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The evolution of the integration of hybrid technologies to improve intelligent interior design systems: a comprehensive review

Zakia Ali Elshaafi
Higher Institute of Science and Technology Benghazi
zakiaali1977z@gmali.com

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Abstract ;

The last decade has witnessed remarkable development in the field of smart technologies and global communication systems, paving the way for innovative smart interior design strategies. This comprehensive review aims to explore the evolution of the integration of hybrid technologies into smart interior design systems, focusing on their role in improving functionality, sustainability and user experience. This paper relies on qualitative review methodology using a meta-synthesis approach to analyze and interpret data from the selected studies. The research reviews the theoretical foundations of smart design, the development of the concept of smart buildings over the past decades, and the basic systems of smart design including building automation systems, the Internet of Things, and artificial intelligence. The research also addresses the impact of smart materials and smart furniture in finding innovative design solutions, strategies for managing resource consumption, and sustainable design applications. The review found that incorporating hybrid technologies into interior design significantly contributes to enhancing energy efficiency, improving indoor environmental quality, and providing personalized user experiences, while reducing the carbon footprint of buildings. She also stressed the importance of using Building Information Modeling (BIM) programs as a pivotal tool in anticipating construction requirements and reducing waste. The results indicate that smart interior design is not just a passing trend, but rather a paradigm shift in the way we design and interact with built environments, which calls for designers and researchers to continue studying and analyzing the implementation of these technologies.

Keywords: Interior design, hybrid technologies, artificial intelligence, Internet of Things, smart materials, sustainability, building automation systems, home care systems, elderly, reinforcement learning, CAD.

1. Introduction

Recent decades have witnessed a tremendous boom in technology and global communication, creating profound transformations in various fields of research, including the field of construction and interior design [1]. These developments have contributed to the growth of computer-integrated systems and control

solutions, opening broad horizons for smart building technologies, which are a crucial step towards achieving smart cities [2]. Smart technologies and their innovations are among the most important results of the industrial revolution, as their applications have expanded in many fields, including medicine, industry, agriculture, economics, engineering, arts, education, and various other areas of life [79].

With the increasingly aging population in contemporary societies, home care systems and smart interior design methods are receiving increasing attention. Smart interior design, IoT applications and big data aim to provide a more comfortable and safer living environment for the elderly by integrating smart technology as a new design concept [68]. A clear example is what Chinese society faces, as the problem of population aging has become more serious, and the issue of retirement has emerged as a prominent living problem. To address this problem, the Chinese government put forward an implementation plan to actively deal with population aging in the 14th Five-Year Plan, aiming to meet the needs of the elderly by improving the home care model [68].

Hybrid technologies in smart interior design represent a paradigm shift that combines advanced digital systems, smart materials and innovative furniture, creating interior environments capable of adapting and responding to users' needs in real time. This integration between different technologies is a natural development in the context of the digital transformation that the building and construction sector is witnessing [3]. With rapid technological developments, smart technologies have become increasingly present in residential environments and within the reach of users, as human needs can often be met with the touch of a button, and in the future smart technologies may anticipate needs and meet them automatically through smart home systems and sensors [79].

In this context, the role of computer-aided design (CAD) techniques and reinforcement learning algorithms emerges as pivotal elements in the development of smart interior design systems. Recent research has proven that integrating reinforcement learning algorithms with CAD systems can significantly improve human-computer interaction functions in the interior design process [Pan & Wang, 2026]. Reinforcement learning algorithms, through intelligent agent strategies, make it possible to plan state transition functions based on the state of the interaction object, and direct automated devices to perform state transitions, enhancing the interactive experience of users in indoor spaces [Pan & Wang, 2026].

The importance of this hybrid integration is its ability to achieve a balance between aesthetic and functional requirements, while enhancing operational efficiency and environmental sustainability. By integrating building management systems, the Internet of Things, and artificial intelligence, designers can create interior spaces that are not only visually attractive, but also adaptable and resource efficient [4]. Smart technologies have become increasingly prominent in the field of interior design, as they are closely linked to modern technologies that save time and effort [79].

In the context of home care for older adults, age-friendly transfer is an essential component of the home care model. Aging-friendly transformation refers to making necessary transformations in the living environment of the elderly, 以适应 their physical and psychological characteristics, and ensuring their safety and comfort. This conversion should be based on safety with comfort as a priority, with the aim of improving the quality of life of the elderly, ensuring the safety of the living environment, improving comfort, and meeting personal needs, taking into account long-term use and sustainability [68].

The primary goal of smart interior design is to create a healthy, safe and comfortable indoor environment. Advanced smart systems contribute to air quality management, monitoring humidity levels, pollutants, and toxic gas emissions, significantly reducing harmful particles using effective natural and mechanical ventilation strategies [5]. When applying smart technologies in interior environments, the main goal of design becomes to create a lively interaction between humans and smart technologies, as function and beauty in interior design acquire new meanings commensurate with the size and development of these technologies [79].

It is worth noting here that the interior design profession, as defined by the National Council for Interior Design Qualifications (NCIDQ), is a multi-faceted profession that requires creative and technical solutions to achieve interior built environments, and these solutions include functionality, enhancing the quality of life and culture of residents, and aesthetics [67]. Interior design includes a range of services to protect and enhance the health, safety and well-being of the public. In the United States, people spend approximately 90% of their time indoors, highlighting the critical importance of quality interior design [67].

This comprehensive review addresses the development of the integration of hybrid technologies into smart interior design systems, and reviews the theoretical and conceptual foundations, the systems and technologies used, their applications in achieving sustainability, their impact on the user experience, and future challenges and opportunities.

2. Research methodology

A comprehensive literature review was conducted to explore: (1) developments and implications of smart technologies in interior design, (2) theoretical principles that support smart design, and (3) applications and benefits of integrating smart solutions into interior spaces. Relevant literature, including scientific articles and books, was collected from multiple databases [6].

This study followed a qualitative research methodology using a meta-synthesis approach to provide in-depth analysis and interpretation of data across the selected studies. The meta-synthesis process included the following steps:

· Defining the research question and objectives

· Systematic search in scientific databases

· Evaluating the quality of selected studies

· Data extraction and analysis

· Synthesize and interpret results

To ensure reliability, this process was repeated using multiple sources, which led to confirmation of the results obtained. More than 80 scientific studies published between 2004-2026 were analysed, providing a comprehensive view of the development of the field. The findings from theoretical and applied studies were combined with practical experiences from interior design studios, especially those focused on healthcare applications and smart technologies [67].

3. The theoretical background of smart technologies in interior design

3.1 The development of the concept of smart buildings

Since the early 1980s, attempts have been made by several organizations to formulate a definition of “smart” buildings, resulting in a variety of definitions that vary in their degree of detail and focus on different building components [7]. The concept of smart buildings was first proposed in 1981 by United Technology Building Systems (UTBS), and was realized on the ground in 1983 with the unveiling of the CityPlace building in Hartford, Connecticut, USA [8]. The researcher believes that the term “smart buildings” appeared around 1980, referring to buildings in which energy, temperature, lighting, sound, and communications systems are linked to each other [79].

The original Smart Building Institute defined a smart building as a structure that promotes a productive and cost-effective environment by optimizing four basic elements: structure, systems, services, and management, as well as the interaction between them, to meet the needs of residents with an emphasis on technological solutions [9].

Subsequently, the European Intelligent Buildings Group (EIBG) proposed a revised definition, emphasizing that a smart building is based on a design environment that enhances building efficiency while facilitating effective resource management, leading to reduced life cycle costs of facilities. This definition shifts the focus towards the needs of the population served by technology [10].

At the turn of the twenty-first century, experts recognized the necessity of new tools to achieve the same goals that motivated the development of green buildings. This technological development led to the recognition of new technologies as potential allies for the creation of the first smart buildings, which were known as smart sustainable buildings due to their primary purpose: reducing the environmental impact of buildings [2]. Smart buildings can be classified according to their stages of development into three main types: automated buildings (1980-1985), which witnessed the introduction of various communications technologies to control building systems, responsive buildings (1986-1991), which were designed to adapt to the changing needs of users, and efficient buildings (since 1992), which focus on the needs ofUsers and technology is used as an aid in design and construction rather than as the primary element [79].

After 2010, the buildings sector's focus shifted towards the end user and their needs. Hence, smart buildings constructed in recent years have been called “people-oriented”. During this phase, technology played a pivotal role, evolving and diversifying to meet different types of buildings, including offices, hospitals, museums, universities, shopping malls, airports and residential buildings. These structures are equipped with different intelligent systems to meet the diverse needs of their users [11].

In the context of interior design, smart technologies can be classified into multiple categories including smart homes, buildings and structures, smart materials, appliances, environmental technologies, energy technologies, and pervasive and ubiquitous computing [67]. Health design interventions expand this list to include smart health products, tools and areas of study such as universal healthcare (Ubi-Care, UHealth) and telehealth [67].

In terms of home care systems, the emergency response system represents an important security measure for home care, aiming to provide rapid and effective

rescue services for the elderly. The system integrates emergency call buttons, temperature difference detectors, smoke alarms, and other equipment to ensure that older adults can quickly get help in emergency situations [68].

3.2 Definition of smart interior design

Rushdan (2016) concluded with a definition that smart interior design can be considered a multi-dimensional profession, where innovative and technical solutions must be combined with smart materials, furniture, appliances and sensors. In addition, all functions must be coordinated and communicate with each other via an IP network and mobile app, supported by a robust analysis system. This system must be able to quickly respond to residents' requests and determine the most efficient way to provide a comfortable, safe, and productive environment to raise residents' quality of life [12].

Kellicott, Beattie, and Ghatikar (2011) assert that smart buildings are self-aware and network-aware, interacting with the smart grid with an emphasis on real-time demand response and increased precision of controls. The theme of responsiveness, adaptability and flexibility recurs in more descriptions of smart buildings, and is a key area in which smart buildings can differentiate themselves from previous generations [13].

Wang et al (2012) agreed that smart buildings are an integral part of the next generation of the construction industry. They suggested that such buildings address issues of intelligence and sustainability together by using computer and intelligent technologies to achieve optimal combinations of comfort and energy consumption [14].

The most recent definition, formulated in the wake of the emergence of IoT technologies, emphasizes that intelligent design is based on IP networks, online platforms, and databases that collect and analyze all building services data without human intervention [15].

In the context of practical applications, interior design studios, such as the Topics studio at the University of Texas at San Antonio, have demonstrated how students can apply extensive research into healthy design strategies and smart technologies to design projects. These projects focused on Alzheimer's disease, aging in place, and comprehensive health care, demonstrating a deep understanding of the different application levels of technology in building systems [67].

3.3 Effectiveness of smart interior design

The effectiveness of smart interiors can be evaluated based on four basic characteristics [16]:

Integration: Successful integration of smart interior design solutions with numerous design components can lead to improved performance, simplified operation, and reduced utility consumption throughout the life of the design [17]. Seamlessly integrating technology into design elements enhances not only the aesthetic appeal but also the functionality of the space, making it more responsive to users' needs.

Communication: includes a wide range of interactions, including interactions between people, people and machines, and machines and machines, both in the internal environment and with the outside world. This connectivity connects buildings in a cloud network, forming an indispensable element in smart cities [18]. Connectivity lies at the heart of intelligent design, enabling effective and efficient management of building systems and creating a more interactive and engaging environment for residents.

Adaptability: The ability of a design to easily adapt to changes in space and to be flexible enough to accommodate new technology requirements [19]. This adaptability is a key feature of intelligent design, enabling it to evolve with changing needs and technologies, thus ensuring its continued relevance and effectiveness.

Control: Controlling building systems enables optimization of energy use while providing real-time and historical insights into occupant behavior patterns. The incorporation of smart materials and furniture, along with smart lighting and acoustics solutions, allows residents to adapt to the interior design theme more easily, thus enhancing their comfort and satisfaction [5].

In the context of elderly care, intelligent lighting systems have proven to be of outstanding importance in elderly care facilities. These systems provide unprecedented lighting solutions using advanced sensor technologies, efficient network communications, and precise intelligent algorithms, to achieve a highly efficient and comfortable lighting experience. The system can not only perceive the current time, but also accurately determine the intensity of indoor lighting, and even take into account real-time changes in indoor activities. Based on these accurate perceptions, the system can automatically adjust the brightness, color temperature and uniformity of lighting, ensuring that the lighting environment in elderly care facilities always remains in the most appropriate state [68].

4. Smart interior design systems and technologies

4.1 Building Automation Systems (BAS)

A building automation system (BAS) represents the core layer of a smart building. It is a technology that helps users manage the electrical aspects of a structure,

converting static resources into active assets that can support their occupants. BAS functions vary from automation and energy management to security, safety and assisted living [20]. Operating systems in smart buildings operate through a central computer (server) connected to an integrated network, which works similarly to the human nervous system, where sensors are distributed around the entire perimeter of the building to collect data from the internal environment through pre-configured systems [79].

BAS consists of a wide range of sensors and output devices designed to perform specific tasks and provide a variety of functions. These sensors monitor and regulate various aspects of indoor climate systems, including temperature, relative humidity, pressure, ventilation, and air conditioning. On the other hand, output devices, such as relays, dampers, and valve actuators, translate electronic signals or mechanical actions into control commands. BAS is a crucial part of a smart building because it automates routine tasks and facilitates effective management of the building's indoor environment [21]. Operating systems in the smart residential environment can be divided into two main categories: communications systems and management systems. These systems include digital control systems, digital surveillance cameras, central networks for receiving television broadcasts, fire alarm and suppression systems, remote control systems, and smart lighting systems [79].

In the context of healthy interior design, BAS systems have been used innovatively in projects such as homes for Alzheimer's patients and health clinics. These projects included virtual applications of remote control technologies, automation technologies, monitoring technologies, reminder/alert technologies, and forecasting technologies [67].

4.2 Intelligence of Home (IoH)

"Intelligence of Home" (IoH) refers to the application of smart technologies and artificial intelligence to make homes more connected, efficient and comfortable. This concept is in line with the broader idea of the smart home, where different devices and systems within a home are interconnected, often via the Internet, allowing them to communicate with each other and with residents [22].

In an IoH system, systems such as lighting, heating, security, and entertainment can be automated and controlled remotely using a smartphone or other devices. These systems can also learn from residents' behavior patterns over time to predict and adapt to their needs, enhancing convenience and efficiency. The "intelligence" of a home refers to its ability to adapt, learn, and make decisions based on the data it collects from various sources, leading to improved functionality, safety, and comfort for residents [23].

Studio studies have shown that interior design students have developed a deep understanding of distributed, ambient and holistic interactions. Ambient intelligence has been characterized by a range of paradigms including tactile interaction, augmented reality, mixed reality, and ubiquitous computing that are sensitive, adaptable, and responsive to the presence of people [67].

4.3 Internet of Things (IoT)

The Internet of Things (IoT) system forms the third layer in the smart building architecture. With the advent of IoT technology, designers are increasingly integrating IoT sensors within indoor structures to collect data about movement, heat, light, and space usage [24]. When analyzed, this data turns intelligent design into a dynamic, predictive and personalized system that can adapt the building environment in real time. By customizing the environment to the preferences and needs of its occupants, it enhances comfort and efficiency. Furthermore, comprehensive tracking of usage allows for better management of resource consumption, which contributes to sustainability [25]. It should be noted that the smart environment consists of multiple layers, each of which contains technologies that support data production, classification, and analysis while maintaining the ability to respond optimally. These layers include communications, data centers, analytics, and applications [79].

In studio projects, sensors were among the most common tools used by interior design students. Sensors were everywhere, from shoes to track location, to displays, showers, and even pets. Understanding the types of sensors and small devices/applications was an important step for students in applying pervasive computing to software and spatial design needs. Technology diffusion in space has been mainly implemented through sensors and wireless technologies [67].

4.4 Artificial intelligence (AI) in interior design

The main component of AI is “data”. Rich and diverse training data leads to better AI and machine learning results. IoT devices generate a huge amount of data that carries crucial information about the physical environment. Traditional programming methods fail to recognize patterns and irregularities within this data. Artificial intelligence comes in to analyze patterns and trends and make informed decisions. Cloud computing facilitates the processing of big data, enabling intelligent decision-making through machine learning and big data analysis [26].

Artificial intelligence technologies in interior design offer unique services such as [27]:

1. Personalized Services: Wearable IoT sensors and robots provide personalized assistance to residents, providing automatic lighting, optimal air conditioning, automated assistance, etc., based on their movements and activities.

2. Preventive services: Monitoring systems that detect unsafe or unauthorized actions, raise alarms, and disable devices or devices used incorrectly.

3. Predictive Services: Leveraging AI technology, smart furniture and appliances learn from residents' behaviors to anticipate needs, automate actions and save time.

4. Advisory services: Decision support systems, which are artificial intelligence technology embedded in smart furniture and devices, provide advice and solutions for everyday home situations that require special attention, such as elderly care or child care.

In health design projects, students focused on monitoring techniques in clinic design. Popular tools were self-check-in kiosks, body detection walls, and chairs equipped with sensors to monitor vital signs or calculate BMI [67].

In the context of elderly care, intelligent temperature control systems play a vital role by adjusting indoor environment conditions according to the activity status of the elderly and their body temperature. This means that the system can provide a suitable thermal environment for them no matter what they do [68].

4.5 Reinforcement learning algorithms and their integration with CAD systems

Integrating Reinforcement Learning algorithms with computer-aided design (CAD) systems represents a qualitative leap in the development of smart interior design systems. Reinforcement learning is based on the principle of an intelligent agent interacting with the environment, making decisions and obtaining rewards by learning the optimal strategy [Pan & Wang, 2026]. The reinforcement learning task can be described using Markov Decision Processes, where the transformation of the relationship between actual 3D spatial coordinates and human-computer interaction objects is represented by mathematical equations [Pan & Wang, 2026].

In the context of interior design, reinforcement learning algorithms for intelligent systems make it possible to:

· Intelligent planning of state transition functions: Based on the state of the interaction object, the intelligent agent can guide robotic devices to perform optimal state transitions [Pan & Wang, 2026].

· Improving the quality of feature point capture: Studies have shown that using reinforcement learning algorithms significantly improves the quality of feature point capture in the data collection process for human-computer interaction [Pan & Wang, 2026].

· Accelerating the efficiency of interactive feedback: Improving reinforcement learning algorithms accelerate the efficiency of communication and feedback between the user and intelligent machines within the space [Pan & Wang, 2026].

The mathematical relationship of human-computer interaction can be expressed through the following equations [Pan & Wang, 2026]:

Equation No. (1): The transformation of the relationship between the actual 3D spatial coordinates and human-computer interaction objects is represented by:

$$\left(P_x^w, P_y^w, P_z^w\right) = P^w$$

Equation No. (2):

$$i_0 + P^W C_{IW}^i = p$$

Where w represents the internal spatial coordinates.

Equation No. (3): Positioning for human-computer interaction can be transformed from perspective in the following way:

$$P_x \frac{f}{P_z} = x$$

Equation No. (4):

$$P_y \frac{f}{P_c} = y$$

Equation No. (5): As for the optimal strategy sought by the agent, the reward is given in the form:

$$r\left(s_t, a, s_{k+1}\right) \sum_{K=0}^{i-1} = G$$

Equation No. (6): The expectation factor is usually entered into the training function and rewritten as:

$$G_t = \sum_{}^{i-1} rY^k \mid s,\ a$$

Equation No. (7): In the context of interior design applications, integrating reinforcement learning algorithms with CAD systems has proven effective in improving human-computer interaction functions in interior design software, by adding intelligent navigation and positioning systems that provide users with more services.[Pan & Wang,

4.6 Multi-agent systems based on large language models (LLM)

The emergence of multi-agent systems based on large language models (LLM) represents an important development in the field of intelligent interior design, providing new possibilities for interaction and participation in the design process [Lim & Dai, 2025]. Innovative frameworks have been developed that rely on specialized agents that collaborate to transform textual and image descriptions into 3D designs, enhancing interactive engagement and reducing reliance on large datasets for training [Lim & Dai, 2025].

This framework includes four specialized agents working collaboratively [Lim & Dai, 2025]:

1. Reference Agent: Extracts spatial relationships from reference images and provides a structured description that guides the space agent's decisions.

2. Spatial Agent: Selects furniture categories and generates appropriate spatial rules, taking advantage of user input and Retrieval Augmented Generative (RAG) technology to provide design knowledge without the need for extensive training.

3. Interactive Agent: It converts complex spatial rules into clear, natural language, enabling non-specialist users to actively participate in the design process by reviewing, rejecting, or accepting suggestions.

4. Grader Agent: It evaluates the spatial output and compares it to reference images, providing automatic quality control.

These systems allow users to participate in three main stages of the design process: selecting objects, defining spatial constraints, and defining evaluation criteria. The results showed that designs resulting from interaction with users received higher ratings in user intent alignment, aesthetic cohesion, functionality, and spatial distribution design compared to non-interactive designs [Lim & Dai, 2025].

5. Smart materials and innovative interior design solutions

5.1 The concept of smart materials and their applications

Smart materials, capable of changing their properties in response to stimuli such as light, temperature and electric fields, have redefined interior design. These versatile materials have introduced dynamism and responsiveness, as seen in kinetic facades or thermally color-changing wallpaper [28].

Interaction design companies use light and sound to engage users, transforming spaces to interact with users or the environment. Examples include the interactive retail space (Dalziel & Pow 2015) and the Aegis Hyposurface kinetic wall, which use capacitive coating and shape-changing mechanisms, respectively. Other fixtures include interactive LEDs, such as Light-Form and Philips Luminous patterns. Such designs enhance the user experience by introducing dynamic elements, going beyond traditional static designs [29].

Organic user interfaces (OUI) advance this innovation. They can change shape, texture, opacity or color in response to external stimuli, while some have sensing rather than operational qualities. Examples include conductive fabrics and flexible sensors. Projects such as Morphing Lumina Architectural Skins and Living Surface explore these potential applications [30].

In the studio's projects, concepts are developed through invisible technology in the smart home project, and through visible technology in the smart clinic. Students created ambient intelligence environments mostly through walls and

objects. Surface applications provided interior design students with a variety of design opportunities using different materials [67].

5.2 Advanced smart materials

Other examples include smart paints and coatings, known for their durable performance, properties-changing capabilities, and energy-exchanging materials [17]. One such innovative material is the smart dichroic material, which changes color in response to changes in the angle of incident light or the perspective of the viewer [31].

Another exciting development is privacy film glass. It can go from transparent to opaque by rearranging the components of its crystalline molecules through electrical currents, providing enhanced privacy to residents. Although it uses electricity which makes it less energy efficient, privacy film helps smart systems reduce cooling and heating leakage in the long term without sacrificing natural light [32]. Smart windows are one of the modern technologies used in smart homes, as they turn opaque white when the outside temperature is high to prevent unwanted solar heat from entering the building, and they become transparent when temperatures drop to allow natural light to pass through [79].

Interior designers consider these smart materials to be one of the most exciting developments in recent years, enabling them to envision dynamic and innovative interior design solutions. These materials bring a high level of adaptability and responsiveness to design, allowing spaces to reflect and respond to the changing needs and moods of their occupants. The ability of smart materials to transform their properties provides a unique opportunity to create multifunctional spaces with less reliance on additional design components [33].

5.3 The impact of smart materials on sustainability

Smart materials significantly enhance the environmental and economic efficiency of interior design. Supports sustainability by reducing the need for different design components, reducing material waste and energy use. At the same time, they contribute to the economic efficiency of design solutions by extending the life of the interior atmosphere. The ability of these materials to change and adapt to different moods and needs means that designs remain fresh and relevant for longer periods, reducing the need for frequent updates or renovations [34].

Furthermore, the use of smart materials can contribute to energy efficiency. For example, thermochromic materials change their appearance based on temperature, which may reduce the need for artificial lighting or heating. Photochromic materials, which change their properties in response to light, can

help regulate light levels and reduce reliance on artificial light sources. These materials, combined with energy-efficient design strategies, can significantly reduce the overall energy consumption of a building [35].

6. Smart furniture and innovative interior design solutions

6.1 The evolution of smart furniture

Furniture, fixtures and equipment (FF&E), important components of any interior design plan, are evolving alongside technological advances to embrace smart sustainability. This evolution requires furniture that provides lasting functionality, incorporates smart materials, and integrates seamlessly with the system of smart appliances and systems within the space. Moreover, this furniture must have adaptable structural mechanisms that meet the dynamic needs of the residents. Furniture integrated with innovative technologies and offering multi-functional utility are design solutions that conserve resources and shape the future of interior design [36]. The design and production of furniture has witnessed a qualitative leap in both function and aesthetics as a result of the integration of smart and digital technologies, as furniture is no longer just a fixed object used in its traditional form, but rather has the ability to sense, recognize, interact and respond to the needs of users through the integration of computers and electronic components. Inside it [79].

In the context of health design, smart technologies have been applied to facilitate activities of daily living for patients and caregivers. Projects have been designed with mail alert systems, smart refrigerators with self-ordering function, light paths for nighttime bathroom trips, smart curtains, chairs equipped with sensors to monitor vital signs, and many other technological features [67].

6.2 Smart furniture applications

The world of smart furniture offers endless possibilities for innovation. Interior designers can leverage available technologies to create resource-efficient, interactive environments that enhance residents' experiences. For example, interactive computer systems can provide valuable information to residents, enabling them to create the desired environmental mood with minimal expenditure of resources. Interactive touch-sensitive OLED displays hidden under the partitions can adapt their display to suit different moods, creating a user-responsive and dynamic atmosphere. Wall-sized displays, connected to the cloud, can display useful information in different rooms, providing a highly interactive and integrated environment [37].

Innovative smart furniture applications include the smart kitchen table, which is one of the smart technologies used in smart homes. It is characterized as a multi-purpose interactive table that turns the kitchen into a comfortable space for relaxing even while preparing food. It includes a touch screen, multimedia integration, and a dynamic interface that operatesWireless powered,wireless sensor networks [79]. Smart kitchen countertops can simplify daily tasks by compiling grocery lists or suggesting recipes based on inventory in the refrigerator and pantry [38]. In retail environments, mirrors can provide fashion advice, transforming the shopping experience. Sensor technology can help keep indoor plants healthy by notifying residents when watering is needed. Furthermore, IoT-enabled surfaces can create immersive and realistic environments by displaying detailed content via augmented and virtual reality. This technology allows residents to browse merchandise, conduct meetings, or visit art galleries without leaving their current location [39].

In health clinic projects, smart tools such as MediBabble have been used for non-English speaking patients. In consulting rooms, the quality of healthcare was ensured by a set of sensors to detect whether a disinfectant dispenser had been used before seeing the patient or by monitoring the steps of medical staff while caring for the patient [67].

6.3 The impact of smart furniture on user experience

These smart furniture significantly impact interior design solutions by creating highly responsive and personalized environments. By incorporating smart technology into furniture, designers can create spaces that are not only functional and aesthetically appealing, but also interactive and highly personal. Furthermore, the use of smart furniture can contribute to sustainability by reducing resource consumption. Furniture that adapts to the needs of residents reduces the need for additional or replacement elements, resulting in reduced material waste and energy consumption. In addition, by offering multi-functional utility, smart furniture can optimize space utilization, contributing to overall resource efficiency [40].

The main features of smart furniture include providing excellent service through sensors, where smart mirrors can recognize the user and display customized information, or the bed has the ability to monitor the user's body and adjust the climate control system accordingly. Smart furniture is also characterized by responding to user activities by being programmable and interactive using touch surfaces, and performs multiple functions that support a range of virtual activities, entertainment, relaxation, work, and control of other devices, including control of the building's climate system [79].

7. Intelligent design strategies to manage internal resource consumption

7.1 Strategic use of resources

Intelligent design systems enable strategic use of resources by employing equipment with start-stop control and monitoring of space and occupancy conditions. These systems can implement sophisticated strategies to reduce energy use. For example, they can restrict the operation of lighting, heating, ventilation, and air conditioning (HVAC) systems to specific hours and areas of the building where they are required [41]. The internal space is managed through three main stages: first, data collection and statistical analysis; Second, analyze the collected data to support decision making; Third, controlling the building by responding to external conditions and influencing factors [79].

In the context of sanitary design, advanced technologies are integrated to generate new uses and thus new spaces and spatial relationships in the planning and programming of projects. Most projects included an IT room in residential and clinical programs [67].

7.2 Analysis of consumption patterns

Intelligent Design software plays a crucial role in analyzing consumption patterns. These systems can accurately identify residents' lifestyle needs, predict energy load requirements, notify residents of irregular or high consumption, and provide energy efficient solutions [42]. For example, systems that monitor weather conditions can control smart shading devices to ensure consistent daylight lighting throughout the interior space. By understanding usage patterns, intelligent systems can maintain indoor temperature in line with occupants' comfort preferences [43]. Interior lighting control systems work through automatic timers that operate according to a pre-determined schedule. Some systems use infrared sensors to automatically activate lights when motion is detected, while other systems monitor the intensity of artificial lighting within interior spaces and adjust lighting levels to maintain constant brightness. Using solar cells [79].

7.3 Reduce resource consumption

Intelligent design is fundamentally about reducing resource consumption. Integrating smart systems into interior spaces can significantly reduce the consumption of a wide range of resources. For example, smart systems can initiate cross ventilation by creating negative air pressure via mechanical ventilation systems. It can also manage hot water systems and adjust heating and cooling systems. Reducing heating by 1°C can result in annual energy savings of approximately 7% [44]. Furthermore, smart appliances contribute to overall energy efficiency. For example, water-saving sinks, smart faucets, and smart irrigation systems can significantly reduce water use [45]. Examples include infrared faucets that automatically turn water on and off when hands are placed under or removed, resulting in significant water savings, as well as flushers that turn on immediately after using the bathroom, seat heating systems that turn on when sitting, and hand dryers and paper towels. Which works through sensors [79].

8. Intelligent design strategies for sustainable construction

8.1 Intelligent Modeling (BIM) Software

The first aspect involves leveraging intelligent software that predicts upcoming building requirements, the most prominent example of which is Building Information Modeling (BIM) software. BIM software is introduced as a repository for sharing knowledge and resources related to various design features and functions, and facilitates best practices in various interior construction techniques and techniques. It takes into account the natural characteristics of the site, including topography, local climate and cultural characteristics. Moreover, it anticipates future needs by reducing the need for subsequent modifications. BIM software helps designers evaluate performance effectiveness and provides a reliable basis for decision making throughout the design life cycle such as building management, cost savings and maintenance [46].

Furthermore, BIM software guides designers in selecting optimal locations for insulation materials, which are pivotal in creating sustainable indoor environments. Accurate estimation of insulation placement can lead to significant energy savings and carbon reduction improvements over the life of the building [47]. Thus, BIM software supports interior designers in making sustainability-related decisions by providing them with the information they need in choosing construction methods that reduce infrastructure and material waste, positively impacting construction time and cost, and mitigating harmful impacts on the natural environment [48].

8.2 Smart building technologies

The second aspect includes smart building technologies that provide the dynamism required for different functions. An example of this is phase change materials, which help regulate and maintain thermal environments within a building [49]. Another example is the use of mechanically transformable interior design surfaces. These surfaces can be adapted to support different functions. For example, wall finishes and ceiling tiles can change their appearance to enhance interior acoustics, provide flexibility in smart lighting, and change the ambiance of a design using smart materials [50].

These advanced technologies enable the creation of a dynamic and adaptable interior environment that can be shaped to suit changing needs or moods, ushering in a new era of flexible and sustainable design. The intersection of smart building technologies and design-oriented software such as BIM forms a synergy that enhances not only the aesthetics of interior spaces, but also their functionality, efficiency and long-term sustainability [47].

In the context of elderly care, intelligent interior design stands out with great advantages over traditional designs, especially in improving quality of life and safety. Traditional designs are often limited to spatial planning, color combinations, and furniture choices, while intelligent design integrates technological elements to make interior design more intelligent, personalized, and humanized, which greatly improves quality of life and safety [68].

9. Intelligent design to improve indoor environmental quality

9.1 Indoor air quality management

The ultimate goal of interior design is to create a healthy, safe and comfortable indoor environment. Advanced intelligent design systems have the ability to

actively manage air quality, monitoring humidity levels, pollutants, and toxic gas emissions. These systems can significantly reduce harmful particles using effective natural and mechanical ventilation strategies [5].

Achieving this involves precise control of air pressure through heating, ventilation, and air conditioning (HVAC) systems, automation systems that initiate the opening of specific windows to allow natural ventilation. Intelligent design systems can also operate filters within mechanical ventilation systems, making it easier to replace stagnant air with fresh air and maintain a high-quality indoor environment [51]. Fire detection and suppression systems are linked to the safety and security system and work to detect the start of fires using sensors and heat detectors that identify gases and smoke, and are directly linked to alarm mechanisms to enable users to evacuate the building quickly [79].

9.2 Safety and security systems

There are multiple safety systems built into intelligent design solutions. For example, smart security systems provide residents with the means to monitor their property, providing an enhanced sense of security. Fire alarm sensors and evacuation guides enhance safety mechanisms, ensuring quick and effective responses in emergency situations [52]. Digital surveillance cameras monitor movement and activity inside and outside the building through sensors that activate recording when specific movements are detected in the space. Cameras are distributed strategically in the interior areas while ensuring that areas that enjoy a certain degree of privacy are excluded [79].

In the context of home care, the emergency response system is an important security component that aims to provide rapid and effective rescue services for the elderly. The system integrates emergency call buttons, fall detectors, smoke alarms, and other equipment to ensure seniors can quickly get help in emergency situations. Emergency call buttons are an essential component and are usually placed in places where the elderly can easily access them (e.g. bedside, bathroom, etc.) to ensure that they can be quickly pressed to send a distress signal in an emergency [68].

In health design projects, the needs of Alzheimer's patients were taken into account, and technology assistance was sought accordingly. Open plan, wayfinding, wandering, forgetting, falling, and disorientation have been especially taken into account in space planning [67].

9.3 Promoting health and well-being

Incorporating interactive displays throughout a space can play an effective role in promoting physical and mental health. These screens can provide useful advice on a variety of health-related topics, such as nutrition, sport, exercise and mental health. This not only cultivates a healthier environment, but also stimulates the overall productivity and happiness of the residents [53].

San Antonio's overall health profile is taken into account by diabetes, especially childhood diabetes. An interactive play wall, persuasive games for kindergarteners for healthy eating behaviors, and a smart lunch tray (context awareness + interactive media persuasion) were some of the mnemonic techniques used by students [67].

Intelligent interior design provides customized services according to residents' preferences and needs, such as automatically adjusting indoor temperature and

humidity, and lighting brightness, making residents feel more comfortable and cared for. It also plays an important role in improving the safety of elderly care facilities through comprehensive monitoring using smart monitoring systems that monitor the activities of elderly people in real time, detect abnormal conditions and raise alarms to ensure their safety [68].

10. Discussion

The emergence of smart technologies represents a qualitative shift in the field of interior design. These technologies offer a range of potential benefits, ranging from enhancing sustainability and efficiency to enriching the user experience and facilitating dynamic and personalized environments [54].

10.1 Integration of intelligent systems

At the heart of the intelligent design approach lies the integration of intelligent systems within the built environment. Three main systems have been identified – building automation system (BAS), integration system, and Internet of Things (IoT) system. BAS regulates indoor climate systems through a sophisticated network of sensors and output devices. The integration system provides central control over various aspects such as lighting, security, fire suppression and indoor climate. IoT systems provide a wealth of data about space usage and other indoor parameters, enabling real-time adjustments and personalized changes to the building environment [55].

In the context of interior design, practical experience has shown that the choice of technology is a key aspect of the profession. The range of choices has been expanded from modular equipment, furniture, fixtures, systems, materials and colors to smart technology. The research phase supported the design not only as a body of knowledge but also by providing a range of technology options [67].

10.2 Resource consumption management

Smart technologies hold huge potential for managing resource consumption in indoor spaces. Offers advanced energy conservation strategies, using start-stop controls and intelligent design software to optimize energy use based on residents' lifestyle needs and consumption patterns. Innovative mechanisms such as smart shading devices and temperature control systems ensure optimal comfort levels while reducing energy expenditure. Furthermore, smart systems can significantly reduce resource consumption by improving ventilation, heating and cooling systems, and using energy-efficient appliances [56].

10.3 The role of artificial intelligence and the Internet of Things in elderly care

Incorporating the application of IoT and artificial intelligence (AI) technologies into interior design is a pivotal shift, especially in the field of elderly care. IoT components, embedded in furniture and appliances, provide essential data to AI systems to help create a comfortable and productive living environment for seniors. This gives interiors new capabilities, leading to unique services such as personalized, preventive, predictive and advisory services [57].

Intelligent systems can analyze collected data to predict and warn about potential security risks. For example, by analyzing indoor temperature and humidity data, home appliance failure risks can be predicted; By analyzing household electricity consumption, safety risks such as electrical circuit overload can be predicted. This data analysis-based early warning system detects and addresses potential

security issues in a timely manner, ensuring the safety and stability of the living space [68].

10.4 Multi-agent systems and participatory design

The emergence of multi-agent systems based on large language models represents an important advance in the field of intelligent interior design, as they enhance interactive engagement and reduce reliance on large data sets [Lim & Dai, 2025]. Studies have shown that designs resulting from interaction with users achieve better results in user intent alignment, aesthetic cohesion, functionality, and spatial distribution compared to non-interactive designs [Lim & Dai, 2025].

Survey results indicate that 77% of participants were satisfied or very satisfied with the participatory aspects of the system, with 51% preferring the new system compared to traditional design software [Lim & Dai, 2025]. However, some professional designers have indicated their desire to reduce the level of automation to retain manual control of the design process, indicating the importance of balancing automation and human involvement in future design systems [Lim & Dai, 2025].

10.5 Challenges and opportunities for the future

In the rapidly evolving landscape of smart technology, it is essential for interior designers to stay on top of the latest developments. This entails active communication with technology suppliers and a collaborative approach to innovation. The integration of technology with interior design has opened a world of possibilities, creating a future where spaces are not only aesthetically attractive, but also highly functional, personalized and responsive to the needs of residents [58].

The experience of the Topics studio at the University of Texas suggests several perspectives for the integrative design-build intervention of smart technology and interior design [67]:

· Technology through use: Interior designers' work is informed by knowledge of behavioral science and human factors. Introducing, branding or marketing smart technologies through functional use will expand the circle of interior design engagement.

· Technology through storytelling: Topics Studio's experience has shown that technology is clearly understood through stories, as in the Microsoft EasyLiving Project. Students used stories to bring smart technology content into the design.

· Technology through flexibility and convertibility: In interior design, convertibility is characterized by the ability to add or remove modules or components. In computer science, resilience refers to interoperability. In interior design, flexibility and convertibility lead not only to multifunctionality but also to creativity.

· Technology through implementation: Interior design concepts, principles and theories relate to construction methods, materials and systems. Illustrating the smart techniques of interior design itself is essentially through the practice of the profession.

The integration of hybrid technologies into smart interior design represents an important development in the field of interior design, providing tools to create

dynamic, efficient and sustainable spaces. The continued exploration and integration of these technologies will undoubtedly shape the future of interior design, ushering in a new era of smart, adaptable and sustainable built environments [59].

11. Conclusion

The rapid development of technology, despite its unfortunate contribution to global challenges such as climate change and resource depletion, represents innovative solutions that, when harnessed effectively, can revolutionize industries. This is especially true for the construction and interior design sectors. From conception to demolition, smart technologies can streamline operations, enhance efficiency, and create a new paradigm in interior design [60].

Smart technologies in interior design can transform spaces into highly efficient, flexible and personalized environments. Deploying intelligent design facilities and systems allows for comprehensive monitoring, control and data storage across all elements within a building. The data generated, when properly interpreted, can provide a wealth of insights into population behavior patterns, facilitating better use of space and more efficient management of resources [61].

In the context of elderly care, the application of intelligent interior design in elderly care facilities not only provides a more comfortable and safer living environment for the elderly, but also greatly improves their quality of life and safety. By applying smart technologies such as smart lighting systems, temperature control systems, emergency response systems, and barrier-free design, the daily life of the elderly becomes easier and more comfortable, with the ability to deal with emergencies and ensure their safety. The application of these technologies makes the management and service of elderly care facilities more efficient and meets the diverse needs of older people [68].

The integration of smart materials and furniture creates dynamic interiors that can adapt to the needs of residents, thus extending the life cycle of the design. These innovations enhance comfort, safety, security and sensory stimulation while improving the overall health of indoor environments. Hence, smart design solutions meet not only the functional aspects of the space but also the emotional and psychological well-being of the residents [62].

Technological advances have also seen the emergence of BIM software, a powerful tool that can predict construction requirements, reduce waste, and reduce the need for modifications. BIM software supports designers in making informed decisions during the design life cycle and contributes positively to the cost efficiency and effectiveness of interior construction [47].

In the face of the ever-evolving smart technology, it is crucial for interior designers to stay up to date with the latest innovations. Maintaining active communication with technology suppliers can ensure they stay up to date on emerging

technologies and can provide manufacturers with valuable feedback for future development. This collaborative approach can foster innovation and pave the way for future smart designs [63].

In short, smart technologies are reshaping the interior design industry, creating environments that are not only aesthetically attractive but also highly efficient, flexible and personalized. By harnessing these technologies, we can create spaces that truly respond to the evolving needs and lifestyles of residents, ushering in a new era in interior design [64]. As technology continues to advance and its applications deepen, intelligent interior design will bring more innovations and breakthroughs to the elderly care industry in the future, creating a better living environment for the elderly [68].

Recommendations for future research

Future research could delve deeper into the role of artificial intelligence and machine learning in interior design. As these technologies develop, there is potential for predictive designs that not only react to the needs of residents but anticipate them, allowing for more personalized and intuitive interior spaces [65].

Another area worth exploring is the seamless integration of intelligent design principles with sustainable and green practices. While this paper highlighted the transformative power of smart technologies, understanding their symbiosis with green building practices can offer comprehensive solutions that marry efficiency and environmental conservation [66].

The experiences of interior design studios also indicate the importance of developing a common language between interior design and the field of smart technology for joint intellectual and practical efforts in the future. Future research could focus on developing frameworks and guidelines for integrating smart technologies into interior design practices, while addressing challenges related to cost, implementation and scalability [67].

In addition, future research could explore specific applications of smart technologies in different cultural contexts, especially in regions such as the Middle East where elderly care needs are increasing. Research could also focus on developing affordable smart systems that meet the needs of low-income groups, while ensuring that the benefits of smart interior design are accessible to all segments of society.

It is also important to study the integration of multi-agent systems based on large language models into interior design practices, focusing on improving human-machine interaction and enhancing participatory engagement [Lim & Dai, 2025]. Future research could include developing interactive multimedia interfaces, including graphics and augmented reality, to expand the accessibility of these systems and make them more accessible to users from different backgrounds [Lim & Dai, 2025].

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