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Complexity of Smart Home Setups: A Qualitative User Study on Smart Home Assistance and Implications on Technical Requirements

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Abstract: Setup and management of smart home systems is a complex task, and thus challenging for technically inexperienced users. We conducted a qualitative user study to evaluate whether an assistance system could empower users to make better and informed decisions regarding the selection of devices, their interoperability, the resulting set of features and their price. A group of 20 participants used our assistance app on a smartphone to configure a smart home while optimizing for features, interoperability, and the price-performance ratio. The results of our user study show that our assistance app can ease the problem of selecting useful devices and at the same time users become aware of new features resulting from the interoperation of selected devices. Furthermore, the assistance app can counteract the inherent interoperability problem between devices of different vendors or platforms. Finally, users are not only interested in individual device prices. They want to learn the cost of a certain feature set, including the cost of all devices necessary to realize this feature. Interestingly, none of the current smart home systems on the market offer a comparable assistance mechanism. Third-party solutions are not available either, because an assistance app requires meta data about features, interoperability, and usage of devices. This meta data is currently not available via APIs in state-of-the-art smart home systems and marketplaces. Therefore, we present a smart home architecture resulting from our research that can, among other benefits, provide the necessary meta data. Our research indicates that commercial smart home systems should invest more effort in user assistance to gain widespread adoption among technically inexperienced users. This in turn requires substantial changes to the meta data management in smart homes, because otherwise these assistance systems cannot be realized.

Keywords: smart home; human-centered computing; cyber-physical systems; internet of things

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1. Introduction

Cyber-physical systems, and by extension smart homes, are constantly evolving and subject to continuous change as new devices are added, removed or updated. One of the most important aspects is connectivity with other devices, where robust connectivity is the key to predictable system behavior.

Particularly in the case of smart homes, user interaction and the user's limited technical skills need to be considered as well. Problems arise when smart home systems are too complex for non-technical users, i.e., they do not understand which functionalities are available to them and how devices could work together. Apart from the user perspective, there is also the problem of longevity because smart home systems should have a long lifespan comparable to other non-smart installations in a house.

To achieve widespread adoption of smart homes, especially among technically inexperienced users, new mechanisms need to be explored. Longevity and better user inclusion in smart homes are our main research challenges. In particular, we focus on user assistance for the process of choosing compatible devices to extend the functionality of a smart home.

Supporting inexperienced users with assistance systems is a wide research field. For example, systems are developed to assist elderly people who have difficulties performing technical tasks or systems that automatically call for help when a person falls [1]. This notion of assistance can be thought of either as support in decision-making or as intervention in situations in which the user can no longer act (e.g., in the event of accidents). In our case, we seek to assist the user in smart home systems technically as much as possible so that the user is not hindered in his usual interaction with the smart home system. Especially the selection and installation of new smart devices is challenging for users. The task cannot be fully automated because the user must remain in control of his purchases and his system. Therefore, assistance systems can help in empowering the user.

In this work, we investigate methods that guide the user through this process and evaluate whether this positively influences the user's decision. We take into account that the interoperability of smart home devices is not a first order goal in their development process [2]. This makes it difficult for inexperienced smart home users to understand which devices can be combined.

Therefore, it is not only important to think about how to increase interoperability with other devices or services, but also how a user can recognize meaningful connections between devices and also configure them [3]. Mennicken et al. [3] point out that smart homes must offer users services that help them to recognize whether there are devices that fit their needs and their current situation. This should enable them to identify the automation potential of devices they already own so that they can gradually expand their installations [3]. Therefore the trust and interest of users in automated functionalities should be increased [3].

To this end, we developed an application that guides the user through a virtual setup process in a simulated smart home system, with the goal of introducing new smart devices into the system. The application uses smart home meta data to suggest suitable devices that extend the functionality of the system.

The developed application explains each of its suggestions such that the user can comprehend the decisions and select the one that fits best based on his preferences. We evaluated this process in a qualitative study and showed that active assistance is ideal for enabling users to make informed decisions when setting up and expanding their smart homes (see Section 3). These results indicate that with active assistance, we may improve other aspects of smart home interaction (e.g., maintenance) for non-technical users, thereby improving more widespread adoption.

Smart home maintenance is key to a functioning smart home system and is fundamentally technical in nature. It entails essential architectural considerations for key maintenance features. Smart homes change over time because devices are added, removed or updated. These alterations change the expected behavior of devices and possibly introduce errors that are challenging to troubleshoot.

To ease the maintenance and setup complexity, we use the Longevity Digital Twin (LDT) architecture to provide meta data about devices, monitor the usage of installed smart devices and predict the impact of planned changes [4]. Longevity is the ability of a system to withstand the test of time through robustness, adaptivity or repairability. IoT systems such as smart homes specifically require components that age well, and our hypothesis is that smart devices are not able to achieve this on their own.

Furthermore, there is no uniform information source on smart home devices from which the necessary data for the implementation of a fitting smart home assistance system can be inferred. The reason for this is that smart home devices are usually vendor locked and API access or information about a smart device is therefore not accessible externally [4]. Therefore, in order to make our assistance approach technically feasible, we use an LDT architecture that provides us with the aforementioned meta data. Our assistance system requires (1) information about rooms, (2) smart home devices currently in use, (3) an up-to-date list of all LDT-capable smart home devices that can be used, and (4) dependencies between smart home devices and services including services that have dependencies on

other services. We leave the more technical details aside and refer to our previous work on LDTs [4].

The scientific contribution of this paper is twofold. First, we show that assistance improves the experience of managing a smart home. Users are empowered in their decision making and the application significantly improved their perceived understanding of a particular smart home setup. Secondly, we show that adding new devices is greatly simplified if the essential smart device meta data is widely available. However, our proposed assistance system is not realizable with current smart home systems, as there is no unified method for finding services, devices, and their dependency information.

The paper is organized as follows: First, related work in the area of pervasive, ubiquitous, and human-centered computing is surveyed in Section 2. Since the user is the focus of this work, a user study of our proposed setup assistance is presented in Section 3. There we describe our application in detail, which we evaluated in a qualitative survey in Section 4. In Section 6, we describe our LDT architecture, which is critical for our proposed assistance system. LDTs act as the underlying layer that provides us with the technical specification and definition to make the assistance implementable. Based on our findings in Section 4, we found evidence that assisting the user in a smart home scenario is very effective and that we were able to use our LDTs to filter out unwanted technical details and provide the information that the user needs. Section 7 summarizes these findings.

2. Related Work

Smart homes have been increasingly developed and advanced [5,6]. Primarily, smart homes are intended to enhance the comfort, safety, and entertainment of the smart home's occupants, thereby making daily life easier [5,7]. In this context, smart home devices communicate not only with users, but also with each other by being digitally connected in a network to exchange information creating new functionalities [8,9].

Fadhil et al. [10] conducted a survey on "smart home applications" and outlined various applications from the areas of security, environment, assistance (e.g., elderly care), automation and entertainment. A survey by Sepasgozar et al. [11] also reviews 160 papers and provides a comprehensive overview of "[. . .] key findings of smart home efforts, over the last decade". However, both surveys do not address assistance systems that future-proof a smart home. This shows that assistance in the maintenance process of the smart home itself has not caught on with many smart home practitioners or researchers yet.

The problem we address in this paper related to smart homes is twofold, as there is the technical problem of architectural implementation and the problem of designing human-centered processes. At their core, these must be treated and evaluated differently. The evaluation of aspects such as the "acceptability" and "usefulness" of our proposed system is fundamentally subjective and must be treated as such. Therefore, a broad range of research topics needs to be addressed, especially those related to human-centric, ubiquitous, and pervasive computing.

A substantial part of the population will require elderly care or assistance within their own home at some point [12]. As such, it is important that smart homes aid old people that experience difficulties with technical tasks as much as possible. However, there are some use cases in the field of activity recognition, such as detecting the wandering of dementia patients or detecting falls, which are of prime importance to the users' lives. Designing systems for the most vulnerable populations requires solutions that require little or no user interaction to be helpful [12]. As such, our system should either be based on systems the user already knows, or it should simplify the decision-making process to a minimum.

This assumption is supported by the findings of Yan et al. [13]. In a survey paper on smart gateways, Yan et al. pointed out that usability, compatibility, scalability, privacy, and security are challenges and future topics in smart home systems [13]. In particular, Yan et al. indicated that the interaction between the user and the smart home must be "intuitive" and "easy to use"in terms of usability [13]. Furthermore, they also clarified that compatibility is important, and a future system must be versatile in order to be

"[. . .] compatible with different communication protocols and specific functions for data collection and distribution in smart devices [. . .]" [13]. All this is taken into account by our LDT approach. In this paper, we focus on the usability challenge as proposed by Yan et al. [13]. In our case, ease of use (or usability) is synonymous with smart home maintenance assistance.

To support usability, discoverability is an important aspect of our LDT architecture. Furthermore, an important aspect of discoverability is standardization so that different catalogs use a similar dictionary for similar objects [14,15]. Gilani et al. describe several suited technologies for this task, such as RDF, OWL and SPARQL [16]. This can be performed manually or automatically through, e.g., keyword extraction, as demonstrated by Gopavarapu et al. [17]. Horvath et al. performed a study in which participants were tasked with discovering an API's functionality and found that prior experience with similar API's affects the ability to find important functionality with a new API [18].

According to Lobaccaro et al., in the near future all homes will be equipped with the necessary smart technology [19]. It will increase the use of artificial intelligence, computing power, communication capabilities, monitoring and control capabilities, thus improving the daily activities of smart home users. Nevertheless, the percentage of smart home device adoption, despite being available for years and the constant further development of smart home devices, is rather low [20–22]. Although there is a wide range of smart home devices and their combination possibilities, the adoption rate remains low [22]. One explanation for this is the lack of interoperability of smart home devices [22]. This results from the fact that smart home devices have different standardizations and platforms [6,22,23]. A study by [24] on smart home devices shows that devices from different platforms are often not interoperable. The main problem of interoperability is that these platforms are developed in isolation and independently of each other [6]. In addition, the rapid growth of services, applications and devices in the smart home environment makes it difficult to implement systems that are interoperable [2]. The need for interoperability is not considered [2]. In addition, standards at the hardware and software level are not supported by the majority of vendors for market policy reasons [21]. Therefore, with the multitude of smart home devices from a wide range of suppliers, it is easy for smart home users to lose track of how they can upgrade their smart home by purchasing new devices or linking existing devices correctly.

3. Approach to Setup Assistance

When setting up a smart home, it is not clear which devices are interoperable with each other or which devices require functions from other smart devices. This can be a problem for inexperienced users, as it is not clear to them which device can bring the desired benefit to their smart home. This hinders new purchases and therefore the expansion of already existing smart home systems. The challenge for a smart home environment and its use is to recognize and assess interoperable systems. Our developed application suggests suitable devices to the user. Therefore, interoperability detection is important for our assistance system (application) to be able to make meaningful device suggestions. The device suggestions should best meet the user's requirements and match the existing smart home devices. In this way, the application is intended to counteract the interoperability problem and the resulting user confusion, in order to support inexperienced users in particular.

We conducted a user study to evaluate the application. Individual interviews were used to record and evaluate the experiences of the test persons. We show that a suitable recommender application is a useful tool to address the problem of interoperability of smart home devices and helps the user to obtain an overview of the available devices. The application helps users to set up a smart home and minimize possible hurdles. The recommendations of the application not only improve product selection, but also increase the satisfaction with the selected products. The structure of the application and the results of the study are discussed below.

3.1. Structure of the Application

The developed application is intended to provide users of smart home devices with suitable product recommendations for existing devices in their smart home. In addition, we show which services are already being used and which can be used when a device is added. Furthermore, the recommendations are based on services that are already provided by existing devices, but are not yet used by other devices. In order for the user to weigh up which new equipment purchase makes sense, the reason for a recommendation must be clearly communicated by the application. In addition, the number of recommended products is determined by the user so that he or she is not overwhelmed or confused while using the application. This is realized, for example, by filtering the recommendations according to the price of the products. In the application, a house is simulated in which smart home devices can be inserted. This house is divided into different rooms that can be selected individually.

For study purposes, the initial situation at the start of the application will always be the same. For this purpose, the rooms are predefined in the application and they contain different, predefined products. At the same time, it is possible to remove the products from the rooms in order to replace them with alternatives. The application offers two modes. One mode is to show no product recommendations and the other mode is to show product recommendations. Originally the application was developed with German texts and names. To simplify the description of the application in this paper, the texts on the images have been translated.

3.2. GUI Structure

The basic structure of the application is divided into three tabs: Rooms, Devices and Settings.

By clicking the "Rooms" tab, the user is shown all rooms that can be equipped with smart home devices (see Figure 1). Under the "Devices" tab, the user is shown all devices that he or she owns, as well as the room in which the device is present (see Figure 2). In addition, the user gets an overview of the total costs of the products. Under the "Settings" tab, the user can read tips for using the application and set the recommendation filter (see Figure 3).

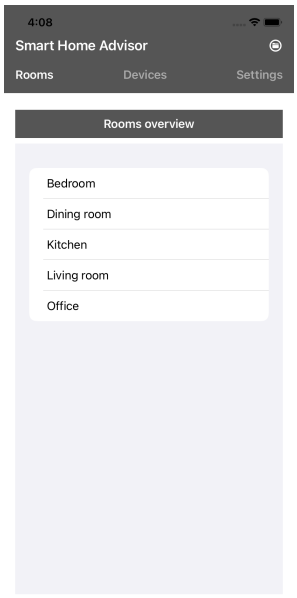

Figure 1. Rooms overview.

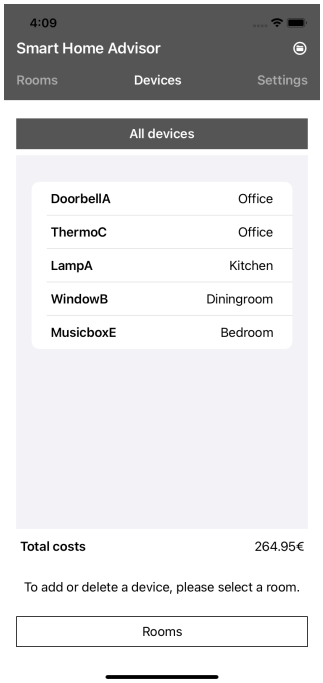

Figure 2. All devices.

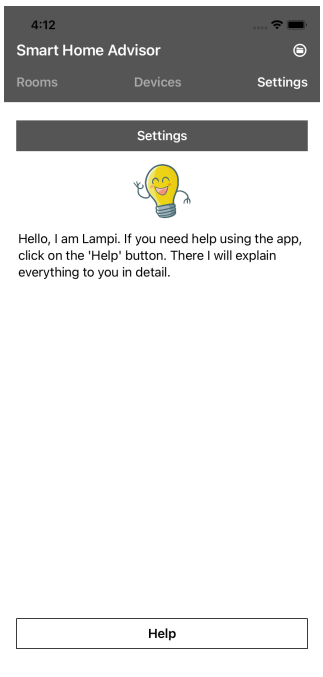

Figure 3. Settings.

If the user clicks on a room on the tab "Rooms", an overview of all devices in the room is displayed (see Figure 4). If the user clicks on "Add devices", an overview of all device types is displayed (see Figure 5) and as soon as a device type is selected, all devices of the type are displayed (see Figure 6).

When clicking on a device, the information about the device is displayed, and it can be added to the room via the "Add" button. In addition, the user has the option to delete devices from the rooms by selecting a room, choosing a product there and clicking on "Delete" instead of the "Add" button. In the basic structure of the application, without recommendations, no recommendations are given to the user. This setting can be changed

by the user clicking on the folder icon above the tabs menu and clicking on the button that says "Recommendation mode on". To reduce the risk of a subject switching between modes on their own during the study, there is an instruction above the button to only press this button when it is desired by the experimenter.

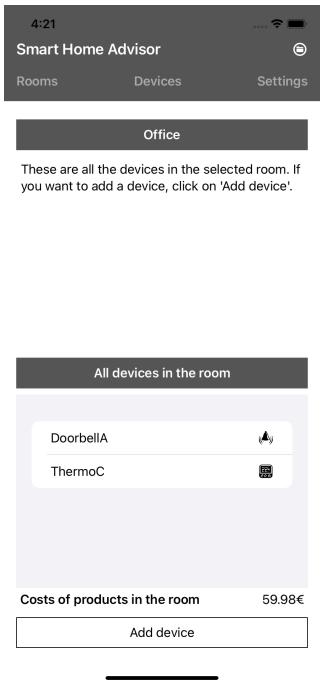

Figure 4. Devices in the room.

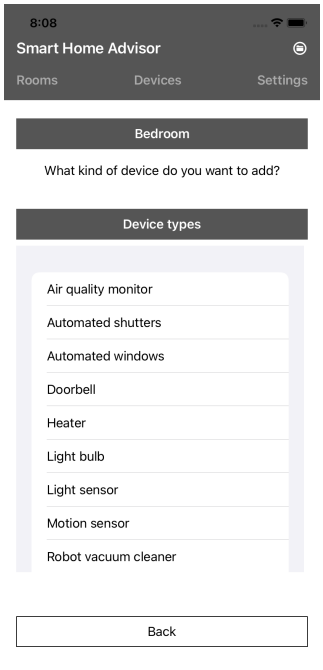

Figure 5. Device types.

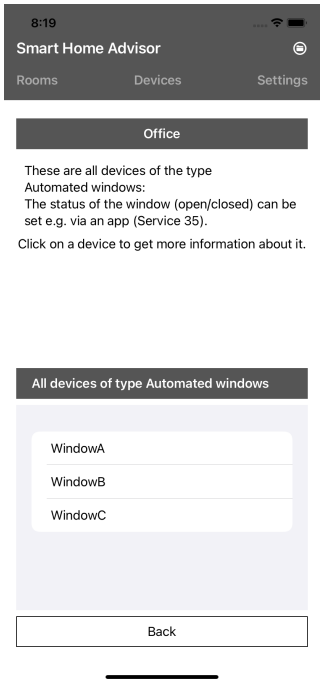

Figure 6. Devices of a device type.

The basic structure of the application does not change when the recommendation mode is switched on. However, the buttons are switched on which the user can use to display recommendations. In addition, when a room is clicked for the first time, a pop-up appears, informing the user of available recommendations and asking him or her to check if recommendations are available for the room. If the user closes this pop-up, all devices available in the room are displayed, as in the previous mode.

A light bulb icon next to the heading "All devices in the room" also shows the user if recommendations are available for the room (see Figure 7). In addition, the user now has the option of displaying recommendations by clicking on the "Recommendation" button (see Figure 8). Furthermore, all products in the room that can fully use all services are marked with a green font. If the user clicks on the recommendation button, recommendations are displayed according to a recommendation order.

The user can also choose whether more or fewer recommendations are displayed by clicking on the button "Show more recommendations" or "Show less recommendations" (see Figure 8). The structure of the pages does not change. Only the list of recommended devices is extended. Here, all products that can provide all services are also marked with a green font. If the user clicks on a recommended product, the reason for the recommendation is given (see Figure 9). In addition, the services and the required services that are available are marked in green and those that are not available are marked in red. If the user first decides to select a type of device by clicking on "Add device" and then on the desired type of device, he or she can have a product recommended by the type of device by clicking on the "Recommendations" button. If no product can be explicitly recommended by the device type, the cheapest product is displayed. If there is a recommendation for the type of device, all products that can be recommended are displayed. If the user clicks on the recommended product, the reason for the recommendation is displayed.

The recommendations can also be filtered via costs. To do this, the user can click on the pencil icon next to the heading "Recommended devices" or on the button "Recommendation filter" under the tab "Settings". On this page, the user can use two buttons to decide whether he or she wants the recommendations to be displayed filtered by cost or unfiltered.

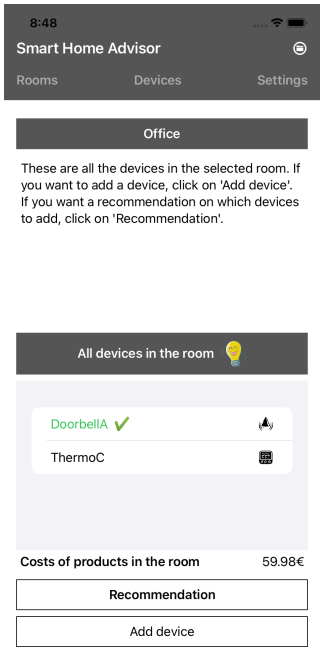

Figure 7. Devices in the room with recommendations.

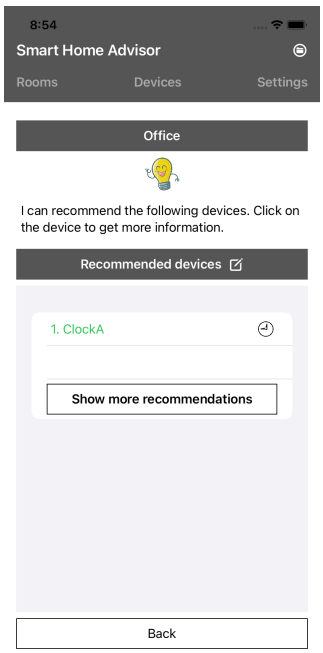

Figure 8. Recommended devices.

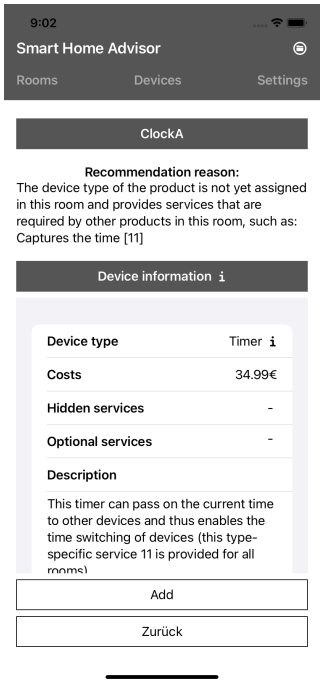

Figure 9. Recommendation details.

3.3. Product Recommendation

The recommendations are displayed to the user by clicking on the recommendation button. The recommended products are divided into three groups, which is also the order in which the products are recommended to the user:

1. Products that provide services that are required by services of already given products.
2. Products that use services whose prerequisites are already fulfilled.
3. The cheapest product of each type of device that is not present in the room yet.

3.4. Recommendation Filter

Initially, the devices are recommended to the user in the order of their recommendation group. That means, if devices of recommendation group one exist, they are recommended first. Devices belonging to recommendation group three are only recommended if there are no recommended devices of recommendation group one or two. If a cost filter is set, the recommended products are sorted by cost within their recommendation group before being displayed. In this way, the user is always shown the cheapest product of each recommendation group first. The user can also choose whether more or fewer recommendations should be displayed.

4. Evaluation (of Setup Assistance)

To evaluate whether the developed application counteracts the problem of finding interoperable smart home devices, a qualitative study was conducted. For this purpose, the test persons were presented with two application modes in succession, with instructions to set up their desired smart home via the application. The test persons were free to set up their smart home as they wished, but were encouraged to keep in mind the goal of selecting products with the best price-performance ratio and those that match the products already available.

As previously mentioned, the first application mode simulates creating a smart home without any further recommendations. The second application mode supports the user with product recommendations based on the devices that are already in the simulated smart home. Afterwards, the test persons were interviewed individually. Twenty persons aged between 20 and 64 years were interviewed. The average age is between 28 and 33 years.

Ten test persons each indicated female or male as their gender. All of them were living in Germany when the study was conducted.

4.1. Study Design

The test persons were asked to test the two application modes: with recommendations and without. Each run lasted 10 min. Afterwards, the test persons were interviewed individually. They were interviewed partly online and partly on site. The interview was based on a previously prepared interview guideline. The interview lasted between 35 and 45 min.

The interview was composed of 27 questions. Six questions were asked before using the application, eight questions were asked after the first run without recommendations and finally 13 questions were asked after the second run with recommendations through the application.

Questions were asked about the choice of products, satisfaction with the selected products and the use of the application.

This study design was chosen in order to gain deep insights into the opinions, attitudes and expectations of the respondents towards the application, as well as behavioral patterns when using the application. This allowed the application and its recommendations to be comprehensively illuminated. The conversation between the interviewer and the respondent was recorded during the interview and then transcribed, coded and analyzed. Furthermore, the click behavior in the application was tracked.

After the transcription, the statements of the test persons were coded according to the questions. Afterwards, a summary with the main statements of the listed passages was prepared for each respondent in order to compare the statements. In this way, a summary of the statements was created for each category and for each respondent, which can be better compared in terms of their conciseness. For the questions asked after both the first and the second run, the statements mentioned were compared and the results were tabulated.

In most cases, the respondents specifically noted whether, for example, their satisfaction with the product choice was higher, lower or the same in the second round. In some cases, the statements were grouped manually (e.g., if "bad" was mentioned in the first round and "good" in the second round, it was concluded that satisfaction was higher in the second one). In such cases, where an increase, decrease or a constant score could not be clearly identified, this was noted in the tables as "not interpretable".

4.2. Results

This study provided insights into the opinions, attitudes and expectations of the respondents regarding the application, as well as behavioral patterns in dealing with it. Although half of the respondents use smart home devices daily and only three respondents do not use smart home devices, the level of knowledge of how to use them is low. On average, the level of knowledge is in the lower middle range. Only three respondents indicated "good" to "very good" knowledge. If we calculate the average number of smart home devices used, we arrive at four devices per respondent. Alexa devices are the most frequently mentioned smart home devices, with ten mentions. This is followed by smart lighting with seven mentions.

4.2.1. Support in Product Selection

The results of the individual interviews indicate that such an application with device recommendations reduces the difficulty of product selection and increases satisfaction with the selected products compared to an application without recommendations (see Table 1).

Table 1. Difficulty of product selection (without vs. with product recommendations).

Number of Test Persons	Difficulty of Product Selection (without vs. with Product Recommendations)
12	simplier/easier
3	equally easy/difficult
3	significantly simpler/easier
1	more difficult
1	not interpretable

3/4 of the respondents said that the application's recommendations made it easier for them to choose products. Furthermore, they were more satisfied with the chosen products. This was explained, among other things, by the fact that it was now clearer which products could interact with each other:

> "Easier actually because now I have also seen through the recommendation app which products can work together." (translated from German)

In addition, the prerequisites of the products became clearer:

> "I got on much better with it. The recommendations made it much easier to see: 'What do you need for what and what is better for you?"' (translated from German)

Only one respondent said that the product selection was more difficult with the recommendation application. He explained this with the fact that more information was available in the run with recommendations and thus more attention has to be paid to the services hidden.

4.2.2. Satisfaction

Not only did the recommendations tend to make it easier for the test persons to choose products, the test persons' satisfaction with the chosen products also increased (see Table 2).

Table 2. Satisfaction with the chosen products (without vs. with product recommendations).

Number of Test Persons	Satisfaction with the Chosen Products (without vs. with Product Recommendations)
15	more satisfied
2	less satisfied
2	not interpretable
1	equally satisfied

Fifteen respondents stated that they were more satisfied with their choice of product if they had chosen it using the recommendation application. One of the reasons given for this is that fewer "unnecessary products" are now chosen on the basis of the application's recommendations. A better overview of the products is also mentioned as a reason, as well as the fact that "breaks in the planning" were avoided through the recommendations. Furthermore, better harmony between the products could be established.

Two respondents stated they were less satisfied with the choice. One reason for this is that it was noticed too late that some of the selected products were not compatible and there was a lack of time to rearrange them. One respondent stated that he was equally satisfied with the choice, with middle satisfaction. The reason for this was that the information that came with the recommendations also led to increasing uncertainty. Two test persons did not clearly indicate whether they were more or less satisfied with the product choice. However, both said they were satisfied with their choice, which they made with the help of the application's recommendations.

4.2.3. Price-Performance Ratio

For most of the test persons product recommendations make it easier to choose smart home devices and thus put together a smart home. This can be attributed to the fact that the interaction of the products now became clear to the test persons, as well as the prerequisites of the products. According to the test persons, the recommendations also increased the likelihood of choosing better products in terms of the price–performance ratio (see Table 3).

Table 3. Price–performance probability of product choice (without vs. with product recommendations).

Number of Test Persons	Price–Performance Probability of Product Choice (without vs. with Product Recommendations)
11	higher/better
4	not interpretable
3	lower
2	constant

Of the total of 20 test persons, eleven persons rated the price–performance probability as higher or better. Only three test persons rated the price–performance probability as lower. This was explained, among other things, by the fact that the price–performance probability was rather in the background when making the choice, as products with more functions were preferred:

> "Whether THESE were always the best-priced products was somehow secondary, I must admit." (translated from German)

Three of the respondents said that they relied on the recommendations in terms of the price–performance ratio:

> "I have followed the recommendations. I rely on the fact that these were accordingly the best value for money." (translated from German)

In addition, two respondents stated that the price-performance ratio did not seem important to them, as they preferred to have more functions or quality. Therefore, the importance of the price–performance ratio receded into the background.

4.2.4. Quantity and Time Saving

Since the smart home market is hardly manageable, especially for inexperienced users [21], a recommendation application can, according to the results of the study, help to gain a better overview of the combinability of products. Furthermore, this can counteract the technology proliferation described by Leitner [21]. Moreover, the compilation of the smart home via such an application leads to an increase in the adaptation rate. More products are chosen, compared to when the user compiles his smart home without recommendations.

Time saving was also observed for half of the respondents. Half of them finished creating their smart home more quickly in the second run with the recommendation application than in the first run without recommendations. Ten respondents stated that they had already finished creating their smart home before the ten-minute processing time had elapsed. Only one respondent finished creating his smart home more quickly without recommendations. All respondents who finished the second round earlier than the first reported being more satisfied (nine mentions) or equally satisfied (one mention) with the product choice. Recommendations in the application made it clear which products matched existing ones and which devices were compatible with each other. This improved overview is one reason for the faster choice of products.

4.2.5. Perception of the Recommendations

In addition to the time savings and the cost-benefit increase, the understanding of which functions of a device can be used and which links or devices are missing to make them usable was also strengthened. The recommendations were largely comprehensible and traceable.

Table 4 summarizes the perception of the recommendations. In total, 17 respondents stated that the recommendations were "traceable". Three of them even stated that they were "very traceable". One test person described the recommendations as only partially comprehensible, and only on a price level. The test person stated that, on a functional level, it was sometimes not clear to him why certain products were recommended even though they were not room-specific to the room:

> "From a price point of view, they were understandable. Functionally, however, not always, because in some rooms something was offered which in my opinion was not necessary in this type of room." (translated from German)

However, two respondents stated that they could not understand why some of the products were recommended to them. It seemed to them that the products were simply put in an order.

Table 4. Comprehensibility of the recommendations.

Number of Test Persons	Statements of the Test Persons
14	traceable
3	very traceable
2	not traceable
1	partly partly (price but not functional)

4.2.6. Usefulness of the Application

There is a positive trend in the information on the usefulness of the application.

In total, nine respondents said they found the application more useful in the second run than the application they used in the first run, and nine respondents said that both application modes were equally useful (see Table 5).

Table 5. Usefulness of the application (in recommendation mode vs. without product recommendations).

Number of Test Persons	Usefulness of the Application (with vs. without Product Recommendations)
9	More useful
8	equally useful
1	not interpretable

Table 6 shows that 13 of the 20 respondents found the second application "very useful/good/valuable". Four respondents found it "useful", and one respondent each found it "significantly more useful" than the application in the first run, as well as "useful" when it is expanded.

Table 6. Usefulness of the application in recommendation mode.

Number of Test Persons	Statements of the Test Persons
13	very useful/good/valuable
4	useful
1	clearly more useful
1	8 out of 10 points
1	useful when expanded

4.2.7. Probability of Use and Recommendation

These positive results are also reflected in the answers to the question of whether the respondent would use the application again if he or she wanted to set up his or her smart home at home.

Table 7 shows half of the respondents said they would "definitely" or "very likely" use the application again. Five respondents also said they would use the application again. Three rated this as "likely". Statements were made such as:

> "So if the app was on the market now, I'd probably get it straight away." (translated from German)

For two respondents, further use of the application is "unlikely". They argued that it was more likely that they would seek advice in a shop. However, it was mentioned that the application could be used to prepare a consultation in the shop from the customer's side. No respondent stated that they would not recommend the application to others. Only one respondent stated that he was still undecided about this. He or she pointed out that the guidance through the application should be further improved so that the products that are needed are listed directly when the products are selected:

> "I think this technical story should then be extended to say: 'If I have electric blinds that are controlled by this, do I need additional devices?'. Then the devices would have to be listed additionally and at that moment I would also like to see the costs for the whole house somewhere." (translated from German)

For five respondents it seemed very likely that they would recommend the application to others. Four respondents each also stated that a recommendation was likely or that they would recommend the application to others. Two respondents also stated that they would definitely recommend the application to others. Four respondents stated that they would recommend the application under certain conditions. One of the conditions mentioned was that it would only be recommended to people who are not familiar with smart home devices or who are faced with the problem of creating a smart home. Moreover, one respondent would recommend the application if he or she really liked it.

Table 7. Probability that the respondent will use the application again.

Number of Test Persons	Statements of the Test Persons
5	very likely
5	in any case
5	yes, I would use it
3	likely
2	unlikely

4.2.8. Benefits of the Application

The interview revealed that recommendations can solve some problems when creating a smart home via an application. In total, 13 respondents stated that the recommendation application made it possible to see which missing products matched the existing ones. It

also made it possible to see the compatibility of the products. Time savings and a better cost–benefit overview were also mentioned as advantages of the recommendation application. Overall, the use and understanding of the application were improved.

Another positive aspect is that the recommendation application provides a better overview of which services are available for a device, which products can be used in full and which services are still needed. An overview of the cheapest products was also provided. All in all, a sensible connection of compatible devices was made possible. Another positive aspect is that the recommendation application provides a better overview of which services are available for a device, which products can be fully used and which services are still needed. An overview of the cheapest products was also provided. All in all, this enabled a meaningful connection of compatible devices and less navigation in the application with recommendations. One respondent also mentioned that it gives the opportunity to optimize the smart home and not just set it up so that the rooms can be perfectly coordinated. It was also mentioned that the application with recommendations provides new incentives for innovative products and enables better comparability. In summary, a recommendation application for compiling a smart home shows itself to be a useful tool for planning to not only set up a smart home, but also to optimize it.

4.2.9. Difficulties

Although the number of difficulties solved by the recommendation mode outweighs the number of difficulties existing, existing difficulties were also mentioned. The lack of a direct comparison of two products by means of a cost–benefit analysis or price assessment was noted. In addition, four respondents mentioned that it was difficult to choose between the options because there were too many choices. Just as often, it was mentioned that there were no room-specific recommendations.

Three test persons stated that they lacked an understanding of the devices and their functions. Two test persons each stated that the individual structure of the house was not taken into account, that the price of the individual products was not clear enough, that the total costs of the house were not displayed clearly enough, and that the presentation of the services was too confusing. In addition, one respondent each criticized the fact that the recommendations could not be individualized, that duplications of services were not displayed and that there was a general lack of visualization. In addition, there was one mention each that the reason for a recommendation should be addressed more clearly, that device names and brands should be included and that more guidance through the application was desired.

It was also mentioned that a better explanation of the colors and additional warnings when devices are missing in order to use all services should be provided. In addition, one respondent noted that an overview of the rooms and the recommendations after selecting a type of appliance were missing. However, since these are available in the application, it can be concluded that the application could make users more aware of these functions.

One respondent also noticed that products of the same product type were recommended twice. However, this scenario could not be reconstructed from the corresponding log file.

4.3. Limitations of the Study

When critically examining the results, it is noticeable that although the test persons of the individual interviews belong to different occupational and educational groups, they are on average between 28 and 33 years old. Overall, 15 of the 20 respondents are between 20 and 29 years old. This means that representativeness for older users is not guaranteed. In addition, most of the people surveyed rarely use smart home devices and are therefore laypersons in the use of such devices. Users who claim to have a good knowledge of smart home devices are hardly represented. Their participation could lead to different results in the study.

The experimental design and the order of the questions asked were chosen to avoid bias as much as possible. For these reasons, it was also decided that the test persons should first use the application mode without recommendations and then set up the smart home with the application mode with recommendations. An application without product recommendations was set here as the prevailing starting position in practice. However, a possible bias cannot be completely excluded. At this point, it must also be mentioned that the test persons already have prior knowledge about the structure of the app when using the application in recommendation mode, due to the previous run-through without recommendations. However, since the focus of the study is on the positive and negative aspects of the product recommendations and the solved and still existing difficulties through product recommendations in the context of a smart home app, the experimental setup is required in this order.

Interviews in a neutral room were not possible due to the contact restrictions caused by the Corona pandemic. Therefore, the survey had to be conducted partly online via Skype. Therefore, possible disruptive factors could not be completely excluded. Furthermore, visual distractions could not be tracked. This may have influenced the test persons' ability to concentrate on the tasks and questions of the study. The reliability of the study must therefore be questioned.

A lack of concentration on the study process was also evident in the fact that some of the test persons did not read the instructions carefully or even skipped them. This could be one reason why the respondents were sometimes not at the place in the application where they should have been when they were interviewed. In addition, they were asked questions afterwards about facts that had already been answered in the introduction to the application.

In addition, the test persons used the application on different mobile devices. This may have led to differences in the GUI, since, for example, text breaks and the size of buttons and text fields vary with different screen sizes. This change in the presentation of the GUI may have led to differences in the use of the application. Additionally, it must be taken into account that the preceding first run with the application without recommendations may have led to habituation effects in dealing with the application. Therefore, dealing with the application in the second run with recommendations was made easier as a result. This may also have influenced the difficulty of the product choice and the speed of the choice.

As this is a qualitative study with free statements by the respondents due to the individual interviews, it must generally be noted that not mentioning aspects of a question does not necessarily mean that they do not apply. For example, other positive and negative aspects of the application can influence the user's choice of product, but these were not mentioned.

5. Scientific Contribution and Discussion

We demonstrably show the lack of scientific research for a future-proof smart home in terms of low-level technical requirements and high-level user interfaces as well as applications. In a survey paper by Sepasgozar et al. [11], 160 papers are reviewed and a comprehensive overview of smart home trends in academia is provided. Sepasgozar et al. [11] do not list any work in which future-proofing smart homes is a key research objective.

Empowerment is demonstrated by an increase in knowledge as shown by Iatraki et al. [25]. In our study, we show this increase in knowledge. The results clearly show that product selection is greatly facilitated by the app with product recommendations. On the whole, 3/4 of the test persons described interactions with the app that included product recommendations as easier, compared to interactions with the app without recommendations. This is due to the fact that the interaction and interoperation between the smart home products became clearer for the test persons. Likewise, the product recommendations made the requirements for the smart home products clearer to the test persons. When the app did not include recommendations and lacked a comprehensive overview of smart

home products, eight test persons criticized the app for lacking the information to make an informed decision.

Our study shows that our recommendation application provides users with a better overview of smart home products, and thus potentially counteracts the problem of proliferation of mostly non-interoperable technologies. Mennicken et al. [3] describe the need for a system that makes devices clear to users that match their existing devices, identifies the potential for automation and helps to expand installations to gradually increase user confidence and interest in automated functionalities. Our proposed application and underlying LDT system match the system described by Mennicken et al. [3] and show evidence that this system indeed helps in interacting with the smart home and empowering the users. Furthermore, we show that Leitner's [21] theory that users who do not have an overview of the combination and selection of devices are inhibited in the adaptation of smart home devices is demonstrably true. Thus, the majority of test persons selected more products in the application with recommendations. In summary, it can be stated that the product recommendations were gladly used by the test persons and not only seemed to facilitate the product selection, but also more products were selected. Furthermore, we demonstrably show that future-proofing smart home systems is an important research area and demonstrate a gap in research in this area.

6. Longevity Digital Twins (LDT) for User Assistance

Setting up and maintaining a smart home is a constant necessity that is often complex and hard to perform correctly. In previous work, we have shown that traditional smart home architectures are ill-suited and too limited for these types of tasks [4]. In order to make our assistance system feasible in the real world, we must consider these technical aspects. For this, we rely on our Longevity Digital Twin (LDT) architecture. We assume the following facts about a smart home:

- A smart home connects a set of smart devices through a platform or hub.
- Interaction between smart home and user occurs through the platform or actuators on the devices.
- It is technically possible to monitor interactions between users and their smart home.
- There is global knowledge of the deployed smart devices, their capabilities and relationship.

The first two assumptions are reasonable because they reflect the current state of technology. The latter two are open problems, as they depend on the implementation of the smart home. In previous works [4], we proposed an architecture that utilizes digital twins to separate the smartness from the sensor tasks of smart devices. This architecture provides several benefits to traditional smart devices. One example is the ability to consistently monitor interactions between users and their devices. Therefore, we must be able to observe the interaction, services, capabilities (etc.) in a centralized manner.

In an LDT architecture, the smartness is implemented in the digital twin and the device implements only basic functions, e.g., light control. Figure 10 summarizes our approach on LDTs. The left side shows a conventional smart thing connected to a smart home hub with smartness implemented in a device itself.

Our LDT approach is also applicable on the edge. The LDTs do not necessarily have to run remotely in the cloud. Instead, the LDTs can run on a user-owned device, which is located on premise. This way the smart home is still operable without an internet uplink. Similarly, a device does not necessarily have to give up its smartness. For backwards-compatibility with current smart home systems, a device may keep its smartness on the device itself, allowing it to operate autonomously. In this case, its LDT becomes merely a proxy for the device such that it integrates with the LDT architecture.

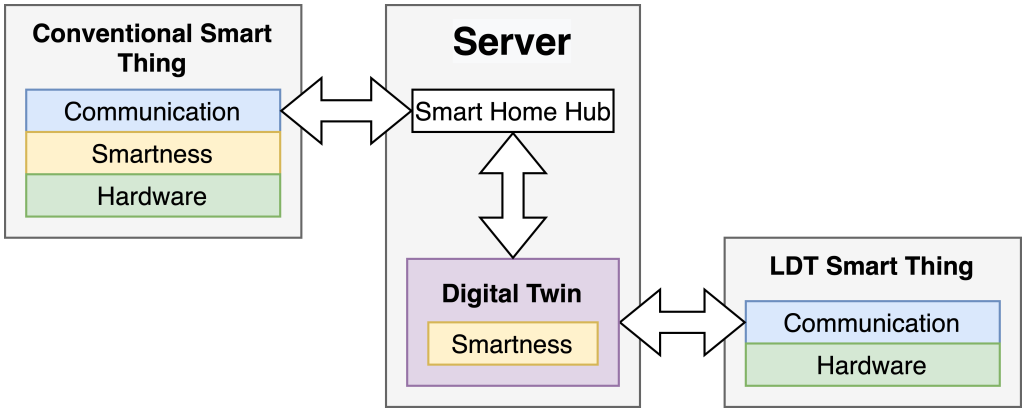

Figure 10. The left side shows a conventional smart thing connected to a smart home hub with smartness implemented in the device itself. In an LDT architecture, the smartness is implemented in the digital twin, and the devices implement only basic functions (lighting control etc.) as well as required communication capabilities.

Further Assistance Considerations

With an ever-increasing set of devices in a smart home, setting up dependencies and automation and maintaining them can become a time-consuming task. The mechanism in smart homes that monitors the state of a smart home and the user's interaction with specific devices is based on our LDT architecture. By tracking smart home usage data, it is possible to detect tuples of services that are used almost exclusively in combination with other devices. An example of this is light bulbs, blinds or similar devices that are usually used together and thus can be grouped together. By inspecting the time, weather conditions, sunlight conditions and other metrics, the system could learn automation rules. As a consequence, users do not need to setup automation rules manually because the system is able to deduce the user's intention.

Our LDTs are capable of updates in a transparent way, without the need to be mindful of potentially broken dependencies between devices. The proposed LDT architecture is able to bridge non-functional updates until a fix is implemented. Therefore, upgradeability is a welcome side effect of using LDTs.

Furthermore, since smartness is handled on the digital twin and knowledge about the capabilities of a smart object is provided, we can measure the usage frequency of smart home features. Unused features can be displayed to the user with additional information. Since usage varies between users, this has to be done individually.

7. Conclusions

The lack of knowledge and experience of users makes it difficult for them to manage their smart homes and obscures their view of the actual system capabilities. The interoperability problem of smart home devices, as well as the problem of the unmanageability of devices described by Leitner [21], leads to people being discouraged from purchasing and using smart home devices.

Therefore, we developed an assistance application that provides recommendations to the user. We conducted a survey and found that recommendations solve certain problems when setting up a smart home. A total of 13 out of 20 respondents said that recommendations from an assistant made it easier to understand the interoperability of different smart home devices. The recommendations also saved time and improved the cost–benefit overview. In addition, the recommendation assistant helps the user to explore yet unused features and shows how to enable additional features by extending the system with more smart devices. For this assistance system to become technically feasible, we need more information about a smart home than provided by state-of-the-art commercial systems. To this end, we leveraged our Longevity Digital Twins (LDT) architecture that provides us with the required meta data about the system and its usage.

In summary, we have shown that an application that provides assistance in setting up a smart home enhances the user experience of a smart home and counteracts the interoperability problem described by Leitner [21] through empowerment. We also showed that there is a lack of research on assistance systems that future-proof smart homes, both in terms of the underlying back-end architecture and the front-end user applications [10,11]. Furthermore, appropriate recommendation systems lead to user empowerment. For instance, Iatraki et al. [25] showed that pre-filtering medical information according to personal relevance increases the patient's knowledge. This increase in knowledge is commonly referred to as empowerment. In the patient's use case, dependence on the doctor's information is reduced, and confidence is increased [25]. We show that this effect occurs in the context of smart home installation, alteration and expansion. Setting up a smart home and deciding which newly acquired devices are interoperable with the smart home needs the empowerment of the user. This is supported by our application, which in particular helps the user to understand the interoperability of the devices and encourages them to set up the smart home. Additionally, we have demonstrated that if the essential smart device meta data is widely available, adding new devices becomes much simpler.

However, the technical basis of smart home devices does not permit the implementation of such an application in the real world yet. Smart Home systems need to make more data about deployment and usage available to enable support for the user. There is no unified approach for locating service, device, and dependency information, preventing our proposed assistance system from becoming implementable with current smart home systems. Therefore, we use an LDT architecture that gives us crucial information and makes our approach for smart home assistance technically feasible.

Our proposed human-centered approach demonstrates the need to provide further assistance in the smart home in general.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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