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EVOLUTION OF ARCHITECTURAL SOLUTIONS FOR INTELLIGENT HOMES

The overarching task to create the intelligent environment for human existence becomes the hot area of application of recent developments in information technology. The large number of articles dedicated to ambient intelligence creates the need for analysis and reflection on different aspects of this. The article aims to provide comparison and insights into the evolution of architectural solutions for intelligent homes. It starts with the definition of main terms, provides the requirements for smart home systems. The analysis of recent surveys in intelligent homes allowed to build the concept map of the area. Next, different architectural solutions proposed in literature are discussed using multi-layer model. The recent developments in the security and access rights management for intelligent homes were also analyzed. The article explores the evolution of architectural solutions for intelligent homes that ensure comfort, security, and energy efficiency in residential spaces. By analyzing historical trends, modern innovations, and promising technologies, key stages of development in architectural solutions for smart homes are identified. The focus is on integrating Internet of Things (IoT) technologies, automation systems, energy-efficient technologies, and their impact on architectural planning and residential design. The article covers aspects such as the adaptability of architectural solutions to technological changes, the integration of smart systems into building structures, the provision of convenient management and monitoring of home systems, and the enhancement of energy efficiency and environmental sustainability of residential buildings. Issues of security and privacy in the context of smart technologies are also addressed. Research methods include literature analysis, comparison of existing architectural approaches and technological solutions, and expert evaluation. The results of the study demonstrate how architectural solutions have evolved from traditional approaches to modern integrated systems that ensure high levels of comfort, security, and efficient resource use. The scientific novelty of the study lies in the comprehensive analysis of the evolution of architectural solutions for intelligent homes, focusing on technological innovations and their impact on the residential environment. The article offers practical recommendations for architects, designers, and developers of smart systems, contributing to the creation of comfortable, secure, and environmentally sustainable living spaces.

Keywords: Evolution of architectural solutions, smart homes, internet of things, automation systems, energy efficiency home, security residential comfort, integrated systems, technological innovations, sustainability home system, management privacy.

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ЕВОЛЮЦІЯ АРХІТЕКТУРНИХ РІШЕНЬ ДЛЯ РОЗУМНИХ БУДИНКІВ

Основне завдання створення інтелектуального середовища для існування людини стає гарячою сферою застосування останніх досягнень інформаційних технологій. Велика кількість статей, присвячених інтелекту навколишнього середовища, створює потребу в аналізі та роздумах над різними аспектами цього. Метою статті є порівняння та розуміння еволюції архітектурних рішень для інтелектуальних будинків. Починається з визначення основних термінів, наводиться вимоги до систем розумного будинку. Аналіз останніх досліджень в інтелектуальних будинках дозволив побудувати концептуальну карту території. Далі обговорюються різні архітектурні рішення, запропоновані в літературі, з використанням багатошарової моделі. Також були проаналізовані останні розробки в сфері безпеки та управління правами доступу для інтелектуальних будинків. У статті досліджується еволюція архітектурних рішень для розумних домів, що забезпечують комфорт, безпеку та енергоефективність житлових приміщень. На основі аналізу історичних тенденцій, сучасних інновацій та перспективних технологій, визначено ключові етапи розвитку архітектурних рішень для інтелектуальних будинків. Увагу приділено інтеграції технологій Інтернету речей (IoT), систем автоматизації, енергоефективних технологій та їх впливу на архітектурне планування і дизайн житлових приміщень. Стаття охоплює такі аспекти, як адаптивність архітектурних рішень до технологічних змін, інтеграція розумних систем у будівельні конструкції, забезпечення зручного управління та моніторингу домашніх систем, а також підвищення енергоефективності та екологічної стійкості житлових будинків. Окремо розглянуто питання безпеки та конфіденційності в контексті використання розумних технологій. Методи дослідження включають аналіз літератури, порівняння існуючих архітектурних підходів та технологічних рішень, а також експертне оцінювання. Результати дослідження демонструють, як архітектурні рішення еволюціонували від традиційних підходів до сучасних інтегрованих систем, що забезпечують високий рівень комфорту, безпеки та ефективного використання ресурсів. Наукова новизна дослідження полягає у комплексному аналізі еволюції архітектурних рішень для розумних домів з акцентом на технологічні інновації та їх вплив на житлове середовище. Стаття пропонує практичні рекомендації для архітекторів, дизайнерів та розробників розумних систем, що сприяють створенню комфортних, безпечних та екологічно сталих житлових приміщень.

Ключові слова: еволюція архітектурних рішень розумні будинки, інтернет речей, системи автоматизації, енергоефективність, безпека житла, комфорт житлових приміщень, інтегровані системи, технологічні інновації, архітектурне планування, управління домашніми системами, конфіденційність.

Introduction

The development of computer hardware and information technology, resulting in the growth of computing power and the reduction of the cost of computations is reflected in the evolution of the usage architectures [1]. Thus, in the early stages of the computer era, users were taking turns in working with large computers (mainframes) or programs were processed in batches from multiple users. Next, when time-sharing systems appeared, users could work simultaneously, while the processing unit was switching its processing power between the processes of users. The advent of personal computers allowed us to supply each user with a dedicated computer. With the appearance of

the Internet and mobile devices, the number of computers used by a single user has increased even more. According to statistics, the average number of devices and connections per capita globally was projected to grow from 2.4 in 2018 to 3.6 by 2023. This includes various forms of devices, such as smartphones, tablets, and IoT devices [2]. In regions like North America, the average number of devices per person is significantly higher. For example, by 2023, it was estimated that individuals in North America would have around 13.4 devices each, while in Western Europe, the average was expected to reach 9.4 devices per person [3]. In the United States, the average number of connected devices per household reached 17 by 2023 [4]. In parallel with the growth of the use of computing technology by humans, with the development of Internet of Things (IoT) we observe the substantial growth of M2M (machine to machine) information exchanges. Internet of Things (IoT) has become a system in which people, processes, data, and things connect to the Internet and each other. It is projected that M2M connections will grow 2.4-fold, from 6.1 billion in 2018 to 14.7 billion by 2023 (Fig 1). According to estimates there will be 1.8 M2M connections for each member of the global population by 2023 [2]. The proliferation of devices connected with IoT networks and the recent advances in Artificial Intelligence (AI) creates the possibility to implement the old idea of making the intelligent ambience for humans which would support and provide for fulfilled life. This survey is organized as follows. In the first part we provide the definitions of most important terms in ambient intelligence. We also discuss the requirements and purpose of ambient intelligence as a foundational constraint along with basic function decomposition for such systems. In the second part we review the recent surveys in the area of intelligent homes, their methodology and build the concept map of terms and relationships. The third part is dedicated to the review and analysis of the evolution of architectural solutions in the area of smart homes using the multi-level model. In the last part we briefly discuss the recent developments and trends in security and access rights management of smart home.

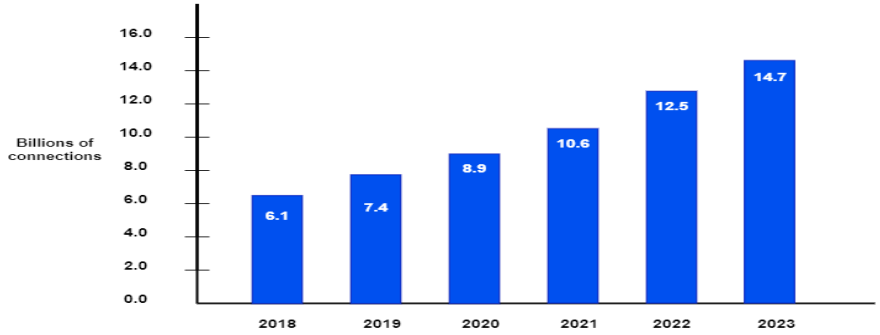

Fig. 1. The rate of M2M connections growth

Vision and requirements for intelligent home system Terms and definitions

The evolution of intelligent ambience follows the Galls law stating that every complex system evolves from simple systems [5]. In development, it is important to start with minimal viable product, adding complex features iteratively.

Thus, the implementation of the idea of ambient intelligence started with the development of simple **home automation** systems, including smart home appliances monitored via a central controller. Typically, home automation uses the Internet of Things (IoT) network. There are following definitions of home automation:

- "A home automation system is a network comprising various home sensors, devices, and appliances (such as lighting, fans, air conditioners, entertainment systems, surveillance cameras, electronic doors, and alarm systems) designed to monitor and manage the home environment without human intervention". [6]
- Home automation systems "typically consist of a central controller that manages appliances like power outlets, temperature sensors, lights, and security systems. They enable users to control and monitor home appliances remotely through devices such as smartphones, laptops, tablets, and desktops, offering benefits like energy savings, ease of use, and improved quality of life" [7]
- [8] uses the term **Domotics** to designate the research and development field dedicated to intelligent homes.

The definition of **smart home** stresses the usage of simple intelligence:

- A smart home is a residence equipped with technologies that include sensors, wired and wireless networks, actuators, and intelligent systems [9]

The next stage of development of ambient intelligent systems in homes used the term **intelligent home** with such properties:

- Intelligent homes are defined as environments that integrate IoT devices and cloud services to optimize various aspects of home management, including energy use, security, and comfort. These systems enable real-time data collection and analysis to provide adaptive and personalized services [10].
- Intelligent homes utilize data mining and machine learning techniques to create models that recognize and respond to residents' activities. This approach aims to improve the automation of routine tasks and enhance overall home efficiency [11].

- Another perspective describes intelligent homes as knowledge-driven environments where data from various sensors and devices is used to understand and predict user behaviors, thereby facilitating proactive assistance and improved user experience [12].
- Emphasizing user-centric design, intelligent homes aim to provide seamless and intuitive interactions, enhancing the quality of life by making daily activities easier and more efficient. These systems are designed to adapt to the specific needs and preferences of the users [13].

The availability of large numbers of interconnected devices as a basis for various kinds of applied systems is implied in the concepts of **pervasive and ubiquitous computing**. Pervasive computing studies the provision of distributed computational services which are context-aware and travel with the user seamlessly across different environments [14]. Ubiquitous computing is more broadly associated with Human Computer Interaction whilst pervasive computing as a stronger emphasis on devices, their networking and the processing of the data they produce.

In the context of applications in ambient intelligence, **artificial intelligence** (AI) describes the ability of device to perceives its environment and take actions that maximize its chance of successfully achieving its goals The ideal state of artificial intelligence is thinking humanly, thinking rationally, acting humanly, and acting rationally. [15].

The shift from the intelligent home to the larger notion of intelligent ambience is reflected in the terms of smart, intelligent environments and ambient intelligence.

Smart environment is an environment enriched with sensing devices, some of them with capability to store and process data locally [14]

An **intelligent environment** is one in which the actions of numerous networked controllers (controlling different aspects of an environment) is orchestrated by self-programming pre-emptive processes (e.g., intelligent software agents) in such a way as to create an interactive holistic functionality that enhances user experiences. Intelligent environments build on all the previous concepts and aims at creating systems which integrate a Smart Environment with Ambient Intelligence and is based in the pervasive/ubiquitous availability of services. [14]

Ambient intelligence is

- A developing technology that will increasingly make our everyday environment sensitive and responsive to our presence [1]
- The presence of a digital environment that is sensitive, adaptive, and responsive to the presence of people [1]
- A digital environment that supports people in their daily lives in a nonintrusive way [1]
- refers to the intelligent software that supports people in their daily lives by assisting them in a sensible way [14]

Summarizing, from technological perspective ambient intelligence is based on the large number of sensors and connected and interacting computing devices, using the artificial intelligence algorithms to provide services to people in the adaptive and inobtrusive way.

Foundational features and principles of ambient intelligence systems

When thinking about the ambience intelligence we should align our effort with the ultimate goal, the mission of it. The vision of intelligent environments helping humans to live fulfilled lives is a recurrent theme in literature on smart homes and ambient intelligence.

However, there are different understandings of the notion of human well-being. [16] mentions that two approaches for promoting well-being of users emerged. *Hedonic* approach focuses on supporting positive affect and emotions, happiness, removing hurdles and struggles from life. *Eudamonic* approach argues for the meaningful life, values self-realization, viewing well-being as an effort to fully reveal the person's potential, including necessary and beneficial struggles. The common understanding today is [16] that these approaches are complimentary, and well-being is a multi-dimensional construct.

Ambient intelligence systems follow the principles of Human-centered design, which can be summarized as follows.

1. **User-Centric Approach**. Design process begins with understanding the users, their needs, preferences, and daily routines. This involves extensive user research, including interviews, observations, and surveys to gather insights about the users' lifestyle and challenges [17]

2. **Accessibility and Inclusivity**. Intelligent homes should be accessible to all users, including the elderly and people with disabilities. This involves designing interfaces that are easy to use and providing multiple modes of interaction (e.g., voice, touch, gesture). [18]

3. **Adaptability and Personalization**. The system should adapt to the changing needs and preferences of the users. Personalization features can be learned from user behavior and adjust settings accordingly, such as adjusting lighting, temperature, and security settings based on the time of day and user habits [19]

4. **Seamless Integration**. The technology should integrate seamlessly into the home environment, minimizing obtrusiveness and ensuring that the user's interaction with the system feels natural. This includes integrating with existing devices and infrastructure. [20]

5. **Privacy and Security**. Ensuring the privacy and security of user data is paramount. Users should have control over their data and be informed about how it is being used. Security measures should protect against unauthorized access and breaches [21].

Human-Centered in Intelligent Homes implement such features.

1. **User-Friendly Interfaces**. Interfaces should be intuitive and easy to navigate. This can include voice-activated systems, touchscreens, and mobile applications that allow users to control various aspects of their home effortlessly.

2. **Being context aware**. Intelligent homes use sensors and AI to understand the context of the environment and the user's activities. This allows the system to provide relevant responses and automate tasks without explicit user commands.

3. **Using feedback to learn and improve themselves**. Systems should provide feedback to users about their interactions and the state of the system. This can include visual, auditory, or haptic feedback that helps users understand the system's actions.

4. **Proactive Assistance**. Intelligent homes can anticipate user needs and provide assistance proactively. For example, a smart refrigerator can notify users when they are running low on groceries and suggest items to order.

5. **Energy Efficiency and Sustainability**. Designing for energy efficiency not only helps the environment but also reduces costs for users. Smart homes can optimize energy usage by controlling lighting, heating, and appliances based on occupancy and usage patterns.

Ideally, the system with ambient intelligence should become so natural for end user that it will require no cognitive effort to deal with. The problem in the implementation of such highly tailored to personal needs system lies in the variety and volatility of human needs and preferences. This requires that every implementation of intelligent home to be unique, which is not commercially viable. This problem could be solved by building adaptable and self-learning home automation systems, using artificial intelligence.

The functions of Intelligent home system

The article [16] proposes to base the functions of intelligent home on the World Health Organization International Classification of Functioning, Disability and Health (ICF) which lists all human functions and activities. In the ICF, the concept of "functioning" encompasses all aspects of body functions, activities, and participation. Conversely, "disability" is a broad term that includes impairments, limitations in activities, and restrictions in participation. Fig 2 shows the relationships between groups of factors from ICF model used as a basis for conceptualization of intelligent home.

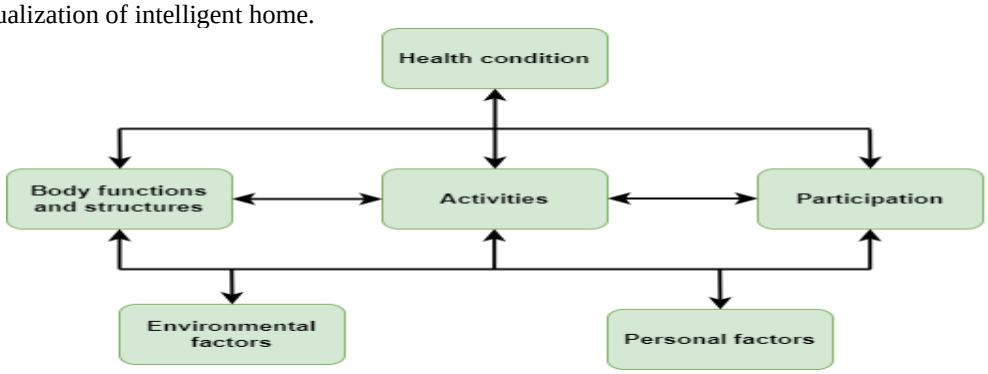

Fig. 2. Using ICF model for conceptualization of intelligent home

The authors [14] emphasize the need for intelligent home to recognize the situations where it can help and is allowed to offer its services. Those services should be delivered according to needs and preferences of users. Intelligent system should not demand the technical knowledge from its users. Privacy and safety should be prioritized. User should be in command of system, not system commanding user. The article [1] proposes to consider Intelligent home in functional areas of Sensing, Reasoning, Modeling, Acting and Security. It also highlights the importance of the implementation of Decision making and Preemptive reasoning in such homes. The article [22] explores the concept of the Social Internet of Things (SIoT), which combines social networks with IoT devices to develop environments capable of intelligent interaction with users. It examines how these environments can facilitate social interactions, enhance quality of life, and deliver personalized services tailored to user preferences and behaviors. SIot is used all interconnected things all over the world to create a social network based on common interests and motivation to provide better services to end-users. Another intelligent home functional decomposition [23] considers smart home through application areas: Energy management, Security, Health, Entertainment, Environment.

Trends in ambient intelligence development – the review of surveys

Given the popularity and intense development of intelligent ambience systems, the abundance of works both in scientific and technical sides of the problem, there's many surveys [1, 23-26] aiming to summarize and find

trends in the progress of this area. The review of these works helps to understand the dynamics and structure of tasks/problems in the intelligence ambience development.

For the overall understanding of concepts and relationships in the area of intelligent homes it is useful to consider a concept map derived for this area from corresponding sources (Fig. 3)

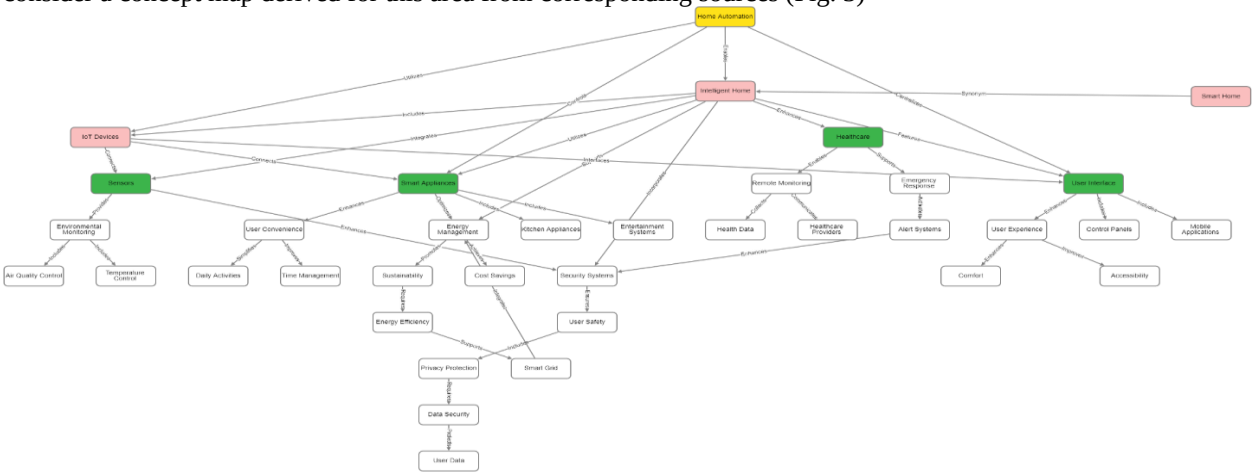

Fig. 3. The concept map of terms and relationships in the area of intelligent homes

This map groups concepts under intelligent homes application areas, reflecting the current trends and dependencies perceived in literature on this topic. Let's consider intelligent home and smart technologies area surveys in more detail. The article [24] provides in-depth analysis of smart homes technologies and development areas, stating that smart homes apply previously developed solutions for voice and face recognition, image processing; virtual and augmented reality and robotics. The connectivity is provided typically by IoT networks. Authors split the keywords describing the area in groups corresponding to Science, Technology, Development, Social aspects of smart home development. They specify the prevailing problems resolved by smart home technologies, such as Healthcare and quality of life, security and data management, optimal sustainable energy management. The authors of [24] also analyze the distribution of publications in ambience intelligence and smart homes by publishers, publication types, geographical areas, popular aspects, and scientific methods used looking for development trends. However, [24] focuses mostly on technological, social and bibliographic aspects of smart home development, missing for example the analysis of architectural solutions, scientific problems or use of artificial intelligence as a central point of intelligent ambience. The work [25] uses the main path analysis method to track the threads of development in the intelligent home area based on analysis of research articles citations. The articles were reviewed taking in consideration the g- and h- indexes of publishing authors in the following application areas: healthcare, recognition sensors, energy management, IoT, augmented reality systems, monitoring technologies. In all areas the growth dynamics in the year range 2000-2016 was plotted. However, being purely bibliographical, the research [25] doesn't provide insights related to the typical solutions or existing problems in intelligent home development. In [23] paper provides a comprehensive explanation of the concept of smart home, its elements, application areas and services, review of related works, challenges and future direction. The unique perspective of this article is that it considers the smart home as the development and application of technologies, stemming from the Internet of Things. The application areas of smart home, according to authors are Healthcare, Environment, Energy Management, Entertainment, Security and Safety.

The article [26] focuses on the uses of Artificial Intelligence in intelligent homes. Similarly to [24,25] authors are providing extensive literature and product analysis. The authors extracted the six functions of products with AI in smart homes: energy management, entertainment system, healthcare, personal robot, intelligent interaction, and security. Next, they grouped the AI functions in smart homes into six clusters, such as activity recognition, data processing, decision-making, image recognition, prediction-making, and voice recognition. Data processing included data mining, semantic analysis, and rule-based technologies. In [26] two patterns of interaction between users and smart home implementations of AI are found. The first one includes the end user giving commands and controlling each smart device separately. Second one has a central intelligent controller managing smart devices. The end user interacts with this controller unit. In the first approach the intelligence is distributed between the smart devices, in second – they are intelligently coordinated by controller. The study [26] found that intelligent interaction and coordination of functions is becoming more and more important both in literature and products, so the smart homes in future will be based on the interaction between people and the intelligent environment to make buildings more sustainable and personalized.

An article [1] analyses the notion of ambient intelligence (AmI) and existing technologies contributing to its the development. As a result of literature analysis, it was found that AmI features include being Sensitive, Responsive, Adaptive, Transparent, Ubiquitous, and Intelligent. The main contributing technologies and functions of AmI are intelligent sensors, reasoning and modeling, making actions, interaction with end users via adaptable

interfaces, providing security and privacy. The reasoning function is further divided into modeling, activity prediction and recognition, decision-making, spatial and temporal reasoning (Fig 4) [1]. Human interaction with ambient intelligence should be context-aware, using natural and seamless interfaces. The analysis of surveys shows that ambient intelligence is built on the top of multiple technologies, each one being the area of independent and active development. Some of them provide low-level services such as connectivity and communication (IoT), getting information from environment (sensors). Other, such as Security and Privacy, relate more to the general issues of all kinds of information systems, not specifically to the intelligent homes. The most important part of ambient intelligence, in our opinion, is artificial intelligence, which encompasses not only reasoning and modeling, but also intelligent perception (sensors) and intelligent actions. The solutions of artificial intelligence are reflected in the architecture of intelligent homes.

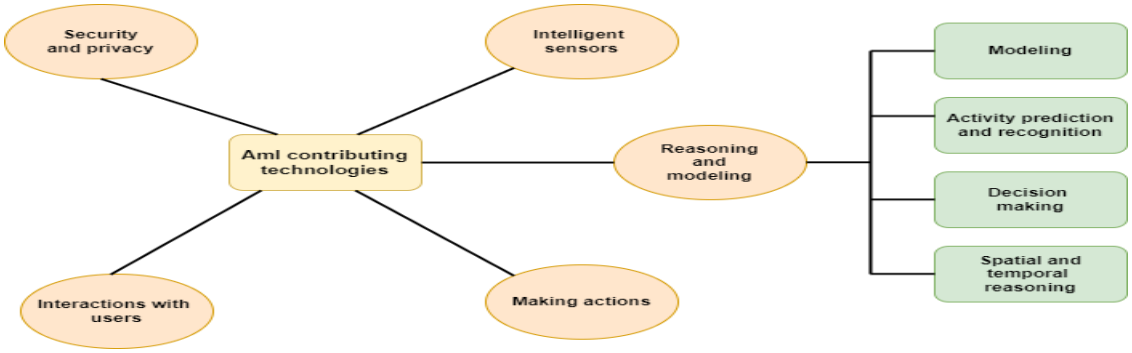

Fig. 4. Technologies, contributing to ambient intelligence

The analysis of architectural solutions for intelligent home

The architecture of an information system refers to its structure and components and how they work together [27]. It encompasses:

1. Hardware: Physical devices like computers, network equipment, and peripherals.
2. Software: Programs and data that instruct the hardware.
3. Network Communications: Connections to other systems and devices.
4. Data: Raw facts processed by the system.

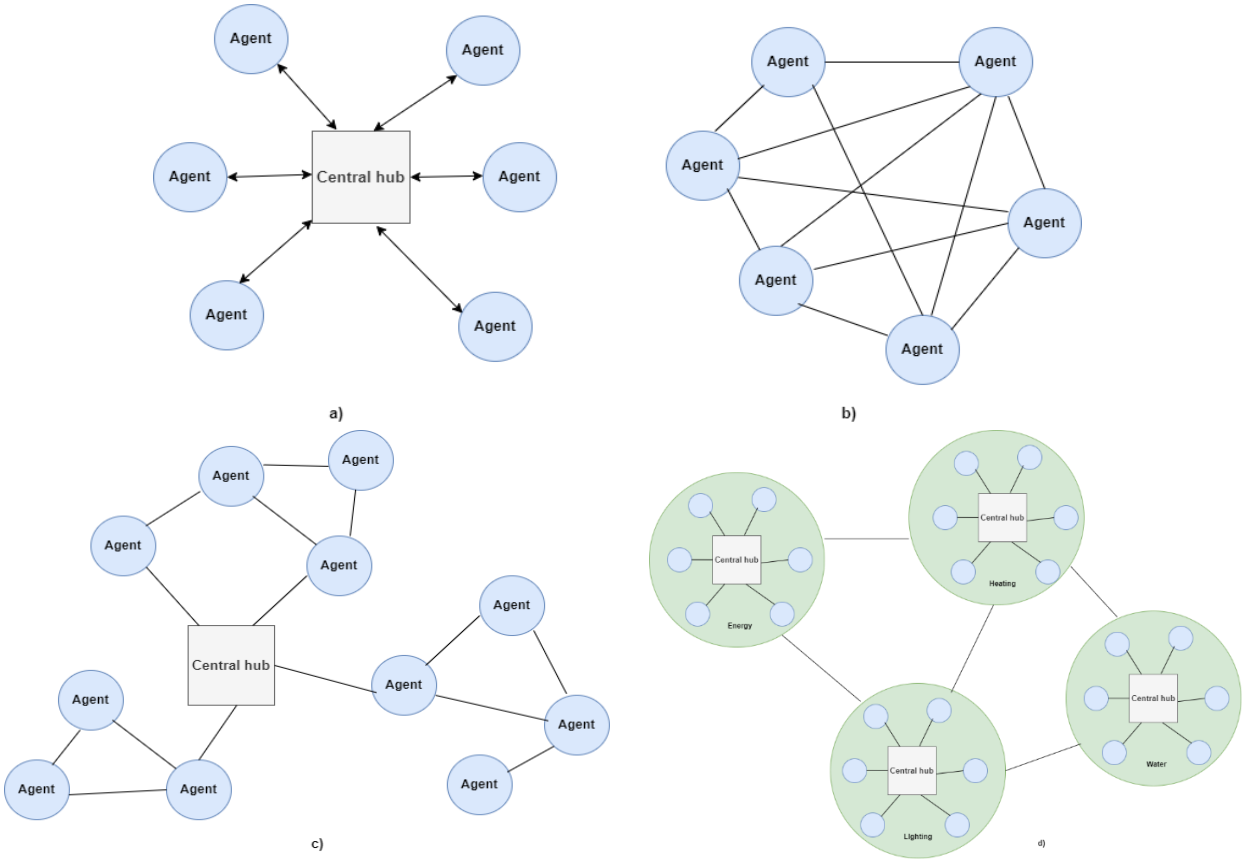

Figure 5. The network topologies of smart home networks:
a) centralized network; b) mesh topology; c: hybrid cluster network; d) alternative hybrid network

5. People: Users who input, output, and use the data.
6. Processes: Rules and procedures defining how the system operates.

The analysis of the evolution of intelligent home architectures illustrates the challenges standing in intelligent home implementation and proposed solutions.

The early works on home automation systems [28] presented the vision of such a system. It focused mainly on providing data communication within a home network which can be used by all products as a general-purpose data highway supporting information transfer and control. The article [28] discusses the need for diverse network options in home systems due to varying data rates and cost considerations, emphasizing the importance of multiple network choices for different applications. First home automation devices performed specific functions (such as doorbell, or surveillance camera), implemented in local device agent. They were not integrated with other home-automation devices and were devoid of intelligence. In the next stage, when other devices appeared, they were linked via a common hub, forming a centralized network. Later, more sophisticated topologies emerged, such as mesh, hybrid cluster networks [29] featuring multiple hubs, or direct communication between agents (Fig. 5.) The architectures of intelligent home today typically follow the multi-layered model. In its simplest form it is presented in [30]. In the lowest level is physical layer, including sensors and actuators. The purpose of this layer is to gather data from the environment and perform actions. Intermediate layer provides data processing capabilities, including intelligence. The application layer consists of applications which are using smart home system. Not every kind of smart home system relies on complex data processing. For example, in [31] is described a simple, smartphone and chat-bot based system, which interacts with home devices via the Internet. In general, the evolution of smart home architectures is going in the direction of increasing intelligence, gathering and analyzing more data and proposing more functions. In some way intelligent home architectures are mirroring and reusing the important solutions developed in other areas of information technology. Thus, in [8] an architecture for a smart home is presented, based on service-oriented architecture with dynamic service compositions generated by AI (Fig.6). As a result, the convenience and security for end-users is enhanced. The intelligent home architecture proposed in [8] has typical sensor (perception) and application layers, but the proposed solution resides in the middle layer. The author highlights the problem of large variety of users, the changing situations and the volatility of intelligent home environment and states that this problem could not be solved in traditional service-oriented systems. The authors propose to use rule-based artificial intelligence system to select the relevant composition of services based on the current context.

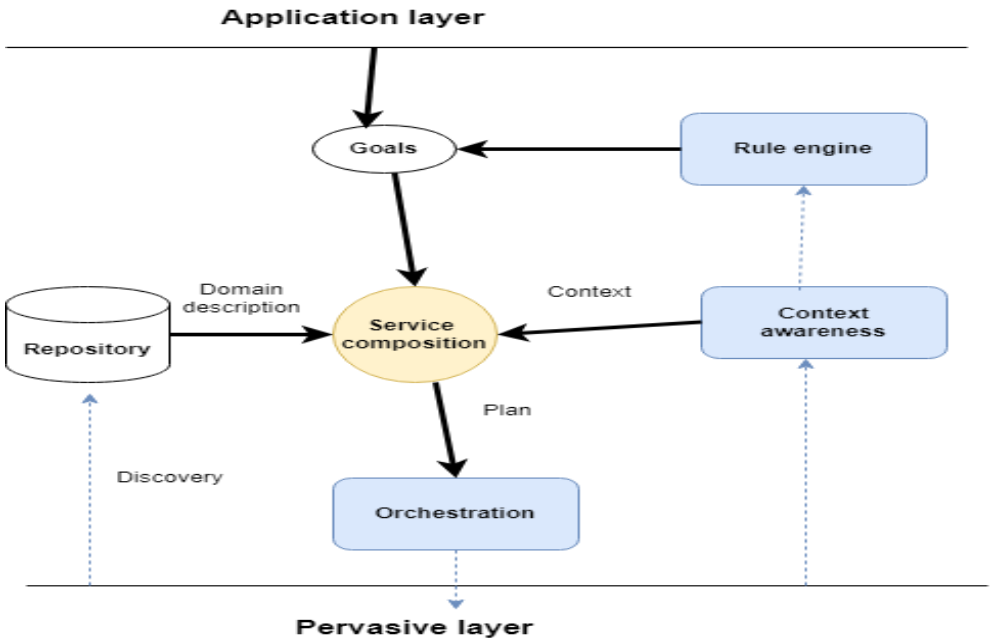

Fig. 6. The architecture of intelligent home based on service composition

Authors in [32] focus on the implementation of intelligent agent control system taking in consideration the hierarchy of goals, proposed by Hamilton [33-34] (Fig. 7). In this hierarchy the high-level goal could be decomposed into tasks, immediate intention, immediate goal, actions and movements. In the proposed architecture each task and goal are performed using the models of environments including relevant elements and their relationships. In each level of model, the changes in the models are planned using the environments and on the last level translated into the sequence of actions (Fig 8). The work [35] focuses on building smart appliances. The intelligent home architecture is based on Model-Based Systems Engineering (MBSE) and a Multi-Agent-System (MAS) approach. These systems exhibit intelligent, self-optimizing behavior at the individual appliance level, which is then scaled up to achieve a global optimum by connecting appliances and negotiating for available energy.

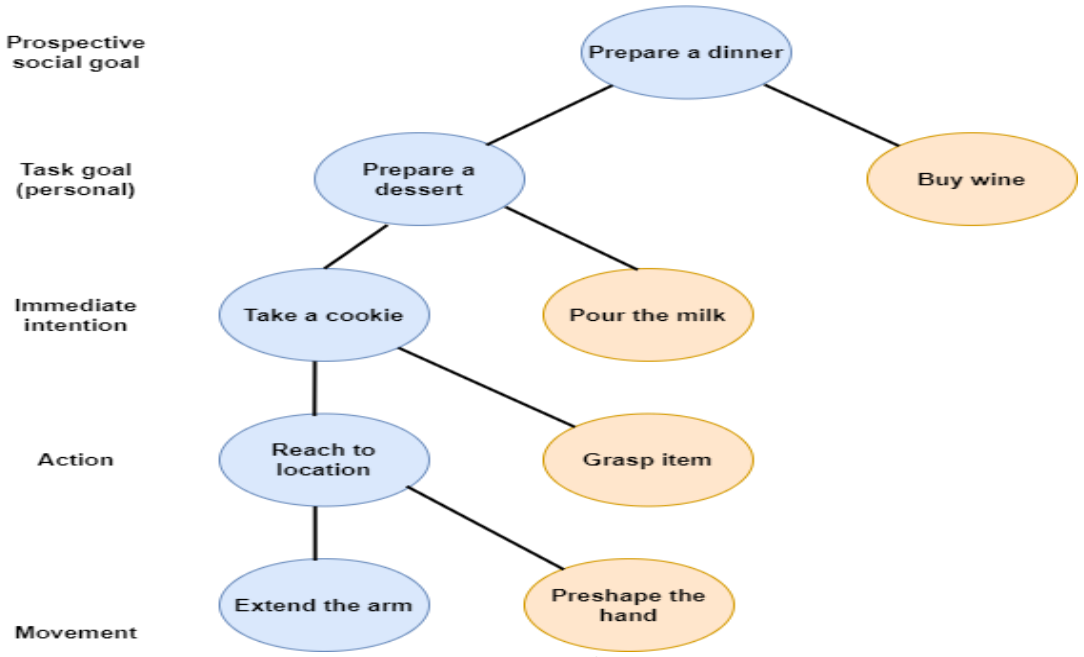

Fig. 7 Hierarchical organization of goals and intentions

For each smart appliance there are three-layered architecture. In the bottom layer is non-cognitive regulation (simple controller), with different configuration presets. In the middle, reflective layer is implemented the monitoring of current state, detecting emergency situations. The highest, cognitive operator level uses simulation models to provide self-optimization, depending on current state or situation detected. However, the article [35] provides only a conceptual model of architecture, not specifying how it could be implemented.

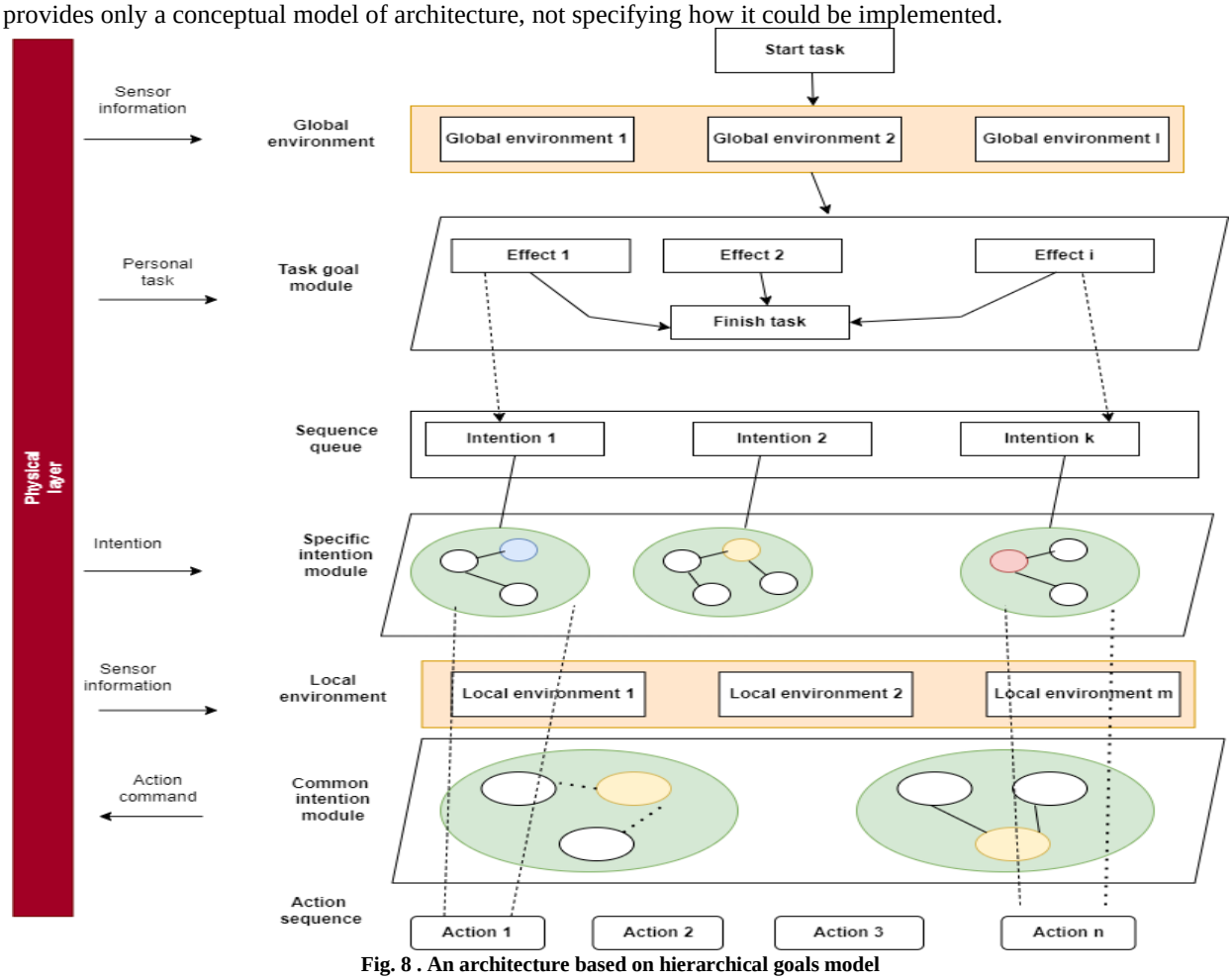

Fig. 8 . An architecture based on hierarchical goals model

The article [36] is centered around the activity discovery in intelligent homes. Various sensors are continuously generating large streams of data. An efficient algorithm needs to be implemented that can identify new types of activities, that can later be used for recognition using unsupervised learning methods to discover patterns in data. Activity recognition and prediction enables the intelligent environment to react to what the user is doing. The processing of large amounts of data requires computational power not available in local settings. Therefore, authors [36] propose intelligent home architecture with cloud, edge or fog computing used to offload computations from local system. Similarly, the [37] presents a secure and efficient smart home architecture that integrates blockchain and cloud computing technologies. It utilizes the decentralized nature of blockchain technology to provide processing services and ensure the security of collected user data from smart homes. The proposed model employs multivariate correlation analysis technique to analyze network traffic and enhance the security of the smart home network. Through evaluation using parameters like throughput, the study demonstrates that blockchain serves as an efficient security solution for the future Internet of things network.

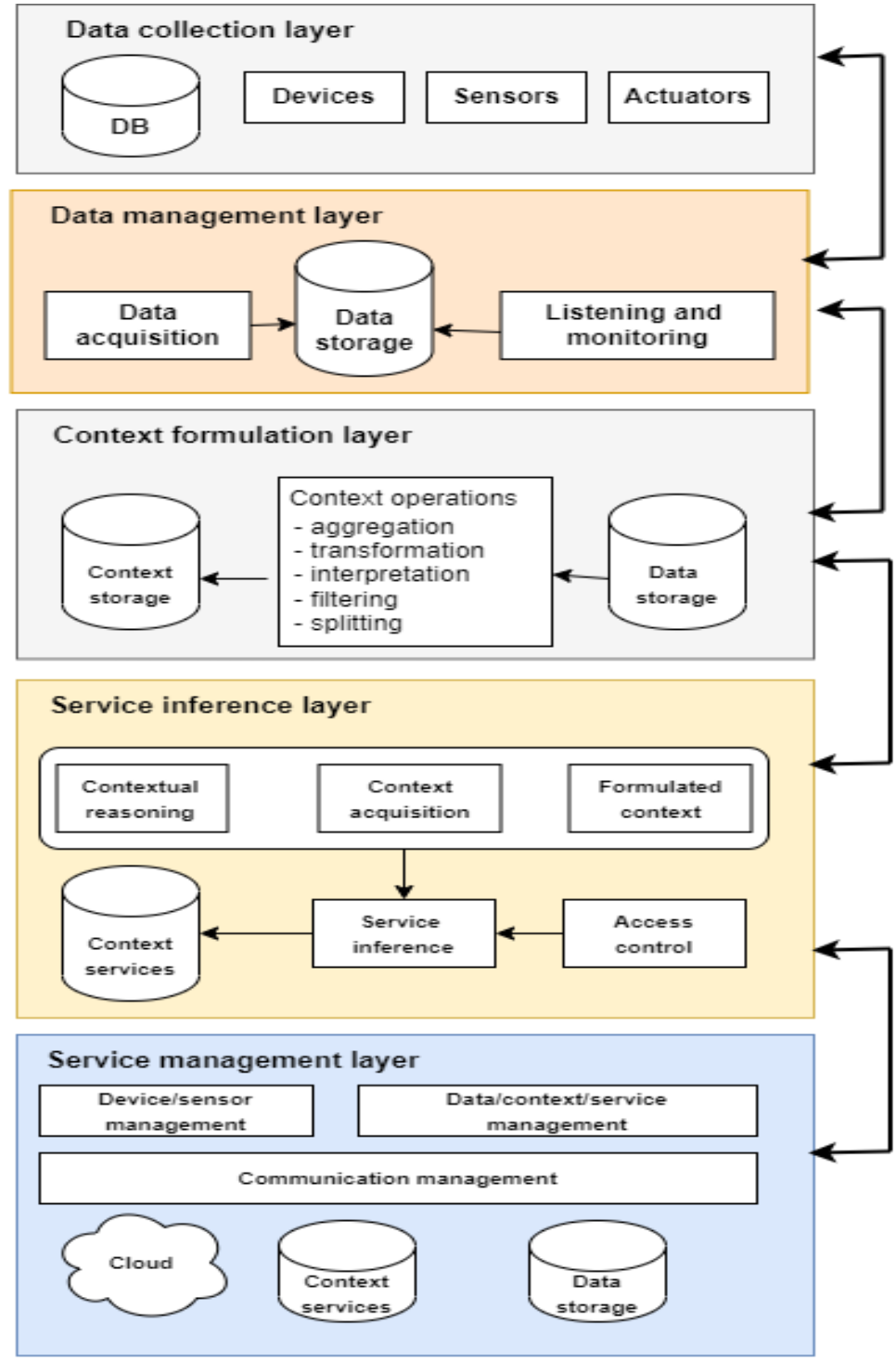

Fig. 9. Intelligent home architecture with context awareness

The article [30] proposes smart home architecture implementing context awareness. The system consists of five layers (Fig. 9). **Data collection layer (DCL)** is responsible for collecting data from various user devices, sensors, actuators and databases. **Data management layer (DML)** provides required data to the Context Formulation Layer (CFL) through the Data Acquisition component. All data collected in the DCL is sent to the central server (Data Storage). It will be used for analysis, visualization, and presentation. **Context formulation layer (CFL)** aggregates data from multiple sensors in order to fully understand the situation. CFL layer additionally provides aggregation, transformation, interpretation, filtering and splitting functions for data processing. **The Service Inference Layer's (SIL)** infers appropriate context services which are related to the formulated context given by CFL layer and/or any acquired/reasoned context. The inference process is based on Access Control for security reasons.

Service Management Layer (SML) implements the management of all components included in the system.

The summary of architectures analyzed is presented in table 1. We classified the articles on their focus on the main architectural parts of intelligent home and on their implementation of AI functions, analyzing users' intentions and context.

Table 1.

The summary of architectures analyzed

Article,	Physical layer implementation	Middleware, computation, data management	Application layer	AI functions	Context	Analyzing and predicting user goals
Fanshawe, 1990	Providing efficient connectivity.	-	-	-	-	-
Donode, 2021	+	in agent's software	Chat-bot on smartphone	-	-	-
Kaldeli, 2013	+	Service-oriented solutions	+	Rule-based engine to select service composition	Context awareness provided by AI, selecting the available services, according to context.	Goals are represented by explicit commands
Yang, 2016	+	+	+	Goal modeling	-	User intention decomposition
Michael, 2016	+	-	+	Self-optimization of smart appliance	Acting according to situation	-
Mocrii, 2018	+	Computations are in the cloud	+	-	-	-
Singh, 2019	+	Blockchain and cloud for security and computations	+	-	-	-

+ means that topic is implied but not considered in detail, – not considered.

Security and access rights management in intelligent homes

Current trends in access control and rights management solutions for intelligent homes are increasingly leveraging advanced technologies such as blockchain, artificial intelligence, and the Internet of Things (IoT). The current trend in access control and rights management solutions for smart homes involves integrating blockchain technology, specifically utilizing the Hyperledger Fabric platform. This approach addresses limitations like limited distribution, security issues, and privacy concerns found in traditional IoT access control systems. The proposed solution in the paper includes a trust management center and multiple smart contracts, such as identity, trust, and access control contracts. These contracts facilitate device registration, record access behavior, evaluate device trustworthiness, and make logical access judgments. The experiment conducted validates the effectiveness of the trust management algorithm, ensuring applicability in smart home environments [38]. In [39] paper, an intelligent face recognition access control system based on OpenMV, Arduino, RC522, Esp8266 WiFi module and Ali Cloud Internet of Things is presented. The current trend in access control and rights management solutions for smart homes involves the development and evaluation of advanced access control policies like Extended Generalized Role-Based Access Control (EGRBAC). This new variant aims to address the complex user-device-context interactions in smart home environments. Researchers [40] are focusing on analyzing administrative EGRBAC policies by simplifying them to the security analysis of administrative RBAC policies. This approach ensures that only authorized users have access to home devices, emphasizing security requirements such as availability and privilege escalation in realistic smart home scenarios. In [40] the authors demonstrate that the task of analyzing administrative EGRBAC policies for security can be performed by reducing it to the security analysis of administrative RBAC policies, and they also conduct a case study on a realistic smart home to prove the viability of their approach with respect of security requirements such as availability and privilege escalation. The current trend in access control for intelligent

homes involves utilizing artificial intelligence, specifically deep neural networks, for efficient image recognition. This technology allows for accurate identification of objects such as pets and human faces with high precision even with limited data. The proposed system in the paper [41] demonstrates the feasibility of integrating AI into home access control systems, showcasing a promising trend towards more advanced and intelligent solutions for managing access rights in smart homes. Furthermore, the integration of communication and monitoring technologies in intelligent houses is a significant trend, with a focus on applications such as recognition sensors, energy management, and activity recognition systems, reflecting the broader adoption of IoT in enhancing the functionality and security of smart homes [25]. These advancements collectively indicate a move towards more secure, flexible, and intelligent access control solutions in the realm of smart home technology. Summarizing, blockchain technology, particularly platforms like Hyperledger Fabric, is being used to enhance security and privacy in access control systems. These systems incorporate smart contracts for device registration, trust management, and access control, ensuring secure and efficient management of access rights in smart home environments [38].

Additionally, intelligent face recognition systems are gaining traction, utilizing components like OpenMV, Arduino, and Esp8266 WiFi modules to provide multiple access methods, including face recognition, NFC recognition, and app-based controls, thereby offering users flexibility and convenience [39]. The development of sophisticated access control policies, such as Extended Generalized Role-Based Access Control (EGRBAC), addresses the complex interactions between users, devices, and contexts in smart homes, enhancing security by preventing unauthorized access and privilege escalation [40]. Artificial intelligence, particularly deep learning, is also being applied to improve image recognition capabilities in access control systems, enabling accurate identification of both human faces and pets with minimal data, which is crucial for efficient and secure home access management [41].

Conclusions and discussion

This article analyzes the evolution of architectural solutions for smart homes that ensure comfort, security, and energy efficiency in residential spaces. The study revealed that with the development of Internet of Things technologies, automation, and energy-efficient solutions, architectural approaches have significantly changed, leading to the creation of more integrated and adaptive systems for managing residential buildings. Modern architectural solutions for smart homes are based on deep integration of IoT, automation, and energy-efficient technologies, enabling the creation of living spaces that are not only convenient and safe but also efficiently use resources. Contemporary homes must be adaptable to rapidly changing technologies and user needs. This requires flexible architectural solutions that can be easily updated and modified without significant costs. The application of energy-efficient technologies not only reduces operational costs but also contributes to environmental sustainability, which is an important aspect of modern construction. Smart homes must ensure a high level of security and privacy for residents' data, necessitating the development of reliable systems to protect against cyber threats. Intelligent management systems should be intuitive and easy to use, providing a high level of comfort for residents.

As a result of the research, practical recommendations have been provided for architects, designers, and developers of smart systems on optimal solutions for creating comfortable, safe, and energy-efficient residential spaces. Further research may focus on studying the latest technologies and their impact on architectural planning, as well as developing new standards and protocols for integrating smart systems into residential buildings. The review of intelligent homes architectures trends shows that current developments are organized as solutions proposed for the clusters of problems, existing in different layers of system, using existing technologies. Thus, on the physical layer we observe the development of intelligent sensors and devices. On application level the solutions are centered in health and well-being support, energy efficiency, smart interfaces, security and access rights management. The middle layer provides the intelligent services to applications. However, there’s no unifying architecture for smart homes; different works promote the architectures based on smart services or intelligent agents or central intelligent orchestration.

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