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Review

Commercial ICT Smart Solutions for the Elderly: State of the Art and Future Challenges in the Smart Furniture Sector

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Abstract: Within a ubiquitous environment, home and office furniture can be maximally utilized to provide ease, especially if the items are designed based on smart technology. For this reason, the acceptance of smart furniture has soared over the years. Given the vast influence of the Internet of Things (IoT) and Industry 4.0 on technological advancement in furniture design, it is imperative to examine information and communication technology (ICT) solutions for the elderly in the context of smart furniture design and implementation. This article presents a review of the state-of-the-art literature in smart solutions for the elderly based on publications under ICT smart solutions for these elderly, along with smart furniture options and manufacturer activities in terms of fixing market prices for these furniture materials. Furthermore, patenting rights on some existing smart furniture designs for the elderly, given the current trends in worldwide acceptance, are examined. Moreover, this article also highlights opportunities introduced by IoT-based solutions for the elderly as current trends in research and their effects on human life. Some smart product examples from different enterprises are also presented. New, innovative and active designs must be developed, focusing upon human healthcare, and in turn providing greater comfort and convenience for elderly people. To fulfil these requirements, the also selected technical aspects of new Smart Furniture solutions in connection to the cost of these solutions are discussed. Simultaneously, Smart Furniture solutions need to be flexible, low-cost, easy to buy and install without expert knowledge, and widely available on the market.

Keywords: smart furniture; elderly; Internet of Things; market; investment; ambient assisted living; quality of life

1. Introduction

In recent decades, research on the improvement of indoor spaces has increased dramatically in most countries worldwide [1,2]. While these studies are crucial to ensure human health and safety [1], they also contribute to the occupants' well-being and comfort [2]. Thus, the so-called jet age-birthed Industry 4.0, a term that refers to all the services and activities related to and dependent upon Internet of Things (IoT) applications, provides a wide range of technological advances, where almost everything and anything, anywhere and everywhere, can be linked within a ubiquitous environment. These technologies have been widely used in the well-known world of smart homes, coupling the most advanced and recent technological developments in terms of sensors, remote controls and other appliances/devices. Thus, this area has become a very interesting and competitive business sector, with recognized benefits for users, such as the elderly or caregivers, in the case of seniors or individuals with debilitating conditions, rational energy users, and technophiles. Even for healthy people, smart homes can contribute to a better quality of life.

Smart homes include smart furniture. There is no universal definition for smart furniture. Nevertheless, the most recent definition was proposed by Reference [3]. This research group defined smart furniture as well-crafted and networked furniture comprising an intelligent or remote-controlled system that is able to manage users' data, and which works based on some form of an energy source. According to Reference [3], smart furniture has the ability to interact with and predict the needs of users as a result of inbuilt and programmed actuators and sensors within the user's surroundings, thereby providing ease of living for the individual. Other definitions have explained smart furniture as a specialized furniture that gathers information from its immediate vicinity to provide ease of functionality for users. In a nutshell, smart furniture is a type of furniture that can carry out dual to multiple functions using integrated Internet connectivity as the control, and ease the use of a number of household appliances.

As part of smart furniture development in managing spaces and carrying out multi-functions, convertible bedrooms have become popular [4]. Within these bedrooms, foldable beds or computerized wall-beds can be hung upon the wall or completely scrambled to create temporary living room spaces. According to [5], further improvements in smart-beds have witnessed the design of interactive medical beds with inbuilt controls. Control functions allow patients to easily manipulate the beds to suit specific sitting positions. In terms of achieving expansion within the market, medical beds have been further improved to function unaided with improved mechanical advantages [5]. For instance, disabled patients can convert their beds into wheel chairs within the realm of continuous-use bed design by Panasonic [6]. Beds such as the *Stryker iBed*, that come with embedded alarm systems and other technological communication functions, can also help patients interact with caregivers without necessarily having to speak [7]. Thus, many improvements in the global market for medical beds have resulted in serious competition for market places [8]. This phenomenon, coupled with other updated bed designs, is poised to change the face of smart-bed commercialisation. Additionally, environment-based and patient-based bed designs, such as bariatric (Hill-Rom Excel), domiciliary beds, the Rakusho series elderly care bed design, as well as paediatric beds, are now very popular with many unique designs [5]. A few ultramodern beds also combine the functions provided by all of the aforementioned bed types [5]. According to [9], a number of other innovative projects have attempted to upgrade and upscale spaces used for the elderly; for instance, foldable shower seats [10] and various types of household appliances for the aging.

Commercial sales of smart furniture have grown and are almost on par with the number of ageing individuals in many developed countries, promoting the enjoyment of fruitful markets and an improved design [11]. This is because older people are most commonly the highest users of smart furniture, due mainly to health and disabilities challenges related to ageing. In the United States, it is

estimated that over one billion dollars is spent annually on healthcare [9,10]. Other estimates from the Who Health Organization (WHO) (2012) indicate that the population aged 65 years and over is expected to surpass the number of children under 14 by 2050.

Technical innovative solutions are the basis of and the key to future changes in society, to higher efficiency, savings or to improving the quality of life [12–14]. However, many innovative solutions have never been launched. Quite often, a technical solution alone is not enough to make a contribution to society. Only a small share of innovative solutions can successfully reach the market [15–19]. Unfortunately, new products have a very low success rate on the market. Almost 95% of new products introduced each year fail, resulting in massive losses [20,21], and yet it is often enough to add very little to a unique solution, where sometimes it is a factory matter, such as design, careful execution and friendliness for the target group that will ensure success in the target market. The aim of the article is therefore to describe not only the purely technical aspects of innovative IT solutions, but in a broader context the commercial solution itself in relation to the selected target group. This is so that the article draws the attention of scientists to facts that can increase the success and chance of the real use of innovative solutions in the future.

In the context of the current paper, we examine prevailing smart furniture solutions and commercialisation. Figure 1 shows the conceptual framework for this study, describing the relationship between important concepts within the present study that may have some significant economic impact on society, especially regarding the influence of smart furniture, given its importance in the ageing population. Although this study discusses smart furniture solutions that are useful for achieving comfort and ease of living by aging people, other solutions for other groups of the population are also described.

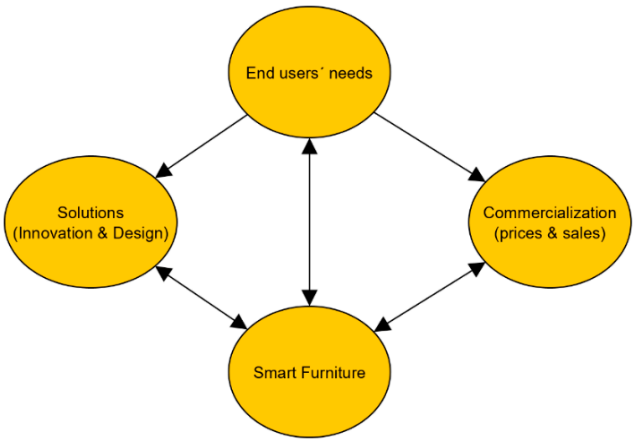

Figure 1. Conceptual framework for the study.

This article presents the current state of research on ICT smart solutions developments in terms of their usefulness, prices, patent ownership and patenting procedures. Ultimately, based on this knowledge, we are able to analyse the current research trends and future needs in smart furniture systems. Section 2 describes the research procedure used in this paper, and seeks to shed more light on smart furniture by listing the prices of some existing solutions by a number of renowned marketers. The section that follows examines selected commercial ICT solutions for the elderly (Section 3), and patents (application and ownership) of smart furniture (Section 4). Section 5 discusses study findings as derived from evaluating solutions and their patenting procedures. Future needs in terms of smart furniture are also discussed in this section. Finally, Section 6 discusses the main conclusions, outlines the contributions of the literature and provides recommendations for future research.

2. Methods

Our search was oriented within the context of existing commercial solutions focused on database scientific sources, on intellectual property (IP) as patents at patent databases, as well as on any available materials of commercial products at web sources.

2.1. Data Selection from ISI Web of Knowledge Database

One of the main goals of this article is to provide an overview of the current state of the art in smart ICT solutions for the elderly. Apart from the description of published articles, an overview of the topic trends was also included.

The literature review was performed for original research papers based on PRISMA guidelines. The literature search was undertaken between 1 October 2019 and 25 October 2019 to find peer-reviewed original articles or review-type publications produced in the English language.

Keyword combinations of ("Smart Furniture" OR "SMART ENVIRONMENTS" OR "Intelligent ENVIRONMENT" OR "Smart Home" OR "Smart indoor" OR "Smart Room" OR "AAL" OR "Ambient Assistive Living" OR "Enhanced Living Environment") AND ("ELDERLY" OR ("Older" AND "people") OR ("OLD" AND "people") OR ("seniors" OR "senior")) were used.

Records from the Institute for Scientific Information (ISI) Web of Knowledge (WOK) were restricted to the years between 2000 and 2019. A total of 1136 records were identified (Figure 2). Ultimately, 439 journal records were included for analysis with document type limited to article or review.

Table 1 summarizes the top ten journals for "smart ICT solution" and "elderly" in ISI WOK, where the technical ones are visible as Sensors (Q1, Q2, Q2) from the MDPI publisher, IEEE Access (Q1) and IEEE Communications Magazine (Q1, Q1). The remaining journals are focused on the Ubiquitous Computing topic, while Journal of Medical Systems (Q2, Q2) is published by Springer.

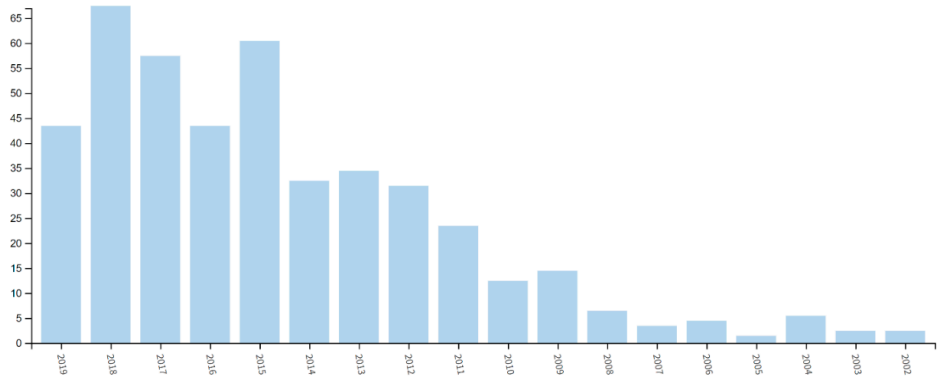

Figure 2. Institute for Scientific Information (ISI) Web of Knowledge (WOK) activity based on records for the "Smart Furniture" phrase in the Title, Abstract and Keywords.

Table 1. Top ten journals for "Smart ICT Solution" AND "Elderly" in ISI WOK. (Where ICT stands for information and communication technology).

Source Titles	Record Count	% of 439
Sensors	39	8.88
Journal of ambient intelligence and smart environments	19	4.33
Personal and ubiquitous computing	12	2.73
IEEE access	11	2.51
Journal of ambient intelligence and humanized computing	9	2.05
Indoor and built environment	8	1.82
Ambient intelligence and smart environments	7	1.60
Handbook of ambient assisted living technology for healthcare rehabilitation and well-being	6	1.37
Journal of medical systems	6	1.37
IEEE communications magazine	5	1.14

2.2. Commercial Smart Furniture and ICT Solutions Analysis Using Web Sources and Company Materials

ICT solutions are mostly marketed without the deep information published in research sources such as journals or conference articles. Thus, our search strategy was enhanced by using Google. The commercial solutions search was undertaken between 1 September 2019 and 15 November 2019 to find marketed solutions on the global market, with descriptions available in the English language.

The search conditions were selected as the need to cover at least four parameters among the following: Sensors; Active effect; Remote; Mobile; User; Smart; Potential; Price (€). Finally, 14 solutions were selected as the most relevant for our detailed analysis (Table 4).

Most solutions are provided by well-known Companies like Google, Ikea, Samsung and Panasonic. Since they are key market players, patent databases were also screened.

2.3. Patent Analysis

A search of patents by patent databases (ESPACENET, Patent Inspiration and Google) with Smart ICT Solutions and Elderly was executed as ("Smart Furniture" OR "SMART ENVIRONMENTS" OR "Intelligent ENVIRONMENT" OR "Smart Home" OR "Smart indoor" OR "Smart Room" OR "AAL" OR "Ambient Assistive Living" OR "Enhanced Living Environment") AND ("ELDERLY" OR ("Older" AND "people") OR ("OLD" AND "people") OR ("seniors" OR "senior")) in the "topic" search (title or abstract or claims) or "title" only search, from 1 January 1999 up to 31 December 2018. Forty-four results from the patent databases were obtained for the topic search, while 41 outcomes were found based on the title search string. For patent applications, forward citations are also very useful when searching for some specific topic. Thus, we also covered FW citations for these 44 patents. Table 6 summarizes the main features of the 57 selected patent applications.

3. Results

3.1. Literature Review

Based on the search results from the Web of Science database, within the Smart Furniture topic, we found that changes in technological advances are likely to affect the manner of living indoors at home, as well as the spatial needs and preferences of those living there. Smart Furniture contains computers, sensors, devices and other appliances. The combination of the Smart Furniture's physical structure, hardware devices, and software technology can transform the legacy space into a smart space. Tokuda et al. [22] identified three distinct kinds of smart furniture: Pole, Lamp and Mirror types. The Pole type is mainly focused on the use of public places, e.g., train stations, bus stops. In such places, smart furniture provides a public service to non-specific people with various devices. Thus, Pole-type smart furniture was designed as an extendable pole, to which various devices and sensors can be attached. As such, Pole-type smart furniture is composed mainly of three parts: a Case, a Pole and a Base. In most cases, to maintain the extendibility and reconfigurability of smart furniture, each part is designed with a reusable modular material, and can be adapted to various services [22]. The system is sometimes designed with an IrDA reader for user detection. Lamp-based smart furniture is mainly designed for home use. Since there is quite a lot of information that can be gathered by sensors and other devices within the home, this type of smart furniture is mostly designed to map various information to specific colours [22] and shapes. This furniture type is a cylindrical lamp that consists of six coloured lights in series. Each colour light contains green, blue and red light emitting diodes (LEDs). The LED colour can be assigned via a computer programme (RS-232C). The average height and diameter of the lamp are approximately 1450 mm and 70 mm, respectively [22]. The length of each colour lamp is approximately 200 mm, so the 1200 mm lamp is used to show encoded information. Finally, the Mirror type is designed to coordinate with other smart furniture, such as Pole and Lamp-based smart furniture [22]. This type is often designed with an internally-installed iPAQ (pocket PC and personal digital assistant). According to the design, this furniture could comprise a liquid-crystal display (LCD), a speaker, a radio-frequency identification (RFID) reader, and a half mirror.

When the LCD is turned off, the smart furniture looks just like a mirror. In the design by [22], a wireless-connection Linux (LAN: IEEE 802.11b) is installed within the iPAQ. Additionally, mirror-based smart furniture can be used as a personal reminder or a controller for several household appliances.

The ten most frequent research areas covered by results from ISI WOK are summarized in Table 2. In this respect, the most research areas are computer science, engineering and telecommunications, covering more than 91% of the results.

Table 2. Top ten research areas for "Smart ICT Solution" AND "Elderly" in ISI WOK.

Field: Research Areas	Record Count	% of 439
Computer science	212	48.29
Engineering	112	25.51
Telecommunications	83	18.91
Instruments instrumentation	48	10.93
Medical informatics	45	10.25
Chemistry	43	9.80
Electrochemistry	40	9.11
Health care sciences services	35	7.97
Geriatrics gerontology	28	6.38
Mathematical computational biology	15	3.42

Table 3 presents the countries represented in author's affiliations. It is possible to observe a similar involvement of the countries.

Table 3. Top ten countries for "Smart ICT Solution" AND "Elderly" in ISI WOK.

Field: Countries/Regions	Record Count	% of 439
Spain	48	10.934%
Italy	40	9.112%
France	39	8.884%
USA	39	8.884%
England	36	8.200%
South Korea	35	7.973%
Germany	32	7.289%
China	31	7.062%
Canada	20	4.556%
Netherlands	19	4.328%

The literature search can be analysed using clustering, where we use the VOS Viewer SW solution, which provides visually indicative clusters. From the total number of 439 analysed articles from ISI WOK, we got 1681 keywords, for which we used Full counting clustering (one co-occurrence means one line). Figure 3 shows the four clusters with 57 items (keywords) and 906 links between keywords (the minimum number of occurrences of a keyword was eight). The green cluster groups the technologies and technically-oriented keywords, such as Smart Home, Activity recognition (with various forms) and Sensors (overlapped by ambient intelligence at Figure 3), among others. The red cluster includes elderly with health, Quality of Life (QoL), Assistive technologies, care, tele care/monitoring, and independent living, among others. Moreover, the blue cluster covers supporting technologies and frameworks grouped around Ambient Assisted Living, Ambient Intelligence and the Internet of Things. The last cluster in yellow represents systems and elderly in a smart environment with information around them provided by sensors and IoT.

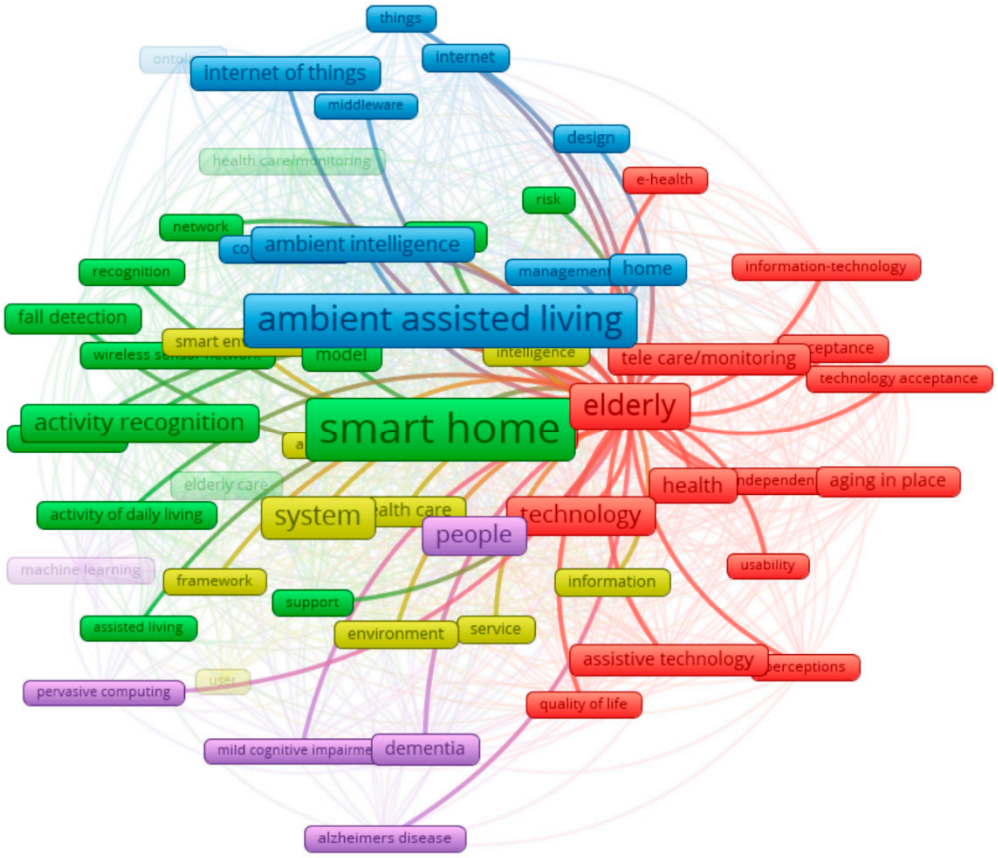

Figure 3. Clustering the keywords from ISI WOK records for the "Smart Furniture" phrase by Topic.

3.2. Selected Commercial Smart Furniture and ICT Solutions

Based on the literature search, a summary of the currently available commercial solutions in the Smart Furniture and ICT Smart Solutions area is provided. Table 4 summarizes 16 smart furniture or ICT solutions based on the following characteristics:

- Sensors—which sensors are used within the Smart solution
- Active effect—what is the output of the solution to the (Smart) environment
- Remote—if the solution provides remote access
- Mobile—if the solution can control or monitor via a mobile device
- User—what experience level is needed to use the solution
- Smart—can the solution be characterized as Smart?
- Potential—is there potential to attach the solution to the Smart environment as it is?
- Price (€)—value of the solution

According to Reference [23], intelligent mattresses are now able to recognize a user's voice and to determine whether the user slept well or not. With inbuilt sensors and actuators, these products help to manage sleep-related disorders, such as snoring, as well as to carry out body massage. The technologies behind these functionalities are *SleepIQ* and *Active Comfort*. Intelligent mattresses can also gather information about the users' heartbeat and level of breathing to ensure an individual remains healthy while asleep [24].

In the medical context, there are now temperature-monitoring smart thermometers, which constantly gather body temperature data and send the data to an individual's smartphone. Developed by Reference [25], the *Fever-Scout* thermometer is designed with wearable patches that can be placed around the armpit. In principle, the farthest distance needed for an effective smartphone Fever-Scout interaction is approximately 130 ft [25].

This smart device also bears rechargeable batteries, making it useful at any point in time, especially for nursing mothers who always need to monitor the temperature of their babies. Although the thermometer is water-resistant, the manufacturer encourages users to avoid immersing the device completely in water to avoid abrupt temperature fluctuations [25].

Currently, steam cleaners are also common. Steam vapor machines are smart furniture, useful at home and in medical facilities to remove pathogens from clothing or from surfaces [26]. As reported by Reference [27], the activities of Gram-negative bacilli, coupled with those of *P. aeruginosa,* were drastically reduced under the influence of steam disinfectant. The researchers of Reference [28] found that hospital room surfaces which were frequently touched had reduced bioburden levels after steam disinfectant based on the principles of steam cleaning smart furniture systems. Furthermore, the post-surgical cleaning of garments and robes of medical staff is now easily monitored to be free from unwanted pathogens prior to new surgical procedures. Although Reference [26] noted that it is important to remove unwanted solids from the surface of materials earmarked for steam cleaning, this technology, as offered by smart home furniture (e.g., LG's steam cleaner), is useful for cleaning a number of untidy surfaces (hard or soft) [27]. The smart steam cleaner adopts *Hot Steam* and True Steam spray technologies to carry out cleaning and disinfectant procedures [29]. The system also bears a set of vibrating hangers.

Smartphone charging is one of the great annoyances of the digital age. The researchers in Reference [30] introduced "*FurniQi*", a smart bamboo table that is able to remotely charge smartphones. FurniQi adopts Qi technology, which makes it possible to execute this function. Another smart table solution is the *Ideum multitouch table*, from which a user can access the Internet while having a coffee mug placed on the table surface. Herman Miller recently developed Live OS tables (and other office/home furnishings) that work based on connection to a central cloud [31]. These tables gather real time data based on individual user commands and preferences. Live OS tables can also be remotely adjusted to suit height differences Reference [31], and are able to notify users when they maintain the same position or posture for too long.

The researchers of Reference [32] introduced a smart furniture package that allows users to access a variety of needed information. The setup can be embedded in any household furniture, such as wall frames, tables and mirrors. It comprises two applications: the first one, the so-called Silhouette Counter, gives feedback on the features and data of items placed on a table, when embedded or linked to a table; the second application, Miragraphy, when embedded into a wall frame of a mirror placed onto the wall, allows the user to have access to the weather forecast while getting dressed.

In the report by Wired UK, a commercial blogspot that discusses the latest trends in IoT and Industry 4.0 [24], it is explained how smartphones can be used to manipulate the use of living room sofas. Acclaimed the foremost computerized sofa globally, *Lift-Bit*, a smart sofa idea by Carlo Ratti Associates, comprises several mobile modular units that can assume different positions in a sitting arrangement. The sofa, currently a prototype, is made of stools that can be controlled to increase or decrease in height [24]. In addition, the different component stools of the sofa can be controlled from a smartphone or any other smart device. *Lift-Bit* can also be operated with hand-gestures based on the proximity of the controller [24]. The individual stool height varies between 480 mm to 780 mm, with the possibility of the production of different shapes. As noted by [24], this smart sofa is yet to make a market entry, but it is expected to be valued at approximately €12,000. It can be remote-controlled for component stools to merge, forming a king sized mattress. Similarly, research tailored towards understanding the pattern and length of time an individual sits down to work using a laptop (in an office setting), or while having a meal at home, have also been given a boost by some smart chair innovations. In a study carried out by Reference [33], the authors designed a smart chair that could detect users' sitting posture as well as detect how the hands and head of the user are placed. This was possible by wiring the chair with sensors capable of monitoring pressure. Those researchers in Reference [34] also used the same technology to monitor the specific body movements/gestures of a number of individuals in their seated position. This process was carried out within eight different live

presentation classes on six seated individuals per presentation. The detection accuracy of the chair was approximately 75%.

Infurmia Actiu is another smart chair innovation that is gradually gaining particular attention in the market. The chair is designed by the Biomechanics Institute of Valencia (IBV) and aims to correct postural defects using smart technologies [35].

As part of a smart security step at home and at the office, Google has developed the so-called *Nest×Yale* smart lock [36], which reduces the stress of having to move around with a bunch of keys. The smart-lock works with an application, "*Nest app*", through which information is gathered regarding who gains entry into a home or office. A homeowner or occupant can merely share the *Nest×Yale* password with friends or family members from any part of the world. The app also works remotely, and is able to identify the user's voice using Google assistant. A homeowner immediately receives an alert in a situation when a burglar tries to forcefully gain access to an apartment. The lock system can also work with Wi-Fi technology, and needs to be charged with an average of 9 V power source when the battery is running low [36].

In the realm of smart cooking, a number of smart pan manufacturers are now making waves within the market. As reported by Reference [37], the *Pantelligent* smart pan is an ultramodern cooking pan. This smart kitchenware is designed with sensors that gather information on the degree of heat on the food surface. A Bluetooth device embedded within its handle allows easy accessibility with an application that is specifically designed to work with the pan. This combination makes cooking a lot easier. By using the application, a user can learn to cook any meal on the menu list via a voice tutoring procedure [37]. Similarly, Reference [38] described another smart pan brand that is similar to Pantelligent, and is able to determine the amounts of ingredients needed by the user at specific times. This information is based on the food temperature and on the time of day of cooking. *Smart pans* also work with an application that specifically monitors food and determines the amount of time required for different food items [39]. Restaurants and bars are not left out of smart innovation concepts such as *Somabar,* an intelligent bartender [40]. This device mixes cocktails with the help of software, which are ready to be served with a tap [40]. Somabar can be operated without a waiter/waitress. The system also comes with a standardized self-cleaning effect that makes it a self-sufficient unit.

The electronic giant Panasonic has developed a revolutionary smart mirror, which is a level ahead of the common make-up kits and mirrors used by beauticians [41]. Known as the *Snow Beauty Mirror & Make-up Sheet* (SMBMS), this smart mirror captures the facial image (shape and skin type) of a user, and subsequently generates beauty tips using processed data stored within its memory. As a step further, SMBMS can provide a user with a printable make-up that can be placed on the face in the place of conventional make-up. To achieve this goal, the mirror captures the facial image and prepares a model for the user to check [41]. Afterwards, the user can select items based on the sample prepared by the mirror. In practice, SMBMS is able to provide makes-ups that cover facial wrinkles and acne. A special feature of SMBMS is that it can be used by individuals with different skin colours [41]. The researchers of [42] recently introduced another smart mirror onto the market. The *Open Mirror* has an international award of innovation, and acts both as a mirror and a radio. The oval-shaped mirror has a music-based design that can be controlled merely by using hand gestures on the screen of a smartphone connected to the mirror. According to Reference [42], Open Mirror can be synchronized with a smartphone, where audio files can be linked and played on the speaker embedded on the mirror. Open Mirror currently sells for approximately €950. The manufacturing powerhouses IKEA and Hyundai also have a range of smart furniture and household items.

Table 4. Selected Smart Furniture solutions on the market.

Name	Focus	Sensors	Active Effect	Battery	Remote	Mobile	Communication Protocol	User	Smart	Potential	Price (€)
Hyundai Livart [43]	Living room, kitchen	-	Air cleaner by UV LED Violeds	220 V	Yes	Yes	-	Basic	No	No	-
IKEA [44]	Range of household smart items	-	Lightning control, wireless charging, wireless speakers	2x AAA/230 V	Yes	Yes	2400 MHz~2483.5 MHz	Basic	No	No	Varying prices (e.g., wireless electric blind sells for €162)
Smart Sofa [24]	Households	Posture monitoring	Furniture shape change	230 V	Yes	Yes	IoT/WiFI	Basic	No	No	800–12,000
Smart BED [10,11]	Households	Heart rate, temperature, sleep monitoring, breath rate	Foot warming, bed shape change, lightning control	-	Yes	Yes	-	Basic	No/passive functions	No	1500–4000
FurniQi Smart Table [30]	Households	-	Charging mobile phones	230 V	No	No	-	Ignorant	No	No	180
LG Clothing Steamer [29]	Households	-	Cleaning clothing (*E. coli* and *S. epidermidis*), steam, drying,	120 V/1500 W	Yes	Yes	WiFi, SmartThinQ Technology	Basic	No	No	1800
Elflow Cooling Mist [46]	SoHo	Temperature, humidity	Mist generator	-	-	Yes	-	Basic	No	No	-
Fever scout [25]	Households	Temperature, humidity, pressure	No	Chargeable	Yes	Yes	BLE (max range 13 ft)	Basic	Yes	Yes	60
Google Nest Yale Smart lock [36]	Households	-	Lock, voice recognition	4xAA LiPol	Yes	Yes	Weave AES 128-bit and Bluetooth	Basic	Yes	Yes	250
Panasonic Mirror [41]	Households	Skin condition, image processing,	Recommendations on what product use	-	Yes	Yes	-	Basic	Yes	Yes	950
Somabar robot bartender [40]	SoHo	Flowmeter, temp	Drink maker	230 V	No	No	WiFi	Basic	No	No	390
Samsung Family Hub 3.0 Smart Fridge [45]	Households	Camera, Thermostat, Bixby	Display schedule, shopping list, music syncing	230 V	Yes	Yes	WiFi/Bluetooth	Basic/ Advanced	Yes	Yes	2100–2200
Smarty Pans [37,39]	Households	Temperature, weight	Diet monitoring	Magnetic charging	Yes	Yes	BLE 5.0	Basic/ Advanced	No	No	200
Smart Chair [33]	SoHo	Pressure, pressure distribution	Movement in the seated position	5500 mAh/36 h	Yes	No	2.4 GHz ZigBee	Scientist	No	Yes	Medical: 1800–2700 Posture: 1400
Herman Miller Live OS Smart table [31]	SoHo	-	Height change	-	Yes	Yes	Live OS—ANT wireless mesh network	Basic	No	No	1450
Infurma Actiu Smart chair [35]	SoHo	Posture, air quality, temperature, humidity, lighting and noise levels.	Chair design	-	Yes	Yes	Smart IoT	Basic	Yes	No	-

From smart kitchens to smart mattresses, the *Livart* range of Hyundai products are mainly manufactured in Korea, with a world-class touch of modern design [43]. The IKEA products are mostly household materials ranging from lighting items and WiFI speakers of different designs to electric window blinds, among others [44]. IKEA's Frytur electric blind is a battery-powered, wireless blind that can be remote-controlled to manage the level of light entering a room, depending on the ongoing activity in the room. The item is currently sold at €162. As part of the many smart furniture and smart home innovations, Samsung also developed the Samsung smart refrigerator [45]. This range of products, popularly called the "Family Hub", is able to take stock of items stored within the fridge, so that the user acquires information on all items on their mobile phones without opening the refrigerator.

The refrigerator can be remotely locked using the application on the mobile phone. Samsung's smart refrigerators also come with "French door" screens, from which an individual can access the Internet and play music [45]. From the application that comes with Family Hub refrigerators, users can remotely open and close the doors of the home. The fridge is designed based on a series of sensors, IoT tools and actuators, so that the smart functions are uniquely performed.

3.3. Patent Applications of Smart Furniture Solutions

One of the most important pieces of information in patent application is the International Patent Classification (IPC) Code, which is assigned by the patent authority after initial screening. The IPC scheme is accompanied by a set of IPC definitions explaining how to use the IPC scheme to classify and search a specific technology. These IPC codes provide relevant information, such as the location of the target area of patent applications in the patent pool (results of patent search)—in our case for 57 patent applications (Figure 4). The new version of ICP, called the Cooperative Patent Classification (CPC), was not possible to use because not all patent applications in our pool had any CPC classification.

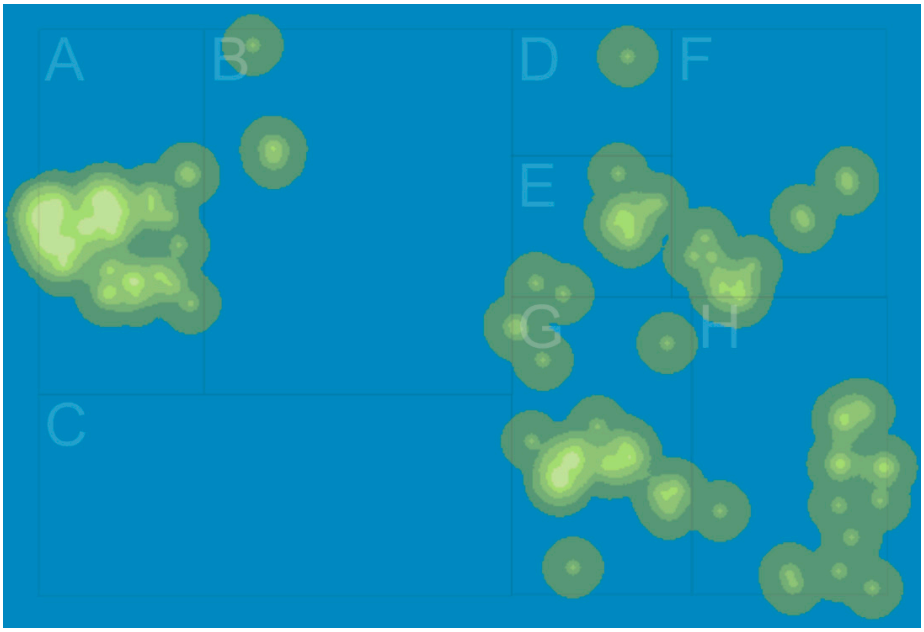

Figure 4. IPC Code Map for our patent pool based on selected patents from the search of the "Smart Furniture" phrase in Title, Abstract, Claims and Description.

The IPC Code map shows a graphical of similarity between patents and codes, since the human mind is used to and can readily understand the use of maps to correlate distance between two items. This analysis indicates which IPC codes are used in our patent pool (Figure 4). The most used IPC codes in our pool are represented by topics covering Programme-control systems (G05B19/00), followed by Systems controlled by a computer (G05B15/00) and Sofas (A47C17/00), as shown in Figure 5.

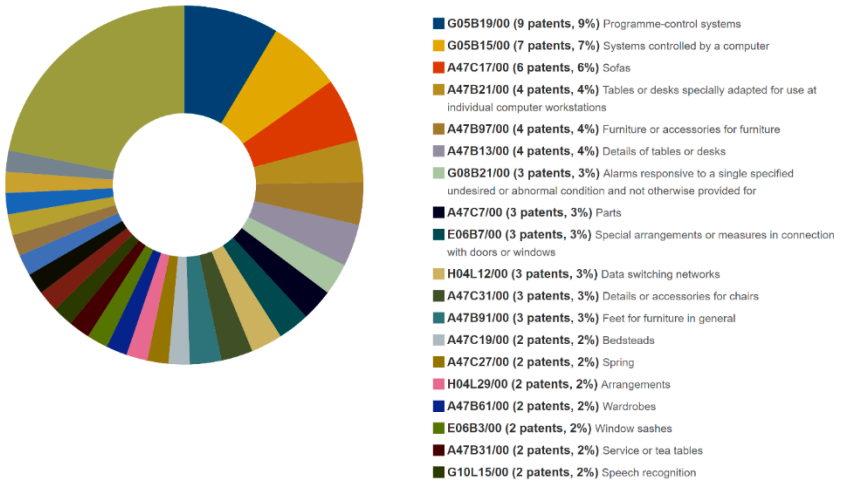

Figure 5. International Patent Classification (IPC) Codes for our patent pool.

Based upon IPC codes, the technologies are clustered in groups. The clustering algorithm assumes IPC codes that are very similar to each other to form technological areas (Table 5). Technological areas, which are mentioned in patent applications, are divided into five main groups, where the technology is mentioned with the number of patents represented in our patent pool (Table 5).

Table 5. Technological analysis based on IPC Code clustering.

Section	Technology	Count
Electrical Engineering	Electrical machinery, apparatus, energy	5
	Audio-visual technology	3
	Telecommunications	1
	Digital communication	4
	Computer technology	2
	IT methods for management	1
Instruments	Optics	1
	Measurement	3
	Control	13
	Medical technology	6
Chemistry	Surface technology, coating	1
	Chemical engineering	2
Mechanical Engineering	Thermal processes and apparatus	2
	Mechanical elements	1
Other Fields	Furniture, games	27
	Other consumer goods	2
	Civil engineering	6

One of the most important results can be seen in the evolutionary potential analysis, where properties has been extracted and described as most relevant in the patent text, as well as those that have not yet been explored. This is possible because every property is backed up with a list of synonyms (Figure 6). It is evident that "Information" is a part of every patent application, while 20 patents use "surface" or "Integration", and others remain without a huge interest.

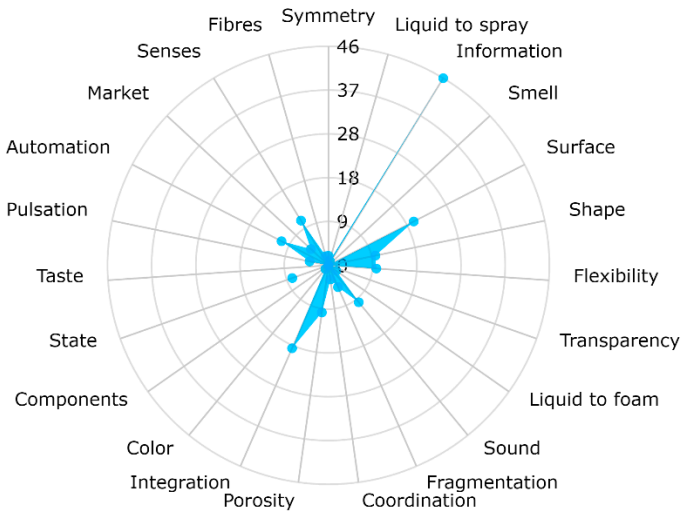

Figure 6. Evolutionary Potential analysis of the patent pool of the "Smart Furniture" phrase in Title, Abstract, Claims and Description for all years (1999–2018).

Over time, an extensive literature has developed on patenting, but nevertheless, only one study has focused on smart furniture patent application and assignment. In fact, [3,47] are two of the most recent studies that have discussed patents and patenting, particularly in relation to smart furniture and smart homes, respectively.

3.3.1. Review of Selected Smart Furniture Patents

Since this section focuses on existing patents and how the right holding capacity of the patent holders may influence smart furniture markets and prices, we also attempt to understand current trends in smart furniture commercialisation. First, it is important to carefully examine some smart furniture patents. Given very few forgone/related studies, we focus on the systematic review of Krejcar et al. (2019) [3], to select a few patents and analyse them accordingly. Additionally, patenting ideas described by Carsten Guderian, also in 2019 [47], are used as the basis for creating an argument for future needs in this regard.

In 2017, PayPal filed an application for a worldwide patent for devices wired with sensors that could read the movement of other objects relative to their surface [48]. This is useful in disallowing damage to smartphone screens, since the user is rapidly notified as soon as the smartphone begins to slip as a result of vibrational motion over any surface. The rights to a Korean patent for a smart furniture power supply unit developed by [49] were given to Filament and Co., Limited. The power unit is able to remotely supply power to different kinds of smart furniture. Reference [50] invented a transmitter that is able to help change the position of smart furniture. The invention describes intelligent movement by furniture in all directions within a ubiquitous environment. The transmitters bear a communication part and a central processor, and they help to position the smart furniture through the receipt of wireless signals that are processed by the central processor to supply movement instructions to the furniture. A smart bed disclosure by [51] has been observed to possess the ability to work with other household furniture materials such as chairs. It works based on the principles of pressurized sensors that raise an alarm when in contact with any external body. This discovery is particularly useful in hospital settings for monitoring bedridden patients [51] and preventing sores. Moreover, since some of these patients are immobile, the technology allows for proper monitoring, so that when the patient bed becomes wet, the sensor is able to alert the caregivers.

In another Chinese-based worldwide patenting situation, Woka Smart Furniture Ltd., (Guangzhou, China) a Guangzhou-based firm, was assigned the rights to a smart desk technological innovation. Developed by [52], the initial design for the *intelligent desk*, as it is called, comes with a function that allows it to locate suitable postural positions. The invention consists of a main part, an upper outer part,

and another part that is used for mounting its groove. The desk generally allows for better efficiency in a seated position at work. Another innovation by [53], similar to the smart desk, was again assigned to Woka Smart Furniture, Ltd. This invention describes a smart table that is controlled by a set of sensors. The table, as described by [53], possesses a display motor that controls its display function, which is nevertheless hidden. The table works in line with the ideas explained in the invention by [52], except that one helps to maintain good posture while the other has the display functions.

The discovery made by [54], for a wall-mounted, light source-based, contactless monitoring unit that detects light sources, can be traced to many existing smart furniture innovations today. The invention's functions are based on interconnectivity between a computer-controlled source, a part that reads-up data, and another that stores it. Read and stored data is processed, and the result is displayed after it has been processed by a gauge displacement unit [54]. Results from the units are quite accurate and reliable due to the data gathering process. Similar to the smart bed invention by [51], an anonymous inventor also proposed another intelligent bed model [55]. This smart bed comprises a main bed and a sub-bed separated by a plate. Both beds can be remotely adjusted to create space, thus combining two unique operation processes, that is, traction and decompression. As reported by [55], this smart bed supports the overall physiological balance of the human body through a gentle decompression motion.

Assigned to Taizhou Zhizi Technology Co., Ltd. (Taizhou, Zhejiang, China) in 2019 is a smart ventilation door that makes for easy ventilation [56]. The door is designed with door frames that are arranged adjacent to a set of mounting plates, in a vertical position. On the left part of the composition is an air inlet, which is designed to act as a support to the plates, and which rests fully towards the left. Additionally, a number of telescope-like systems are systematically arranged at the upper part of the door, and at the base, all on the left part of the door. The door ultimately provides security while regulating ventilation [56].

Those in [57] disclosed another smart innovation, being a stereoscope-based furniture design, which produces oblique and floating images based on the function of a display unit with a flat background, a lens and a layer that resembles a microstructure [57]. The invention tends to thrill users who are able to look through the lens to view the floating bodies.

In addition, due to the common challenges faced with dirt on the external walls of buildings, reference [58] developed a smart idea to tackle this problem. The inventor came up with a unit that is capable of smartly combining blowing and washing activities to clean external walls. The system comprises a cylinder that bears pressurized air, among others [58]. The cylinder is connected to a rod with a length that can be remotely adjusted. The unit is common today, and is especially useful for maintaining good sanitation of buildings made of glass or bricks. According to the work of [59], it is possible to remotely secure an apartment or office space using wireless communication. The inventors demonstrated this using security instructions programmed by a user. First, the display unit shows the user instructions and then stores them. This keeps the entire system ready to detect by triggering the alarm when there is a break-in or when foreign information is supplied to the system. Once there is an intruder, the pyroelectric sensing unit within the system senses it and signals the inbuilt vibration unit. This engages the alarm and sends information to the display [59].

According to [60], an invention such as a bed that can rotate without the bed switching its position is a step ahead of the typical electric bed in which the user needs to move the bed to suit certain needs. The invention of a rotatable bed frame means that the bed can be adjusted to specific angles and sides within a room. This is particularly useful for hospital patients, whose beds may need to be adjusted in a timely manner to administer injections and drugs.

As invented by [61], some smart furniture can be wired with hidden sockets, which can be embedded within the furniture in a way to prevent dust. Furthermore, such sockets can subsequently be used to charge a number of electronic units and to power others, without any form of the traceability of the cable wiring unit [61].

An invention by [62] explained a movable dryer made of pipes that contains blades, which produces air that dries external materials. A unique feature of this smart furniture invention is that it can be moved with ease from one room to another. Similarly, reference [63] described an invention that tries to resolve the problem associated with debugging, which before now could not be easily achieved as a result of an installation situation; as such, the adoption of a mechanical unit is often important to facilitate debugging. The system has the ability to support home electronics and consists of a set of rods (telescopic and connecting) and plates that are connected to the unit to function. Patent rights of the system have been assigned to Tianjin Nanyang Hushi Furniture Manufacturing Limited, a China-based organization.

The invention disclosure by [64] described a number of household furniture items that all work based on sensors. Windows, curtains, lighting, as well as the heating unit (water and indoor rooms) all work based on sensors that can be assessed through a main control unit within the wireless network domain. The system has been applied in hotels to provide ambience and convenience to users.

As a sleep-improvement unit, [65] invented mattresses comprising several unique layers with pressure equally distributed all around the body of the mattresses via the presence of a smart spring. Elasticity provided by the spring helps improve the strength of the mattresses and provides better user convenience in terms of the quality of sleep achieved using the unit. Similarly, the research by [66] gave rise to a multipurpose smart bed. The bed, which could also function as a cabinet, is made up of a set of frames and a pair of plates.

The bed has two sides, each with a seat that is otherwise referred to as *sofa seat*. A unique feature of the bed is its foldability, thereby allowing the creation of more space within the home.

Certain mattresses, such as the one invented by [67], are capable of disallowing sleep-related challenges such as snoring. Assigned to the Cixi Lianxing Intelligent Furniture Co., Ltd. (Hong Kong, China), the smart bed receives several sound signals and immediately notifies the individual when he/she begins to snore, as such, the snoring period is cut short. Furthermore, other individuals within the room can also enjoy sound sleep as soon as the snoring person changes their sleep position. The detection of different sounds during sleep is mainly carried out through a voltage comparison unit embedded on the bed.

Another smart bed invention by [68] reduces the effect of fatigue through the presence of an attached stepping motor. The bed consists of three parts all connected by a telescope-based board, belts that allow stretching, and a number of tubes. The combined efforts of these items reduce any fatigue in the user.

The discovery made by [69] in the smart furniture domain is a cutting edge intelligent curtain that acts based on a set of "zigbee" instructions, so that it is able to monitor and regulate temperature and humidity outdoors (through the use of sensors), to create good conditions inside the room. As such, the room is never too cold nor too hot for the occupants.

The researchers in Reference [70] noted that tea tables can also be used as lighting sources. This can be achieved by merely attaching light-producing plates around the edges of a smart table made of tampered glass. The table according to these same researchers [70] is wirelessly charged and can be controlled through a touch panel assembled on the unit.

The researchers in Reference [71] developed a furniture that is capable of adjusting itself to any position taken by the body of the user. Thus, in addition to adjusting to a sitting position, the furniture is able to automatically switch to a sleeping furniture if the user decides to sleep. The furniture immediately senses and gathers physiological information about the user's body to provide comfortability in a position. Some newer smart furniture also acts based on voice recognition and control. For instance, Reference [72] modelled a smart furniture that makes use of processed voice data. Specifically embedded on a sofa, the furniture is made up of a voice encoder and decoder, so that the stored user's voice data, when recognized, causes the sofa to perform its functions. Pick-up keys are linked to both encoding and decoding devices within the furniture; it is on this basis that the voice controller works according to the inventor's model.

A heating floor model design by Reference [73] is amongst the modern inventions in energy-saving floor units. The floor consists of a hollow plate on which is clamped a tank containing water. The tank is designed in a way that allows water inlets at the upper part and is perfectly sealed. Additionally, the plates are placed on a crystal-like structure made of carbon. Heat dissipation by the unit is well monitored so that blackening can be prevented.

A Taiwanese-based invention by Reference [74] is a device that is able to massage the human body either in a sleeping or sitting position. It is made up of a valve, a massager, a pump and a cushion. It is the cushion effect that allows the device to be able to change position. A set of balloons at both ends of the massager connects the valve to carry out the massaging function of the furniture. The researchers in Reference [75] also described a smart furniture, but in this case, splints and a set of boards all connected to two inter-connected plates make up the working system on which the furniture is based. In principle, the splint movement and board rotation together cause a lifting for one of the plates for the performance of the furniture.

To prevent unwanted odour within a room in the home, the researchers in Reference [76] invented an air purifier. The unit contains a motor that is designed inside the inner part of the innovation. A casing is attached to the motor, beneath which is a casing that bears a bamboo-based purifier. As the unit works, unwanted odours are removed.

The researchers in Reference [77] disclosed a sporting hand band that can be worn by a user to monitor movement during sporting activities. The hand band follows IoT function and possesses a grip and hanging units. A touch screen helps the hand band user to set specific limits. The unit embeds infrared, RFID and wireless components in its functions.

The work by the researchers in Reference [78] is a home-security invention using wireless communication. The unit automatically synchronizes all smart home appliances so that it is able to monitor the entire home via a control unit. Only synchronized and saved information is allowed for entry into the apartment, so that safety is assured within the home. According to the researchers in Reference [79], a disclosure of a combined control for doors and windows can yield a reduction of $PM_{2.5}$. To achieve this goal, $PM_{2.5}$ sensors are embedded on windows and doors to reduce the effect of particulate matter.

Both inventions by the researchers in Reference [80] are based on healthy sleeping. First is an electric bed that raises an alarm when a user gets too close to the edge of the mattresses placed upon the bed, helping to prevent falls. Moreover, it also helps the user to enjoy restful sleep by preventing some problems that may affect sleep, as discussed by the researchers in Reference [67].

One of the simplest smart furniture technological inventions is the design of a photocatalytic piece of furniture described by the researchers in Reference [81]. This was achieved by priming the inner and outer surfaces of a furniture with paint, and subsequently coating it using a photocatalytic material. This prevents loss of the volatile primer due to reaction with air. The priming and coating thickness should be in the same range. The furniture is useful for preventing fouling in and around the home by merely purifying the air within the vicinity.

Having earlier underlined how important smart furniture is to the aged, it is important to describe an invention that specifically meets the needs of the elderly in the comfort of their homes. While research in telemedicine and personalized emergency units have received a boost by moving from older studies such as those of the researchers in Reference [82,83], to more recent ones [84,85], telecare and personalized emergency alarm systems have become more robustly fashioned. The invention by the researchers in Reference [86] is a very good example. It describes a sensor that can be embedded in any household furniture that triggers an alarm when the furniture has not been in use for a long time, or when the pattern of usage has not been consistent during a period of time. It helps to monitor elderly individuals who live alone or who are no longer able to move due to ill health. The level of alarm is dependent on the length of disuse in most cases. It is this alarm that alerts the caregiver to check on the user (usually an aged person).

3.3.2. Summary of Selected Smart Furniture Patents

In brief, smart furniture technological innovation systems cover a large variety of furniture types and designs. While patent ownership remains crucial to discussions related to the commercialisation of smart furniture technologies, inventors' rights must also be protected. Patent laws and patenting procedures in many countries must continue to undergo necessary fine-tuning that will allow for smart furniture discoveries and innovations to continue to solve the challenges emanating from daily living in the home. Furthermore, exploration of the inter-relationship between the need and preferences of users, solutions (innovation and designs), as well as commercialisation in terms of patenting rights, prices and sales must remain at the forefront of smart furniture discussions.

Having so far explored a number of patents within the smart furniture domain, Table 6 summarizes some of the latest smart furniture ideas, showing current patent holders, as well as the country where such rights have been granted. It also supplies brief details on the date of issuance of patent rights and inventors' names, among others.

Table 6. Summary of selected Smart Furniture patents.

S/N	Inventor	Description	Patent Right Holder	Patent Issue Date	Country
1	[48]	Embedded sensors that disallow damage of an item (e.g., smartphone) by notifying users during vibrational movement on a surface (e.g., a table)	PayPal	April 2019	U.S.A.
2	[49]	Power supply unit on all kinds of smart furniture	Filament and Co., Ltd.	April 2019	Korea
3	[50]	Transmitter-based smart system for multi-directional positioning of a table	Beijing Hongtai Tongchuang Information Technology Co., Ltd.	February 2019	China
4	[51]	Pressurized sensor smart bed	Evelyn Torres	February 2019	U.S.A.
5	[52]	Position and posture management desk	Woka Smart Furniture (Guangzhou) Co., Ltd.	February 2019	China
6	[53]	Automated display desk	Woka Smart Furniture (Guangzhou) Co., Ltd.	February 2019	China
7	[54]	Light source-based monitoring system	Zhejiang Institute of Furniture and Hardware	February 2019	China
8	[55]	Physiology-supporting decompression bed	Jining Yinzhou District Reading Wood Furniture Co., Ltd.	January 2019	China
9	[56]	Smart ventilation-assisting doors	Taizhou Zhizi Technology Co., Ltd.	January 2019	China
10	[57]	Stereoscope-based furniture design	Group Rui Co. Ltd.	January 2019	China
11	[58]	Smart external windows/wall cleanser	Dongguan Fangfan Intelligent Technology Co., Ltd.	January 2019	China
12	[59]	Automated theft detection unit	Nanjing Haiyin Communication Equipment Co., Ltd.	January 2019	China
13	[60]	Stationary and rotatable bed frame	Huizhou Fuleshi Smart Home Co., Ltd.	November 2018	Taiwan
14	[61]	Hidden smart furniture socket	Dongguan Lianzhou Intellectual Property Management Co., Ltd.	December 2018	China
15	[62]	Movable drying system	Hefei Digital Electronic Information Technology Co., Ltd.	December 2018	China
16	[63]	Automated supporting unit	Tianjin Nanyang Hushi Furniture Manufacturing Co., Ltd.	February 2019	China
17	[64]	Wireless smart home unit	Heilongjiang University	December 2018	China
18	[65]	Environmentally friendly matrass	Dongtai Daidaihong Furniture Co., Ltd.	December 2018	China
19	[66]	Multipurpose smart bed	Anlu Shengmao Smart Home Design Co., Ltd.	December 2018	China
20	[67]	Snoring-disallowing bed	Cixi Lianxing Intelligent Furniture Co., Ltd.	November 2018	China
21	[68]	Fatigue-preventing smart bed	Zhejiang Yueqiang Furniture Technology Co., Ltd.	November 2018	China
22	[69]	Zigbee-based weather monitoring curtains	Foshan University of Science and Technology	November 2018	China
23	[70]	Lighting table with smart functions	Chizhou Qingxi Information Technology Service Co., Ltd.	July 2018	China
24	[71]	Physiology-enhancing smart furniture (with chair and mattress features)	Teslink (Beijing) Technology Co., Ltd.	November 2018	China
25	[72]	Household voice identification unit	Wang Jianlong	November 2018	China
26	[73]	Heating floor with energy efficiency	Xiaogan Kaixin Smart Home Design Co., Ltd.	November 2018	China
27	[74]	Massage and rest chair/bed unit	Huizhou Fuleshi Smart Home Co., Ltd.	August 2018	Taiwan
28	[75]	A smart furniture unit	Hangzhou Siwenke Technology Co., Ltd.	November 2018	China
29	[76]	Smart air-purifying unit	Zhengzhou Weihaojia Electronic Technology Co., Ltd.	October 2018	China
30	[87]	Automated furniture	Huang Yonghuai	October 2018	China
31	[88]	Automated radio-frequency-based furniture	Xi'an University of Technology	October 2018	China
32	[89]	Smart switch unit	Huzhou Nanxun Meiruixin Furniture Co., Ltd.	September 2018	China
33	[90]	Smart desk structure	Huisen Furniture (Longnan) Co., Ltd.	September 2018	China
34	[91]	IoT-based furniture	Chongqing Zhengluo Education Technology Co., Ltd.	September 2018	China
35	[92]	Automated audio controller	Guangzhou Pengyi Intelligent Technology Co., Ltd.	September 2018	China
36	[93]	Smart multipurpose furniture	Zhongshan Qujia Intelligent Furniture Co., Ltd.	August 2018	China
37	[94]	Voice-enhancing furniture unit	Hangzhou Zhiren Construction Engineering Co., Ltd.	July 2018	China
38	[95]	Automated tea table with embedded display unit	Chengdu New Kaiers Furniture Co., Ltd.	June 2018	China

Table 6. *Cont.*

S/N	Inventor	Description	Patent Right Holder	Patent Issue Date	Country
39	[79]	Automated joint control unit for windows and doors	Xiong Zhicheng	May 2018	China
40	[78]	Wireless mobile furniture controller	Wuhu Le Ruisi Information Consulting Co., Ltd.	March 2018	China
41	[77]	IoT-enabled sport hand band	Zhuhai Liangchuang Intelligent Internet of Things Research Institute Co., Ltd.	January 2018	China
42	[96]	Wireless lighting controller	Hubei Institute for Nationalities, Hubei Kelan Technology Co., Ltd.	December 2017	China
43	[97]	Smart cabinet with embedded dryer and dehumidifier	Hefei Chaoying Industrial Design Co., Ltd.	December 2017	China
44	[98]	Multipurpose self-cleaning window	Yanggu Zhuowei Smart Home Co., Ltd.	November 2017	China
45	[99]	Multipurpose intelligent mirror	Xiaochang County Ruike Intelligent Technology Co., Ltd.	November 2017	China
46	[100]	Heat and alarm-based sofa	Haining Haipai Furniture Co., Ltd.	September 2017	China
47	[101]	Data storage and decoding furniture	Ningxia Lingzhi Technology Co., Ltd.	August 2017	China
48	[102]	Smart curtains	Anhui Meier Fashion Home Shade Manufacturing Co., Ltd.	June 2017	China
49	[103]	Temperature-regulating sofa	Haining Haipai Furniture Co., Ltd.	June 2017	China
50	[104]	Automated wardrobe	Jaeki Kim	May 2017	Korea
51	[105]	Light-sensing convertible and detachable furniture unit	Sungyong Lee	May 2017	Korea
52	[106]	Health-monitoring furniture	Furniture of America Inc	June 2017	U.S.A.
53	[107]	Wireless particle monitoring window	Henan Linghai Whole Furniture Co., Ltd.	June 2016	China
54	[108]	Exercise-enabled office/home sport chair	Wuxi Tongchun New Energy Technology Co., Ltd.	December 2015	China
55	[81]	Air purifier and foul remover photocatalytic unit	Guangdong Zuofan Smart Home Technology Co., Ltd.	September 2015	China
56	[86]	Elderly monitoring unit	Kevin Doughty	October 2000	U.K.
57	[80]	Sleep-enhancing electric bed	ixi Lianxing Intelligent Furniture Co., Ltd.	November 2018	China

3.4. Technological Achievements of the Smart Entities Embedded in the Smart Furniture

The way how to transform a non-smart object of everyday use into a Smart one and even into Smart Furniture is possible by several ways [3], while the aspect of Smart Entity presence needs to be taken into account every time to fulfil the real transformation of a non-smart object into a Smart one [109]. Smart Entity is entity with sensors and/or actuators [3,109] with their own energy sources, they are reconfigurable, able to communicate with other Smart Devices or the Smart Environment and interoperate in the Ubiquitous environment. Smart Entity can be also embedded into other technological devices and non-smart devices which are turned into Smart once by this upgrade [110].

One of the possible technologies can be use of Smart materials when designing new Smart Furnitures. Smart materials can be used to implement this smart entity into non-smart objects or technologies, like Yanagihara et al. (2005) described [111]. Another article from these authors introduces a novel way to allow non-expert users to create smart surroundings from non-smart objects as furniture and appliances available in homes and offices. Conversion can be done by attaching some kind of Smart entity, like computers, sensors and devices. Authors developed u-Texture, a self-organizable, universal panel that can change its own behaviour autonomously through the recognition of its location, its inclination and surrounding environment by assembling these factors physically [112]. Smart material can be used also as actuators [113] or fiber-optic or piezo sensors to monitor cracks [114], or to form a complex warehouse application, e.g., for mobile robots [115].

From the single purpose, non-smart sensors or devices, technology achieved more complex possibilities of measurements that can be performed using energy-efficient operation in the Internet of multipurpose things [116]. The current research gap is not to measure everything everywhere, all of the time and at a maximum resolution/speed/frequency, but rather it lies in the very precise specification of data and information only in the form and amount of values, that is needed to make a decision or control system or user environment (Ubiquitous Environment). This fact opens a problem of energy efficient dynamic mode selection of the multipurpose devices which authors studied considering the sociophysical parameters of the IoT environment [116] in order to control devices' transmission powers and simultaneously satisfy their QoS prerequisites.

More than ten years ago Kawsar et al. stated three challenges for future Smart object systems that the devices face during their operation in a congested environment [117]. They outlined there three challenges that need to be conformed for the proliferation of smart object systems as:

1. *Decoupling Smart Features from Smart Objects:* Current practices typically connect a physical object with a specific scenario, thus they are tightly coupled with the application scenario which limits the reusability of the smart objects. Developers and designers need to tend that Smart objects should be designed in a generic manner, such that the Smart features are independent of the physical object.
2. *Developing General Purpose Applications Independent of Smart Objects:* Smart solutions need to be designed as much independent and decoupled as possible. Applications for Smart objects need to be designed in a generic way so that the same application could run on multiple Smart objects, and one Smart object could host multiple applications.
3. *Involving End Users in the Deployment, Configuration and Maintenance Processes:* There is still a research gap between research projects and commercial Smart solutions. Focus on the end user as the final customer is still a challenge. The need to design Smart objects systems in a more human-centric way, and also involving end users in the process, leads to higher acceptability and a greater feeling of having control due to their active participations [109,117].

Researchers around Kawsar and Tokuda [117] declared a Smart object which Poslad [109] later transformed into Smart Entity, while he also defined this Smart Entity more precisely and also connected to object programming language. While these definitions are open for more than 10 years, they are still valid, as the limits for the reusability and interoperability of these entities/objects design and functionalities still need to be investigated in every future Smart solution system [117].

4. Discussion

Having discussed a number of existing patents, it is important to analyse the make-up of these innovations, which is crucial to understand the trends. Given a huge number of smart furniture, smart homes appliances, and patents from which some have been drawn for the current study, there are several patents that still appear to be closely related, such that they differ only slightly from one another. As such, it is safe to say that researching previous smart furniture designs, i.e., intelligence gathering in technology [118], is not fully operational in the smart furniture patenting procedure. While the researchers in Reference [119] underline the applicability of an innovation, as well as its competitive strength as some important indicators for differentiating patents, it is becoming more important to add "*distinguishable uniqueness*". This will improve research, especially in relation to the ongoing topic.

All examples of smart furniture innovations within this study add advantages to overall healthy living and/or the convenience of individual users. Nevertheless, as suggested by the researchers in [120], it is important that smart furniture manufacturers produce items based on customer preferences, efficiency and the relationship between proposed products and existing products on the market. Most existing smart furniture has a similar technical function, mainly because manufacturing giants tend to compete across innovative fronts. While these competitions should in the real sense favour users in terms of price reduction, this reality is yet to be seen. Current trends in commercial furniture solutions show that smart furniture has come to stay, especially given the projected market growth to approximately USD 44 billion within the next five years [121]. Nevertheless, this value could be higher, especially considering that some people are yet to fully accept smart furniture, mainly due to the cost of the items. For instance, a chef would rather purchase an ordinary pan between €30–€50, and carry out addition of ingredients to a meal manually, rather than follow the suggestions provided by an application that is linked to a smart pan, which is sold for approximately €200. Additionally, most smart pans are limited in functionality, and can barely understand the rudiments of the nutritional make-up of some particular dishes. For instance, a smart pan manufactured in Europe would most likely have European recipes programmed on the application. If such a pan is sold to a customer in China, the pan may not be able to provide the expected cooking support. The analyses by the researchers in Reference [122] showed that current smart furniture sustainability and innovative trends may not stop anytime soon, and will likely continue to evolve to draw even further development. As such, the authors predict likely changes in smart home innovative trends, which shall be driven by smart furniture.

In terms of patenting, it is clear, from the selected patent works that a larger number of patent applications have been submitted by Chinese individuals/firms within the last two years. While there seems to be a very strong smart furniture market growth in Europe, one would ordinarily expect that more patent rights be held by European firms, or that six out of every ten smart furniture patents would be held by European firms. The case is, however, different, as seen in this study, as many patent rights are traceable to Chinese firms, while only a few patents rights are held by organizations and individuals in other countries, such as the USA, Taiwan, Korea and the UK. While this may only hold true for the selected smart furniture patents within this study, it is important to understand that several studies are being carried out on smart/intelligent furniture in China. While Europeans are the most popular users of smart furniture, patent holding by Chinese firms implies that the rights for production can be franchised to European firms. Although franchising may be a good option for commercial smart furniture solutions at the moment, the researchers in Reference [107] stress the issue of standardisation and flexibility, which may indeed pose serious challenges. Furthermore, while the franchisees of a smart furniture solution may have power over prices for the furniture materials, this power may not be absolute in most cases, as seen in the case of restaurant franchises in the USA [123]. Several other bureaucratic arrangements also surround franchising, as explained by the researchers in [124–126].

While franchising may be a way forward, it is important to look at the activities of European smart furniture giants such as Swiss ABB and ABB Limited, Deutschland's Robert Bosch and Siemens AG, French firms, Schneider Electric and Legrand S.A., Irish Johnson Controls International and

Ingersoll-Rand PLC, as well as Swedish companies, ASSA ABLOY and IKEA, in the area of patenting application. This is because there is a need for more innovations in the area of smart furniture research, so that Europe does not only remain a market for smart furniture sales, but will also grow to be home to several smart furniture patents, like China. While there is no basis for comparison in this context, it is important for European Union (EU) hierarchy to begin to look at funding avenues for more research in smart furniture technology.

In analysing patent applications within the current paper, it was observed that some inventors also hold the patent rights on their smart furniture inventions, such as those seen in [51,79,86,87,104,105]. The implication is that if such invention will attain subsequent production and commercial sales in the market, the individual must have the financial strength to be able to make such progress come to pass. In general, smart furniture solutions are currently gaining increasing acceptance, but with the help of governmental interventions in the area of research and development, they can witness even further improvement. These are the advances that will bring about the expected price reduction of most commercial smart furniture items.

Smart Furniture-Related Costs and Literature Gaps

Smart furniture can be very useful to create a healthy, safe and comfortable environment for people with physical and mental problems, the elderly and individuals in general.

However, although smart furniture is relatively expensive, with economies of scale, the cost is anticipated to plunge in the near future, giving room to a larger number of would-be users to be able to afford these smart items. Europe currently remains home to some of the major manufacturers, dealers and clients of wooden products globally [127], and as such, there is hope that the European Union will sooner or later look into the issue of the cost that is associated with smart furniture. Authors [128] explained other interesting aspects of smart furniture in relation to their cost. The authors refer to the value offered to users in terms of health and health benefits [129], satisfaction [130], and general enhancement of life quality [131]. Thus, for smart furniture to be competitive now and in the future, manufacturers of these products have to concentrate on customers' value requirements coupled to delivery in the most efficient and cost-effective way [120].

This cost-related issue is also the using of available commercial solutions as a part of one's own developing solution. One of the key issues is the wireless communication which needs to be energy efficient and using a license-free sub-gigahertz radio frequency. One of suitable examples running at 868 MHz at Europe (or 915 MHz at North America) which is already standardized is LoRa (Long Range) a low-power wide-area network (LPWAN) technology [132,133]. As the LoRa module is available at the market also with the SPI/I2C connector type, it is easy to implement to one's own Smart Furniture solution.

Another very important issue is the energy source of the Smart Furniture solution. It depends upon the type of data which needs to be transmitted wirelessly, as the high data amount WiFi standard and permanent power source is preferred. On the other hand, if there is only one possible remote power source such as a battery, a low energy aspect also needs to be investigated. One possible solution can be found in energy harvesting which can be used even as a main power source [134–136]. The best example is the window, where is the bid difference of in/out temperatures, which is needed by Thermoelectric Energy Harvesting (TEG) to provide the voltage difference [135].

If smart furniture is going to be available, affordable and accessible to larger user groups, it is expected that the market price should be fair enough to be affordable to an average earner, and high enough for manufacturers to take profit into account in scientific research efforts to produce the most competitive product. Given the financial investment for inventing and manufacturing a piece of smart furniture, it is natural to protect the interest of inventors and manufacturers alike, so that they are able to recoup investment returns.

Moreover, without the explorations of users' preferences in new conditions of living and space in smart homes, one cannot expect a high acceptance of smart furniture among people, and therefore,

a high contribution of smart homes to the future housing industry. This therefore requires government support in invention research, patenting and manufacturing of smart furniture products.

5. Future Challenges

The significant advancement in the technology that enables the development of low-power, small and low-cost sensors, and actuators coupled to modern communication technologies, has paved a new way in recent years. Miniature linear servo drives, micro fluid valves, low power data transceivers, accessible micro controllers with rich peripherals, miniature power MOSFETs and a new type of sensors, can be fitted not only to specialized automotive areas, but of course, can impact also furniture manufacturers.

As we have already discussed in the previous sub Section 2.1., journal articles indexed in ISI WOK can be grouped into four clusters with various meanings. There is no clear difference in the research topics during the years. It can be very helpful to observe current trends in the literature, which form the future needs and directions. Thus, we again investigated the clustering, only selecting articles from the last seven years, beginning in 2010. As shown in Figure 7, the evolution of the research area evaluated by keywords over the years is huge. From the literature review, it is possible to observe a significant move from using technologies such as Smart Home solutions, systems, technology and Elderly with health-related keywords through the extensive use of sensors, assistive technologies, monitoring of daily activities until now, where a clear phenomenon of IoT [137–141] and activity recognition with ambient assisted living (AAL) [2,137,142,143] and quality of life (QoL) [3,144] can be seen (Figure 7).

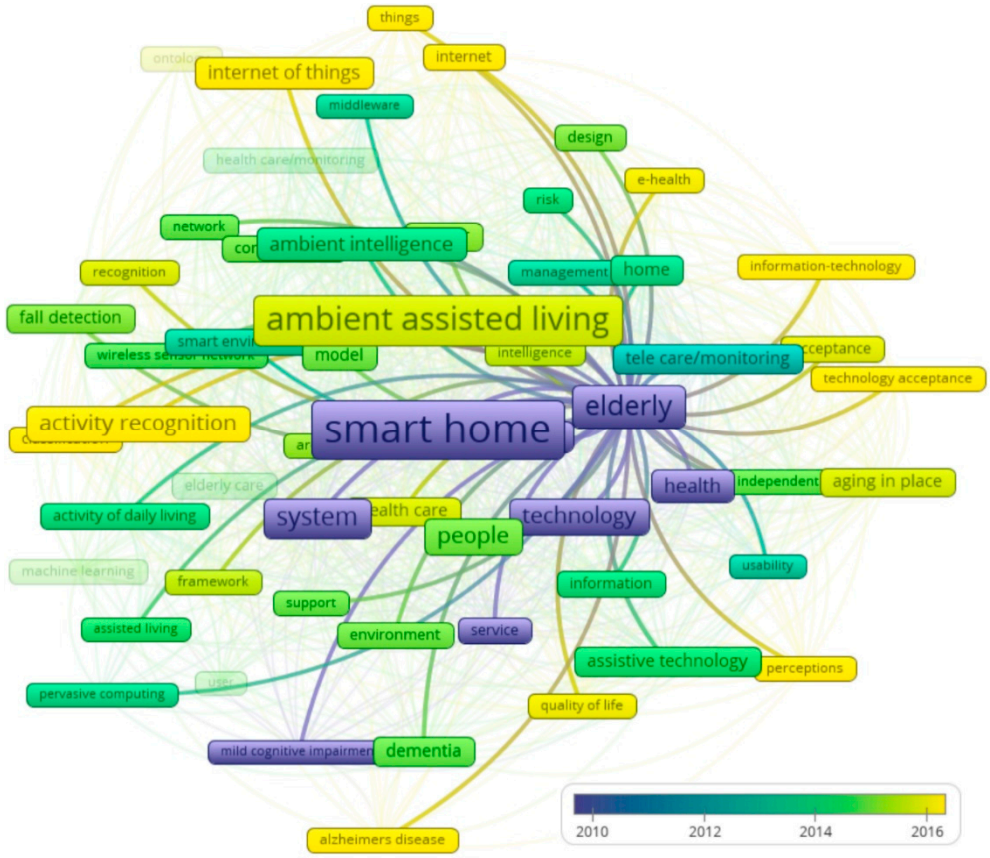

Figure 7. Clustering the keywords from ISI WOK records for the "Smart Furniture" phrase in Topic in recent years (2010–2016) and coloured progress of used keywords.

There are also several journal publications in prominent impact factor journals [137–139,141,145–150] that confirm these findings; the most important one is "Internet-of-things-based smart environments: state of the art, taxonomy, and open research challenges" by Ahmed et al. 2016 [145] published in the IEEE Wireless Communications journal with IF = 11, which is indexed second or fourth in all four web of science categories. This article has already received 70 citations in three years.

The huge investment is another challenge within the associated smart furniture umbrella. There are some problems related to hardware- and software-based IoT solutions, which are not configurable or update-friendly. due to the low investment interest. Thus, the solutions should be flexible enough to enable companies to adapt their systems to changes instead of replacing them with new systems. These features open this area for the real interest of developers and investors.

Beyond the investment are some other challenges that should be taken into account, such as privacy and related ethical issues, energy consumption, networking and compatibility among items, usability and acceptability [120].

Regarding acceptability and usability, one possible way to increase the consumer's interest in smart furniture is implementing functions, which can directly affect users' well-being and comfort, and more likely their health. This type of device does not have strict regulations like other medical devices, and thus, it is easier and cheaper to build. Some of the mentioned furniture designs use "non-invasive" methods to improve users' life environment. For example, high temperature steam, which can disinfect clothes and eliminate body odour, is a good paradigm. The design is quite simple, uses an "old fashioned", well-known technology proven by time, and is clinically harmless. The steam generator is, however, large, heavy, and not eco-friendly, because of its tremendous energy consumption. Substituting the steam with a UVC (ultraviolet C) lamp can achieve the same goal, with minimum space requirements, insignificant power consumption and no price addition, but, as a side effect, ozone is generated. The ozone in higher concentrations can have specific health effects, so it is needed to control their levels in indoor living spaces. This can be done by intelligent timers, which can ignite the UVC emission only under specific conditions. However, this process involves the numerical modelling of inner spaces, where UVC is operated, which also demands an R&D team with specific knowledge, among others. Another example is the pill box, for which a more pleasant and intelligent Smart Pill Box can be used, as already investigated by several researchers [151–158]. As the western society trend leads to an ageing society, incidences of various chronic diseases in elderly individuals also increase, resulting in the need for an increasing amount of medication at the right time. Ensuring that patients consume the right medication at the appropriate time becomes crucial [154], since approximately 50% of patients do not take medications as prescribed. In addition, 30%–50% of medical complication cases are attributable to medical non-adherence [159]. There are several commercial examples of up-to-day Smart Pill Box solutions [159–166], which could be helpful to the elderly, while there is a huge need to investigate the IoT and the connection to remote care via the Smart Phone application, which can significantly facilitate the process of healthcare maintenance, namely, in the home care area.

From the above-mentioned specifics of technical solutions and the needs of the target group, the main challenges in the effort to use smart solutions in the future are:

- verifying the acceptance of a virtual assistant by people who are not very experienced in technology, and ensure that the user is friendly, so that the solution is not only technologically functional, but acceptable by the target group, which can suffer from many limitations (reduced haptic sensitivity, decreased vision, hearing, mobility),
- voice user interfaces can benefit the senior population, as they are more intuitive than touch screens, which can be challenging for people with limited dexterity,
- any future IoT initiatives will need to be implemented in line with a strategy for transforming the fundamental culture and policy,

- one of the greatest barriers to IoT deployment remains to ensure adequate security. Dangerous components, widespread malware and any low-efficiency attempts to take traditional security measures on IoT networks pose huge challenges for all potential IoT users,
- and finally, for many consumers out there, they still need to be convinced that they absolutely need these things, and should continue to digitize their lives, homes and workplaces.

New, innovative and active designs also need to be developed in cooperation with multi-branch researchers and other key stakeholders, with sufficient time for testing in various conditions. Bringing and sharing different perspectives and experts on technologies, IoT, occupants and caregivers' needs, will allow a multidisciplinary approach to promote human health and well-being across the world. Smart Furniture solutions need to be flexible, low-cost, and easy to buy and install without the knowledge of an expert. There is potential in products that primarily not only solve this problem, but also provide greater comfort and convenience.

6. Conclusions

As a result of the above research, there are only a few real original concepts and ideas. It is obvious that the modern type of electronics, ubiquity computing and the IoT have entered the smart furniture area and are slowly growing. Manufacturers are mostly mechanical, workshop-type companies, with no or minimal R&D teams. Current big furniture manufacturers such as IKEA are focused on quantity and cost-effective products. Innovative designs and ideas are based on simple IoT designs at minimal cost. It is also obvious that current consumers also search for cheaper, widely available products with attractive designs, and will not pay significantly higher prices for smart ones.

Moreover, as previously mentioned, the major concerns regarding smart furniture are associated with privacy, energy consumption, obstructiveness, usability, acceptability and costs (initial and/or maintenance). Another related challenge is the networking technology and compatibility issues among items or products.

In summary, a smart furniture, based on the concept of IoT, is a set of advanced technologies—including e.g., robotics, artificial intelligence—integrated into devices, sensors or other appliances used in indoor environments. This technology is expected to provide the healthcare, safety, well-being and support activities of users on a daily basis. Although several smart furniture products are already available on the market, more innovative research and development is needed to obtain the best smart solutions, taking into account the price as well as the target users and correspondent. The new and innovative products would benefit from adopting a multidisciplinary approach that takes into account the major challenges and problems currently faced by users.

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