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Smart Homes: How Much Will They Support Us? A Research on Recent Trends and Advances

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ABSTRACT The advances in the Internet of Things (IoT) provide several chances to develop a variety of innovations supporting smart home users in several industries including healthcare, energy management, etc. Ubiquitous support by intelligent appliances at modern homes, which constantly work to gather information can help us to solve everyday issues. In this article, we present a comparative study of recent advances in smart home development. The study aims to present the main trends in this field. During the analysis of the research reports and patents, we identify the propositions that constitute the main research streams. Through extensive analysis, we provide an outlook on the wide spectrum of the proposed solutions. We also analyze the main market to present which publishers are leading with the innovative science in this field. We also show the leaders of science and technology in the World. Finally, we define the ratio of the developments and outline the next stage of the development in the smart home industry.

INDEX TERMS Internet of Things (IoT), smart home, healthcare, energy management, security.

I. INTRODUCTION

Over time, the type of home was evolving. The shape of the house was evolving during ages, cultural revolutions, and climate changes. We have divided our homes into rooms devoted to sleeping, cooking, work, children, sanitary needs, warehousing, etc. People started to settle in various locations and continents.

This century is giving us one of the strongest technological support, which we introduce to our homes. The entrance to the house is protected by several means like cameras, key locks, and others. Various aspects of security are applied to protect our homes from unwanted access. Some models allow also video calls what improves connection by visual verification. Our corridors and halls have installed control panels, where we can arm and unlock security, control conditioning, electricity, and manage the system of our homes. In the warehousing space, we have installed conditioning to maintain our products fresh or simply avoid fungus or other biological threats. The kitchen is filled with a variety of electronics to support us during cooking, washing, and storing. Devices have various control programs available to set several operation modes for morning dishes, lunch, and dinner.

Such advances help us to run our kitchen but also have fun during our daily routine. Bathroom and toilet are now helping us to maintain the necessary level of warm water, do laundry on time without remembering about it and support us in sanitary and health. There are several electronic brushes and complex laundry machines which have a variety of available options suiting our needs. Our day rooms and offices are equipped with more advanced and complex electronics. Now a laptop or desk computer is a piece of standard equipment which we use for work, communication, and entertainment. We pay duties and buy goods via Internet services, which reduce the time and help us to keep all finances under control. Devices store information and serve as data keep. New possibilities are coming with the development of TV, phone, and several voice assistants. We can now browse information not

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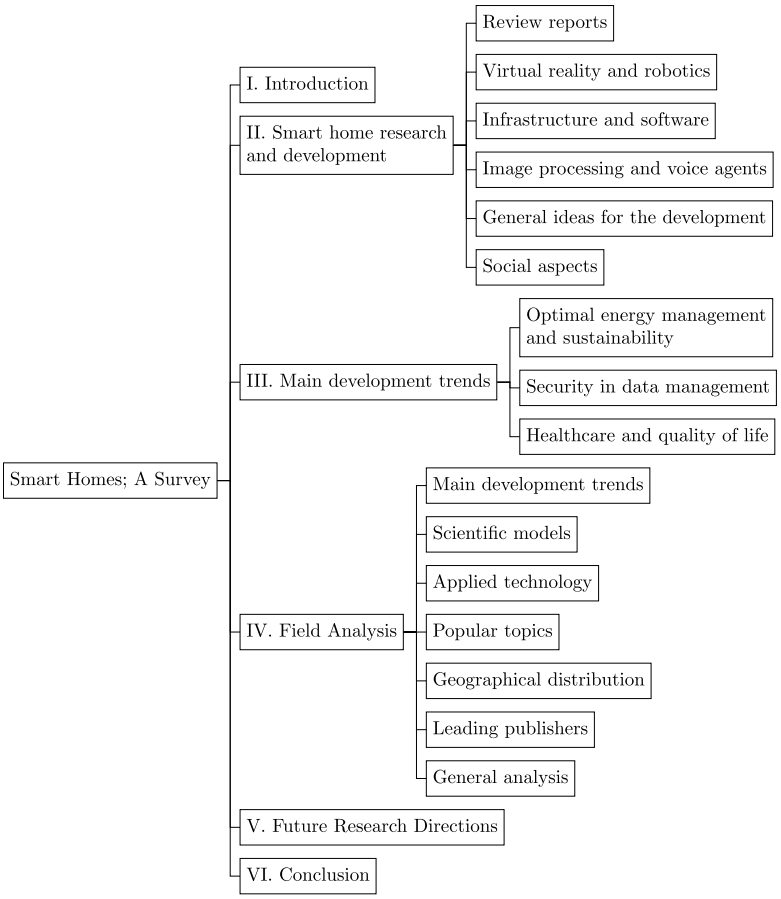

FIGURE 1. The organization of the paper.

only on the computer but on smart TV and our mobile phone, which have the same capacity as computers nowadays. They make the connection and therefore communication very easy and now everybody can call family and friends or get help in danger from official services. Technology even came to our bedrooms and children's rooms. We placed there temperature controls, humidifiers, carbon dioxin detector, voice assistant, and other sensors. All of them help us to care for our family and warn us in case of danger.

Technology has come to our houses for good. And recent years brought vast development in applications in our homes. Houses turn to communicate with users in some way by all electronics and software. Recently the Internet of Things (IoT) standard has dominated electronic devices which are developed to enable the Internet connection and variety of control options via Wi-Fi, Bluetooth, radio-frequency identification (RFID), local area network (LAN), and many routing protocols. All of them are available not only in computers but also TV, mobile phones, Hi-Fi, washing machines, laundry machines, fridges, coffee expresses, air-conditioned, heaters and any equipment which can work with sensors. Therefore we can observe a trend toward ubiquitous technology supporting us in most of our actions at home, turning it into a smart home. Our article is to provide an analysis of the developments in this field, regarding requirements we have from such systems. We have analyzed several articles and patents from various continents in the Globe to find an answer to which technological trends are dominant in recent years. Our analysis leads as to conclusions to answer the question of our research: how much smart home can support us? We want to define which trends will be defining the development of smart house technology in recent years. Fig. 1 shows the organization of the paper. A list of acronyms used in this article is presented in Table 1.

The rest of this article is organized as follows. In Section II we study state-of-the-art in the field of the smart home. The main development trends are presented in Section III. We present our field analysis finding in Section IV. The future research directions and conclusions are outlined in Section V.

II. SMART HOME RESEARCH AND DEVELOPMENT

Smart homes became an important topic, and therefore various aspects were under research and development in recent time. The research covered not only technical aspects but also sociological discussions. Questions important for social adaptivity and acceptance were raised and answered in many articles. In the technological domain, Researchers have solved many problems by developing innovative ideas,

TABLE 1. List of acronyms.

Acronym	Definition
IoT	Internet of Things
RFID	radio frequency identification
LAN	local area network
AI	artificial intelligence
MQTT	message queuing telemetry transport
AWS	Amazon web service
CoSHE	Cloud-based smart home environment
SHCS	Smart home caregivers system
SPHERE	platform for healthcare in a residential environment
TBSA	Trianglebased security algorithm
AFS	Anonymous secure framework
SLASH	Learning and adaptive smart home
SHMS	self-learning home management system
SETS	smart energy theft system
PAR	peak-to-average ratio
PAD	peak load demand

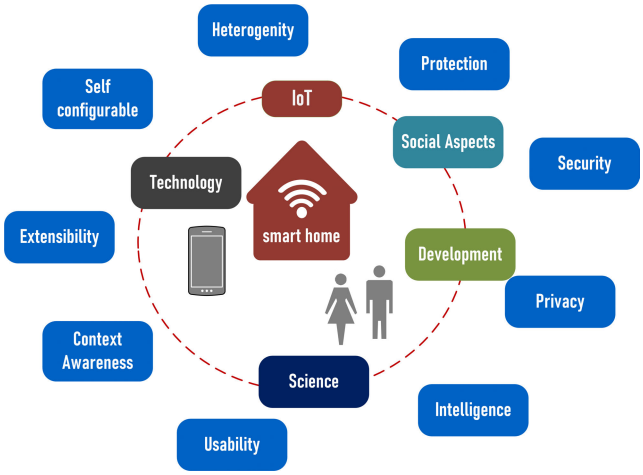

FIGURE 2. Smart home IoT environments support residents in daily routine. The comfort of use and social demands define what are the expectancies we have from such systems and technologies.

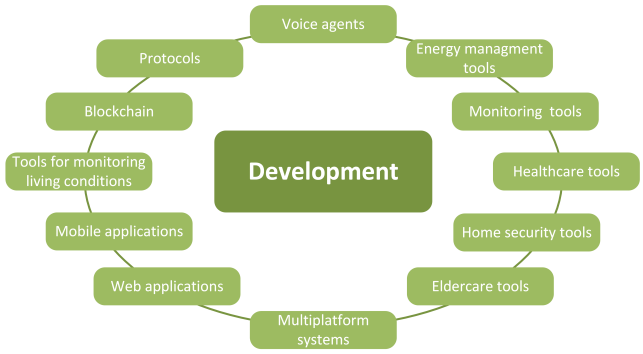

FIGURE 3. The new trends for research and applications in the field of innovative developments for smart home systems.

while industry and academics have patented several solutions to protect their conceptual know-how. Let us now present our findings.

A. SOCIAL ASPECTS

Technological development always faces social acceptance to change standards of living. There are various questions that developments must answer to support new technologies.

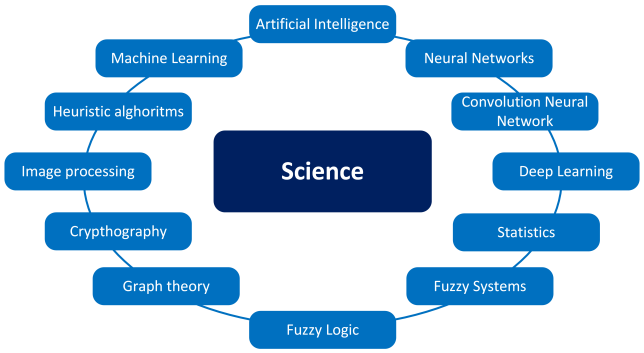

FIGURE 4. The new trends for research and applications in the field of scientific models for smart home systems.

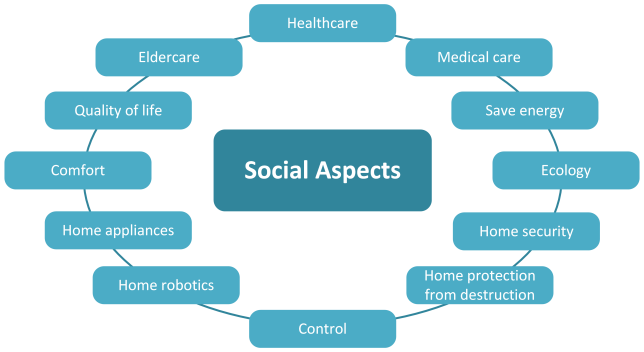

FIGURE 5. The new trends for research and applications in the field of social aspects for smart home systems.

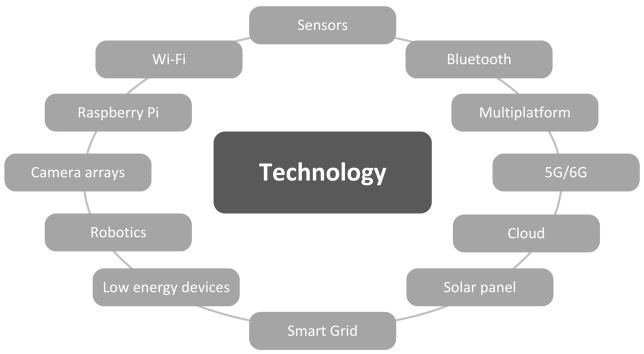

FIGURE 6. The new trends for research and applications in the field of new technology for smart home systems.

In [1] was given an analysis of recent advances in the development of IoT in homes. Authors have posted new trends and features that may influence future development in this field. Among the main topics, we should consider the accessibility and ease of use. The first of them is unfortunately connected with funds each of the potential users can spend on technologies at home. The second is related to technological development where the result should be oriented to the user. Among such people, we must consider elder ones. They potentially may be the biggest benefiters of new solutions. Healthcare and medical support may be one of the most important reasons elder people will reach for smart home technology [2]. Intelligent solutions applied in their homes may help to call

an ambulance or family in case of any danger, which is very important when elderly people live alone in a remote location. Some studies present the point of view from practical application in social media services and industry [6], [31].

A very important example can be discussed for clinical aspects. In [3] was presented what would be barriers for smart IoT systems supporting medical needs and expectation from such systems. One of the main factors to help people accept new technological advances at their close service at home is an integrative service model [4], which will provide an interface of most appliances in one device. In [5] was presented a result of social research for ''smart home users'', from which we can presume that one of the ways to convince people is the presentation of new technology at their homes to show them how would the benefit from using it. Education of people may be also a very important aspect. According to [7] students of technology and science may easily accept and adjust to better control new devices in their possession. In smart homes, the anthropomorphic design of developed assistant may be a key feature to help users on future adaptance [9]. There are also important aspects of gender which developers of new appliances must consider. As presented in [10] men and women, also in various age groups, differently consider the importance of security, productivity, and pleasure from smart home assistance. While [11] presented how elder women perceive the purchase of new wearable and smart home activity sensors. Therefore developers should first assess the target group and after adjust each new solution to fit expectancies. Also, some societies may be in general more oriented on particular details. In [12] was discussed how robotic vacuum cleaner may find new users, by the example of Australian households, was discussed how energetic efficiency of the device may influence the potential purchase of an electrical appliance. Discussion covering households readiness for new devices in service was presented in [13]. One addition to the above aspects is wealth, which is quite clear that the cost of technology may prevent many families from new purchases. Also, sociological features may stand for potential barriers when consumers choose their new device. In [15] was discussed the relation between accepted risk and resistance to new services.

B. GENERAL IDEAS FOR THE DEVELOPMENT

Smart home as one of the major trends in IoT development is presented from various aspects both as a functionality of the released technology and the majority of possible advances. Major requirements from such systems were presented in [16]. The authors defined a few aspects which may have the biggest influence on the development in recent years:

- **Heterogeneity**: differentiation of potential applications and systems which shall be constructed to serve people at various needs, support a variety of data structures and host different functionalities,
- **Self-configurable**: the ease of configuration is a crucial feature for people who are not technology geeks,
- **Extensibility**: the new features, devices, and software must be easy to add and co-work with all yet working ones,
- **Context Awareness**: the things that happen in the house must be related to the context of the family life,
- **Usability**: the features of the home environment must be usable, the system shall not provide complex assistance if nobody wants that but support users with those which they need,
- **Security and Privacy Protection**: information, data, and control cannot be overtaken from the outside, the users of the home system must be safe from any attacks on their privacy,
- **Intelligence**: all appliances and software must support home users by suggesting necessary actions and even predicting the needs of the owners which shall be solved within installed components.

In general, we can that the technology invented for the smart home must have a human in the center, realizing the needs of users by applied software and devices, where cognitive systems may be the main trend of such technology in the nearest future [17]. The vision of future advances was presented by [18], where the architecture of such systems was pointed out as one of the potential key trends. Another key future aspect is energetic efficiency. By analyzing the case of Singapore households, it was defined how the implementations of smart home advance may be beneficial for energy conservation and therefore environmental support [19]. However, the main system efficiency is a derivative of the elements. Therefore in [20] was given an analysis of over 300 home energy appliances to identify key product differences in terms of functionality and quality, which may result in increased or decreased overall efficiency. Also, social aspects may help to reduce energy consumption in smart homes [21], therefore users must be educated that all the technology is to serve them but it is not free of energetic costs. Several aspects to be considered while working on new developments were compared in [22].

Smart home healthcare systems may play a crucial role in providing more versatile application for health monitoring [23], since several societies are getting older according to statistics, which may have a result in increased medical needs in the nearest future. One of the solutions to help solve such needs may be the use of various artificial intelligence (AI) models which will help users to control their health [24]. Also, smart homes may help people to stay at home where they feel safer instead of medical centers or hospitals in cases where intensive hospitalization is not necessary. The key feature to introduce this type of medical service will be patients' adoption of telemedicine [25].

Among several devices installed at smart homes frequently, we may face some failures due to electronics malfunctions or software bugs. The authors in [26] discussed the possibility of self-estimation in intelligent appliances. The more devices would be able to diagnose themselves the better

efficiency of the smart home would be. As a result, more potential new users can be convinced to use smart home technology. The information-gathering between devices and forwarding it to control units will be an important aspect for research in this field [27]. Aspects of clean energy and energy efficiency of smart homes is another key trend for future development. Some researchers [28], [230] discussed an influence of the air quality control on users. Indoor air quality is very important for the comfort of living therefore industrial works shall support such branch of smart homes advances [29].

The innovation of the devices inside the smart home may result in higher involvement of younger audiences. Virtual reality is one of the recently developed advances in games and entertainment. Smart TVs enable virtual environments, which may supply the level of innovation necessary for the involvement of young audiences in the smart home development [30]. On the other hand, elder people need emotion-oriented engineering of technology, which will help them stay happier and healthier longer [31]. In both cases, control aspects for connected devices may be crucial to gain acceptance. Multi-user may need various control panels adopted to the needs of each age [32]. Such differences in technological needs may be solved by smart home communication protocols [33], which will introduce some standards to control models.

A smart home filled with various electronics will be a place where several information about our preferences of food, customs, daily activities, or even friends we contact may suffer from networking threads or simply stealing information and data from information infrastructure. Therefore, the security of the smart home infrastructure is a key topic in the research and development for the next years. In [34] was investigated one of the security solutions, a block-chain model may be used to solve some of the threads from potential attacks on smart home systems. Log in to the system is a gate that simply opens access to all data covered inside. Thus in smart homes login module should be one of the most secured [35]. As discussed also here a block-chain model can serve as an improved communication standard. The information gathered from smart home systems may grow in time, therefore an extension to the infrastructure by using cloud or fog computing may be considered in future models [36]. The general model for transactions between devices was discussed in [37]. The risk of data leakage is potentially high and actually, situational awareness of users may be the best way to protect the information in the smart home infrastructure. There are several situations that may expose the users to threads, the analysis of such situations was given in [38].

C. IMAGE PROCESSING AND VOICE AGENTS

Smart homes are places where the latest technology meets people's needs in daily routine. Recent years have shown that image processing and voice recognition are among the leading aspects of AI. There are several aspects where image recognition can be applied in the smart home. In [39] was discussed meal delivery model based on image processing. However, the main trends in this field would be rather a security aspects and healthcare monitoring [40].

It is quite obvious that we can use the camera at the entrance to the home to verify if entering people are users or burglars. In [41] some aspects of using cameras in such models were discussed. In such systems, Convolutional Neural Networks and their derivatives are most reported as those with the highest efficiency [42].

Another aspect of applied image processing would be to pose detection. In healthcare such a possibility would be important to detect when elder people have fallen and need help to rise, but also suspicious types of silhouette moves may raise the alarm when burglars are stealing goods from the smart home. In [43] human activity recognition was using depth silhouettes analysis to differentiate residents of the home, while the model developed in [44] has defined triaxial accelerometer-based motion recognition. The system was reported to be considering the statistical features of human poses on the way to recognize them. A typical example of a healthcare system designed to help elder residents when fallen was presented in [45]. Fall detection in this model was solved by using posture classification from the proposed Support Vector Machine model.

Recently many wearable devices are available on the market. Smartwatches, a variety of bands, or simple body sensors are applied to the infrastructure at home. In [46] an interaction model based on the ergonomic headband was presented. Through the connection model, control over some home appliances was implemented to help residents in faster and more comfortable communication with electronic devices. Nowadays also speech agents are available on the market from several producers. Application of these devices may introduce verbal communication with electronics, which may search the Internet for us or even control some devices at home. To do such things a context-aware voice recognition or simple dictionaries for some communication protocols may be introduced as proposed by research in [47].

D. INFRASTRUCTURE AND SOFTWARE

The variety of devices possible to interact with residents at home is big. We can install smart home electronics like TVs, mobiles, gaming consoles but also kitchen appliances and several control devices and sensors. The difference is only in the simplicity of interaction. While all electronics work with the network just by simple connection, sensors control appliances need calibration and devoted software.

There is a variety of possible configurations to manage IoT connections in the system, we can do it by a web browser, mobile app, or devoted electronic controls. In [48] was discussed a model of management system construction, which was evaluated in accordance with suggestions from two individual groups of users. A mobile app interface to control home automatics was proposed by [49]. The paper presents an efficient and low-cost implementation of control modules. An idea to use just a simple mobile app for the

Android system, which can transform some of the devices into IoT infrastructure reminding a smart home appliance was presented in [50]. A web server system was described in [51], proposed configuration enabled access from any place in the Globe to securely control appliances at a smart home. In connection with the IoT network, we can use LAN or Wi-Fi protocols. The idea shown in [53] described Wi-Fi sensor network which was designed for small house infrastructure. Recently also other methods found application in smart home technologies. In [54] was discussed as a framework for RFID connections, wherein the network main controller is managing signals from objects marked with RFID. Among other types of networking ideas also Bluetooth is recommended in various automation systems [55]. The paper defines such a model as a start for transformation from smart home to smart city [8]. The variety of approaches toward infrastructure configuration and development is big, however, researchers mainly concentrate on systems that are simple in design and configuration [56] and low in cost, both for development and maintenance [57].

Applications for IoT infrastructures can be divided among general healthcare, prevention, and security. In [58] was discussed a model for the system which was designed to serve as ad-hoc prevention against fire. The idea was to use a sensor network for fast detection of fire symptoms and if detected to immediately inform residents and firefighters. In [59] a temperature control model was used as a fire alarm whereas a control platform was used message queuing telemetry transport (MQTT) broker on Amazon web service (AWS). Another interesting fire detection system for smart homes was designed by the analysis of anomaly behaviors in devices like coffee express, heater, tv, humidifier [60]. Wireless flood sensor to detect water leaks in a smart home was proposed in [61]. An alert system for security purposes was presented in [62]. Motion sensors were used to detect intruders and inform the owner about intrusion during the absence. In [63] was discussed a detection model for residents arrival by Wi-Fi enabled authentication model, which identifies the arrival of the owners by their devices connected to the home network. The system for detection of levels of gas in bottles or other substances in use of residents was presented in [64]. Sensors were located in various elements and by applied communication system informed users about the current level.

Information processing and data acquisition in smart home systems are growing with new developments. We can store our photo albums or movie collection on our devices. All the multimedia files need a lot of space but also advanced security options to protect our data from robbery. There are many ideas to solve it. Cloud and fog platforms are using various configurations to store data. In [65] was discussed an idea for IoT web-of-objects which serve as data carriers in cloud infrastructure. Frameworks for fog computing models for smart homes were discussed in [66]. The paper presented frameworks and possible future trends in this field. Big data needs also influence smart home models. A multi-layered architecture for scalable cloud computing was proposed in [67], where a topic of efficient data storing was evaluated in a few options of possible configuration. Scalable architectures of IoT systems may take advantage in the future, since by using them the problem of data transfer limitations may have lower importance. Some interesting examples of distributed systems were presented in [68], while configuration and development to eliminate losses in was discussed in [69]. As a solution to privacy protection in data transfer most often is given an example of blockchain. In [35] it was used with a concept of authority-proof as a tool for safe login into the IoT system. A review about advances in security by using labeled network traffic was presented in [70], while aspects of authentication methods for safe communication were discussed in [71].

Infrastructures in smart homes are also adjusted to fit the needs of security. Using cameras and motion sensors smart homes can offer a service to act as security guards and inform the owner or legal services about intruders in the home. Monitoring of human actions was presented in [72]. The developed system was a plug-and-play type however the concern of energetic efficiency was solved by the proposed switch model. Sensor environments should be non-intrusive so that residents feel comfortable at home [73]. Scenarios of security for smart homes by vision systems can be later migrated to the upper level of the infrastructure. In [74] was discussed how such concepts can be developed in smart cities and towns.

In IoT smart home infrastructures very often are implemented methods of AI. At various levels, data is analyzed and processed by neural networks, fuzzy systems, heuristics, or statistical models. Just to mention some examples besides several other categorized in our survey. Real-time analysis of data for control purposes by the neural network was proposed in [75]. A deep learning approach for recognition of human activity from wearable sensors in smart homes was explained in [76]. A model for resource management in fog computing discussed by [77] was based on optimization strategy using particle swarm algorithm.

Possible configurations and models of smart home infrastructures are many. All of them are based on interactions: man-to-machine and machine-to-machine. In [78] was presented a system for healthcare in which communication between residents and the infrastructure was based on an ontology context-aware system. In [79] was presented as an interaction system with a devoted multi-threaded conversation engine based on natural language processing and interaction technologies. Architectures use various types of configurations. We can find multi-sensor models that control several conditions in smart home [80], automation systems-oriented open-source models [81], user-friendly interfaces that concentrate on ease of operations for residents, and integrated interfaces [82]. The configuration depends on the used sensors. When IoT systems must control home metering for smart automation of mechanical or electrical devices mostly the modules must be developed by developers of the idea [83]. However also some decentralized platform for smart

control can be found on the market, i.e., by using a concept of feedback loops [84]. Sometimes an idea of simple numerical control sequences (also binary code or Gray code) makes the best efficiency of the system. This kind of idea was used in [85] for hybrid triboelectric and photovoltaics energy harvesting at a smart home. Another type was used in [86] for controlling home climate by using the heating, ventilation, air conditioning (HVAC) model of home convection. This model was focused on the plurality of devices connected to the system for higher energetic efficiency.

E. VIRTUAL REALITY AND ROBOTICS

Among devoted devices and electronics [130] two aspects seem to be a trend for future research and development. Virtual reality and robotics may be of great importance for smart environments. In [87] was discussed as an approach to help elderly people by advanced robotics assisting them in their daily routine. The paper proposed a robot-integrated elderly care model, where the control of the robot was done via a special platform module. Similarly in [88] robot design to help people as presented, however, this approach was extended to all home residents, and control was proposed via mobile application. An extension to using robotics at home can be virtual reality [46]. The study discusses the headband for communication with IoT devices located in the smart home. New ideas also involve speakers and voice assistants in the interaction between residents and the IoT system. In [89] was presented ''hands-on'' testing for echo functions available from Amazon device.

F. REVIEW REPORTS

The literature about smart home advances is growing recently, both in technological presentations discussed in the above sections and also in fragmentary reviews covering advances in a particular time or field. Let us now present our findings in this field. In [90] was presented a survey regarding prediction models applicable to smart home technology. The authors considered both aspects of AI and statistical models which may also have a wide impact on the development of the smart home domain. A survey on reasoning was also given by [91], where a systematic literature presentation was proposed to cover prediction, reasoning, and decision support in IoT models for smart homes. Other aspects of such constructions are system architecture and applied technological processes. In [92] architectures, software and communications with aspects of security were discussed in the horizon of various applications and configurations. Processes and coherent taxonomy were presented by [93]. The discussion was lead to define motivation and challenges for further development. As a result the study also suggested some possible recommendation [144] to solve concerns.

Reviews on security for IoT systems are covering the main aspects of safe communication and technology. Among technical topics, we can find reviews of software frameworks like IoTivity, HomeKit, AllJoyn, and SmartThings. Discussion for the applications and efficiency in various tasks was presented by [94]. As a result of comparisons, SmartThings was emphasized and deeper examined in the empirical analysis. A blockchain operations models review was presented in [95]. The review covered Ethereum Blockchain packages describing the speed of work, ease of control policies, and overall capacity. Another interesting presentation of wide spectrum for communication components was given in [96], from the survey we can learn about different advances and innovations in this field presented in the literature. Wi-Fi-based sensing, besides other models using RFID or Bluetooth, also found an interesting survey presentation [97]. As a result of the study, we can see the main areas of applications: health monitoring, gesture recognition, contextual information acquisition, and authentication. Each of them is presented in the wide literature overview very useful both for practitioners and scientists. On each type of network connection, the capacity of work flow depends on the traffic control. Firewalls and other services can detect an attack or data leakage by analyzing traffic. Therefore a review of traffic management and security models is very important for IoT smart homes domain. An interesting example was given in [70], wherefrom the point of inspector variety of approaches was presented. Electronics connected to such networks may all have some vulnerabilities, therefore the faster such wholes are detected and described the faster patches and other solutions will be developed. A systematic survey Arduino platform energy management was provided by [98].

Energy management is developing fast due to the introduction of green energy systems in the cloud [133]. In smart homes optimized heating and convection are widely concerned. An overview of the latest products and trends in this part of smart home appliances was presented in [99]. Responses to growing demands must cover several aspects of adaptive systems managing energy usage at a smart home. Review on recent advances was presented in [100], presented research consider the variability of applicable controllers. The devices use methods that estimate the values. A comparison of stochastic models was proposed by [101], while the interdisciplinary impact on efficiency in energy management was discussed by [102].

Home healthcare models also were covered in reviews of valuable reviews. An important topic is the elderly people's support. Challenges for new models sourced in recent advances of remote diagnostic technologies for telemedicine were presented in [103]. Health monitoring systems overview was presented in [104], the survey presents results on applications and their efficiency. Aspects of users privacy in healthcare monitoring were discussed in [105]. The survey is presenting results from USA citizens suffering from physical, sensory, intellectual, or developmental disorders.

The systematic literature review on developments and advances was given in [106]. The study was conducted from a user perspective to show which aspects may have had the most important impact in the years 2009-2017. Awareness of users and adoption of technological changes were discussed over the recent possibilities by [107]. The challenges for

new advance predictions linked to context-awareness in IoT were discussed in [108]. The literature in IoT smart homes advances however is growing so new discussions will possibly supply the topic.

III. MAIN DEVELOPMENT TRENDS

The analysis of worldwide research developments led us to conclude the main trends of smart home technology for the future. The whole topic of IoT and smart home technology is growing in many directions as presented above. On the other hand, some of the trends are prevailing. We have defined them as:

- **Healthcare and quality of life**: in this area, we classified all the research and industrial applications toward environments that help people in dangerous situations when help from medical services or family is necessary, but also all those solutions which simply increase the standard of living in general understanding,
- **Security in data management**: this section contains both research and technology for networking and data security and privacy when using the Internet services or home infrastructure,
- **Optimal energy management and sustainability**: it is the area of technological developments for smarter devices using less energy, helping to maintain home climate and protect from floods, fires, and other dangers.

A. HEALTHCARE AND QUALITY OF LIFE

The smart home is an environment where sensors can serve the residents both as warning system but also help in case of emergency. The reaction of the system depends on recognition decision models implemented for sensor environments.

In [110] was presented resident indoor location, where Amazon Echo was implemented to serve as an analyzer of ultrasound sensors. Location can be also realized via acceleration-based systems. In [44] triaxial acceleration model was developed from which sensors reading were statistically evaluated to decide if the resident has fallen on the floor. A model of the wrist-worn accelerator was proposed in [111], this solution however requires wearing the armband all the time to work properly. A similar idea was presented in [112]. The model introduces Smart Triboelectric Socks, which are using triboelectric nanogenerator operated via Bluetooth to gather information about the resident and forward it to an AI-powered analyzer. In [113] was proposed semantic behavior detection model called HomeSnitch, where features were analyzed by the device communication module. Other solutions propose to use camera arrays to detect elder people falling [114], however, such a model requires special infrastructure and also may raise objections about privacy features from users. Another vision processing based solution was proposed in [45]. The study discusses the possibility of fall detection by using a Support Vector Machine on frames from installed cameras.

Several solutions propose health analyzers to help people make a decision about their health condition and faster consult a doctor. In [115] was described brain-computer interface developed to analyze health symptoms via the provided Android app. Some solutions enable emotion analysis to help elder people react with IoT systems [31]. An important feature of healthcare analysis is heart failure detection since such a medical problem touches people of any age. A model discussed in [116] presented personalized Beat-to-Beat detection based on ballistocardiogram constructed from piezoelectric elements installed on the chair. A model proposed in [117] discussed monitoring skin diseases system from images for smart home users, where the core analyzer was developed by using a deep learning model. A multi-sensor model for secure remote body health monitoring was proposed in [118]. The main goal of this study was to support a secure diagnosis via remote access. A similar solution for remote medical examinations devoted to citizens of China was proposed in [23]. The healthcare system was using Neural Networks as decision support to diagnose health conditions of people at homes while consulting them remotely with a doctor.

Several papers give a direct examination or recommendation to healthcare systems [169], [174]. In [119] was discussed how such models should be developed and what concerns they need to solve when implementing them in a cloud model called Cloud-based smart home environment (CoSHE). Smart home caregivers system (SHCS) that is based on context-aware methodology was evaluated in [120]. The system provides an option of remote diagnosis and contact with medical support. Sensor platform for healthcare in a residential environment (SPHERE) was discussed in [121]. The study presents a multipurpose platform for monitoring the health of people without the necessity to leave the indoor. HealthEdge model proposed in [122] considered both local and remote consultations via network depending on the current state of health.

Smart home systems are developed to help in various aspects of health but also the quality of life in such environments is important. Mostly in our homes, we use different heating and ventilation options. Therefore control for convection of the air is considered in automation systems. Also air quality can change during the heating season in winter. In [28] was proposed a smart home system to control air quality, while the detection model for carbon oxide level in the air was presented in [123]. The ease of use can much influence how often residents decide to use provided systems. In [124] a design of control elements to fit the needs of elder people was discussed. The solution for this was proposed by a more ergonomic design of elements. Such an idea can be very useful in remote control of home appliances. In [125] was presented a module of Wi-Fi-based management of electric devices from one place with a special concern of the needs of visually impaired persons. The adoption to use all provided controls will influence further development. A discussion of trends regarding barriers and advances was presented in [25]. The activity of users also changes in age. The study presented

in [11] shows how the age and gender of users influence the use of smart appliances. Another factor for development is the price. In [126] was discussed how pricing policies can influence the number of users and satisfaction of purchase. Devoted studies that describe how remote healthcare technologies can be absorbed by elderly users were presented in [103], [209], [224]. A survey on monitoring system and their advances regarding remote health control was presented in [104].

Another aspect of quality of life is secure access to the home. In [127] was proposed a security check for visitors entering possession with different types of detection: burglary, fire, abnormal behavior, temperature, or other abnormal situation. The model presented in [128] can report activities from household policy, which are detected by using one of the implemented monitoring methods via a smart device. In patent, [127] visitors interactions with doorbell were analyzed for security objectives. A patent [129] proposed infrastructure able to detect a visitor at smart home by analyzing features.

B. SECURITY IN DATA MANAGEMENT

Data management in a smart home is a complex problem. Devices use various data types, and not all are multimedia most sensors use only numerical variables while operating. On the other hand in networking systems, we have a computer, TVs, and mobile phones which have a variety of multimedia files and private information about our life. We store pictures, movies, and accounts in several official systems which all need protection from fraud and digital robbery. Another aspect is traffic on the network since most multimedia is high-definition (HD) format which requires special traffic solutions. As a response to such needs, many interesting solutions have been developed for smart home environments.

The latest models of data security and storage consider cloud and fog computing and blockchain. In [131] was considered a case for blockchain model devoted to smart home security. There are three main aspects for blockchain in-home infrastructure: smart contract, private blockchain, and public blockchain. Each of them was defined as a key feature for the correct operation of the whole blockchain model. A multilayer cloud model for data management was defined in [134]. The proposal was oriented on ontology-based security for interactions between smart home devices independently of operating systems. A model of integration for IoT devices by using fog computing was proposed in [135]. Security models for smart home blockchain solutions consider many interesting options. In [136] decentralized security blockchain approach was proposed, which considered a full cycle of information process in edge-IoT infrastructure [109]. An energy-safe microgrid model for blockchain was proposed in [137]. The model proposed devoted transaction codes that eliminate forgery at the network. An approach to use a gateway communication model to verify connections was proposed in [138]. Some data types can be consolidated during transfer. Such an idea was developed in homomorphic consortium blockchain [139]. A discussion on various approaches was presented in [34]. There are also many mechanisms and tools developed to serve as part of the blockchain infrastructure. In [140] SH-BlockCC model was proposed. This architecture was considered to improve the security of data stored on the network. A model proposed in [141] considered emergency service residents of smart home by using software based on JSON Ethereum blockchain. A distributed model of blockchain proposed in [142] was used to manage the energy system in a form of a consumption game formulated to teach residents to minimize the cost of electricity. An important aspect of blockchain models is positioning for optimal service. Such a problem was solved in [138] by developed mechanisms using a gateway-based approach. A solution proposed in [143] uses an idea of hypergraph blockchain structure to optimize data flow.

There are also many protocols and authorization schemes for smart home infrastructures. In [145] was the proposed solution using Privacy-Preserving Communication Protocol, which controls transmission by asymmetric encryption in which secret keys are generated chaotically. A protocol called IOT-CoAP was proposed in [146]. The solution improves the security of data by introducing hash functions SHA-1, SHA224 I SHA 256. A routing optimization protocol called PMIPv6 was discussed in [147]. A model of lightweight authorization stack for all connection types including IoT security was presented in [52], [148]. The solution uses such a model to secure mobile communication via untrusted cloud platforms. The model of secure communication via protocols was proposed in [149]. Some solutions solve the problem of remote control access to all devices at a smart home. A model called Like If-This-Then-That (IFTTT) was proposed in [150]. The solution is based on anti-tracking mutual authentication in which both sender and receiver use key agreement to establish a connection. A similar key exchange model for safe communication was proposed in [151]. This model was based on an adaptive secret key which is quantized by collected RSS measures. In [152] such problem was solved by session-key authentication using public cryptography access any element of IoT infrastructure.

Several tools were developed to help analyze the network at the smart home. In [153] was proposed as a tool that preserves privacy aspects to analyze data in cloud infrastructure. A model proposed in [38] was developed to verify if there is any data leakage. There are also many complex models based on mathematical theories solving network vulnerabilities. An idea proposed in [154] was based on a novel graph mechanism that analyzed the network traffics to show weak elements of IoT infrastructure. In [155] was proposed a gateway system that controls the networking domain of IoT home infrastructure. A review showing many options for security architecture and countermeasures for secure environments was proposed in [156]. Analytical tools use a variety of ways to detect potential networking threads. In [157] was proposed an ontology-based semantic model for cloud infrastructures.

A model for big data cloud was defined in [36]. The proposal defines a solution for cloud and fog computing mechanisms applied in smart home infrastructures.

Another trend in security and privacy is the design of more complex frameworks. In [158] was discussed a general security framework for home appliances. A comparative test of popular frameworks: IoTivity, HomeKit, AllJoyn, and SmartThings was presented in [94]. The article presents a test on permission models for electronic devices. Another example of a smart home system was given in [159]. The tests on UCON model for smart home control were presented in [160]. Aspects of vulnerability in cyber-physical systems using OCTAVE Allegro were presented in [161]. This evaluation focuses on smart home system components such as databases, physical aspects, and users. A triangle-based security algorithm (TBSA) for energy-efficient data encryption was developed in [162]. This model proposes a key generation mechanism for secure data transmission in IoT. Anonymous secure framework (ASF) for smart home connections was proposed in [163]. Solely lightweight operations were composed in operation schema for authentication and key agreement between connected devices. Self-Learning and adaptive smart home (SLASH) framework for big-data analytics was proposed in [164]. Sensor-based PUF IoT authentication model was developed in [165]. The model was constructed for blockchain structures and real-time processing. Tests on various aspects of plug and play security were discussed in [166]. Framework for a sensor network in IoT home systems was proposed in [167]. The model was developed for elderly people using cloud services developed for speech or gesture recognition. A structure for fast data upload was presented in [168]. The model ensures cloud processing without over-monitoring of the data, the proof of concept resulted from computer simulations. Security of communication for IoT devices based on invitation model was proposed in [170]. This patent developed a model of relations between devices, systems, and processing methods. A patent [171] developed secure handling of unsupervised packages transferred on smart home infrastructure.

A framework called EPIC was presented in [172]. The model is constructed to protect home networking infrastructure against Internet attacks by sending all requests to the remote gateway for security checks before entering the infrastructure. Such a model enables information gathering about addresses what can result in a further block of suspicious locations. A very similar idea was proposed in [27]. S2Net model was proposed in [173]. The idea is based on a smart routing model for home networks. For Chaos model to detect DDoS attacks was proposed in [175], whereas forecasting method was used chaos theory. Another algorithm for the detection of malicious traffic was proposed in [176]. A tunnel traffic protection model was proposed in [177], this idea can be very important when from the home infrastructure we want to connect securely to our offices and banks. A secure switch model for networking operations was proposed in [178]. The model was developed for wireless communication to reduce the energy usage of the network. Several frameworks use various strategies to find intrusion. In [179] a gamification model for intrusion detection was proposed, where malicious behavior was detected during gameplay. A framework for the Android platform was presented in [180], the model is developed via MIT App Inventor 2 where the special interest is for Bluetooth communication. Shsec framework model proposed in [181] shows network infrastructure and algorithm to manage traffic and prevent intrusions. The idea proposed in [182] is using mutual authentication via cumulative keyed-hash chain to prevent data encryption by unauthorized people. LoRaWAN framework from [183] supports adaptive connection model for remote access. HomeShield framework discussed in [184] is solving open port attacks problem to operate without special credential where security is provided by an authentication algorithm. An ioT-Connect framework is providing security by communication protocols which operate to control device connections to the infrastructure [33], while tests on intrusion detection models can be found in [185]. The schema is organized to control overcome network attacks from infected data operations.

C. OPTIMAL ENERGY MANAGEMENT AND SUSTAINABILITY

The ecological trend became very important for advanced technology. Smart homes development is also joining this trend for lower environmental impact by optimal energy consumption and sustainability in applied technology.

Among the main advances for energy consumption, we can name developments in infrastructure and smart grid environments. In [186] was proposed architecture for smart energy consumption from industrial system. The model of smart grid system design with energy safety option was discussed in [187]. A self-learning IoT management called self-learning home management system (SHMS) was proposed in [188]. The solution was developed to manage energy consumption from various appliances by learning a strategy to forecast pricing and usage. The proposition of a lightweight authentication model was presented in [189]. This model was developed for metering purposes in the smart grid environment. In [20] important categories of appliances functionalities for smart energy management were proposed. The study presented an extensive analysis of over 300 products to identify key differences in terms of functionality and quality. Developed models also offer integration of electronics and technologies for optimal consumption. In [190] a nano-grid system was composed of hybrid solar-battery elements in a type of plug-in electric model to optimize the use of energy. A model of double-layer plug-in electric control to efficiently filter and flatten load amplitudes was discussed in [191]. The proposed model was developed for smart grid systems of home infrastructures. A model proposed in [192] serves as an optimized convection module for a home heating system with an implemented Android app and web control platform, while a model presented in [193] describes the possible application of fuzzy rules. A smart system to detect dangerous carbon

monoxide levels was proposed in [123], the purpose of this solution was to provide constant measures of such substance in the air available to the home residents. The infrastructure presented in [194] shows a model of renewable energy management for longer battery usage under consumer-based management for smart home appliances.

Software and applications to control the energy usage of various devices from a single panel is also an important field for the development of smart homes. A model called secure appliance scheduling for flexible and efficient energy consumption (SAFE) was presented in [195]. This model shows the possible construction of an integrated control panel. A model called Butler, Not Servant: A Human-Centric Smart Home Energy Management System was developed in [196]. This solution was developed as a human-centered framework to optimize the cost of energy consumption, especially in rush hours by predicting loads on connected appliances. In [100] was presented a review on system options, controller, and technologies, while in [22] the study discussed benefits and costs of using energy optimization systems in smart home infrastructures. A model of the system called smart energy theft system (SETS) was presented in [197]. The proposed energy detection was based on machine learning and statistical approaches. In [198] was presented a system called RESTful. This solution was implemented in the form of a platform for data collection and sharing on the way to integrated energy management. The system presented in [199] is called MANFIS. The idea is based on smart management by using a neuro-fuzzy inference model to adjust the usage to current needs of storage, connected appliances, and renewable energy source. The system proposed in [200] considers voltage transitions to accommodate the highest grid functionality in the reactive power support environment of smart home infrastructure. A system called IntelliHome was presented in [201]. The model is providing a control panel for energy-saving options of connected appliances. There are also many interesting reviews covering software and applications. In [21] was presented a discussion of social impacts on reduced energy consumption in homes. The review presented in [202] is discussing energy management propositions over the literature. In [102] was presented research on the impacts of smart home energy management on the development in other disciplines. The studies cover also technological advances. In [203] was presented an insight into Android platforms developed for energy balance control, while in [98] was presented a survey on Arduino platform applications into energy management for smart homes.

Methods to predict, optimize, and reduce the usage and costs of energy are very often presented for devoted applications. In [204] was proposed decentralized model of energy management for the neighborhood area by using an energy sharing algorithm that optimized storage units loading. A model of stream mining was presented in [205]. The idea is based on misclassified recall value and the fast decision tree model. Forecasting of energy consumption by the deep learning approach was proposed in [206]. The model for the Singapore region was presented in [19]. The study presents various aspects to use such a system that can optimize energy consumption in smart homes and broader infrastructures like smart cities. A devoted model for optimized photovoltaic, wind, and battery storage was proposed in [207]. The idea is based on mixed linear programming integrating with installed renewable energy resources. Algorithms sourced in nature are also often used in optimization due to ease of implementation and no limitations from constraints. Metaheuristic algorithm for optimized energetic demand prediction was proposed in [208], while the differential evolution algorithm as optimizer was used in [210]. A model of classic particle swarm optimization for battery usage was proposed in [211]. The fusion of harmony search algorithm and particle swarm optimization was proposed in [212]. The study discusses how to compose an energy management model for a smart home system, where to hybrid algorithm optimizes scheduling for environmental change, costs of energy, user habits, and various loads of the infrastructure in different periods of the year. In [213] multi-objective evolutionary computing was implemented to control electrical loads regarding demand-response schemes of the appliances. There are also some integrated solutions. In [214] was described how to use measures of peak-to-average ratio (PAR) and peak load demand (PAD) to optimize the consumption of energy. A model using power cost scenarios as switching element was presented in [215]. Sometimes optimization models are devoted just to some elements or devices. In [216] optimization of home, appliances were oriented on the shower, fridge, ventilation, and water heater. The model presented in [217] use a multi-agent strategy to optimize voltage supply to all electrical equipment at a smart home. A min-conflict algorithm was proposed in [218]. The method solves the problem of power scheduling to keep the battery efficiency longer. In [219] was developed an integrated system which overlooks all aspects of energy management, well being, and health in a single solution [14]. In smart homes we can gather a variety of information from appliances, thus statistical models are efficient in planning and scheduling. In [220] was proposed stochastic optimization for the solar battery to use at smart home, where the main concern was a balanced thermal load of the solar panel. In [101] was presented a comparative study of stochastic modeling for various applications in smart home infrastructures, most of such models are used for renewable energy resources. In [221] was proposed hybrid robust-stochastic optimization for two options: a day ahead or real-time model concerning costs of energy and PV generation. The model presented in [222] was constructed for prediction at different times of day and week. The model proposed in [223] was based on random disturbance analysis from loads of renewable energy generators and battery storage. In energetic systems also very important place is taken by the neural network, fuzzy systems, and other models sourced in AI. Method for energetic demand prediction proposed in [225] is using neural network-based Q-learning algorithm. A composition of deep learning models for neural networks and rule based systems to control home

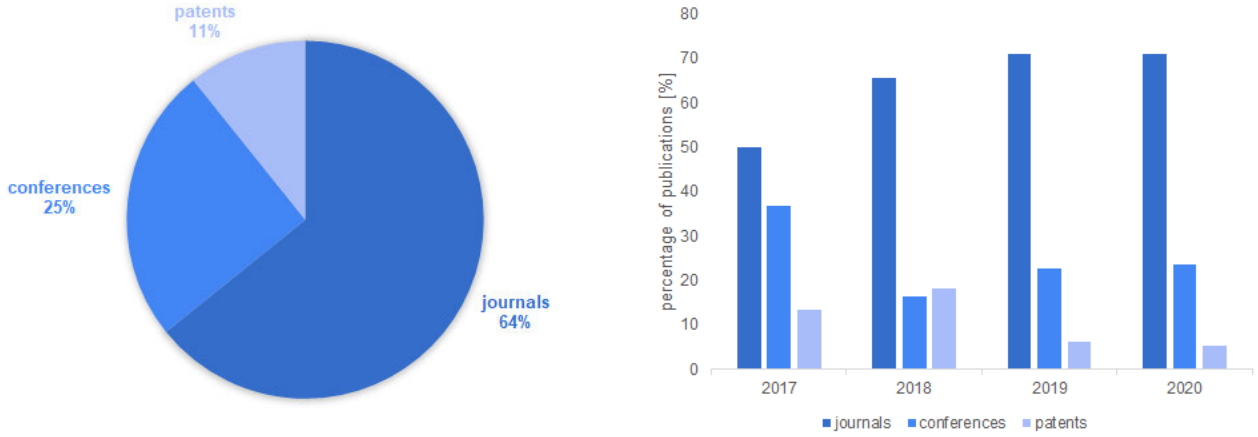

FIGURE 7. Distribution of publications because of the form of publication: on the left distribution throughout the period of time 2017-2020, and on the right distribution in each of the years studied separately.

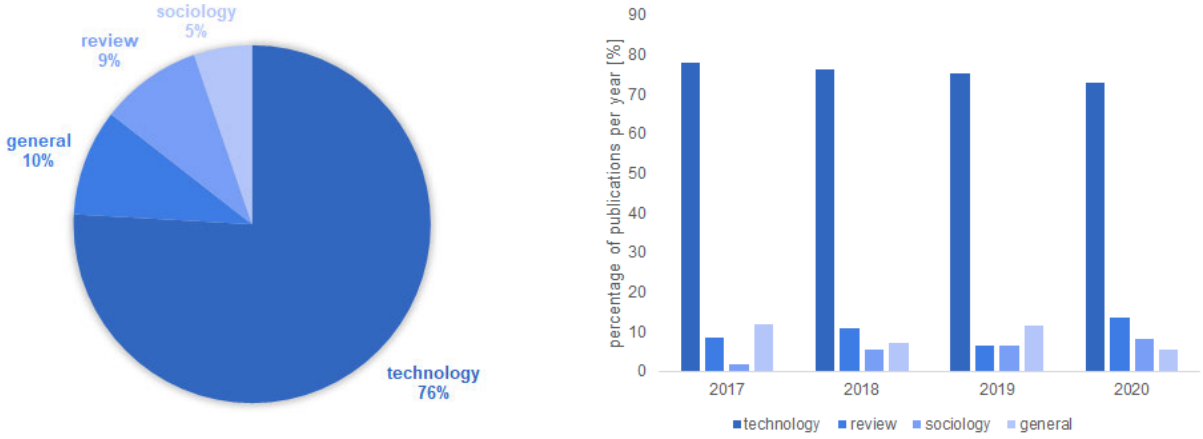

FIGURE 8. Distribution of publications by type: on the left distribution throughout the period of time 2017-2020, and on the right distribution in each of the years studied separately.

temperature was discussed in [226]. The reinforcement learning model for usage scheduling was developed in [227]. The study proposed energy management necessary to implement an efficient scheduling algorithm working in real-time mode. The model of fuzzy control proposed in [228] was constructed for heating system positioning, while in [229] was developed the composition of fuzzy logic and reinforcement learning for energy management system concerning demands of residents.

IV. FIELD ANALYSIS

Based on the study of the literature related to the subject of smart home research and technology, several analyzes were carried out. Our findings allowed us to calculate many characteristics of the discussed area. The discussion is to present the spread of the topics over continents and countries to define which of them are technological leaders in this field. We have also analyzed publishers and their coverage to show which is the most chosen by practitioners and scientists when working with smart home development. For the defined main development trends we have done a similar analysis to make a complex discussion and draw conclusions for future trends that may lead to further development of smart home technology. Let us now present bibliometric analysis and our assumptions in the field of smart home science and technology development.

A. GENERAL ANALYSIS

In the beginning, we present the characteristics which illustrate the division of the publications, where the division criterion in the form of publication, i.e. whether the publication is a publication in a journal, conference publication, or patent. In Fig. 7 it can be seen that nearly 2/3 of all publications are publications in journals. A large part, over 10% are patented, which proves commercial interest in the subject of smart home by business investment and industrial applications. Many solutions used in the smart home have been patented. Of course, the smart home topic is also regularly present at conferences both organized by computer science societies

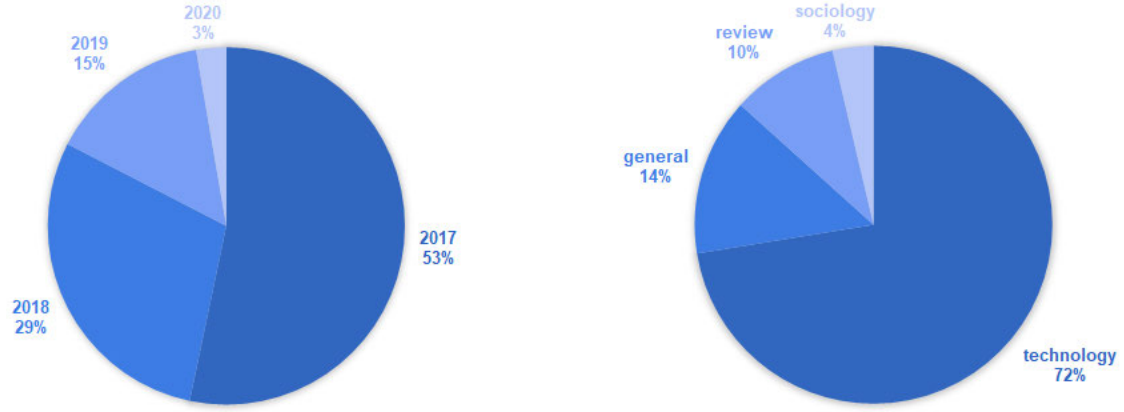

FIGURE 9. Percentage distribution of citations of publications by year of publication (left side) and by type of publication (right side).

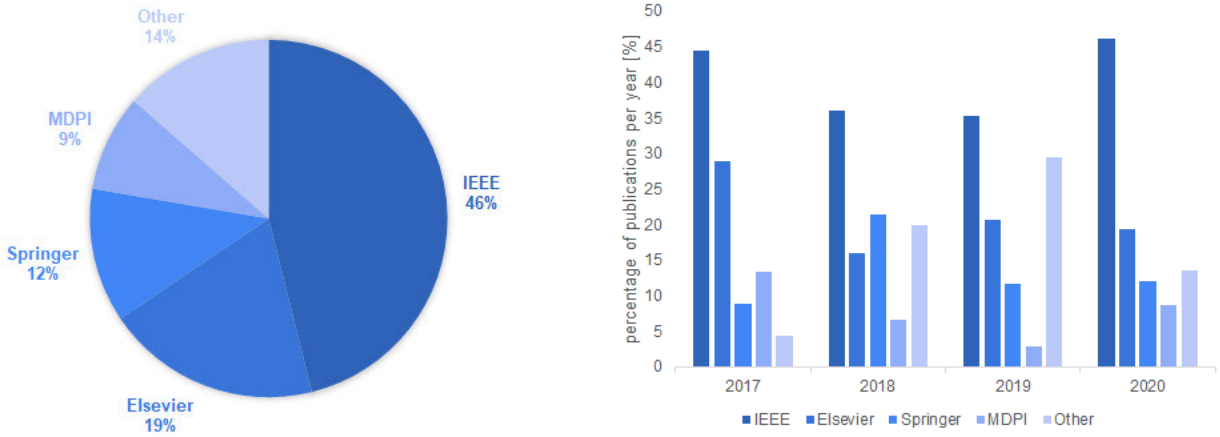

FIGURE 10. The division of works by publishing house: for the entire period under study 2017-2020 (left) and taking into account subsequent years for the 4 most popular publishers (right).

and energy industries, and even the subject of a smart home is discussed in sociological aspects.

In our research on the literature, we have also divided bibliographic items according to the type of publication. Each of the publications was classified into one of the following groups: technology, sociology, general, or review publication. The distribution of publications according to this criterion is shown in Fig. 8. We can see that over 75% come from the technological field which shows a very strong trend in the development of new applications and models. In each of the evaluated years, technology is the prevailing trend.

Another important aspect that was covered by our research was the citation characteristics of publications according to the publication data from the Google scholar data set. Fig. 9 presents the general characteristics of the citations in terms of the years of publication and the type of publication. The distribution of citations depending on the year of publication, of course, shows that the oldest works have the greatest total number of citations. As a result, those published close to the date of our research this year have relatively few of them. The distribution of citations of publications according to their type shows that general and review publications are cited more often than other types of publications, which can result from the small number of such papers which therefore gain more citations.

B. LEADING PUBLISHERS

Another interesting comparison characterizing the researched domain is a division of publications according to the publishing house, which is presented in Fig. 10. The presented classification of publications in terms of publishing house shows that each year, the most frequently (almost half) publications related to the subject of a smart home are published by the IEEE. The second most popular release here is Elsevier and the third and fourth place can be shared by Springer and MDPI. This characteristic shows that these four publishers publish almost 90 % of publications related to the subject of the smart home. In each of the evaluated years, IEEE publishes about 15% more than the second publisher Elsevier.

C. GEOGRAPHICAL DISTRIBUTION

Let us now analyze how the topic of a smart home is popular in various geographic regions. In this respect, the first characteristic shows the division of labor regarding continents.

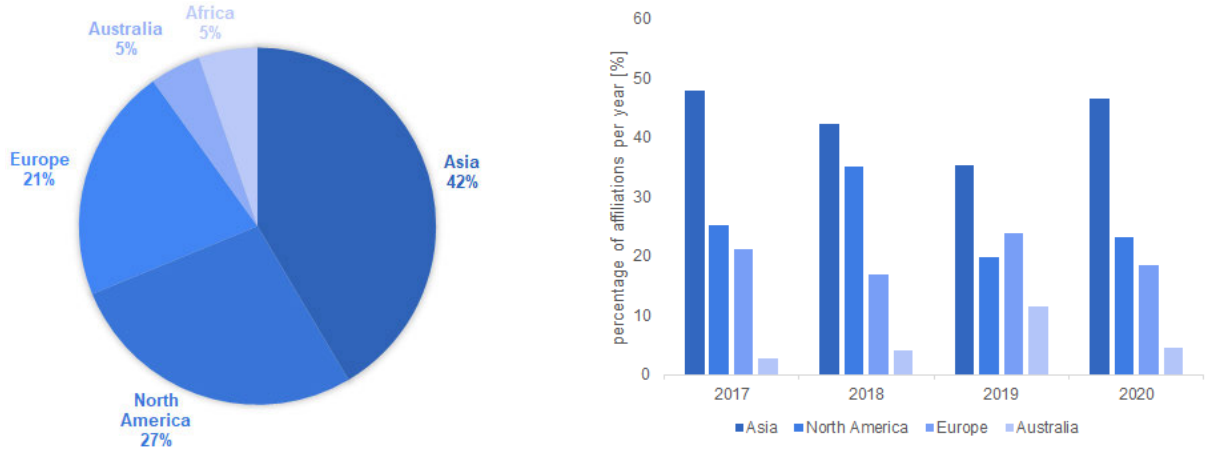

FIGURE 11. Percentage distribution of publications by continents in 2017-2020 (left side) and the characteristics of this distribution for the following years 2017-2020 (right side).

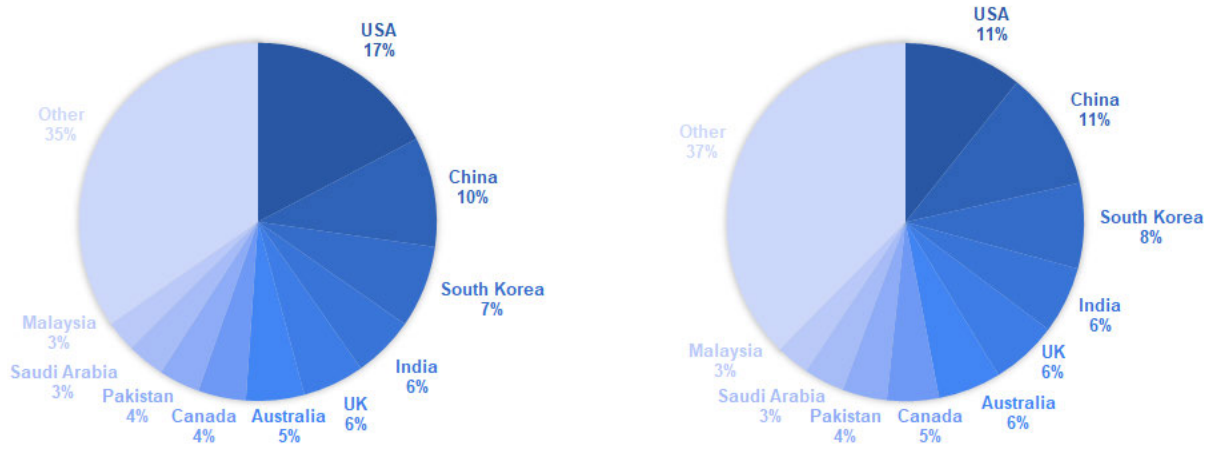

FIGURE 12. Percentage distribution of publications by country of authors for all types of publications (left side) and distribution of publications by country of publication without patents (right side).

Fig. 11 shows the distribution of works about continents, where the left image shows the characteristics for the entire studied period 2017-2020, and the right one shows the characteristics for each of the studied years separately. The characteristics of the distribution of works according to continents shows that the most frequently published works on the subject of smart home come from the Asian continent. Asia is far higher than other continents in each of the analyzed years. The second major force is the continent of North America. Europe has a similar share, especially in 2019-2020, which significantly exceeds Australia in terms of the number of works. It is also noteworthy to show interest in the subject of smart homes in African countries. There is practically no interest in this subject in South America. Such distribution of works is related to the technological development of each continent and the amount of funding available for both scientific work but also applications that find industrial partners. Also, the number of potential clients to buy and install such appliances at homes influences the statistics.

Another characteristic details the division into continents and presents a list of countries where the subject of the smart home was most often addressed. Fig. 12 shows the distribution of all publications by the country of authors' affiliation, including patents right figure and without them (right figure).

TABLE 2. Percentage distribution of citations of publications including publication year and the country's affiliation.

Country	Year			
	2017	2018	2019	2020
USA	16.9%	25.9%	11.7%	16.7%
China	10.8%	16.0%	4.5%	10.4%
South Korea	7.2%	8.6%	7.2%	6.3%
India	9.6%	2.5%	5.4%	4.2%
UK	8.4%	1.2%	8.1%	2.1%
Australia	1.2%	3.7%	9.9%	4.2%
Canada	6.0%	4.9%	4.5%	0.0%
Pakistan	1.2%	4.9%	4.5%	4.2%
Saudi Arabia	4.8%	1.2%	3.6%	4.2%
Malaysia	1.2%	3.7%	2.7%	4.2%
Germany	0.0%	2.5%	3.6%	2.1%
France	2.4%	2.5%	0.9%	2.1%
Poland	0.0%	1.2%	2.7%	4.2%
Taiwan	3.6%	0.0%	0.0%	4.2%
other	26.5%	21.0%	30.6%	31.3%

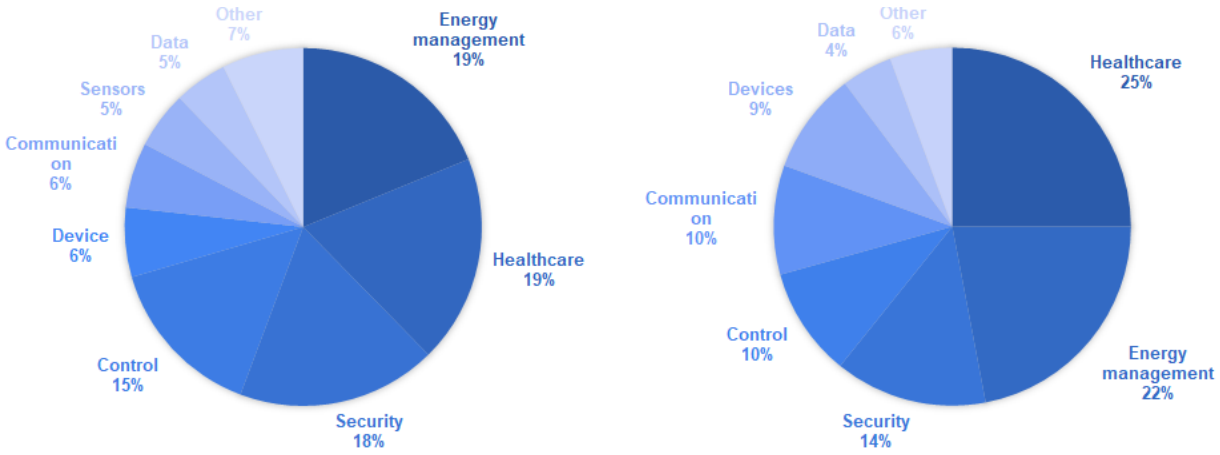

FIGURE 13. The division of works by subject in 2017-2020 (left image) and in 2019-2020 (right image).

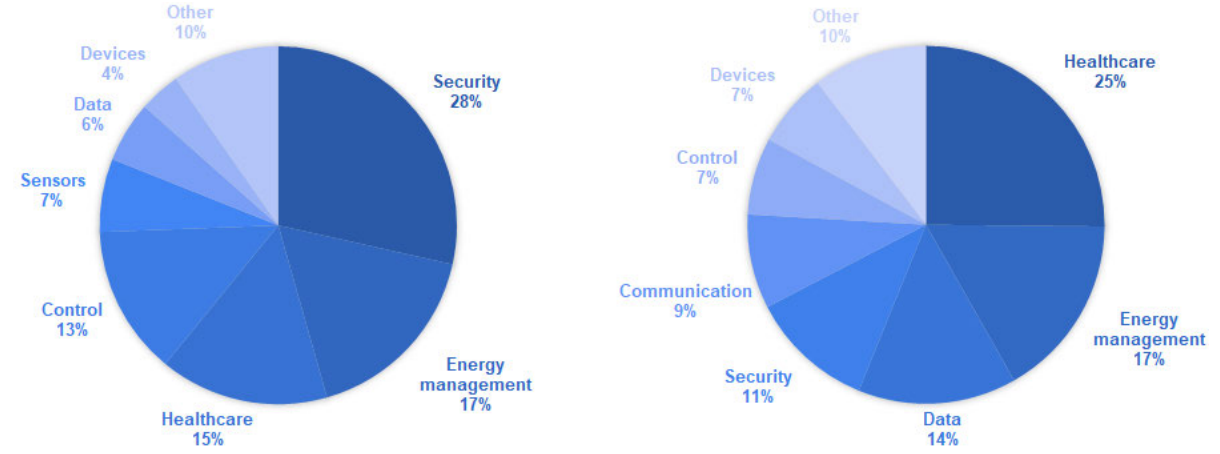

FIGURE 14. Percentage distribution of citations by topics in years 2017-2020 (left picture) and in years 2019-2020 (right picture).

The presented analysis shows that the vast majority of patents are authored by the USA. Excluding the patents, both the US and China show very similar interest in the subject of a smart home. Another thriving group of countries in this area is South Korea, India, the UK, Canada, and Australia. You can also notice that 2/3 of works related to the subject of the smart home are carried out just in 10 countries. The exact distribution of the share of individual countries in publications on the subject of a smart home for individual years of the period 2017-2020 is illustrated by Tab. 2. The data contained in the table show that the countries most actively involved in publications related to the subject of smart home each year of the surveyed review period provide a similar amount of work. Moreover, it can be noticed that in recent years the interest in the subject of the smart home has been systematically growing in Poland and Malaysia, while is almost constant in France.

D. POPULAR TOPICS

Another scope of research work was to identify and classify the most popular topics investigated in publications on smart homes and determining which of these topics are the most often cited. The analysis of the literature showed that the largest number of works on a smart home is devoted mainly to energy management, healthcare, and security. Fig. 13 shows the most important topics in the works in 2017-2020 (left figure) and the last two years (right figure). This comparison shows that in recent years there has been an increased emphasis on providing favorable conditions for its users in a smart home, with an emphasis on ensuring health protection and comfort of life, in particular for the elderly. The trend related to the need for optimal energy management also continues and the aspect of ensuring the security of IoT infrastructure of a smart home is also often discussed. In addition to these leading topics, the significant interest in the subject of control should also be noted. Additionally, a summary shows that the number of papers dealing with the subject of sensors has decreased. A similar analysis was performed to determine the distribution of citations according to the subject. Fig. 14 shows the distribution of citations by topic in the 2017-2020 perspective and 2019-2020 perspective. The list shows that in recent years the most frequently cited works on security are replaced by works related to healthcare and energy management. It should also be noted that these three topics account for more than half of all citations of works related to the topic of the smart home.

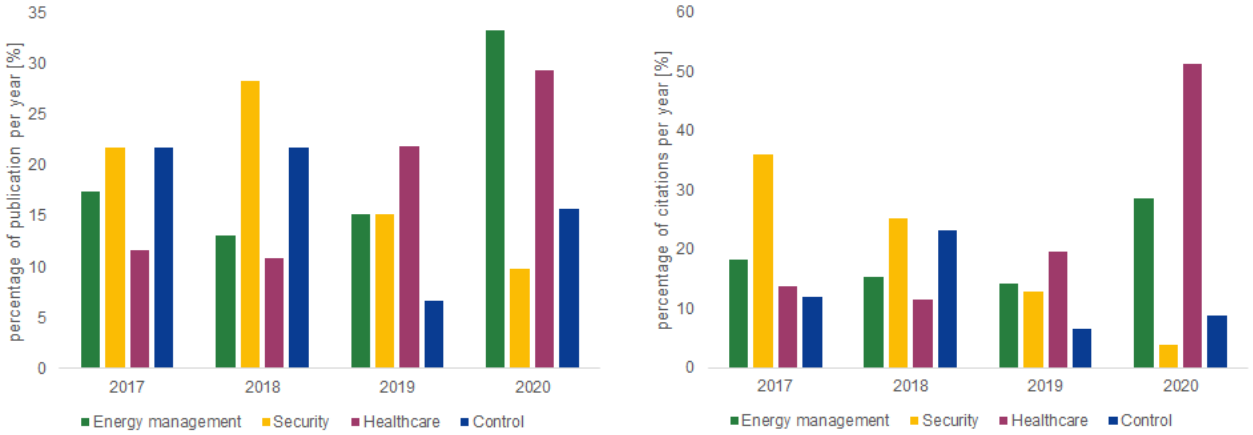

FIGURE 15. Percentage distribution of the four most popular topics due to the number of works (left image) and the number of citations (right image).

TABLE 3. Percentage distribution of publications, taking into account the year of publication and the topic.

Year	Security	Energy management	Control	Healthcare	Sensors	Data	Devices	Communication	Other
2017	21.7%	17.4%	21.7%	11.6%	7.2%	4.3%	4.3%	1.4%	2.9%
2018	28.3%	13.0%	21.7%	10.9%	15.2%	6.5%	0.0%	0.0%	4.3%
2019	15.2%	15.2%	6.7%	21.9%	1.9%	5.7%	9.5%	13.3%	3.8%
2020	9.8%	33.3%	15.7%	29.4%	0.0%	2.0%	7.8%	2.0%	0.0%

TABLE 4. Percentage distribution of citations of publications, taking into account the year of publication and the topic.

Year	Security	Energy management	Control	Healthcare	Sensors	Data	Devices	Communication	Other
2017	36.0%	18.1%	12.0%	13.6%	5.3%	1.8%	4.3%	1.0%	7.9%
2018	25.1%	15.3%	23.2%	11.5%	14.5%	7.3%	0.0%	0.0%	10.1%
2019	12.8%	14.1%	6.6%	19.6%	1.8%	17.0%	7.1%	10.1%	10.9%
2020	3.9%	28.6%	8.9%	51.3%	0.0%	1.9%	4.6%	0.8%	0.0%

Fig. 15 shows the share of the four most popular topics and their citations for each of the years of the analyzed period 2017-2020 separately. Bar charts show that energy and healthcare issues tend to increase at the expense of control and security. Similar tendencies can be noticed in the case of the distribution of citations. The number of citations to the subject of security regularly decreases every year, and healthcare tends to increase strongly. The exact distribution of the share of individual issues in publications concerning smart home is presented in the Tab. 3. A detailed distribution of citations due to the topics is presented in Tab. 4. The data in these tables show that the interest in sensors is declining, communication has a significant increase in 2019, but this does not translate into the following 2020, remembering our review has been made in mid-2020.

E. APPLIED TECHNOLOGY

Another aspect of the research was to identify and classify works related to a smart home in terms of the technologies used in them. This process showed that the most frequent works included technological aspects related to Wi-Fi, software, infrastructure, and blockchain. The division of works according to applied technologies is shown in Fig. 16. It can be seen that in each of the studied years, Wi-Fi dominates at a very similar level of popularity. The comparison for the last two years shows that the interest in software has significantly decreased in favor of the work with infrastructure. The exact distribution of the use of technologies in annual statements is presented in Tab. 5, which shows the share of each of the technologies identified in a given year.

For technical issues used in smart home solutions, a citation analysis was also carried out, the result of which is presented in Fig. 17. We can see that publications in 2017-2018 most frequently cite works about software and blockchain (they account for over half of all citations for smart home). In the last two years, there has been a decrease in the number of citations in favor of Wi-Fi and infrastructure. The citations of which in the last two years account for over half of all citations of works containing technological applications. The exact distribution of citations of publications based on technological applications is presented in Tab. 6. Additionally, the distribution of publications and their citations for the four most popular technologies in the following years are presented in Fig. 18.

F. SCIENTIFIC MODELS

Another aspect of the analyzes was the definition and classification of scientific tools used in publications on the smart home. The most frequent use of algorithms was found in works that appeared in over half of all works in which there

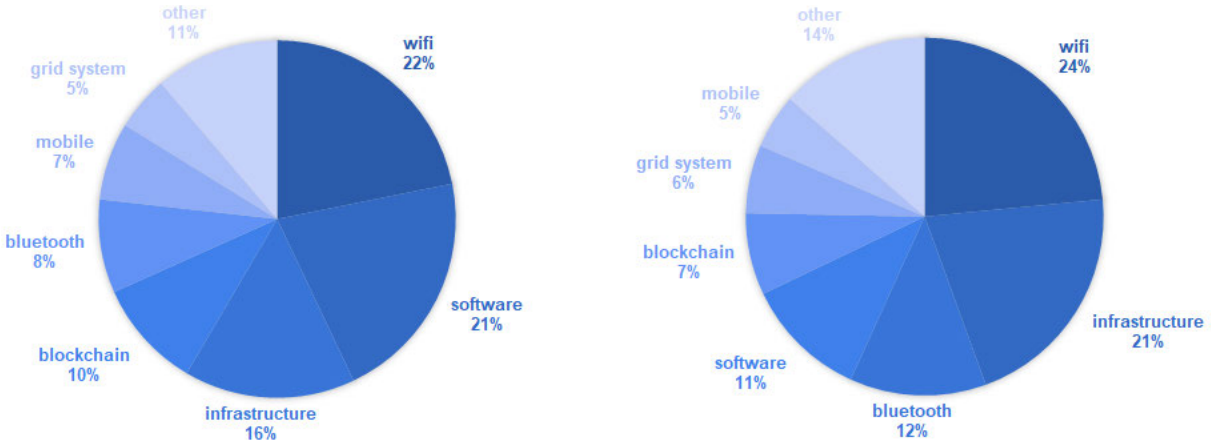

FIGURE 16. Distribution of the use of technology in the field of smart home: for the entire period 2017-2020 (left image) and 2019-2020 (right image).

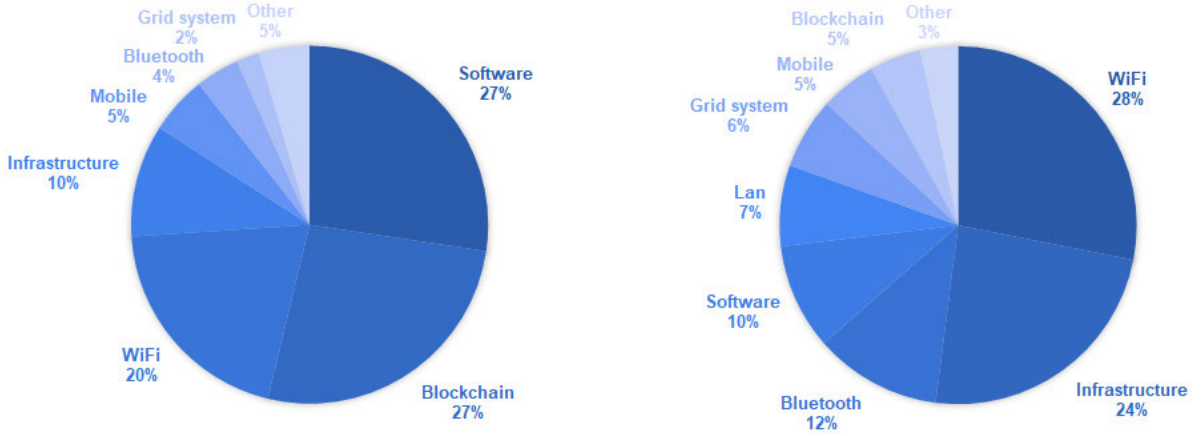

FIGURE 17. Distribution of citations for publications classified in technologies: left image for the entire period, right image for the 4 most cited technologies.

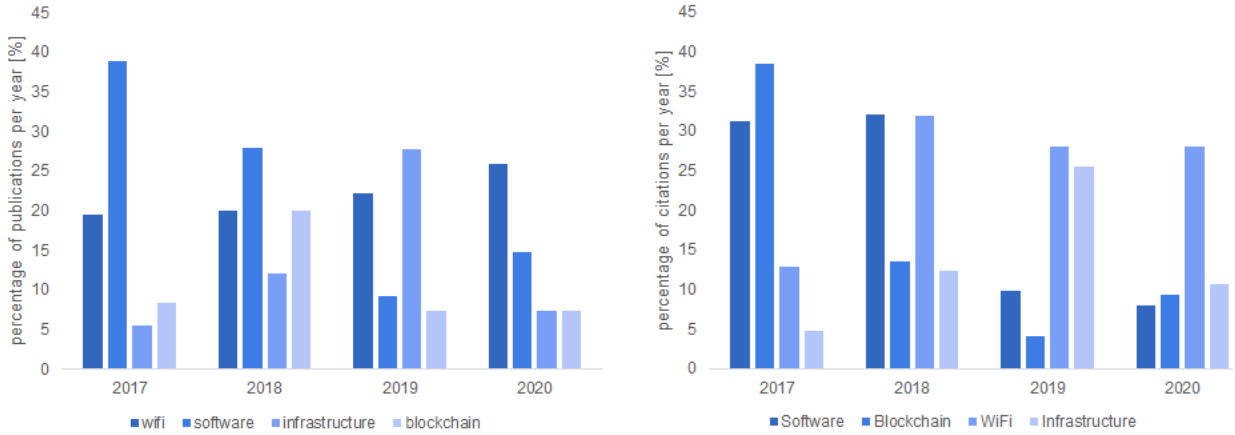

FIGURE 18. Summary for the four most popular technologies: the number of publications (left image) and the number of citations (right image) in subsequent years.

was a scientific aspect. In addition, infrastructure, software, heuristic algorithms, statistic models, and neural networks should also be distinguished. These appeared in a comparable number of works. The distribution of various scientific tools used in the works is presented in Fig. 19. It can be seen that this distribution does not show large changes in the last four years. Additionally, the exact distribution can be seen in Tab. 7, where results are shown separately for each of the years.

TABLE 5. Percentage distribution of publications, taking into account the year of publication and applied technology.

Year	WiFi	Software	Infrastructure	Blockchain	Mobile	Bluetooth	Grid system	Other
2017	19.4%	38.9%	5.6%	8.3%	11.1%	5.6%	5.6%	5.6%
2018	20.0%	28.0%	12.0%	20.0%	8.0%	0.0%	0.0%	12.0%
2019	22.2%	9.3%	27.8%	7.4%	1.9%	11.1%	5.6%	14.8%
2020	25.9%	14.8%	7.4%	7.4%	11.1%	14.8%	7.4%	11.1%

TABLE 6. Percentage distribution of citations of publications, taking into account the year of publication and applied technology.

Year	Software	Blockchain	Infrastructure	WiFi	Bluetooth	Mobile	Grid system	Other
2017	31.3%	38.6%	4.8%	13.0%	3.1%	6.3%	1.5%	1.5%
2018	32.0%	13.5%	12.4%	31.9%	0.0%	2.8%	0.0%	7.4%
2019	9.8%	4.0%	25.6%	28.1%	10.6%	4.2%	6.9%	10.8%
2020	8.0%	9.3%	10.7%	28.0%	18.7%	12.0%	2.7%	10.7%

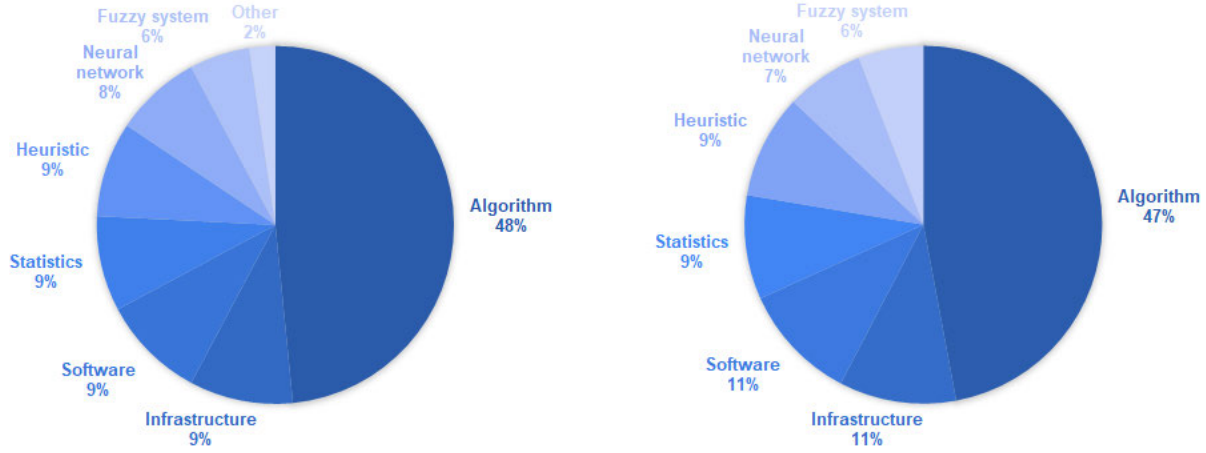

FIGURE 19. Distribution of the use of scientific tools: entire period (left image), last two years (right image).

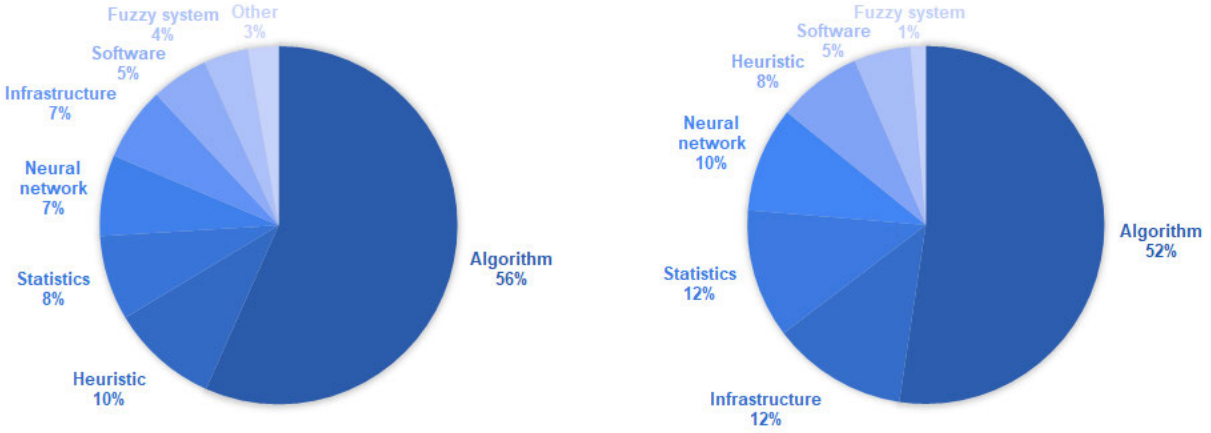

FIGURE 20. Distribution of citations of publications in relation to scientific tools for the entire period (left image) and the last two years (right image).

In the case of scientific tools, a citation analysis was also carried out, as shown in Fig. 20. It can be seen that the citation for scientific tools corresponds to the number of works. In this case, works containing algorithms are dominant. The citations of the remaining scientific tools show some minor changes. A significant change in the trend can only be noticed in the citations of works from 2020, but their number is still not large, so it is difficult to assume whether this trend will continue in the long run. The exact distribution of citations of works containing scientific aspects is presented in Tab. 8. The distribution of works and citations for the four most important scientific tools in the following years is presented in Fig. 21.

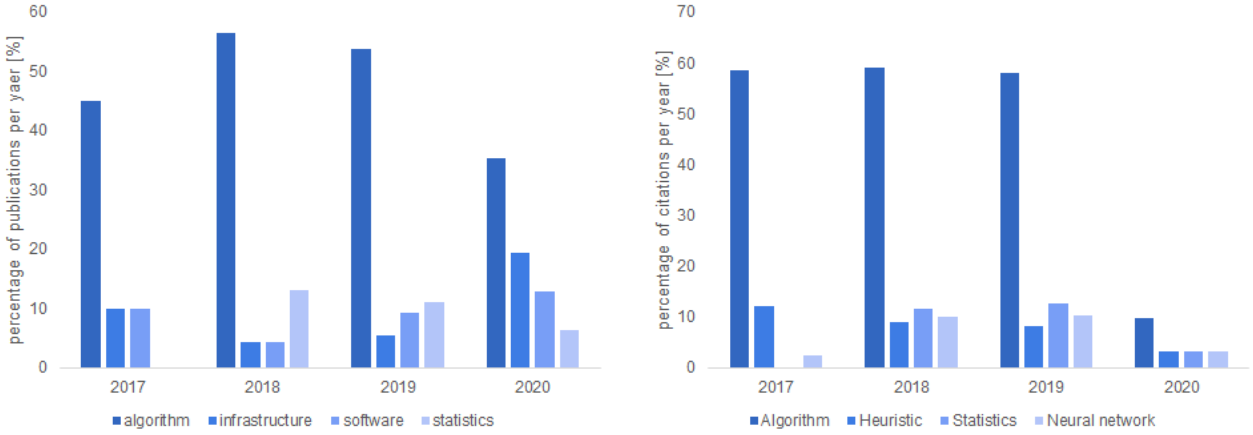

FIGURE 21. Distribution of publications in relation to scientific tools and other topics (left image), distribution of citations of publications by scientific tools (right image).

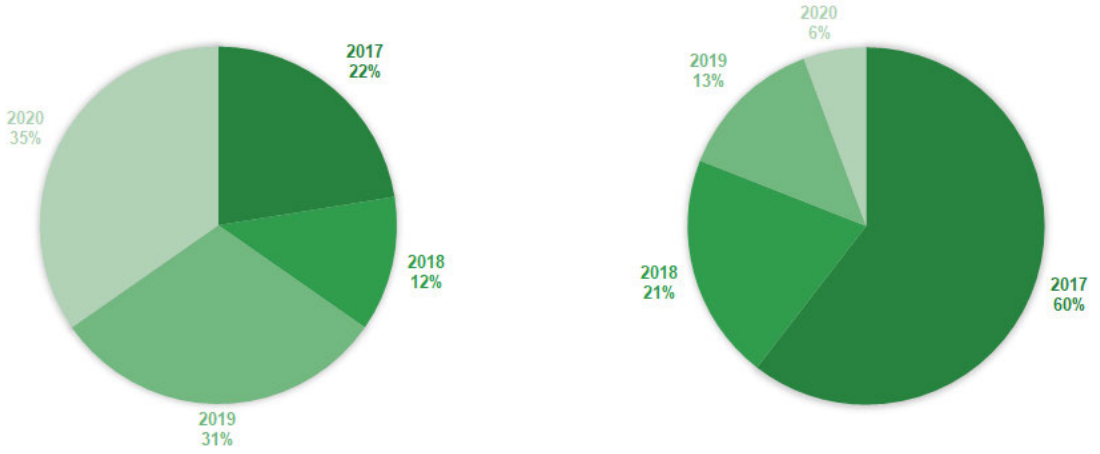

FIGURE 22. Distribution of energy management publications throughout the period (left image), distribution of energy management publications citations throughout the period (right image).

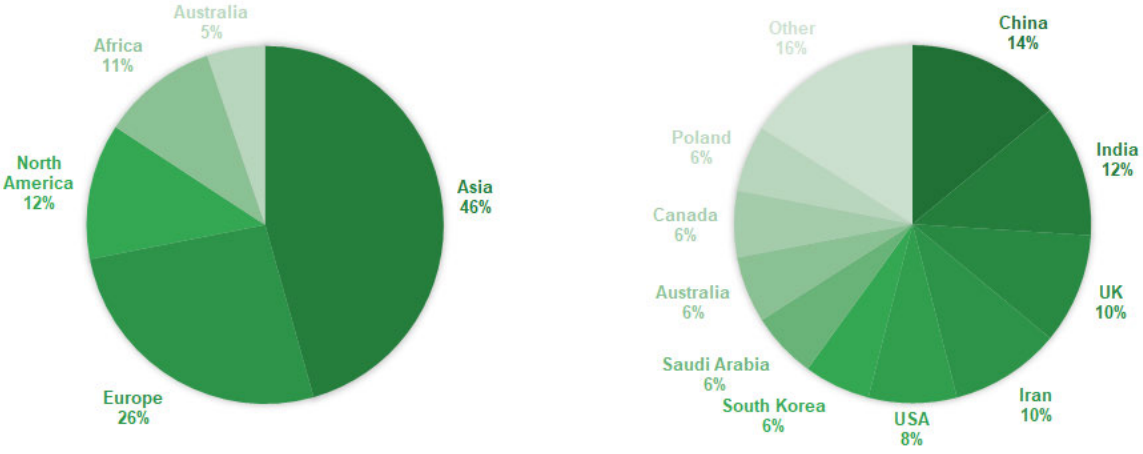

FIGURE 23. Distribution of energy management publications by continent (left image), distribution of publications by country (right image).

G. MAIN DEVELOPMENT TRENDS

Additionally, we have analyzed the three most important development trends for the subject of smart homes.

a: OPTIMAL ENERGY MANAGEMENT AND SUSTAINABILITY

First of all, publications related to the subject of energy management will be analyzed. Fig. 22 shows the distribu-

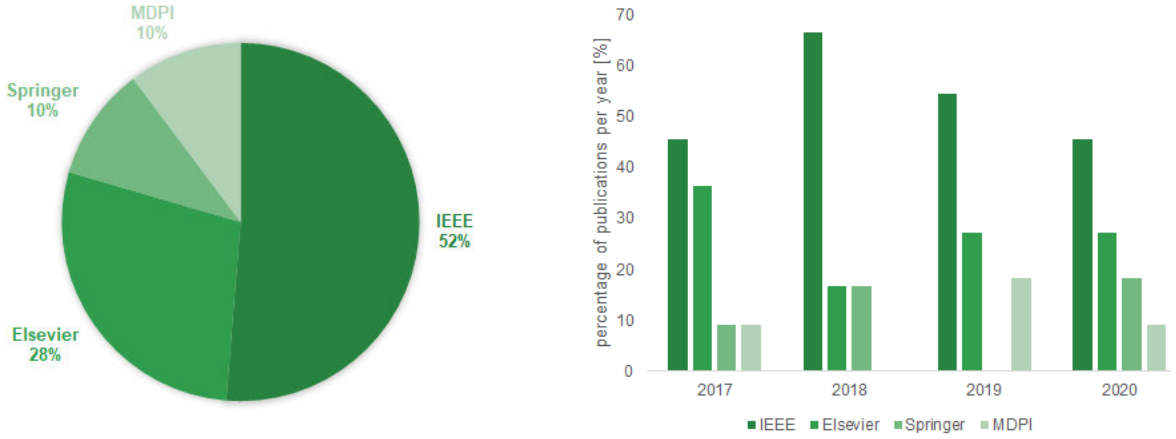

FIGURE 24. Distribution of energy management publications by publisher (left image), distribution of energy management publications by publishing house (right image).

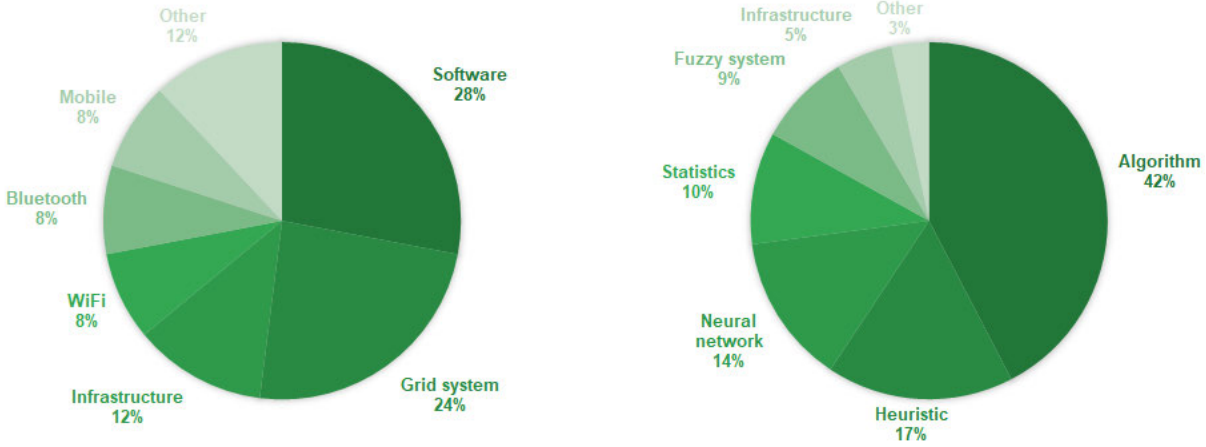

FIGURE 25. Distribution of energy management publications according to technologies (left image), distribution of energy management publications according to scientific tools (right image).

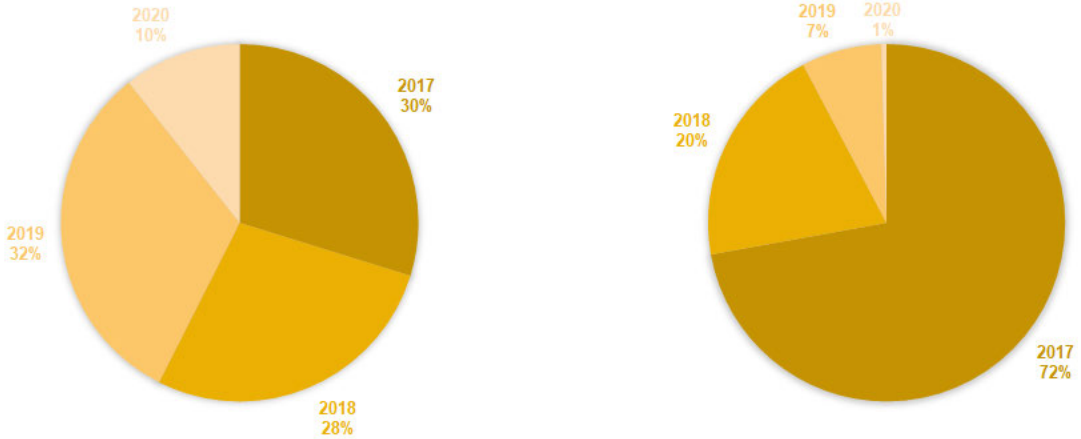

FIGURE 26. Distribution of security publications throughout the period (left image), distribution of security publications citations throughout the period (right image).

tion of publications on energy management in the following years and how they were cited in the following years. It can be seen from the aforementioned drawing that the number of works on energy management is growing in recent years.

As we can see from Fig. 23, by far the most publications come from Asia (46%), followed by Europe (26%). This trend is different than for all publications on the smart home. The figure also shows the percentage share of countries with the largest number of publications related to the subject of

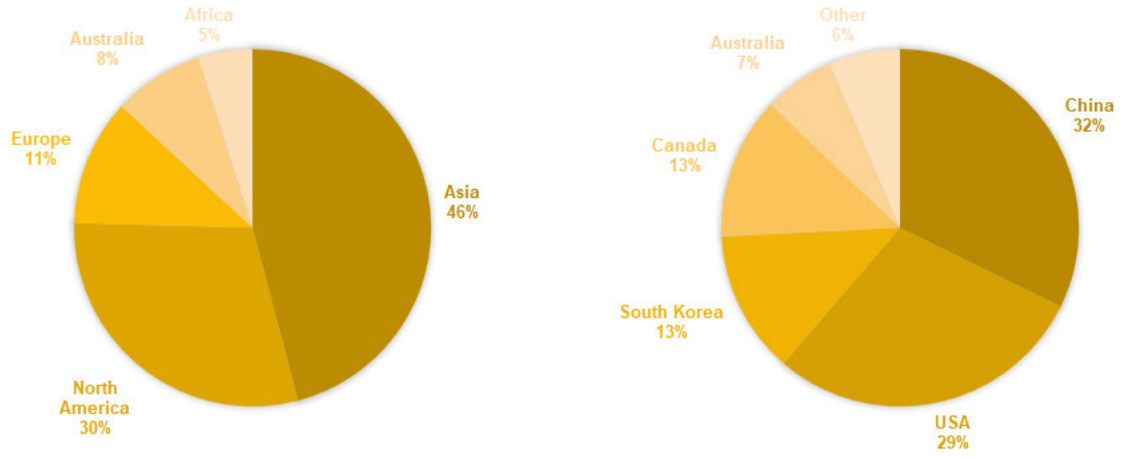

FIGURE 27. Distribution of security publications by continent (left image), distribution of publications by country (right image).

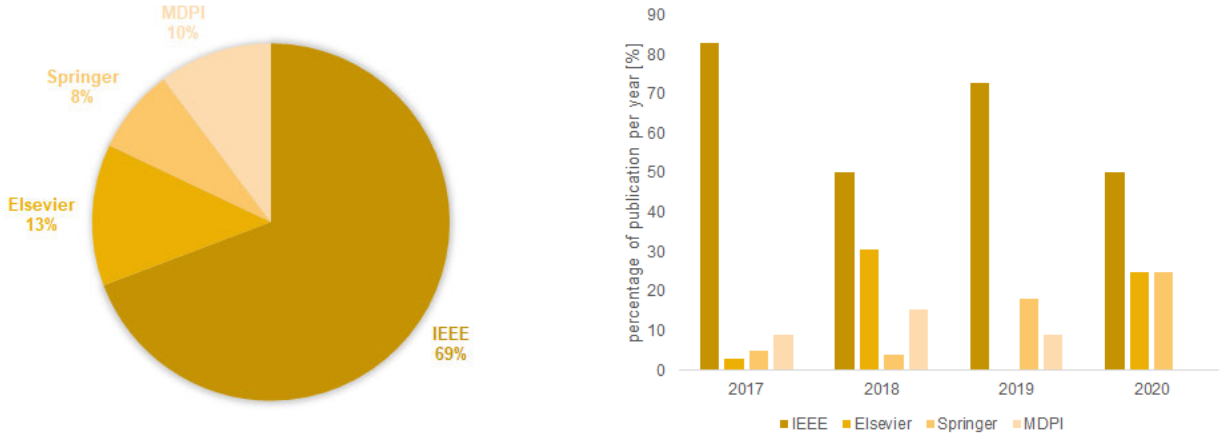

FIGURE 28. Distribution of security publications by publisher (left image), distribution of security publications by publishing house (right image).

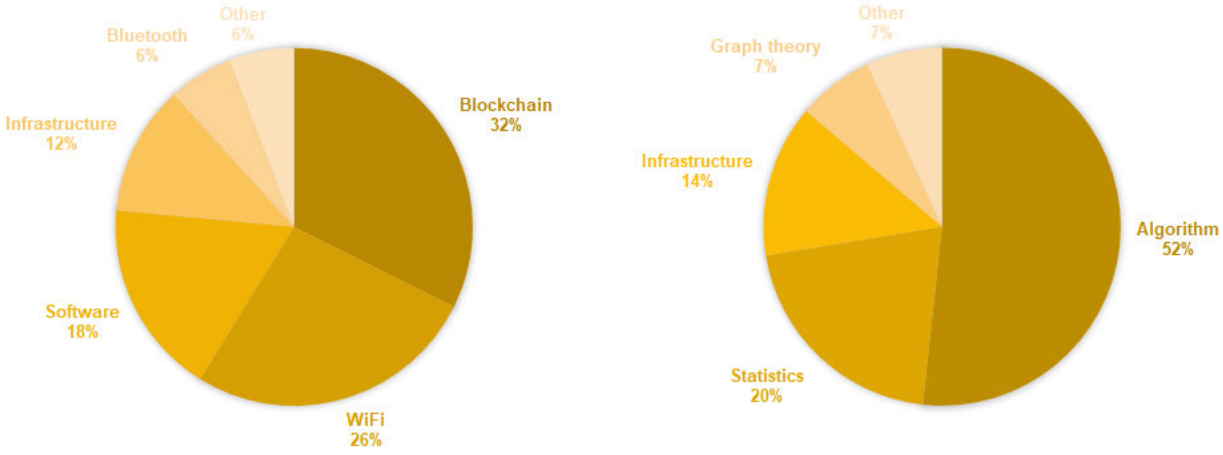

FIGURE 29. Distribution of security publications according to technologies (left image), distribution of security publications according to scientific tools (right image).

energy management. From this distribution, we can see that there are 10 countries which are significantly involved in this topic. Fig. 24 shows the distribution of publications on energy management in the publishing houses. In this case, as in the case of the entire topic of smart home, IEEE dominates, which publishes more than half of all works. This distribution has similar characteristics over the years studied.

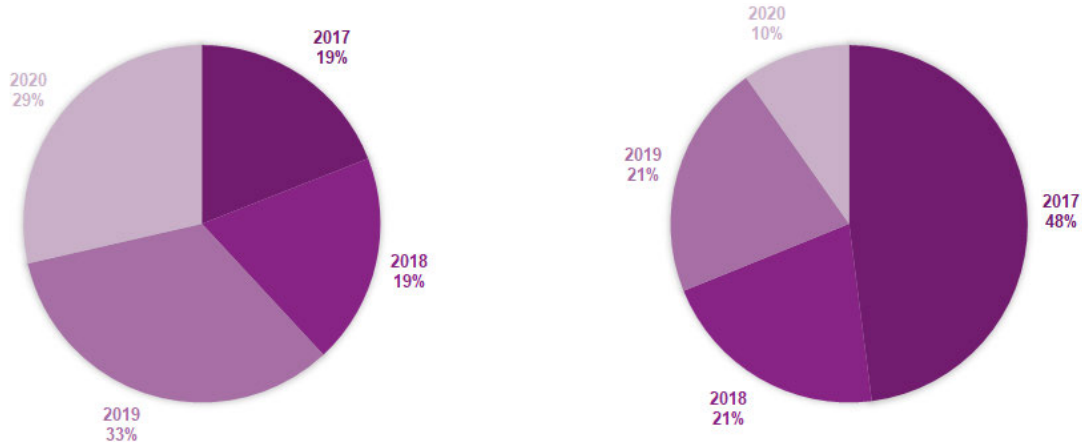

FIGURE 30. Distribution of healthcare publications throughout the period (left image), distribution of healthcare publications citations throughout the period (right image).

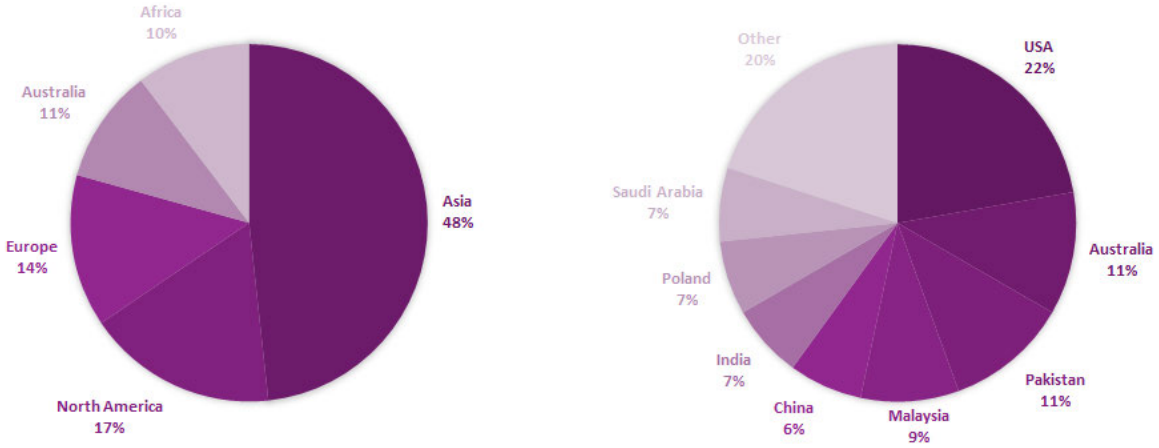

FIGURE 31. Distribution of healthcare publications by continent (left image), distribution of publications by country (right image).

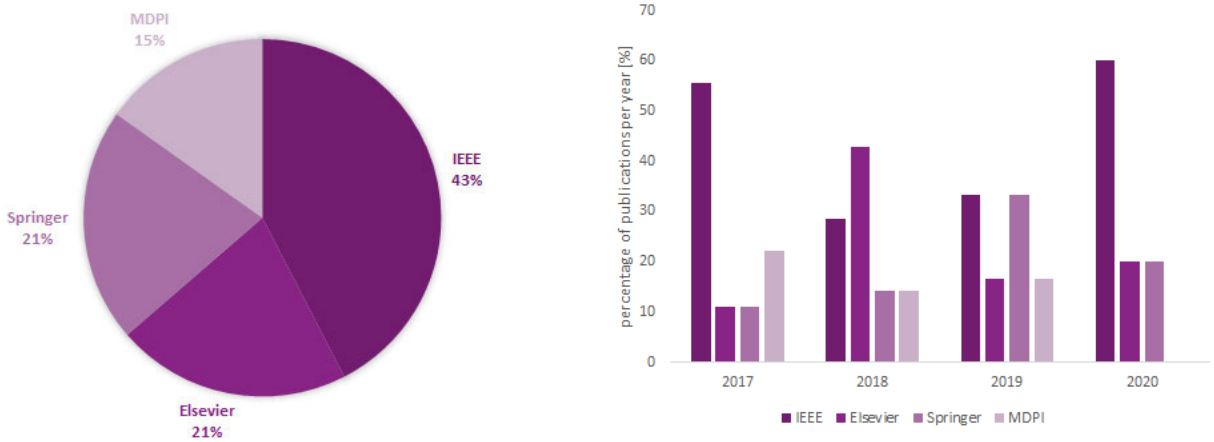

FIGURE 32. Distribution of healthcare publications by publisher (left image), distribution of healthcare publications by publishing house (right image).

Comparison in terms of the technologies used in works and the use of scientific tools is shown in Fig. 25.

In the case of applied technologies, most of the works concerned software, but also a significant part was the smart grid and infrastructure. The basic scientific tools used here were algorithms, but also, to a significant part belongs to heuristics, neural networks, statistics, and fuzzy sets.

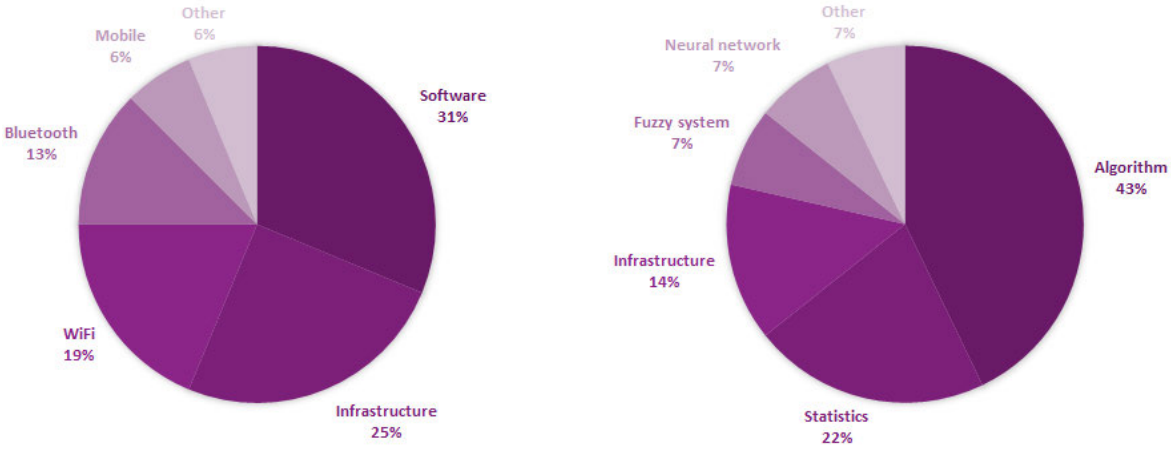

FIGURE 33. Distribution of healthcare publications according to technologies (left image), distribution of healthcare publications according to scientific tools (right image).

TABLE 7. Percentage distribution of publications, taking into account the year of publication and scientific tools.

Year	Algorithm	Infrastructure	Software	Statistics	Heuristic	Neural network	Fuzzy system	Other
2017	45.1%	10.2%	9.8%	0.0%	10.3%	10.1%	9.9%	4.6%
2018	56.5%	4.3%	4.3%	13.0%	4.3%	8.7%	0.0%	8.7%
2019	53.7%	5.6%	9.1%	10.5%	7.4%	9.3%	3.7%	0.8%
2020	35.5%	19.2%	12.7%	6.3%	12.8%	3.2%	9.7%	0.7%

TABLE 8. Percentage distribution of citations of publications, taking into account the year of publication and scientific tools.

Year	Algorithm	Heuristic	Statistics	Neural network	Infrastructure	Software	Fuzzy system	Other
2017	58.6%	12.3%	0.0%	2.6%	4.1%	9.1%	10.3%	2.9%
2018	59.0%	9.1%	11.7%	10.2%	3.5%	1.0%	0.0%	5.5%
2019	58.0%	8.2%	12.8%	10.4%	4.8%	5.0%	0.9%	0.0%
2020	9.7%	3.2%	3.2%	3.2%	68.8%	6.5%	5.4%	0.0%

b: SECURITY IN DATA MANAGEMENT

A similar analysis was carried out for security issues. Fig. 26 shows the distribution of works and their citations for analysis. It can be seen here that a similar amount of security works is published every year. Two continents, Asia and North America, as well as two countries, China and the USA, dominate. More than 60% of the works come from these countries, as shown in Fig. 27. Significantly fewer countries are involved in this subject, including 5% publishing significant ones. Therefore, since security issues are primarily of technology, most of them are published in IEEE, about 70 %, which is illustrated in Fig. 28.

The most common technological solution in publications on security is blockchain, while the most commonly used scientific tools are algorithms, statistics, but also solutions based on graph theory, as shown in Fig. 29.

c: HEALTHCARE AND QUALITY OF LIFE

The third of the main development trend is related to health protection and quality of life. In Fig. 30 can be noticed that the number of works on this subject grows significantly in the following years. In mid-2020, the number of works almost reached the number of works in 2019. A growing tendency also took place in 2018. Similarly, the number of citations has been higher in recent years compared to the entire smart home topic. Most often, these works are published in the IEEE publishing house, but in this case, the share of other publishers is more important, as shown in Fig. 32. It can even be seen that in 2019 the disproportions between the number of published works on this subject were as large as in most cases of works on the smart home. The characteristics of the technology choice show that over 50% of cases in health care-related works were described as software or infrastructure, as illustrated in Fig. 33. For scientific tools algorithms dominated in most cases, but also the essence of some of the works used the statistics, neural networks, and fuzzy systems.

V. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

The IoT in a smart home is an interesting topic for many new applications and scientific models. The main trends of development identified in our research are shown in Fig. 34. The model shows identified development trends in a form of a knowledge map to help conclude what can be the most important trends in the future or which new technologies may influence the development most. When we take a look at the proposed map a conclusion comes that technology will be

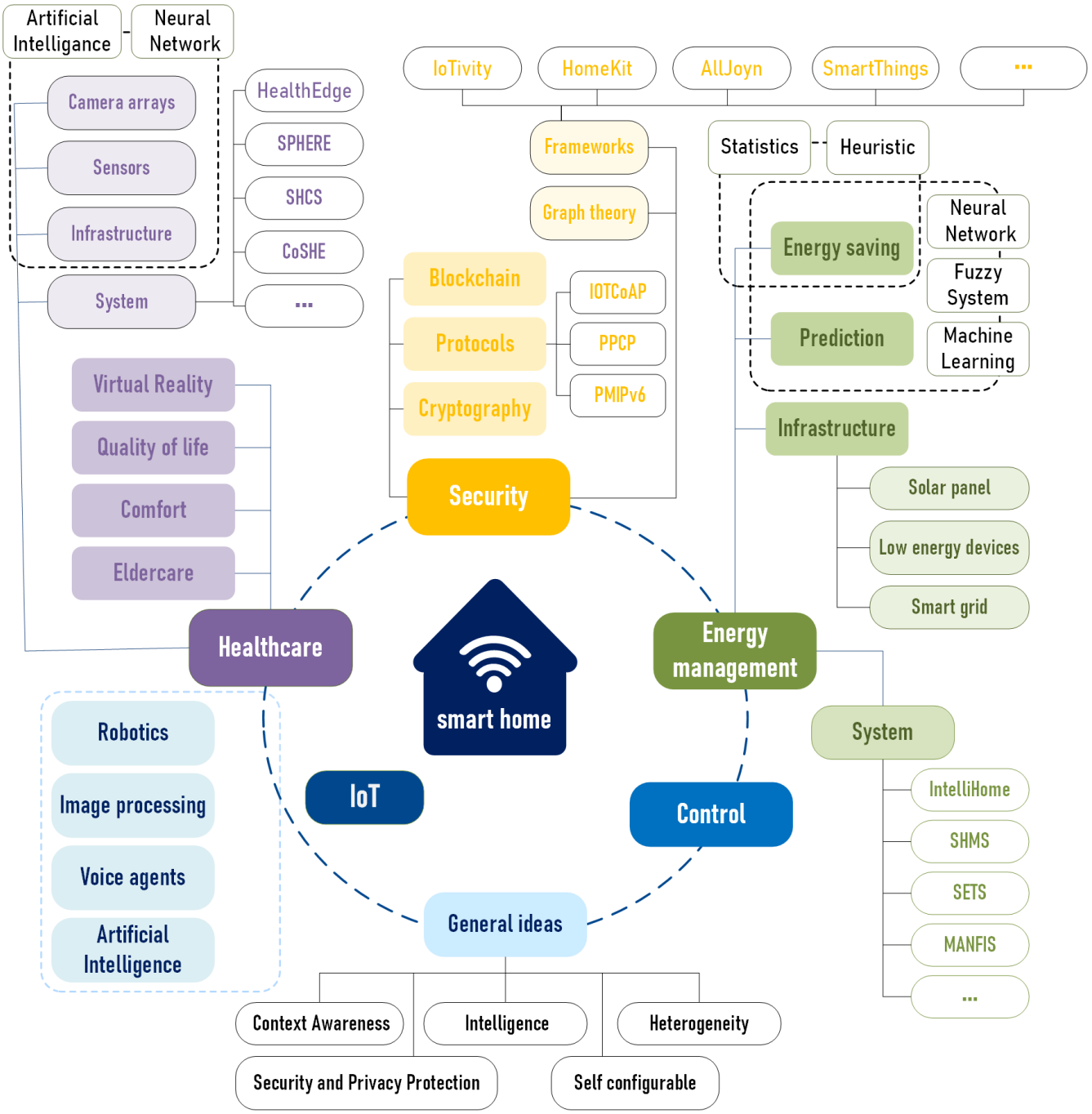

FIGURE 34. Knowledge map for new trends of development in smart home technology for the following years.

oriented on human-centered models in which interaction with devices will take place via implemented interfaces. Technological development will be based on the main two streams. Software frameworks will dominate the are of developing interaction, while models of applied decision making will be dominated by AI.

In-home infrastructures more devices will find applications and therefore connection will grow. Homes will be composed of networks of bigger infrastructures, which together with other smart buildings, services and transportation compose smart cities. As a result, the variety of data types and the total amount of information will grow very fast. Residents, users, and all citizens may use web interfaces, terminals, and mobile apps to have instant connections to their homes, cars, and other devices connected to the infrastructure. Additionally, new ways of communication between people extend the need for broad pass transmission for video calls and multimedia. Therefore current networking infrastructures may not provide

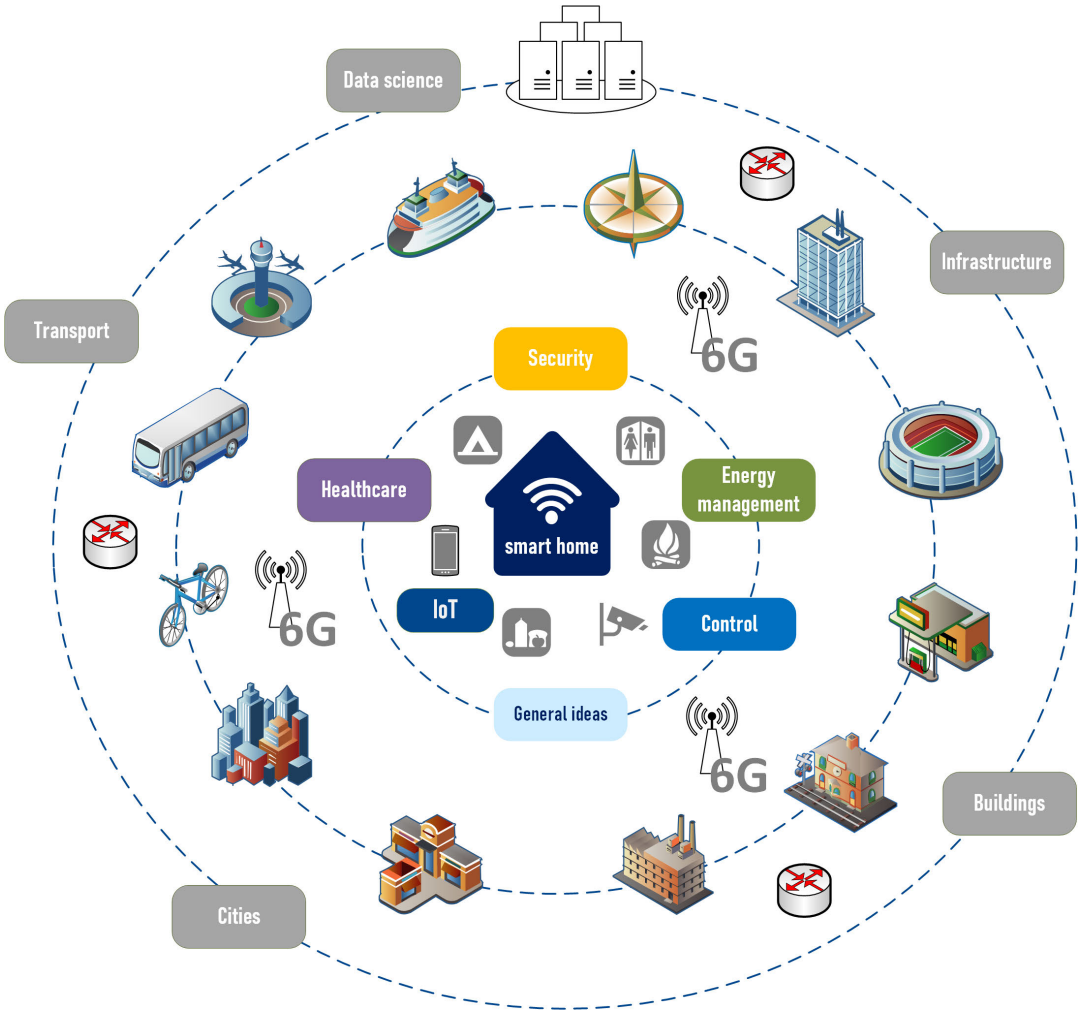

FIGURE 35. Development toward 6G connection model installed at local, regional and global level to support faster multi data type exchange between single devices, users and whole network areas in local and broader area.

enough capacity. As a solution 6G model can be used to solve such capacity problems. As shown in Fig. 35, devices and all the infrastructure connected to the network will find enough space to work without problems. The development of a 6G networking system can serve as another boost for technological development. Home systems will be capable to host a wide variety of multimedia in HD quality. Such streaming will improve the entertainment at homes but security and remote healthcare consultations. Some of the main new advances from using the 6G connection type:

- Location of sensors in the wide-area may support weather forecast. Local conditions may be immediately available for forecasting services to present possible weather changes to residents without any delay in service.
- Possibility of extending monitoring system for elderly people, who can have much better support with cameras and devices to contact doctor and family in case of any danger.
- The speed of data transmission will allow for remote consultation for the people under care, the system will quickly recognize vital parameters in terms of detecting critical conditions, such as heart attack, stroke, and allows for a quick response.
- Forecasting from a variety of conditions may be beneficial both at the local and global level.

The introduction of the 6G network connection will help to construct more efficient systems both at the local, regional, and possibly global level. Faster data flow will improve decision making in smart environments and communication between people.

The new aspects of possible development in IoT for smart homes can be considered in the field of medical applications, security, and prevention from disasters, and the extension of new appliances. In medical examinations and new IoT, models can efficiently support remote diagnosis and treatment to help in direct consultations. Detection of weather changes may help to prevent our homes from possible damages. Such improvement will be much expected in locations

where hurricanes and other weather sudden changes affect humans. On the other, since IoT appliances apply to any home device, we can benefit from many new features available in our homes.

Scientific development of models will help to introduce new possibilities of faster and more efficient control. New computers bring higher capabilities of data computing, therefore composed models are expected to be more precise. In the domain of deep learning, we can expect new architectures devoted to tasks on the type of data taken from various sensors at our homes. Security of the data will need blockchain architectures to support data encryption and protection in cloud systems to which IoT appliances are connected.

There are several possibilities to improve presented IoT solutions. Demands of users will also reveal new trends. With new types of connections like 6G, we will face much faster data transfer, and this will be one of the most important aspects for development both in technology and scientific models. We can yet see new smartphones using such connection but it seems to be just a start for the growth of 6G enabled devices in multimedia, security, and home robotics.

To sum up, in the paper we present an analysis of the technological and scientific developments in the field of the smart home. Our findings show which are the most important trends and based on the predicted possible new developments. In our analysis, we have also defined which countries and continents may be a technological leader in the field of smart home technology. Future trends and works can be oriented in the development of healthcare systems, quality of life, optimal energy consumption, and various aspects of better data transfer. The introduction of new connection types may also speed up this process. We think that the next few years will define the way toward new trends in this field which will dominate the research for next years.

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