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Assessment of the challenges influencing the adoption of smart building technologies

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Introduction: Over the past few decades, there has been an increasing focus on Smart Building Projects (SBP) and the technologies associated with them. Numerous studies have been conducted globally to define smart building technologies (SBT), identify challenges, and explore areas for improvement. This study aims to examine the concept and terminology of SBT and the expertise and experience of participants in SBP in the Arab Gulf countries, specifically Saudi Arabia. The study also investigates the challenges faced by SBT throughout its life cycle.

Methods: To identify and assess the challenges affecting the adoption of smart building technologies. This approach included a literature review, pilot-testing, and a questionnaire survey. The survey targeted a sample of 90 architects/engineers, managers, and contractors.

Results: A total of 55 challenges were identified and categorized into four groups, corresponding to the key phases of the project life cycle. These phases include the programming and feasibility analysis phase, design phase, installation and commissioning phase, and operation and maintenance phase. The findings of this research expand the body of knowledge by providing architects/engineers, managers, and contractors in the architecture, engineering, construction, and facility management (AEC/FM) industry with insights into the influential challenges related to the adoption of SBT. In conclusion, this study sheds light on the concept and terminology of smart building technologies and explores the challenges faced by SBT during its life cycle. By identifying and categorizing these challenges, the study provides valuable information to AEC/FM practitioners, enabling them to overcome obstacles and improve the adoption of SBT.

KEYWORDS

smart building technologies, challenges, buildings lifecycle phases, building automation, smart city

1 Introduction

The purpose of buildings is to fulfill the requirements and preferences of their inhabitants, with an increasing focus on enhancing comfort within the living environment (Hamida et al., 2022). The planning of building systems holds a pivotal position in elevating user contentment and the overall standard of living (Hamida et al., 2022). Smart buildings, in particular, have surfaced as a method to enhance the efficiency, safety, and comfort of users' lives (Hamida et al., 2022). The phrase "smart building" made its debut in 1981 when the United Technology Building Systems (UTBS) Corporation in the United States first introduced the concept. Their emphasis was on employing building automated systems (BMS) for the regulation of security and HVAC systems. A notable milestone occurred in 1983 with the construction of the City Place building in the United States, which was proudly marketed as the world's inaugural intelligent building (Fabi et al., 2017a; Pramanik et al., 2019). Essentially, a smart building integrates various systems such as HVAC, power management, lighting, security, safety, and shared networks to efficiently manage resources and enhance building performance (Hamida et al., 2022). It combines the best available technologies, designs, materials, and systems to improve occupants' lives and provide cost-effective environments (Hamida et al., 2022). Smart buildings leverage technology to enhance building services and operations for the benefit of users (Ghansah et al., 2020). They aim to provide a dynamic infrastructure that optimizes energy efficiency, flexibility, cost, and comfort (Hamida et al., 2022). The concept of smartness in buildings encompasses characteristics such as green energy, zero emissions, space flexibility, population health, and working efficiency (Hamida et al., 2022). Smart buildings are described as equipped buildings with interconnected sensors, communication networks, and controllable devices (Fabi et al., 2017a). They are also defined as flexible buildings that interact and connect with the ecosystem while generating and storing energy (Fabi et al., 2017a). The aim of smart building technologies is to reduce energy consumption and improve comfort conditions and human welfare (Fabi et al., 2017a; Pramanik et al., 2019).

Recent definitions of smart buildings focus on the adoption of structure connectivity solutions (SCS) to address various building systems, including security, data networking, and environmental control (Sathesh and Hamdan, 2021). Designers of smart buildings should consider a range of smart building technologies and user characteristics, adopting a "respondents-oriented" approach (Pramanik et al., 2019). However, the definition of intelligent buildings remains ambiguous, with diverse definitions across different countries (Sathesh and Hamdan, 2021). Initially, early definitions primarily focused on automated functionalities, but subsequently, newer definitions have broadened their scope to encompass additional aspects. During the 1990s, the concept of smart buildings evolved to emphasize the integration of building occupants, intelligent systems, and environmental considerations to elevate the overall quality of life. Within the body of literature dedicated to smart buildings, there is a general consensus on three key defining characteristics: the incorporation of technology, the delivery of services, and the capacity to fulfill user requirements (Da Xu et al., 2014; Jacobsson, 2016; Pašek and Sojková, 2018). The core technologies of a smart building encompass hardware and software components, including sensors and home appliances. Sensors, whether physical devices or technological tools, detect changes in human behavior and environmental challenges (Belani et al., 2014; Ghaffarianhoseini et al., 2016; El-Rashidy et al., 2021; Saad et al., 2022). By integrating sensors into household equipment and connecting them through wired or wireless systems, residents' habits during activities such as watching television, cooking, sleeping, and cleaning can be observed and tracked (Fabi et al., 2017b). The system, consisting of a variety of appliance and sensor configurations, facilitates a wide range of tailored tasks and services to meet the needs of the inhabitants (Pramanik et al., 2019; Alsolami, 2022; Alanne and Sierla, 2022). A smart building can be defined as a dwelling equipped with sensors and connected domestic devices that form a communication network, providing lifestyle support (Pašek and Sojková, 2018; Sánchez-Corcuera et al., 2019). In essence, a smart building integrates smart devices and sensors into an intelligent system that provides management, surveillance, assistance, and responsive services. This convergence yields a multitude of advantages spanning diverse areas, including the economy, society, health, emotional wellbeing, sustainability, and security, among others (Jacobsson, 2016; Gadakari et al., 2014).

In the last 30 years, numerous institutions around the world have undertaken comprehensive research to define and gain insight into smart building projects (SBPs) along with their fundamental principles and objectives (Sathesh and Hamdan, 2021; Iwuagwu et al., 2014). Thus, this study aims to enhance the knowledge regarding the challenges and barriers that SBTs may face, providing valuable insights for stakeholders to promote effective SBT implementation in the big cities of the Arab Gulf (Marigo et al., 2023).

Sustainable and smart building is a growing trend that is catching on in public opinion and making its way into the agendas of researchers and city authorities worldwide. Indeed, 5G technology can significantly impact building construction, operation, and management by providing high-quality services and efficient functionalities. Singapore is one of the top smart cities in the world and among the first countries to adopt 5G technology in various sectors, including smart buildings. This article discusses the international trends in 5G applications for smart buildings, R&D, and test-bedding works conducted in 5G labs. It also reviews 5G technology development, use cases, applications, and future projects supported by the Singapore government. Lastly, the study discusses 5G use cases for smart buildings and building environment improvement applications. This research can serve as a benchmark for researchers and industries for future progress and development of smart cities in the context of big data (Huseien and Shah, 2022).

Large amounts of data are generated daily by sub-meters and smart sensors in residential buildings. Properly leveraging this data could help end users, energy producers, and utility companies in identifying unusual power consumption and understanding the causes of each anomaly (Himeur et al., 2021).

Currently, analyzing, detecting, and visualizing unusual power consumption patterns of households are some of the main challenges in finding ways to decrease power usage (Himeur et al., 2020).

Smart cities strive to achieve their net-zero emissions targets by minimizing wasted energy, enhancing grid stability, and fulfilling service demand. This is achievable by adopting advanced energy systems that utilize artificial intelligence, the Internet of Things (IoT), and communication technologies to gather and analyze large amounts of data in real time, thus efficiently managing city services. However, training machine learning algorithms to perform various energy-related tasks in sustainable smart cities presents a difficult data science challenge.

2 Research methodology

To examine the hindrances and possible remedies related to the adoption of smart building technologies, a research methodology was implemented, encompassing both qualitative and quantitative methodologies. This research approach encompassed the following steps: as shown in Figure 1.

1. Literature Review: To acquire an understanding of the challenges that smart building technologies encounter across their life cycle, a thorough examination of pertinent literature was conducted. In total, 55 challenges were pinpointed and sorted into four primary categories aligning with the various life cycle phases: programming and feasibility, design, installation and commissioning, and operation and maintenance.
2. Questionnaire Development: A Likert-scale questionnaire with five points was created to gauge the level of severity associated with the identified challenges. The term "severity" here denotes the influence of each challenge on the adoption of smart building technologies. A pilot test was executed, involving five participants from each relevant discipline, to assess the validity, comprehensiveness, and readability of the identified challenges. Subsequently, a questionnaire comprising 55 questions was formulated and distributed among professionals encompassing architects, engineers, constructors, facility managers, architects, and developers who are actively engaged in the domain of smart building projects in Saudi Arabia. The primary objective of this questionnaire was to delineate the principal challenges faced by smart building projects in Saudi Arabia.
3. Survey Administration: The pilot-tested questionnaire survey was administered to a targeted sample of 90 architecture/engineering/construction/facilities management (AE/C/FM) practitioners in Riyadh, Saudi Arabia. The sample comprised 30 architects/engineers (A/Es), 30 facilities managers, and 30 contractors. The selection of respondents was based on their years of experience and the nature of the projects they had been involved in. Table 1 provides an overview of the general information of the respondents.
4. Tabulation and Analysis: The relative challenging index (RCI) was calculated for each factor to determine its importance rating. The RCI is a percentage parameter based on a weighted mean, commonly used to quantify the significance of Likert-scaled questions (Hamida et al., 2022). It serves as an analytical method for prioritizing influential variables in professional practices, particularly in the construction industry (Iwuagwu et al., 2014; Hamida et al., 2022). In this research, the RCI was adopted to rank the challenges according to their relative importance as perceived by the respondents of the questionnaire survey. Both group and overall rankings were determined to identify the most important challenges within each group and across all groups of challenges.

Through the execution of this extensive research methodology, the study sought to collect valuable data concerning the obstacles related to the adoption of smart building technologies and to evaluate their level of severity as perceived by AE/C/FM practitioners in Riyadh, Saudi Arabia. Table 1 furnishes details about the demographic characteristics of the respondents, specifically architects/engineers (A/Es), contractors, and facilities managers. The data encompass the frequency and percentage of respondents in each category, stratified by their years of experience and their engagement in the design or construction of smart building systems (Jayasinghe et al., 2023; Kaklauskas et al., 2019).

Figure 2 illustrates the dispersion of participants within each group categorized by their years of experience. It provides data on the count and proportion of respondents falling into various experience brackets, including 1–5 years, 6–10 years, 11–15 years, and over 15 years. Furthermore, the table also displays the percentage of respondents who indicated their involvement in the design or construction of smart building systems, which is notably high across all three groups (El-Rashidy et al., 2021).

3 The literature review

The purpose of this article is to examine and evaluate the challenges that impact smart building technologies (SBTs) in the Arab Gulf States across their entire life cycle, spanning four crucial phases: the conceptual planning and feasibility study phase, the design and engineering phase, the construction phase, and the operation and maintenance phase (Pašek and Sojková, 2018). The following is a review of the existing literature and pilot testing; a total of 55 challenges that influence the adoption of smart buildings throughout their life cycle were identified. These challenges were categorized within the aforementioned four key phases, and their descriptions are presented in the following overview (Ahmed et al., 2021).

3.1 Challenges pertaining to the programming and feasibility analysis phase

The integration of smart building technologies can be affected by a range of challenges that arise during the programming and feasibility analysis phase. These 22 challenges have the potential to influence the decision-making procedures of stakeholders and organizations contemplating the adoption of smart building technologies. The following is an overview of the 22 challenges within the programming and feasibility analysis phase that have the potential to impact the adoption of smart building technologies:

A. The lack of a clear definition of smart buildings, a smart building is a structure that integrates advanced technologies and systems to enhance its performance, functionality, and sustainability (El-Motasem et al., 2021).

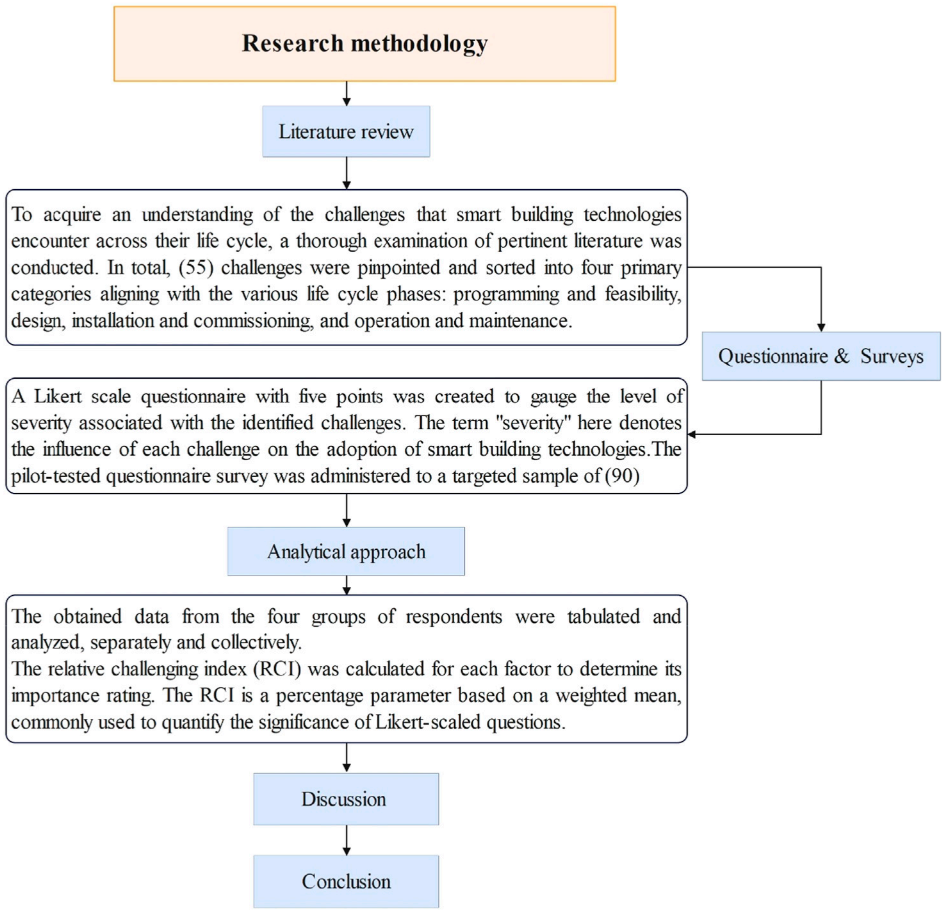

FIGURE 1
Research methodology.

TABLE 1 Profile of the AE/C/FM respondents.

Parameter	A/Es Frequency (n = 30)	%	Contractors Frequency (n = 30)	%	Facilities managers Frequency (n = 30)	%
Years of experience						
1–5 years	5	16.66	8	26.66	5	16.66
6–10 years	12	40.00	7	23.33	11	36.66
11–15 years	7	23.33	9	30.00	9	30.00
More than 15 years	6	20.00	5	16.66	5	16.66
Being involved in designing or constructing smart building systems	23	76.00	24	80.00	26	86.66

Note(s): A/Es, Architects/Engineers.

B. The lack of a clear taxonomy for smart buildings, a clear taxonomy for smart buildings, or the organization of their various components and subsystems, is currently lacking in the field (Alfalouji et al., 2023).
C. The lack of identified basic dimensions of smart buildings, the absence of identified basic dimensions of smart buildings contributes to the difficulty in defining and assessing their performance (Ejidike and Mewomo, 2023).
D. The lack of design standards of smart buildings, the lack of design standards for smart buildings can create challenges in the development and construction of these buildings (Aguilar et al., 2021).
E. The lack of sustainability measures for smart buildings, the lack of sustainability measures for smart buildings refers to the absence of clear and agreed-upon criteria for evaluating the environmental performance of smart buildings (El-Motasem et al., 2021, De Groote et al., 2017; Bibri, 2021; Ghansah et al., 2021).

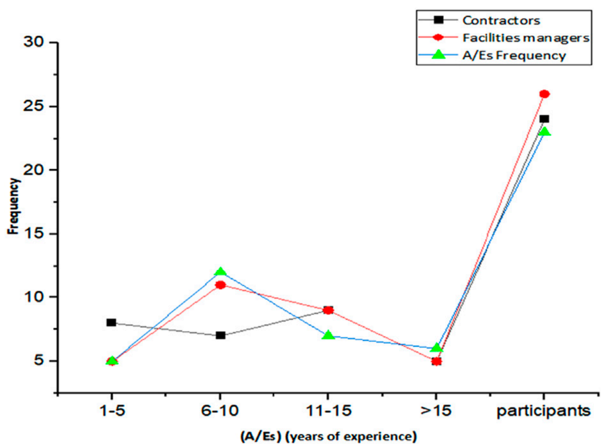

FIGURE 2
The distribution of respondents in each group based on their years of experience (Alsolami, 2022).

F. The lack of automated evaluation schemes of smart building design, the lack of automated evaluation schemes for smart building design is an important challenge in the field (Ghaffarianhoseini et al., 2016).
G. The lack of knowledge and expertise of smart building systems, the lack of knowledge and expertise in smart building systems is a significant challenge that can hinder the successful implementation and operation of smart buildings (Zhao et al., 2021).
H. The lack of understanding of users' needs for smartness, the lack of understanding of users' needs for smartness in the context of smart buildings is a significant challenge that can impact the adoption and effectiveness of these technologies (Zhao et al., 2021).
I. The lack of historical databases of existing smart buildings' performance, the lack of historical databases of existing smart buildings' performance is indeed a challenge that can hinder the advancement and optimization of smart building technologies (Alanne and Sierla, 2022, Zhao et al., 2021).
J. The lack of regulations on a vision for achieving a specific level of smartness, the lack of regulations regarding a specific level of smartness for smart buildings is indeed a challenge that can impact the widespread adoption and integration of smart technologies (AlMuharraqi et al., 2022, Zhao et al., 2021).
K. Simplify technical jargon: Smart building technologies often come with complex technical terminology that can be overwhelming for consumers (Saad et al., 2022, Ghaffarianhoseini et al., 2016).
L. The lack of specialized and qualified suppliers and manufacturers for smart building systems, the lack of specialized and qualified suppliers and manufacturers for smart building systems is indeed a challenge that can hinder the widespread adoption and implementation of these technologies (Jacobsson, 2016, Li et al., 2020).
M. The cost of human technical expertise is relatively high over the benefits of smart buildings, smart buildings can come at a significant cost. Here are a few challenges that contribute to the relatively high cost: specialized skillset: designing, implementing, and maintaining smart building systems (Pašek and Sojková, 2018, Ghansah et al., 2020).
N. The total cost of ownership of smart buildings is unclear or relatively forecasted as a high investment, the total cost of ownership of smart buildings is unclear or relatively forecasted as a high investment due to several challenges.
O. The lack of motivational regulations on the choice and implementation of smart buildings, these buildings incorporate advanced technologies and design features that make them more energy efficient and environmentally sustainable (Sovacool and Furszyfer Del Rio, 2020).
P. The lack of provision of insights into smart building impacts (positive or negative) to policymakers, a lack of understanding may cause policy-makers to overlook the potential benefits and opportunities that smart buildings offer, resulting in missed opportunities to promote sustainability and energy efficiency.
Q. The insufficient basis of stating users' needs and requirements, without information about users and requirements, it is hard for companies and designers to create products or buildings that meet their customers' expectations.
R. The difficulty in forecasting the selected systems' cycles of upgradeability and the changes of their technologies, it is important to choose systems that will last and be able to adapt to new technologies. However, it can be difficult to know exactly when and how these changes will happen, making it challenging to plan and budget for them.
S. Smart buildings are not self-sufficient; there are performance risks based on dependability on specific energy sources (no power, no smartness), if there is a disruption in the energy supply, the smart features in these buildings may not function properly. This can lead to decreased efficiency and potential issues.

3.2 Challenges pertaining to the design phase

In the process of implementing smart building technology, the design phase presents several challenges that demand careful attention. These challenges have the potential to affect the effective design and incorporation of smart building systems. The following is an overview of the 11 challenges typically associated with the design phase of smart building technology.

a. The lack of descriptive guidelines for the design of different systems in smart buildings, there may not be enough information or clear instructions on how to design the various systems in a smart building (Alsolami, 2022)
b. The technological lack of systems integration and interoperability capabilities, there may not be enough availability of resources or tools for making different systems work together and communicate with each other in smart buildings.

c. The lack of available visions of principal directions for the design thinking of smart buildings, this can make it difficult for architects and engineers to create a building that meets the needs and expectations of those who will use it.
d. The lack or absence of authoritative action plans to manage the design process of smart building projects, without these plans, it can be difficult to make sure that the building is designed in a way that meets the goals and requirements of the project.
e. The lack of measures to maintain the privacy and data security of users, there should be enough rules or systems in place to protect the personal information and privacy of those who use smart buildings.
f. The lack of regulations to maintain the privacy and data security of users, if there are not enough regulations to maintain privacy and data security, this could lead to unauthorized access to personal information, identity theft, and other serious issues.
g. The complexity of the design process, the complexity can also lead to increased costs and delays in the construction process. Having better resources and tools to simplify the design process would help make it easier to create smart buildings that meet all the necessary standards and requirements. (Ghaffarianhoseini et al., 2016, Kaklauskas et al., 2019)
h. The inability of specifying qualified and quality local manufacturers. Even if qualified and quality manufacturers are available, it can be challenging to find the right products for the building or the information and resources needed to identify and work with these local manufacturers. (El-Rashidy et al., 2021, Ejidike and Mewomo, 2023, Himeur et al., 2023)
i. The lack of distinguishing between the smartness requirements of owners, users, operators, and facility managers, the owners, users, operators, and facility managers may all have different ideas about what makes a building "smart" and how it should function.
j. The lack of understanding of the basis of design responsiveness of occupational health and safety precautionary measures from a technological point of view, many advanced technologies and systems in smart buildings can help keep the respondents safe and healthy, but designers and builders may not understand how to incorporate these technologies effectively (Alanne and Sierla, 2022).
k. The lack of specification of protection ratings and testing of systems, materials, and components, without standards for testing and rating the safety and protection of the systems, materials, and components used in smart buildings, it can be difficult to know whether the building and its various parts are safe and reliable. (Jacobsson, 2016, Kaklauskas et al., 2019)

3.3 Challenges pertaining to the installation and commissioning phase

The following is an overview of the 9 challenges commonly associated with the installation and commissioning phase in various industries:

a. Smart building projects are subject to scope variations that result in an excessive increase of budgets allocated, the accurate design of smart buildings is difficult, as is estimating the cost of the project and staying within budget. This can lead to delays and other complications.
b. Smart building projects are subject to variations that result in an excessive increase of time allocated, the construction and design of smart buildings often involve changes that can lead to an increase in the time allocated for the project. (Pramanik et al., 2019, Ahmed et al., 2021)
c. The lack of logistical support/logistical challenges for procuring smart systems, this indicates that logistical issues may make it difficult to procure the tools, supplies, and systems required for smart buildings. (Belani et al., 2014, Himeur et al., 2023)
d. The lack of experience in testing smart behaviors and systems, this indicates that the testing of intelligent systems and behaviors in intelligent buildings lacks knowledge and skill.
e. The lack of well-trained labor that can work on smart buildings, this indicates that there is a lack of trained and experienced professionals who can operate on smart buildings. (Hamida et al., 2022, Taktak, 2016)
f. The lack of systems' compatibility with domestic utilities and national information and communication technologies and services, this implies that certain systems or equipment might not function properly with the country's current technology and services. Users may find it challenging to use and link them appropriately as a result of this.
g. The lack of expertise, support services, and skills for installation and commissioning, it is important to make sure the technology is compatible with existing systems and that there are professionals with the right expertise to help with any installation and support.
h. The high costs of devices and installations, due to the high costs of devices and installations, purchasing and configuring the equipment required for smart buildings may be prohibitively expensive (Hamida et al., 2022, AlMuharraqi et al., 2022).
i. The requirement of high cash flow and financing for smart building projects, the start-up and completion of smart building projects may require significant funding. This might entail both having enough cash on hand and having the ability to borrow money if necessary (Hamida et al., 2022, Alanne and Sierla, 2022, AlMuharraqi et al., 2022).

3.4 Challenges pertaining to the operation and maintenance phase

There are several challenges that need to be considered. These challenges can impact the successful operation and maintenance of smart building systems.

a. The operations and maintenance costs (OPEX) are relatively high compared to regular buildings, it costs more to run and maintain smart buildings compared to regular buildings. This includes costs for aspects such as repairs and energy consumption.
b. The absence of operations and maintenance teams during early project phases means a lot of risks evolve during the operation

TABLE 2 Challenges facing the adoption of smart building technologies (SBTs) in previous studies.

No.	Challenges	References
G1	Challenges pertaining to the programming and feasibility analysis phase	
1	The lack of clear definition of smart buildings	El-Motasem et al., (2021); Alfalouji et al., (2023)
2	The lack of clear taxonomy of smart buildings	Alfalouji et al. (2023)
3	The lack of identified basic dimensions of smart buildings	Ejidike and Mewomo (2023)
4	The lack of design standards of smart buildings	AlMuharraqi et al. (2022)
5	The lack of sustainability measures for smart buildings	Alsolami (2022)
6	The lack of automated evaluation schemes of smart building designs	Alsolami (2022)
7	The lack of knowledge and expertise of smart building systems	Roman et al. (2016)
8	The lack of understanding of users' needs for smartness	Ghaffarianhoseini et al. (2016)
9	The lack of historical databases of existing smart buildings' performance	McLauchlan et al. (2020)
10	The lack of historical feasibility assessments of smart building systems	Ejidike and Mewomo (2023)
11	The lack of regulations on a vision for achieving a specific level of smartness	El-Motasem et al. (2021)
12	The limited demand from consumers for smart buildings	Ejidike and Mewomo (2023)
13	The lack of awareness by consumers (e.g., designers, owners, and users) of the benefits of smart buildings	ASRIC (2021)
14	The lack of consumers' (e.g., designers, owners, and users) awareness of the technical specifications of smartness	Alfalouji et al. (2023)
15	The lack of specialized and qualified suppliers and manufacturers for smart building systems	Pramanik et al. (2019)
16	The cost of human technical expertise is relatively high compared to the benefits of smart buildings	Bashir et al. (2022)
17	The total cost of ownership of smart buildings is unclear or relatively forecasted as a high investment	Ghansah et al. (2020)
18	The lack of motivational regulations on choice and implementation of smart buildings	Bashir et al. (2022)
19	The lack of provision of insights into capabilities of smart building impacts (positive or negative) to policymakers	Ghansah et al. (2021)
20	The insufficient basis of stating users' needs and requirements	Ghaffarianhoseini et al. (2016)
21	The difficulty of forecasting the selected systems' cycles of upgradeability and the changes of their technologies	Bibri (2021)
22	Smart buildings are not self-sufficient; there are performance risks based on dependability on specific energy sources (no power, no smartness)	Pramanik et al. (2019)
G2	Challenges pertaining to the design phase	
1	The lack of descriptive guidelines for the design of different systems in smart buildings	Alsolami, (2022); El-Motasem et al. (2021)
2	The technological lack of systems integration and interoperability capabilities	Da Xu et al. (2014)
3	The lack of available visions for principal directions for design thinking of smart buildings	Alanne and Sierla (2022)
4	The lack or absence of authoritative action plans to manage the design process of smart building projects	Sathesh and Hamdan, (2021); El-Motasem et al. (2021); Da Xu et al. (2014)
5	The lack of measures to maintain the privacy and data security of users	Sathesh and Hamdan, (2021); Da Xu et al. (2014)
6	The lack of regulations to maintain the privacy and data security of users	El-Motasem et al. (2021), Salkuti, (2021)
7	The complexity of the design process	Salkuti, (2021); Da Xu et al. (2014)
8	The inability of specifying qualified and quality local manufacturers	Li et al. (2020)
9	The lack of distinguishing between the smartness requirements of owners, users, operators, and facility managers	Pašek and Sojková, (2018); AlMuharraqi et al. (2022); Attoue et al. (2018)

(Continued on following page)

TABLE 2 (*Continued*) Challenges facing the adoption of smart building technologies (SBTs) in previous studies.

No.	Challenges	References
10	The lack of understanding of the basis of design responsiveness of occupational health and safety precautionary measures from a technological point of view	Ejidike and Mewomo, (2023); Bashir et al. (2022); Ibrhem et al. (2020)
11	The lack of specification of protection ratings and testing of systems, materials, and components	Ghaffarianhoseini et al. (2016); Gadakari et al. (2014); Bibri, (2021)
G3	Challenges pertaining to the installation and commissioning phase	
1	Smart building projects are subject to scope variations that result in an excessive increase of budgets allocated	Alsolami, (2022); El-Motasem et al. (2021)
2	Smart building projects are subject to variations that result in an excessive increase of time allocated	AlMuharraqi et al. (2022); Alsolami, (2022); Alanne and Sierla, (2022); Aguilar et al. (2021)
3	The lack of logistical support/logistical challenges for procuring smart systems	Belani et al. (2014); El-Motasem et al. (2021); Ibrhem et al. (2020)
4	The lack of experience in testing smart behaviors and systems	El-Motasem et al. (2021); AlMuharraqi et al. (2022)
5	The lack of well-trained labor that can work on smart buildings	El-Motasem et al. (2021)
6	The lack of systems' compatibility with domestic utilities and national information and communication technologies and services	Balta-Ozkan et al. (2013)
7	The lack of expertise, support services, and skills for installation and commissioning	Alfalouji et al. (2023)
8	The high costs of devices and installations	Alfalouji et al. (2023); Taktak, (2016)
9	The requirement of high cash flow and financing for smart building projects	Saad et al. (2022); Gadakari et al. (2014); Ejidike and Mewomo, (2023)
G4	Challenges pertaining to the operation and maintenance phase	
1	The operations and maintenance costs (OPEX) are relatively high compared to regular buildings	Pašek and Sojková, (2018); Belani et al. (2014); El-Motasem et al. (2021)
2	The absence of operations and maintenance teams during early project phases means a lot of risks evolve during the operation and maintenance phase	Pašek and Sojková, (2018); Belani et al. (2014); El-Motasem et al. (2021)
3	The need to reduce replacement cycles of systems	Salkuti (2021)
4	The need to reduce replacement cycles of systems	Aguilar et al., (2021); Bibri, (2021); Bashir et al. (2022)
5	The lack of skilled and specialized maintenance and operation technicians	Pramanik et al. (2019); Alfalouji et al. (2023); De Groote et al. (2017)
6	The lack of ensured guaranties and warranties	Saad et al., (2022); Alsolami, (2022); El-Motasem et al. (2021); AlMuharraqi et al. (2022)
7	There is a continuous change in operation and maintenance requirements, which affects systems' effectiveness	Ghaffarianhoseini et al. (2016); Belani et al. (2014)
8	There is a continuous change in users' lifestyles and behaviors	Belani et al. (2014); Zhenxing et al. (2009)
9	Reliability (smart building systems must aim to be robust)	Da Xu et al., (2014); Da Xu et al. (2014); Zhenxing et al. (2009); Sathesh and Hamdan, (2021)
10	The changing demand for security that affects systems' effectiveness	Ghaffarianhoseini et al. (2016); Da Xu et al. (2014)
11	The changing functional requirements for controlling and monitoring capabilities	Fabi et al. (2017a), Balta-Ozkan et al. (2013)
12	The social implications of the accessibility of smart technologies (e.g., elderly use of technologies, gender requirements)	Balta-Ozkan et al. (2013), Hoy, (2016), Salkuti (2021)
13	The lack of understanding of human–smart systems interactions and behaviors (involvement of virtual reality, augmented reality, and responsive intelligibility)	Belani et al. (2014); Ghansah et al. (2021)

and maintenance phase, during the initial phases of the project, a team should be in place to handle the maintenance and upkeep of smart buildings.

c. The need to reduce replacement cycles of systems, it is crucial to find solutions to extend the lifespan of the technology employed in these buildings if we want to limit the number of times that systems need to be replaced (Ghansah et al., 2020).

d. The lack of skilled and specialized maintenance and operation technicians, it is important to make sure there are enough skilled technicians available and to provide training and education to help them become specialized in this area. (Hamida et al., 2022, Alanne and Sierla, 2022, Alfalouji et al., 2023, AlMuharraqi et al., 2022, Balta-Ozkan et al., 2013, Holt, 2013)

e. Lack of ensured guarantees and warranties, this could make it difficult for the users to get help if something goes wrong or to be confident in the quality of the technology they are using.
f. There is a continuous change in operation and maintenance requirements, which affects systems' effectiveness, for the systems to remain effective and efficient, they should be adapted and adjusted as needed to ensure they can still perform well even as changes occur.
g. Reliability (smart building systems must aim to be robust), to ensure the best possible reliability, there must be high-quality components, regular maintenance should be regularly performed, and systems should be closely monitored.
h. The changing demand for security that affects systems' effectiveness, this has an impact on how well systems operate and perform. It is crucial to be flexible and modify systems as necessary to satisfy shifting security requirements.
i. The changing demand for privacy that affects systems' effectiveness, this has an impact on the effectiveness of systems in various industries. There are increasing concerns about data protection and privacy regulations.
j. The changing functional requirements for controlling and monitoring capabilities, the changing functional requirements for controlling and monitoring capabilities refer to the evolving needs of organizations to manage and oversee their operations, products, and services (Himeur et al., 2023, Taktak, 2016, Attoue et al., 2018).
k. The social implications of the accessibility of smart technologies (e.g., elderly use of technologies, gender requirements), the social implications of the accessibility of smart technologies include improving the lives of elderly individuals and individuals with disabilities.
l. The lack of understanding of human–smart systems interactions and behaviors (involvement of virtual reality, augmented reality, and responsive intelligibility), the lack of understanding of human–smart systems interactions and behaviors, including the involvement of virtual reality, augmented reality, and responsive intelligibility, is indeed a complex challenge. (Jacobsson, 2016, El-Rashidy et al., 2021, De Groote et al., 2017)

4 Assessment of the challenges affecting the adoption of smart building technologies

4.1 Data collection

A questionnaire survey was created employing a five-point Likert scale to evaluate the significance of the 55 challenges, as detailed in Table 2. The participants, comprising AE/C/FM practitioners located in Riyadh City, Saudi Arabia, were tasked with assigning importance ratings to each of the factors. The rating options included "Extremely challenging" (4), "Very challenging" (3), "challenging" (2), "Somewhat challenging" (1), and "Not challenging" (0). The ratings were determined according to the perceived influence of each challenge on the capacity to adhere to project schedules, financial limitations, and investor anticipations related to work excellence. It was presumed that client requisites had already been addressed and integrated during the architectural programming phase, with an emphasis on the long-term robustness and excellence of the construction. The survey garnered responses from a total of 90 professionals, with equal representation from architects/engineers (A/Es), contractors, and facilities managers, with each group encompassing 30 respondents.

TABLE 3 The adopted weighting and scale of interpretation for each challenging rating.

Challenging rating	Weight (ai)	Scale (%)
Extremely challenging (x0)	4	87.5–100
Very challenging (x1)	3	62.5–87.5
Challenging (x2)	2	37.5–62.5
Somewhat challenging (x3)	1	12.5–37.5
Not challenging (x4)	0	0–12.5

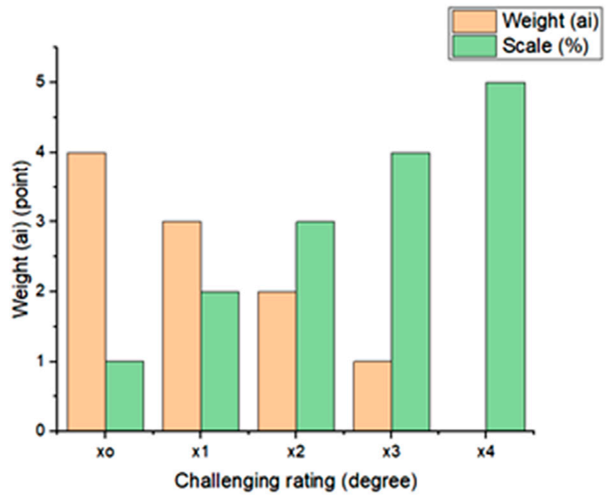

FIGURE 3
The adopted weighting and scale of interpretation for each importance rating (Alsolami, 2022).

4.2 Data analysis

The obtained data from the four groups of respondents were tabulated and analyzed, separately and collectively. The relative challenge index (RCI) was calculated for each factor, using the following equation (1):

$$RCI = \frac{\sum_{i=0}^{4}(a_i)(x_i)}{4\sum_{i=1}^{4}(x_i)} \times 100 \tag{1.1}$$

Where:
i: Response category index.
a_i: Weight given to i response.
x_i: Variable expressing the frequency of (i).

To calculate the RCI, the appropriate values for the weights (a_i) and frequencies (x_i) need to be substituted into the equation. The weights (a_i) represent the importance or significance assigned to each response category, and the frequencies (x_i) represent the number of occurrences or observations for each category, as listed in Table 3 (Figure 3) (Sathesh and Hamdan, 2021; Jayasinghe et al., 2023; Attoue et al., 2018; So and Wong, 2002; Adelgren et al., 2012).

TABLE 4 Correlation among the groups of respondents.

Paired comparisons	ρ	Interpretation of the level of correlation
A/Es and contractors	0.43	Moderate positive correlation
A/Es and facility managers	0.77	Moderate positive correlation
Facility managers and contractors	0.41	Moderate positive correlation

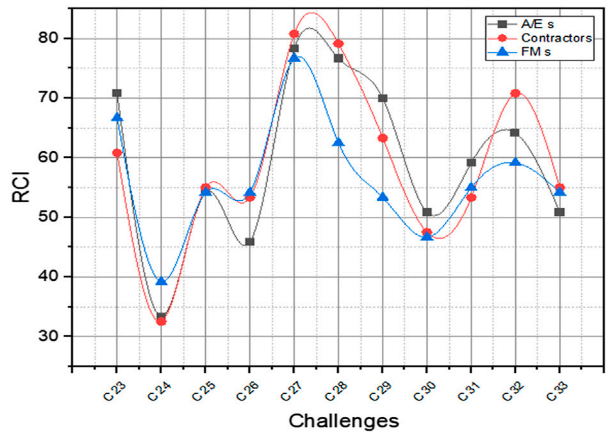

FIGURE 4
RCI of programming and feasibility analysis phase (Alsolami, 2022).

Based on the ranking of the challenges, the correlation among the three groups of respondents was analyzed to determine their level of agreement on the importance of the challenges. Spearman's coefficient of rank correlation was used to determine the level of agreement on the importance of the challenges. The analysis of the agreement was performed through three-paired comparisons, namely, A/Es and contractors, A/Es and facilities managers, and contractors and facilities managers (Hamida et al., 2022). The following equation was used to calculate the Spearman's coefficient of rank correlation: as shown in Table 4

$$\rho = 1 - \frac{6\sum D^2}{N(N^2 - 1)} \quad (1.2)$$

Where:

ρ: Spearman's coefficient of rank correlation.

$\sum D^2$: Sum of the squared differences in ranks of the paired comparison.

N: Number of parameters for which the ranking is made (Zhao et al., 2021).

A summary of Figures 4–7 showcasing the relative challenge index (RCI) as a percentage pertaining to different phases of smart building projects is provided. These phases encompass the programming and feasibility analysis phase comprising 22 challenges, the design phase comprising 11 challenges, the

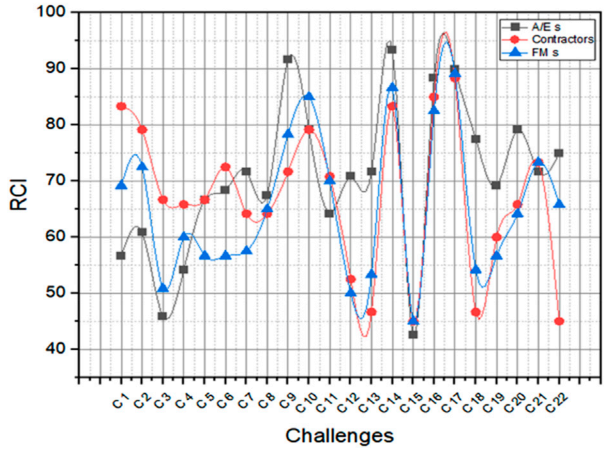

FIGURE 5
RCI of the design phase (Alsolami, 2022).

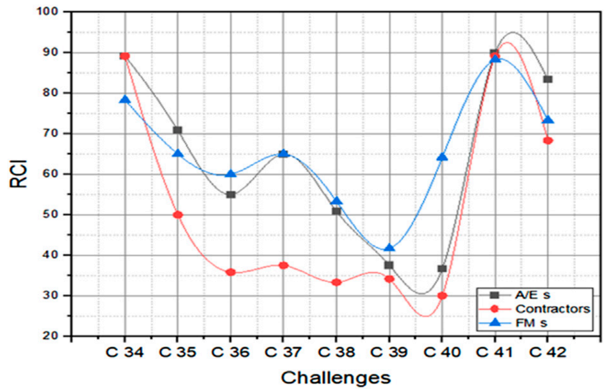

FIGURE 6
RCI of the installation and commissioning phase (Saad et al., 2022; Alsolami, 2022).

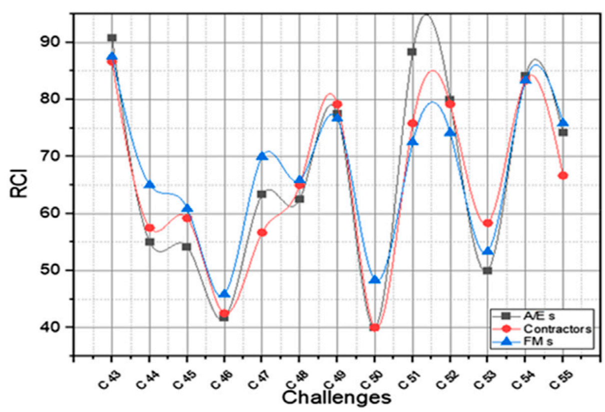

FIGURE 7
RCI of the operation and maintenance phase (Saad et al., 2022; Alsolami, 2022).

installation and commissioning phase comprising 9 challenges, and the operation and maintenance phase comprising 13 challenges. Over recent decades, smart building projects have garnered substantial attention, leading to a multitude of studies aimed at establishing global definitions for smart building technologies (SBTs), recognizing the challenges encountered, and identifying areas for enhancement. The study highlighted here centered on the examination of the concept and terminology associated with SBTs, in addition to the proficiency and hands-on experience of individuals engaged in smart building projects within Saudi Arabia. Moreover, the study sought to determine the features, challenges, and hindrances encountered by SBTs throughout their entire life cycle. While the specific challenges within the Figures are not specified, it can be inferred that the RCI reflects the relative level of complexity or challenge associated with each phase.

5 Findings and discussion

Table 5 illustrates the findings of the assessment. It presents the RCI, challenge rating, challenge group ranking, and overall ranking of each challenge.

5.1 Programming and feasibility analysis phase

This category encompasses 22 challenges. Among these, the respondents identified "The total cost of ownership of smart buildings is unclear or relatively forecasted as a high investment" as the most critical factor and assigned it a rating of "Very Challenging." The authors concur with this evaluation as many respondents tended to perceive a smart building as being at the forefront of technology. However, in reality, a smart building is characterized by its capacity to seamlessly and efficiently integrate various categories and types of diverse technologies. This discovery aligns with the findings of other studies as well (Ibrhem et al., 2020; Bibri, 2021). "The lack of consumers" (e.g., designers, owners, and users) awareness of the technical specifications of smartness" was rated "Very Challenging" and was ranked first by A/Es and second by facility managers. This finding is also in agreement with the outcomes of different studies (Belani et al., 2014; Ahmed et al., 2021; Zhao et al., 2021).

This is a reasonable assertion as awareness levels are also contingent on several challenges, including the accessibility of information. The findings reveal that A/Es ranked "The lack of historical databases of existing smart buildings' performance" as the second most crucial challenge in this phase, attributing it an "Extremely Important" importance rating. The authors concur with this evaluation as comprehending the concept of smart buildings is a fundamental step in gaining a better grasp of smart buildings, and the historical databases related to this concept remain ambiguous, lacking a well-defined framework.

5.2 Design phase

This category encompasses 11 challenges, as outlined in Table 3. A/Es, contractors, and facilities managers all identified "The lack of measures to maintain the privacy and data security of users" as the most critical challenge during this phase, assigning it a rating of "Very Challenging" in terms of importance. The authors concur with these assessments as a substantial number of respondents were driven to transition to smart technologies due to their notable advantages in enhancing efficiency, curbing energy expenses, and furnishing analytics that underpin environmentally sustainable initiatives. Nevertheless, the more technology a business integrates, the more exposed it becomes to potential data breaches (Gadakari et al., 2014; Sathesh and Hamdan, 2021). "The lack of descriptive guidelines for the design of different systems in smart buildings" was rated second by facilities managers and third by A/Es, with an importance rating of "Very Challenging." This is justified, since acquiring users with the needed information of smart features is a vital aspect of persuading them to adopt smart building technologies (Saad et al., 2022).

5.3 Installation and commissioning phase

This group consists of 9 challenges. As shown in Table 2, most of the challenges that face implementing smart building technologies in Saudi Arabia during installation and commissioning phase are due to the high costs of devices and installations. This finding is also in agreement with the outcomes of different studies (El-Motasem et al., 2021; AlMuharraqi et al., 2022). The secondary source of challenges encountered during the installation and commissioning phase relates to "scope variations in smart building projects that lead to significant budget overruns." This can be rationalized by the absence of a facility management team at this stage and the absence of an all-encompassing framework capable of meeting the objectives related to the life cycle costs of smart building technologies.

5.4 Operation and maintenance phase

This category comprises 13 challenges. The respondents ranked "The operations and maintenance costs (OPEX) are relatively high compared to regular buildings" as the most significant factor in this group, assigning it a "Very Challenging" rating. The authors concur with this evaluation, given that many of the challenges tend to surface during the operation and maintenance phase, often resulting from unresolved and cumulative issues. Contractors and facilities managers identified "The social implications of the accessibility of smart technologies (e.g., elderly use of technologies, gender requirements)" as the second most crucial challenge during this phase, giving it a "Very Challenging" importance rating. This factor was rated third by A/Es, with identical importance ratings. These findings are consistent with previous research (El-Motasem et al., 2021; AlMuharraqi et al., 2022; Ejidike and Mewomo, 2023).

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TABLE 5 Assessment of challenges affecting the adoption of smart building technologies in Saudi Arabia (ref. author).

No.	Challenges affecting the adoption of smart building technologies in Saudi Arabia	A/Es				Contractors				FMs				Overall			
		RCI	CR	CGR	OR	RCI	CR	CGR	OR	RCI	CR	CGR	OR	RCI	CR	CGR	OR
	Challenges pertaining to the programming and feasibility analysis phase																
C1	The lack of clear definition of smart buildings	56.67	C	19	38	83.33	VC	3	6	69.17	VC	9	20	69.72	VC	9	20
C2	The lack of clear taxonomy of smart buildings	60.83	C	18	36	79.17	VC	5	11	72.5	VC	7	16	70.83	VC	7	18
C3	The lack of identified basic dimensions of smart buildings	45.83	C	21	48	66.67	VC	11	22	50.83	C	20	48	54.44	C	21	43
C4	The lack of design standards of smart buildings	54.17	C	20	41	65.83	VC	13	25	60	C	13	32	60	C	17	34
C5	The lack of sustainability measures for smart buildings	66.67	VC	16	30	66.67	VC	12	23	56.67	C	17	37	63.34	VC	14	28
C6	The lack of automated evaluation schemes of smart building design	68.33	VC	14	23	72.5	VC	8	17	56.67	C	18	38	65.83	VC	11	23
C7	The lack of knowledge and expertise of smart building' systems	71.67	VC	17	22	64.17	VC	15	28	57.5	C	14	35	64.45	VC	13	26
C8	The lack of understanding users' needs for smartness	67.5	VC	15	29	64.17	VC	16	29	65	VC	11	24	65.56	VC	12	24
C9	The lack of historical databases of existing smart buildings' performance	91.67	EC	2	2	71.67	VC	9	18	78.33	VC	5	8	80.56	VC	5	9
C10	The lack of historical feasibility assessments of smart building systems	79.17	VC	6	13	79.17	VC	7	10	85	VC	3	5	81.11	VC	4	8
C11	The lack of regulations on a vision for achieving a specific level of smartness	64.17	VC	17	32	70.83	VC	10	19	70	VC	8	18	68.33	VC	10	21
C12	The limited demand from consumers for smart buildings	70.83	VC	12	23	52.5	C	18	41	50	C	21	49	57.78	C	19	38
C13	The lack of awareness by consumers (e.g., designers, owners, and users) of the benefits of smart buildings	71.67	VC	10	21	46.67	C	20	44	53.33	C	19	44	57.22	C	20	39
C14	The lack of consumers' (e.g., designers, owners, and users) awareness of the technical specifications of smartness	93.33	EC	1	1	83.33	VC	4	8	86.67	VC	2	4	87.78	VC	2	4
C15	The lack of specialized and qualified suppliers and manufacturers for smart building systems	42.5	C	22	50	45	C	21	46	45	C	22	53	44.17	C	22	50
C16	The cost of human technical expertise is relatively high compared to the benefits of smart buildings	88.33	EC	4	7	85	VC	2	5	82.5	VC	4	7	85.28	VC	3	6
C17	The total cost of ownership of smart buildings is unclear or relatively forecasted as a high investment	90	EC	3	4	88.33	EC	1	3	89.17	EC	1	1	89.17	VC	1	1
C18	The lack of motivational regulations on choice and implementation of smart buildings	77.5	VC	7	15	46.67	C	20	44	54.17	C	18	40	59.45	C	18	6
C19	The lack of provision of insights into smart building impacts (positive or negative) to policymakers	69.17	VC	13	27	60	C	17	32	56.67	C	16	38	61.95	C	15	31
C20	The insufficient basis of stating users' needs and requirements	79.17	VC	6	12	65.83	VC	14	25	64.17	VC	12	28	69.72	VC	9	20
C21	The difficulty of forecasting the selected systems' cycles of upgradeability and the changes of their technologies	71.67	VC	11	20	73.33	VC	7	16	73.33	VC	6	14	72.78	VC	6	15

(Continued on following page)

TABLE 5 (*Continued*) Assessment of challenges affecting the adoption of smart building technologies in Saudi Arabia (ref. author).

No.	Challenges affecting the adoption of smart building technologies in Saudi Arabia	A/Es				Contractors				FMs				Overall			
		RCI	CR	CGR	OR	RCI	CR	CGR	OR	RCI	CR	CGR	OR	RCI	CR	CGR	OR
C22	Smart buildings are not self-sufficient; there are performance risks based on dependability on specific energy sources (no power, no smartness)	75	VC	8	18	45	C	22	47	65.83	VC	10	22	61.94	C	16	32
	Challenges pertaining to the design phase																
C23	The lack of descriptive guidelines for the design of different systems in smart buildings	70.83	VC	3	24	60.83	C	5	31	66.67	VC	2	21	66.11	VC	3	22
C24	The technological lack of systems integration and interoperability capabilities	33.33	C	11	55	32.5	SC	11	54	39.17	C	11	55	35	SC	11	55
C25	The lack of available visions for principal directions for design thinking of smart buildings	54.17	C	7	42	55	C	6	38	54.17	VC	6	41	54.45	C	7	42
C26	The lack or absence of authoritative action plans to manage the design process of smart building projects	45.83	C	10	49	53.33	C	8	39	54.17	VC	7	42	51.11	C	9	46
C27	The lack of measures to maintain the privacy and data security of users	78.33	VC	3	14	80.83	VC	1	9	76.67	VC	1	10	78.61	VC	1	11
C28	The lack of regulations to maintain the privacy and data security of users	76.67	VC	2	17	79.17	VC	2	12	62.5	VC	3	30	72.78	VC	2	16
C29	The complexity of the design process	70	VC	4	26	63.33	VC	4	30	53.33	C	9	45	62.22	C	5	30
C30	The inability of specifying qualified and quality local manufacturers	50.83	C	8	44	47.5	C	10	43	46.67	C	10	51	48.33	C	10	48
C31	The lack of distinguishing between the smartness requirements of owner, users, operators, and facility managers	59.17	C	6	37	53.33	C	8	40	55	C	5	39	55.83	C	6	41
C32	The lack of understanding of the basis of design responsiveness of occupational health and safety precautionary measures from a technological point of view	64.17	VC	5	33	70.83	VC	3	20	59.17	C	4	34	64.72	VC	4	25
C33	The lack of specification of protection ratings and testing of systems, materials, and components	50.83	C	9	45	55	C	7	38	54.17	C	8	42	53.33	C	8	45
	Challenges pertaining to the installation and commissioning phase																
C34	Smart building projects are subject to scope variations that result in an excessive increase of budgets allocated	89.17	EC	2	6	89.17	EC	1	1	78.33	VC	2	9	85.56	VC	2	5
C35	Smart building projects are subject to variations that result in an excessive increase of time allocated	70.83	VC	4	25	50	C	4	42	65	VC	4	25	61.94	C	4	32
C36	The lack of logistical support/logistical challenges for procuring smart systems	55	C	6	39	35.83	SC	6	51	60	C	7	33	50.28	C	6	47
C37	The lack of experience in testing smart behaviors and systems	65	VC	5	31	37.5	C	5	50	65	VC	5	26	55.83	C	5	40
C38	The lack of well-trained labor that can work on smart buildings	50.83	C	7	48	33.33	SC	8	53	53.33	C	8	46	45.83	C	7	49
C39	The lack of systems' compatibility with domestic utilities and national information and communication technologies and services	37.5	C	8	53	34.17	SC	7	52	41.67	C	9	54	37.78	C	9	54
C40	The lack of expertise, support services, and skills for installation and commissioning	36.67	SC	9	54	30	SC	9	55	64.17	VC	6	29	43.61	C	8	51

(Continued on following page)

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TABLE 5 (*Continued*) Assessment of challenges affecting the adoption of smart building technologies in Saudi Arabia (ref. author).

No.	Challenges affecting the adoption of smart building technologies in Saudi Arabia	A/Es				Contractors				FMs				Overall			
		RCI	CR	CGR	OR	RCI	CR	CGR	OR	RCI	CR	CGR	OR	RCI	CR	CGR	OR
C41	The high costs of devices and installations	90	EC	1	5	89.17	EC	2	2	88.33	VC	1	2	89.17	EC	1	1
C42	The requirement of high cash flow and financing for smart building projects	83.33	VC	3	10	68.33	VC	3	21	73.33	VC	3	15	75	VC	3	14
	Challenges pertaining to the operation and maintenance phase																
C43	The operations and maintenance costs (OPEX) are relatively high compared to regular buildings	90.83	VC	1	3	86.67	VC	1	4	87.5	VC	1	3	88.33	VC	1	3
C44	The absence of operations and maintenance teams during early project phases means a lot of risks evolve during the operation and maintenance phase	55	C	9	40	57.5	C	10	35	65	VC	9	27	59.17	C	9	36
C45	The need to reduce replacement cycles of systems	54.17	C	10	43	59.17	C	8	33	60.83	C	8	31	58.06	C	10	37
C46	The lack of skilled and specialized maintenance and operation technicians	41.67	C	12	51	42.5	C	12	48	45.83	C	13	52	43.33	C	12	52
C47	The lack of ensured guarantees and warranties	63.33	VC	7	34	56.67	C	11	36	70	VC	7	19	63.33	VC	8	29
C48	There is a continuous change in operation and maintenance requirements, which affects systems' effectiveness	62.5	VC	8	35	65	VC	7	27	65.83	VC	8	23	64.44	VC	7	27
C49	There is a continuous change in users' lifestyles and behaviors	77.5	VC	5	16	79.17	VC	3	13	76.67	VC	3	11	77.78	VC	4	12
C50	Reliability (smart building systems must aim to be robust)	40	C	13	52	40	C	13	49	48.33	C	12	50	42.78	C	13	53
C51	The changing demand for security that affects systems' effectiveness	88.33	EC	2	8	75.83	VC	5	15	72.5	VC	6	17	78.89	VC	3	10
C52	The changing demand for privacy that affects systems' effectiveness	80	VC	4	11	79.17	VC	4	14	74.17	VC	5	13	77.78	VC	4	12
C53	The changing functional requirements for controlling and monitoring capabilities	50	C	11	47	58.33	C	9	34	53.33	C	11	47	53.89	C	11	44
C54	The social implications of the accessibility of smart technologies (e.g., elderly use of technologies, gender requirements)	84.17	VC	3	9	83.33	VC	2	8	83.33	VC	2	6	83.61	VC	2	7
C55	The lack of understanding of human–smart systems interactions and behaviors (involvement of virtual reality, augmented reality, and responsive intelligibility)	74.17	VC	6	19	66.67	VC	6	24	75.83	VC	4	12	72.22	VC	6	17

Notes: c, challenging; A/Es, architects/engineers; FMs, facilities managers; RCI, relative challenge index (%); CR, challenge rating; CGR, challenge group ranking; OR, overall ranking; EC, extremely challenging; EC, very challenging; and C challenging.

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6 Conclusion and recommendations

This study explored the challenges that impact the adoption of smart building technologies throughout their life cycle in Saudi Arabia. Through a combination of a literature review and pilot testing, a total of 55 challenges were identified and subsequently categorized based on their alignment with the life cycle phases, which include the programming and feasibility analysis phase, design phase, installation and commissioning phase, and operation and maintenance phase. To assess the significance of these challenges, a five-point Likert-scale questionnaire survey was developed and pilot tested. This questionnaire served as a valuable tool for quantifying the qualitative research variables that were identified. As a result, it streamlined the process of prioritizing and rating the importance of these challenges with regard to their influence on the execution of smart building technologies in Saudi Arabia. This assessment was primarily focused on understanding the significance of these challenges in terms of their impact on the successful implementation of smart building projects while adhering to specified budget constraints, targeted project durations, and the mandated quality criteria that align with stakeholder expectations.

The evaluation process involved the engagement of three distinct practitioner groups, namely, A/Es, contractors, and facilities managers. Each group provided 30 responses to the questionnaire survey, and these responses were carefully tabulated and analyzed to compute the relative challenge index (RCI) value, rate index percentage, group ranking of challenges, and overall rankings for each factor. Furthermore, an extensive analysis encompassing all 90 responses from all three groups was conducted to ascertain the overall assessment of the challenges. This process also entailed an examination of the consensus among the three groups of respondents.

These challenges are evidently linked to different stages of the project's life cycle. The results substantiate the interrelation and direct influence of these challenges on the successful execution of these projects, especially within the context of a life cycle. Furthermore, the outcomes from both the comprehensive evaluation and individual assessments align with the discussions and conclusions presented in the existing literature. Remarkably, a high level of consensus regarding the significance of these challenges was evident among all three respondent groups. This underscores the critical importance of all the identified challenges in realizing smart building projects while adhering to the specified time, quality, and budgetary constraints.

Based on the research findings, the following recommendations are proposed to improve the practice of smart buildings:

- Encourage more research and development in smart building technologies for better adoption in Saudi Arabia.
- Provide incentives to real estate developers and building owners to implement smart buildings practices in their projects.
- Develop a comprehensive regulatory framework and standards for the adoption of smart building technologies.
- Promote public awareness and education about the benefits of smart building technologies.
- Foster collaboration between stakeholders, including the public sector, industry, and academia, to promote the adoption of smart buildings practices and technologies.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

SB: Formal Analysis, Validation, Writing–original draft. AS: Project administration, Visualization, Writing–original draft. MH: Writing–original draft, Formal Analysis, Software, Visualization. AA: Writing–original draft, Investigation, Methodology, Resources. ME: Investigation, Methodology, Resources, Writing–original draft, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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