A Two-Decade Journey of Evolution in Smart Homes: A Systematic Review and Thematic Analysis on Health and User-Centric Innovations

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Abstract

Background: The smart home industry, powered by AI and IoT, has grown significantly, with market size expected to double by 2026. Academic projects like Georgia Tech's Aware home have enhanced our understanding of smart home technologies. However, current research often focuses narrowly on technology. This study aims to broaden the perspective by reviewing two decades of smart home literature using bibliometric analysis and thematic analysis, to better align future research with evolving user needs and market trends.

Objective: This study analyzes smart home trends from 2000 to 2023 using bibliometric and thematic analysis to understand broader industry trends. It examines technological advances, service innovations, and shifts in user demands, aiming to inform future research and industry developments.

Methods: The analysis is conducted in four steps: data collection from Web of Science, gathering 5,983 abstracts from 2000 to 2023.1H; data pre-processing and refinement; topic modelling of 1,003 selected articles; and combined bibliometric network analysis and qualitative in-depth analysis for interpretation.

Results: This study reviews 1,003 articles on smart homes, highlighting advancements in technology, applications, and user-centric research over 20 years. It notes a shift from IoT and AI in basic functions to broader uses in energy management and healthcare, with a focus transitioning from affluent early adopters to more inclusive support for vulnerable groups. This evolution indicates a significant paradigm shift in the smart home sector, affecting future technology and service development.

Conclusions: The results of this research provide significant academic and practical insights by offering a comprehensive overview of the smart home domain’s evolution over the past twenty years, highlighting the shift from a technology-centric to a user-centric approach. This shift enhances academic understanding and opens new commercial opportunities, particularly in healthcare, focusing on user satisfaction and quality of life, paving the way for future real-world solutions.

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Review

A Two-Decade Journey of Evolution in Smart Homes: A Systematic Review and Thematic Analysis on Health and User-Centric Innovations

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ABSTRACT

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Keywords: Smart home; Systematic literature review; Thematic Analysis; Bibliometric analysis; Healthcare; User needs

1. Introduction

The smart home industry, fuelled by core technologies of the Fourth Industrial Revolution such as artificial intelligence and the Internet of Things (IoT), has attracted significant attention, permeating various products, services, and platforms. Over the past two decades, particularly since 2010, smart homes have witnessed substantial advancements in both industry and academia. Initially conceived within the realm of home automation in the early 2000s, the landscape has evolved dramatically with the advent of wireless Internet, smartphones, IoT proliferation, and advancements in artificial intelligence. With the advent of wireless Internet and smartphones, coupled with the expansion of IoT devices and the growth of artificial intelligence, smart home research and applications have entered a phase of rapid development, signalling a new era of innovation and integration.

Market projections also indicate a remarkable growth trajectory for the smart home industry, with a projected Compound Annual Growth Rate (CAGR) of 14.76 percent. This growth is expected to propel the industry from a value of $104.41 billion in 2021 to $207.81 billion by 2026. In 2021, the United Kingdom emerged as the frontrunner (41.6 percent) in smart home penetration, followed closely by the United States (40.1 percent), South Korea (36.8 percent), Norway (35.65 percent) and Australia (32.7 percent). Moreover, the global average smart home penetration rate is expected to more than double over the next five years, escalating from 12.3 percent in 2021 to 25.2 percent by 2026[1]. These projections underscore the burgeoning global demand for smart home technologies and the exponential growth anticipated in the near future.

Given this context, several experimental studies have been conducted at renowned academic institutions, including the Aware home at the Georgia Institute of Technology, PlaceLab at MIT, R-House at Indiana University, Easy Living at Microsoft Research, the UKDRI Smart Home at Imperial College London, and Keio The Smart Space at Uiku University in Japan.[2]. These seminal studies have played a crucial role in advancing our understanding of smart home technologies and

their implications. By delving into user behaviors, preferences, and acceptance of smart home technologies in real-world settings, these studies have provided invaluable insights[3]; The findings from these studies have not only informed the development of user-centric smart home solutions but have also shaped the trajectory of future research and innovation in the field. By addressing user needs and preferences, researchers and industry practitioners can design more intuitive and effective smart home technologies that enhance the overall user experience and promote widespread adoption.

Nonetheless, existing research reveals a pressing need for a comprehensive synthesis at this stage of development. While numerous theoretical studies exist, the majority tend to adopt a single perspective, often focusing solely on technology-centric viewpoints. Consequently, there is an urgent call for a more diverse approach from a macro-level standpoint within the industry. It is necessary to undertake a comprehensive review of literature spanning the last 20 years from a macro perspective to assess the appropriateness of current industry and research trajectories. This study aims to enhance the overall understanding of the industry through a macroscopic lens and provide profound insights into future research directions.

The concept of the smart home and user expectations and desires have undergone substantial evolution over the past two decades, driven by technological advancements. As technology has progressed, the understanding and expectations surrounding smart homes have also diversified over time. This evolution is evident in the shifting demographics of smart home users, reflecting changes in age groups and preferences. These transformations also influence approaches in both industry and research, underscoring the need for a macro-level approach that encompasses the diverse needs and expectations of users. Departing from traditional technology-centric research, such an approach is essential for effectively addressing the multifaceted requirements of users and aligning with evolving trends in the smart home landscape[4].

Therefore, this study is driven by the necessity to recognise the limitations of existing research and cultivate a comprehensive understanding of the smart home industry from a

longitudinal and broad perspective. This pursuit is particularly crucial in the swiftly evolving field of smart homes, offering foresight into future research and industry directions.

This study aims to synthesize the conceptual framework and scholarly research pertaining to smart homes over the past two decades, while also prospectively examining future research directions. To achieve this objective, the methodology employed encompasses bibliometric analysis and thematic analysis. These methodologies are utilized to identify and classify smart home literature across a temporal spectrum, facilitating a comprehensive understanding of the field's evolution over time.

This study compiled 5,981 articles published between 2000 and 2023 from the Web of Science database, utilizing search terms associated with smart homes and users. Subsequently, a systematic literature review was undertaken, followed by topic modelling on 1,003 articles. Further, 42 selected papers underwent in-depth analysis through literature review. The present research scrutinized the time-series change process, yielding comprehensive insights into the domain of smart homes. Its significance lies in its capacity to explore various facets, including smart home products, services, and user dynamics, thereby facilitating adaptability to future developments. This study aims to address the following questions:

RQ1. *What are the perspectives in smart home research so far?*

RQ2. What is the overarching academic *status of smart home research over the past 20 years?*

RQ3. *What are the characteristics of each period, and how does the field evolve from a diachronic perspective?*

RQ4. *What are the directions for future research?*

1.1 Theoretical Literature Background

1.1.1 Changing the Concept of a Smart Home

The concept of the “smart home” traces back to 1975, when it was defined as a residential system equipped with interactive automation technology, empowering residents to manage various home functionalities like lighting, temperature control, multimedia utilization, and security monitoring. The actual term was coined by the American Home Builders Association in 1984, when the concept gained momentum.

In the early 20th century, the advent of electronic technologies like vacuum cleaners, food processors, and washing machines marked a significant stride towards enhancing convenience and comfort within households [2]. The commercialization of the first home automation platform, X10, in 1970 represented a milestone, transmitting digital data via radio frequencies through existing electrical wiring. [5]. The late 1990s witnessed a surge in home network development opportunities, propelled by the widespread adoption of high-speed internet. The emergence of the Internet of Things (IoT) has significantly changed the concept of smart homes. In the late 2000s, the widespread adoption of smartphones increased the popularity of smart homes through mobile applications. Throughout its evolution, smart homes have been denoted by various names, such as home networks, digital homes, home automation, and intelligent homes, reflecting the expanding scope and definition of the concept[6].

In the industrial sector, major technology companies including Google, Amazon, Apple, Samsung, Huawei, among others, have introduced various smart devices and home automation systems[2]. The advent of integrated home automation solutions has significantly expanded the scope of smart homes. Since 2010, the proliferation of voice-controlled AI speakers such as Amazon Echo and Google Home has been remarkable. These devices have expanded beyond their initial function of controlling home appliances through voice recognition, evolving into comprehensive platforms offering a wide array of services. These services range from accessing music content to

facilitating online shopping[7].

While the traditional concept of the smart home primarily focused on providing convenience and comfort, the modern smart home landscape, particularly from 2018 onwards, has shown its potential to deliver practical services aimed at enhancing quality of life. These services encompass aspects such as security, energy saving, and telehealth underscoring the evolving nature of smart home technology towards more holistic and user-centric functionalities[8].

[9] delineated 11 different definitions and interpretations of the smart home between 1992 and 2019. [10] defined a smart home as a concept integrating information and communication systems. Building upon this, [7] defined a smart home as one capable of anticipating and responding to the needs of its occupants through computing and information technology, thereby providing comfort, convenience, security, and enhanced entertainment [11] broadened the definition to encompass a home offering remotely monitored and controlled services. Finally, [4] elucidated the overarching objective of smart homes as providing personalized services to end users through state-of-the-art technologies [9].

In the early stages of smart home development, the primary focus revolved around integrating products and services through communication technology. The overarching goal was efficiency, with this integration aimed at simplifying user control and management, ultimately saving time. While there was some discourse regarding the necessity for services to align with user needs, the predominant focus of research and development centered on early adopters exploring products or services with new technologies. These experiments were conducted by constructing and evaluating specific environments, albeit often detached from the authentic user experience.

In recent years, significant strides in IoT and sensor technology have ushered in transformative changes. These technologies empower devices to detect electricity and water usage, learn from user behaviors, and autonomously adapt. Consequently, personalized services have emerged, capable of tailoring energy usage to align with users' lifestyles, thereby facilitating energy

conservation. These developments signify a paradigm shift in smart home technology, evolving beyond efficiency to enhance users' quality of life.

1.1.2 An Analytical Framework for Insights into Smart Home

Although the smart home industry is diversified and has gradually entered the mainstream market, research remains predominantly skewed towards the technological perspective, often neglecting the importance of user needs[12].

Existing studies tend to concentrate on technical aspects such as device capabilities, infrastructure and architecture development, and applications, thereby leading some scholars to call for a more user-centric approach that prioritizes the actual beneficiaries of smart homes technology[4]. From a technology perspective, research on smart homes typical revolves around the integration of various technologies, including home automation, automatic control systems, communication networks, connected devices and services, remote access and control, and home intelligence. Conversely, the service perspective primarily focuses on control, monitoring, and response support for technology management, with additional exploration into various services such as telehealth services for promoting healthy living[13].

Research from the user perspective has centered on understanding user adoption and utilization patterns, primarily delving into adoption factors, challenges barriers, and post-adoption usability evaluations. According to Charlie Wilson's findings, the adoption rate of smart home systems remains sluggish, potentially attributed to a discrepancy between developed products and users' actual needs[4]. Therefore, there is a pressing need to account for user diversity, including ageing demographics.

In this study, we will conduct research from the following three perspectives. Conducting a macro-level study encompassing technologies, services, and user dynamics will enable us to explore user needs and identify gaps between technologies and services in future smart homes. This holistic approach is crucial for bridging the divide and ensuring alignment between technological

advancements and user expectations.

1.2 SLR and Thematic Analysis

Systematic quantitative analysis methods serve as invaluable tools for scientific evaluation, enabling the identification of contributions and impacts made by pioneers and practitioners in a field. These methods also facilitate the examination of underlying influences and afford a macro view of the existing literature [14]. By employing scientific methodologies and systematic quantitative analysis, researchers can gain comprehensive insights into the landscape of a particular domain, thereby advancing knowledge and understanding within the field. SLR centered on thematic and content analysis using tools like Leximancer, has been applied across a wide range of disciplines. Recent studies have used this method to conduct comprehensive literature reviews in diverse areas including digital banking, e-market publishing, cross-cultural psychology, small and medium-sized enterprises (SMEs), and studies on entrepreneurship evolution.

These research methods enable researchers to systematically observe and analyze changes and continuities in thematic interests over time, mitigating distortion caused by fluctuations in the volume of literature. Such analyses provide insights into the emergence, evolution, and eventual disappearance of certain concepts, providing a nuanced understanding of the topic under investigation[15]. As a result, this approach contributes to a more foundational and contextualized interpretation of trends and opportunities within the field of study, thereby enriching academic and practical knowledge. Moreover, by comparing Prominence Interest (PI) values using this method, discrepancies between periods across different timeframes can be readily discerned, facilitating a more refined interpretation of these disparities. This allows for a deeper exploration of temporal variations and enhances the overall interpretative capability of the analysis.

In a study investigating the evolution of business-to-business (B2B) marketing topics, researchers analyzed 328 articles from B2B marketing journals from 1993 to 2014. The scientific analysis revealed four themes and 86 concepts, categorized across four distinct time periods.

Notably, a consistent theme throughout the various time frames underscored the significance of relationships in B2B marketing. Utilizing Prominence Interest (PI) analysis, the study elucidated the evolution of these concepts over time, highlighting changes and differences between time periods[15].

Another literature review traced three decades of research within the field, using Leximancer to conduct content analysis. The study analyzed 211 articles from the journal Electronic Markets, along with 356 presentations from the Bled eConference. The analysis identified 13 main themes, with notable overlaps including information, services, business, online, social, and systems. The study detailed the similarities and discrepancies between these identified themes, providing a thorough assessment of their impact on the field[16].

In addition, a literature review exploring the application of AI in the banking sector since 2005 conducted a systematic analysis of 44 articles. Thematic and content analysis using Leximancer uncovered several pivotal themes, leading to the proposal of an AI banking services framework designed to reconcile the disparity between research and industry practices. The analysis identified strategy, process, and customer relationships as key areas of research, providing insights into strategic planning and value optimization for the future use of AI technology within banking operations[17].

As shown in previous research, a systematic review offers a comprehensive understanding of a subject matter, revealing overarching insights and subtle changes and trends within the field. Building upon this premise, the current study aims to analyze a wide range of literature pertaining to smart homes spanning the last two decades. The primary objective of this study is to discern evolving characteristics across different time periods, thereby furnishing a macro view from three distinct perspectives. To achieve this goal, the study adopts a hybrid approach, combining qualitative research methods with quantitative research methods using Leximancer. This integrated approach not only facilitates a nuanced comprehension of the subject but also enables a deeper exploration of its

evolution over time. By synthesizing qualitative and quantitative insights, the study aims to contribute significantly to the body of knowledge surrounding smart home technologies and their evolution.

2. Data Collection and Methodology

2.1. Dataset Collection

For data collection, we utilized the Web of Science platform, renowned for its credibility and extensive coverage of peer-reviewed articles across diverse disciplines [18]. Leveraging the broad scope of this database, we conducted a thorough search and filtering process to ensure inclusivity and breadth in our literature selection. Our aim was to compile a comprehensive collection of literature on smart homes by combining various types of literature [19]. Aligned with our research framework, we structured our queries as follows:

Query = (“smart home” OR “smart home user”) AND (“behavior”, “acceptance”, “adoption”, “perspective”, “learning”, “use”, “evaluate”)

For the primary search, we selected the period between 1998 and 2023 as a reasonable time frame for capturing the initial literature on smart homes. We reviewed the highest quality literature related to smart home technologies, services, and users to identify potential keywords for the search string. Additionally, input from relevant literature reviews helped construct a diverse keyword dictionary focusing on verbs related to user behavior, such as "behavior", "acceptance", "adoption", "perspective", and "learning". Using these terms in the final search string, we retrieved 7,003 papers. After excluding four papers published before 2000 and 1,016 duplicates, 5,983 remained for screening. In the second step, we conducted SLR to evaluate the content and quality of these articles. In the third step, we analyzed the 1,003 screened articles using Leximancer, a software that employs statistical algorithms to extract topics from text data by analyzing word frequency and co-occurrence patterns. The extracted topics were analyzed in-depth, focusing on a total of 42 articles. This comprehensive approach facilitated the gathering of a diverse range of literature, providing valuable

insights into the evolving landscape of smart home research over the past two decades. It empowered us to address the first question regarding the overall changes in the smart home over time and the second question concerning the primary themes in each time period. In addition, through qualitative in-depth analysis of the final sample of literature via SLR, we were able to explore future perspectives in the field.

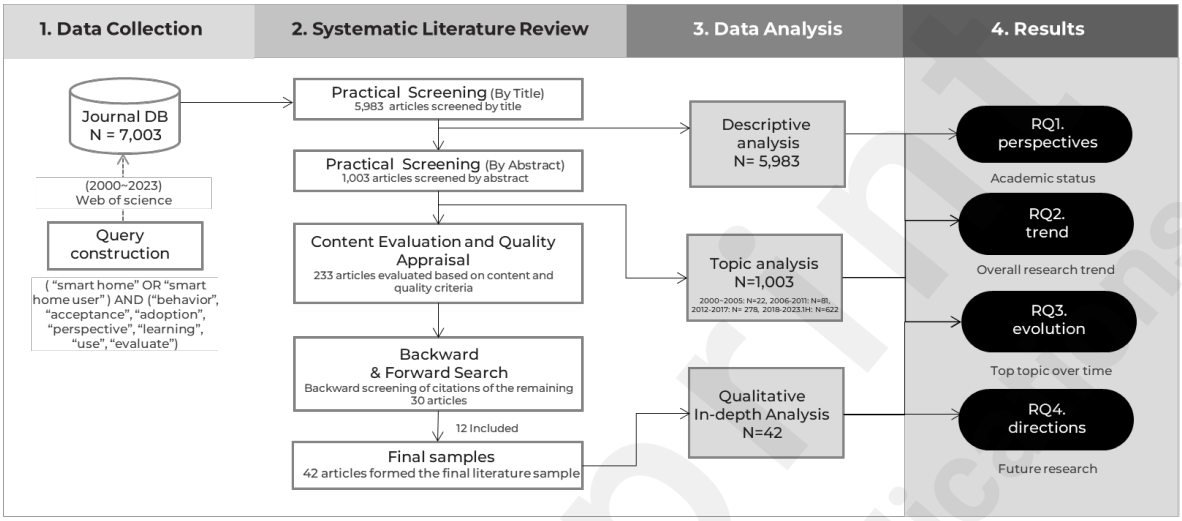

Figure 1 Research methodology

2.2. SLR

Figure 1 reveals overall representation of this research methodology. Out of the 7,003 collected data points, a rigorous manual review process was employed, involving scrutiny of titles and abstracts, content and quality assessment, and conducting backward and forward searches. This process resulted in the selection of a final sample comprising 42 papers for comprehensive content analysis.

The initial stage involved a passive review based on titles and abstracts, resulting in the selection of 1,003 papers. Subsequently, these papers underwent a meticulous screening process, wherein abstracts were thoroughly examined, and promising ones were further scrutinized by reviewing relevant sections of the full text. These 1,003 papers were then subjected to topic modelling to identify themes for each time period. During this phase, particular attention was paid to the thematic relevance of each paper, with a focus on encompassing a broad spectrum of smart home technologies, services, and user perspectives. Papers predominantly focused on specific

technological aspects were excluded to maintain the study's comprehensive scope. Additionally, studies limited to specific products or lacking generalizable insights about smart products were also omitted from the final selection[20].

The subsequent phase involved a thorough assessment of the remaining 233 papers for their content and relevance. Recognizing that much of the recent literature may have been initially presented at conferences before undergoing peer review for journal publication, special attention was paid to conference papers. A subset of 30 papers, was selected as an initial sample, including those presented at esteemed conferences such as Human Factors in Computing Systems. Furthermore, backward and forward searching through references was conducted to ensure the completeness and reliability of the literature list, which is a critical step in concept-driven literature reviews [21-23]. Through this process, 12 additional papers were identified, resulting in a final literature list comprising 42 papers for in-depth analysis and data extraction.

Visual concept maps and statistical output were employed to identify key concepts. Through the creation of a visual concept map, complemented by statistical output, we determined the main themes inherent in the textual data, elucidated the interrelationships among themes, and indicated which files from which time periods can be characterised by particular themes or topics[24]. This approach proved invaluable for uncovering key themes and concepts within the text data, offering a graphical representation (i.e. concept maps) for analyzing clusters of text data and exploring deeper contextual connections as the text was mined [25].

By identifying concept maps, we could analyze patterns of concepts organized into themes and delve into the thematic clusters that underlie relationships within the literature over time. Clusters of words proximate to the main text indicative of possible concepts were identified based on their frequent co-occurrence and subsequently grouped into a network comprising all concepts. These concepts were then clustered into higher-level topics, guided by discerned dimensions of awareness, represented by coloured circles and displayed as a heat map to highlight the relationships among

concepts and the proximity of each concept to a topic. The closer a topic aligns with a concept, the stronger the association between them. The literature data processed through this methodological approach was analysed through a visual/graphical framework as concept maps[26]. The rationale behind employing text mining analysis with Leximancer is to visually chart the conceptual structure of smart homes, interpret thematic emphases and their interrelations, and reveal the interdependencies and proximities among themes across each time period, thereby enhancing comprehension and interpretation of the past and potential future[27].

To mitigate disparities arising from variations in the number and volume of articles across different time periods, we employed the Prominence index (PI) provided by the Leximancer programme[28, 29]. The Prominence Index serves as a correlation metric between categories and attributes, facilitating comparative analyses and rooted in Bayesian statistics [24, 30, 31]. The PI formula is as follows:

$$\text{Prominence Index(PI)} = P(C \text{ and } T)/P(C) * P(T) \quad (1)$$

where P(C) represents the probability that a textual region originates from a particular concept, while P(T) denotes the probability that a textual region originates from a particular time period. The specific time periods are categorized by the literature of each year, resulting in four distinct categories. P(C & T) reflects the probability that a text region originates from a specific concept and a specific time period simultaneously[24, 31].

The null hypothesis, stated as 'P(C) and P(T) are uncorrelated', suggests that there is no association between concepts and time periods. If the PI is less than 1, it indicates a negative correlation between concepts and time periods, meaning that the observed co-occurrence is lower than expected based on the null hypothesis (Ho). Conversely, a PI greater than 1 indicates a positive

correlation, indicating that the observed co-occurrence exceeds the expectation under the null hypothesis. A PI greater than 2 is considered noteworthy, while a PI greater than 6 suggests a strong correlation between a concept and a category at a specific time[28, 29]. Prominence analysis serves to rectify analytical discrepancies stemming from variations in the quantity and quality of literature.

Third, we conducted a qualitative in-depth analysis, specifically content analysis, to classify the topics identified according to their respective time periods. This qualitative scrutiny enabled us to extract nuanced insights and provide a contextual understanding of the emerged topics. The results of this qualitative analysis served as a foundation for interpreting the outcomes of the thematic analysis.

3. Results

3.1. Descriptive Analysis

The periodic distribution of research and journal frequency data concerning smart homes provided insights into the trends in research popularity and the primary research areas. Figure 2 shows a gradual increase in the number of published papers on the topic since 2000, with a sharp increase of over two-fold per year observed since 2014. This acceleration indicates a rapid growth in academic interest and popularity, a trend that has persisted similarly since 2018 ($R^2 = 0.617$).

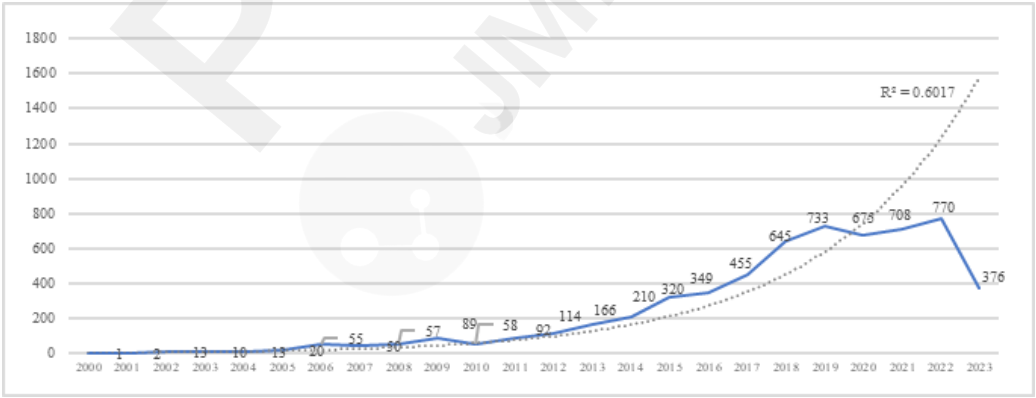

Figure 2 Publication Frequency (2000~2023. 1H)

The statistical analysis of journal frequency yielded insightful findings, with a total of 3,082 journals containing 5,981 abstracts, Figure 3 shows the most influential journals in smart home research since 2000. Sensor, a multidisciplinary journal focusing on sensor technologies, leads with

232 publications, followed by IEEE Access and IEEE Internet of Things Journal, each with over 100 articles. Energies, Applied Sciences-Basel, Journal of Ambient Intelligence and Humanised Computing, Sustainability, and Electronics also boast more than 40 articles. Technological Forecasting and Social Change has consistently contributed since 2018, with eight papers to date.

Among the search results, the IEEE Internet of Things Journal article "Edge Computing: Vision and Challenges" stands out as the most cited, with 3,527 citations, emphasizing various implementation cases of edge computing and future challenges. An analysis of the top 20 journals and conferences by citation rankings reveals IEEE’s dominance, with 10 related journals. Computer Networks, Energy Policy, Expert Systems with Applications, Future Generation Computer Systems: The International Journal of eScience, The International Journal of Medical Informatics, Pervasive and Mobile Computing, and Science Advances were frequently cited. The conferences associated with IEEE were Security and Privacy (SP), Pervasive Computing and Communications, and Computer Vision and Pattern Recognition, which primarily focused on technical literature from an engineering perspective.

Other journals like Energy and Sustainable Cities and Society cover service and social impact articles, while Behavior & Information Technology, International Journal of Human-Computer Interaction, Technical Forecasting and Social Change receive relatively fewer citations. Conference papers tend to have higher citation rates, suggesting their prompt publication and coverage of timely topics.

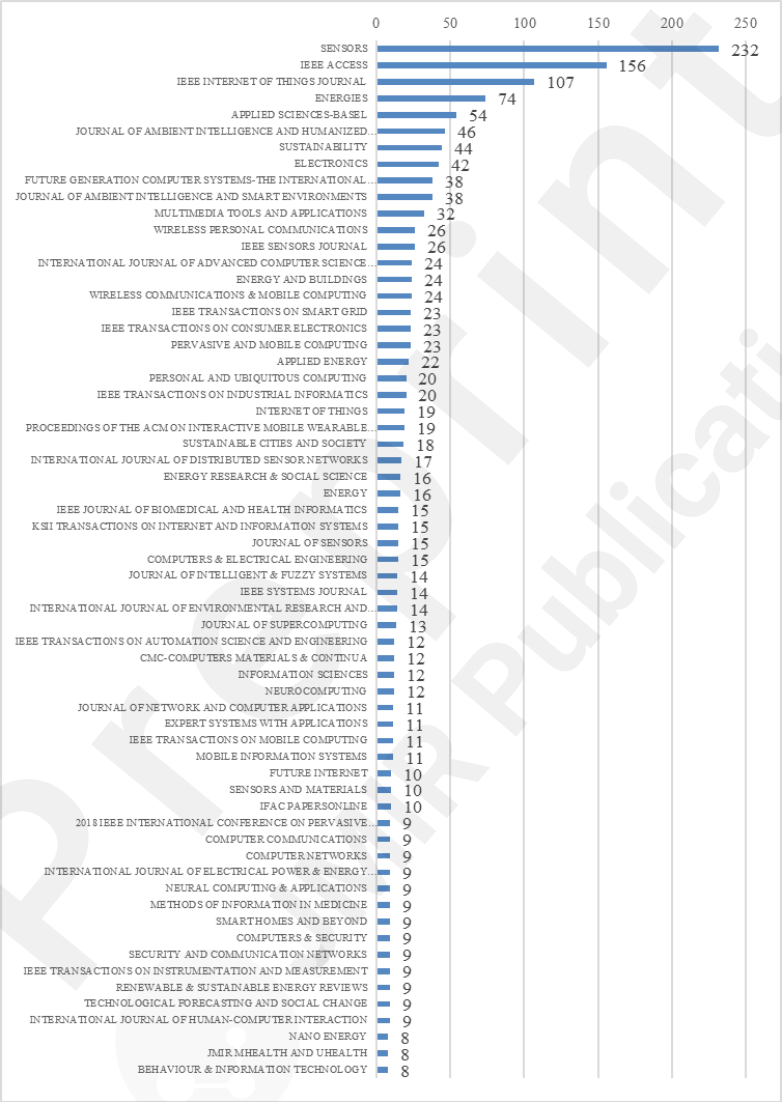

Figure 3 Top influential journal list (2000-2023.1H)

3.2. Deep Analysis Based on Thematic Analysis : Total Period

A total of 7,003 articles were selected and subjected to SLR, with 1,003 selected for topic extraction using Leximancer and subsequent in-depth analysis alongside 42 articles from SLR. Through this process, 69 concepts were identified and grouped into seven themes, as illustrated in Figure 4.

The analysis initially focused on the overall time span of the 1,003 smart home article abstracts, visualized in the concept map. Concepts are represented by dots, with larger dots indicating greater prominence. Proximity between concepts indicates grouping into themes, represented by colored bands. The most important themes are highlighted in red, while less important themes are in purple[32].

The concept map reveals seven key themes for analyzing trends across periods, correlating with papers related to smart homes in each timeframe. Presented as a heat map, this map serves to thematic focus and relationships between topics, facilitating a visual depiction of the conceptual structure and unveiling dependencies and proximity of topics. This comprehensive approach aims to better understand and interpret past and potential future trajectories. Future details of the results are described in [33], while the methodology is thoroughly analyzed in the literature[24, 34].

Out of the 5,983 articles from 2000 to 2023, 1,003 articles were preprocessed and selected to represent a proportional distribution across the time periods. The analysis was performed using 22 articles (2%) from 2000-2005, 81 articles (8%) from 2006-2011, 278 articles (28%) from 2012-2017, and 622 articles (62%) from 2018-2023. This distribution underscores a noteworthy trend: the number of articles from 2018 onwards accounts for more than half of the total number of articles, indicating a substantial surge in research activity during the last six years. This quantitative insight serves as empirical evidence of the heightened research engagement in the field within the recent timeframe.

In the concept map, the red folders representing papers from each time period are labelled CTAG. Their positions relative to topics and concepts signify the similarity in timing and content of the text across different periods. For example, the literature from 2000-2005 and 2012-2017 appears relatively close to each other and very close to concepts such as “People” and “Smart”, as indicated by the lines connecting each folder marker and concept. The proximity of the folders suggests similarity in concept content, while the links between each folder and concept indicate that the folder

contains a substantial proportion of text coded as that concept and the concept, in turn, has a high proportion of text linked to it.

Figure 4 shows that the period from 2000-2005 is closely associated with concepts comprising “Smart” and “People” themes, whereas the period from 2006-2011 is more connected to “People” and “Activity” themes. The period from 2012-2017 shows closer ties to “Smart” and “Energy” themes, while the period from 2018-2023 appears to diverge from the other three periods, being closer to the “IoT”, “Use”, “Activity”, and “Energy” themes. This suggests a shift in focus compared to the previous periods. In Table 1, there are 4,648 blocks of text coded for the four time periods. The most frequent topic is “Smart” (3,620), followed by “Use” (2,807) and “IoT” (2,744). The title of each topic was derived based on the most important concept among the associated concepts. CTAGs were coded for each time period, with the priority of the concepts shown in Table 1.

The 1,003 full-text articles were divided into time periods and examined from three perspectives based on the results from Leximancer: (A) technological capabilities, (B) their implications on various services, and (C) benefits to users'- lives. Through a semantic analysis of closely related themes (and concepts) and reviewing contextual text samples (focus papers) that contribute to the themes, we identified smart home research into three focus areas: (A) technology-based, (B) services grounded in the underlying technology, and (C) users experiences with the services and products. The analysis revealed that technology-based research (labelled as A in blue) has received the most attention. This focus revolves around the technological aspects of smart homes. Meanwhile, the focus on services (labeled as B, comprising concepts like “control and management”, “systems”, “energy” and “IoT” related to the underlying technology and services derived from it) underscores the evolution towards exploring how these technologies can be harnessed to offer various services. Initially, smart home technology concentrated on managing home appliances through communication and control, leveraging the rapid advancements in electricity and

information technology.

User-centered research themes in smart homes have consistently been considered important but have received relatively little attention (highlighted as C in orange). Despite ongoing discussions since the early 2000s regarding the importance of adopting a user-centered perspective in research, as evidenced by key concepts within the theme such as “elderly”, “active environment” and “usage behavior”, there is relatively little research on user wants and needs directly. Recent studies focusing on users have primarily focused on usability, examining how users interact with and perceive completed products or services, and whether they are inclined to continue using them. However, user-related research remains a low-ranking theme within the theme. Moreover, within the realm of activity and its sensing and environment, research has tended to focus on specific demographics such as the elderly or chronically ill individuals who are presumed to benefit from smart home technologies, rather than delving into the nuanced needs and preferences of users themselves (note that “elderly”" and “people with assistance needs” are important concepts within the People theme). This llimited attention to user-based research is primarily observed in the context of usability evaluations, often through pilot tests (note that "data" is linked to “IoT” within the “Uses” theme) [35]

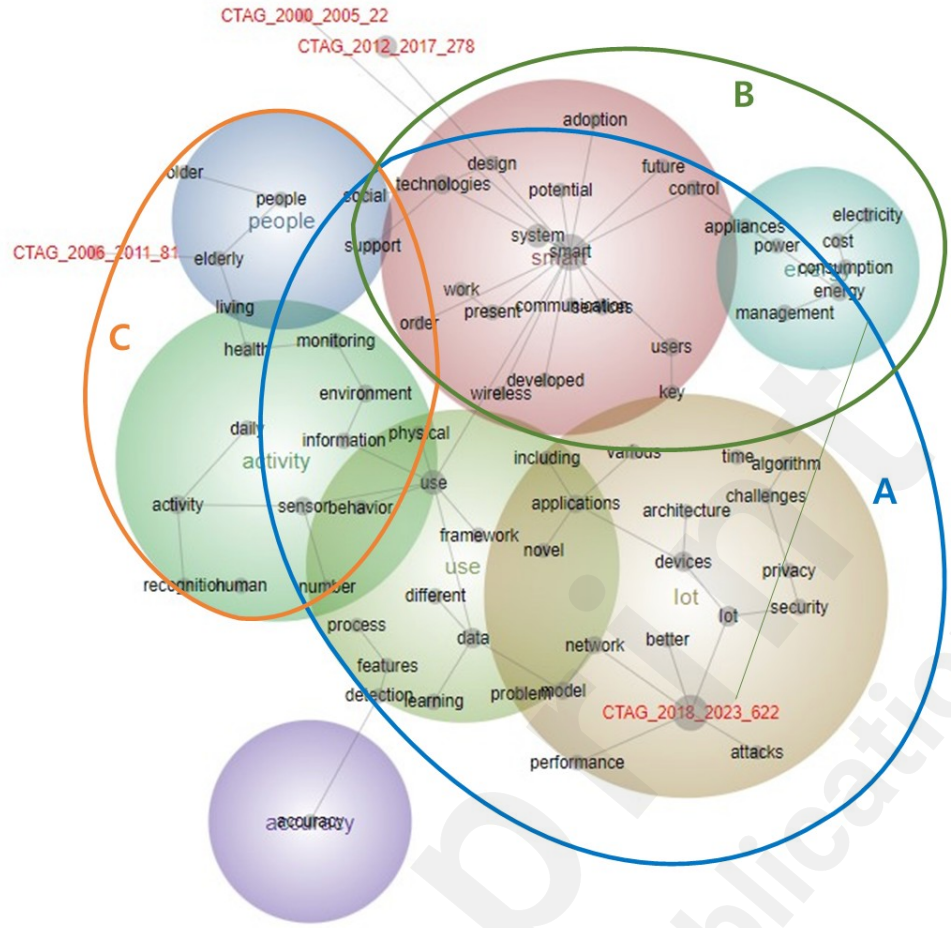

Figure 4 Total period (2000-2023) Concept map

Concept	Count	Relevance percentage
smart	2612	86
use	1293	43
system	1161	38
Iot	770	25
devices	761	25
data	760	25
energy	756	25
technologies	720	24
activity	599	20
model	551	18
users	547	18
sensor	537	18
applications	509	17
environment	496	16
network	490	16
security	408	13
services	400	13
learning	355	12
information	322	11
management	319	11
different	319	11
recognition	315	10
present	297	10
control	296	10
monitoring	285	9
consumption	283	9
human	265	9
performance	261	9
time	252	8

Table 1 Total period concept ranking

Figure 5 presents the results of correspondence analysis, illustrating the topics and concepts that exhibit close associations with each time period. By “close”, we refer to the statistically significant correlations determined through the PI values. Several key observations can be made from the analysis: Concepts such as technologies, smart, use, and system demonstrate a positive correlation with all time periods, with a PI greater than 1. The concept of environment is positively correlated across all three time periods. Topics like services and information exhibit positive correlations with the 2000-2005 and 2006-2011 time periods. Activity and sensor are positively correlated with the 2007-2011 and 2012-2017 time periods. Data and energy show positive correlations with the 2012-2017 and 2018-2023 time periods. Specific concepts like appliances, model, applications and network demonstrate correlations with individual time periods; 2000-2005 is correlated with appliances(4), 2006-2011 with model(1.1), 2012-2017 with applications(1.1), and 2018-2023 with network(1.1).

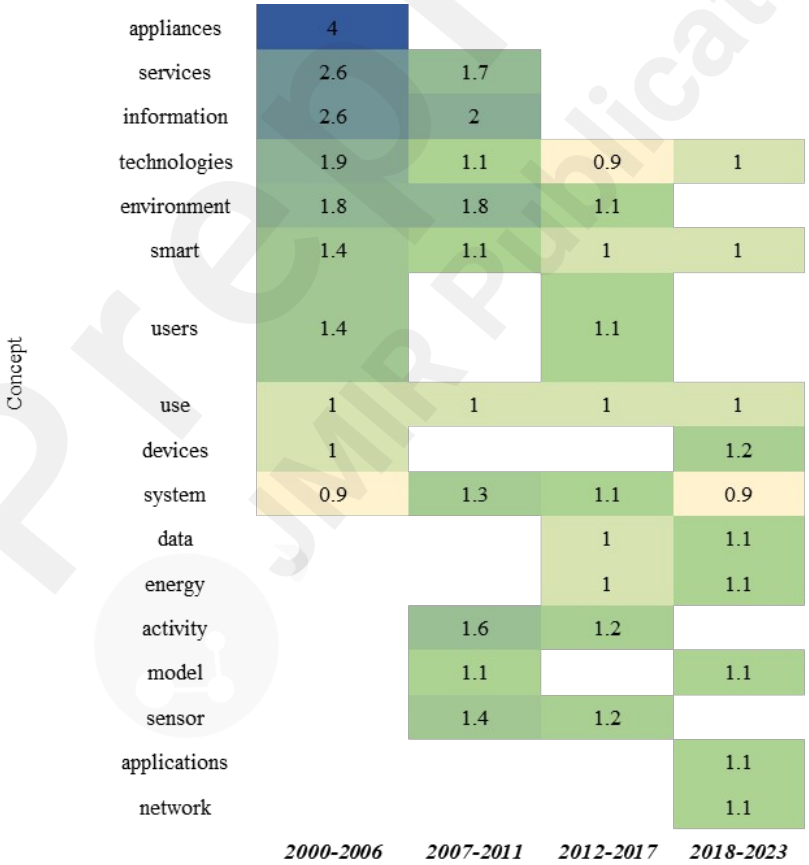

Figure 5 Prominence Index (PI) hitmap of common concepts by time of year

2000-2006 Concept	**Prominence**
appliances & information	17
appliances & services	16.4
appliances & problem	15.2
information & communication	12.1

appliances & communication	11.7
appliances & control	11.1
2007-2011 Concept	**Prominence**
sensor & wireless	10.8
activity & problem	7.3
technologies & older	6.7
activity & human	6.7
environment & human	6.4
services & process	5.7
environment & wireless	5.3
2012-2017 Concept	**Prominence**
activity & recognition	7.8
energy & consumption	7.1
energy & electricity	6.4
sensor & wireless	5.2
activity & daily	4.9
energy & power	4.9
2018-2023 Concept	**Prominence**
energy & consumption	6.1
energy & electricity	5.5
energy & management	4.7
energy & power	4.2
technologies & adoption	3.7
energy & cost	3.7

Table 2 Comparing the Prominence Index (PI) of compound concepts over time

The compound words shown in Table 2 for each time period provide valuable insights into the prevailing themes and areas of focus within smart home research: For the period 2000-2005, the emphasis appears to be on appliances and information (17), appliances and services (16.4), appliances and problems (15.2) and information and communication (12.1). In the years 2006-2011, prominence is on terms such as wireless and sensors (10.8), activities and problems (7.3), technology and older people (6.7), environment and people (6.4), people and activities (6.7). The period 2012-2017 sees a notable focus on behavior and sensing (7.8), behavior and daily (4.9), energy and consumption (7.1), energy and electricity (6.4), electricity and power (4.9). For 2018-2023, the emphasis shifts to energy and consumption (6.1), electricity and energy (5.5), energy and management (4.7), technology and adoption (3.7). The period 2006-2011 is characterized by user perspectives, with concepts related to activities, people and older people appearing frequently, while the remaining periods all seem to be dominated by research related to technology and services. The period from 2000-2005 was characterized by a predominant emphasis on technology-related research, with appliances emerging as the most significant concept. The periods 2006-2011 and 2012-2017 focus on sensor and activity, with wireless sensors and elderly and technology being notable topics in the 2006-2011 period. In the period 2012-2017, user is observed for the first time in the concept analysis, and behavioral sensing and electrical energy and energy consumption are the most important thematic terms with a correlation of 6 or more among the compound concepts. The periods 2012-2017 and 2018-2023 have energy and data as common themes. The period 2018-2023 observed emerging concepts like model, application, and device which are composite concepts that are highly correlated with energy consumption, power, management, and technology adoption.

As shown, the analysis highlights a progression from technology-focused explorations towards more user-centric and energy-conscious approaches in smart home research over time. These findings set the stage for further in-depth analysis of emerging topics and their implications in shaping the future of smart homes.

3.3. Deep Analysis Based on Thematic Analysis : Time Series

In Section 4.2, thematic analysis was performed on the entire dataset of 1,003 papers to provide a comprehensive overview of the entire period, and in Section 4.3, the period was temporally divided into four equal segments of six years for a more granular understanding of the thematic focus during each distinct period. By analyzing the literature from each period separately, the study aimed to understand the evolution of smart home research over time and identify any shifts or trends in research themes across different timeframes.

A. Period 01 (2000-2005)

The first period (2000-2005) represents the early literature phase, comprising 22 papers, which accounts for 2% of the total literature, with the smallest number of text blocks (89). During this period, the key themes revolved around home, technology, services, and devices, with notable concepts including appliances, information, and services (Figure 6). The literature review shows that this period was mainly dominated by technology-focused electrical equipment suppliers (e.g., switches, sockets, and distribution boards) aiming to commercialize smart home solutions. The concept closely associated with technology was “system”, mentioned 23 times throughout the literature from this period (Table 3).

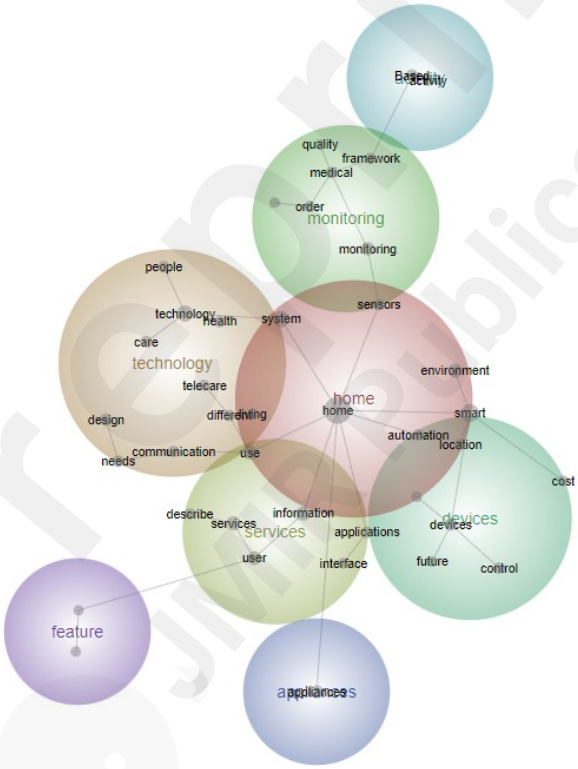

Figure 6 Period 1 (2000-2005) concept map

Concept	Count	Relevance percentage
home	79	100
smart	38	48
technology	26	33
system	23	29
services	20	25
use	17	22
environment	17	22

appliances	17	22
information	16	20
user	15	19
monitoring	11	14
devices	11	14
design	10	13
activity	10	13
control	9	11
needs	8	10
people	8	10

Table 3 Period 1(2000~2005) concepts ranking

In the literature, smart homes are often described as advanced systems that leverage electricity and information technology to control household appliances. These systems encompass various functionalities, including but not limited to audio, video, home office equipment, telecommunication devices, intercom systems, security features, lighting controls, HVAC(heating, ventilation, and air conditioning) systems, and even lawn sprinklers [7].

During this period of smart home literature, the focus was primarily on basic communications technologies, often centered around services such as information provision and remote monitoring, particularly related to electricity usage. However, critiques emerged regarding the predominant emphasis on technological feasibility over user preferences and needs. User-centric considerations were not adequately integrated into the design and development processes, with minimal attention given to the user perspective and desires. Keywords related to users ranked relatively low in frequency (i.e, the tenth highest among all concepts) compared to other concepts during this period (Table 3). Moreover, specific terms directly referencing users were notably absent. Instead, concepts such as “needs” and “environment” were more prevalent in discussions involving users. Critically, it was observed that the design and development of smart homes predominantly catered to the preferences and lifestyles of men, overlooking the needs of women who typically manage domestic tasks and are primary users of household technologies. Consequently, there was a recognized necessity to align smart home implementations with user needs, emphasizing the importance of user-

oriented research. However, existing studies primarily remained theoretical, lacking empirical case studies to inform practical applications and implementations [7, 36].

B. Period 2 (2006-2011)

During the second period (2006-2011), which comprised 81 articles constituting 8% of the total literature (307 text blocks), the thematic focus shifted towards activity, sensors and the elderly. While technology remained an important theme from the previous period, key concepts associated with it now included Information, Health, and Monitoring (Figure 7). The literature during this period witnessed the emergence of environments equipped with sensor technologies, enabling continuous monitoring capabilities. Situational awareness systems also gained prominence, facilitating communication network-enabled information dissemination to residents while collecting sensor-based data to deliver tailored services.

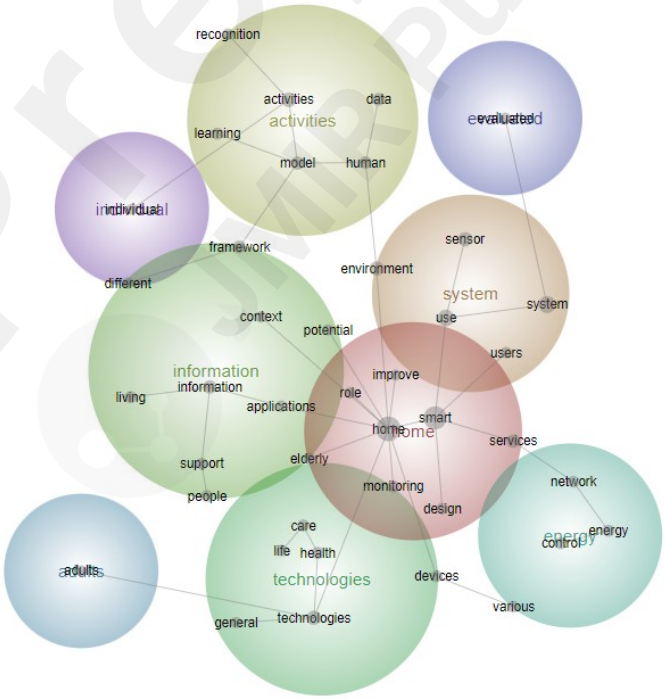

Figure 7 Period 2 (2006-2011) concept map

Concept	Count	Relevance percentage
home	192	100
smart	166	86
system	101	53
use	84	44
activities	64	33
technologies	52	27
sensor	50	26
environment	47	24
services	43	22
information	42	22
model	41	21
data	37	19
framework	32	17
human	28	15
learning	26	14
energy	25	13
control	25	13
health	23	12
living	23	12
monitoring	21	11
support	21	11
recognition	21	11
care	19	10
devices	19	10
network	19	10
people	18	6
applications	18	6
elderly	17	6
different	17	6
users	16	5

Table 4 Period 2 (2006-2011) concepts ranking

During the second period, the integration of technology with health-related applications became prominent, particularly in addressing the needs of the elderly and disabled individuals. Early research endeavors during this time aimed to empower these demographics with greater independence through smart home technologies [28].

Despite the growing recognition of the importance of end users in smart home design and implementation, user-related keywords, particularly those related to the elderly, emerged but remained relatively infrequent (Table 4). However, concepts such as Device, Service, and Activity began to emphasize a more user-centered approach, enhancing end user engagement and understanding. This involved using virtual environments, such as smart home simulations, to provide users with deeper insights into the setup and operation of smart devices and services [37].

C. Period 3 (2012-2017)

The third period (2012-2017) comprised 278 articles, representing 28% of the total period, with 1,222 text blocks. Significant themes observed during this period included activity, technology, and energy, with users emerging as a major theme for the first time (Figure 8). Concepts related to technology, such as Communication, Living, and Health, were highly ranked during this time (Table 5). In the literature of this period, a smart home was defined as a dwelling equipped with technology designed to anticipate and fulfill the needs of its occupants. There was a growing emphasis on the importance of well-managed technology and its integration with external connectivity to promote occupant comfort, convenience and security. This connection to the outside world emphasizes the concept of an information home, where new information services are interactively connected, rather than simply automated [7, 38].

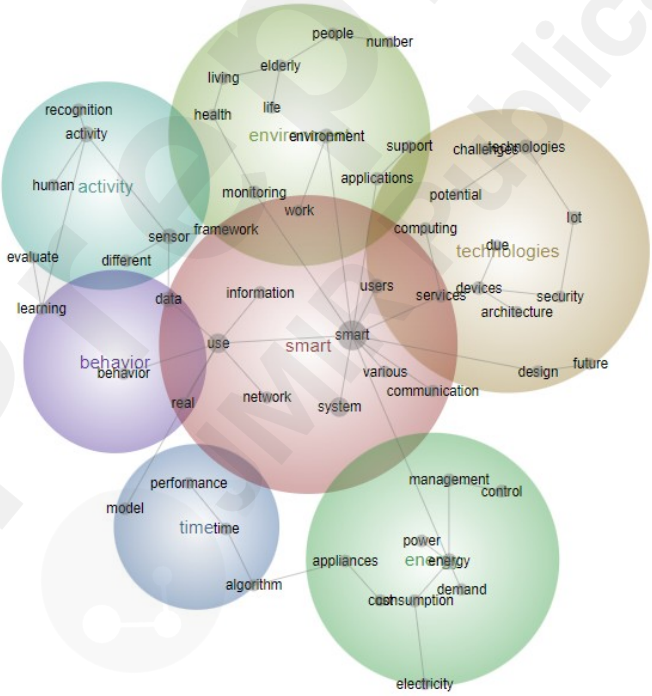

Figure 8 Period 3 (2012-2017) concept map

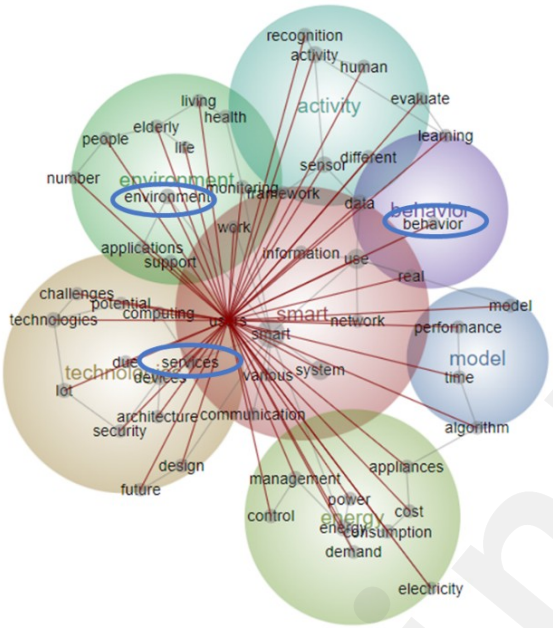

Figure 9 Selected Concept: Users

Concept	Count	Relevance percentage
smart	739	100
use	349	47
system	343	46
activity	205	28
energy	200	27
data	193	26
sensor	175	24
technologies	167	23
users	154	21
environment	148	20
Iot	128	17
devices	115	16
recognition	105	14
monitoring	98	13
services	90	12
applications	90	12
control	90	12
model	87	12
different	84	11
management	82	11
time	80	11
consumption	79	11

power	74	10
design	71	10
living	69	9
information	68	9
elderly	67	9
appliances	66	9
security	65	9

Table 5 Period 3 (2012-2017) concepts ranking

During this period, energy emerged as the fifth most important theme, with concepts linked to energy management, consumption, and control (Figure 8, Table 5). Research on users in smart homes delineates three main perspectives: functional, instrumental, and social. Functional perspectives focus on enhanced functionality and efficiency in smart homes. Instrumental perspectives emphasize energy savings and responsiveness to information and prices. Social perspectives focus on the adoption and use of technology in complex households [39]. Energy has mostly appeared in the literature revolving around services embedded in appliances that can monitor and control the power usage of appliances.

[40] emphasized the concept of "healthy smart homes" within the context of "Aging in Place", expanding the definition of smart homes to include not only improvements in quality of life but also access to home care for the elderly and disabled [41].

During this period, the user emerged as the ninth most important concept, with user- related concepts including environment, behavior and services (Table 5, Figure 9). The proliferation of smart home solutions and services led to the emergence of empirical studies focusing on user adoption intention, utilization, and perception. For instance, research in China delved into the psychological aspects of end-users [42], while another study applied the theory of planned behavior to investigate how user attitudes and subjective norms influence intentions to use smart home services [43]. Additionally, there was a study on the emerging issue of single-person households, exploring strategies to enhance perceptions of social support in socially isolated environments [44].

D. Period 4 (2018-2023)

Finally, the fourth period (2018-2023) stands out as the most numerous, comprising 3,030 text blocks, which account for 62% of the total literature. This indicates a substantial surge in research activity during the last six years. Key themes during this period include IoT, data, and energy, highlighting the growing emphasis on interconnected technologies, data management, and energy efficiency. Emerging concepts such as models, applications, and adoption reflect the evolving landscape of smart home research, with increasing attention on developing models, practical applications, and strategies for the widespread adoption of smart home technologies and services (Figure 10, Table 6).

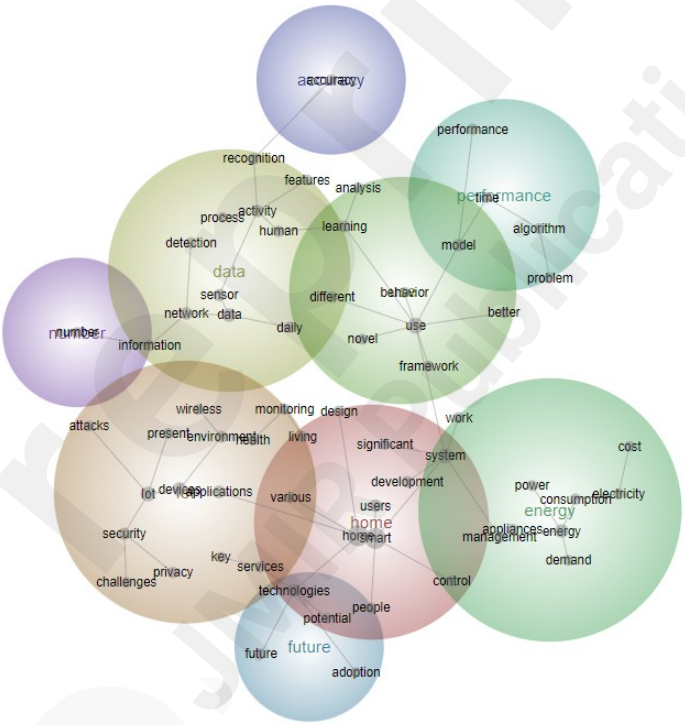

Figure 10 Period 4 (2018-2023) concept map

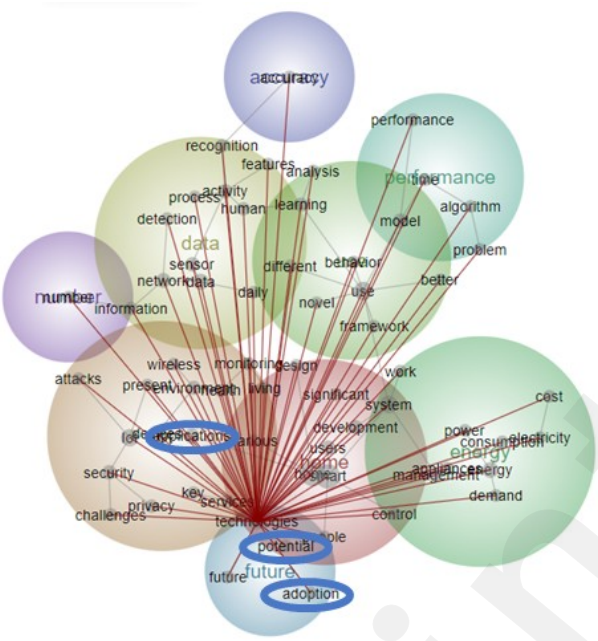

Figure 11 Selected Concept: technologies

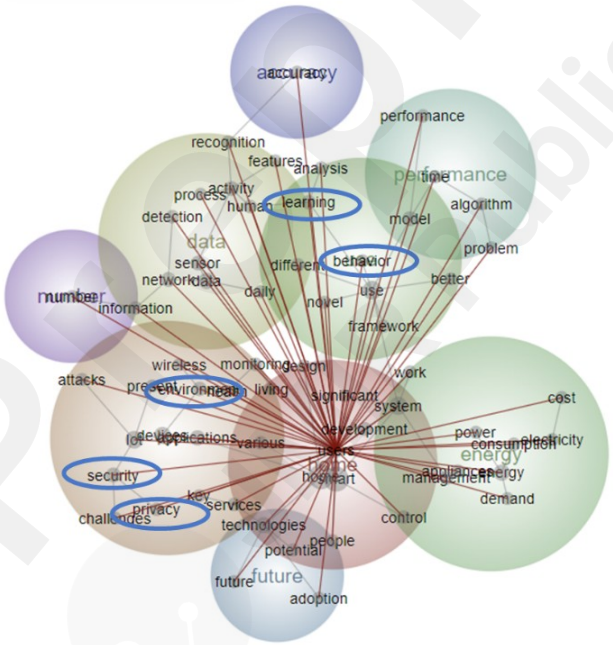

Figure 12 Selected Concept: user

Concept	Count	Relevance percentage
home	1,443	100
smart	1,442	100
use	843	58
system	712	49
Iot	644	45
devices	580	40

data	501	35
energy	482	33
technologies	466	32
model	378	26
network	362	25
applications	361	25
users	354	25
security	329	23
activity	321	22
sensor	307	21
environment	268	19
learning	263	18
development	237	16
management	213	15
different	212	15
information	196	14
performance	188	13
recognition	182	13
human	179	12
control	172	12
consumption	170	12
privacy	170	12
various	166	12
detection	166	12
services	160	11
challenges	157	11
monitoring	156	11

Table 6 Period 4 (2018-2023) concepts

The concepts of Adoption, Application, and Potential highlight technological advancements and the increasing integration of IoT within smart home systems (Figure 11). These advancements have led to continuous improvements in smart home services, allowing for seamless connectivity and control from anywhere at any time. A typical smart home system consists of various sensors and switches centralized around a main gateway, enabling users to access and manage their smart home devices through digital platforms such as smartphones or desktop personal computers[45].

In this period, concepts related to users are intricately linked with notions of privacy, security, and the overall environment. Additionally, concepts related to usage, such as behavior and learning, underscore the importance of understanding user behavior, learning patterns, and the creation of models to enhance user experiences (Figure 12). The literature of this period includes empirical studies conducted in the UK, Finland, and China which have provided valuable insights into users adoption and continuous usage of smart home technologies. However, despite the growing interest and adoption, several barriers to widespread adaption have been identified. These include mistrust and resistance, limited awareness of smart home capabilities, financial constraints, concerns regarding privacy and security, technology-related anxiety, and potential negative social impacts. [46]. Moreover, recent literature has analyzed the literature of the last 20 years and categorized the evolution of smart homes into three generations, with the third generation characterized by IoT-based environments, emerging as the center of technological change and innovation. This generation is recognized for its transformative potential in urban and social contexts [14].

Health emerges as a consistent theme across all periods of smart home research, reflecting users' desires for improved healthcare support and quality of life. From the early stages, there has been a focus on leveraging smart home technologies to effectively assist individuals with chronic conditions and aging populations, thereby enhancing their well-being and independence. The home environment offers a conductive setting for continuous health monitoring and disease prevention, aligning with users' preferences for staying in familiar surroundings while receiving care. Currently, various experimental and observational studies have been conducted on healthcare applications in smart homes, aiming to address users' needs for healthy living through IoT and sensor technologies. However, there still remains a gap between user expectations and the technologies and services currently available in smart homes. Practical energy services, and tangible benefits like energy savings, cost reduction, and environmental sustainability are areas where users seek more direct and tangible impacts. Nevertheless, healthcare continues to emerge as a fundamental user need, driving ongoing efforts to improve quality of life through smart home solutions [13]. As a result, smart homes will increasingly be able to provide automated, contextualized and personalized solutions to a broader user base, catering to diverse needs and preferences [47].

4. Discussion: *Future Research Agendas: The Distinction Between Product Intelligence in Meeting Users' Needs and User-Perceived Intelligence*

The smart home market is expected to make significant advancements in the coming years, driven by the increasing integration of advanced technologies such as sensors and IoT. As these technologies continue to mature, smart home systems are expected to evolve into sophisticated platforms capable of understanding and adapting to the unique preferences and requirements of each user. By harnessing AI technology, these systems will learn from user interactions, adapt and anticipate user needs, ultimately providing optimized experiences [47]. This evolution is in line with the spirit of the Regional Bell Operating Company's (RBOC) marketing slogan is ”If technology fails to meet the needs of users, it is not fulfilling its purpose” [48]. The evolution of technology will move beyond the mere extension of functionality to a paradigm that comprehensively addresses and anticipates user needs and expectations. Therefore, bridging the gap between technological advancement and user-centered value provision will be crucial for ensuring the continued success of smart home products.

The concept of the smart home has evolved over time to encompass a wide range of home appliances and services aimed at enhancing users' lives. In a study by [23], a comprehensive framework was proposed to capture the essence of user-centric smart products. This framework analyzed smart products based on 16 key features, reflecting a holistic approach to understanding and evaluating the user experience within the context of smart technology integration into the home environment.

The core value that smart products deliver to users is often referred to as intelligence. This concept goes beyond mere technological capabilities and emphasizes the tangible benefits and enhancements that these products bring to users' lives. Intelligence in the context of smart home products, encompasses the value and benefits provided through the interaction of smart home products with users. It can be perceived at various levels of intensity, reflecting the extent to which users experience and appreciate the value provided. Therefore, the intelligence of a smart home product transcends its technical features and revolves around the meaningful value that it provides from the user's perspective.

The essence of smartness in a smart home has been claimed to be its ability to facilitate interaction with the user and the evaluation of smartness should be centered on the value derived from this interaction, rather than solely on technical advancements. Ultimately, what matters most is the tangible value and convenience that users experience through their interactions with smart home systems. This perspective also emphasizes that the smartness provided by a smart product or service is meaningless in itself if it does not provide direct value or benefit to the user [49]. Therefore, the development of smart homes must prioritize user-centric approaches and acknowledge the significance of delivering tangible benefits from the user's perspective. By doing so, smart homes can truly fulfill. their potential and be considered truly smart [50-52].

5. Conclusions: From Technology to User-Centric Solutions: The Evolution of Smart Homes Towards Enhancing Health and Quality of Life

This study conducted a thorough analysis of 5,983 articles published in over the past 20 years to uncover trends and evolutionary patterns in smart home literature. Through systematic and scientific analysis methods, representative research keywords and topics were identified, allowing for the examination of trends from technology, service, and user perspectives over time. Utilizing thematic analysis techniques, the research delved into the evolving landscape of smart homes, revealing developments, changes, and interrelationships across different dimensions. This comprehensive approach provided insights into the trajectory of smart home research and its multifaceted evolution over the years.

The findings of this study highlight a significant surge in smart home research over the past six years, comprising nearly half of the total literature. Notably, technology-focused journals like Sensor and IEEE emerged as predominant sources with high citation rates. Through thematic analysis and in-depth analysis, the research discerned a notable evolution in smart home services, showing a shift from basic functionalities such as monitoring and remote control facilitated by early communication technologies to more user-centric services such as energy management and healthcare, driven by advancements in sensors, IoT, and data technologies.

In particular, healthcare in the smart home is the first and earliest expanded research direction [14, 53], indicating that the ultimate purpose of the smart home will evolve towards facilitating independent living and improving the quality of life through remotely managed services, catering to the needs of a diverse user base[54].

The findings of this study offer several significant contributions. It provides a broad and comprehensive scholarly overview of the evolution of the smart home domain over the past two decades. This structured understanding of trends across different time periods allows scholars to grasp the overarching developments in the field. Researchers can use the analysis to identify current and future research trends within the smart home domain. In particular, the study confirms the transition from technology-driven diffusion patterns to user-driven trends in smart home development. This shift opens up new opportunities for commercializing user-centric products and services, aligning more closely with user needs and preferences. By highlighting user needs and quality of life enhancements, particularly in areas like healthcare, the study provides valuable insights for future research directions. Understanding these needs can inform the development of tailored solutions to address user requirements effectively. Finally, as a practical implication, the understanding of technological trends and changes in smart homes can be used by industry professionals to plan products or services for commercialization.

While our review offers valuable insights, itis important to note some limitations. First, the topic analysis was conducted using only the titles and abstracts of the papers, and thus details in full papers can potentially be missed. Also, our selection process may have overlooked relevant studies, and we focused solely on academic papers, possibly neglecting commercial perspectives. Future research could address these gaps by analyzing full texts, conducting systematic literature reviews, and including insights from industry stakeholders through empirical investigations.

In conclusion, our comprehensive analysis of the smart home domain highlights academic advances in the field as well as practical implications. By elucidating the evolution of the field and identifying key trends, the analysis serves as a valuable roadmap for future research, shaping commercialization strategies, and fostering industry innovation. The emphasis on user-centered research in smart homes highlights the critical importance of prioritizing user needs and enhancing

the quality of life in both academic and industry endeavors.

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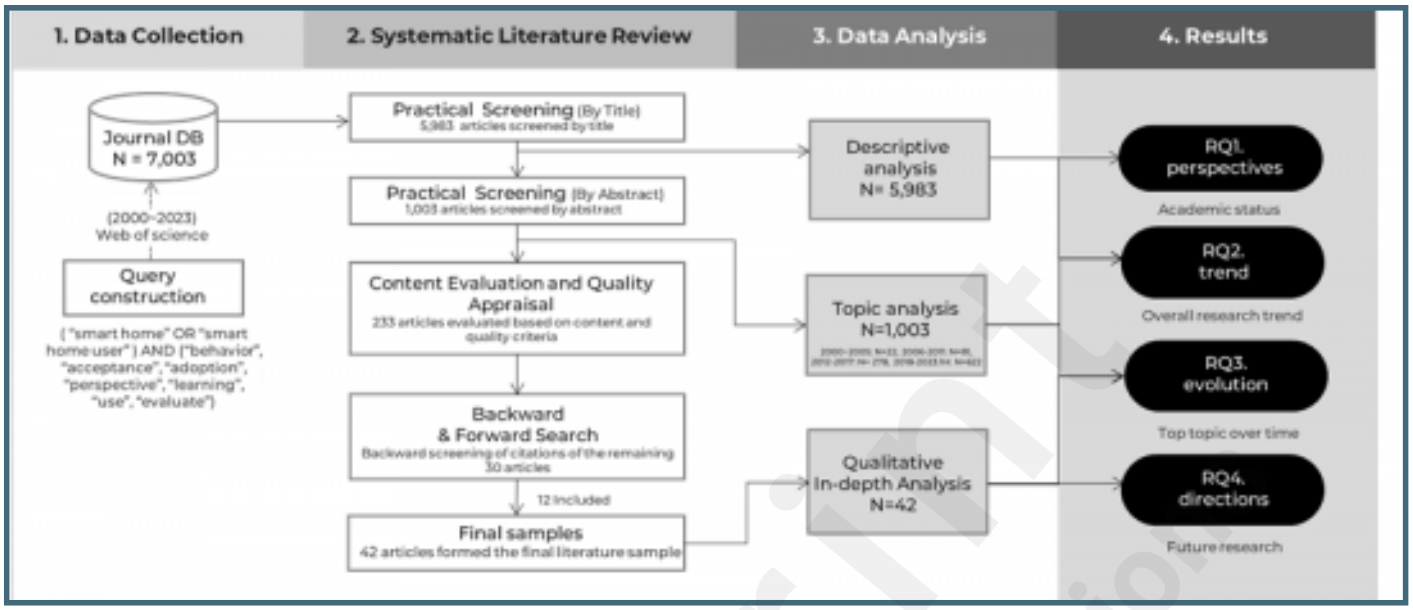
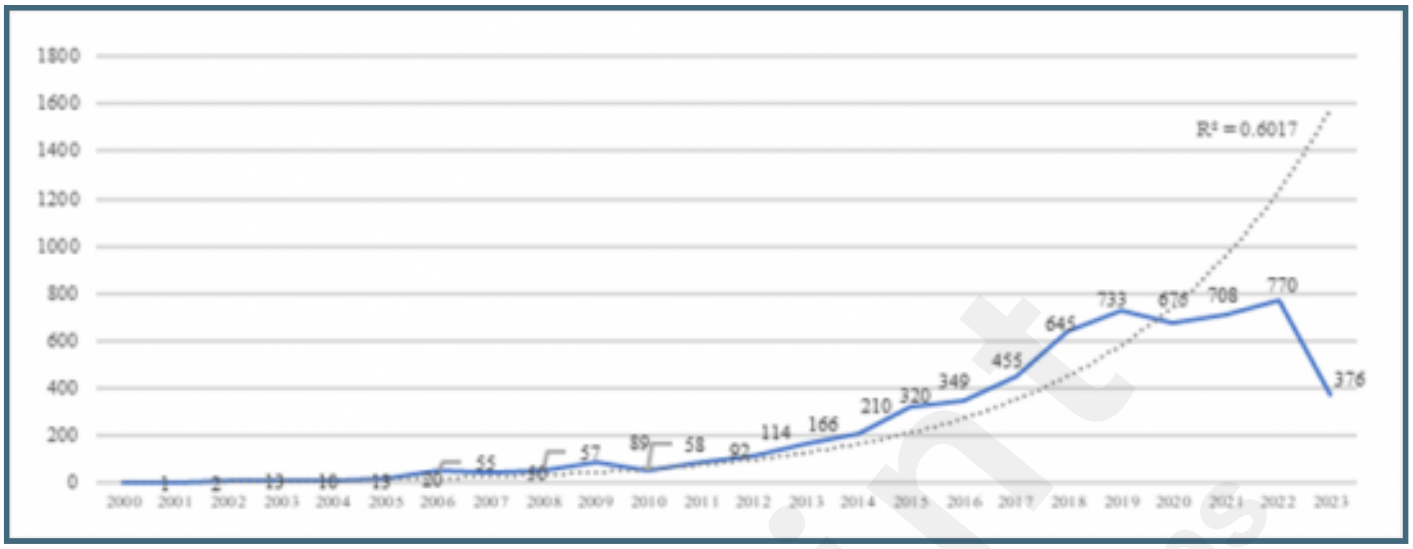
Supplementary Files

Figures

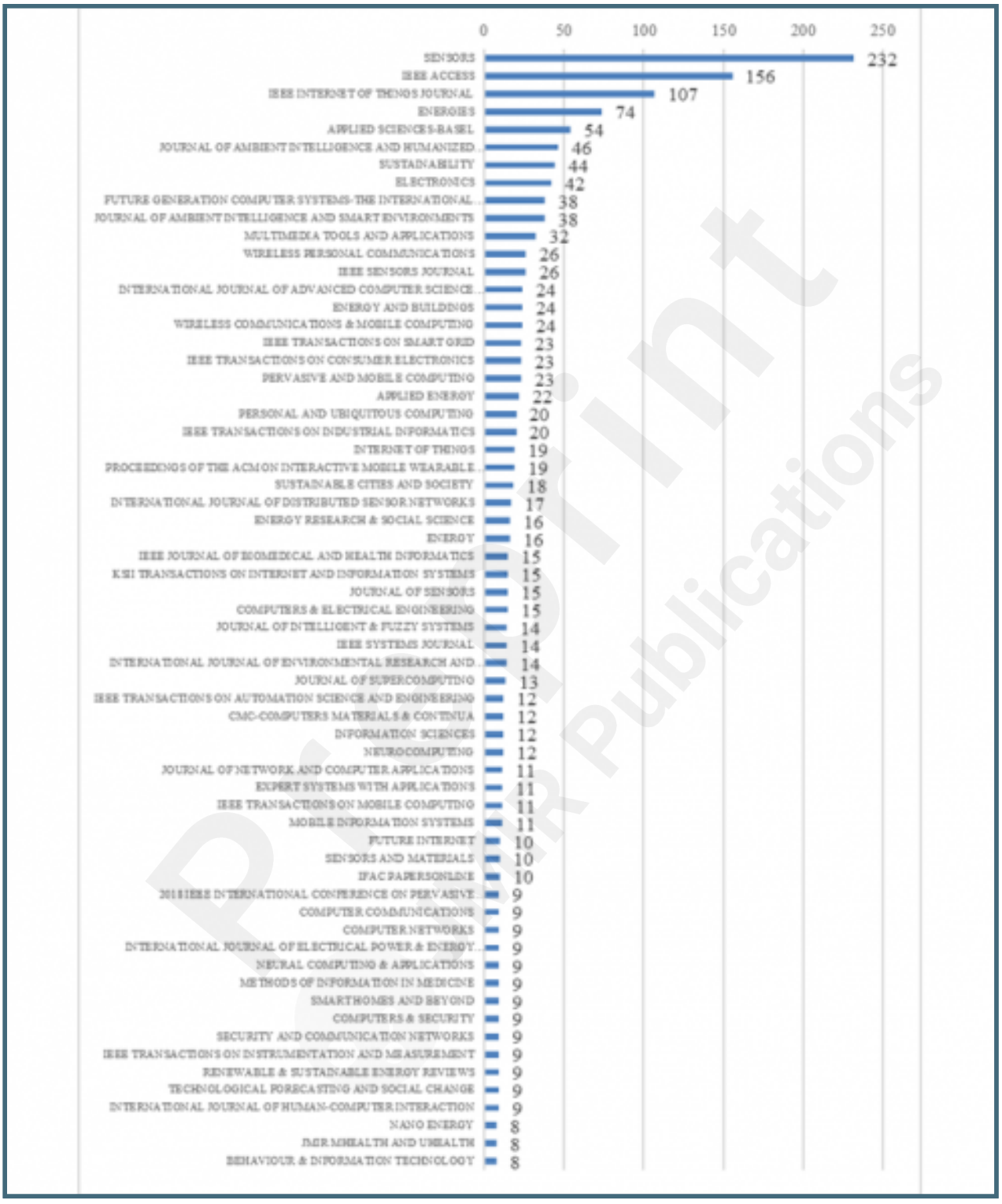
Research methodology involves collecting data from a journal database, performing a SLR, conducting descriptive analysis, topic modeling, and qualitative in-depth analysis to produce comprehensive results.



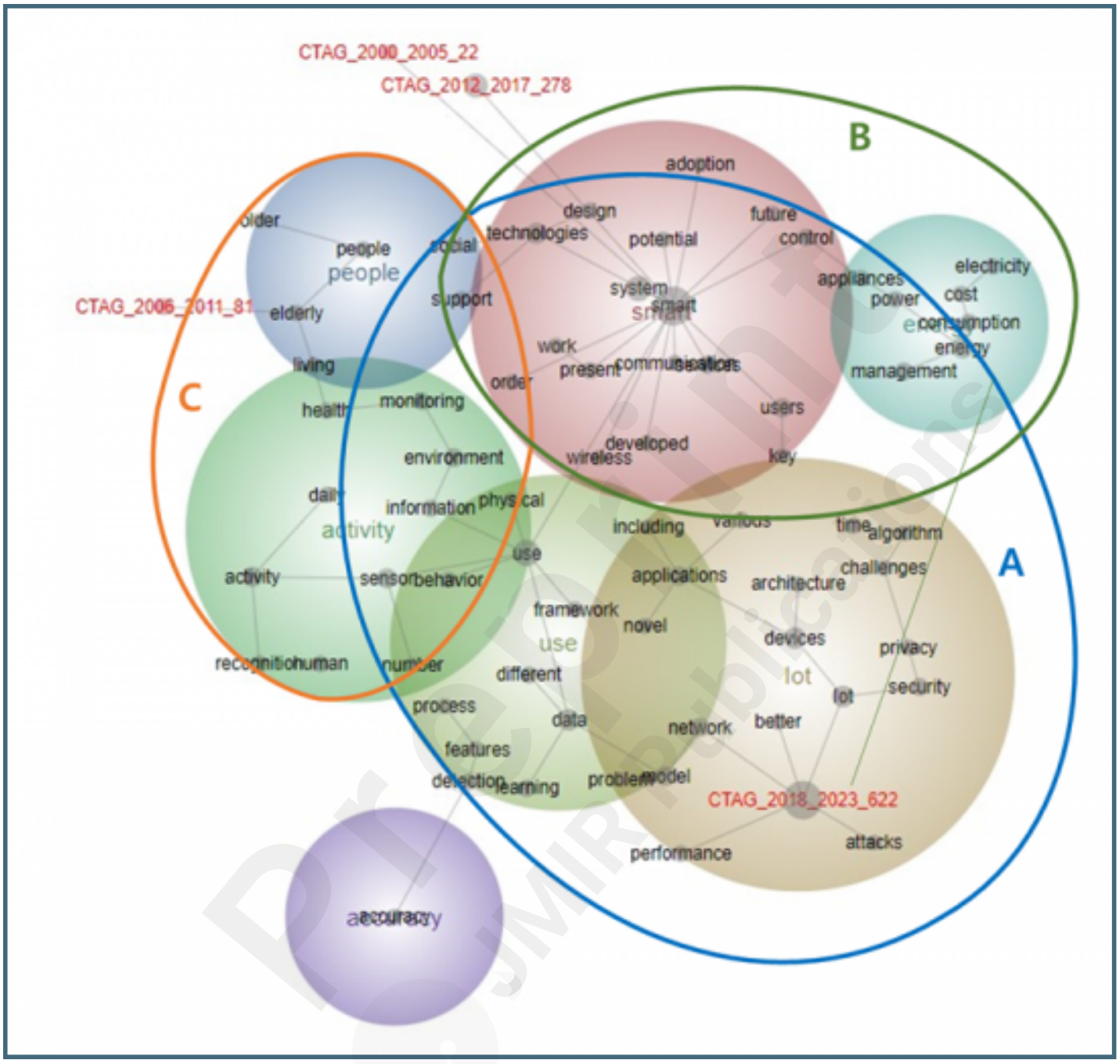
This graph displays the publication frequency of literature from 2000 to 2023.



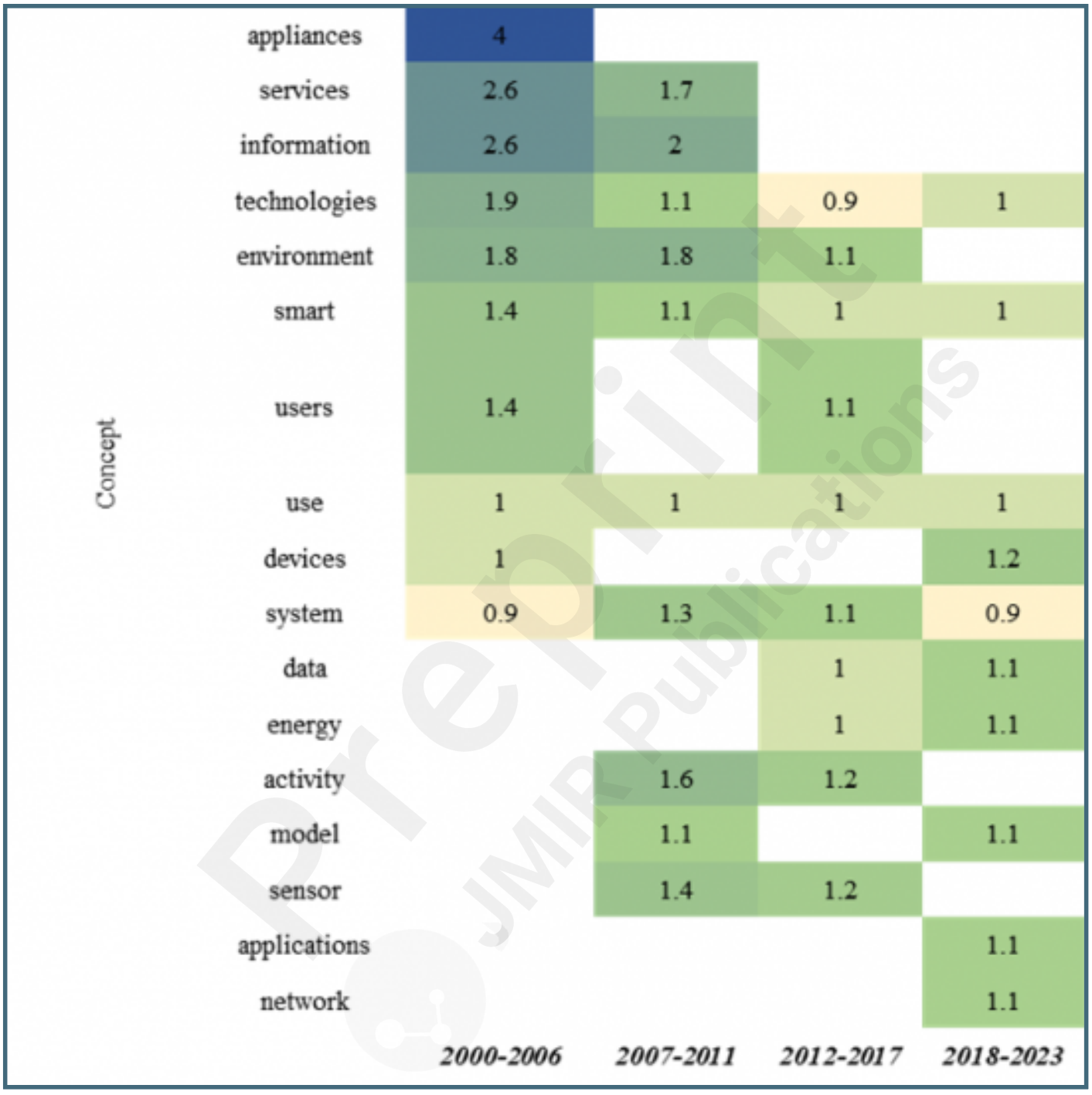
This graph represents the list of top influential journals from 2000 to 2023 based on publication frequency.



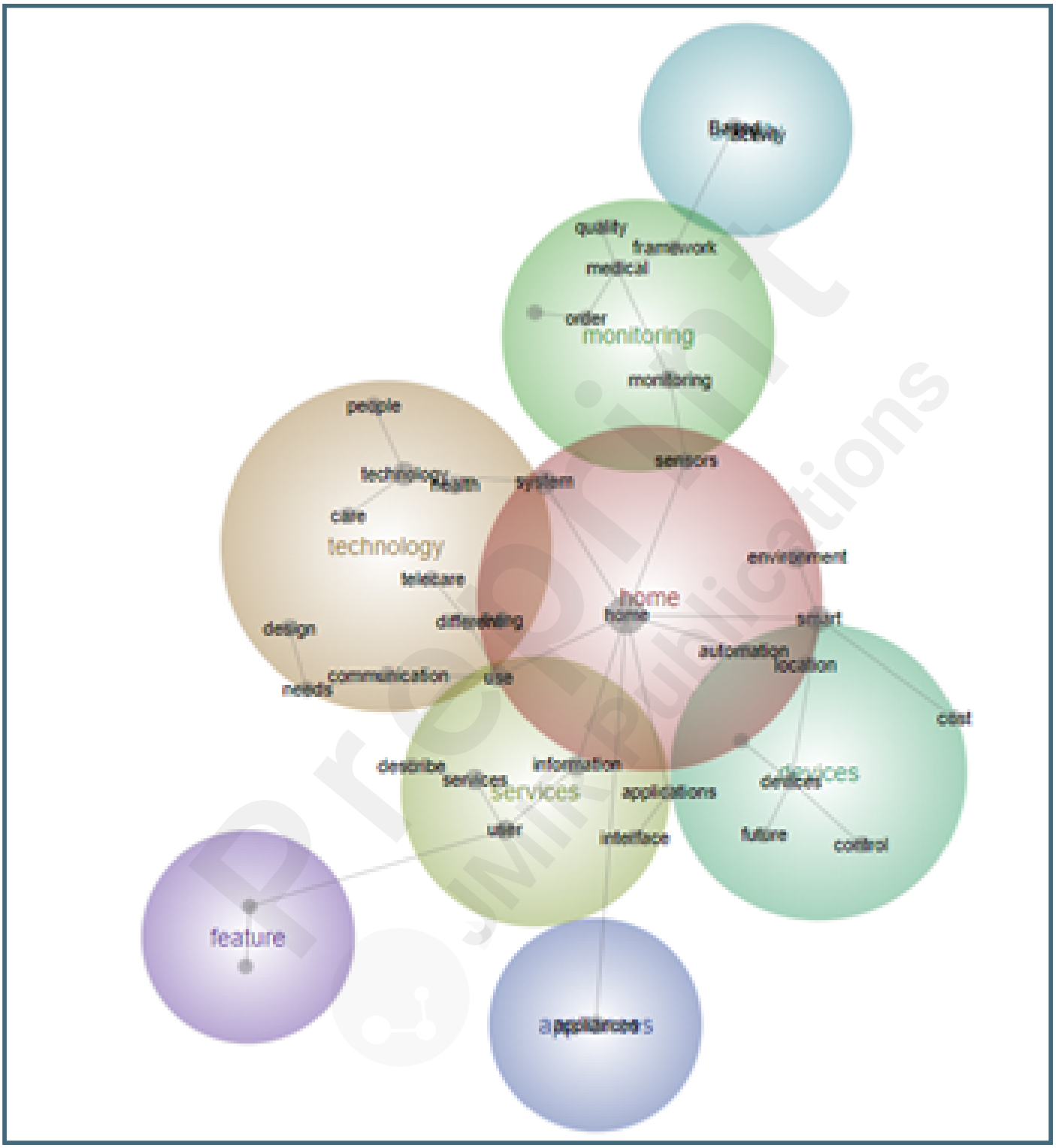
This picture is a concept map representing the total period from 2000 to 2023.



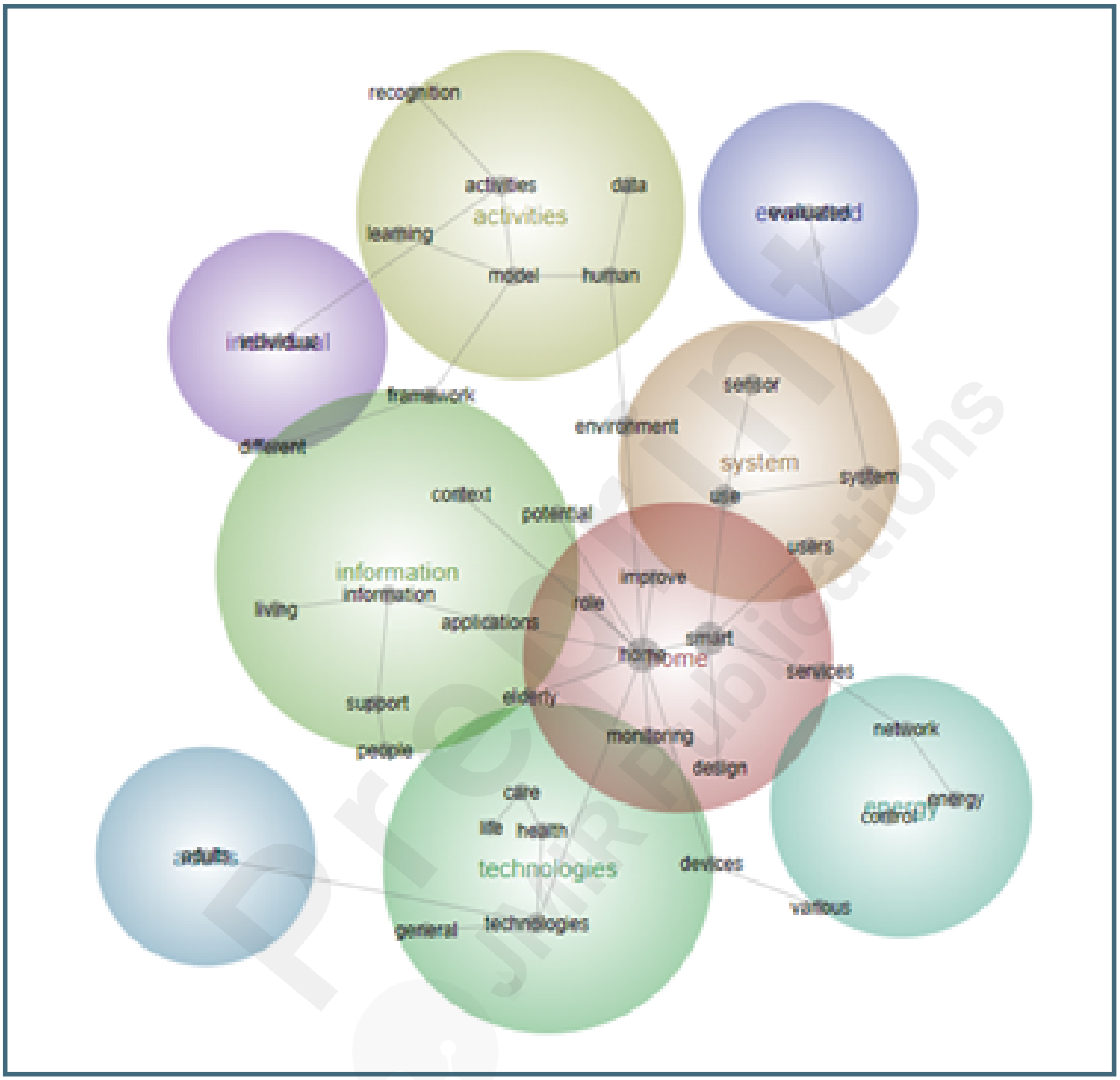
This hitmap represents common concepts expressed by the Prominence Index (PI) across four different periods.



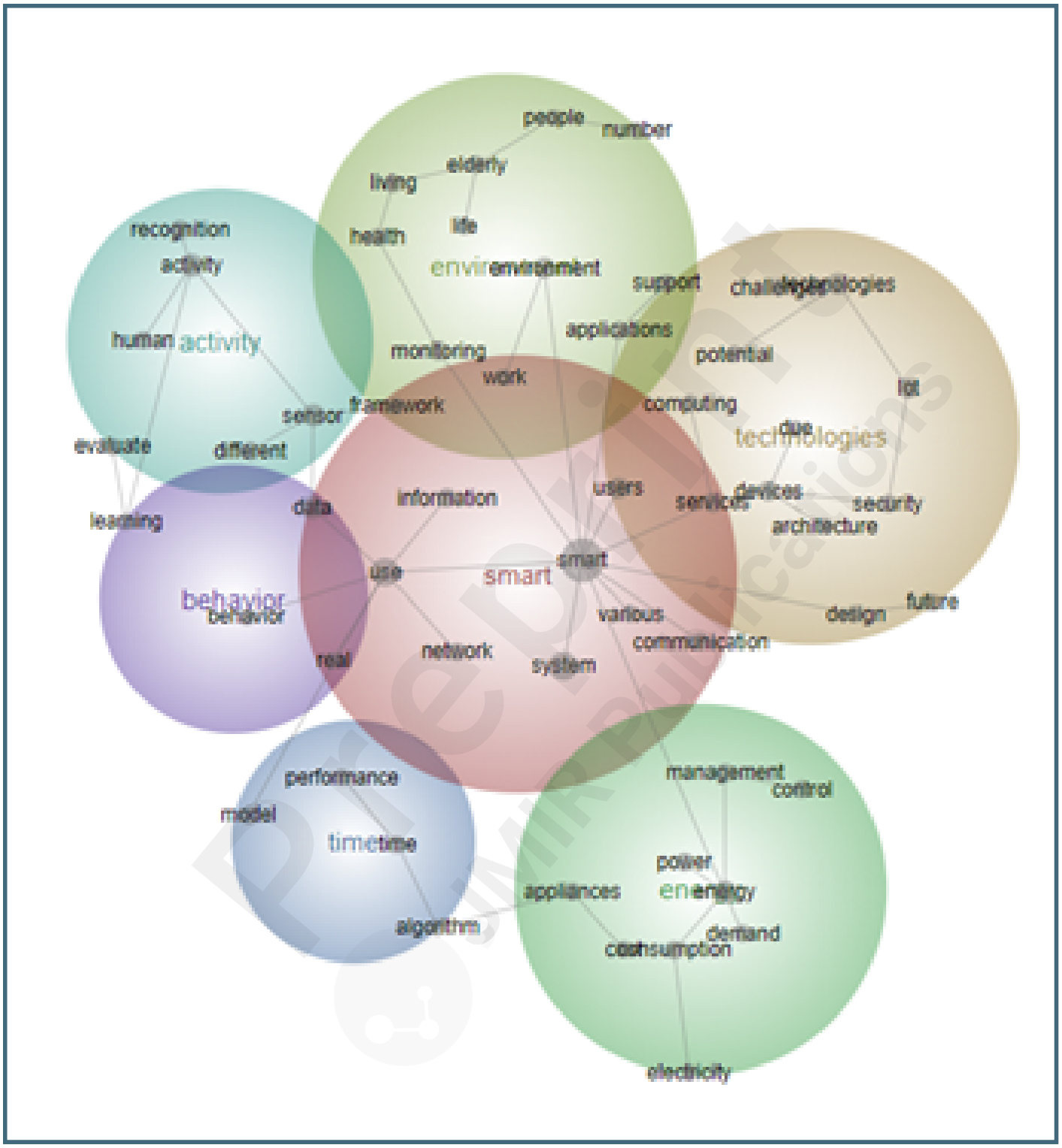
This is the result of a concept map extracted from literature spanning the years 2000 to 2005.



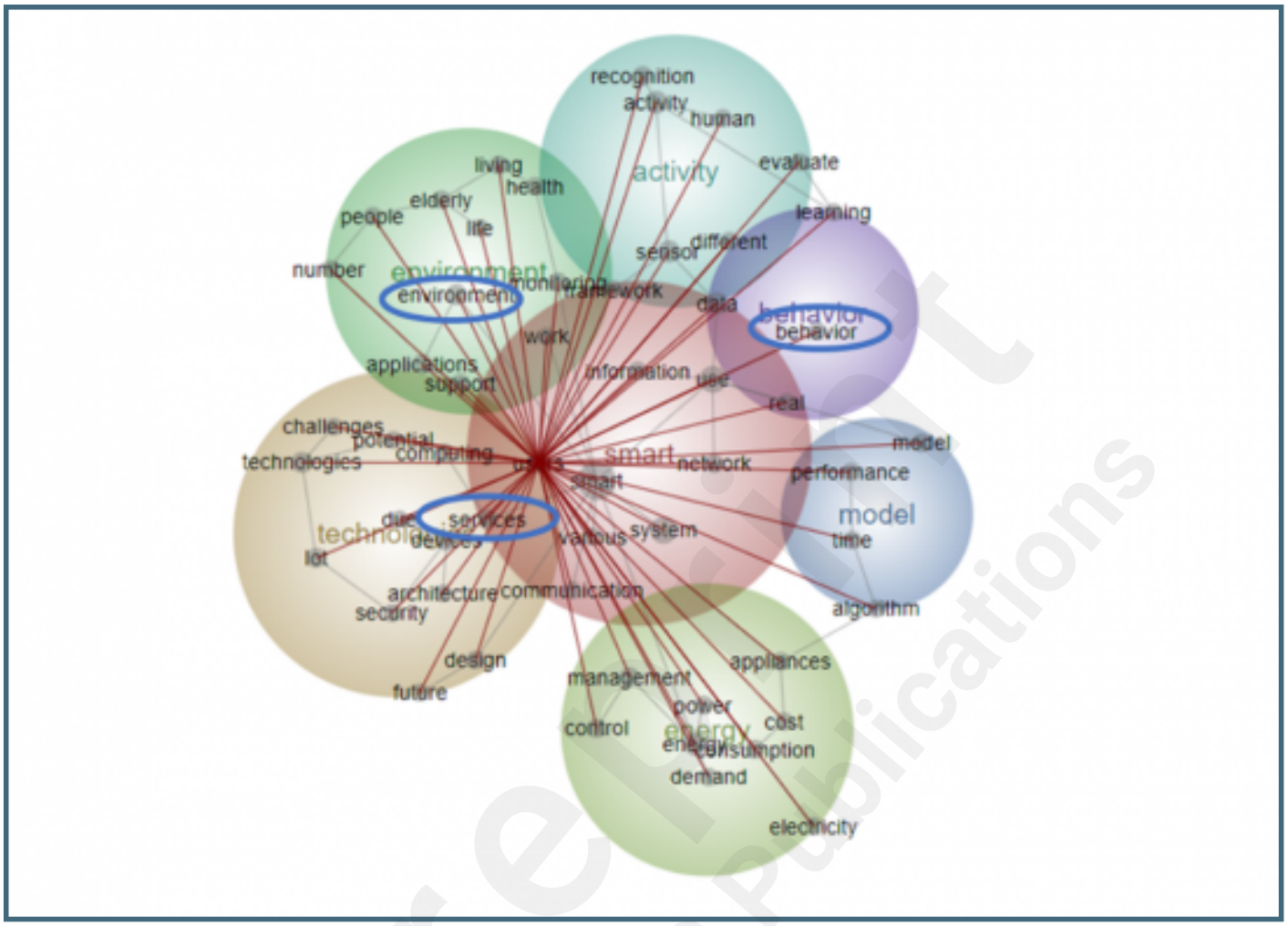
This is the result of a concept map extracted from literature spanning the years 2006 to 2011.



This is the result of a concept map extracted from literature spanning the years 2012 to 2017.

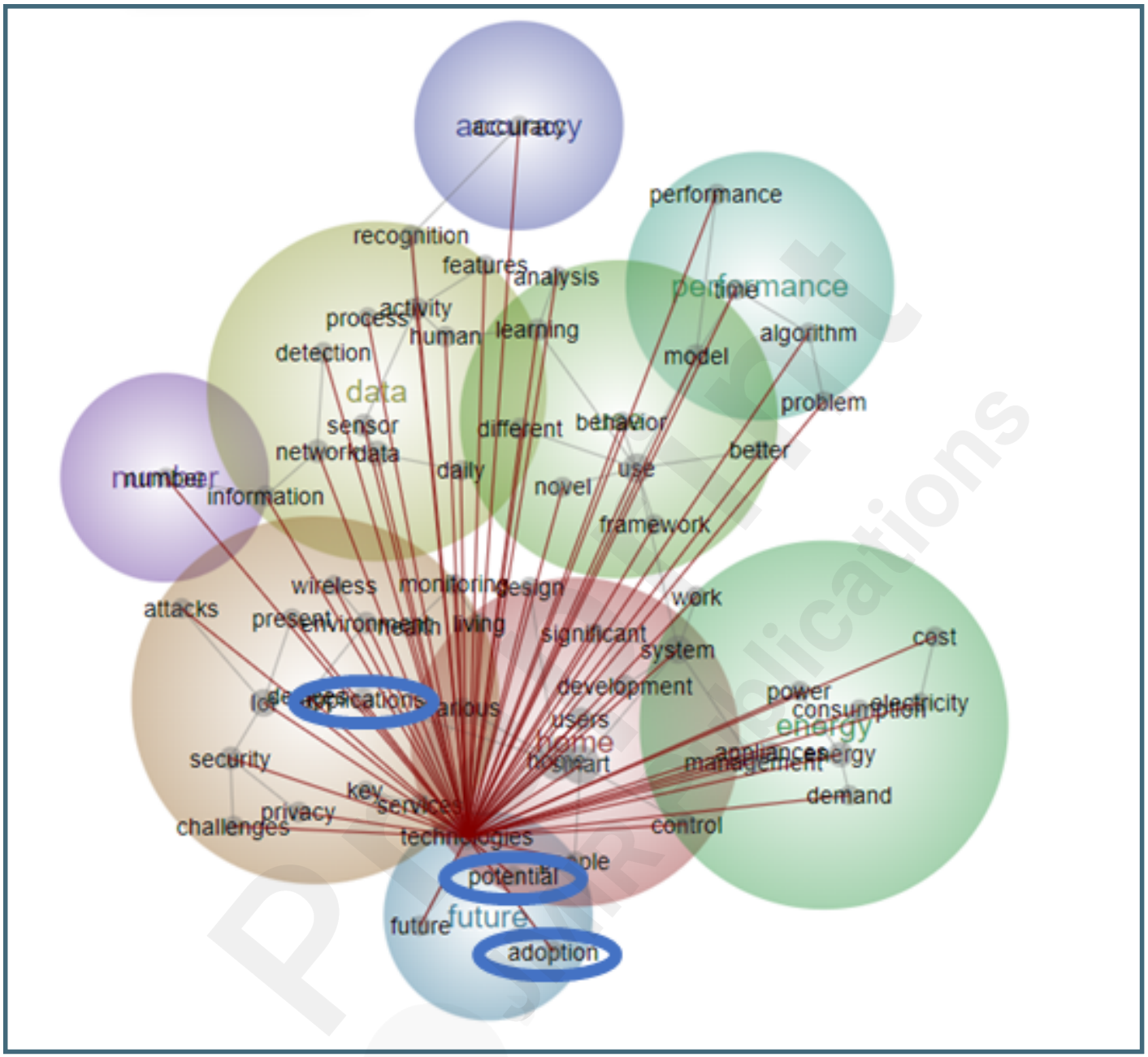


This picture shows the concepts connected to 'User'.



This is the result of a concept map extracted from literature spanning the years 2018 to 2023.

This picture shows the concept connected to 'Technologies'.



This picture shows the concept connected to 'User'.