Analysis of User Accep tance of Residential Intelligence in the Past 20 Years

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Abstract. From 2005 to 2024, the global smart home market has achieved a leap from "technological prototype" to "large-scale industrialization", with the market scale increasing from less than 5 billion US dollars to over 150 billion US dollars. However, user adoption behavior has always been restricted by multi-dimensional factors: differences in economic costs lead to the differentiation of product choices among different income groups; the complexity of technical operations reduces the acceptance willingness of the elderly; data privacy risks trigger public trust anxiety; and the regulatory role of social demonstration effects and policy guidance on acceptance has become increasingly prominent. Against this backdrop, systematically sorting out the research evolution of user acceptance of residential intelligence in the past 20 years is of great significance for analyzing the adaptation law between technology diffusion and user needs. Using the literature review method and stage analysis method, this paper divides the research in the past 20 years into three stages: technology-driven stage, social-psychological expansion stage, and value integration stage. It compares the theoretical frameworks (such as the Technology Acceptance Model (TAM) and Diffusion of Innovations Theory, core variables, and empirical conclusions of each stage, analyzes the mechanism of key influencing factors in economic, technical, psychological, and social dimensions, and puts forward targeted suggestions for academic research and industrial practice paths, so as to provide theoretical support for the sustainable development of residential intelligence.

Keywords: Residential intelligence; user acceptance; phased evolution; influencing factors.

1. Introduction

Against the background of the global digital economy’s rapid development and the continuous upgrading of residents’ living demands, residential intelligence has gradually evolved from a marginal technological concept in the early21st century to a core driver reshaping the global residential industry ecosystem [1]. This transformation is not only a result of technological breakthroughs in Internet of Things (IoT), Artificial Intelligence (AI), and big data but also a direct response to the shift in residents’ living needs—from the traditional pursuit of "basic functional satisfaction" (such as shelter and basic living support) to the modern demand for "efficiency, comfort, safety, and sustainability". In the early 2000s, residential intelligence was still in the embryonic stage, with products mainly limited to single-function smart devices such as remote-controlled air conditioners and intelligent lighting. At that time, the market penetration rate of smart homes worldwide was less than 1%, and users’ cognition of residential intelligence was mostly confined to the "novelty of technology" rather than recognizing it as a necessary upgrade for living quality. Most consumers held a wait-and-see attitude, and only a small number of high-income groups with strong technological acceptance would try such products.

After 2015, with the maturity of IoT technology and the significant reduction in the cost of smart hardware, residential intelligence entered a period of rapid development characterized by "scenario-based integration" [2]. Smart devices from different categories began to realize interconnection and intercommunication—for example, smart thermostats could automatically adjust temperature based on data from smart door locks (to determine whether residents are at home), and smart smoke detectors could link with smart windows to achieve automatic ventilation [3]. This scenario-based application greatly enhanced the practical value of residential intelligence, pushing the global smart home market penetration rate to exceed 10% by 2020. During this period, users’ demands for residential intelligence expanded from simple "remote control" to "comprehensive life convenience and safety guarantees". However, this stage also exposed new contradictions: while technology promoted the diversification of smart functions, problems such as incompatible protocols between products of different brands, complicated operation interfaces, and unclear data collection boundaries emerged one after another, leading to a significant gap between users' expected experience and the actual use effect. For instance, many middle-aged and elderly users reported that they could not fully master the multi-step operation of smart home control panels, and some young users expressed concerns about the risk of personal data leakage from smart cameras and voice assistants.

Since 2021, the global emphasis on sustainable development (such as the "carbon neutrality" goals proposed by various countries) and the upgrading of consumers' value concepts have further pushed residential intelligence into a new development phase centered on "value integration" [4]. Users no longer only pay attention to the functional attributes and ease of use of smart products but also increasingly consider whether these products conform to environmental protection concepts (such as energy-saving performance), long-term economic benefits (such as reducing energy consumption costs), and social responsibility (such as promoting the development of green industries) [5]. Market research data shows that by 2024, over 65% of consumers in major economies such as Europe, North America, and China will take "energy efficiency" and "eco-friendliness" as key indicators when purchasing smart home products, and more than 40% of users are willing to pay a 10%-20% premium for smart devices with green certifications. This shift in user demand has not only changed the product Research and Development (R&D) direction of smart home enterprises but also put forward new requirements for the academic research on user acceptance of residential intelligence.

2. Theoretical Model Evolution Trajectory

Throughout the past 20 years, user acceptance has always been a core link restricting the development of residential intelligence [6]. It is not only a direct reflection of the matching degree between technological supply and user demand but also a key factor guiding the adjustment of industrial strategies and academic research directions. However, existing academic studies still have obvious limitations in systematically sorting out the evolution of user acceptance of residential intelligence over the past two decades. On the one hand, most studies focus on a specific stage or a single influencing factor—for example, some studies only discuss the impact of perceived usefulness and ease of use on user acceptance in the early stage of technology promotion, while others only analyze the role of privacy risks in the middle stage. These fragmented studies fail to construct a complete logical framework to show the dynamic changes of user acceptance and its driving mechanism over the long term. On the other hand, the "stage adaptability" analysis of influencing factors is insufficient. For example, economic cost, as a key factor, had a more significant restrictive effect in the early stage (when smart products were expensive), but its influence gradually weakened with the popularization of technology and the reduction of product prices; in contrast, social influence (such as recommendations from relatives and friends) and environmental value played a negligible role in the early stage but became important driving factors in the middle and late stages. The lack of in-depth discussion on such stage-specific differences makes it difficult for existing research to provide targeted theoretical support for industrial practice.

Against this background, this study takes the 20-year period from 2005 to 2024 as the research time frame, focusing on solving three core research questions: First, what are the clear phased characteristics of the research on user acceptance of residential intelligence in the past 20 years? How have the theoretical foundations and core research focuses (such as technical attributes, social psychological factors, and multi-value integration) of each stage evolved? Second, in different development stages, how do factors in economic (such as product price and cost-effectiveness), technical (such as ease of use and compatibility), psychological (such as risk perception and trust), and social (such as social demonstration and policy guidance) dimensions affect user acceptance? What are the differences in the intensity and mechanism of their influence? Third, based on the systematic sorting of the evolution law of user acceptance and the mechanism of influencing factors, what targeted suggestions can be put forward for the deepening of academic research (such as the construction of interdisciplinary theoretical frameworks) and the optimization of industrial practice (such as product design and marketing strategies) in the field of residential intelligence?

By answering the above questions, this study aims to fill the gap in the systematic review of user acceptance of residential intelligence over the past 20 years, construct a complete analytical framework for the phased evolution of user acceptance, and provide theoretical references and practical guidance for promoting the sustainable development of the global residential intelligence industry.

The in-depth development and extensive penetration of intelligent residential technology have become an important dimension of the evolution of contemporary urban life. Over the past two decades, research related to user acceptance has not only grown significantly in quantity but also shown clear phased evolution characteristics in theoretical depth and research paradigms. The academic understanding of this issue has gradually expanded from an early single perspective of technical functionality to incorporate social psychological variables, and further developed into a comprehensive framework focusing on the integration of multiple values. This transformation path reflects the researchers' increasingly systematic and profound understanding of the interaction between "people-technology-environment". Overall, this field can be roughly divided into three main development stages: the technology-driven initial stage, the mid-stage of social psychological expansion, and the current integration stage centered on the synergy of multiple values. The advancement of each stage not only echoes the improvement of technological maturity but also reflects the changes in users' values and consumption mentality.

3. Analysis of Key Influencing Factors

In the early stage of theoretical construction, the Technology Acceptance Model (TAM) served as the dominant framework and was widely applied to explain users' willingness to adopt smart home systems [7]. This model posits that perceived usefulness and perceived ease of use are the two core variables for predicting whether users are willing to use a certain technology. For instance, empirical studies on smart thermostats, lighting control systems, and home security systems have found that if users believe these devices can effectively enhance the convenience of daily life, achieve energy savings, and have an intuitive and simple interface design, their intention to purchase or use them often significantly increases. Most of the research at this stage was based on the rational behavior assumption, viewing smart homes as tools for improving efficiency and emphasizing their functional value. However, this perspective has not fully incorporated non-rational factors such as social influence, emotional responses, or symbolic cognition, revealing the limited explanatory scope of the model. This is because smart homes were still emerging at that time, and consumers were more concerned with "whether the technology could solve practical problems" rather than the social identity expression or cultural significance it might carry. Although TAM laid a solid theoretical foundation for the entire field, its limitations have prompted scholars to seek more comprehensive theoretical perspectives in subsequent research.

With the popularization of Internet of Things (IoT) technology and the gradual entry of smart devices into the home environment, users are no longer confronted with the simple issue of technology adoption but rather complex decision-making behaviors embedded in social networks. If the Technology Acceptance Model framework is still used for analysis at this point, it is often difficult to fully explain the behavioral differences among different groups of people. Therefore, researchers have begun to introduce interdisciplinary frameworks such as Social Cognitive Theory and Diffusion of Innovation Theory, attempting to explore the key variables influencing adoption behavior from a broader social and psychological perspective. Specifically, the following types of factors have gradually gained attention: First, social influence has become an indispensable explanatory variable. User decisions are often embedded in specific social relationships, and the attitudes and behaviors of relatives, friends, colleagues, or opinion leaders in the community significantly affect an individual's evaluation and acceptance of new technologies, especially the demonstration effect of early adopters, which often becomes an important force driving technology diffusion. Second, the data security and privacy risks associated with connected devices have raised widespread concerns. If users have doubts about the data protection mechanisms or policy transparency of enterprises, even if the product is highly attractive in terms of functionality, it may still reduce their willingness to adopt it. Third, the symbolic value and social identity function of smart home products have gradually become prominent. Especially among young consumer groups, they tend to showcase their technological taste, modernity awareness, or environmental identity through these technological products, expanding the consumption motivation from pragmatism to expression and emotion. Overall, research at this stage has broken through the limitations of traditional technology models, emphasizing the joint role of social interaction, trust building, and psychological perception in shaping user attitudes, thereby revealing the complexity and multi-level nature of acceptance behavior.

Current research has entered the third stage characterized by "value integration". Against the backdrop of the rise of sustainable consumption and the deepening of digital transformation, scholars are increasingly incorporating environmental psychology, behavioral economics, and sociological theories into their analytical frameworks, emphasizing that the adoption of smart home technologies is not only about personal convenience but also the result of multiple values such as functionality, economy, environment, and society working together. Green values have become a core consideration in many consumers' decision-making processes [8]. Recent market surveys show that over 60% of millennials and Generation Z consumers prioritize energy efficiency, material recyclability, and carbon footprint levels when purchasing household appliances. This indicates that environmental attributes have evolved from supplementary conditions to one of the main driving forces [9]. On the other hand, long-term economic and social benefits are also receiving increasing attention. Users may be willing to pay a premium for more energy-efficient smart energy systems because they can reduce long-term household energy costs and help reduce overall carbon emissions, demonstrating the dual realization of personal interests and social responsibilities. Methodologically, current research is more inclined to adopt mixed research methods, integrating quantitative modeling with qualitative interviews, and introducing big data analysis and machine learning technologies to provide a more detailed depiction and prediction of user behavior. The progress in this stage marks an important paradigm shift: academic focus has gradually shifted from "whether to adopt" to "why to continue using", and the research focus has also shifted from the technology itself to the value experience and meaning construction of people in the process of technology embedding into life.

In addition to the evolution of theoretical models, the actual acceptance of residential intelligence by users is also influenced by a series of practical factors, which span across economic, technological, social, psychological and even policy dimensions, jointly shaping the specific context of adoption decisions. Economic factors always remain at the core, as the purchase cost of equipment and subsequent maintenance expenses directly affect the purchasing intention of most families. Middle and low-income groups often pay more attention to the cost performance and long-term energy-saving benefits of products, while high-income families may prefer high-end brands, highly integrated and function-leading intelligent systems. With the advancement of industry technology and the intensification of market competition, the prices of various intelligent devices are gradually decreasing, which helps to increase the overall market penetration rate. Usability is equally important. The intelligence of technology should not come at the cost of operational complexity. Research has found that if the setup process of intelligent lighting, temperature control or security systems is overly complicated and the feedback mechanism is unclear, it may instead lead to a decline in user experience and even generate resistance. Therefore, the intuitiveness of the interaction interface, the accuracy and timeliness of system responses, become the key to maintaining user satisfaction and continuous use.

Compatibility and scalability are also aspects that users are highly concerned about. If the smart home ecosystem is highly closed, restricting the interconnection and interoperability between devices of different brands or platforms, it will weaken users' freedom of choice and the future upgradability of the system. On the contrary, open protocols and cross-platform compatible designs can significantly reduce users' migration costs and enhance the overall attractiveness of the system. In terms of privacy and security, although data collection helps enterprises provide more accurate personalized services, users' concerns about privacy leaks, hacker attacks, or commercial abuse of data have never subsided. The key to building user trust lies in whether enterprises adopt reliable encryption technologies, whether they clearly and publicly disclose data usage policies, and whether they provide users with control over their own data. Generational differences and digital literacy also constitute important moderating variables. Older users, due to limitations in cognitive habits and technological adaptability, usually show lower adoption willingness than younger groups. For this group, smart home design needs to particularly focus on simplifying interaction, such as introducing voice control, one-click scene modes, or remote assistance functions, to lower the usage threshold.

Furthermore, long-established usage habits and inherent psychological resistance should not be overlooked. Some users are dependent on traditional home appliances and may show inertial resistance or learning anxiety when faced with new interaction methods. Enterprises can alleviate such "habitual resistance" through demonstration training, experience marketing, and progressive guidance strategies. The social demonstration effect plays a positive role in promoting adoption. Recommendations from friends and family, open displays in offline experience stores, and the establishment of case demonstration communities can effectively enhance users' understanding and trust in the functions and reliability of intelligent systems. Finally, policy and institutional incentives play a crucial role in promoting the popularization of specific types of smart devices. Government policies such as financial subsidies, tax reductions, or energy efficiency standards can directly reduce users' purchase costs, especially in areas such as solar photovoltaic systems, home energy management systems (HEMS), and smart grid interaction devices. Policy intervention often becomes an important external driving force for triggering large-scale adoption.

4. Conclusion

In summary, the research on user acceptance of intelligent residential systems has undergone an evolutionary process from an early focus on technical functions, to an expansion into social and psychological aspects in the middle stage, and now to the current integration of multiple values. The factors influencing users' adoption decisions cover multiple dimensions such as technical attributes, economic conditions, social networks, psychological cognition, and policy environments. There are also complex interactions among these factors. Future research urgently needs to explore the coupling mechanisms and dynamic evolution paths among different value dimensions under an interdisciplinary theoretical framework, with particular attention to the correlation between cultural differences and long-term usage behaviors. At the practical level, efforts should be made to balance the relationships among technological innovation, humanistic care, and social responsibility, and to promote the continuous development of intelligent residential systems towards a more humanized, green, and democratic direction through the design of inclusive, safe, and sustainable smart living solutions.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Zhou C, Qian Y, Kaner J. A study on smart home use intention of elderly consumers based on technology acceptance models. PLoS ONE, 2024, 19(3): 300-305.

[2] Shuhaiber A, Mashal I. Understanding users' acceptance of smart homes. Technology in Society, 2019, 58(3): 101-110.

[3] Chen C, Xu X, Arpan L. Between the technology acceptance model and sustainable energy technology acceptance model: Investigating smart meter acceptance in the United States. Energy Research & Social Science, 2017, 25(6): 93-104.

[4] Schill M, Godefroit-Winkel D, Diallo M F, Barbarossa C. Consumers' intentions to purchase smart home objects: Do environmental issues matter? Ecological Economics, 2019, 16(1): 176-185.

[5] Basarir-Ozel B, Turker H B, Nasir V A. Identifying the Key Drivers and Barriers of Smart Home Adoption: A Thematic Analysis from the Business Perspective. Sustainability, 2022, 14(15): 90-95.

[6] Chang S, Nam K. Exploring the sustainable values of smart homes to strengthen adoption. Buildings, 2022, 12(11): 19-29.

[7] Li W, Yigitcanlar T, Erol I, Liu A. Motivations, barriers and risks of smart home adoption: From systematic literature review to conceptual framework. Energy Research & Social Science, 2021, 80(2): 102-121.

[8] Guhr N, Werth O, Blacha P P H, Breitner M H. Privacy concerns in the smart home context. SN Applied Sciences, 2020.

[9] Cannizzaro S, Procter R, Ma S, Maple C. Trust in the smart home: Findings from a nationally representative survey in the UK. PLoS ONE, 2020, 15(5): 231-236.