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RESEARCH ARTICLE

The Effectiveness of 5G Technology for Smart Buildings' Energy Management

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ABSTRACT
This study highlights the necessity for developing smart building and cities across the globe in order to conserve natural resources and energy. The aim of the study is to investigate the efficacy of 5G technologies in the architecture and construction industry. The study benefits from an extensive literature review to discuss the advantages and challenges in incorporating 5G in smart buildings. 5G is found to be needed to maximize the use of artificial intelligence (AI) and IoT in architecture in order to be able to efficiently enhance the features of smart buildings by managing energy and waste.

Keywords: Smart buildings, architecture, 5G, energy management

1. Introduction

According to estimates, the construction and maintenance of buildings use between 30%-40% of the total energy produced worldwide and contribute to greenhouse gas emissions in the global environment. Because buildings use a lot of energy and resources, anthropogenic activities associated with buildings are harmful to the environment (Ghansah et al., 2021). For instance, construction makes up 40%, 73%, 20%, 90%, and 56% of the respective energy used in the European Union, Saudi Arabia, the United States, Hong Kong, and Africa (Fazli et al., 2021). Consequently, 36%, 40%, 60%, 33%, and 32% of CO_2 emissions in these same locations can be attributed to building stock. Buildings are responsible for 39% of the world's carbon emissions and 40% of its total energy use (Adams et al., 2019). Providing sufficient and comprehensively constructed infrastructures (e.g., efficient energy management, a reliable water supply, occupant comfort indoors, waste management) for construction sites has become a difficult task for the building industry as a result of skyrocketing population growth, city growth, and globalization.

Significant CO_2 emissions pass into the atmosphere as a result of building construction, operations, and management in Pakistan. The construction industry faces a number of problems and difficulties in reducing CO_2 emissions. Measures to reduce CO_2 emissions in the building sector have been hampered by the use of non-renewable energy sources, subpar building designs, and a lack of sustainability concern in urbanization (Butt et al., 2021). The development and enhancement of new technologies is greatly needed in Pakistan's construction industry by following the footsteps of developed countries that apply new smart technologies in their building construction and design processes.

Architects have introduced the concept of smart buildings in Pakistan for dealing with construction issues and carbon emissions. The concept of smart buildings has already been implemented in various developed countries of the world (e.g., China, Singapore, Sweden, Germany, USA, UK). The idea of smart buildings is used to increase a building's efficiency both inside and out and to help deliver services to users in accordance with their needs for available space (Nazir et al, 2023). A core network connected to the Internet of Things (IoT) serves as the foundation for smart buildings. IoT devices can be sensors that gather and transmit data securely back to the central network and are frequently found in outlying or difficult-to-reach locations. These may be automated systems that regulate temperature, lighting, window shades, and ventilation, or they can link to and improve the adaptability of conference room equipment and office furniture to increase workplace productivity. These might also be tools for security, such as badge scanners, remote cameras, and electronic door locks (Apanaviciene et al., 2020).

Among many of the other latest technologies, 5G technologies have become renowned and significantly useful in developed countries' building construction and management. 5G refers to the fifth generation of mobile networks and is intended to link

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practically everyone and everything, including tools, objects, and gadgets. The 5G network is expected to provide ultra-low latency, robust cybersecurity, high bandwidth data (multi-Gbps speed), greater reliability, and a high number of devices per square kilometer (Park et al., 2021). Additionally, 5G attempts to deliver a far superior and consistent user experience. Compared to 4G LTE or 3G, 5G focuses more on improving mobile broadband experiences for a wider range of use cases. All spectrum types, including shared, unlicensed, and numerous bands, are supported by 5G. 5G can also be utilized for a variety of deployment methods, from hotspots to conventional macro-cells, and also offers brand-new connectivity options such as device-to-device communication and multi-hop routing (Rinaldi et al., 2021).

The present study intends to highlight how a 5G network system can be incorporated in building construction and maintenance and what benefits will be achieved by installing it in smart buildings. This study will also make recommendations for working upon solutions and how to use new technology effectively.

2. Literature Review

Information and communication technologies (ICTs) generally have key importance in advancing sustainability goals through lower energy consumption and emissions. Due to the presence of billions of cloud-connected devices, 5G will be crucial in lowering energy use, influencing new procedures and applications, and improving energy efficiency. With 5G, new features can be created to instantly identify environmental changes, which will help with disaster recovery efforts. 5G aims to minimize energy, resource, and material consumption by facilitating improved automation and digitization across such industries as manufacturing, construction, transportation, and agriculture. High energy efficiency is being achieved as a result of technological developments such as smaller chipsets that reduce power usage and device footprints.

A study (Chew et al., 2020) was conducted in Singapore to assess the efficacy of 5G technologies in building maintenance. According to the study, the incorporation of 5G technology in the construction industry can provide an enabling effect by making the system efficient and reliable. This technology can strengthen smart grid and metering systems, IoT-based monitoring, and AI-enabled analytics and enable smart energy management across a variety of industries. Working remotely, utilizing cutting-edge technologies like augmented reality (AR) and virtual reality (VR), and doing so from home reduces the need for office space, and travel would also become easier with 5G technology. Moreover, 5G will result in just-in-time efficiency in larger processes, with little waste and proactive planning. The intelligent management of people and cargo in transit results in shorter travel times and is also another feature of 5G technology.

In recent years, smart grids, wiser energy consumption, and smart home technologies have all gained popularity. These technologies without question are becoming more prevalent and influential. Smart buildings may considerably increase resident comfort in addition to being essential for enhancing cities and their infrastructure (Sovacool & Del Rio, 2020). This involves being able to enhance comfort levels, service accessibility, quality of life, safety features, and energy efficiency. Numerous definitions are found for the term *smart building*, and the majority of these are centered on the efficient energy usage and the idea of a smart grid. Features in intelligent management systems allow large amounts of data to be stored and analyzed. As a result, using these features in construction and management can greatly enhance energy management and utilization. This happens because electrical equipment on a grid has the capacity to work and adjust to novel situations, which is basically what distinguishes a smart building system from other types of construction and buildings. Services that leverage IoT and Big Data technologies are therefore clever for making extensive use of analytical data and machine learning (Jia et al., 2019).

2.1. Applying 5G Technologies in Smart Buildings

Many developed countries that are looking forward to managing environmental and health issues and making efficient systems in different domains in their countries have started applying 5G- enabled IoT systems in their infrastructure. Huseien and Shah (2021) presented the summary of different countries' usage of 5G in Table 1.

As discussed in the previous sections, the construction industry is a highly dynamic field in which communicating with moving parts (e.g., machinery, personnel) is critical. Wired communications are not an option in this kind of situation, because they cannot respond quickly to changes or facilitate user mobility. Therefore, using wireless communications in this setting is crucial.

Various wireless technologies have been suggested for implementing IoT in the construction industry. Cellular networks, short-range networks, and long-range networks are the three categories into which the suggested wireless technologies fall. However, these technologies are unable to meet every need in this industry.

Table 1. 5G in Developed Countries

Country	Application	Source	Purpose of Use	Reference
Singapore	Residential Structure	IoT	Enhancement and management of energy system for smart grids in residential buildings.	Viswanath et al. (2016)
China	Medical centers and hospitals	IoT	Location of the occupant for hospital department route	Chunjiang (2016)
Malaysia	Medical centers/hospitals	AI	AI used for drug research and discovery.	Mak & Pichika (2019)
USA	Medical centers/hospitals	Machine Learning	The Health Guard facility continuously assesses & compares body functions using associated devices.	Newaz et al (2019)
Italy	Business plazas	IoT	User-oriented building maintenance applications.	D'Elia et al. (2010)
South Korea	Smart Factory	AI	Improve system performance, remove delays in real-time processing, support numerous machines and multiple single protocol products, reduce time and cost, resolve data loss issues, and increase the effectiveness of horizontal data distribution and exchange activities.	Kim & Jeong (2019)
Sweden	Smart Industry	AI	Big data management and predictive maintenance.	Akerman et al. (2018)
Finland	Smart Factory	AI	Enables the division of network functions among commercial entities across various network domains.	Walia et al. (2019)

Three service categories have been defined: ultra reliable low-latency communications (URLLCs), massive machine-type communications (mMTCs), and enhanced mobile broadband (eMBB). New features have also been included, such as network slicing. Massive Multiple-Input Multiple-Output (MIMO), multi-connectivity (MC), and vehicle communications are the three main 5G features that enable it to satisfy the demands of the construction industry.

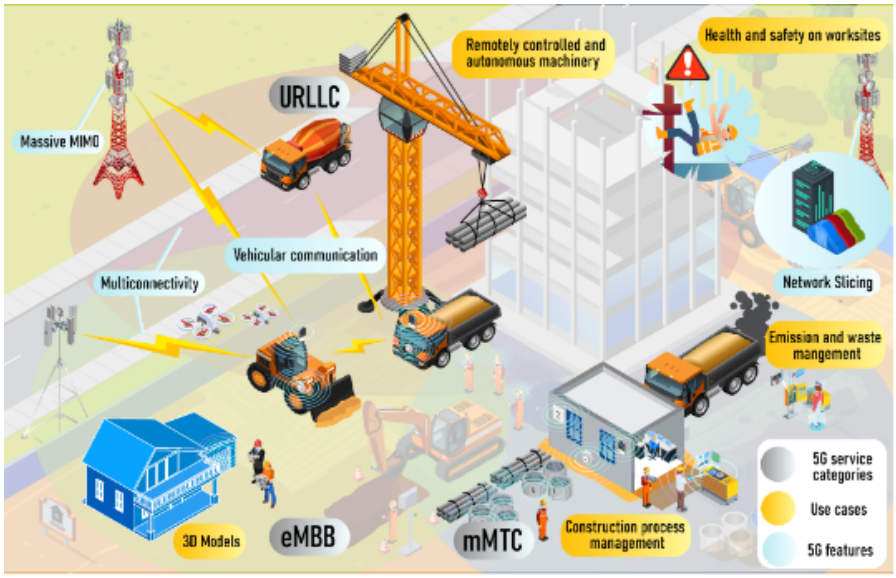

Figure 1. Implementing 5G at a site (Mendoza et al., 2021).

2.2. Categories of 5G Services

Figure 1 is depicting an effective implementation of 5G at a site with all its features that are being explained below.

- eMBB: Enhanced mobile broadband has to do with applications that demand fast data rates over a wide area. These types of services will be useful for applications related to the construction industry that have rigorous throughput requirements, such as the visualization of 3D models using AR and VR services and the observation of work sites using high-quality video cameras.
- mMTCs: Massive machine type communications feature an unusually large number of connected devices that often only require a small amount of traffic. The most significant application of this type of service is in IoT networks. Numerous sensors and other gadgets (e.g., cameras, wearables) can be utilized in the construction sector to monitor job sites.
- URLLCs: Ultra reliable low-latency communications have emerged as a crucial component in critical applications with stringent reliability and latency requirements (e.g., behicle communications, remote monitoring).

2.3. 5G in Architecture and Construction

This subsection presents a high value plan for incorporating 5G in the construction sector. Information sources, communications technologies (5G), data processing, applications, and network administration make up the bulk of this design.

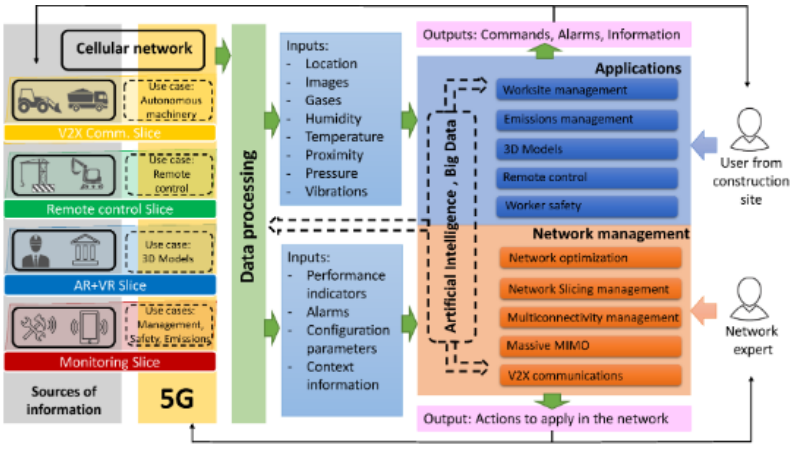

Figure 2. Incorporating 5G into the architectural system (Mendoza et al., 2021).

Figure 2 shows how 5G technology can be used at different stages of smart building construction and maintenance. Previous studies have shown the impact of its application on the efficacy of a new architectural system for obtaining better outcomes in construction and infrastructure. Meanwhile, the present study focuses on future opportunities where a 5G network can be utilized more beneficially to enhance productivity in the construction sector, especially in developing countries such as Pakistan.

3. Methodology

Table 2. Summary of Evaluated Papers

Study Title	Study Objectives	Methodology	Study Outcomes	Authors
Evaluating the roadmap of 5G technology implementation for smart building and facilities management in Singapore.	To evaluate the effectiveness, challenges, and benefits of 5G technology used in SFM applications.	Literature review	A framework was developed for teaching and training students to increase their motivation and understanding of 5G networks.	Chew et al. (2020)
Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies.	To critically examine smart home technologies.	Dataset including expert interviews, site visits, and a literature review.	Provided seven policy recommendations for smart home sustainability.	Sovacool & Del Rio (2020)
Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications.	This study looks into cutting-edge initiatives and IoT adoptions for the creation of smart buildings in academic and commercial settings.	Literature review	A number of current IoT building apps that help achieve the essential objectives of smart buildings are chosen and presented.	Jia et al. (2019)
Potential Applications of 5G Network Technology for Climate Change Control: A Scoping Review of Singapore	Reexamines the advantages of 5G network technologies for improving Singapore's smart city efficiency and reducing the effects of climate change, resulting in a clean environment conducive to healthy living.	A scoping review	Showed Singapore's clever approach to managing energy, waste, water resources, agriculture, risk factors, and economy to greatly help slow down climate change and meet the country's sustainability objectives.	Huseien & Shah (2021)
5G for Construction: Use Cases and Solutions	Discusses the advantages of utilizing 5G mobile networks in construction.	Literature Review	Established many use cases and associated requirements associated. Noted the primary 5G features that cater to these use cases and suggested a global framework for 5G tech usage in construction.	

The study is based upon an extensive literature review. The summary of all the articles that were reviewed is given in Table 2. For this purpose, the studies that are to be considered in the present study must:

- Have a focus on smart construction and architecture, the latest technologies in the sector of construction, and the use of 5G in construction,
- Have been published between 2019-2023,
- Be in English,
- Be systematic reviews, a literature review, or evaluation study.

The relevant literature was searched with the help of published papers in different reputed journals using reliable databases such as Google scholar, MDPI, Science Direct, and Research Gate. Some of the main keywords used to explore the literature are: smart buildings, AI, 5G network, architecture, and technology.

The study has reviewed and critiqued each paper. A code sheet was created to record important study-related information to help with this process. The study used the reference lists of articles that had been retrieved through the databases and employed the snowball method to find more material. Following the same procedure, databases were searched first by title, then by abstract and conclusion, and then by full text to find the relevant articles.

4. Discussion

A 5G network can make a fully mobile and connected society possible as a complete ecosystem. Additionally, 5G can enable the creation of innovative business models that add value. The amount of traffic and the demand for data transmission over mobile broadband will both dramatically rise in the next years. Mobile broadband will also be employed in more situations. 5G will greatly aid the creation of new services that can be used more extensively and help develop currently available mobile broadband services. 5G represents how a large variety of applications, from those with minimal bandwidth to those with high data throughput and latency requirements, will be able to use 5G (Blanco et al., 2017). The features of smart buildings are being showed in Figure 3.

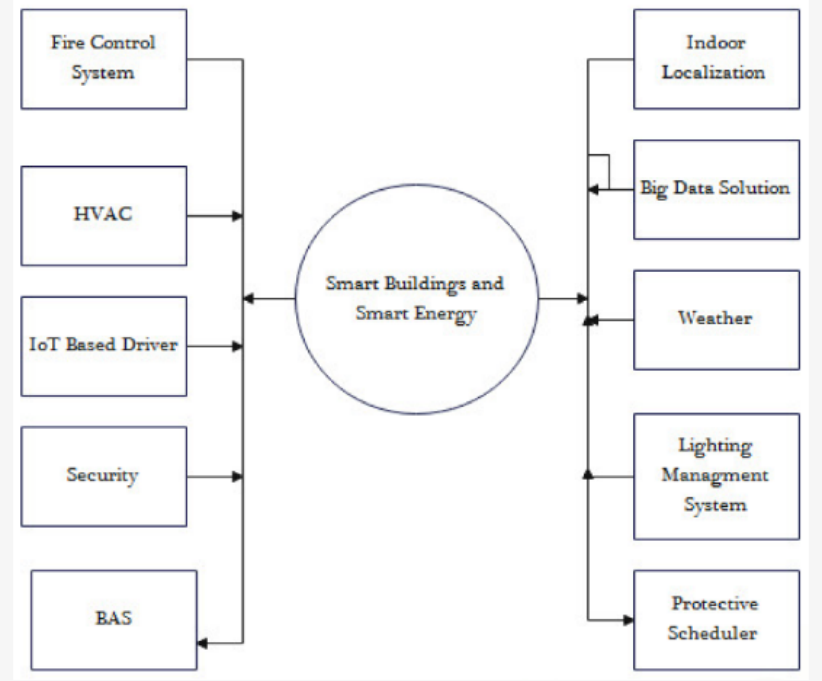

Figure 3. Smart building features (Mazhar et al., 2022).

By combining many various types of urban infrastructures and having them function together, smart and efficient cities aim to create more friendly and creative urban surroundings. In this case, smart buildings are crucial to smart cities and are essential to their viability. Residents of smart cities and buildings can rest easy knowing that IoT technologies and AI are protecting them. Sensor data is used in IoT smart buildings to reduce energy use and improve operational efficiency. Energy use can be controlled

by incorporating IoT devices into smart cities and buildings (Ahsan et al., 2021). To save energy in smart buildings, IoT gathers and investigates environmental variables such as air pressure, temperature, and humidity. IoT sensors are used in smart buildings to monitor and control lighting by turning on and off lights as needed. IoT solutions can enhance crisis response and management, which will enhance outcomes in risky situations.

Incorporating 5G technologies into the construction industry is possible with the help of government authorities and other stake holders who aim to construct smart buildings. Information sources, communications technologies (5G), network management, and data processing applications make up the bulk of this design. The various elements of the architectural sector are defined in the following subsections:

- Sources of Information: These sources are connected to the many components of a construction site and have been employed in the use of Construction 4.0. As a result, sensors installed in vehicles, machinery, people, and other objects are potential information sources at a construction site, as well as cameras for worksite surveillance, vehicle communications, and drone remote control; these can be wearable for worker safety or involve AR and VR technology for displaying building information modeling (BIM).
- Communication Technology: This category of services permits the development of preexisting usage cases related to pollution control, waste control and management, and the majority of applications for construction and construction management. 5G technology helps in this category through network slicing.
- Data Processing: This block's primary objective is to produce a set of inputs that have been effectively chosen and utilized for each algorithm specified in the work system. Big data, data analytics, and AI will all be crucial for this.
  - o Cloud, fog, and edge computing are taken into account for processing data. The usage of network resources is referred to as cloud computing. High availability on-demand data processing and storage services are offered via cloud computing. However, cloud computing is limited in its ability to conduct real-time processing tasks because of the separation between nodes for processing and storage and for information gathering plans (information sources). Distributed data processing and storage duties are respectively referred to as fog computing and edge computing. These kinds of methods have the processing and storage nodes located closer to the information sources.
- Application: This area contains all the technologies and applications specified for Construction 4.0's automation, digitization, and process optimization. The inputs in this block are numerous. Applications for worker safety may make advantage of the position of the personnel, high-quality video images, and data on gas concentrations, humidity, or temperature. Applications involving the management of garbage or construction may also use this environmental data. Applications such as remote machine control or AR also use precise location data and high-quality photos. These programs will use the data they get as input to carry out such tasks as automated decision-making, forecasting the potential condition of a construction site, finding and identifying issues, or computing them.
- Network Management: The primary goal of these apps is to maximize 5G's features to achieve the greatest building automation outcomes. These applications can also automatically adjust to changes in the workplace thanks to the use of data analytics and AI technology.

5. Conclusion

The study has intended to review the advantages of incorporating 5G technologies in construction, such as are being used in developed countries like Singapore. This article has examined the use of AI and the potential issues with 5G technology in smart building management and smart energy, as well as their possible fixes as 5G technology becomes more widely utilized in the fields of infrastructure management and smart building. These programs need a range of instructions and inputs, such as configuration parameters, performance indicators, and background data regarding the condition of the workplace, including machinery and equipment quantities, number of workers, and necessary use cases. The execution of these applications can yield a variety of outcomes.

This study may also facilitate developing countries in understanding the benefits and challenges of 5G technology so that their architectural systems can be revised. This article is an educational resource for providing information to stakeholders working in the construction industry.

6. Recommendations

The incorporation of numerous IoT-based smart devices is necessary for smart building management activities as a source of big data production. To achieve real-time performance targets and to integrate with smart building infrastructures, a decentralized cloud storage system must be designed. Future research on the cost-effective design and execution of this storage system will

therefore be crucial to increasing the global focus on smart city strategies. Utilizing renewable energy sources is essential for addressing the challenges related to scarcity of non-renewable sources of energy and for ensuring the viability of city functions and operations.

Due to the advancements and broad usage of new technologies, fifth-generation technologies have the potential to improve the functionality of structures, communities, and cities. The rules of usage, including the domain-specific language, must be developed alongside machine learning- and AI-based methodologies in order to employ them in 5G smart city technologies.

Keeping sensitive data in networked environments secure is crucial. Citizens often choose not to use ICT platforms that have any ambiguity in this regard, as such issues reduce the viability and dependability of city operations. Thus, the application of group security techniques in smart cities is a crucial field for future research.

The gaps in the body of knowledge on how ML, DRL, and AI techniques based on 5G technologies can be applied to raise the effectiveness of smart cities can also become a focus for researchers and industry experts.

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