International Journal of Hybrid Information Technology
Vol.2, No.1 (2022), pp.23-46
http://dx.doi.org/10.21742/ijhit.2653-309X.2022.2.1.03

The Present State of Home Automation: A Systematic Literature Review

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Abstract

Since ancient times, people have been trying to make life easier, for example, by bringing water to homes and taking care of wastewater through channelization. With the advancements in technology over the past few decades, people have gained access to smart devices and computerized systems, enabling us to automate tasks. For example, motion sensors help to automatically turn on the lights when entering a building. Also, remote-controlled, voice-controlled, and gesture-controlled devices are becoming smarter and enabling various types of activities. The objective of this literature review is to be a valuable source for software engineers to gain a better understanding of the current achievements in smart home development. This paper explores technological advancements, including the usability and security aspects of home automation. The authors choose four digital libraries to research published case studies related to the selected number of smart home domains. Papers with distinct titles that are written in English and are more than three pages are selected as research material. Furthermore, thematic analysis was performed to extract data linked to the research questions. Most of the chosen case studies are performed in labs. This literature review found that a portion of the current products overlooked the basic security and privacy enhancements in favor of usability or vice versa. The present research concluded that adequate knowledge management has the potential to improve smart home technology. Additionally, developers should not skip any of the three layers of the development architecture (UI layer, communication layer, and software system layer) because each stage is dedicated to addressing existing weaknesses in smart home products. The paper's findings provide potential solutions for developing better smart home devices in the future.

Keywords: *Smart home, Home automation, IoT, Remote monitoring, Home security, Healthcare, Energy efficiency*

1. Introduction

Internet of Things (IoT) devices such as sensors, smartphones, and controlling and monitoring devices surrounding us. Weiser and Brown predicted the arrival of ubiquitous computing, and with IoT, one can see this vision come to life [9]. Modern home automation is dependent on IoT devices [47]. Smart home systems need to deal with saving energy and other resources. It is estimated that by the year 2025, there will be 75 billion IoT devices installed, and these devices should provide solutions rather than becoming part of the energy

Article history:
Received (April 26, 2022), Review Result (June 30, 2022), Accepted (August 21, 2022)

mismanagement problem [34]. There are smart plugs and smart meters that enable users to manage and monitor energy consumption [28], yet most smart devices have specific standards and cannot be easily integrated [2]. One solution is to develop a standardized approach by using middleware and frameworks to generate communication between IoT devices and software to provide better energy management and energy-saving systems [8]. However, Home automation systems have some drawbacks. The development of home automation systems with a proper balance between usability, user experience, performance, and security can be challenging [12][27]. Smart homes have a wide variety of users in different age groups [14], and because of the age group diversity, developers have to level down the differences in people's interaction with IoT.

Usability and User Interface (UI) design are playing an important role in smart home development because the user interacts with the system through the UI. Smart home products should have a simple yet effective interface for the remote administration of the house [47]. In addition to controlling smart devices through the UI, providing valuable information, such as house temperature and humidity, may have a use case and be valuable for many users. Furthermore, in connection to elderly and patient monitoring, smart home systems are capable of analyzing and sending a patient's health status to interested parties [11]. Workflow management is a rather new subject linked to home automation, and the system needs to execute tasks based on a trigger, for example, turning on a coffee machine when someone enters the home [41]. Many smart devices are shared and used by different residents at home or in a building, and a home automation system can manage these shared devices through a usage timetable to provide comfort and ease for all users. [26]

Security issues are another concern that smart home users have. Software systems are capable of collecting critical metadata about the users through smart devices, and the gathered data are subjected to security risks [10]. These security concerns can compromise the total system's functionality, and users are worried about their home privacy and safety [2]. Still, proper security is not the only factor users are after, Zhen Ling et al., [50] and the current paper goes through the other concerns smart home users have.

Smart home and home automation devices come in all types and shapes. Such systems are becoming more advanced every year and are getting more attention from consumers. Inspecting the current state of the art of home automation systems in the literature and the provided guidelines to improve them can help developers and designers make better choices and improve products. The objective of the current paper is to study the current state of the art and the identified benefits and drawbacks of smart home systems, as described in the literature. This will be achieved by conducting a systematic literature review to answer the following research questions (RQ):

RQ1: What topics concerning smart home systems can be found in the literature?

RQ2: What are the identifiable concerns, that is, the benefits and drawbacks of smart home systems?

RQ3: How can the systems be optimized based on the identified benefits and drawbacks?

Answering the first question (RQ1) determines the topics addressed in the literature concerning home automation systems (including devices). Smart home devices can collect information about residents' behavior and even have a view of the inside of the house. This can present a notable security risk to homeowners. The second question (RQ2) covers concerns like the one mentioned. Recognizing such potential drawbacks can help all stakeholders expect and produce more sufficient systems. The question also addresses the

benefits of utilizing a smart home system. The answer to the last question (RQ3) provides a set of guidelines for the developers for optimizing smart home systems based on the findings of the systematic literature review. The current paper stays away from basic and purely historical information; the objective is to examine the current state-of-the-art situation, so material published before 2013 would be excluded from the research scope. The cutoff period was selected based on the evolution of home automation systems and increased activity in the field. Google's trend data for the term smart home can be found in [Figure 1], which shows the term gained noticeable popularity in 2013.

Figure 1. Google's trend data for the term smart home. A value of 100 is the peak popularity

This document covers several topics linked to the development of smart home systems. The identified interrelated topics including usability, design, performance, and security are set to uncover the benefits and drawbacks of existing systems. In addition to the mentioned objectives, this paper aims to uncover real-world issues to help improve future smart home products e.g., compromising security in favor of usability and vice versa is not recommended.

2. Related work

The related work about the main contributions of this paper is discussed below. This study considered advancements and concerns linked to smart home systems; this can help gain an understanding of the completed work and how best to continue the research on the related study topic. Smart home research adds considerable value to people's lives because it has environmental, social, and ethical benefits. Having a clear view of smart technologies would assist stakeholders who are interested in the topic.

Smart home systems are becoming more advanced with the growth of technology. Mehedi Hasan et al [20] explain new ways to control a digital home through voice recognition, gesture control, and Wi-Fi. According to Hasan et al., [20] a variety of weaknesses have yet to be fixed when considering the mentioned technologies. For example, a voice-controlled system may give false and unpredictable results because of the surrounding noise; a smart light switch may turn on/off based on the similarity between the command word and some other words. Wi-Fi and Bluetooth systems also have some pros and cons. As stated by [20], a Bluetooth-based system is easy to use. However, the operating range of such systems is around 10–20 meters, and Wi-Fi-based systems are more flexible because of their wide range. Such systems have a high initial cost that can be less applicable to people with a lower budget.

In the literature, one can see important challenges linked to smart home development [39]. Availability and remote accessibility are some of the challenges developers are facing. This can be solved by utilizing cloud servers as a communication gateway between the potential

controlling devices, for example, smartphones and smart home systems. However, Stojkoska and Trivodaliev [39] conclude that connecting to cloud servers has some drawbacks, including more bandwidth usage. Risteska, Stojkoska, and Trivodaliev [39] present several communication techniques, such as fog computing, to address the mentioned issue. Based on the study by Hisham Albataineh et al., [1] a combination of edge and cloud computing is more energy-efficient and has positive performance effects because most of the data analysis occurs locally, so the smart home system does not have to wait for the cloud server's response.

Smart elderly care with the help of smart homes is reviewed [30][31]. Monitoring the health status of users is possible with the use of sensors and monitoring devices. The authors start the discussion by going through the health-related needs of older adults. The elderly population is struggling with common diseases such as diabetes and blood pressure, and according to Petra Maresova et al., [30] the challenge is to encourage older adults to accept health-related smart solutions. Developing easy-to-use products in combination with artificial intelligence (AI) for automation and decision-making is a way to explore and potentially enhance smart healthcare. Wearable devices and sensors can collect valuable data linked to the movement and other activities of patients, and based on the findings of, [31] the collected information can be analyzed to measure users' health decline or improvements on a day-to-day basis.

Smart home energy efficiency is reviewed [42][44][45]. Smart electricity meters provide the possibility to monitor energy consumption and collect related data for further analysis. According to researchers, [42] smart thermostats can save up to 20% of heating and cooling costs each year, and based on the review completed by Vishwakarma et al., [45] the user can control the flow of electricity by utilizing a home automation dashboard. Member states of the EU are required to provide smart metering systems to consumers; a digital meter enables many possibilities. Combining a prepayment system with a smart meter's alert functionality can inform the customer about energy consumption, which may have positive environmental effects. For instance, smart electricity with a "traffic light" function can warn customers about high electricity loads [44].

Security and privacy have been a big burden when developing a smart home product because such devices are connected to the internet, and most of the time, the data travel between the home network and cloud servers. Some of the security threats addressed in the smart home concept are presented by Almusaylim and Zaman [4], in which the researchers recommend proper user authentication techniques and secure frameworks for communication between smart devices and smart home gateways. Privacy concerns in the smart home domain have been studied before [19]. Authors Guhr, Werth, and Blacha present privacy issues as potential barriers to smart home usage, they propose a common definition for information privacy: one's ability to control information about oneself [19].

The current literature review intends to continue on these related works. This paper explores eight topics linked to the study of smart homes that were found during the analysis phase. In addition to covering the current state of the mentioned subjects, this document examines topics such as design, performance, development process, and usability. The next section explains the research process and related activities.

3. Methodology

To complete the current paper, the process proposed by Kitchenham is applied, a systematic literature review method is used, and four digital libraries (databases) are selected

to perform an automatic database search [25]. The process was managed by the first author of the paper, and other authors joined in to confirm and review the results. The literature review is drawn on the planned research questions for the current paper; that is, aiming to create an overview of smart home systems and their concerns by analyzing published articles and based on the findings; create some guidelines for smart home system developers. Built on the research questions, the authors have created a general search query ("home automation" OR "smart home" OR "internet of things") AND "case study." Derived from the process proposed by Kitchenham, four databases have been selected to apply the query parameters, as shown in [Table 1].

Table 1: The list of digital libraries and the applied search parameters

Library name	Search parameters
ACM Digital Library	[[Publication Title: "home automation"] OR [Publication Title: "smart home"] OR [Publication Title: "internet of things"]] AND [Publication Title: "case study"] AND [Publication Date: (2013 TO 2022)]
Springer Link	"home automation" OR "smart home" OR "internet of things" title=case study facet-start-year=2013 facet-end-year=2022
IEEE Digital Library	(("Document Title": "home automation" OR "Document Title": "smart home" OR "Document Title": "internet of things") AND ("Document Title": "case study")) ranges=2013_2022_Year
Science@Direct	("home automation" OR "smart home" OR "internet of things") AND "case study" date=2013-2022

The initial search resulted in 468 matches. The first step was to exclude everything except published journal articles and conferences. On further inspection, it was discovered that some of the papers' titles are not in line with the expectations, so a title-based exclusion is applied in the second step. The third filter excluded the papers not written in English, and the fourth step allowed papers of more than three pages to be included. Duplicate papers were excluded in step five, and finally, analyzed the content to see if they are in line with the research questions. After applying the inclusion and exclusion filters, the number decreased to the final set of 56 papers, as shown in [Figure 2]. Thus, the following set of inclusion and exclusion criteria was applied to the search results:

- Inclusion Criteria:
  - Published journal article or conference paper
  - Primary study
  - Clear case study reports related to the research questions
- Exclusion Criteria:
  - Book chapters and magazine articles
  - Languages other than English
  - Papers that focus on the basics and history of smart homes and home automation

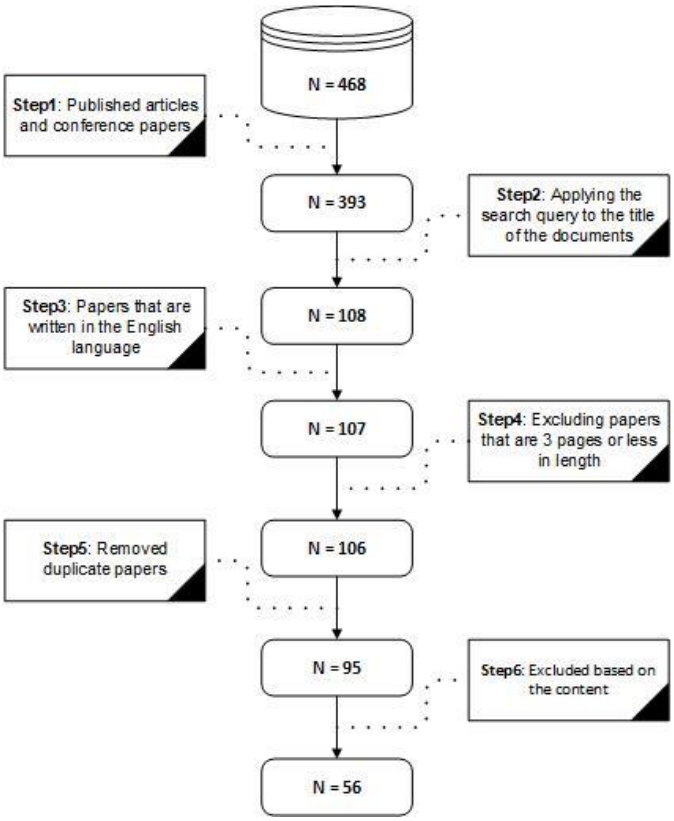

Figure 2. Number of papers after applying the inclusion and exclusion filters

Table 2. Number of papers per database after applying the inclusion and exclusion filters

Database	Initial number	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
ACM Digital Library	25	24	14	14	14	9	6
Springer Link	363	297	22	21	21	21	12
IEEE Digital Library	61	54	54	54	53	53	33
Science@Direct	19	18	18	18	18	12	5
Total:	468	393	108	107	106	95	56

[Table 2] presents the exact number of papers per database in every step after the filters were applied. As stated earlier, the objective is to answer the research questions, and as a result, an extra query is added to the data extraction form. (For which research question can the paper be utilized?). The data extraction description can be found in [Table 3].

Table 3. Data extraction

Item	Description	Research Question
Title	The title of the paper	RQ1
Year	Publication year	Metadata
Venue	The publication type: journal or conference	Metadata
Direct link to the document	A direct link to the document	Metadata
Special note	Free text about the paper (important remarks and reminder notes about the paper)	Metadata
Assumptions for benefits	What are the assumed benefits for the product analyzed in the paper?	RQ1
Assumptions for drawbacks	What are the assumed drawbacks of the product analyzed in the paper?	RQ1
Realized benefits	What are the realized benefits?	RQ2, RQ3
Realized drawbacks	What are the realized drawbacks?	RQ2, RQ3
What equipment and features are in used	What are the types of equipment and features used in the paper?	RQ1, RQ2
Study context	What does the paper aim to cover in connection to benefits and drawbacks? Is it security, price, or usability related? There can be more categories that are not defined here.	RQ1, RQ2, RQ3

Thematic analysis was performed by the first author on the research material; the process started by reading the material to highlight and extract the data relevant to the research questions. The extracted data were validated against the research questions by the other authors. The process continued by tagging the papers with their corresponding topics, and then, the topics were reviewed and combined appropriately. Finally, the papers were added in groups based on the realized categories; the results are shown in [Figure 4]. Additionally, Appendix 1 presents the realized study topic(s) for each analyzed paper.

4. Results

The current section is dedicated to answering the research question. The section starts with a presentation of the study topics found in the literature, which is followed by an explanation for each topic. Finally, the current section looks at the concerns linked to smart home systems and the ways to optimize them. The number of selected studies per year is shown in Figure 3. Additionally, the selected studies are divided into four categories based on the study settings; the results are shown in [Table 4].

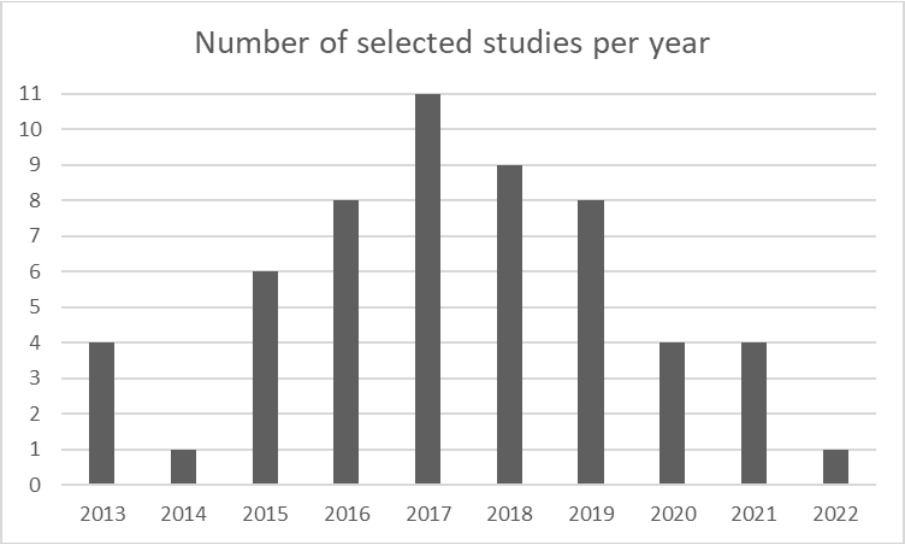

Figure 3. Number of selected studies per year

Most of the selected case studies were completed in laboratories, the devices were set up in a lab, and the developers conducted experiments to obtain the results. Furthermore, some of the case studies were done in simulated settings, meaning there was a controlled environment with the same features as the real environment. Field studies were done in real settings, and the developers set up a system to monitor the interactions between the user and smart home products. Finally, theory-based case studies were conducted to test a theory, which could include interviews with people in the smart home industry or analyzing the data from an existing product to report weaknesses and strengths.

Table 4. Number of papers per study setting

Study settings	Number of papers
Lab study	21
Field study	10
Simulating real settings	18
Theory-based study	7

4.1. Realized smart home topics (RQ1)

To find the answer to the first research question (RQ1), the first author analyzed the selected studies by reading the content and keywords of the documents to find the study topic(s) for each paper. Eight different topics were identified based on discussions among the authors; these topics were covered in the majority of the papers. Some papers address more than one topic, which was counted in the list of results. Improving future home automation products is the motivation behind covering the eight identified topics, and based on the performed analysis, refining security and the privacy of the home automation systems is the most popular study topic. Home automation systems are collecting a considerable amount of data; the question is then on securing and controlling the data, which may travel across networks throughout the world [23].

IoT systems have a wide range of applications. In addition to task automation, they monitor, analyze, and report. Improving the design and smart healthcare are the second most popular topics of the selected case studies. Having a design that can follow the requirements is a crucial factor in the success or failure of a product [5][22]. As mentioned in the introduction, the focus of the present paper is to help smart home developers and designers develop better products. The selected topics shown in [Figure 4] cover technical aspects and consumer concerns and development practices. Reviewing these topics covers the three high-level phases of the development process: planning, implementation, and improvement.

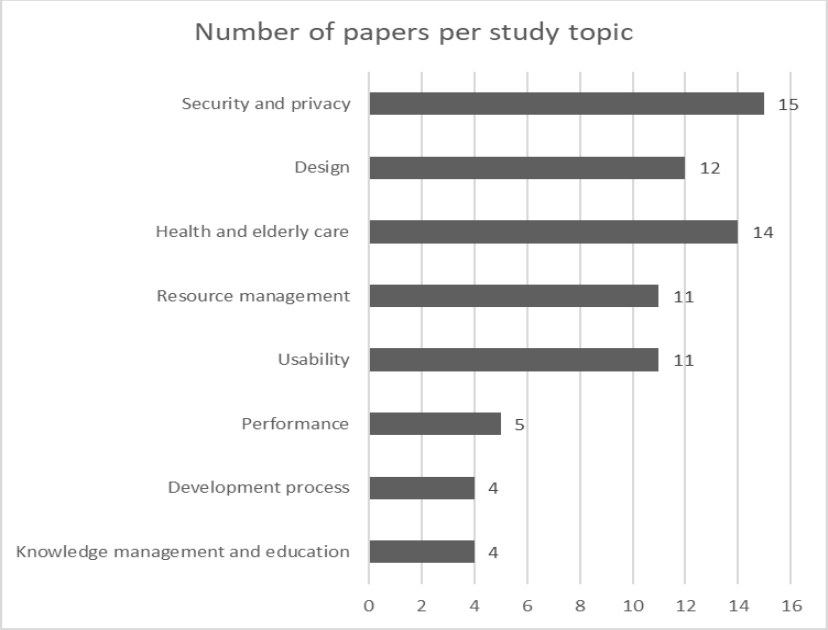

Figure 4. Number of papers per study topic

[Table 5] presents the distribution of the study topics per year. The data is collected to present the coverage of the topic within the given time range from 2013 until 2022. This can clearly show how important a topic is if it is covered repeatedly for several years. E.g., security and privacy are the most popular research subjects, and the topic is covered since 2013.

Table 5. Distribution of the study topics and the number of papers per year

Topic	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Security and privacy	2			1	4	3	4	1		
Design	1		2			3	4	2		
Health and elderly care	1		2		4	2	2	1	2	
Resource management			4	2	2	1	1			1
Usability	2	1		2	1	1	2	1	1	
Performance				1	2	1				
Development process			1	1		1	1			
Knowledge management and education				2				1	1	

4.2. Topics

To answer the second and third research questions (RQ2, RQ3), the current section explains the presented topics in Figure 4 and explores the benefits and drawbacks of smart home systems.

4.2.1. Security and privacy

IoT devices play an important role in various domains, such as home, agriculture, healthcare, tourism, transportation, and education [7]. Home automation products generally consist of several IoT devices that are connected to complete an objective. Furthermore, home automation products are inseparable parts of smart cities, so having proper security measures is a must. Security vulnerabilities may be in the IoT devices or in the way data travels between them and are stored in smart home storage for further analysis. One can attempt to hack a smart home system or even use a smart home system as a tool to hack the entire network of connected smart products or smart cities [50].

A way to handle the security concerns is by giving the power to the product users to control the flow of data, which means permitting the storage of data, monitoring the data flow, and restricting access to the data. According to Aung and Tantidham [7], this is possible by utilizing Ethereum (ethereum.org). Ethereum is a private blockchain, it is used to handle data flow based on the smart contract or authorized policies that are created by the user. Security and privacy can be taken care of in peer-to-peer networks with the utilization of blockchain. Applications running on Ethereum are available from anywhere, and the data flow is controlled by smart contracts between private and public networks. A smart home system is private data storage, while communication and sharing the data with the cloud for statistical purposes can be handled through public contracts specified in the Ethereum platform.

Improving privacy is a challenging topic, and according to Yulistiyan Wardhana et al [46], it should not compromise the well-being of the user. For example, limited access to a private room to just one person can have a negative outcome if the user gets a heart attack there and no one else can enter the room to help. In this case, smart devices should be able to inform and provide access to health officials. To address this issue, Wardhana, Hardian, and Guarddin are recommending a system for monitoring the user's status and habits when using a private room [46]. However, the developed system in question is not always accurate and cannot adapt to the habit changes of the user.

Security vulnerabilities can be in the hardware or software of smart home devices. It is almost impossible to implement flawless software. However, it is recommended that more resources be allocated to improve the security level of smart devices [13]. One of the ways to do this is by leveraging cryptographic techniques instead of using plain and human-readable text for storing sensitive data or communication between devices. Regarding the hardware, it is better to avoid using hardware with known security weaknesses like Bluetooth, which is vulnerable to Bluetooth signal-interfering attacks [49]. Most IoT devices focus on new features and cost reduction. Smart devices are often not designed with security in mind. One solution to the mentioned problem is for developers to implement new features by adapting existing frameworks and services to improve the security of the products [38].

4.2.2. Design

Among other benefits, a well-designed smart home system can reduce processing power, for example by dividing the load between the cloud server and local servers. The difference is more noticeable with the rising interest in IoT devices. According to research, it is possible to divide the load between the main server and local devices using a technology called edge computing. Most commercial IoT and smart home devices depend on cloud servers for processing data. Edge computing suggests using processing locally to save bandwidth and processing power. However, the cloud server can still be responsible for data storage. In this case, the local device does not have to wait for the cloud server to analyze the data and respond [32][35].

Smart home systems have a variety of different users, and the design should consider different people's needs. It is not possible to make a device that satisfies everyone, and the aim should be to fulfill the target group's requirements. It is correct to say that a smart home system is an integration of space, users, and smart devices. For example, scenario-based design can help users complete tasks based on user's actions, and this can be as simple as switching off the lights automatically when residents leave the house or turning up the heating during the winter when users arrive home [24].

4.2.3. Health and elderly care

The world's population is aging, and healthcare costs are growing because of this. The demand for automated healthcare and patient assistance services is growing. Smart home product developers are taking this growing demand into an account. This section will cover some of the benefits and drawbacks of the existing systems linked to the mentioned subject. One of the solutions proposed in the literature is elderly monitoring technology, which is a series of sensors such as infrared motion detectors and magnetic door sensors that are placed in different areas of a house e.g., kitchen, bathroom, and front door to check the irregularities in residents' activities. Usually, people have a routine of living; for example, people wake up and go to sleep around the same time. The sensors look for changes in such activities, and if enough abnormalities are detected, the system triggers a fitting response. [29]

Independent living is one of the issues concerning the elderly population. The user, in this case, may forget an important activity like taking medicine on time, which may result in the individual entering a dangerous state. In addition to the remote monitoring of a smart home's resent which may not be enough, a case study shows that it is possible to develop a system to assist the user in completing daily tasks [6]. An easy-to-use UI is the most important aspect when developing smart home systems for the elderly and a study shows that portable touchscreen devices with audio and video communication ability can fulfill most requirements. Furthermore, an event-based solution results in the automation of many tasks, and the user does not have to specifically interact with the system because an event-based design automatically reacts to certain conditions [43].

In addition to elderly assistance, IoT solutions can remove the pressure on hospitals by remotely monitoring patients at home. Some heart patients need continuous heart rate monitoring and case studies show that this can be done at home thanks to the collected data obtained through sensors and machine learning algorithms. There are some concerns related to the accuracy of the proposed solutions, and ongoing work aims to improve these remaining concerns, such as security concerns, energy efficiency, and data visibility. Health-related data are highly confidential and must be encrypted. However, the data should be visible to the user

in real time, and because most health devices are wearable sensors, energy efficiency plays a crucial role. A device without sufficient power does not have any use [3][15].

4.2.4. Resource management

Enhancing home energy and water usage efficiency is a focus area of smart home systems. Creating a detailed profile of household equipment's energy consumption helps create a better model for saving energy. Smart systems can optimize energy usage by optimally scheduling and controlling household appliances. One of the realized drawbacks linked to the development of resource-efficient systems is finding and purchasing monitoring devices because some cannot be found off the shelf [16][37][48]. Sustainable IoT can have positive environmental impacts. People communicate through a massive network of sensors and IoT devices, and to save energy, product developers must consider the energy consumption of IoT devices in the early development phases, including the planning and design phases [23][40].

4.2.5. Usability

Integration between IoT devices is a challenge for smart home developers. Different manufacturers are following different standards for creating their products, and this can harm usability because most of the time, controlling the smart devices through a centralized system might not be possible. The need for middleware to integrate devices in the same network is an approach that can help address the mentioned problem, and a successful attempt has been made to connect a Rovio service robot to a smart system and automate the tasks. However, because of the large number of existing products, there is still a need for a standard communication channel between smart devices [8].

The designers of smart home devices do not explicitly or systematically consider usability in designing security features. Instead of relying on the technical support team, the users themselves should be able to configure the security features of the smart home systems. Consulting with security experts in the design phase to enhance the usability of the security features is costly, but the extra cost can be justified because cyberattacks are targeting smart homes and even using smart home systems as a hacking tools [10]. Another way to enhance usability is to automate tasks as much as possible by equipping home furniture with sensors and single-board computers. In this case, the user does not have to interact with the system through a dedicated UI. For example, a smart chair can identify the user and trigger a customized predefined event [21][43].

4.2.6. Performance

Using middleware and standard communication protocols has a positive effect on a digital home's performance. A standardized communication protocol allows for the circulation of data between the smart devices, in return resulting in a boost in performance because the devices do not have to independently collect the data and a network of connected devices is devoted to gathering the data, which can then be analyzed by software systems [17]. The importance of communication becomes more visible when talking about smart cities because the collected data from a network of smart homes can contribute to smarter environmental and social decisions [16].

Using standard communication protocols has positive performance effects; they have the potential to enhance developers' productivity. However, analyzing middleware components shows some inhibitors in the code, which indicates the need for further development to

enhance the components [5]. In summary, utilizing middleware in combination with edge computing architectural techniques may potentially boost performance. The current literature review presents the definition of edge computing in the design section; additionally, it is important to mention that bandwidth can be saved and communication delay between the IoT devices and the cloud can be improved by edge computing techniques [35].

4.2.7. Development process

It is essential to take a look at the development process of smart homes and IoT devices; the lack of a systematic approach can result in security and design compromises. According to Gartner, IoT systems would be in 95% of new electronics products, meaning that smart devices have an enormous impact on society, businesses, and the environment. Dividing the product architecture into three layers a UI layer, a communication layer, and a software system layer is a way to make structural improvements and focus on the weaknesses of each layer [33]. The need for flexible and user-friendly solutions is undeniable, and the case study shows that etiquette requirements gathered from the stakeholders, prototyping, and a user-driven design can further improve the product. In this case, the user gets to test the product in the early stages of development, which means the final solution has a greater chance of meeting the requirements [36][43][47].

4.2.8. Knowledge management and education

Knowledge is an important asset for people in general and, in particular, for organizations to grow. Most often, different projects rely on a similar set of data, and keeping a record of the use cases in one project may be beneficial for other smart home projects. Furthermore, knowledge management can have positive environmental impacts; smart home residents can share their experience, for example, in a platform of connected digital homes to help the other residents make better choices linked to resource management [18]. Including the possibility for students to learn how to develop IoT solutions as part of their studies will help produce better smart home systems in the future. Students who participate in such courses have considered it enjoyable and gave positive feedback to the organizers. It is essential to improve the learning process linked to IoT development for students to gain hands-on knowledge and experience in the subject [22].

4.3. Smart home concerns (RQ2)

The current section is dedicated to answering RQ2. Table 6 offers a brief explanation of the benefits and drawbacks linked to the home automation-related topics covered in this paper. The table is summarizing the results provided in section 4.2, in addition, the reader can find sources associated with the benefits and drawbacks in the description column for further and more in-depth analysis. The collected items are based on the authors' analysis of the selected sources for this research.

Table 6. Benefits and drawbacks linked to home automation–related topics

Topic	Category	Description
Security and privacy	Benefits	Accessing the data through security protocols (contracts). [7] Smart home systems can make smart adjustments to privacy protocols [46]. Existing frameworks and services can improve the security of smart products [38].
	Drawbacks	Smart home systems can be used as a hacking tools [50]. Utilizing compromised hardware and insecure data handling [49]. Smart homes are not very accurate enough to decide on their own [46]. Cost reduction can lead to weak security features [38].
Design	Benefits	A well-designed system uses less power to operate [32][35]. Bandwidth usage can be reduced through the design [32][35] A scenario-based design can complete tasks based on users' actions. [24]
	Drawbacks	Some smart devices have to wait for the cloud server to respond [32][35]. The age gap of the users is not taken into account when designing smart homes [24][43].
Health and elderly care	Benefits	Elderly and patient monitoring is possible with the help of smart home systems [3][29]. Activity monitoring looks for changes in a patient's routine and notifies the interested parties [29]. An elderly-friendly smart home makes independent living possible for its users [6].
	Drawbacks	The accuracy of patient monitoring systems is still questionable [29]. Security, energy efficiency, and data visibility are other concerns related to patient monitoring features [15].
Resource management	Benefits	Reducing energy and water consumption is possible when utilizing smart home products [16][37][48]. Creating an energy consumption profile of household equipment [16].
	Drawbacks	Purchasing monitoring devices is difficult because some cannot be found off the shelf [48].
Usability	Benefits	Developers can use middleware to integrate the smart devices, and the user can control them through a centralized system [8]. Automating tasks with smart home products [21].
	Drawbacks	Integration between IoT devices is a challenge [8]. Usability in designing security features for smart home devices is not explicitly or systematically considered [10].
Performance	Benefits	A standardized communication protocol boosts performance because the devices do not have to independently collect the data and they can share the tasks [17]. Edge computing architectural techniques may potentially boost performance [35].
	Drawbacks	Middleware components show some inhibitors in the code [5].
Development process	Benefits	Requirements gathering from the stakeholders, prototyping, and a user-driven design can further improve the product [33].
	Drawbacks	The lack of a systematic development approach can result in security and design compromises [43][47].
Knowledge management and education	Benefits	Keeping a record of the use cases in one project may be beneficial for other projects [18]. Knowledge management can have positive environmental impacts, and smart home residents can share their experiences to help others make better choices [18].
	Drawbacks	It is essential to improve the learning process linked to IoT development [22].

4.4. Ways to optimize smart home systems (RQ3)

The answer to the last research question (RQ3) is discussed in this section. The aim is to provide brief guidelines based on the information found in the literature for improving smart home products, both in terms of their functional and non-functional features. The table below is divided into eight parts containing the related recommendations. The recommendations are collected after analyzing the selected sources (Appendix 1) and more information can be found in section 4.2 which covers the eight mentioned topics. The recommendation is for the reader to look for the provided sources in the table below to gain a better and more detailed understanding of the topic.

Table 7. Recommended guidelines for the selected topics

Topic	Guidelines
Security and privacy	Users need to have more control over the data flow. [7] Avoid using compromised hardware and use data encryption. [49] Allocate funds for developing the security features. [38, 49]
Design	Divide the load between the main server and the local devices. [32, 35] Design based on the target group's requirements. [24, 43] User-friendly design for the security features. [10]
Health and elderly care	Develop an easy-to-use and easy-to-control system, such as a voice-controlled system. [43] Automate tasks based on user activity. [6, 29] Provide wearable sensors to monitor users' health. [15]
Resource management	Creating an energy usage profile for the home equipment to optimize the energy usage of such devices. [16]
Usability	Middleware can provide the possibility of controlling the smart device through a centralized system. [8] Consult with the design expert to improve the product. [10]
Performance	Edge computing architectural techniques help to save bandwidth and processing power. [35]
Development process	Detailed requirements gathering from the stakeholders, prototyping, and a user-driven design can improve the product. [33]
Knowledge management and education	Documenting the system's use cases and developing solutions can help to improve future products. [18]

5. Discussion and lessons learned

Smart home systems have been constantly gaining popularity over the past few years, as shown in [Figure 1]. Furthermore, IoT and smart homes are inseparable parts of software development and software engineering research. The presented research may contribute to improving smart home products and the related development process.

The current paper presents some of the use cases for smart home systems, for example, smart healthcare. Smart home developers must find and research the problems they are trying to solve. The next step is to find a solution to the discovered problem by examining different ideas and scenarios. Prototyping and observing the end-user when interacting with the prototype can help improve the design and better equip the product with features that stakeholders require. Nevertheless, features like data security and user privacy should not be compromised, even though the user may not understand their importance immediately [49].

There is an important lesson to learn from the case studies. Smart home designers and developers must explain the real effect of weak security protocols to stakeholders to obtain adequate resources for fixing and enhancing security issues. The education system also plays an important role in training the computer since students have a critical viewpoint on security designs. It would be easier to discuss the required features for a product when both the

developers and stakeholders are on the same page about the importance of the features in question.

Security and privacy improvements are constantly raised in the literature, and most of the recommended improvements are basic security enhancements such as encryption [49]. However, based on the content of Table 5, these security issues are not solved. It is almost impossible to implement flawless software. However, allocating more resources to improve the security level of smart devices can reduce security issues [13]. A case study shows that having a clear architecture and development process is beneficial in implementing the different features (UI, performance, security, etc.) of a product [33]. For example, it may be the case that enough attention is not given to usability in favor of performance improvements or vice versa [12][27]. A clear development process that does not skip any of the steps will lead to better results [33]. Documentation is an important step in the development process. Documentation helps share some ideas between the development teams and not to repeat the mistakes made before.

Following a clear development process is a must when talking about enterprise products that can potentially compromise people's privacy. The important lesson here is to find a process that is acceptable to the entire team and that can result in the development of a product based on the gathered requirements. Each stage of the process must be considered and not skipped. Dividing the development into separate layers, such as UI and communication layers, can help direct the focus on the entirety of each layer and its related features, which results in a more complete product.

In summary, the study results recommend producing smart home systems that can solve real problems through proper planning and interactions with actual users. The development team should consider both functional and nonfunctional features, document the development process, and further improve the product as technology advances and user requirements change. The current paper covered eight topics related to the three high-level phases of the development process (planning, implementation, and improvement). Topics such as resource management and elderly care are linked to the planning phase because the development team is discovering the user requirements and use cases. Other topics such as security, privacy, and performance are related to the implementation phase, and finally, topics such as knowledge management and education are linked to improving the product's functionality and stability.

6. Conclusion

The current paper has examined the status of home automation, including the benefits and drawbacks of such systems. Four digital libraries are selected to research published case studies related to the selected number of smart home domains. Papers with distinct titles that are written in English and are more than three pages are selected as research material. Furthermore, thematic analysis was performed to extract data linked to the research questions to study the current state of the art and to identify the benefits and drawbacks of smart home systems, as described in the literature. The positive impact of smart home products in automating some daily tasks has been shown. The research material is divided into eight topics, and Table 5 presents the distribution of the study topics per year.

As mentioned earlier and presented in Figure 4, security and privacy are the most popular research subjects. Table 5 shows that this topic has been covered since 2013. One can assume that this is because of the ongoing interest in current smart home products. Furthermore, studies show that even commercial products have security vulnerabilities [10][49]. The authors recommend going back to the whiteboard and focusing on solving the issues early on,

in the planning and the design stage; this can result in a chain reaction and solve the other issues mentioned in this paper.

[Figure 4] also shows that not enough attention is given to knowledge management and home automation-related education. A knowledge management platform can help developers learn from each other's experiences, further improve their products, and solve real problems through proper planning and interactions with actual users [18]. More courses in the educational system, with a focus on home automation and IoT, may result in the development of better products. Studies show that such courses are welcomed by students [22]. In conclusion, more attention should be given to education and knowledge management to improve design and security, privacy, and performance. Additionally, developers should not skip any of the three layers of the development architecture (UI layer, communication layer, and software system layer) because each stage is dedicated to addressing existing weaknesses in smart home products [33]. Following the mentioned recommendations in [Table 7] and this section may improve future smart home products and set a baseline for future research.

This document is based on academic case studies. However, for future work, industrial contributions that are usually considered grey literature may be included. Grey literature was out of the scope of this paper.

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Appendices

Realized study topic(s) per each analyzed paper

Topic	List of related paper ids
Security and privacy	S1, S2, S4, S5, S6, S10, S12, S14, S15, S31, S32, S34, S37, S38, S48
Design	S1, S5, S6, S11, S15, S18, S19, S26, S39, S40, S44, S45
Health and elderly care	S1, S7, S13, S20, S21, S23, S26, S28, S36, S41, S46, S49, S52, S55
Resource management	S3, S8, S15, S16, S23, S24, S27, S35, S39, S47, S56
Usability	S4, S11, S15, S20, S25, S29, S43, S44, S45, S50, S54
Performance	S8, S9, S17, S19, S33
Development process	S6, S22, S41, S42
Knowledge management and education	S3, S30, S51, S53

Id	Document's title
S1	Emotion-oriented requirements engineering: A case study in developing a smart home system for the elderly
S2	Cyber-physical systems information gathering: A smart home case study
S3	Knowledge Management in Construction Using a SocioBIM Platform: A Case Study of AYO Smart Home Project
S4	Integration of service robots in the smart home using UPnP: A surveillance robot case study
S5	Factoring User Experience into the Security and Privacy Design of Smart Home Devices: A Case Study
S6	Make it and Break it: An IoT Smart Home Testbed Case Study
S7	Maintaining multiple sclerosis patients' quality of life: a case study on environment control assistance in a smart home
S8	Proposing the need for a protocol standard for Internet of Things: Internet of Things water heater case study
S9	Door and light control prototype using Intel Galileo-based Internet of Things: (Case study: Embedded and robotics laboratory, department of computer engineering, Diponegoro University)
S10	Internet of Things (IoT) in Enterprise Systems for Process Improvement: A Case Study in Home Security
S11	An Analysis of the Impact of Uncertainty on the Internet of Things: A Smart Home Case Study
S12	Review of Ethereum: Smart home case study
S13	Monitoring and detecting outliers for elder's life activities in a smart home: A case study
S14	Context-aware door access control on private room using fuzzy logic: A case study of smart home
S15	The Case Study of Smart Home in LH
S16	Smart home appliances modeling and simulation for energy consumption profile development: Application to Moroccan real environment case study
S17	Describing the Internet of Things with an ontology: The SusCity project case study
S18	Edge-Cloud Collaborative Processing for Intelligent Internet of Things: A Case Study on Smart Surveillance
S19	Edge Computing for the Internet of Things: A Case Study
S20	Rapid prototyping Internet of Things solutions through a model-driven approach: A case study in AAL
S21	An Internet of Things (IoT) Management System for Improving Homecare - A Case Study
S22	How do Startups Develop Internet-of-Things Systems - A Multiple Exploratory Case Study
S23	Internet of Things for smart homes: Lessons learned from the SPHERE case study
S24	A case study of the internet of things: A wireless household water consumption monitoring system
S25	A Case Study for Workflow-Based Automation in the Internet of Things
S26	Fog Computing in Healthcare Internet of Things: A Case Study on ECG Feature Extraction
S27	Application of the Internet of Things (IoT) Technology in Consumer Electronics - Case Study
S28	Logging mechanism for Internet of Things: A Case Study of Patient Monitoring System
S29	Internet-of-Things Based Smart Resource Management System: A Case Study Intelligent Chair System
S30	Integrating the Internet of Things (IoT) into STEM undergraduate education: A case study of a modern technology infused courseware for embedded system course

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S51	A Case Study of Project-based Learning on Internet of Things Course
S52	Edge-Assisted Control for Healthcare Internet of Things: A Case Study on PPG-Based Early Warning Score
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S56	Energy-Aware Smart Home Planning: A Real Case Study in Montevideo, Uruguay

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