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Systematic Review

Operability of Smart Spaces in Urban Environments: A Systematic Review on Enhancing Functionality and User Experience

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Abstract: This literature review highlights the emergence of the Internet of Things (IoT) and the proliferation of connected devices as the driving force behind the adoption of smart spaces. This review also discusses the various applications of smart spaces, including smart homes, smart cities, and smart healthcare: (1) Background: the aim of this research is to provide a comprehensive overview of the concept of smart spaces, including their key features, technologies, and applications in built environments and urban areas; (2) Methods: The study adopts a qualitative approach, drawing on secondary sources, such as academic journals, reports, and online sources; (3) Results: The findings suggest that smart spaces have the potential to transform the way people interact with their environment and each other. They could improve efficiency, safety, and quality of life. However, there are also concerns about privacy and security in relation to the collection and use of personal data; (4) Conclusions: The study concludes that smart spaces have significant theoretical and practical implications for various fields, including architecture, urban planning, and healthcare. The theoretical implications include the need for new models and frameworks to understand the complex relationships between technology, space, and society. The practical implications involve the development of new standards and regulations to ensure the responsible and ethical use of smart spaces.

Keywords: smart spaces; interoperability; user experience; artificial intelligence; Internet of Things (IoT); smart space management

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1. Introduction

Smart spaces refer to physical environments that have been enhanced with technology to enable them to respond intelligently to the needs of their users (Cook, Augusto, and Jakkula, 2009) [1]. According to Gilman and Riekki (2012) [2], the aim of smart spaces is to create intelligent and adaptive environments that can adapt to the needs and preferences of their occupants. These spaces can range from homes and offices to public spaces, such as shopping malls and transportation hubs. The potential impact of smart spaces on daily life is significant. By incorporating technology, such as sensors, cameras, and other Internet of Things (IoT) devices, smart spaces can optimize energy usage, improve security and safety, enhance productivity and convenience, and provide personalized experiences for users. However, there are also potential concerns around privacy, data security, and the potential for these technologies to be misused. As smart spaces become more prevalent, it will be essential to establish guidelines and regulations to ensure that these technologies are used ethically and responsibly. In other words, to contain the excesses of smart spaces, as we look forward to intelligence communities, it is imperative that we take stock through a systematic review of what is known and unknown about smart spaces from the perspective of the built environments and urban areas. Given that, while the built environments play a critical role in how people interact with the physical world, smart spaces in urban areas can improve energy efficiency, reduce waste, optimize transportation systems, enhance public safety, and promote sustainable development, while urban areas in smart spaces lie in their ability to enhance the quality of life for individuals and communities.

The application of smart spaces faces challenges that need to be overcome for a successful implementation. Privacy and security concerns arise from the use of sensors and IoT devices, necessitating the establishment of guidelines and regulations (Narayanan et al., 2019) [3]. Ambiguity in the conceptualization of smart spaces within built environment research calls for a better understanding of their scope [1]. Interoperability issues require standardized communication protocols and data formats (Nguyen and Aiello, 2013 [4]. User acceptance and adoption can be hindered by resistance to change and privacy concerns, requiring education, user-friendly interfaces, and transparent data-handling practices (Abdel-Basset et al., 2021) [5]. Technical and social challenges, including privacy, security, and collaboration, need to be addressed for effective implementation (Markman et al., 2019) [6]. Overcoming these challenges necessitates interdisciplinary research and collaboration to realize the potential benefits of smart spaces in enhancing the quality of life and urban environments.

For instance, the use of wireless networks also raises concerns about data security. Wireless networks can be vulnerable to hacking and cyber-attacks, necessitating the implementation of appropriate security measures to protect against unauthorized access. Despite these concerns, the benefits of wireless networks in smart spaces, including convenience, energy efficiency, and improved decision-making, outweigh the potential risks.

Furthermore, the study shows that both thin films and wireless networks contribute significantly to the functionality, efficiency, and overall user experience of smart spaces. Thin films offer versatile, functional coatings, while wireless networks enable real-time communication and data exchange among devices. Together, they drive advancements in various applications, from smart windows and sensors to smart homes, buildings, healthcare environments, and cities.

Hence, the research on smart spaces is not performed in isolation but rather in conjunction with other concepts, such as smart cities, smart places, smart technologies, and shared spaces. Since nature does not allow for a vacuum, there is limited literature providing a clear separation, direction, or conceptualization individually without recourse to the other. This makes it difficult to determine what constitutes a smart space within the context of built environment research. This ambiguity highlights the dearth of research on smart spaces in urban studies and built environments. Nevertheless, the principles of agility, sensory experience, and multifunctionality, including how smart spaces connect with smart cities and technologies, promote the functionality of the daily activities of urbanists, especially in terms of promoting improved connectivity and interaction with artificial intelligence (AI).

The key focus within the field of artificial intelligence (AI) is to create intelligent agents capable of interacting with humans in a natural and intuitive way (Weiss, 1999; Shabbir and Anwer, 2018) [7,8]. The widespread adoption of smart devices and the Internet of Things (IoT) has sparked a growing interest (Elgazzar, Khalil, Alghamdi, Badr, Abdelkader, Elewah and Buyya, 2022; Madakam, Lake, Lake, and Lake, 2015) [9,10] in the concept of smart spaces—physical environments that are enriched with intelligent technologies to augment and improve human activities [1]. The potential of smart spaces to revolutionize sectors, such as healthcare, education, entertainment, and transportation, is significant.

Smart spaces emerged from the convergence of several fields, including ambient intelligence, ubiquitous computing, and context-aware computing (Gollan et al., 2018) [11]. The aim was to create intelligent environments that could adapt to the needs and preferences of their occupants without requiring explicit commands or interactions [1]. According to Ferrand and Onaindia (2013) [12], they were designed to be context-aware, meaning that they can sense and interpret the context of the environment, such as the presence of people, objects, and events, and use this information to provide proactive and personalized services.

Smart spaces have significant implications for various domains, including healthcare, education, entertainment, and transportation. By creating intelligent and adaptive environments that can support human activities, smart spaces have the potential to enhance the quality of life of their occupants, improve productivity and efficiency, and reduce costs and environmental impact. Therefore, it is essential to understand the key challenges and opportunities in smart space research to ensure that these technologies are developed in a responsible and sustainable manner.

The purpose of this article is to provide an overview of state-of-the-art smart space research, highlighting the key trends and opportunities in the area. By so doing, it presents a comprehensive analysis of the current trajectories and future directions for the field, based on systematic evidence. Smart spaces have the potential to revolutionize the way we interact with our environment [8] by creating intelligent and adaptive environments that can support a wide range of human activities (Poslad, 2011) [13]. However, there are several technical and social challenges that create a barrier to the fulfillment of smart spaces, such as privacy, security, interoperability, and user acceptance. The shortcomings and inefficiencies of the individuals working in isolation have resulted in significant institutional losses, highlighting the pressing need for a revolutionary management approach through smart space [6].

This study takes a comprehensive approach to examining the combined impact of several smart technological infrastructures, such as thin films, wireless networks, and oxygen vacancies in smart spaces. This research addresses the need for a holistic understanding of their incorporation and how they enhance functionality, efficiency, and user experience. By considering the synergistic effects of these elements, the study fills a crucial gap in existing research that often focuses on individual contributions. This comprehensive approach bridges the gap in existing research that often focuses on individual contributions, providing a more integrated perspective.

What sets this study apart is its integration of practical findings with broader theoretical frameworks such as energy efficiency, automation, privacy, and optimization. This approach goes beyond the mere exploration of practical applications and provides a deeper understanding of the underlying principles and theoretical underpinnings. By linking practical findings to theoretical frameworks, this study adds depth and context to its findings, distinguishing it from research that solely focuses on technical aspects, and it enriches the theoretical foundations of smart space research.

By acknowledging the challenges associated with data security, stability, and optimization in smart spaces, this discussion contributes to the theoretical knowledge by identifying areas that require further research and development efforts. This identification of research challenges provides a basis for future theoretical explorations and informs the development of new theoretical models and frameworks.

Overall, this research highlights the significance of several key technologies and concepts in the development of smart spaces. Such as the operability of thin film, wireless networks, reset voltage, plasma-enhanced atomic layer deposition, good data retention, Internet of Things devices, ZnO NP, Lu_2O_3, switching endurance data retention, rectifier nonlinearity, redox reactions, endurance cycles, and heterostructures. For instance, thin films offer a wide range of functional coatings for smart windows and sensors, improving energy consumption and user comfort (Patel et al., 2009; Niklasson and Granqvist, 2007; Panagopoulou et al., 2017) [14–16]. Wireless networks enable real-time communication and data exchange, enhancing convenience, energy efficiency, and decision-making in smart spaces (Bhardwaj et al., 2012; Bello and Zeadally, 2014) [17,18]. Oxygen vacancies provide promising avenues for smart materials in sensors, smart windows, and energy storage, improving functionality and efficiency (Sathasivam et al., 2016; Zhang et al., 2019, 2018) [19–21]. Memory devices play a crucial role in storing and retrieving data, enabling AI applications, and optimizing system performance (Ma et al., 2021; Lu et al., 2019; Graaf et al., 2018) [22–24]. These technologies have significant impacts on functionality, efficiency, and user experience, driving advancements in industries and offering improved outcomes (Schroeder et al., 2019; Raza et al., 2020) [25,26].

For clarity and comprehension, this study is structured as follows: first, we provide a definition and overview of smart spaces, highlighting their key features and characteristics; second, we discuss the technical challenges of smart spaces, including context awareness, data management, and interoperability; third, we explore the social challenges of smart spaces, such as privacy, security, and user acceptance; fourth, we review the current state-of-the-art in smart spaces research, highlighting the most significant contributions and achievements; finally, we conclude the article by discussing the future directions of smart space research, and the potential implications of smart spaces for various domains.

1.1. Smart Space Management

Smart space management involves the use of advanced technologies, such as the Internet of Things (IoT), big data, and artificial intelligence (AI), to optimize the functionality of smart spaces (Zhang, Zhang, and Chen, 2021) [27]. Smart spaces are physical environments equipped with sensors, devices, and systems that can collect and analyze data to improve their functionality and efficiency (Lee et al., 2019) [28]. The goal of smart space management is to enhance the quality of life for individuals and make the space more efficient and sustainable.

IoT devices and sensors are used to collect real-time data from various systems and infrastructures within the smart space, and this data is analyzed using big data and AI algorithms to identify patterns, trends, and anomalies, enabling data-driven decision-making (Varshney and Sarker, 2019) [29]. Some of these components or devices include Building Automation Systems (BAS), which are used to integrate and control multiple building systems, such as lighting, heating, ventilation, air conditioning (HVAC), access control, and security (Jin et al., 2020) [30]. Cloud-based services are used for data storage, analysis, and remote control and monitoring of the space, while user interfaces, such as mobile apps, online portals, and chatbots, are used to provide easy access to various services and information within the space (Sikdar and Jha, 2019) [31]. Standards and protocols are essential for the interoperability of different smart devices and systems within the space, ensuring that they can work together seamlessly (Lee et al., 2019) [28]. According to Apanaviciene et al. (2020) [32] and Kanellopoulos et al. (2023) [33], their operability is central to the functionality of the smart architecture or infrastructure within a smart area, building, or city. Thus, smart space management encompasses predictive maintenance, automatic fault detection, and energy-efficient scheduling of systems to optimize the performance of the space (Chen et al., 2021) [34]. By utilizing data-driven decision-making and real-time monitoring, smart space management enables better energy and resource management, leading to increased efficiency and cost savings (Choi and Cho, 2019) [35].

Smart space management also provides a personalized experience to the users and easy access to information, resulting in improved safety and security and a better user experience (Rahmani, Gia, Negash, Anzanpour, and Azimi, 2018) [36]. Through real-time monitoring and analytics, smart space management can quickly detect and address safety and security issues, ensuring a safer environment for users (Wang, Hu, and Wen, 2020) [37]. Additionally, smart space management can promote environmental sustainability by optimizing energy consumption, reducing waste, and promoting sustainable practices (Choi and Cho, 2019) [35].

The implementation of interoperability standards and protocols is crucial for the successful management of smart spaces, as stated ab initio. Standards, such as the Open Connectivity Foundation (OCF) and the Thread Group, assist in ensuring that devices and systems within the space can communicate and work together seamlessly (Lee et al., 2019) [28]. This is particularly important as the number of devices and systems within a smart space continues to increase, and ensuring interoperability can help prevent issues such as data silos and incompatible devices (Lehne, Sass, Essenwanger, Schepers, and Thun, 2019) [38].

The management of smart spaces is thus a complex process that involves the integration and optimization of various systems and infrastructures within the space. Advanced technologies, such as IoT, big data, and AI, are crucial for collecting, analyzing, and utilizing data to optimize the performance of the space. Building Automation Systems and cloud-based services provide real-time monitoring, analytics, and control of the space, while user interfaces, such as mobile apps and chatbots, provide easy access to services and information. Interoperability standards and protocols are also necessary to ensure that devices and systems within space can work together seamlessly.

The benefits of smart space management include improved efficiency, enhanced user experience, better sustainability, increased productivity, and improved safety and security. Going forward, it is important for organizations to continue investing in smart space management and always leverage advancements in technologies to create more efficient, equitable, sustainable, and user-friendly smart spaces.

To overcome the issues in smart spaces and address their limitations and challenges, several key factors need to be considered, including the role of energy harvesters, Lu_2O_3 thin films, stability, performance, and interoperability. By implementing the following strategies, we can promote energy efficiency and the use of clean energy in urban environments:

1.1.1. Enhancing Energy Harvesters

Improving Power Output and Efficiency: Research and development efforts should focus on increasing the power output and efficiency of energy harvesters through advancements in materials, design, and fabrication techniques.

Environmental Adaptability: Designing energy harvesters that can operate effectively under different environmental conditions, such as temperature, humidity, and vibration, will enhance their practicality in smart spaces.

1.1.2. Addressing Lu_2O_3 Thin Film Issues

Cost Reduction: Developing cost-effective production methods and optimizing the manufacturing process can help reduce the production cost of Lu_2O_3 thin films, making them more economically viable for smart space applications.

Yield Improvement: Investigating and optimizing the fabrication process to enhance the yield of Lu_2O_3 thin films will ensure more reliable and scalable production.

Stability Enhancement: Conducting research to understand and mitigate stability issues related to Lu_2O_3 thin films, such as degradation and aging, will improve their reliability and long-term performance.

1.1.3. Ensuring Stability and Performance

Monitoring and Analysis: Implementing systems for continuous monitoring and analysis of various parameters, such as temperature, humidity, and air quality, will enable proactive detection of issues and anomalies in smart space systems and devices.

Predictive Maintenance: Utilizing data analysis and machine learning algorithms to predict maintenance requirements based on stability and performance metrics, enabling timely interventions to reduce downtime and extend system lifespan.

1.1.4. Promoting Interoperability

Adoption of Standards: Implementing interoperability standards and protocols, such as those provided by the Open Connectivity Foundation (OCF) and the Thread Group, will facilitate seamless communication and integration among devices and systems within smart spaces.

Preventing Data Silos: Ensuring compatibility and interoperability between different devices and systems will help prevent data silos and enable efficient data sharing and utilization across the smart space ecosystem.

By considering and implementing these strategies, we can outlive the challenges in smart spaces, promote energy efficiency, and facilitate the use of clean energy in urban environments.

1.2. Justification of This Study

This study differs from the existing research within the field in several ways. While the existing research has explored the individual contributions of thin films, wireless networks, and oxygen vacancies in smart spaces (Li et al., 2019; Liao et al., 2019) [39,40], this study takes a comprehensive approach by examining the incorporation of all three elements and their combined impact on functionality, efficiency, and user experience. By considering the synergistic effects of these elements, this study provides a holistic understanding of how they work together to enhance smart spaces.

Furthermore, this study goes beyond the individual applications of thin films, wireless networks, and oxygen vacancies by linking them to relevant theories and concepts, such as energy efficiency, automation, connectivity, privacy, reactivity, and optimization. It establishes connections between the practical findings and broader theoretical frameworks, adding depth and context to the study's findings and distinguishing it from existing research that may focus solely on technical aspects without considering their theoretical underpinnings.

Overall, this study's comprehensive approach, integration of theoretical frameworks, and emphasis on addressing existing challenges set it apart from existing research within the field. It provides a unique perspective on the incorporation of thin films, wireless networks, and oxygen vacancies in smart spaces and offers valuable insights for researchers, practitioners, and stakeholders involved in the development and optimization of smart environments.

2. Materials and Methods

2.1. Data Search

Data were derived using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) logic. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is a widely recognized and accepted guideline for reporting systematic reviews and meta-analyses (Moher et al., 2009) [41]. The PRISMA statement includes a 27-item checklist and a flow diagram that outline the minimum standards for transparent and complete reporting of systematic reviews and meta-analyses.

The PRISMA statement is used by researchers, journal editors, and peer reviewers to assess the quality and transparency of systematic reviews and meta-analyses. Adherence to the PRISMA guideline can help ensure that systematic reviews and meta-analyses are conducted and reported in a rigorous and transparent manner, which, in turn, can increase their credibility and usefulness for informing clinical practice, policy development, and future research (Moher et al., 2009) [41].

2.2. Data Selection Criteria Using PRISMA

The systematic review, particularly when conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, is considered a robust and reliable approach for synthesizing evidence. There are four main reasons that make the systematic review and PRISMA guidelines preferable to other models.

First, a systematic review follows a predefined protocol that ensures a comprehensive and unbiased search for relevant studies (Higgins et al., 2011) [42]. This rigorous methodology reduces the risk of bias and enhances the validity and reliability of the findings.

Second, the PRISMA guidelines provide a transparent framework for reporting the review process and results, promoting transparency and replicability (Moher et al., 2009) [41]. By adhering to these guidelines, the researchers can provide clear information on search strategies, inclusion and exclusion criteria, data extraction, and quality assessment, making it easier for readers to assess the study's credibility.

Third, the systematic review and PRISMA guidelines enable a systematic and structured synthesis of evidence from multiple studies, allowing for a comprehensive overview of the available literature (Popay et al., 2006) [43]. This approach helps identify patterns, trends, and inconsistencies across studies, contributing to a more reliable and balanced assessment of the topic.

Fourth, the systematic review and PRISMA guidelines facilitate evidence-based decision-making by summarizing the existing literature and identifying research gaps (Higgins et al., 2011) [42]. This information can inform policy development, guide future research directions, and support evidence-informed practice.

Overall, the systematic review in the identification and screening of included results, particularly when conducted following the PRISMA guidelines, offers a robust and transparent approach to evidence synthesis, ensuring credibility, replicability, and a comprehensive understanding of the topic under investigation.

Figure 1 of the PRISMA logic has three main indicators: identification; screening; and inclusion. These three indicators exhibit different levels of data gathering and exclusion criteria. The first indicator—identification—shows that the records from the artificial intelligence software (2023 version) called www.dimensions.ai (accessed on 21 October 2022) returned 27,591 results by adding both the smart spaces = 17,009 and controlled spaces = 10,582. At the elementary stage of data cleaning, there were duplicates = 4 and ineligible data = 394. In the second stage of data collection, the screening stage, such issues as data extraction, study characteristics, study selection, and the synthesis of results were taken into cognizance to produce the result used for data estimation in this study.

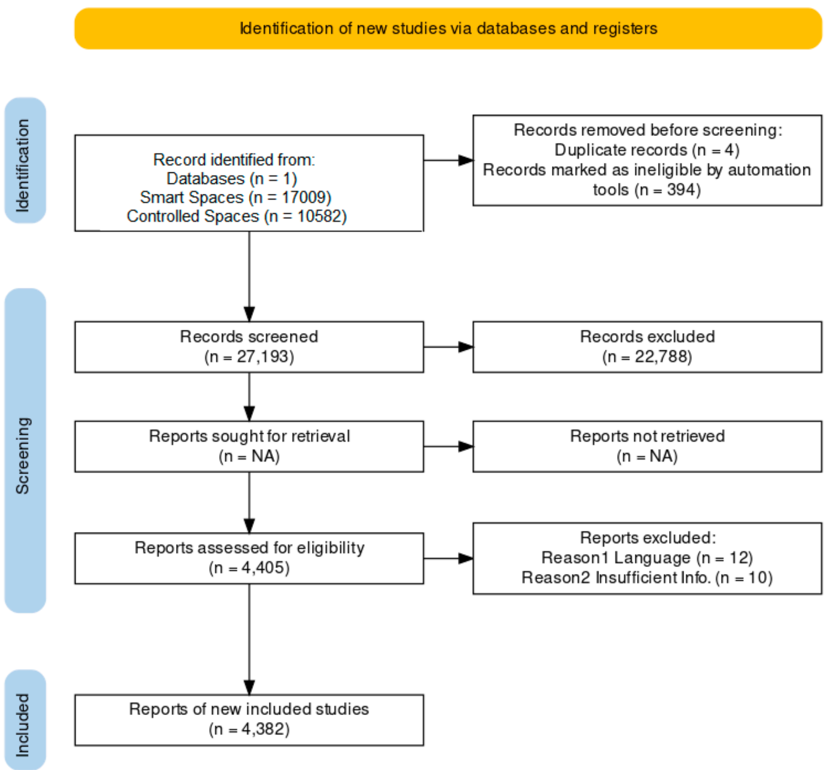

Figure 1. PRISMA Logic.

From the screen record of 27,193 results, 22,788 were excluded as they did not fall into any category for discussion of smart spaces. Some of the factors that reduced the dataset included the exclusion of the field, with a focus on the urban and built environments, and the nature of publication types which was limited to this article alone. The record shows that the number of eligible studies was 4405 when articles in other languages and others were excluded; it was left at 4383, which became the data utilized for this systematic review analysis.

2.3. Data Analysis

In this section, Citespace software version 6.1.R3 was employed. Despite inputting 4383 studies into the Citespace computational analytical software for analysis, the result generated by the software was only included to about 2775.

Citespace maps are the conceptual metrics of keywords based on themes by using two methods: LLR (Locally Linear Regression): Locally Linear Regression; and TFIDF (Term Frequency Inverse Document Frequency): Term Frequency-Inverse Document Frequency. Newey demonstrates that LLR is a much more reliable statistical measurement tool compared to kernel regression (Ndaguba et al., 2022) [44]. LLR uses locally fitted lines rather than a constant and has a lesser tendency for bias, particularly when the model is linear. In statistical analysis, the LLR test is utilized for comparing the fit between two statistical nodes. In this case, it compares the TFIDF, mutual information (MI), and cluster labels (USR) to generate the LLR. According to Shi and Liu, LLR can be used to estimate the p-value or, in comparison to a critical value, to either accept or reject the null hypothesis (Shi and Liu, 2019) [45]. According to Havrlant and Kreinovich, TFIDF is a commonly used method for keyword detection (Havrlant and Kreinovich, 2017) [46].

3. Result

This section presents the findings from the artificial intelligence platform www.dimensions.ai. The results demonstrate the trends and dynamics in research concerning smart spaces. There are two levels of results discussed in this study, the first is descriptive analysis, and the second is content analysis. The descriptive analysis discusses the trajectories and numbers of scholars and fields leading the research in this area. The content analysis section deals with the trends and themes that have been developed over time in the research of smart spaces in the built environment and engineering, among other fields.

3.1. Descriptive Analysis

Despite research on this topic taking place between 2012 and 2022, this study strived to understand the trajectory of its citations much before 2012. The analysis was drawn from 1992 to demonstrate whether there existed a growth or development in smart spaces (Figure 2). Over time, between 1992 and 2001, the citation remained below 20 for the decade. In the next decade, from 2002 to 2011, research in smart spaces witnessed less progress. However, between 2012 and 2021, the research on smart spaces surged tremendously; the progress in citation rate grew to above 100% growth rate. One thing that comes to mind is why there was such rapid growth in the third decade. The answer is simple; the growth rate can be attributed to the rise in environmental studies, the growth, and popularity of research on climate change and global warming, including an increase in the use and adoption of EVs, growth in IoT, smart offices, homes, and much more.

Figure 3 demonstrates the major research on smart spaces (see also Table A1 in Appendix A for the top 25 research studies on smart spaces), while Figure 4 shows that the National Natural Science Foundation of China (NSFC) appears to have invested the most long before contenders in the investment on smart spaces globally. This investment is followed by the European Union, which comes in second place in research investment. Figure 5 pointed out that the Institute of Electrical and Electronic Engineers (IEEE) published the most material on smart spaces than the SAGE publication.

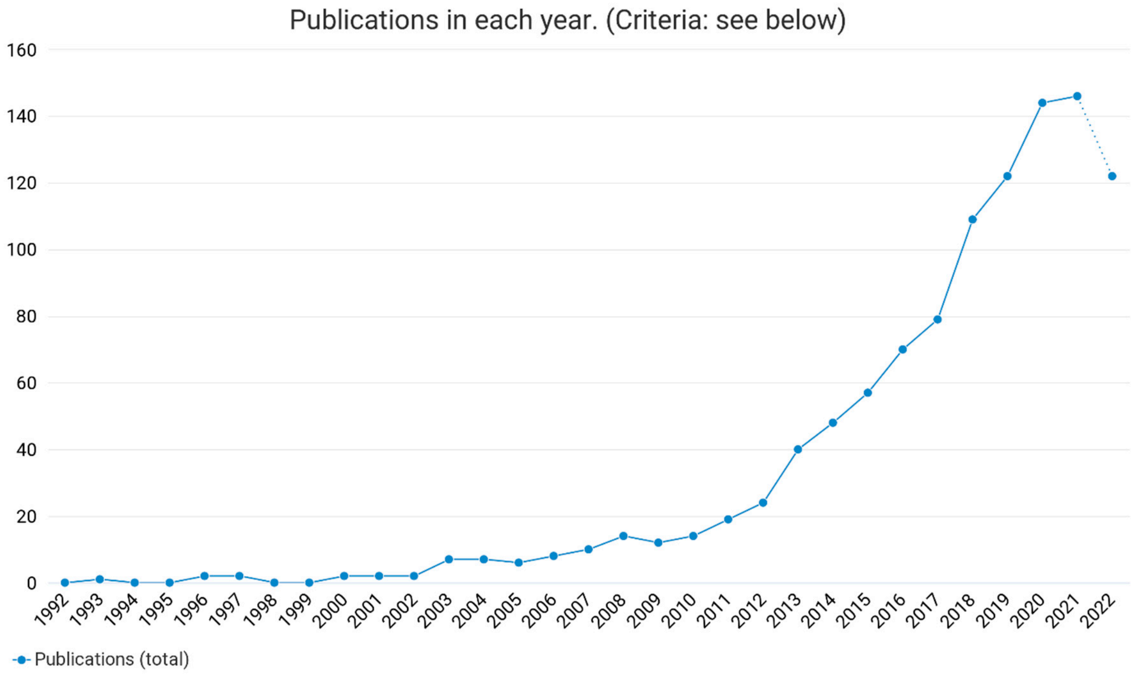

Figure 2. Publications in each year (1992–2022). (Source: https://app.dimensions.ai, Exported: 23 November 2022. Criteria: "Smart Space" in full data, Fields of Research (ANZSRC 2026) is 46 information and Computing Sciences or 40 Engineering or 35 Commerce, Management, Tourism and Services, Unit of Assessment is B12 Engineering; Publication Type is Article. ©2022 Digital Science and Research Solutions Inc. All rights reserved. Non-commercial redistribution/eternal reuse of this work is permitted subject to appropriate acknowledgement. This work is sourced from Dimensions at www.dimensions.ai. Same for Figures 4–6.

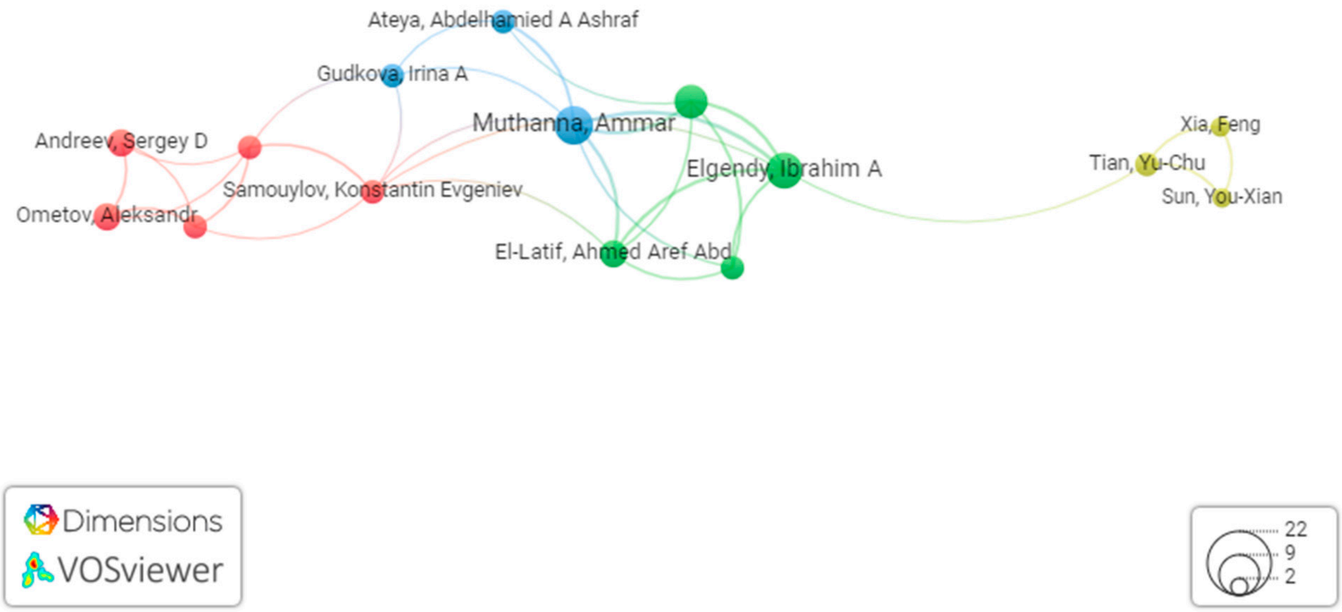

Figure 3. Most impactful researchers in smart spaces.

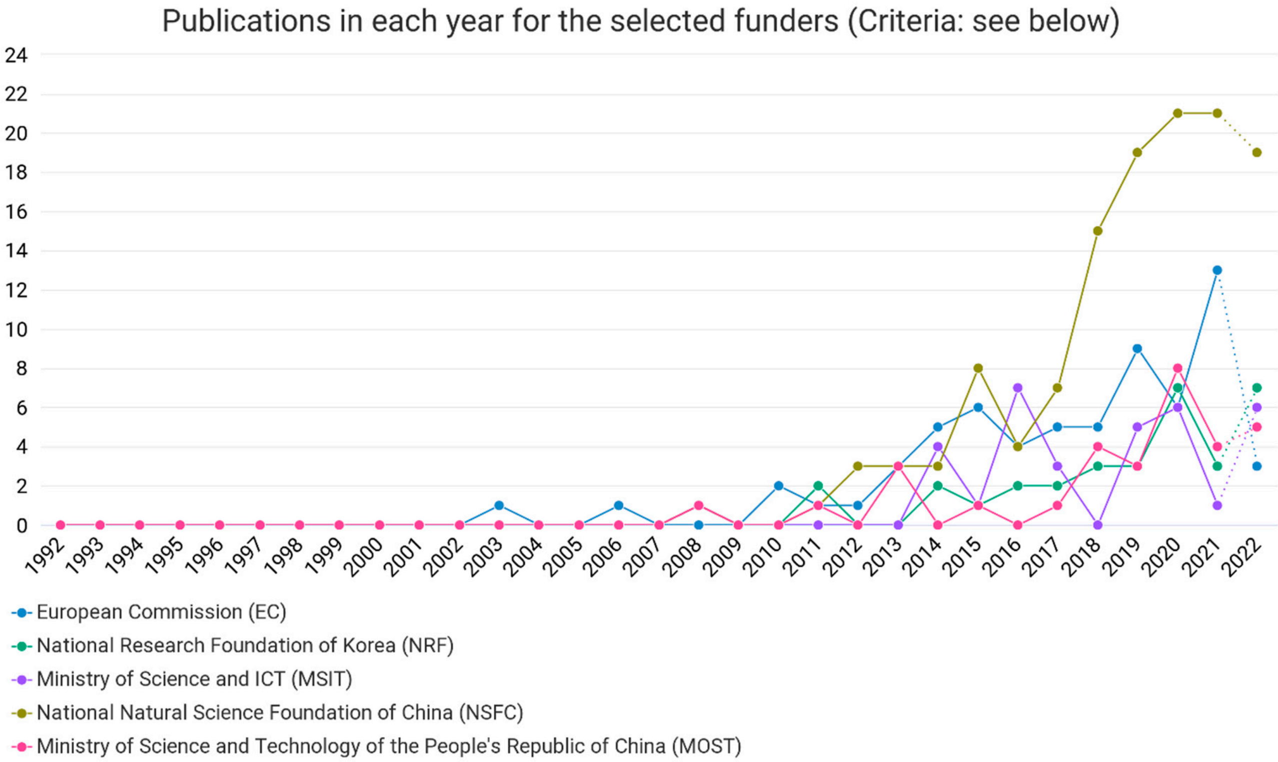

Figure 4. Funders or investors in smart space research.

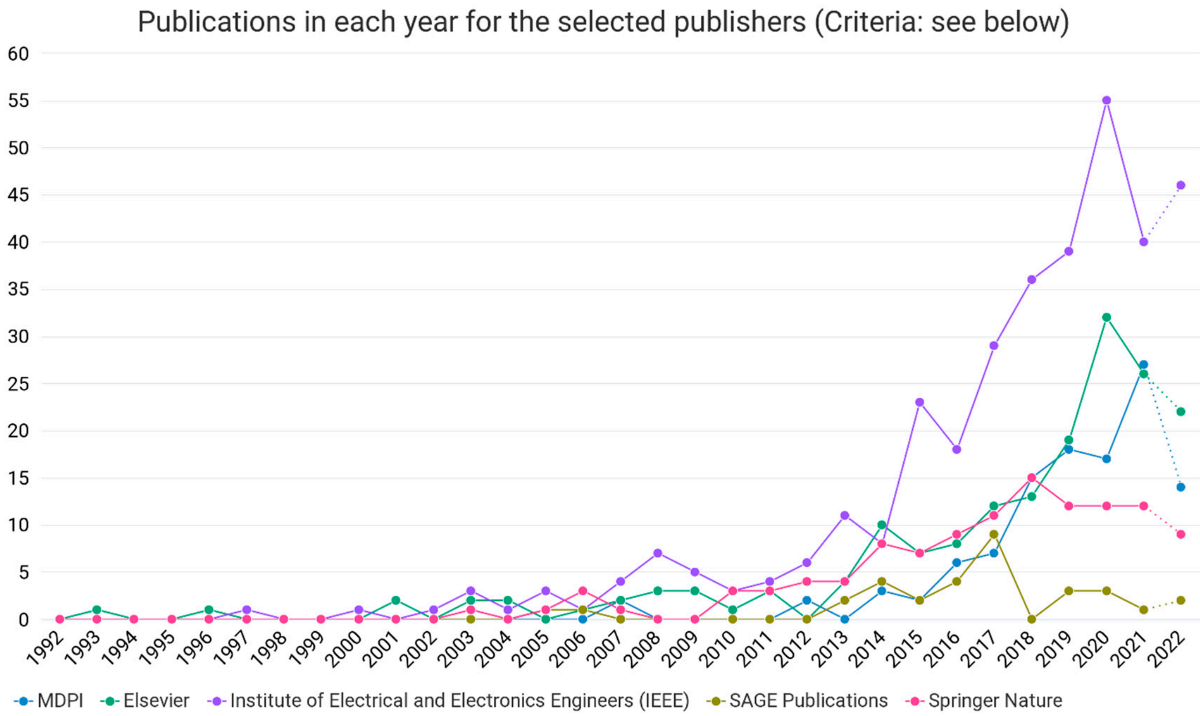

Figure 5. Major publishers and stakeholders in smart spaces.

Inherently, the MDPI, which has been recently launched and only became operational in the publication of smart spaces in 2006, tends to compete with Elsevier in the publication based on the publication house.

Based on the location of the publication, Figure 6 shows that research on smart spaces commenced in the United States and the United Kingdom before 1992. However, sponsorship, as seen in Figure 5, shows that MOST was the only organization investing in research on smart spaces as early as 1992. Nonetheless, while the USA and UK were well-known for their publications on smart spaces, based on the documentary evidence, between 2017 and 2022, the Chinese research tripled the research of both the US and the UK.

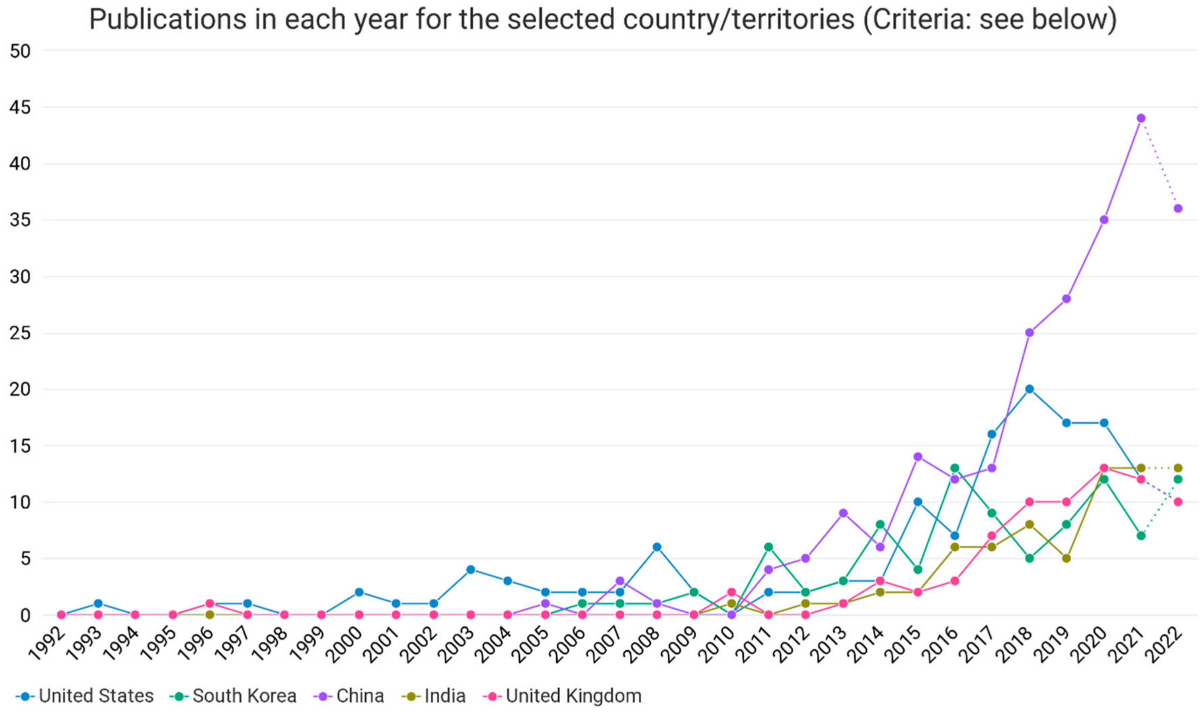

Figure 6. Countries.

3.2. Content Analysis: Establishing Themes and Trends

To comprehend the complexity of smart spaces, it is necessary to comprehend thirteen key clusters, as exhibited in Figure 7 and Table 1. Thin film, wireless networks, reset voltage, plasma-enhanced atomic layer deposition, good data retention, Internet of Things devices, ZnO NP, switching endurance data retention, rectifier nonlinearity, redox reactions, endurance cycles, and heterostructures are included in these clusters. A thorough discussion of these thirteen major clusters would facilitate a deeper comprehension of their potential applications in smart technology and management.

Table 1. Summary of the largest 13 clusters.

Cluster ID	Size	Silhouette	Label (LSI)	Label (LLR)	Average Year
0	**119**	0.793	thin film	thin film	2013
1	**53**	0.97	wireless network	reconfigurable intelligent surface	2018
3	**47**	0.98	oxygen vacancies	reset voltage	2017
4	**39**	0.911	oxygen vacancies	plasma-enhanced atomic layer deposition	2010
5	**36**	0.915	memory device	good data retention	2011
6	**35**	1	stability index	iot device	2014
7	**35**	0.979	zno np	zno np	2016
8	**28**	0.938	lu2o3 thin film	lu2o3 thin film	2010
9	**27**	0.999	energy harvester	rectifier nonlinearity	2015
10	**23**	0.998	off current ratio	redox reaction	2008

Table 1. *Cont.*

Cluster ID	Size	Silhouette	Label (LSI)	Label (LLR)	Average Year
11	**11**	0.98	resistive switching device	endurance cycle	2016
14	**8**	0.988	heterostructure	heterostructure	2010
18	**6**	0.994	positive formation polarity	cycle	2010

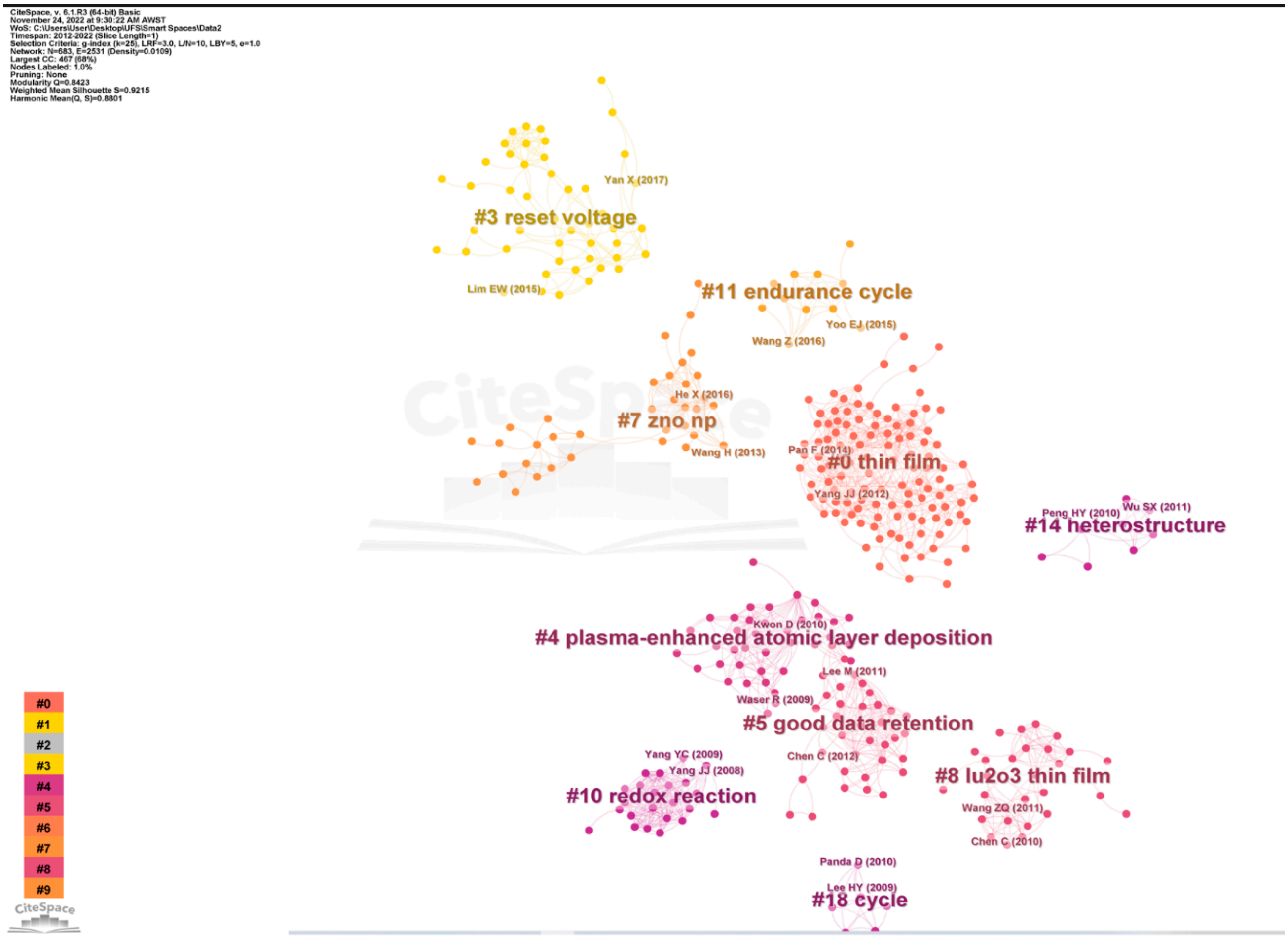

Figure 7. Visualization of the document co-citation network by themes, 2012–2022 (Modularity Q = 0.8423; Average silhouette score = 0.9215 (Q, S = 0.8801).

3.2.1. Thin Film

Thin films have numerous applications in smart spaces, ranging from smart windows to sensors (Patel, Panchal, Kheraj, and Desai, 2009) [47]. The use of thin films in these applications can have a significant impact on the functionality, efficiency, and overall user experience of smart spaces [15,16].

Thin films are thin layers of material deposited on a substrate, typically using techniques, such as chemical vapor deposition or sputtering (Crowell, 2003) [48]. They can be used to create a wide range of functional coatings, such as conductive, insulating, and optical coatings.

One example of the use of thin films in smart windows is in the development of electrochromic windows, which can change their transparency in response to an electric current (Tönbül, Can, Öztürk, and Akyıldız, 2021) [49]. This technology can help to reduce energy consumption in buildings by controlling the amount of heat and light that enters space, as well as improving user comfort and productivity (Kamalisarvestani et al., 2013) [50].

In the development of sensors, thin films can be used to create coatings that can detect changes in temperature, humidity, or chemical composition (Majidi, 2020) [51]. These coatings can be integrated into smart buildings to monitor conditions and adjust systems accordingly, such as adjusting the temperature or humidity to create a more comfortable and energy-efficient environment (Malakooti et al., 2020) [52].

Overall, thin films are a versatile technology that can be used to create a wide range of functional coatings for smart spaces. Their ability to create coatings with unique optical, electrical, and chemical properties makes them a valuable tool in the development of smart spaces.

3.2.2. Wireless Network

Wireless networks have become an integral part of smart spaces (Bhardwaj, Ozcelebi, Lukkien, and Uysal, 2012) [17], enabling a range of smart devices to communicate and exchange data in real-time environments [18]. The use of wireless networks in smart spaces has had a significant impact on the functionality, efficiency, and overall user experience of these environments [18].

One application of wireless networks in smart spaces is in the development of smart homes. Smart homes use wireless networks to connect various smart devices, such as thermostats, security cameras, and lighting systems, which enables users to control these devices remotely using their smartphones or other internet-connected devices (Popescul and Genete, 2016) [53]. This technology can help improve energy efficiency, enhance security, and provide greater convenience for users.

Wireless networks have been used in varying forms, but within the context of smart spaces in smart buildings, they are used to enable the collection and analysis of data from various home sensors and devices. For example, wireless sensors can be used to monitor temperature, humidity, and occupancy, enabling building systems to adjust in real time to create a more comfortable and energy-efficient environment.

In the healthcare industry, wireless networks are used to create smart healthcare environments where medical devices and sensors can be connected to enable real-time monitoring of patient health (Raza et al., 2020) [26]. This technology can help to improve patient outcomes, reduce healthcare costs, and provide greater convenience for healthcare providers and patients.

The use of wireless networks in smart spaces has also led to the development of smart cities. Smart cities use wireless networks to connect various systems and devices, such as traffic management systems, public transportation, and environmental sensors, enabling real-time data analysis and decision-making (Gao et al., 2020) [54]. This technology can help improve urban planning, reduce traffic congestion, and enhance public safety.

Despite the many benefits of wireless networks in smart spaces, there are also some potential drawbacks. One of the main concerns is the potential for data security breaches, as wireless networks are vulnerable to hacking and other cyber-attacks (Li et al., 2021) [47]. To address this concern, various security measures, such as encryption and firewalls, are used to protect wireless networks from unauthorized access.

Overall, wireless networks have become an essential technology in smart spaces, enabling real-time communication and data exchange between various devices and systems. The use of wireless networks has had a significant impact on the functionality, efficiency, and overall user experience of smart spaces, enabling greater convenience, energy efficiency, and improved decision-making. While there are some concerns about data security, the benefits of wireless networks in smart spaces far outweigh the potential risks.

3.2.3. Oxygen Vacancies

Oxygen vacancies are defects in the crystal structure of materials where oxygen atoms are missing) [23]. While these vacancies were traditionally considered undesirable defects, recent research has shown that they can have a significant impact on the functionality of smart materials used in smart spaces [19].

One application of oxygen vacancies in smart spaces is in the development of oxygen-sensitive sensors. These sensors are based on the principle that oxygen vacancies in certain materials can react with oxygen in the environment, causing changes in electrical conductivity, optical properties, or other physical properties [19]. Oxygen-sensitive sensors can be used in a range of applications, including environmental monitoring, industrial process control, and medical diagnostics.

Another application of oxygen vacancies in smart spaces is in the development of smart windows. Smart windows are designed to dynamically adjust their transparency based on the intensity of incident light or temperature changes. Oxygen vacancies can be used to create a variety of smart window technologies, including electrochromic, thermochromic, and photochromic windows (Zhang et al., 2019) [20]. These windows can help to improve energy efficiency and user comfort in buildings by reducing the need for artificial lighting and HVAC systems.

Oxygen vacancies can also be used to develop smart materials for energy storage applications. For example, oxygen-deficient lithium cobalt oxide ($LiCoO_2$) has been shown to exhibit improved electrochemical performance in lithium-ion batteries compared to its oxygen-rich counterpart (Zhang et al., 2018) [18]. The oxygen vacancies in $LiCoO_2$ can facilitate lithium-ion diffusion, leading to higher battery capacity and longer cycle life.

Despite the potential benefits of oxygen vacancies in smart spaces, there are also some challenges that need to be addressed. One of the main challenges is controlling the concentration and distribution of oxygen vacancies in materials, as this can have a significant impact on their properties and functionality (Sathasivam et al., 2016) [19]. Additionally, the stability of oxygen vacancies over time and under different environmental conditions needs to be studied and optimized.

Overall, oxygen vacancies have emerged as a promising avenue for developing smart materials and devices in smart spaces. The use of oxygen vacancies in oxygen-sensitive sensors, smart windows, and energy storage devices can lead to improved functionality, energy efficiency, and user comfort. While there are still some challenges to be addressed, the potential benefits of oxygen vacancies in smart spaces make them a promising area of research and development.

3.2.4. Memory Devices

Memory devices are an essential component of smart spaces, as they store and retrieve information that is used to control and optimize various systems and devices. One of the primary applications of memory devices in smart spaces is in the field of artificial intelligence (AI). AI algorithms require large amounts of data to be trained and optimized, and memory devices are used to store this data. Memory devices are also used to store the parameters and weights of trained AI models, which are then used to make predictions and decisions based on new input data (Ma et al., 2021) [22]. The use of memory devices in AI has revolutionized many industries, including healthcare, finance, and transportation, by enabling more accurate and efficient decision-making processes.

Another important application of memory devices in smart spaces is in the storage and retrieval of sensor data. Sensors are used to collect data on various parameters, such as temperature, humidity, and air quality, and this data is then stored in memory devices. Memory devices are also used to store historical data, which can be used for trend analysis and predictive maintenance (Lu et al., 2019) [23]. By using memory devices to store and retrieve sensor data, smart spaces can optimize various systems and devices based on real-time data and historical trends.

Memory devices are also used in smart homes and buildings to store user preferences and settings. For example, a smart thermostat in a home can store user preferences for temperature and humidity settings and adjust the HVAC system accordingly. Similarly, a smart lighting system can store user preferences for lighting intensity and color temperature and adjust the lighting accordingly. By using memory devices to store user preferences and settings, smart spaces can provide a personalized and comfortable environment for users (Graaf et al., 2018) [24].

The impact of memory devices on smart spaces can be seen in various ways. Firstly, memory devices enable more efficient and accurate data storage and retrieval, which is essential for the functioning of various systems and devices. Memory devices also enable the storage of large amounts of data, which can be used for trend analysis and predictive maintenance. This can lead to cost savings and increased efficiency in the maintenance of smart systems and devices. Additionally, the use of memory devices in AI has led to the development of more accurate and efficient decision-making processes, which can have a significant impact on industries, such as healthcare and finance.

However, there are also some challenges associated with the use of memory devices in smart spaces. One of the main challenges is the security of data stored in memory devices. With the increasing amount of sensitive data being stored in memory devices, it is essential to ensure that appropriate security measures are in place to prevent unauthorized access and data breaches. Additionally, the longevity of memory devices needs to be considered, as frequent data storage and retrieval can lead to wear and tear on the devices.

Memory devices are an essential component of smart spaces, enabling efficient and accurate data storage and retrieval, personalization of user settings, and the development of more accurate and efficient decision-making processes. While there are some challenges associated with the use of memory devices, the benefits of their use in smart spaces far outweigh the challenges.

3.2.5. Stability Index

Smart spaces rely on the interaction of sensors, devices, and networks, necessitating the monitoring of stability and performance. A stability index is a metric used to measure the stability and robustness of these systems. It evaluates various systems and devices in smart spaces, including HVAC, lighting, and security systems, based on such parameters as temperature, humidity, and air quality (Dong et al., 2019; Habibi, 2016) [55,56].

Predictive maintenance is a key application of the stability index in smart spaces. By using the stability index as an input for predictive maintenance algorithms, potential issues can be identified and addressed proactively, reducing downtime and extending the lifespan of systems and devices (Zonta et al., 2022) [57].

Another important application is optimizing energy consumption. Monitoring the stability index allows smart spaces to identify areas where energy consumption can be reduced without compromising stability. For example, adjusting temperature and humidity settings in HVAC systems based on the stability index helps conserve energy while maintaining user comfort (So et al., 2001) [58].

The impact of the stability index on smart spaces is significant. It enables more efficient predictive maintenance, reducing downtime and prolonging system lifespan. Optimization of energy consumption based on the stability index leads to cost savings and environmental benefits. Additionally, ensuring stability enhances user satisfaction and comfort.

Challenges exist in the use of the stability index. Data accuracy is essential for reliable calculations, and tailoring the index to specific smart spaces is crucial to account for variations in parameters. The stability index is a vital metric for evaluating the stability and robustness of smart spaces. Its applications include predictive maintenance and energy optimization, leading to reduced downtime, prolonged system lifespan, cost savings, and enhanced user satisfaction. Addressing challenges associated with accuracy and customization is key to leveraging the full potential of the stability index in smart spaces.

3.2.6. ZnO NPs

Zinc oxide nanoparticles (ZnO NPs) have gained significant attention in recent years for their potential use in various smart space applications. ZnO NPs are a type of semiconductor material with unique optical and electrical properties that make them suitable for use in smart sensors, displays, and energy harvesting systems. This article explores the use and impact of ZnO NPs in smart spaces.

One of the most significant advantages of ZnO NPs in smart spaces is their high sensitivity and selectivity in detecting various gases and environmental factors. ZnO NPs can be used as gas sensors for detecting harmful gases, such as carbon monoxide, nitrogen dioxide, and methane, which can pose a significant risk to human health in smart spaces. Additionally, ZnO NPs can be used as humidity and temperature sensors for maintaining optimal environmental conditions in smart spaces.

Several studies have demonstrated the effectiveness of ZnO NPs in gas-sensing applications. For example, Pineda-Reyes et al. (2021) [59] and Tonezzer and Lacerda (2012) [60] showed that ZnO NP-based gas sensors could be used for detecting carbon monoxide in smart homes. The sensor showed high sensitivity and selectivity towards carbon monoxide, with a response time of less than 5 s. Similarly, Kim et al. (2018) [61] developed a ZnO NP-based gas sensor for detecting nitrogen dioxide in smart office spaces. The sensor exhibited high sensitivity and selectivity towards nitrogen dioxide, with a response time of less than 10 s.

ZnO NPs also have potential applications in smart displays and lighting systems. ZnO NPs can be used as transparent conductive electrodes in smart displays and lighting systems, providing a high level of transparency and conductivity. Additionally, ZnO NPs can be used in light-emitting diodes (LEDs) and ultraviolet (UV) detectors for various smart space applications.

Several studies have investigated using ZnO NPs in smart displays and lighting systems. For example, Li et al. (2019) [39] developed a transparent conductive film using ZnO NPs for smart windows. The film exhibited high transparency and conductivity, making it suitable for use in smart windows that can regulate the amount of light and heat entering a smart space.

However, using ZnO NPs in smart spaces raises concerns about their potential toxicity and environmental impact. ZnO NPs can be released into the environment through various routes, including wastewater and air emissions, which can pose a risk to human health and the environment. Therefore, it is crucial to develop comprehensive risk assessment and management strategies for using ZnO NPs in smart spaces.

Using ZnO NPs in smart spaces has significant implications for various applications, including gas sensing, displays, and lighting systems. ZnO NPs exhibit high sensitivity and selectivity towards various gases and environmental factors, making them suitable for use in smart sensors. However, the potential toxicity and environmental impact of ZnO NPs also need to be carefully considered and managed to ensure their safe use in smart spaces.

3.2.7. Lu_2O_3 Thin Film

Lutetium oxide (Lu_2O_3) thin films have gained significant attention in the field of smart spaces due to their unique optical, electronic, and mechanical properties (Kaminaga et al., 2018) [62]. These properties make them suitable for various applications, such as sensors, actuators, and transparent conductive coatings in smart spaces.

One of the significant applications of Lu_2O_3 thin films is in gas sensors. The sensitivity and selectivity of gas sensors depend on the material used for the sensing element. Lu_2O_3 thin films have been reported to exhibit high sensitivity and selectivity towards different gases, such as NO_2, CO, and H_2. For instance, the sensor exhibited high sensitivity and selectivity towards NO_2 gas at room temperature, making it suitable for practical applications in smart spaces.

In addition to gas sensing, Lu_2O_3 thin films have also shown promising results in electronic and optoelectronic applications. Lu_2O_3 thin films exhibit high dielectric constant and low leakage current, making them suitable for being used as gate dielectric materials in field-effect transistors (FETs). Zhang et al. (2021) [27] developed a Lu_2O_3 thin film-based FET with high performance and stability, making it suitable for use in smart spaces.

Moreover, Lu_2O_3 thin films have also been used as a transparent conductive oxide (TCO) material in smart spaces. TCOs are essential for producing various optoelectronic devices, such as touchscreens, displays, and solar cells. Lu_2O_3 thin films have been reported to exhibit high transparency, low resistivity, and high stability, making them a suitable candidate for TCO materials. For instance, Choi et al. (2016) [63] developed a transparent conductive Lu_2O_3 thin film-based electrode for use in touchscreens. The electrode exhibited high transmittance and low sheet resistance, making it a promising candidate for practical applications in smart spaces.

However, the practical applications of Lu_2O_3 thin films in smart spaces are limited by their high production cost and low yield. Moreover, the stability of Lu_2O_3 thin films is affected by various environmental factors such as temperature, humidity, and radiation, which may limit their practical applications.

The use and impact of Lu_2O_3 thin films in smart spaces have significant potential for various applications, such as gas sensing, electronic and optoelectronic devices, and TCO materials. Lu_2O_3 thin films exhibit unique optical, electronic, and mechanical properties that make them suitable for various smart space applications. However, their high production cost, low yield, and stability issues need to be carefully addressed to ensure their practical application in smart spaces.

3.2.8. Energy Harvester

Energy harvesting is a process that involves converting energy from the environment into electrical energy that can be used to power electronic devices. Energy harvesters have gained significant attention in the field of smart spaces due to their ability to provide power to low-power electronic devices without the need for external power sources. Energy harvesters have a significant impact on smart spaces, as they can provide a reliable and sustainable source of power for various smart space applications.

One of the significant applications of energy harvesters in smart spaces is in the field of wireless sensor networks (WSNs). WSNs are used in smart spaces for various applications, such as environmental monitoring, security, and healthcare. Energy harvesters can be used to power WSN nodes, eliminating the need for battery replacements and reducing the maintenance cost of smart spaces. Zhang et al. (2019) [20] developed an energy harvester that can convert mechanical energy into electrical energy, which can be used to power WSN nodes. The energy harvester exhibited high power density and efficiency, making it suitable for practical applications in smart spaces.

Moreover, energy harvesters can be used to power wearable devices in smart spaces. Wearable devices, such as smartwatches, fitness trackers, and health monitoring devices, require a reliable and sustainable source of power. Energy harvesters can provide a sustainable source of power to these devices, eliminating the need for frequent battery replacements. For instance, Ma et al. (2019) [64] developed an energy harvester that can be integrated into a wristband to power a smartwatch. The energy harvester was able to generate enough power to operate the smartwatch, making it a promising candidate for practical applications in smart spaces.

Furthermore, energy harvesters can be used to power smart home devices, such as smart thermostats, smart locks, and smart lights. These devices require a constant source of power and energy harvesters that can provide a reliable and sustainable source of power, eliminating the need for external power sources. Xu et al. (2021) [65] established an energy harvester that can convert thermal energy into electrical energy, which can be used to power smart home devices. The energy harvester exhibited high power density and efficiency, making it suitable for practical applications in smart spaces.

However, the practical applications of energy harvesters in smart spaces are limited by their low power output and efficiency. Moreover, the stability of energy harvesters is affected by various environmental factors, such as temperature, humidity, and vibration, which may limit their practical applications.

The use and impact of energy harvesters in smart spaces have significant potential for various applications, such as WSNs, wearable devices, and smart home devices. Energy harvesters can provide a reliable and sustainable source of power for these devices, eliminating the need for external power sources and reducing the maintenance cost of smart spaces. However, their low power output and efficiency, as well as stability issues, need to be carefully addressed to ensure their practical application in smart spaces.

3.2.9. Off-Current Ratio

The off-current ratio (OCR) is a critical parameter in modern semiconductor technology, which measures the magnitude of leakage current. It is defined as the ratio of the off-current to the on-current, and it impacts device energy efficiency, reliability, stability, and design in smart space devices (Mistry et al., 2019) [66]. In low-power modes, devices should consume minimal power to conserve energy.

However, leakage current can result in significant power consumption, reducing device standby time and overall battery life. Devices with low OCR values are preferable in smart spaces as they exhibit reduced leakage current and improved energy efficiency (Kumar et al., 2018) [67]. High OCR values can cause voltage drops and affect device performance, leading to erroneous readings or system failures. Therefore, smart space devices must have a low OCR value to ensure high reliability and stability (Koo et al., 2017) [68]. Research studies have proposed various techniques to reduce the OCR, such as using SAM layers or back gates in FETs, which have shown promising results in reducing leakage current and improving device performance (Mistry et al., 2019; Kim et al., 2018) [40,57].

3.2.10. Resistive Switching Device

Resistive switching devices (RSDs) have emerged as potential building blocks for smart space applications due to their non-volatile and low-power operation, fast switching speed, and compatibility with CMOS technology [39]. Metal-oxide RSDs (MORSDs) are a popular type of RSD, with resistive switching attributed to the formation and rupture of conductive filaments (CFs) in the oxide layer [38]. MORSDs are suitable for in-memory computing, neuromorphic computing, and energy-harvesting applications in smart spaces. In-memory computing reduces data transfer, improving speed and power efficiency, while synaptic plasticity in RSDs makes them suitable for pattern recognition and classification in neuromorphic computing (Wu et al., 2020) [69]. The resistive switching behavior of RSDs can also be used to control energy flow, improving the efficiency and reliability of energy harvesting systems (Yu et al., 2021; Yu et al., 2021) [70,71]. As the field of RSDs continues to develop, they are expected to play a crucial role in next-generation smart systems.

3.2.11. Heterostructure

Heterostructures are arrangements of materials in layers of different compositions commonly used in smart spaces to design electronic devices due to their unique electrical and optical properties. The use of heterostructures has led to significant advancements in the field of smart spaces. Heterostructures can be designed in various ways, such as the type of materials used, the thickness of the layers, and the order of the layers. For example, a common heterostructure is a semiconductor–oxide-semiconductor (SOS) structure, where a thin oxide layer is sandwiched between two semiconductor layers. The oxide layer controls the electrical properties of the semiconductor layers, making it an essential component in electronic device design (Nurunnabi et al., 2019) [72].

The development of heterostructures has led to the creation of high-performance electronic devices, such as transistors and LEDs, with improved electrical properties. For instance, heterostructures have been used to design field-effect transistors with high electron mobility, low noise, and high stability, making them ideal for use in smart spaces (Liu et al., 2021) [47]. Additionally, heterostructures have been used to design LEDs with high brightness and efficiency, making them useful in lighting applications in smart spaces (Björk et al., 2019) [9].

Moreover, heterostructures made from two-dimensional materials have been shown to exhibit unique electronic and optical properties, such as tuneable bandgap and valley polarization. These properties have potential applications in the development of novel electronic devices, such as spin valves and quantum computing devices (Liu et al., 2019) [54]. Heterostructures have also been used to design photodetectors with high sensitivity and fast response times, making them useful for optical communication and imaging applications (Wu et al., 2020) [69].

However, the fabrication of high-quality heterostructures with precise layer thickness and composition remains a challenge. This is particularly challenging when using two-dimensional materials, where slight variations in layer thickness can significantly affect the electronic and optical properties of the heterostructure. Another challenge in heterostructure design is the integration of different materials with different lattice constants, which can lead to defects and strain in the heterostructure, affecting its electrical and optical properties (Nurunnabi et al., 2019) [72].

Overall, the use of heterostructures in smart spaces has led to significant advancements in the design of electronic devices with improved electrical and optical properties. The development of heterostructures has also led to the creation of novel optical and electronic properties that have potential applications in quantum computing and other advanced electronic devices. Future research in heterostructure design is necessary to overcome the challenges in their fabrication and fully realize their potential in smart spaces.

3.2.12. Positive Formation Polarity

Positive Formation Polarity (PFP) is a phenomenon observed in some oxide-based resistive-switching memory devices where the high resistance state is formed by applying a positive voltage. PFP has been an area of interest in the field of smart spaces due to its significant impact on the performance and reliability of resistive switching memory devices. Studies have shown that PFP devices exhibit better endurance and retention properties compared to devices with Negative Formation Polarity (NFP), as PFP devices experience less oxygen vacancy accumulation at the metal/oxide interface, which reduces the likelihood of forming conducting filaments that can cause device degradation over time. Additionally, PFP devices require lower power for switching and exhibit better uniformity in their resistance-switching characteristics, forming a uniform conductive filament throughout the oxide layer. PFP devices also tend to form oxygen vacancies and oxygen ion vacancies as conductive filaments, which can affect the device's switching speed and reliability. These findings highlight the importance of considering PFP as a key factor in the design and optimization of resistive-switching memory devices for smart space applications (Huang, Xie, Zhang and Lv, 2019; Kim, Kim, Choi, Choi and Kim, 2017; Choi, Kim, Kim, Choi, and Kim, 2016; Zhu, Li, Xu, Zou, Zhang and Zhang, 2019) [63,73–75].

4. Summary of Findings

The findings below highlight the significance of thin films, wireless networks, oxygen vacancies, memory devices, stability index, and ZnO NPs in the development and functioning of smart spaces. These concepts and applications contribute to improved functionality, efficiency, and user experience in smart spaces, while also presenting challenges and considerations for further research and development.

Thin films: Thin films are versatile coatings used in smart spaces, such as smart windows and sensors. They can enhance functionality, efficiency, and user experience. The concept of thin films is linked to such techniques as chemical vapor deposition and their ability to create unique properties.

Wireless networks: Wireless networks play a crucial role in smart spaces, enabling communication between devices. They impact functionality, efficiency, and user experience. The concept of wireless networks is linked to such applications as smart homes, healthcare, and smart cities, as well as concerns about data security.

Oxygen vacancies: Oxygen vacancies in materials have emerged as valuable for smart spaces. They are used in sensors, smart windows, and energy storage. Oxygen vacancies can impact functionality and energy efficiency. The concept is linked to such applications as oxygen-sensitive sensors and challenges related to controlling their concentration and stability.

Memory devices: Memory devices are essential for storing and retrieving data in smart spaces. They are used in AI, sensor data storage, and user preferences. Memory devices enhance efficiency, personalization, and decision-making. The concept is linked to such applications as AI algorithms and challenges related to data security and longevity.

Stability index: The stability index is a metric used to measure the stability of systems in smart spaces. It is applied in predictive maintenance and energy optimization. The stability index improves efficiency, performance, and user satisfaction. The concept is linked to such applications as predictive maintenance algorithms and challenges related to accuracy and customization.

ZnO NPs: Zinc oxide nanoparticles (ZnO NPs) have various applications in smart spaces, including gas sensing, displays, and lighting systems. They offer high sensitivity and selectivity in detecting gases and provide transparency and conductivity in displays. The concept is linked to gas sensors, smart displays, and studies on their effectiveness.

The findings discussed above can be linked to several theories and concepts. For example, the concept of energy efficiency is supported by the application of thin films in smart windows, which regulate light transmission and contribute to climate control. The concept of automation and intelligent decision-making within smart spaces is linked to the use of thin film sensors for detecting environmental parameters. The theory of connectivity and seamless communication is supported by the role of wireless networks in enabling real-time data exchange and personalized user experiences. The concept of privacy and data security is highlighted in the need to address concerns associated with wireless networks and memory devices. The theory of reactivity and sensing is relevant to the use of oxygen vacancies in oxygen-sensitive sensors for gas detection. The concept of stability and optimization is linked to the importance of stability indices and reliable memory devices in smart spaces. Overall, these findings demonstrate the practical application of various theories and concepts in enhancing the capabilities of smart spaces.

5. Discussion

The integration of thin films, wireless networks, and oxygen vacancies in smart spaces has revolutionized their functionality, efficiency, and user experience. These technological advancements have initiated a wide range of applications and benefits, making smart spaces more convenient, energy-efficient, and personalized.

Thin films have proved to be versatile and valuable in various aspects of smart spaces (Chung et al., 2011) [76], from smart windows that regulate light transmission for energy efficiency and climate control to thin-film sensors that enable automation and intelligent decision-making. Thin films inadvertently enhance the capabilities of these spaces significantly by creating diverse applications that highlight what is imperative for a more advanced and efficient environment.

Wireless networks play a crucial role in enabling seamless communication and data exchange among devices within smart spaces (Qiao et al., 2015; Noura et al., 2019) [77,78]. This real-time data exchange enhances decision-making, promotes energy optimization, and enables personalized user experiences. However, it is crucial to address data security concerns associated with wireless networks to protect sensitive information and maintain privacy.

Oxygen vacancies have emerged as valuable components in creating oxygen-sensitive sensors, energy storage materials, and smart windows. Their reactivity allows for the detection and measurement of gas concentrations, making them ideal for environmental monitoring and safety. Additionally, they enhance the performance and efficiency of energy storage materials (Silva et al., 2020) [79]. Ongoing research is necessary to optimize oxygen vacancy quantity and distribution and ensure the longevity of memory devices.

To fully unlock the potential of smart spaces, ongoing research and development efforts are imperative. Overcoming challenges related to data security, stability, and optimization will contribute to creating user-friendly, efficient, and sustainable environments. The continuous advancements in these areas will lead to improved outcomes in healthcare, environmental monitoring, and various other applications of smart spaces.

6. Theoretical Implication

This research contributes to the theoretical understanding of smart spaces by discussing their implications in various academic disciplines and industries, such as human–computer interaction, data analytics, privacy and security, and urban planning. It highlights the interdisciplinary nature of smart spaces research and the need for new models and frameworks to understand the complex relationships between technology, space, and society.

Theoretical repercussions of intelligent spaces include:

- Human–computer interaction: Smart spaces provide a new platform for human–computer interaction. New opportunities for user experience and interaction design are created by the integration of physical spaces with technology;
- Smart spaces generate massive amounts of data that necessitate sophisticated analysis and processing techniques. This can lead to the development of new tools and techniques for data analytics;
- Privacy and security concerns are raised by the integration of technology into physical spaces. The need for new privacy and security measures to protect personal data is one of the theoretical implications of smart spaces;
- Smart spaces can be utilized to optimize urban infrastructure and public services, which has implications for urban planning and design.

In general, the theoretical implications of smart spaces are extensive and have the potential to influence a variety of academic disciplines and industries in applying various technologies in smart space research, such as IoT devices, sensors, big data, and artificial intelligence. It addresses the technical challenges related to interoperability, data security, and user acceptance, highlighting the need for ongoing research and development efforts in these areas.

7. Conclusions

The scope of this research is to provide a comprehensive overview of the concept of smart spaces, including their key features, technologies, and applications in built environments and urban areas. This research aims to explore the potential benefits and challenges associated with smart spaces, as well as their theoretical implications and practical implications in various fields. This study adopts a qualitative approach and draws on secondary sources, such as academic journals, reports, and online sources, to gather relevant information.

This research covers the following areas:

Definition and Characteristics of Smart Spaces: This research aims to define smart spaces and highlight their key features, including their ability to respond intelligently to user needs and preferences. It explores the concept of context-awareness and the use of sensors and devices to create adaptive environments;

Technologies and Applications of Smart Spaces: This research discusses the various technologies used in smart spaces, including IoT devices, sensors, big data, and artificial intelligence. It explores the applications of smart spaces in such domains as healthcare, education, entertainment, transportation, and urban planning;

Challenges and Opportunities: This research identifies the challenges faced in implementing smart spaces, including privacy and security concerns, interoperability issues, user acceptance, and technical and social challenges. It also explores the opportunities and potential benefits of smart spaces, such as improved efficiency, safety, and quality of life;

Theoretical Implications: This research discusses the theoretical implications of smart spaces, particularly in relation to human–computer interaction, data analytics, privacy, security, and urban planning. It highlights the interdisciplinary nature of smart space research and its potential impact on various academic disciplines and industries;

Smart Space Management: This research explores the concept of smart space management, which involves the use of advanced technologies, such as IoT, big data, and AI, to optimize the functionality of smart spaces. It discusses the role of IoT devices, sensors, building automation systems, cloud-based services, and user interfaces in managing smart spaces.

This research provides a roadmap for researchers and practitioners interested in the design, development, and evaluation of smart spaces in urban environments. It highlights the significance and relevance of smart spaces in the future of urban areas. Additionally, this study identifies the need for further research and development in such areas as materials science, data security, interoperability, and user acceptance, to ensure optimal performance, security, and sustainability in smart spaces.

This is because smart spaces, also known as intelligent or connected spaces, have emerged as a significant trend in recent years, offering exciting possibilities for improving functionality and efficiency in cities.

This article aimed to provide a comprehensive overview of the concept of smart spaces, including their key features, technologies, and applications that fulfilled its mandate. The research thesis exhibited that smart spaces have the potential to create more efficient and sustainable urban environments that benefit both individuals and society.

In summary, this research discussed the definitions and characteristics of smart spaces, key technologies, and applications, including the challenges and opportunities of implementing smart spaces, thus providing an avenue to comprehensively overview the concept of smart spaces, including their definitions, characteristics, and key features. It explores the concept of context awareness and the use of sensors and devices to create adaptive environments. It also discusses the integration of emerging technologies and the conceptualization of smart spaces within the broader context of smart cities, smart technologies, and shared spaces.

In conclusion, the discussion on emerging technologies for smart spaces demonstrates the importance of material science in the development of new technologies. The promising developments in Lu_2O_3 thin films, energy harvesters, ZnO nanostructures, and heterostructures demonstrate the potential for using new materials to enhance the functionality of smart devices. Future research should focus on developing new materials and exploring their potential applications in smart devices. Additionally, research on the stability index, off-current ratio, and positive formation polarity should be further studied to ensure the performance and reliability of smart devices. Overall, the continued development of new materials and technologies will be essential for realizing the full potential of smart spaces. Lastly, research on smart spaces emphasizes their potential benefits, such as improved efficiency, safety, and quality of life. It also identifies the challenges that need to be overcome for successful implementation, such as privacy and security concerns, interoperability issues, and user acceptance. This research provides a roadmap for researchers and practitioners interested in the design, development, and evaluation of smart spaces and emphasizes the need for further research and development in such areas as material science, data security, interoperability, and user acceptance.

8. Future Advancement

Based on the discussion in this study, we can, therefore, point the researchers in the field of smart spaces to several future advancements that will uplift and further enrich the field.

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Appendix A

Table A1. Top 25 Keywords with the Strongest Citation Bursts.

Keywords	Year	Strength	Begin	End	2012–2022
Amendola S, 2014, IEEE INTERNET OF THINGS JOURNAL, V1, P144, DOI 10.1109/jiot.2014.2313981, DOI	2014	**13.3**	2017	2019	
Waser R, 2009, ADVANCED MATERIALS, V21, P2632, DOI 10.1002/adma.200900375, DOI	2009	**11.87**	2012	2014	
Zeng Y, 2016, 2016 15TH ACM/IE . . .. . . SENSOR NETWORKS (IPSN), V0, P1, DOI	2016	**10.3**	2019	2022	
Yang JJ, 2012, NATURE NANOTECHNOLOGY, V8, P13, DOI 10.1038/nnano.2012.240, DOI	2012	**10.08**	2014	2017	
Pan F, 2014, MATERIALS SCIENCE AND ENGINEERING R REPORTS, V83, P1, DOI 10.1016/j.mser.2014.06.002, DOI	2014	**10**	2016	2017	
Yang JJ, 2008, NATURE NANOTECHNOLOGY, V3, P429, DOI 10.1038/nnano.2008.160, DOI	2008	**8.56**	2012	2013	
Sawa A, 2008, MATERIALS TODAY, V11, P28, DOI 10.1016/s1369-7021(08)70119-6, DOI	2008	**8.56**	2012	2013	
Lee M, 2011, NATURE MATERIALS, V10, P625, DOI 10.1038/nmat3070, DOI	2011	**8.07**	2013	2016	
Wang W, 2016, PROCEEDINGS OF T . . .. . . UBIQUITOUS COMPUTING, V0, P363, DOI	2016	**7.4**	2020	2022	
Yang YC, 2009, NANO LETTERS, V9, P1636, DOI 10.1021/nl900006g, DOI	2009	**7.08**	2012	2014	
Strukov DB, 2008, NATURE, V453, P80, DOI 10.1038/nature06932, DOI	2008	**6.27**	2012	2013	
Kwon D, 2010, NATURE NANOTECHNOLOGY, V5, P148, DOI 10.1038/nnano.2009.456, DOI	2010	**6.25**	2012	2015	
Wong HSP, 2012, PROCEEDINGS OF THE IEEE, V100, P1951, DOI 10.1109/jproc.2012.2190369, DOI	2012	**5.72**	2014	2017	
Wang H, 2013, ADVANCED MATERIALS, V25, P5498, DOI 10.1002/adma.201301983, DOI	2013	**5.56**	2016	2018	
Gubbi J, 2013, FUTURE GENERATION COMPUTER SYSTEMS, V29, P1645, DOI 10.1016/j.future.2013.01.010, DOI	2013	**5.41**	2017	2018	
Costanzo A, 2016, IEEE MICROWAVE MAGAZINE, V17, P30, DOI 10.1109/mmm.2016.2525119, DOI	2016	**5.34**	2017	2019	

Table A1. *Cont.*

Keywords	Year	Strength	Begin	End	2012–2022
Lim EW, 2015, ELECTRONICS, V4, P586, DOI 10.3390/electronics4030586, DOI	2015	**5.26**	2019	2020	
Sun B, 2015, PHYSICAL CHEMISTRY CHEMICAL PHYSICS, V17, P6718, DOI 10.1039/c4cp04901b, DOI	2015	**5.01**	2015	2017	
Huang C, 2019, IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, V18, P4157, DOI 10.1109/twc.2019.2922609, DOI	2019	**4.96**	2020	2022	
Renzo MD, 2019, EURASIP JOURNA . . .. . . NS AND NETWORKING, V2019, P129, DOI	2019	**4.96**	2020	2022	
Welkie A, 2017, PROCEEDINGS OF . . .. . . OT TOPICS IN NETWORKS, V0, P36, DOI	2017	**4.66**	2019	2022	
Zanella A, 2014, IEEE INTERNET OF THINGS JOURNAL, V1, P22, DOI 10.1109/jiot.2014.2306328, DOI	2014	**4.63**	2016	2019	
Jeong DS, 2012, REPORTS ON PROGRESS IN PHYSICS, V75, P076502, DOI 10.1088/0034-4885/75/7/076502, DOI	2012	**4.55**	2015	2017	
Sun B, 2015, JOURNAL OF MATERIALS CHEMISTRY C, V3, P12149, DOI 10.1039/c5tc02732b, DOI	2015	**4.36**	2017	2018	
He X, 2016, ACS APPLIED MATERIALS AND INTERFACES, V8, P10954, DOI 10.1021/acsami.5b10414, DOI	2016	**4.22**	2017	2018	

Appendix A demonstrates the nature of strength conferred on this article by the Citespace software. For instance, the paper of Amendola S, 2014, published in IEEE Internet Of Things, the red lines shows gives an average of the impact or the period when the publication received significant citation between 2012–2021, as between 2017–2019.

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