Smart Home Management Systems: from Conceptual Model to Improved Customer Experience

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Abstract. The paper aims at providing insights on knowledge, experience and attitude of people towards smart home management systems as well as analyzing the domain and assessing the current solutions that are present on the market. First of all, in-depth semi-structured interviews are conducted to find out insights on people's perception of smart home management systems. Then a formal smart home management system (SHoMS) ontology is designed that may be used as a conceptual model for a smart home management system. Finally, the score model is composed to compare the most popular systems. The analysis also includes the description of the perspective standard that may contribute to the development of the smart home technology. The deliverables of the study may help people to understand smart home systems better and support them in terms of decision making when choosing the system that suites their needs best. Moreover, the research aims to support developers of smart home products by focusing their attention on the Human-Centered Design aspects as well as the whole set of functionalities and services that are required by the users and available from the technology perspective in the smart home management system domain.

Keywords: Internet of Things, Human-Centered Design, Smart Home Management System, Conceptual Model, Ontology Modeling, SHoMS Ontology, System Comparison.

1 Introduction

Over the last years, our daily lives have been significantly transformed by the Internet of Things (IoT) which is "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things" [23]. These days houses, offices, airports and even whole cities have become "smart". Thus, demand for smart building management systems has dramatically increased. The more technology develops, the harder it may become for some people to understand the way it works. Users may find a technology, for example, the Internet of Things, quite complicated that may lead to avoiding and abandoning it by some users [17]. David W. Cearley, a prominent Gartner analyst, stresses the importance of a detailed understanding of a human and business context before a new technology development [45].

The existing body of research on Human-Computer Interaction (HCI) suggests that the design of most products contradicts the crucial Human-Centered Design (HCD) approach, which takes into consideration customer needs, behaviors, and capabilities [30]. According to Don Norman [30], in order to assure a positive user experience, both developers and users should have proper conceptual models of a particular system in mind. Such models provide a general understanding of the domain, explain the ways the product should work, which data is collected by a system, how data is collected and processed. Such models can serve different needs from providing a general understanding of the domain to explaining the ways the product should work, which data is collected by a system, how data is collected and processed. The author defines a conceptual model as a simplified explanation of how a system operates. It is a domain image in people's minds that should guide them while using a product [30]. According to the author, good conceptual models help customers to feel comfortable when using the product, lead to higher customer satisfaction and loyalty. Moreover, they help to bridge the gap between user's and designer's perceptions of the world and technology itself.

2 Research Questions

The research focuses on identifying people's knowledge about smart home management systems as well as determining customer goals, desires, experiences, issues, and frustrations associated with the use of these systems.

The research aims to figure out what can be done to help people to better understand how smart home management systems work. For that, a conceptual model of a smart home management system is built. According to Lou et al.[27], conceptual models should be built with customer's needs and psychological traits in mind. That is why the conceptual model is designed based on the interview findings.

Moreover, the research focuses on finding out which smart home management systems people use nowadays. These systems are analyzed and compared based on the interview findings and proper literature analysis. The team expects that the most popular systems are ones created by Google, Apple, and Amazon. Furthermore, based on the analysis of the systems, the research aims to find out possible improvements to system functionalities to enhance customer satisfaction.

Therefore, the following research questions are addressed in the study:
RQ0: How can a smart home be understandable and easy to use?
RQ1: What is an effective conceptual model for a smart home management system?
RQ2: What are the most popular existing smart home management systems and what are their pros, cons and development perspectives?

3 Methodology

The main methodology for this study is the Human-Centered Design approach that considers user research as one of the most important stages of the design process. Therefore, the study obtains user opinions through interviews. Based on the interview findings the conceptual model and system comparison are designed using the methodologies described below.

3.1 Interview Methodology

The research team conducts interviews with actual and potential users of smart home systems to gain information about which smart home solutions are used nowadays, which functions people like and do not like and why, what is the level of understanding of the smart home concept and what are possible issues with smart home systems. As for methodology, the team uses semi-structured interviews for data collection because it ensures a good balance between composing a detailed question plan and interviewing a person freely with a possibility to skip some questions and to alter the plan in response to the interviewee's answers [22].

3.2 Conceptual Modeling Methodology

After the discovery stage, the research focuses on analyzing the interview results and suggesting practical artifacts that may make user experience with smart home management systems better. One of that artifacts may be a conceptual model of a smart home. According to Norman [30], one product can have multiple conceptual models. Based on the level of abstraction and complexity, conceptual models can be built either from a customer or designer perspective. Conceptual models can be retrieved from a system image which is a combination of all available information.

There are several methodologies to develop conceptual models. Abbasi et al. [8] look at the conceptual design from the designer's rather than user's perspective. The authors propose a thorough classification of methods pointing out that there is no single best approach for conceptual modeling. The scholars believe that the best way to model the IoT domain is hierarchical modeling. The most common hierarchical modeling technic is ontology modeling [38]. According to Schlenoff et al. [37], an ontology is a tool for structuring knowledge about the domain and arranging system components.

Although the ontology-based modeling approach was invented decades ago, it is still actively used for different purposes ranging from a domain understanding [29] to product customization [39]. Therefore, in this study the smart home management system conceptual model is built in the form of ontology.

Moreover, the ontology modeling method is chosen for its flexibility and scalability. The research team believes that the ontology-based conceptual models, especially in their graphical representations, can be easily understood by the untrained users as well as domain experts and designers. Scalability implies that one ontology-based conceptual model (for example, customer's conceptual model) can be further adapted and extended to multiple conceptual models that serve the needs of different stakeholders (for example, system designers, developers, integrators).

This research mainly concentrates on the conceptual model for experienced users with a potential scalability of this model to a more sophisticated designer's perspective. Therefore, the research contributes to a creation of a comprehensive description of a smart home domain. Moreover, the conceptual model can be later simplified to assure its understandability by users who are not familiar with the smart home concept.

3.3 Existing Systems Analysis Methodology

Another artifact is a comparison of existing smart home management systems. The comparison may be conducted with both qualitative and quantitative methods such as analyzing user experience with different systems, exploring systems' documentation, comparing their functionalities and compliance with the Human-Centered Design principles. The team has decided to compose a comparison table of smart home management systems functionalities and use a score-model for the weighted evaluation of the indicators. Similar models are widely used for conducting comparisons in various science areas. For example, Parker et al. [31] describe a model that solves the problem of projects prioritizing by assessing each project with different criteria from business and technology domains. Also, the team is inspired by the balanced scorecard model that is used by Chang et al. [14] for assessing the performance of ERP systems.

4 Interview Findings

In the course of the research 15 interviews have been conducted. In order to keep the sample representative, the research team has preserved a 50/50 ratio of actual users of smart home technology and perspective users who are people that do not have smart home solutions yet. However, the latter group in general has heard about smart home technology and has an understanding of the technology. One may refer to Appendix 1 to get familiar with the interview guide. Interviews have revealed the following valuable insights on people's experience with smart home solutions.

4.1 General Understanding of the Smart Home Domain

Most people feel comfortable at home. They see a home as a place where they are safe and happy, where everything is on the right places and should be customized to one's needs.

Interestingly, every person has at least a general understanding of a smart home. According to the interviewees, a smart home is an automated system that allows to control gadgets remotely. It is a system aimed to minimize human efforts and save time on unnecessary routine tasks. For example, a smart coffee machine could prepare coffee once an alarm clock went off or an oven could be heated in advance, while a person is driving from work. Such seemingly simple scenarios can greatly facilitate person's life by saving human's time and resources.

Moreover, some interviewees are able to explain how devices are interconnected in a smart home system. According to them, there is a "central hub" that integrates devices (that are connected wired or wirelessly) and sensors that forward messages and trigger events, so that the sensors act as intermediaries between the hub and the smart devices.

However, a passive user's behavior has been observed in some households [25], meaning that there is one person in a family who understands how the technology works and can actually do something with the technology when it does not work as it is expected, while other family members just use smart home systems and have no idea how they are set up and controlled.

4.2 Smart Home Experiences

The interviewees use Apple Home Kit, Amazon Echo, Google Home, Alisa by Yandex, iRidium, Xiaomi, Siemens, Redmond. Some people also indicate that they use solutions from the vendors that are better represented on the local market of their home countries. For example, one interviewee from France has installed Orange smart home system, while a person from Russia actively uses smart home services by Yandex. Moreover, two interviewees use self-developed systems because they could not find suitable solutions or wanted to integrate several functions in one system.

Interviewees have identified two types of smart home systems: massive systems to automate processes in a private house and less complex solutions for an apartment. These two types of systems provide users with different functionalities and require different levels of domain-specific knowledge and user experience.

The interviewees have mentioned that initially people pursue different goals when integrating smart home technologies. For those, looking for solid systems, the goals are full automation of daily routines, resource management (e.g. energy or water preserving), securitization (e.g. video surveillance), etc., while others integrate smart home technologies for fun and out of curiosity being satisfied with the automation of simple daily routines like switching the lights. Therefore, the latter have ecosystems with a relatively small number of devices that are controlled via a smart speaker or an app with an easy system set up process, whereas the first group struggles with interconnecting several systems or finding one system that provides the whole set of functionalities.

Many people like an idea of a virtual assistant that provides a voice interface to manage a smart home. However, there is a frustration as current virtual assistants, namely Alexa, Google Assistant, Siri and Yandex Alisa, often do not interpret commands correctly. There is a demand for improving virtual assistants so that addressing them with more advanced and differentiated commands would be possible. Pins et al. have come to similar findings [32]. Also, some people have noticed that virtual assistants mainly recognize commands in English but cannot do it well in other languages also struggling with different dialects and accents.

4.3 Smart Home Systems Functionalities and Services

Interviewees have mentioned several functionalities and services that they have already implemented and plan to implement in their smart homes.

The interviews using a smart home technology in apartments mentioned some gadgets and functionalities that they find useful: smart lights, speakers (Siri, Alexa, Alisa), air conditioners and humidifiers, kettles, vacuum cleaners, curtains with electric drive, intercoms, ovens, fridges, dish washers, etc. Besides, they named some useless functionalities and smart home devices: smart TV and Wi-Fi in a dishwasher. Also, the interviewees have explained what functionalities should be added to better fulfil their needs: video monitoring and motion sensors to improve security, smart cooking devices like ovens and kitchenettes, central lighting, temperature control, energy consumption and virtual assistants that could be also a virtual friend for lonely people.

One of smart house owners has mentioned that he already has an integrated system for electricity, heating, and air management. The system also includes an anti-flooding system, water supply controllers and access control with an automatic entrance gate, remote barrier and garage controls. He also would like to implement a robotic lawnmower, a security system with cameras and motion and noise sensors, a fire system and an irrigation system for his garden that could smartly water the plants by being synchronized with the sun so that it will not damage the plants. Another smart home system owner has mentioned a feature called “vacation scenario” that simulates a human presence in the house when there are no people inside. This function can greatly complement all security measures.

In general, the interviewees are looking for a flexible smart home management system with the possibility to customize settings and create different scenarios. People find it fascinating to have a set of scenarios for their smart home management systems that would adjust to every family member satisfying their individual needs.

Some people mentioned that they tried to use predefined scenarios but did not like them because the set up was complicated or it was impossible to customize these scenarios. In fact, the interviewees believe that it would be much better if their smart home could track their habits and adjust lights, temperature and other parameters of their home and create scenarios automatically for them.

The interviews have revealed that there is no ideal system that fulfills all their desires and is easy to use at the same time. Some interviews do not know the whole set of services and functionalities available on the market or even those provided by their smart home management systems.

4.4 Reasons for the Choice of Smart Home Systems

There are several reasons why people choose a particular solution: availability on the market, particular functionality, promotion campaigns, company familiarity or deployment convenience. Moreover, when choosing a smart home management system, the interviews strive to find a good balance between quality and price of a technology, compatibility of devices and systems, reliability of vendors, their security and data privacy standards. Support from manufacturers, reliability, durability, and convenience of use have been also mentioned as important criteria.

Another interesting finding is that people do not tend to use support of producers of devices when installing and setting them up. Interviewees have shared that they usually find solutions themselves via Internet on forums and YouTube. However, some interviewees have shared an idea that it would be more convenient if a smart home solution could be planned, installed and set up during the construction of the house. This would be especially convenient if there are many devices in the house to be deployed.

4.5 Concerns Regarding Fully Automated Smart Homes

There are three categories of interviewees who have different opinions with respect to smart home solutions. Firstly, a large group of technology fans who support the developing of smart home systems and believe that the future holds wide application and great improvement of the technology. Second group consists of people who do not trust smart homes. This group is concerned with privacy aspects and overreliance on the technology. Both groups think that smart home technologies are on the initial stage of development. The difference is that the first group is optimistic in evolving new smart home solutions, whereas the second group thinks that such technologies are immature and can make the life even harder. There is also a third group that contains people who do not know much about smart homes.

In general, most people are open for new technologies and are not afraid of fully automated houses as long as they have means to control them. People would like to have not only virtual but also physical control over a smart home (i.e. manually switching off smart devices).

4.6 Typical Issues of Smart Home Systems

There are several common issues that people have mentioned during the interviews. Many interviewees have reported the importance and difficulty of choosing the devices that are interoperable with their ecosystems. So, usually people use devices from the same vendor to be on the safe side from the compatibility perspective.

Some people are afraid that their data may leak from their smart home systems as a result of hacker's attacks or provider's actions. A problem with rights of being forgotten has been also mentioned as some systems may keep data of a person's behavior quite long.

Many interviewees have experienced reliability issues. For example, some smart home systems do not work if internet connection is unstable. People also consider privacy in a smart home as an issue and, therefore, feel insecure and surveilled in a smart home. Another big concern is that smart home technologies remain to be quite expensive and not affordable for many people.

People who are not familiar with modern technologies find it difficult to set up smart home solutions and interact with them. Thus, they may give up fast which is especially applicable to elder generations and passenger users [25].

Generally, frustration and disappointment may result from a negative user experience of smart home technologies. For example, one interviewee has tried to use some advanced answering functions of Alexa and set of rules for morning mode but those functions were buggy which made a person feel frustrated and forced him to switch to less complicated functions.

5 Conceptual Model Development

Today ontologies are widely used in a vast number of domains including Computer Science and Artificial Intelligence for the purposes of knowledge management, data integration, data processing, linked data development [44].

However, many of these ontologies are not standardized and do not comply with common modeling processes; each ontology presents its own terminologies that lead to a terminology mess [40]. Therefore, to deal with these issues the W3C SSN XG group [15] has developed Semantic Sensor Networks (SSN) ontology which is a domain-independent generic model that can be further reused, extended or adapted by other researchers.

In this study the goal of ontology engineering is to create a conceptual model of the smart home management systems to show the whole set of their functionalities, and to define a place of services in the scope of the domain. The main focus of the ontology is drawn to the service categories and possible services themselves that should be provided by the smart home management systems to satisfy human needs.

5.1 Ontology Modeling Methodology

There are several approaches to build an ontology that were defined more than ten years ago but they are still in wide use. According to Suarez [44], the most common approaches are METHONTOLOGY, On-To-Knowledge, DILIGENT, and NeOn. The research team decided to build an ontology, based on the NeOn [43] method that implies reuse and reengineering of existing ontologies as well as non-ontological resources (NORs). It is also known as a scenario-based approach, with nine scenarios available for the developers. In this research two scenarios are combined: reusing, merging, and re-engineering ontological resources and restructuring ontological resources by pruning and extending an existing ontology IoT-Lite [12] that is based on SSN ontology [15]. Moreover, the research team has studied a comprehensive literature survey by Sengupta et al. [38] who have analyzed several ontologies, computing systems, and architectures in the smart building domain. The authors' findings have been used to create an exhaustive ontology by re-using some classes, properties, as well as borrowing non-ontological resources and domain-specific terminology.

5.2 Ontology Languages

Ontologies are built using RDF or OWL languages that are used to represent resources in the World Wide Web. OWL is built upon RDF, thus, is considered more expressive and powerful. In this research the OWL 2.0 language is used which is an improved extension of OWL. Both languages support querying techniques by means of the SPARQL language.

5.3 Ontology Modeling Tool

There is a vast amount of ontology tools that serve different purposes. Suarez [44] classified all tools in five categories: ontology management tools, querying and reasoning tools, ontology engineering tools, processing tools, and instance generation tools. In this research an ontology editor Protégé is used as an engineering tool supporting ontology modeling and knowledge acquisition. The tool allows to re-use existing ontologies; supports both OWL and RDF formats; allows classes, object, data, and annotation properties definitions; supports ontograph composition and SPARQL querying over the ontology. The research team uses Protégé 4.2 Version that supports OWL 2.0. language [21].

5.4 SHoMS Ontology Engineering

Smart home management system (SHoMS) ontology engineering has started with the import of the IoT-Lite ontology [12]. The following classes and related properties have been removed from the target ontology because they are not relevant to the conceptual model: Unit, Metadata, Coverage, Point, Quantitykind, Atttribute and Entity. Then, several classes and properties have been added to the ontology using borrowing and reusing techniques.

Ontology Classes. Firstly, five disjoined classes have been added to the ontology as NORs borrowed from Nguyen et al. [47]: *Subject*, *Vendor*, *SmartHomeManagenmentSystem*, *Environment*, *CommunicationTechnology*. The *Subject* represents a controlling person (i.e. a system user), while the *Vendor* class allows to define a developer of a system, platform or device. The *SmartHomeManagementSystem* is an overarching class of the main concept. Since the external environment has a direct impact on the state of control objects, the authors also suggest including the *Environment* class which has been added with subclasses

Time, *Date* and *Indicators*. Moreover, the *CommunicationTechnology* class has been added with several subclasses suggested by Al-Fuqaha et al. [11].

Secondly, the *Sensor* class (imported from the IoT-Lite ontology) has been extended with the subclasses proposed by Rayes and Salam [36] who define eleven types of sensors that can be attached to an IoT platform: temperature, pressure, flow, imaging, fluid level, noise, air pollution, proximity and displacement, infrared, moisture and humidity, and speed sensor. Moreover, this class has been set as an equivalent class of the *EnvironmentalIndicators* class.

Thirdly, five disjoined classes have been added as subclasses of the *SmartHomeManagementSystem* class: *Object*, *Platform*, *System* and *Service* (imported from the IoT-Lite ontology [12]), plus *Scenario* borrowed from [10].

The *System* class has been extended with three disjoined subclasses: *Middleware*, *Software*, and *Hardware* borrowed from Gubbi et al. [18]. According to the authors, in the IoT paradigm the system consists of three main components: the *Hardware*, made up of *SensingDevices*, *ActuatingDevices*, and *TagDevices*; the *Middleware*, consisting of *Storage* and *ComputingTools* for data analytics; and the *Presentation* which is a *Software* component that includes all types of system *Interfaces*.

Arguably the hardest part for all interviewees was to understand how devices are interconnected and how data is transmitted in a smart home. It is done by the *HardwareDevices*. The *SensingDevices* capture and produce data continuously, they measure performance, conformance, state of the IoT object and re-translate this data to the *Platform*. *ActuatingDevices* actuate over an object. *TagDevices* such as QR code or bar code allow to track and identify objects [12].

Each control scenario is one or more chains of rules consisting of three key elements that have been added as subclasses of the *Scenario* class: *DataSource*, *Condition* itself that consists of an *Operation* plus a *Constant* and *Action* that can be either a *Command* or *Notification*. These elements are linked together using "if-then-else" pattern [10].

In the SHoMS ontology the term *Services* is used to define sets of specific functionalities of IoT objects. The same term is used in the IoT-Stream Ontology [**?**] which defines how the services can be implemented and used to gather analytics in the IoT platforms. As for future work, the ontology proposed in this research can be integrated with IoT-Stream Ontology to create a more sophisticated conceptual model to be used by the IoT-platform developers.

Ontology Class Services. Based on the interview findings, analysis of the functionalities of the smart home management systems mentioned by the interview partners and literature survey, 18 service categories have been created as subclasses of the *Service* class. For each category several services have been identified.

Services definition has been mostly stemmed from the interview findings, in particular, from the services currently used by the interviewees (e.g. smart lighting or cooking services) as well as from their desires and needs (e.g. smart gardening and environmental care services).

Some services have been found directly in the functionality sets of smart home management systems. For instance, the access control, security, emergency and resource management services have been taken from Siemens [2] and Amazon [4]; while entertaining, socializing and booking services have been borrowed from iRidium platform [3].

The indoor climate control services also called HVAC (heating, ventilation, air conditioning) services have been found in Lu's work [28]. Inspiration for the time management service enabled by the Intelligent Agent has been found in the work by Kirrane [24].

Object Properties. In addition to the object properties defined in the IoT-Lite ontology, five new object properties have been added to specify connections between new classes: Device *developedBy* Vendor; Device *compatibleWith* Device; Service *providedBy* System; System or Subject *create* Scenario. In future work domain experts should be consulted in order to identify more object properties of the SHoMS ontology.

Data Properties. Two new disjoined data properties *forSmartApartmentOnly* and *forPrivateHousesOnly* have been added to the ontology class *Service*. Both are boolean values that specify whether the *Service* is applicable for apartments or private house settings. If both properties are equal to false, then the service is universal and can be used by all smart home management system users.

5.5 Ontology Validation and Future Work

Developed SHoMS ontology has been validated using two techniques: SPARQL queries over the ontology and user testing by means of the second round of interviews with the interview partners who participated in the research. Validation has revealed that future work is needed to make the conceptual model more user-friendly by providing a simpler user interface for the non-expert users. Moreover, it can be improved by adding the actual entities of the classes in order to simplify the understandability of the conceptual model and provide customers with more information on smart home management systems.

Developed ontology can be useful for both customers and developers. Customers can learn about the domain as well as realize the full potential of a smart home, while system developers can consider the whole technological scope to enable integration of several services in order to create products that can better satisfy customer needs.

The resulting ontology hierarchy can be found in the Appendix 2 and 3. To make a conceptual model more user-friendly, developed ontology has been also presented in the form of an ontograph (see Appendix 4 and Appendix 5).

6 Existing Smart Home Management System Analysis

Currently different smart home management systems are present on the market. Substantial work has been done in comparison of various smart home solutions in terms of technical aspects. A nice overview of six different smart home systems classes is presented in the work by Hasan et al. [19].

However, works like that may contain details and abstractions that are too complicated and unnecessary for most users. That is why there is a need to provide a more user-friendly comparison of actual systems that are most popular on the market. There are a lot of technology-oriented internet resources with different degree of trustworthiness that provide a comparison of existing systems. For example, authors of [26,20,33,34] analyze Amazon, Google and Apple smart home systems in a quick and easy-to-follow manner. As for academic articles, the team has found only one scientific article by Sharma et al. [42] that contains the analysis of several modern smart home management systems from both technical and user perspectives. However, this article focuses mainly on describing the functionality of different solutions. So, to the best of the team's knowledge, there is no work that suggests a comparison model that would assess popular smart home management systems based on a criteria model.

6.1 Popular Solution Analysis

The interviews have identified systems that are most popular nowadays. The team uses interview findings and the literature described above to analyze these systems. Apple smart home solution is the least popular among interviewees in comparison with its main competitors and has the smallest number of devices that are compatible with it. A survey, which is conducted by Abdi et al. [9], shows that the number of Apple smart home users is quite small. One reason is that Apple has stricter internal certification standards for smart home devices than Google and Amazon have. Also, the smart speaker HomePod is considered as the securest solution out of the three ones compared. However, it is not perfect. For example, Chalhoub et al. [13] have reported some issues with authentication of devices because of conflicting password managers of Apple solution and a device of another producer. The HomePod is more expensive in comparison with Amazon Echo and Google Nest. The price for Apple solutions fluctuates in the range between 100 and 349 US dollars whereas most Google and Amazon smart speakers cost from 50 to 180 US dollars [42,1].

Amazon often is perceived by interviewees as the first major company to come to the smart home solutions market [34]. It has the largest market share compared to its competitors. Amazon has a quite developed procedure to pass its smart devices certification, gives a possibility for third-party developers to integrate their solutions with Alexa and provides the most differentiated range of compatible devices, for example, it currently has a build-in Zigbee interface [7]. Amazon solutions are considered as quite well-balanced by the interviewees, however, some of them are disappointed with not working scenarios, connectivity losses and difficulties that occurred while using Alexa voice assistant.

As for Google, the interviewees value capabilities of Google voice assistant. It is considered to better understand commands and has more working functions available. In addition, Google is aiming at integrating more devices to develop its smart home ecosystem and outperform Amazon in terms of the number of compatible devices [26]. Google may also strengthen its positions if it fixes some privacy issues and reassures people of its trustworthiness. Chalhoub et al.[13] have described a situation that some participants of a smart home ethnographic study have experienced malfunctions of their Google Home solutions if people withdraw some consents that should not affect that functions. Another example is previous exposure of Google solutions to attacks that might compromise information on network and user devices that is mentioned by Edu et al. [16].

6.2 Matter Standard

Matter is a unified connectivity standard for smart home solutions that has been launched in May 2021 by The Connectivity Standards Alliance (CSA) [5]. First devices working with the standard should be issued by the end of 2021. Matter as a protocol should create a common language that will allow smart home devices to communicate with any smart home ecosystem. Matter uses a combination of Wi-Fi, Thread, and Bluetooth Low Energy (LE) for connection purposes. Matter mark may help a user to find devices that are compatible with the system that a user currently has. The main idea is to increase interoperability and make it easier for the customer to connect and choose smart home devices. The current usage of hubs of different producers to support effective cooperation of devices may be not necessary as Matter evolves. It "breaks down the walls of the walled garden," said Michelle Mindala-Freeman, the Head of Marketing at the CSA [41]. With Matter standard it should b possible for developers to create only one version of Matter compatible device that will suit all smart home ecosystem vendors. So, there may be no need for companies to pass different internal certification procedures. Also, setting up a system should be easier. A device may contain a code, namely QR code or simple digital code that would initialize the setting automatically for simple devices on entering or scanning. As for complex devices, there may be a guide for installation that may be accessed with a URL encrypted in the code [6].

There are 4 core principles behind Matter. *Simplicity* stands for easiness of purchasing, installation and usage of the smart home system. *Interoperability* means that devices from different producers should work seamlessly together in one ecosystem. *Reliability* can be defined as local connectivity, so there is no need for a working Internet connection for a smart home system to operate. The fourth principle is *security* meaning that users' and developers' data and private life are secured [5].

Google and Apple that are members of CSA have announced that they support the development of Matter. Apple has shared at WWDC 21 that Matter should be added in Home app during the update to iOS 15 [48]. Google has published plans to integrate Matter into its smart home solutions as well [46].

6.3 The Comparison Model

Three currently most popular smart home solutions are compared using a score model that is suggested by the research team. Assessment criteria for the model

Table 1. The comparison of smart home management systems.

Systems	Simplicity	Interoperability	Reliability	Security	Cost (-)	Total score
Google Home	4	2	2	1	3	6
Apple HomeKit	3	1	3	3	5	5
Amazon Echo	3	3	2	2	3	7
Baseline	4	4	4	4	3	13

are simplicity, interoperability, reliability, security and cost. Similar criteria are used by Sharma et al. [42]. Also, the first four criteria are the principles of Matter. Cost criterion is important because many interviewees have told that they consider the cost as one of the obstacles to buy smart home devices. The cost criterion has a negative influence on the overall score. So that the lower the cost, the better. The cost criterion includes the price of a smart speaker as it is the main device or hub of the smart home system. Other devices are complementary and there are a vast majority of devices that may be controlled with a hub so there is no need to include their prices in the measure. The systems are compared against a baseline that is the closest to the ideal solution in the near future. The baseline system is one that uses Matter standard. Table 1 shows the comparison of smart home management systems.

A score table is used to provide information on what is meant by particular scores. The team has decided to utilize five scores as used by Quiroz et al. [35] to compare results of Alexa usage skill for depression and anxiety self-tests. Score table: 1) very low, 2) low, 3) moderate, 4) high, 5) very high. The higher is the total score, the better is the system.

The comparison shows that the Amazon solution is currently slightly better than others. It has nice overall characteristics, wins in interoperability and is affordable. However, Google is close to its competitor. All three current leaders are really close according to conducted assessment. Moreover, they expected to improve solutions as Matter standard evolves.

7 Conclusion, Limitations and Future Work

The study provides insights on user experience with smart home management systems and their expectations. The findings of the study are based on the in-depth interviews and literature review on the topic. As a result, the conceptual model in the form of ontology and the comparison of existing smart home management systems are designed.

The main deliverables of the study complement each other: the conceptual model explains what the smart home management systems are on the theoretical and more abstract level providing information on the main components of such systems and describing all possible services that can be potentially offered by these systems, while the system comparison looks at the concrete examples of smart home management systems available on the market providing practical guidance to the users willing to choose the system that suits their needs best and offering possible improvement ideas for smart home systems developers.

The study may be useful for people who would like to get a deeper understanding of smart home management systems, learn more about existing solutions on the market and choose the one that suits one's needs best by considering different aspects provided by the system comparison. In addition, smart home systems designers may use the study to better understand user's desires and pain points to improve and integrate existing systems and to develop comprehensive, all-in-one smart home management systems that provide a customer with a vast range of services and functionalities. Developed ontology has been published on the Github repository to assure collaboration between developers for further refinement, extension and reuse of the SHoMS ontology.

The biggest limitation of this work is that the developed conceptual model lacks a user-friendly visual representation. The user testing has revealed that neither the ontology class hierarchy nor the ontograph can be easily interpreted by non-experts. However, the tech-savvy users have found it useful and quite comprehensive especially from the service perspective. Therefore, further work is required to fully address the research questions and reach the goal of creating a conceptual model or several conceptual models based on the SHoMS ontology that can help average users to understand smart home systems better.

Thus, in future work it is important to think about better knowledge representation. For instance, the ontograph can be extended, firstly, with the annotations that appear when a user hovers over a term, secondly, with the instances of ontology classes and their graphical representations (e.g. when clicking on the class *ActuatingDevice* a user realizes that it is nothing but the actual smart things such as kettles, computers, curtains, etc.). When it comes to the services, the user-friendly conceptual model could provide sample videos that in addition to the textual description create a clear image of how the services actually work.

Moreover, the work is theoretical and, while being useful for the developers and domain experts, it might be not of interest to an average user. Therefore, both the ontology and system comparison could be explained in an additional non-scientific and easy-to-read article that would concentrate on the usage of the ontology and the comparison model rather than technical implementation.

As the smart home systems are expected to develop further quite fast, the future work may include updating, reassessing and adding new meaningful details to the research. However, Human-Centred Design principles are here to stay even if the technology develops. Thus, the ontology can be extended and merged with other existing ontologies, the conceptual model can be visualized in a more user-friendly way, the comparison of the existing systems can be extended by analyzing more systems or using different criteria and standards.

Another possible direction for future work is to explore the psychological aspect of the interaction between people and virtual assistants and find out more how people perceive virtual assistants of different companies. Also, the ontology may be improved with a focus on the intelligent agents that could later use it as a knowledge base.

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8 Appendix

Appendix 1: Interview Guide .

Part 1. Warm-up questions (build a connection with a user, empathize, get people's emotions):

1. Where do you feel most comfortable and happy? How do you find your home? Please tell us more how do you feel at your home?

2. Do you know what is meant with the term "smart home"?

a. yes: What is your idea about this term?

b. no: What comes to your mind when you hear the term "smart home"?

3. What do your friends think of smart home technology? What is your opinion on smart homes? Did you change it along time? Why?

Part 2. Experience with the domain and understanding of the domain:

4. Do you use any smart home technologies (for example, Alexa)?

a. yes: What are they? What do they help you with?

b. yes: How many smart home gadgets do you have?

c. yes: From which vendors do you have smart home products?

d. yes: How did you choose exactly this system? What were other options? What are the reasons for choosing exactly this smart home system?

e. no: Would you consider integrating smart home technology into your home?

f. no: What are aspects that would (or have already) convince you to increase your usage?

5. Have you planned to install (new) smart home technologies in your home?

a. Yes and no: If you could automate any process at your home, which one would it be?

6. Do you understand how devices in a smart home system are interconnected? Could you shortly explain it?

a. How is data transmitted and collected?

b. Which data is collected by smart home devices?

Part 3. General Part to reveal challenges, positive and negative experiences:

7. How do you find using your smart home solution?

a. How do you control your smart home devices?

b. Do you have control centrally or in several different apps?

c. Is your connection with your devices stable?

8. What was your experience setting up your smart home devices initially?

a. How much time did you invest into setting up your current smart home application system?

b. Was it worth the effort?

c. How fast or tedious has your setup been?

d. What have been challenges in setting up your smart home applications?

9. How often do you have to change the settings? How do you find changing settings? What do you think about making changes to your current smart home settings?

10. Do you have access to support when setting up your smart home?

11. Have you ever created rules for your smart home? Can you give an example of such rules?

12. Does your system allow you to choose pre-defined rules (for example, turn off the light every day after 11 p.m.)?

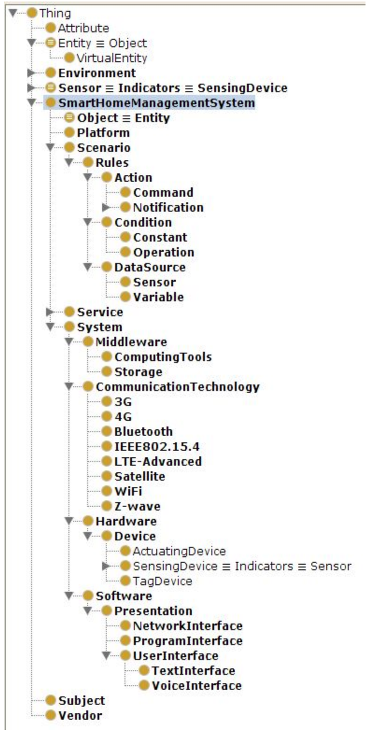
Part 4. Concluding questions

13. What do you think about fully-automated smart homes? How would you feel in a fully-automated smart home?

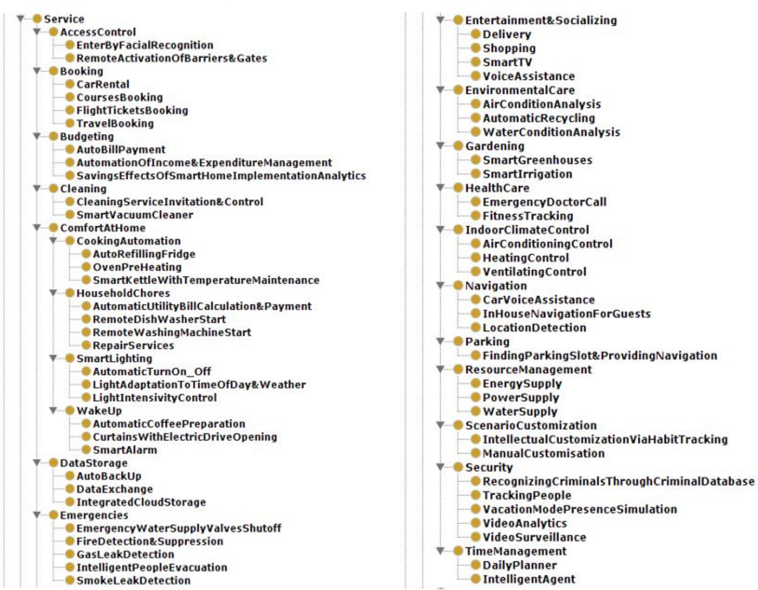
14. In which situations does your smart home not live up to your expectations?

15. Have you had any new insights or learnings yourself during this interview?

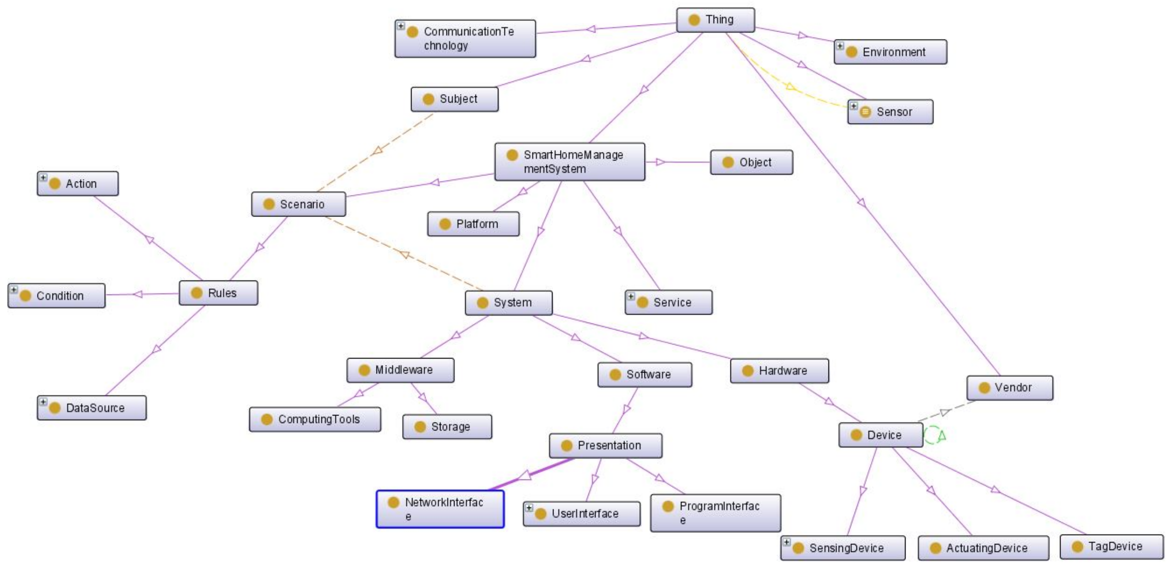
Appendix 2: Ontology Class Hierarchy .



Appendix 3: Ontology Class Service .



Appendix 4: Conceptual Model. Ontograph .



Appendix 5: Conceptual Model. Services Ontograph .