A Review of Energy-Saving Home Applications: Innovation Opportunity Applying with User-Centered Design Principles

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ABSTRACT

This systematic review article encompasses 515 publications and screens narrowed down to 97 articles by the criteria of inclusion and exclusion. It concludes that three main problems exist for energy-saving home applications: 1) experts and non-experts do not understand the energy efficient home data presented, 2) they are not designed for middle-aged and elderly users, and 3) the graphic communication is difficult to understand. Therefore, the aim of this article is to outline the issues, research gaps, and guidelines pertaining to the development of energy-saving home applications that are accessible, usable, understandable, and desirable for all users. Related review articles were analyzed by researching the correlation of three variables: application, user-centered design (UCD), and energy data. In summary, user experience, user interface, and UCD are recommended to optimize the design of accessible energy-saving home applications.

1. INTRODUCTION

The usage and energy demand of residential energy have experienced an exponential increase since the inception of modern society. Over the past decade, numerous studies have endeavored to tackle this matter by concentrating on the reduction of domestic energy loads, which have an influence on total energy consumption. [1-3]. Reducing household energy consumption can be accomplished through behavioral changes, appliance monitoring, and the implementation of energy-saving recommendations. These techniques for home energy conservation are part of creating an energy-saving home or smart home [3-4]. This concept can identify, detect, and monitor energy used by appliances. Users can then check on activities in the smart home environment through applications or websites [3-5]. For example, if a user inadvertently leaves certain appliances running, the smart home application will detect this and prompt the user to switch them off. Moreover, the smart home application can identify which appliances consume and increase energy loads and present recommendations for users [6-7].

However, research shows that smart home applications present several issues, including: 1) they are difficult to understand, 2) they are not user-friendly for everyone, especially older adults, and 3) they have a poor graphic design [8-11]. In 2018, researchers developed a computer program known as COMET_61 (a computer program to test the benchmark of homes' energy efficiency in Thailand) with the purpose of gathering data to validate that the energy consumption of homes in Thailand was commensurate with the established benchmark [12].

Subsequently, each of the three evaluation and training sessions achieved a remarkable degree of effectiveness. However, the programs were criticized by both technical experts and non-specialists for their complexity, with interfaces, point displays, data, and graphics proving to be perplexing. [12]. These issues are similar to results from the world-wide studies mentioned earlier. Hence, this review article endeavors to conduct a comprehensive examination of the challenges, research deficiencies, and prospects associated with the advancement of smart home or energy-related applications, focusing on three key variables: application, user-centered design (UCD), and energy data.

The structure of this article is arranged as follows: Section 2 provides a concise overview of the methodology, outlining the criteria for inclusion and exclusion. Section 3 discusses research gaps by searching for and paring two variables to check trends and opportunities. In Section 4, the researchers elucidate opportunities for applying user experience (UX) and user interface (UI) design, and UCD principles for energy-saving home applications are discussed in Section 5. Finally, the researchers conclude the article and present guidelines in Section 6.

2. METHODS

The researchers employed a systematic literature review method following the guidelines outlined by PRISMA (Preferred Reporting Items for Systematic Reviews and

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Meta-Analyses). [13] by searching the keywords “Application,” “User Experience,” “User Interface,” and “Home/Smart Home/Home Energy” in the database ScienceDirect. The search terms were used with the title, abstract, keywords, and established criteria for inclusion and exclusion, as presented in Table 1.

Table 1. Inclusion and exclusion criteria
(Source: Own elaboration)

Inclusion	Exclusion
Article or review indexed in ScienceDirect	The inclusion criteria encompassed books, book chapters, conference reports, and proceedings papers.
Publications in English	Publications in languages other than English were included in the review process.
Search terms: Title, abstract, and keywords	
Publication in the 2013–2022 period	
Keywords: “Application” “User Experience” “User Interface” “Home/Smart Home/Home Energy”	

Using the keywords, researchers identified 515 studies in ScienceDirect during their initial search. Following that, researchers defined the time frame as 2013–2022 and identified 201 studies. Then, the inclusion criteria for this review were refined to comprise only review articles. As a result, the overall quantity of studies was reduced to 97, as illustrated in Figure 1. The annual enumeration of the studies was provided in Table 2 and Figure 1. Table 3 lists the studies that have been cited the most frequently (SLR analysis).

Table 2. Distribution of articles by years

Inclusion	Exclusion
2022	20
2021	18
2020	13
2019	21
2018	10
2017	4
2016	3
2015	3
2014	3
2013	2

Table 3. Top 10 cited publications
(Source: Own elaboration)

No	Authors	Title	Total Citation
1	Terence K. L. Hui, R. Simon Sherratt, Daniel Díaz Sánchez [8]	"Major requirements for building smart homes in smart cities based on Internet of Things technologies" - Future Generation Computer Systems (2017)	327
2	Debajyoti Pal, Vajirasak Vanijja [14]	"Perceived usability evaluation of Microsoft Teams as an online learning platform during COVID-19 using System Usability Scale and Technology Acceptance Model in India" - Children and Youth Services Review (2020)	212
3	Chien-wen Shen, Min Chen, Chiao-chen Wang [15]	"Analyzing the trend of O2O commerce by bilingual text mining on social media" - Computers in Human Behavior (2019)	157
4	Samer Zein, Norsaremah Salleh, John Grundy [16]	"A systematic mapping study of mobile application testing techniques" - Journal of Systems and Software (2016)	154
5	Shohin Aheleroff, Xun Xua, Ray Y. Zhong, Yuqian Lu [17]	"Digital Twin-as-a-Service (DTaaS) in Industry 4.0: An Architecture Reference Model" - Advanced Engineering Informatics (2021)	152
6	Aristea Kontogianni, Efthimios Alepis [18]	"Smart tourism: State of the art and literature review for the last six years" - Array (2020)	111
7	Md Rajibul Hasan, Ashish Kumar Jha, Yi Liu [19]	"Excessive use of online video streaming services: Impact of recommender system use, psychological factors, and motives" - Computers in Human Behavior (2018)	97
8	Mona Masood, Menaga Thigambaram [20]	"The Usability of mobile applications for pre-schoolers" - Procedia - Social and Behavioral Sciences (2015)	80
9	Md.Moniruzzaman, Seyednima Khezr, Abdulsalam Yassine, Rachid Benlamrib [11]	"Blockchain for smart homes: Review of current trends and research challenges" - Computers & Electrical Engineering (2020)	58
10	Christoph Rieger, Tim A. Majchrzak [21]	"Towards the definitive evaluation framework for cross-platform app development approaches" - Journal of Systems and Software (2019)	55

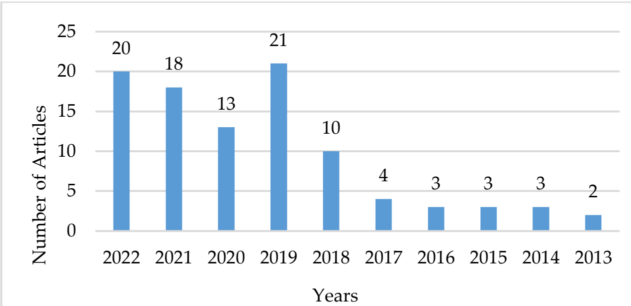

Fig. 1. Distribution of articles by years.

From this table, the most cited journal is Future Generation Computer Systems, followed by Computers in Human Behavior, Children and Youth Services Review, Journal of Systems and Software, and Advanced Engineering Informatics.

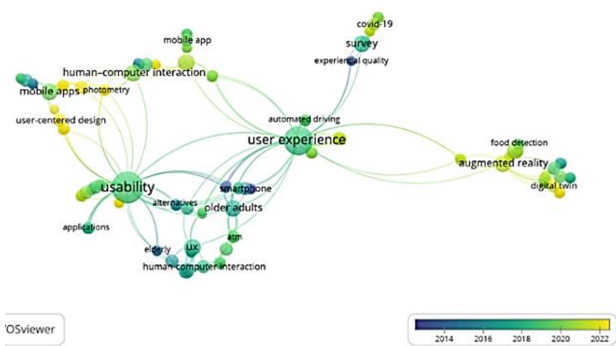

Fig. 2. Most Cited Publications on the Research Topic (Source: Own Elaboration using VOSviewer).

2.1. Word Co-Occurrence Cluster Analysis

The analysis was conducted using the VOSviewer software [22]. The criteria to use a co-occurrence cluster analysis was based on the title, abstract, and keywords. As a result, the most prominent subjects were “Usability” (15 occurrences), “User Experience” (14 occurrences), and “User Interface” (13 occurrences). This analysis is commonly used to find the link between subjects and keywords using the VOSviewer software text mining tool. Figure 3 presents an overview of the relationship between keywords as reflected by the number of publications published together [22-23].

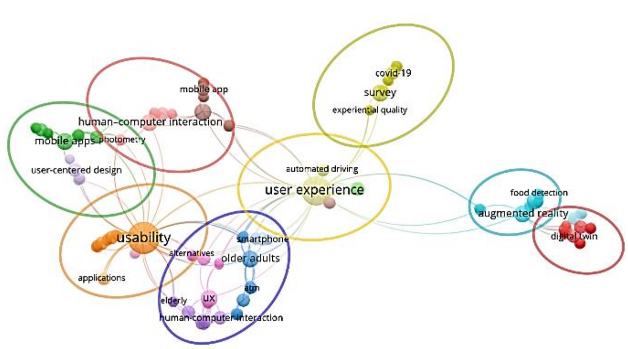

Fig. 3. Word Co-occurrence Analysis (Source: Own elaboration using VOSviewer software)

The researchers completed their examination of the 97 articles by thoroughly examining the titles, abstracts, and keywords, as well as by perusing the complete articles. Studies failing to satisfy the inclusion criteria in this phase with respect to the keywords "Application," "User Experience," "User Interface," "Energy-Saving Home," and "Home/Smart Home/Home Energy" were excluded from consideration. Only five articles met the criteria, and they are presented in Table 4 with details on the research problem, aim, method, and results.

Table 4. Related articles in the area of energy-saving homes and smart homes

Authors	Year	Title	Problems	Aim	Method	Results
Terence K. L. Hui, R. Simon Sherratt, Daniel Díaz Sánchez [8]	2017	Major requirements for building Smart Homes in Smart Cities based on Internet of Things technologies	The recent boom of the Internet of Things will turn smart cities and smart homes from a hype into a reality.	The objective is to create a list of requirement recommendations for building smart home systems.	It reviews the application of contemporary Internet of Things technologies for building smart homes and classifies them according to the proposed requirements.	A new paradigm for humans interacting with a large number of invisible computers at home is a new and evolving topic.
Md.Moniruzzaman, Seyednima Khezr, Abdulsalam Yassine, Rachid Benlamrib [11]	2020	Blockchain for smart homes: Review of current trends and research challenges	Few researchers focus on the large-scale adoption of blockchain-based homecare systems.	It improves the underlying information technology infrastructure to ensure the transparency, security, and privacy of user data.	The main contributions of this survey were intended to fill the gap and provide useful insights, methods, and applications for smart homes.	A feasible prototype was developed by implementing the blockchain platform for different smart home applications.

Authors	Year	Title	Problems	Aim	Method	Results
Abir Ghoraye, Rob Comber, RachaelGooberman-Hill [24]	2021	Older adults' perspectives of smart home technology: Are we developing the technology that older people want?	Older people may have negative perceptions of new technology and smart homes.	It explores older people's views and expectations of smart home technology.	Conducted a focus group study involving elderly individuals. Participants tested SPHERE, a smart home technology. Perceptions of participants were compared.	Older adults' acceptance of smart home technology increased with time and use.
Kristine Mae P. Escanillan-GaleraCenie M. Vilela-Malabanan [10]	2019	Evaluating on User Experience and User Interface of EnerTrApp, a Mobile Web Energy Monitoring System	With the rise of energy consumption, the Philippine government released an administration to reduce monthly energy consumption by at least 10%.	It evaluates the EnerTrApp mobile web application user interface.	User satisfaction, interface, and usability were tested.	The mobile web application worked as a tool to help reduce energy consumption.
Martin Kruusimagi, Sarah Sharples, Darren Robinson [9]	2017	Living with an autonomous spatiotemporal home heating system: Exploration of the user experiences through a longitudinal technology intervention-based mixed-methods approach	Increasing energy demands exert pressure on household energy consumption.	It investigates the user experience of residing with an automated heating system.	Implementation of a semi-autonomous spatiotemporal home heating system. Provision of a smartphone control application for users. Integration with a self-learning heating algorithm.	Automated home systems were designed with a focus on user experience.

From researching these articles, three main issues are summarized [8-11, 24]:

• Professionals and non-experts do not understand the energy-saving home information presented.

• The mobile application disregards the user, particularly elderly and middle-aged individuals.

• The graphic communication (i.e., the image on the display of the application) is difficult to understand.

When encountering these issues, the next step is to search for research gaps to check whether there are related studies and opportunities for solutions in designing energy-saving home applications.

3. RESEARCH GAP

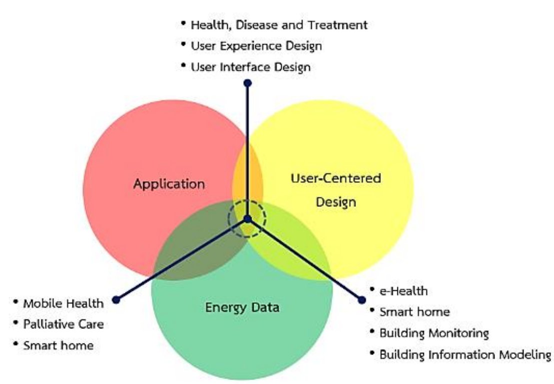

Fig. 4. The research gap of this study from the linkage of all three variables (Source: Re-searcher).

3.1. Search Results from a Pair of Variables Between Keywords "Application" and "User-Centered Design"

After reading carefully through the articles, researchers found that the two variables have several themes, but they are mostly related to:

• Health, disease, and treatment [25-29].

• UX and UI design [30-33].

It was found that these themes involve a lack of motivation, attractiveness, user interest enjoyment, participation of users apply at low, user-centric features and application performance of users. The issues were not about energy-saving home applications or smart homes.

For these problems, researchers suggest applying the UCD principle to understand user needs and UI design to increase interest in energy-saving home applications.

3.2. Search Results from a Pair of Variables Between Keywords "User-Centered Design" and "Energy Data"

The research findings indicate that the two variables exhibit common themes, including:

- The integration of electronic health (e-Health) and the public health system [34].
- Intelligent buildings, building information modeling, and building monitoring [35-38].

These themes point to an unfriendly design for users' daily lifestyles. There is also a low rate of using smart home technology due to the gap between functions and experience or user expectations. These are the main issues to be solved.

Thus, implementing User-Centered Design (UCD) processes, involving designers and users in application development, could provide a solution aligning with users' needs in energy-saving home applications.

3.3 Search results from a pair of variables between "Energy data" and "Application"

From the search results, it was found that the two variables have themes about

- Mobile health and palliative care [39-40].
- Smart home [41-45].

It was found that the problems arise from the limitation of communication between Individuals with occupations and age differences and today's smart homes are not connected and do not encourage human-building interaction. The design of smart home services must be responsive to diverse user needs and needs to be considered. User safety in smart home is the primary concern.

The aforementioned issues may be resolved by implementing user-centered design (UCD), user experience design (UX), and user interface (UI) to examine the obstacles encountered by users when utilizing smart home applications. This would improve usability and foster an emotional connection between the end user and an energy-efficient home application.

Based on this research gap, it can be inferred that the majority of studies investigating the three variables in question are concentrated on health and smart homes, while there is a dearth of research examining the application of user-centered design (UCD) principles to energy data-related applications. After researching the connection of these three variables, the problems are about a lack of motivation, enjoyment, friendliness, or adaptation to the user, as well as the limitations of interpersonal communication with heterogeneity, leads to diminished optimism stemming from the absence of user-centered design features that fail to cater to the diverse needs of users. Therefore, researchers suggest how to solve these through applying user experience design (UX), user interface (UI) and a user-centered design (UCD) model to solve and design a proper energy-saving home application.

4. UX AND UI DESIGN IN APPLICATION

The use of smartphones is steadily increasing over time. In addition, applications on smartphones are expected to increase in the future and result in the development of applications tailored to meet users' needs. [46]. Application user interfaces (UIs) are essential for displaying screen designs such as icons, colors, layout, and images. Additionally, UI optimization pertains to the overall user experience (UX) of the application [47].

User Experience (UX) encompasses the holistic sentiment that users encounter during their interactions with a given service, application, product, or system. It includes elements such as usability, relevance of displayed content, and ease of navigation. [48]. Don Norman supports that a good UX meets the needs of the user in the specific context that they use the product in Norman [49]. In contrast, Jonathan suggests that the UX process begins with identifying a problem and concludes with the development of an outline or prototype. [48].

However, designers should consider using the principles of why, what, and how, shown in Figure 5, to design the product [50-51], starting with a reason before deciding the beginning to last processes to create products that provide users with meaningful experiences. It must be ensured that the main concept of the product is still present and provides a fluid and smooth experience for users.

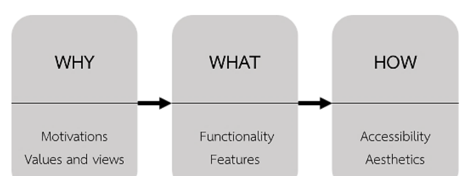

Fig. 5. Why, what, and how principle (Source: Research summary from Interaction Design Foundation).

User Interface (UI) involves the utilization of typography, imagery, and other visual design elements to transform a basic interface into something that is functional and easily comprehensible. UI refers to the systematic procedure of developing an aesthetically pleasing layout and graphical user interface, with the dual purpose of enhancing the product's usability and fostering an emotional bond with the end user. [52].

Mandel (1997) presents the UI design principles as follows: 1) place the user in control—the design should consider the needs of the user and leave them free to choose or interact with the system or control some operations; 2) To minimize the user's cognitive load—the system should be able to remember information that does not change often and remind users when they need to come back later; and 3) make the interface consistent—the dis-play should be provided with the same design standards across all screens.

The UX consists of a large number of UIs combined into a smooth process to create a product. First, when the UX design ends at the research stage, the layout is designed and applied to make the experience usable, attractive, and optimized for different screen sizes.

Table 5. Comparison of the differences between the UX and UI

UX designers	UI designers
• Focuses on interaction design • Charts the user pathway • Plans information architecture • Expert in wireframes, prototypes, and research	• Focuses on visual design • Chooses color and typography • Plans visual aesthetic • Expert in mockups, graphics, and layouts

There are several case studies applying the concept of UX and UI into technology products that create good experiences and solve issues with an unfriendly interface for users. For example, Remote Patient Monitoring, a home-based monitoring system designed to assist patients with chronic conditions, is a good example of applying UX and UI. Pre-viously, it was too complex and had poor self-management and an unclear UI. After applying UX and UI testing with users, the system became easier to use, simpler, and more effectively designed [53].

BIFURCAID: An educational mobile application [54], was applied with UX and UI to simplify and teach complex coronary bifurcation intervention through interactive illustrations.

In cases of virtual museums, the concepts of UX and UI design could be applied with users' preferences and personalization because huge amounts of information cause confusion for users. The Mobile Five Senses Augmented Reality System for Museums project came out with an augmented reality mobile application system that adopted UX and UI to organize loads of works at museums into a simple menu that is more attractive and matches with users' interests and preferences [55].

UX can be defined succinctly as the process of designing and delivering user experiences that are intuitive, simple to use, and conducive to generating positive emotions among users. User interfaces link design principles together, including placement, image, button, and font size. In light of the aforementioned issues (confusing interfaces and unwelcoming experiences), scholars propose that these design factors be implemented in order to enhance energy-efficient home applications.

5. APPLICATION DEVELOPMENT BASED ON UCD PRINCIPLES

Established in 1986 by Norman and Draper, UCD emphasizes the significance of user needs comprehension throughout the entire design lifecycle, encompassing services and products. Users should be prioritized and positioned as the focal point of the design process [49].

UCD is an iterative, purposeful procedure for creating a usable system. By incorporating potential system users into the design process, this is accomplished. [55]. In addition, the design team conducts user research using various techniques and approaches in order to develop a service or product that is exceptionally accessible and user-friendly [55-56].

Prior to beginning the design process, it is crucial to comprehend the context of use. As illustrated in Figure 6, defining the requirements of the users generates solutions for design and evaluation issues that can be iterated at each stage of the process in order to achieve the optimal UX.

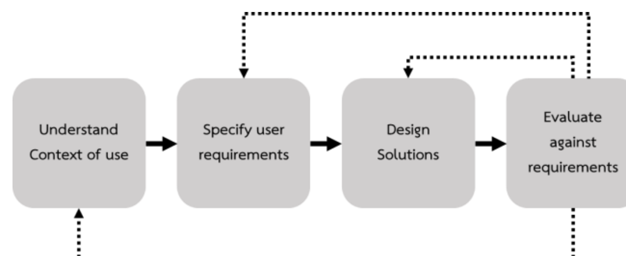

Fig. 6. UCD process (Source: Interaction Design Foundation)

Examples of applying UCD in technology products include Learn to Quit, a smoking cessation application that adopted a variety of UCD methods, the design process incorporates various methodologies, including expert panel guidance, theory-based smoking cessation content, persona development, paper prototyping, and usability testing of the app prototype. These techniques of UCD can result in a good structure and layout designed to minimize usability errors of users [57].

Next, the TiM system, a telehealth service monitoring neuron disease, uses a user-centered co-design approach to collaborate with patients, caregivers, clinicians, and app developers to meet the needs of users [58].

Regarding education, the Program Tutoring System provides interactive content and personalization to support users engaged in learning complex cognitive skills [59].

6. CONCLUSION

This review article collected a total of 515 publications from the ScienceDirect data-base from 2013–2022 and narrowed them down to 97 articles were selected using the inclusion and exclusion criteria outlined in Section 2. (Method). From the studies, the main issues with energy-saving home applications are:

1. Experts and non-experts do not understand the energy-saving home information presented - Because the home energy calculation's information is too specialized and detailed to understand, not for general users. (suggestion: apply UX design).

2. The mobile application does not consider the user, especially those who are middle-aged and elderly - Because the mobile application companies mostly focus on the young and new generation, not considered elderly people as a target group. (suggestion: apply UX and UCD).

3. The graphic communication (i.e., the image on the application's display) is difficult to understand - Because it wasn't tested and researched how users use applications. (suggestion: apply UX and UI design).

Next, this review article was conducted by searching for research gaps. Researchers set up and researched from a pair of keywords to present research gaps in Figure 4 and opportunities for solutions in energy-saving home applications with UX, UI, and UCD principles by searching three variables: “Application,” “UCD,” and “Energy Data.” However, from the research gap section, there is no direct study on this topic, meaning there is an opportunity for innovation.

Therefore, from the three main problems and research opportunities mentioned above, researchers suggest the guideline in Figure 7. Prior to anything else, designers ought to implement UCD principles, given that iterative processes encompass a spectrum of activities including identifying user needs, comprehending the usage context, resolving design issues, evaluating progress, and repeating stages. Following this, they should implement UX design to establish why, what, and how inquiries regarding the use of energy-saving home applications in order to provide users with meaningful and seamless experiences. In order to improve the product's usability and desirability, the application should ultimately implement a UI design that 1) empowers the user, 2) minimizes the effort required for user recognition, and 3) establishes a unified interface. This process should result in an aesthetically pleasing UI.

Overall, through a systematic literature review, this review article contributes new knowledge on designing energy-saving home applications to be more usable, accessible, understandable, and desirable for each group of users. As a result, a guideline for creating energy-saving home applications is presented and recommended. Designers should apply UCD to place users in each stage of the design process, adopting UX design to present smooth experiences and UI design to attract users with interesting and desirable interfaces. This section is not mandatory but can be included to provide information about any patents resulting from the work reported in the manuscript.

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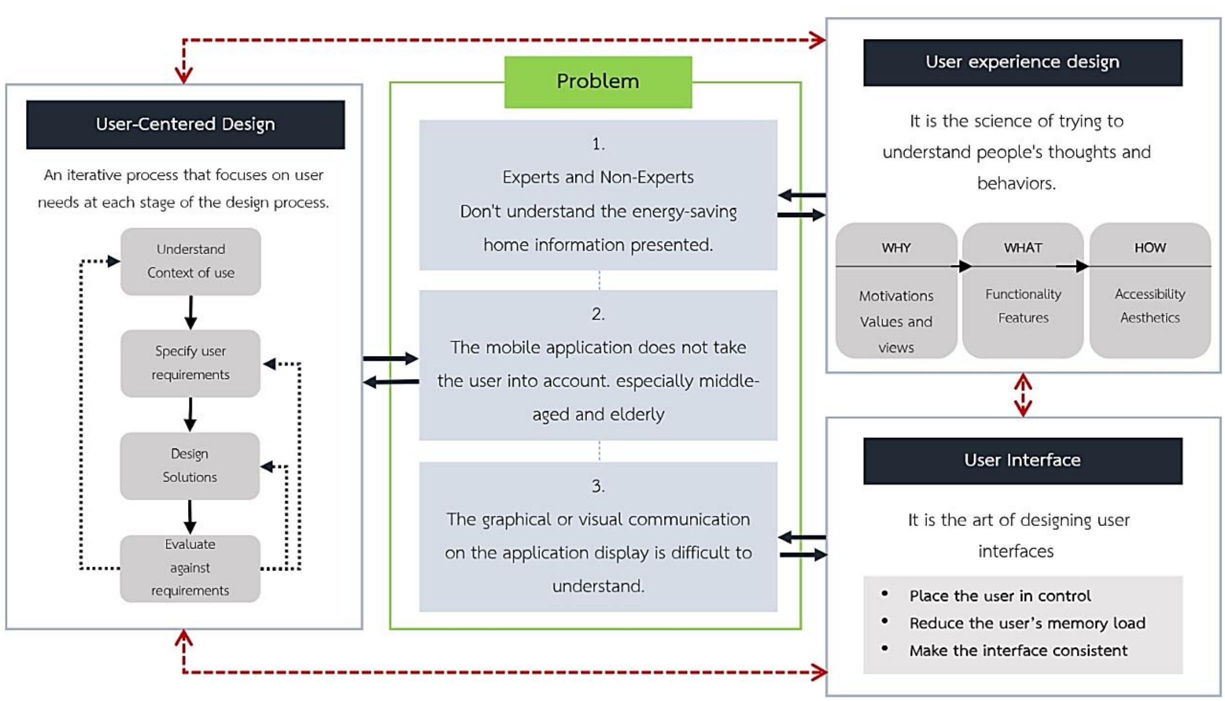

Fig. 7. A guideline for creating energy-saving home applications.

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