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# BACKGROUND AND APPROACH TO A DEFINITION OF SMART BUILDINGS

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## ABSTRACT

There is no doubt that there is no possibility of finding a single reference about domotics in the first half of the 20th century. The best known authors and those who have documented this discipline, set its origin in the 1970's, when the x-10 technology began to be used, but it was not until 1988 when Larousse Encyclopedia decided to include the definition of "Smart Building". Furthermore, even nowadays, there is not a single definition widely accepted, and for that reason, many other expressions, namely "Intelligent Buildings" "Domotics" "Digital Home" or "Home Automation" have appeared to describe the automated buildings and homes. The lack of a clear definition for "Smart Buildings" causes difficulty not only in the development of a common international framework to develop research in this field, but it also causes insecurity in the potential user of these buildings. That is to say, the user does not know what is offered by this kind of buildings, hindering the dissemination of the culture of building automation in society. Thus, the main purpose of this paper is to propose a definition of the expression "Smart Buildings" that satisfactorily describes the meaning of this discipline. To achieve this aim, a thorough review of the origin of the term itself and the historical background before the emergence of the phenomenon of domotics was conducted, followed by a critical discussion of existing definitions of the term "Smart Buildings" and other similar terms. The extent of each definition has been analyzed, inaccuracies have been discarded and commonalities have been compared. Throughout the discussion, definitions that bring the term "Smart Buildings" near to disciplines such as computer science, robotics and also telecommunications have been found. However, there are also many other definitions that emphasize in a more abstract way the role of these new buildings in the society and the future of mankind.

**Keywords:** smart buildings, definition, domotics, intelligent buildings, home automation.

## 1. INTRODUCTION

The evolution of architecture from its origins has always been a reflection of the evolution of the society itself, and during this evolution, the building process has been adopting new technologies that have been redefined it throughout history. For that reason, advances in building technology has always come from influential factors

such as materials, sociological changes, execution times, legislative or regulatory changes, new responsibilities of the agents involved, etc. Today, it rarely a human being can conceive a building without cold water, hot water or electricity, but not always a buildings has included such common and current amenities. Thomas Edison made the first light bulb on October 21th of 1879 (Kurzweil and Schneider 1990), and prior to this date, artificial light was not even a factor to be taken into account in the design of buildings. However, for about 40 years, the building process is in the position to catch up with technology that, until now, were beyond its own nature. A kind of technology with a rate of evolution clearly different from the usual in the building process.

These new technologies shape the domotics, which have led to the emergence of the so-called "Smart Buildings". However, domotics is nowadays a 30-year-old discipline that has not yet defined itself. Nowadays there are very different definitions for the term "Smart Building" thus a critical discussion of the available definitions of this and other terms related to home automation to propose a satisfactory definition of the term that may help in understanding the discipline.

Clarifying the meaning of these terms is important for several reasons. It has been documented that the ambiguity in the meaning of these terms and services offered by Smart Buildings creates confusion between what the user expects from these buildings and what the user finally obtains (Flórez 2004), so that the logical consequence is often the rejection of the society to these new automated services. For that reason, a clear definition could contribute to the architecture, engineering and construction industry by making the home automation services offered in the market more understandable by the customer. Furthermore, proposing a satisfactory definition of the discipline, will help in setting and limiting the scope of the research in this field.

## **2. METHODOLOGY**

In the process of selecting a suitable research method, several considerations specific to the problem associated with data collection for this study were considered. As the research started by documenting the evolution of Smart Building, document analysis was used (Bowen 2009). This document analysis and content analysis has been chosen because this a method that can be used with either qualitative or quantitative data and it is normally represented as three main phases: preparation, organizing and reporting. According to that and in this particular case, the research has been developed as follows:

- Prior to the development of research work, the previous stages of the domestic automation have been studied to understand the qualitative change that led to the recognition of domotics as an independent discipline.
- After understanding the origin of the domotics discipline, the first definitions that have been documented historically have been analyzed.
- Through the evolution of the concept, the use of the expression "Smart Building" has been documented and it has been compared with similar expressions from different countries.
- Other analogous terms with different connotations that have appeared, which often lead to confusion with the term "Smart Buildings", also have been also analyzed and compared.
- Finally, a satisfactory definition of the term that avoids ambiguity and sets the scope of the discipline has been proposed.

After developing these phases of analysis and documentation, the next and final step will be to proceed to formulate the conclusions of the study

## **3. THE BACKGROUND OF THE DISCIPLINE**

Virtually, all of the literature sets the origin of home automation around the 1970s, with the first applications of technology X-10 (Huidobro y Millán 2004). However, there are no references about the previous history of the discipline or about the previous steps that man gave, up to date, to better understand the origin of home automation as a concept.

After a preliminary analysis of the documented work, could be conclude that there was no automation as such until the second half of the twentieth century when isolated automatisms were designed more or less for a domestic purpose and whose use and degree of integration in the architecture was not even taken into account. As

it is going to be shown, in almost any definition of the term "Domotics" or "Smart Buildings" that we can find today, the term "Automation" is included. This is because the automation seeks to automate eminently domestic tasks or to eminently automate domestic tasks or the management, control and supervision of the facilities of a building. We can therefore assume that the immediate antecedent of "Domotics" is the "Automatics".

**Definition 1:** Automatic: (of a device or a process) working by itself with little or no direct human control (Oxford Dictionary 2013).

**Definition 2:** Automatics: Science dealing with a process to replace the human operator by mechanical or electronic devices (R.A.E.2013).

From these and other definitions, in turn, we can infer that the "Automatics", as science, is the result of the evolution process of the "Mechanics". As the "Mechanics" solves the need of muscle motor for a job or a task while the "Automatics" resolves or simplifies the need for decision-making on that task. At this point, we can establish that home automation is the result of a process that follows the sequence of the figure 1:



Figure 1: Home automation process

Based on this sequence, we can now begin to establish the background of the term, and to do so, we must go back to antiquity to find the first devices that were able to perform daily tasks, usually repetitive tasks, that commonly had been made by man. The first automata that appear in the story are isolated mechanical devices that were able to develop a fixed program but not to use the notion of feedback. These early devices were not really very useful, the first mechanisms were devised only for the purpose of the owner's entertainment. Therefore, the first examples of these automata are recorded in ancient Ethiopia in 1500 BC., when Amenhotep built a statue of Memon, the king of Ethiopia, which could make sounds when sun's rays illuminated the dawn. King-your Tse, in China, in 500. BC. invented a wooden flying magpie and a wooden horse that was able to jump. After that, between 400 and 397 BC., Archytar of Taranto constructed a wooden pigeon suspended from a pivot, which rotated with a jet of water or steam, simulating the flight. Archytar is also the inventor of the screw and the pulley. In the year 206. BC., the treasure of Chin Shih Hueng Ti was found, an orchestra consisting of mechanical dolls.

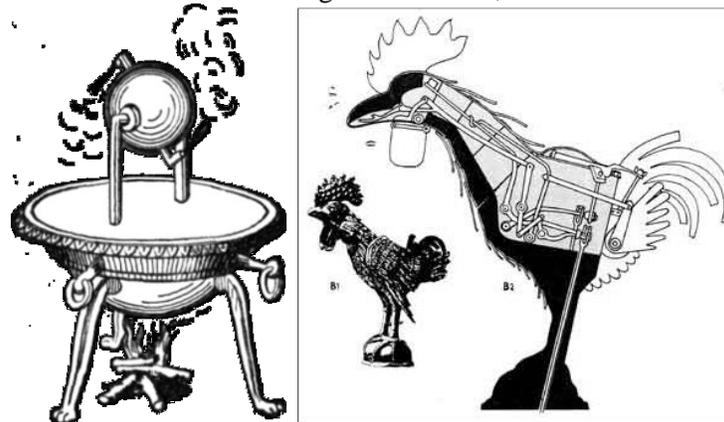


Figure 2: On the left, The first steam device by Hero of Alexandria. On the right Illustration of Cock of Strasbourg (Timerime 2013)

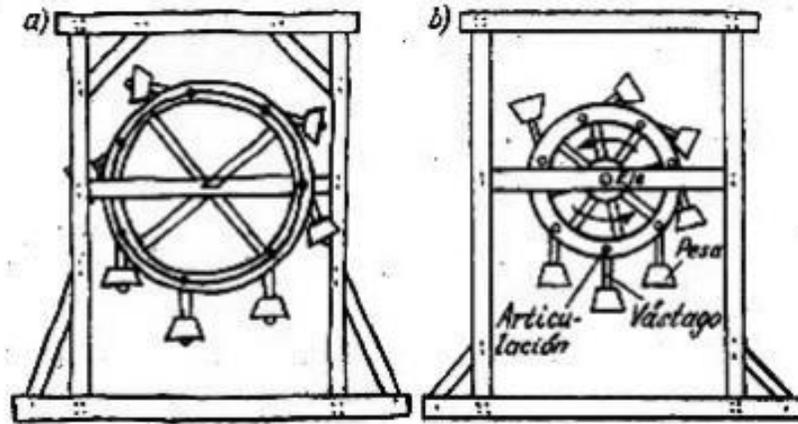


Figure 3: Endless Engine, Villard de Honnecourt (Honnecourt 2001)

Three centuries later, in the first architectural written treaty "The Ten Books on Architecture" (Polión 1995) by the Roman Pollio Vitruvius, we find a description the machines that helped in the construction of buildings, although the drawings associated with that text are not retained. In the 1st century, figures like Hero of Alexandria highlighted (Peláez 2005), who is said deployed a pre-modern attitude of mechanics. He was the author of numerous treatises of mechanics, such as "The Pneumatic", where he studied hydraulics, and "Automata" which was the first book about the history of robotics.

Following the pace of the milestones that mark the evolution of automation in history, and entering in the Middle Ages, there are some detailed references about other automata as the iron man of Albertus Magnus (1204-1282) or the talking head of Roger Bacon (1214-1294) followed by the so-called "Cock of Strasbourg", which was in operation between 1352-1789 and whose peculiarity is the fact of being the oldest automaton preserved to date and an original part of Strasbourg Cathedral (Figure 2).

The watchmakers are the great inventors of robots between the 17th and 18th centuries, they developed automata mostly with human or animal anatomy. After that, in the late 17th and early 19th century, with the influence of the Industrial Revolution, technological advances and inventions changed its objective, focusing on solving mechanical processes of the industry. During this period, industry and transport are the objectives of this stage and there is a loss of interest in everyday domestic problems at home (Freeman 201). For this reason, although the influence of the industrial revolution in domestic architecture was very important, it was not from the point of view of the home automation, but rather from the point of view of manufacturing processes and the inclusion of new materials to the construction process (Benévolo 1999). Put another way, the history of architecture was worried about covering needs of first magnitude in residential buildings, basic needs of health and safety, which would amount to the first two stages of needs in Maslow pyramid.

In 1792 William Murdock invented gas lighting to illuminate the streets of London until 1802, but it is needed to wait until 1821 till the father of electricity, Michael Farraday, builds the first two electrically powered engines. Half a century after, in 1879, Thomas Edison made the first light bulb probably becoming the first man to introduce a new constructive conditioning in buildings design. In the twentieth century the history of technological advances in the so-called "intelligent machines" is divided into two branches, the history of the isolated devices and the history of advances in artificial intelligence and computer skills and telecommunications. In this sense, we are interested in focusing on isolated devices because they are the ones that reflect the man's will to delegate their daily activities in new appliances.

Still in the 13th century, Villard de Honnecourt writes his book and sketches in which, among many sections drawings of mechanical devices, it can be found for example his attempt to the "Endless Engine" (Figure 3). A hypothetical machine that would be able to continue running forever after an initial impulse, without additional external power, its existence would violate the first and second laws of thermodynamics. Historians who have documented the ancestral automatisms of modern robotics usually highlight, in the fifteenth century, the figure of Leonardo Da Vinci with his famous "Mechanic Lion" built by order of Louis XII of France. However, from the

point of view of home automation, Leonardo Da Vinci is important because he was the first person to document artifacts and inventions oriented to perform a domestic work (Figure 4).

Electricity drives industrial automation systems, but above all, drives home automation. Once electricity can be supplied to homes, man is more interested in inventing machines that can make his life easier. Therefore, the era of the "cooling machines" begins. From the first cooling machine of William Cullen in 1784, it is not until 1927 that we can find the first domestic refrigerators (although the first electric refrigerator dates from 1913) and almost immediately, in the 1930s, Willis Haviland Carrier invented the residential air conditioning systems.

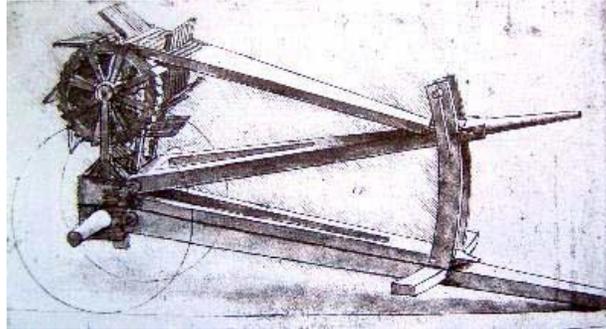


Figure 4: Garlic Grinder by Leonardo Da Vinci (Ignoria 2009)

Then, in the 1970s, "automation" enters architecture with a very different attitude and the term "domotics" began to be used but, what was the qualitative change? Why now? The answer is in the relationship between architecture and new technologies. It is in the 1970s when man sees the possibility of integrate the automation in the construction itself. The milestone that marks this change is the introduction of the X-10 technology in the building process. This technology defines a communication protocol between electronic devices that uses low voltage electrical installation existing in dwellings to connect these devices. Therefore, we can also say that home automation arises when man gets rid of the artifacts and decides to automate directly the environment in which he lives, the architecture, through the inclusion and integration of information networks, computers, electronics and mechanisms.

#### 4. THE ORIGIN AND DEFINITION OF THE TERM “DOMOTICS”

**Definition 3:** Electrical appliances give way to the real domotique: a home transformed by the use of hardware components, microprocessor equipment for connection to personal computers, teletext and the electronic directory, multifunction phones, VCRs and video disc players, hi-fi systems, watches and calculators all terminals and household robots that beyond the traditional functions can handle all types of operations, like as energy costs for heating or cooking (Humbert 1982) ( Author’s translation).

Some references Although there are references that explain that the first appearance of the term is due to the French professor of the Rennes University, Marc Humbert, as usual in the field of new technological terms, French dictionaries are the first to propose, of an official way, the first definition for the term "domotique".

**Definition 4:** Domotique: is the concept of housing that integrates all security automation, energy management, communications, etc (Larousse 1988) (Author’s translation).

**Definition 5:** Domotique: It is the application of computing to housing. It comprises a set of security systems and regulation of domestic tasks in order to facilitate everyday operations and functions. (Nouveau Dictionnaire 1989) (Author’s translation)

The first definition is rather general and unrealistic for the date. However, it is the first attempt to provide us with a definition to the term and reflects the desire to automate the most services offered. The second definition proposes the computing science as the generator of the new discipline which is, in contrast to the above definition, rather partial and incomplete. A group of French organizations: The FIEE, The FNB, The IFB, The FNEE, and EDF proposes, in 1988, the following definition.

**Definition 6:** Set of services in the habitat provided by the systems that perform various functions, which can be connected together and with external communication networks ... These functions include, in particular, energy conservation and management of technology, information and communication, control, comfort and security (FIEE,FNB,IFB,FNEE and EDF 1988 ) (Author's translation).

This last definition is almost coeval with the first definition proposed by Larousse. However, it is much more concrete and introduces a very important concept, the concept of "service". It also refers to communication networks that give unity to the overall system of home automation. Philippe Dard, technician at CSTB (Centre Scientifique et Technique du Bâtiment) proposes another definition, much deeper in the social aspects.

**Definition 7:** Domotics is a social and technical process that uses new technologies in the habitat. This process renews questions about the nature of the habitat and the mission of the agents involved (Dard 1990).

In this last definition is interesting the nature of "process" that is given to the concept, it does not bound the technologies that are involved and recognizes the role of society and therefore the user in defining the objectives of the same.

**Definition 8:** Domotics is the science that studies the application of computing and communications to the home, in order to get a smart-home. The aim of domotics is, for example, to automate the management of lights, heating, etc., depending on external conditions, getting significant energy savings (Mastermagazine 2013).

If we consider science as "systematic knowledge, developed through observations, arguments and evidence methodically organized" is not clear that Domotics can fit in the definition of science, it is rather a discipline that studies the set of systems that are capable of automate a building. A clear agreement about the etymology of the word domotics can neither be found and is often explained as (domus = house) + informatics = domotics, or as domus + robotics = domotics, or domus + tica (automatics in Greek) = domotics.

This need to constantly redefine the term domotics shows that there is no consensus among agents, companies and associations linked to this activity. But besides these disparate definitions of the same term, today we have to deal with other similar terms. Sometimes these terms can be used interchangeably with the term domotics and they can proceed, for example, of translations of terms in other countries. Other times, however, these are terms coined to differentiate the term domotics to intentionally express different connotations, services or aims.

## 5. EVOLVING CONCEPT, "SMART BUILDINGS"

However, and despite what has been presented, automation applied to buildings is called "domotique" in France or "domótica" in Spain, but in international contexts, it is more common the English term "home automation" (Cerdá 2009) or the American expression "smart building/house" (see Table 1). It is known that, almost simultaneously to the birth of the term "Home Automation" in France in 1982, in 1981 was used for the first time in EEUU the term "Intelligent Building" by UTBS Cosporation (United Technology Building Systems Corporation) (So, A.T., A.C. Wong, and K. Wong1999) and "Smart Building" was a term promoted in the 1980s by a group of construction companies (NAHB) and is generally interchangeable with the term "home automation". However, as stated by M. A. Florez de la Colina, when these two last expressions are compared, it is generally considered that "automated house" is a pre-development stage of "smart house". That is to say, the second term implies an additional degree of "intelligence" that mainly refers to a centralized control of information from various automated services.

**Definition 9:** The basic idea of home automation is to employ sensors and control systems to monitor a dwelling, and accordingly adjust the various mechanisms that provide heat, ventilation, lighting, and other services. By more closely tuning the dwelling's mechanical systems to the dweller's needs, the automated "intelligent" home can provide a safer, more comfortable, and more economical dwelling. ... The "smart house" technology is one realization of home automation ideals using a specific set of technologies. In Smart House technology, the dwelling is wired with a single multiconductor cable that includes electric power wires, communications cables for and video, and other conductors that connect appliances and lamps with electronic devices that control the supply and switching of power telephone (Gross 1998).

According Wigginton and Harris (2002) there are about 30 different definitions of intelligence related to buildings. Early definitions focused primarily on the intention of introducing new technologies at dwellings without suggesting any interaction of the system with the user. The most recent definitions, are adding to the

system the ability to "learn" and the ability to self-adjust to the environment and to the user (Derek and Clements-Croome 1997).

**Definition 10:** An Intelligent Building must also be able to respond to individual, organisational and environmental requirement and to cope with changes. It is also believed that a truly Intelligent Building should also be able to learn and adjust its performance from its occupancy and the environment (Yang and Peng 2001).

It seems therefore, that indeed the aim of the terms "domotique" and "smart building" are very similar and, although today they are often explained using different connotations, they are both terms that have tried to evolve since they began to be used to encompass new developments, technologies and disciplines that each day are included in the field of automated building design. That is to say, both terms have evolved to encompass control, management, learning ability of the system ... etc.

Table 1. Comparative table of attempts to establish a definition related to Building/Home Automation

Geographic Area	EEUU	Europe			Asia
		France	UK	Others	
<b>Representative references</b>	(NAHB 1980) (Gross 1998)	(Humbert 1982) (Larousse 1988) (FIEE et al. 1988) (Nouveau Dictionnaire 1989) (Dard 1990)	(Derek, T. and J. Clements-Croome 1997) (Yang and Peng 2001) (Wigginton and Harris 2002)	(Dootingh 1990, ESPRIT PROJECT) Instituto Cerdá. (1990) Flórez de la Colina, M.A. (2004) Huidobro, J.M. and R.J. Millán. (2004)	(So, A.T. et al. 1999) (Wong, J. et al. 2005) (Yiu, C. and Y. Yau 2006)
<b>Commonly used expressions</b>	Intelligent Buildings Smart Buildings/Houses Home Automation	Domotique (Domotics)	Home Automation Intelligent Buildings Smart Buildings	Home Systems Domótica (Domotics) Hogar Digital (Digital Home) Inteligencia Ambiental (Intelligent Ambient) Hogar Digital Conectado" (connected digital home")	Intelligent Building Intelligent Home
<b>Main concepts, features and functions</b>	To employ sensors and control systems to monitor a dwelling  To provide a safer, more comfortable, and more economical dwelling  It speaks about: building structure, building systems, building services and building management.	Use of hardware components  Connection to personal computers  Integrates all security automation, energy management, communications, etc  Application of computing to housing  Set of <b>services</b> in the habitat provided by the systems  Connected together and with <b>external communication networks</b>  Functions included: energy conservation and management of technology, information and communication, control, comfort and security  It is a social and technical <b>process</b>	Intelligence applied to the building  System able to respond to individual, organisational and environmental requirement and to cope with changes  One of the main goals is to achieve efficient management of resources with minimum life-time costs of hardware and facilities	Emphasis is on information technology  Convergence of services: entertainment, communications and the digital management of the house  A structure of independent networks  System that includes the Internet connection  Emphasizes on centralized control  Also emphasizes on the elements that provide the media access (wiring).	Focused on user needs and the requirements of the user  It should provide advanced automatic control systems to monitor services  It should have good networking infrastructure  It should provide adequate tele-communication facilities  Automatic functions: communication automation, office automation and building management automation  Rationalisation of building administration to provide more attentive administrative services with lower cost  Environmental friendly  Space utilisation and flexibility  Image of high technology

Furthermore, these expressions internationally accepted coexist with others with similar nature such as: house of the future, connected home, ambient intelligence or domestic systems. This last one derives from the term "Home Systems", which appeared during the ESPRIT research program in 1990 (Dootingh 1990) and emphasizes on centralized control, but also on the elements that provide the media access (wiring).

## 6. RELATED CONCEPTS

Additionally of what has been presented, we must also know the existence of complementary terminology that is the result of the trade and other business initiatives. Within this complementary terminology, the expression "Digital Home" can be found. This term was defined, powered and used by Telefónica and ASIMELEC, both Spanish companies, and it emerged with a clearly differentiating and commercial will.

According to Telefónica, the Digital Home is the realization of the idea of convergence of services, entertainment, communications and the digital management of the house, infrastructure and equipment (Home Networking). The structure of the digital home is often described as a structure of independent networks in which one of the networks can be called "Home Automation Network." Even though, it is not clear the necessity of the distinction between networks, all devices could be mounted on a single network to manage a scalable and modifiable system. Telefónica also often uses the term "connected digital home", which is not very coherent, because in the definition of digital home the Internet connection of the building is implicit.

Another term used is "Connected Home" sponsored by Plan AVANZ@ for convergence with Europe's Information Society of the Ministry of Industry, Trade and Tourism in Spain. What this plan aims is to encourage and facilitate the recruitment of the internet connection of households, so the background does not define any type or level of smart building.

The truth is that the use of the latter two terms (Digital Home and Connected Home), seems to respond more to the need to ensure that a home automation system includes the Internet connection. Needless to say that a home automation system that includes the internet connection is much more efficient and can offer more possibilities, although the truth is that this Internet connection is not a necessary condition for a home automation installation. It is also very enlightening when, analyzing existing definitions related to automation in buildings, a comparison between countries or continents is made (Table 1). Through this comparison it can be detected that, not only each geographical area prefer to use certain terms over others, through the proposed definitions the emphasis on various aspects of automation can also be detected.

**Definition 11** An Intelligent Building is designed and constructed based on an appropriate selection of quality environment modules to meet the user's requirements by mapping with the appropriate building facilities to achieve long-term building value (So *et al.* 1999).

## 7. APPROACH TO A SATISFACTORY DEFINITION

The proliferation of these new words that describe aspects about Smart Buildings completely or partially, far from helping to define different concepts, is making more difficult to understand what the home automation really is or what its limits are. There a lot of confusion about it today and the truth is that currently these terms are used indiscriminately on Internet, further hindering the understanding in the field of action of home automation. For this reason, it was considered appropriate for this research to propose a definition of the term to describe it satisfactorily and in order to help narrow the scope of any research about this field.

As it has been shown, there are many differences between the definitions discussed, but there are many similarities to what is meant by automation. The most significant similarities and differences are:

- Many definitions describe a set of "systems" capable of automating a home, these systems provide "services" about energy management, safety, welfare and communication.
- Other definitions prefer to focus on the term "services" as a proper end of home automation.
- The systems that make up the installation can be integrated through internal and external networks of communication, yet it is not a requirement that the home automation system is connected to the Internet network. Nowadays there are other ways in case remote control is required.

- It is usual to refer to the overall management and control, this control has certain ubiquity, from inside and outside the home.
- The concepts of "control and management" and "intelligence" alternate between the different definitions studied.
- Some definitions refer to Smart Buildings as a result of the application of certain "science" or "technology" very specifically.
- Some definitions refer to a "process" which reflects an evolutionary will of the term smart building.
- The role of the user and their interaction with the system is not dealt evenly in the analyzed definitions.

From the data collected and these considerations, the following definition of smart building has been developed:

The Smart Building is the one that includes a scalable set of services. This set of services are integrated into the housing and are supplied by systems that can be configured in one or more internal networks; in turn, those systems can communicate with other networks outside the home. These services perform functions related to energy saving, the technical management of facilities, information, communication, entertainment, accessibility, care, comfort ... etc. And the control of this scalable set of services can be performed from one or more points (management centres).

To understand this definition, is necessary to indicate that "service" is the set of automatable actions that meet a particular need of the user of the building, and "system" is the set of components and infrastructure necessary to provide such services.

This definition can be applied to any type of intelligent building located anywhere in the world and it can be extended by setting the "degree of automation" of the smart building, i.e. quantifying the amount of integrated services in the building. Regarding its implementation, the use of the proposed definition in this study has been already adopted in various research on home automation carried out at the Polytechnic University of Madrid (Millán 2009).

## 8. CONCLUSIONS

Throughout this paper the results of research attempted to clarify the meaning of "Smart Buildings" have been presented. This is an expression that currently does not have an uni-vocal definition that allows, for example, the establishment of the scope of any research in this field. From this research, the following main conclusions have been reached:

- The history of this discipline indicate that home automation (expression that comes from the French term "Domotique"), is the result of an evolutionary process that begins with the first mechanisms that led to the automation.
- Smart Building is a term that identifies a residential building that has home automation. The word "Smart" speaks about the level of intelligence of the system. This level is variable and indicates the ability of the system to adapt to changes in the environment and in the user.
- The introduction and integration of automation into architecture allows the gradual disappearance of isolated devices. The moment when man automates his own environment marks the birth of Intelligent Buildings.
- Building automation involves the introduction of communication networks into architecture. This network is similar in nature to computer networks. Within this structure of a network or interconnected networks, connecting the system with external networks like Internet is an option that extends the possibilities of home automation installation.

After analyzing other related terminologies, this research concludes with a proposal of a definition for the term "Smart Building" that takes into account these and other considerations to clear inaccuracies and misstatements of the concept.

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