just with the sound of the voice.

Conclusions

The presented work investigated the State of the Art reached by the research across the smart home applications, through the analysis of 61 papers published between 2014 and 2020, while purposing a case study about the refurbishment of an historical building (originally raised in 1922) and its evolution into a smart home environment.

This kind of innovation, which is actually penetrating the market with a growing success, is gaining an interesting relevance not only from a user entertaining perspective, but also from an energy management point of view. This condition appears to be effective, under some conditions, from an economical perspective, allowing savings in the electric bill.

Accordingly to the recent trend of growing interest by people and governments over environmental-friendly themes and solutions, this kind of innovation opens the path to an acknowledged use of house devices and applications by the users. In an environment rich of history such as the European continent, characterised by a high stock of ancient buildings carrying an historical value, but also high management expenses and a heavy carbon emissions burden, the increase in regulation trying to meet the ambitious emission targets agreed with international conferences and protocols can appear unrealistic and unreachable.

The case study shows how the historical and environmental value of those buildings can be maintained, while effectively integrating renewable energy sources and high-efficient heat generator such as an heat pump, reaching satisfying results not only form an environmental sustainability perspective, but also in terms of economical investment, where the technology is used to increase efficiency, allowing in some years to repay the initial capital expense, leading also to economical savings while protecting the environment.

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