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A review on 5G technology for smart energy management and smart buildings in Singapore

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HIGHLIGHTS

- Various benefits of 5G network applications were reviewed.
- 5G networks were shown to support IoT for the advancement of smart structures.
- Artificial intelligence-based smart energy and building management were discussed.

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ABSTRACT

Sustainable and smart building is a recent concept that is gaining momentum in public opinion, and thus, it is making its way into the agendas of researchers and city authorities all over the world. To move towards sustainable development goals, 5G technology would make significant impacts are building construction, operation, and management by facilitating high-class services, providing efficient functionalities. It's well known that the Singapore is one of top smart cities in this world and from the first counties that adopted of 5G technology in various sectors including smart buildings. Based on these facts, this paper discusses the international trends in 5G applications for smart buildings, and R&D and test bedding works conducted in 5G labs. As well as, the manuscript widely reviewed and discussed the 5G technology development, use cases, applications and future projects which supported by Singapore government. Finally, the 5G use cases for smart buildings and build environment improvement application were discussed. This study can serve as a benchmark for researchers and industries for the future progress and development of smart cities in the context of big data.

1. Introduction

Reports [1–3] indicate that the worldwide urban population is expected to reach 66–70% by 2050. This significant increase in urbanization will undoubtedly have major effects on the management, security and environment of big cities. Thus, in order to develop an effective approach to ensure the services remain energy-efficient and reliable without sacrificing individuals' comfort and happiness, many researchers have investigated the impacts that such urbanization will have on cities, communities, infrastructures and the environment [4–6]. This research topic is still prevalent, even though it has been investigated from many perspectives by other researchers [7,8]. At present, the implementation plan is still in progress and many different types of knowledge and technology from various disciplines are required. The development of smart buildings, communities, and cities has often been considered isolated when it comes to technology. This is primarily because existing internet technologies have several limitations and the sensor networks that have been implemented in buildings, cities, and infrastructures are not seamlessly connected [9]. The fifth generation (5G) wireless networks are on the way to be deployed around the world. The 5G technologies target to support diverse vertical applications by connecting heterogeneous devices and machines with drastic improvements in terms of high quality of service, increased network capacity and enhanced system throughput [10]. With the many advantages of 5G technology (Fig. 1), several problems which are restricted the smart buildings, cities and infrastructures solved.

Over the last two years, 5G technology has been increasingly used in the building industry. Both researchers and practitioners continue to investigate the benefits of 5G technology. For instance, many companies (such as IBM and Intel) have already created and launched smart

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buildings [4], which highlights the competitive edge and the promising future of 5G. Understanding how 5G technology can be used effectively in the creation of smart buildings is thus crucial. Nonetheless, as far as the present researcher is aware, no comprehensive investigation has yet been carried out to explore the implementation of 5G technology in building development, even though some small surveys relating to 5G-based smart buildings have been carried out (see Fig. 2) [11]. Moreover, given the increasing research attention being paid to the topic, an analytical review may serve as a key foundation upon which researchers can develop their investigations in the fields of civil, construction, and architectural engineering. Thus, as the 5G sector is predominantly technology-orientated and plagued by a top-down approach in which users are not the key stakeholders, a more comprehensive understanding of the technological needs of the building industry is required. This will help to enhance 5G technology and speed up the process of creating smart buildings.

The development of 5G technology has been largely driven by smart mobile devices and advanced communication technologies. It may thus serve as a technical enabler for a whole new range of business opportunities and industrial applications. Moreover, it may enable different devices to work together seamlessly. In the future, 5G cellular networks will undoubtedly revolutionize global industries, which will have profound effects on businesses and customers. The most crucial part of smart city applications is IoT, which generates significant amounts of data [12,13]. Given the vast quantity of such data and its complexity, selecting the most suitable and efficient actions is somewhat challenging. The most effective methods to use for analysing big data are advanced techniques such as AI, ML, and Deep Reinforcement Learning (DRL). This can help companies to make the best possible decisions [14] based on their long-term objectives [15]. Moreover, to further improve the accuracy of these techniques, the number of training data can be increased. This can make learning capabilities stronger and improve their decision-making outcomes [16]. In the research carried out by Allam and Newman [17], it was found that the use of advanced big-data analysis methods to create smart cities increased significantly during the same time frame. The use of IoT, Blockchain, unmanned aerial vehicles (UAVs), AI, ML, and DRL-based methods to create smart-cities are relatively new concepts that have promising futures within the world of 5G.

2. Research significant

The ways in which people communicate have significantly changed due to rapid technological advancements. The latter will undoubtedly impact the urban landscape in Singapore soon. Buildings in the future will be much smarter due to the rapidly-growing convergence of new data streams, the development of sensor technology and innovations in the science of building materials. Many old buildings have already been replaced by towering skyscrapers. However, experts have suggested that, as technology and social needs change, the skyscrapers themselves may be subject to major transformations in future. Social needs in Singapore changed continually throughout the 60s, 70s, 80s, 90s. They continue to change today, meaning that urban planners and architects must find ways to address these needs. In the 1960s, social needs were very basic. They became slightly more complex in the 80s and 90s when concepts such as identity and tropical architecture became widely-discussed topics. In the 2000s, issues of sustainability and liveability play a significant role in determining modern Singapore architecture. Over the last two decades, Singapore's building environment has continually developed with an increasing focus on improving sustainability, accessibility and labor productivity within the construction industry.

In 2005, the Building and Construction Authority implemented the Green Mark Scheme. This scheme intended to help developers to ensure that their practices were environmentally-friendly. In 2005, there were just 17 green buildings in the city of Singapore, which has now risen to over 2100. Buildings are becoming increasingly environmentally-friendly and big industry players have suggested that they will also become smarter in the near future as they begin to implement innovative technologies in building design. Singapore's Smart Nation initiative will

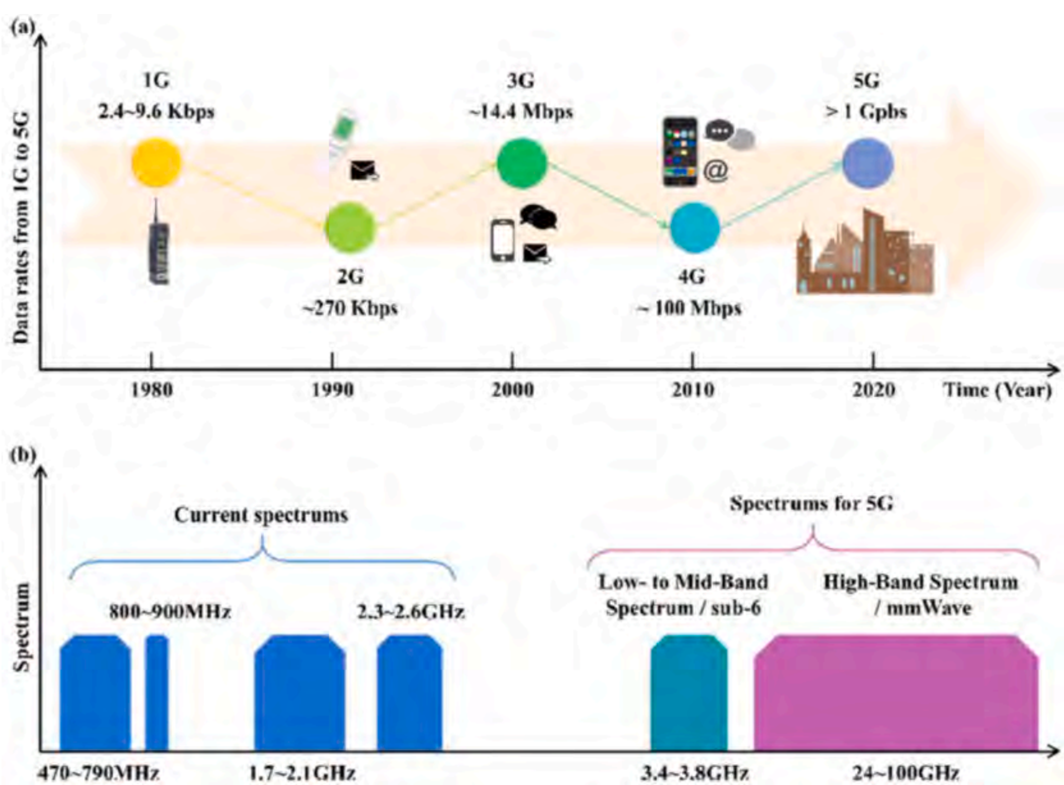

Fig. 1. Development (a) data rates from 1G to 5G (b) spectrum [9].

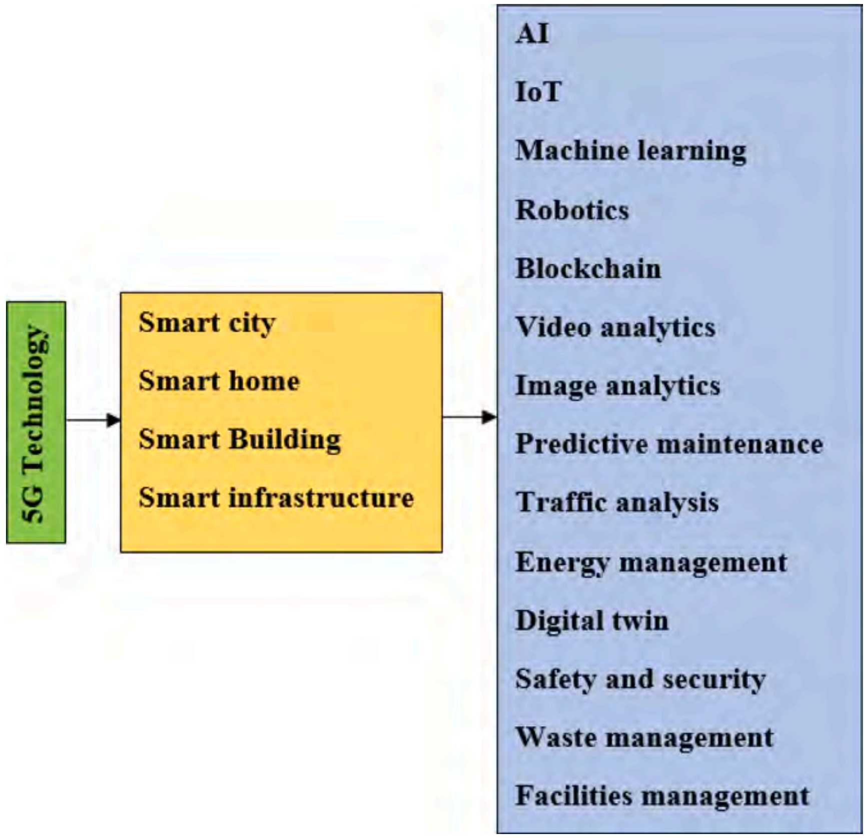

Fig. 2. 5G application cases in smart buildings.

play a significant role in this, as it will rely more heavily on data analytics, and various Infocom and media technologies. An individual can already use their mobile phone to control their ovens, light switches and washing machines. Meanwhile, the new technology offers optimised energy usage solutions in commercial buildings.

As the economy shifts from traditional industry silos to integrated digital ecosystems, businesses will thrive if they focus relentlessly on being able to continuously create new value, incorporate the principles of Services 4.0 (IMDA, 2020), which envisions services to be end-to-end, frictionless, empathetic and being able to anticipate customer's needs, and build on digital economies of scale. With the popularization of deep technologies such as Artificial Intelligence (AI), Internet of Things (IoT) devices, Immersive Media (AR/VR), and cloud-based technologies, players in Built Environment – developers, architecture and planning firms, construction firms, equipment and technology suppliers, estate management companies as well as their security, cleaning, and maintenance partners – will see the entire Built Environment value chain transformed as firms invest in new capabilities.

The motivation for this paper comes from the nature and requirement of smart buildings in Singapore. With the rapid pace of technology development and collaboration trends of different industries, this paper aims to guide stakeholders in the building industry of a better path to properly use 5G technology to address specific issues, and inspire researchers' thinking in the technology industry for future advancing.

3. Overview of 5G technology for smart city

Fifth-generation (5G) technology is often called 'beyond 2020 communication' and this will be the next significant phase in the development of global telecommunications. It has been successfully deployed in many places across the world already. There are three key features involved in 5G networks, namely Enhanced Mobile Broadband, Ultra-reliable Low Latency Communication services and Massive Machine-Type Communications [10]. 4G technology, the predecessor of 5G technology (4G) has some limitations with regard to data transfer speeds, which is limited to 100 Mbits/s downloads. However, as can be seen in Table 1, the innovative 5G technology progresses towards more advanced and smarter uses of technology. 5G is a largely communication-based communication network. Moreover, to ensure that the correct layer of control is used for a specific application, 5G can be dynamically programmed. Given the high-speed data transfer offered by 5G technology, many different businesses will be able to use it [18].

For time-sensitive applications, 5G technology incorporates strict latency requirements of under 1 mS. Alternatively, it incorporates relaxed latency requirements for non-time-sensitive applications. Additionally, 5G could be used in different settings in which stringent process controls and thus high levels of network reliability are required. Alternatively, for applications that are not process-sensitive, network reliability can be more relaxed. 5G technology can also be used in settings whereby vast amounts of information need to be processed in real-time. In settings where only small amounts of information need to be processed, the system can be requisitioned. IoT has now become one of the most fundamental 5G applications and is used in many industries and industrial sectors. In recent years, its popularity has grown exponentially. Gartner explains that, by December 2020, there may be as many as 24 billion IoT-enabled devices [19]. As IoT continues to evolve, an increasing number of points for accessing and sharing information via the network (the Internet) are required. The growth of IoT has been largely supported by centralized data storage systems (like the cloud). Nonetheless, users often have no idea how the information that they have shared on the system is used, thus rendering it a black box. In such cases, a centralised system may be unable to ensure data transparency [37]. Blockchain technology is a possible solution that can be used to improve privacy and security on internet-based networks. In Fig. 3, the benefits of employing blockchain technology with 5G-enabled IoT for purposes of industrial automation are presented. The transformational

Table 1
Advantages of 5G communication technology.

Better network performance	5G networks will be able to give users ultra-high transfers speeds, ultra-low latency, ultra-reliable experiences, ultra-high connection density, ultra-high traffic density and ultra-high mobility access. It will also provide enhanced spectral efficiency for the networks and will lower the costs associated with network operations and maintenance costs whilst simultaneously providing enhanced network energy efficiency.
Smarter network operations	Through 5G technology, intelligent perception and decision-making skills will be significantly enhanced. The innovative features of 5G technology, such as real-time perception and the capacity to analyze user characteristics (such as their preferences, geographic location, network context and terminal status) will largely help companies to develop technological solutions which can ensure that data-driven network functions and resources are efficiently deployed.
Network functions are more flexible	The development of 5G technology is largely based on user-experience. It is thus designed to fulfil mobile internet needs and the requirements of IoT businesses. With regard to access networks, both plug-and-play, as well as self-organising base-station networks will be supported by 5G technology. This will enable a lightweight access network topology to be created, which will ensure that the system is easy to use and maintain. With regard to core networks, the process of using packet-core networks to develop innovative network functions will be redesigned and simplified to ensure that the system and forwarding functions are efficient, and that network control is flexible.
Network ecology is friendlier	The requirements generated by vertical industries and new industry ecologies will also be supported by 5G networks through the provision of a more user-friendly and open network. By enhancing and opening up network capabilities, third parties will be provided with a flexible service deployment service. The purpose of this is to facilitate friendly interactions with third-party applications. Tailored services can be provided on-demand through 5G networks. Moreover, business networks can be enhanced, innovative environments can be developed and ultimately, the value of network services can be enhanced.
Reliability comparison	The data transmission process in industrial automatic control systems is extremely reliable. At present, wired communication systems such as Ethernet, hubs and switches have been around for a while and are highly reliable. In 5G networks, channel coding technology is used to implement verification information. The 5G system is also able to identify any information that becomes lost during transmission and can determine whether any transmitted information is wrong. In such cases, the error will be automatically fixed.
Cost comparison	The information points in 5G communication systems are very flexible, meaning that can be modified and adjusted very easily. No embed pipelines or weak bridges are required, and there is no need to lay cables. This ultimately saves significant amounts of money on network wiring, installation, construction and maintenance costs. Moreover, given the extreme flexibility of the 5G system, it can be adjusted at any time throughout the construction process to suit changed site conditions. The system has the flexibility to react to any changes in demand or issues caused by inter-profession conflicts. The need for any buried pipelines and bridges during the construction process is eliminated and no complex wiring work is required. The process is easy, flexible and cost-effective since there is a significant reduction in project costs.
Comparison of safety	If an unauthorised user attempts to gain access to a wired network, they will first be required to connect to the physical line and then to the network using the network card. Subsequently, they must successfully complete the network's identity verification process. To maximise system security, a firewall is set up on the wired network.

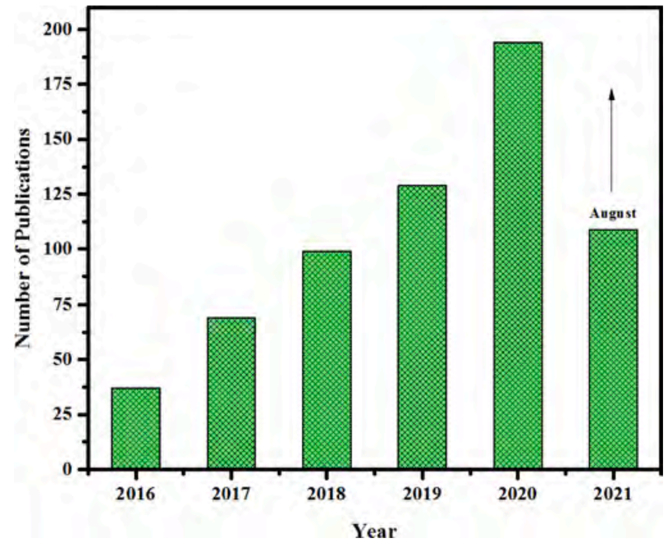

Fig. 3. The convergence of blockchain and 5G.

effects that IoT has on city infrastructure are becoming more well-known, and thus 5G technology plays a vital role in facilitating this process. Many experts are even discussing the benefits of using IoT for other purposes, including connected cars and smart metering. This would enable IoT to be used in all types of business activities across many different vertical industry sectors, including the manufacturing industry and production of raw materials. 5G will open the door innovative Smart City applications in future. Moreover, an increasing number of devices will be able to connect to the internet at any time. This would help to ensure that different vertical applications can be integrated.

4. Applications of 5G technology in construction industry and infrastructures

The services industry gradually moved away from its reliance on manual services (Services 1.0) and progressed towards efficient, internet-enabled services (Services 2.0). Now, the industry is largely orientated towards mobile, wireless and cloud technologies (Services 3.0). The next stage of development will be focused on the provision of seamless, end-to-end, frictionless services that can predict the needs of those using different technologies (Services 4.0). Services 4.0 will be developed to help businesses meet the rapidly-changing demands of customers and to sustain competitive advantages over their competitors. Innovative technologies will enable companies to automate their repetitive tasks and thus enhance productivity. Nonetheless, customers still want human interactions, and thus companies would benefit from providing human-centric services that can be facilitated by advanced technologies. New and enhanced jobs can be created by bringing together automaton and employee augmentation.

Smart home technologies, smart grids, and smarter energy use have become prominent themes in recent years. There is little doubt these technologies are spreading and growing in influence [20]. As well as playing a crucial role in improving cities and their infrastructures, smart buildings can also significantly enhance the comfort of residents. This is because it improves energy efficiency, available services, quality of life, safety controls and general comfort. Many different definitions for 'smart building' have been put forward, most of which are based on energy efficiency and the concept of a "smart grid". Intelligent management systems contain features that enable mass data to be stored and analyzed. Thus, when implemented in buildings, they can significantly enhance energy management. This is because electrical devices on a grid can learn and adapt to new behaviors, which is essentially what makes them 'intelligent' building systems. Therefore, services that incorporate IoT and Big Data technologies are intelligent, because they employ vast amounts of data in analytics and automatic learning [21]. 2019 is the first year of 5G commercialization. Seeing the urgent need for the planning and development of 5G smart cities across the country. 5G-led ubiquitous sensor networks a cornerstone of smart city development; meanwhile, the unique ability of 5G networks to meet differentiated smart city needs, smart edge system built on 5G and other technologies for collaborative intelligence. Several applications of Blockchain for 5G-enabled IoT depicated in Fig. 4. The below table (Table 2) summary several application of developed technology for smart home, building, city, industry and infrastructure.

5. Smart building system and 5G communication technology

5.1. The concept of smart buildings

Intelligent building requires a combination of traditional industry factors and new technology. In intelligent building, the most advanced communication and control technologies are used in the building construction process to ensure that it is comfortable, convenient, energy-efficient and environmentally friendly for those working or living inside [30]. Smart buildings have been defined by Chinese researchers as buildings that integrate advanced communication and technological systems (such as automatic monitoring equipment), organize information resources in the most effective way and receive at least a reasonable return on investment. Such buildings are environmentally-friendly, comfortable, efficient and energy-saving [31]. The development patterns outlined below have been seen in the field of intelligent building [32]:

(1) The control network has become more open and standardised. Given that industrial Ethernet systems are very open; they have been used in a variety of fields. Fieldbus technology will likely be very similar to Ethernet technology in the future.
(2) In future, the integration of more wireless communication technology will be prevalent in intelligent buildings. Wireless Local Area Network (WLAN) technology has grown rapidly in recent years and, as a result, the integration of wireless communication technology in intelligent buildings is set to become even more widespread in future.
(3) With regard to broadband networks, video transmission technology will be increasingly implemented in smart buildings.

Table 2
5G application cases in smart building and infrastructures.

Ref.	Country	Building type	Major use case	Related building system
[22]	Italy	Business building	IoT	Building maintenance applications for end users
[23]	China	Hospital	IoT	Occupant localization for hospital department route direction
[24]	Singapore	Residential building	IoT	Smart grid (energy control) system for residential building.
[25]	Malaysia	Hospital	AI	Using AI for drug discovery applications.
[26]	USA	Hospital	Machine learning	HealthGuard platform to continuously monitors and compare the connected devices operations and body conditions.
[27]	South Korea	Smart factory	AI	Improve the efficiency of horizontal data distribution and exchange operations, reduce the time and cost, the problem of data loss, system performance degradation, real-time processing delays, and the ability to accommodate a number of machines and a number of single protocol products.
[28]	Sweden	Smart industry	AI	predictive maintenance, big data management.
[29]	Finland	Smart factory	AI	The model allows for distribution of network functions between business actors over multiple network domains.

(4) Several different networks are used in smart buildings. To ensure that the network structure is optimal and that functions are not duplicated, investment costs are kept low, resources are centralized and information is shared efficiently, system integration and information fusion technologies are set to become major research focal points.

In light of the development trends outlined above, the key features of intelligent buildings will be integrated system breadth, intelligent depth, scale, environmental-protection capabilities, and sustainability [33].

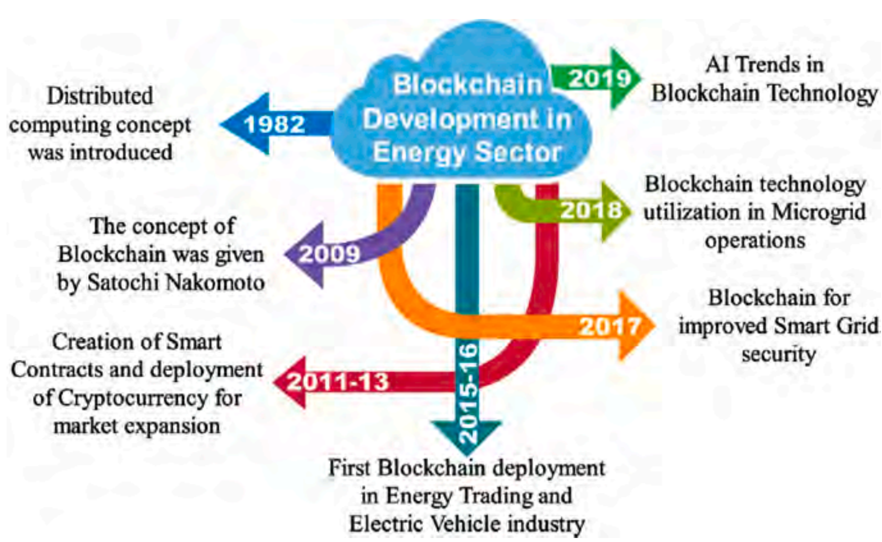

Fig. 4. Applications of Blockchain for 5G-enabled IoT.

5.2. Features of a smart city

A wide range of devices, systems, actuators and sensors are required in smart buildings, all of which must be interconnected and function together effectively. One key aspect of smart buildings is that a communication network which can be controlled remotely is installed in the building [34]. For instance, a sensor will verify that all windows are automatically closed before the air conditioner can be turned on. This sensor may be triggered by a temperature change. In other words, the sensor will trigger the air conditioner, after which information between the air conditioner and windows is shared. With regard to technical interoperability, the systems implemented to control the air conditioner and windows will most likely be produced by different manufacturers. Thus, it is crucial that an integration process is implemented to ensure that the building can be automatically controlled and managed.

5.3. Opportunities of 5G in smart buildings

A 5G network will be a full and comprehensive ecosystem designed to facilitate a society that is completely mobile and connected. It will also allow new business models to be developed that will create value. In the years come, the traffic volume and data transmission demand on mobile broadband will increase significantly. Moreover, mobile broadband will be used in more and more cases. As well as supporting the development of already-established mobile broadband services, 5G will also play a significant role in the development of new services that can be more widely applied. This means that a vast range of application will be able to use 5G, from low-bandwidth applications to services with extensive data transmission and latency demands [35]. A wide range of devices, systems, actuators and sensors are required in smart buildings, all of which must be interconnected and function together effectively to provide inhabitants with comfortable and convenient lifestyles. One key aspect of smart buildings is that a communication network which can be controlled remotely is installed in the building [34]. For instance, a sensor will verify that all windows are automatically closed before the air conditioner can be turned on. This sensor may be triggered by a temperature change. In other words, the sensor will trigger the air conditioner, after which information between the air conditioner and windows is shared. With regard to technical interoperability, the systems implemented to control the air conditioner and windows will most likely be produced by different manufacturers. Thus, it is crucial that an integration process is implemented to ensure that the building can be automatically controlled and managed. Table 3 presents this key feature in more depth, alongside the key functional objectives and technical requirements of smart buildings. To determine how IoT can directly or indirectly influence the achievement of these objectives, various IoT enabled services and the benefits of using them in smart buildings will be explored in the next section.

Table 3
Major goals of smart buildings.

No.	Goals	Descriptions	Technical Requirements
1	Location-based services	Identify building occupants or resources locations and movements for improving convenience of services in building.	Track accurate position of targeted objects.
2	Energy efficiency	Maximize the use of building energy, with the ideal condition to be a Net Zero Building (NZB), while keep a high level of service at the same time.	Communicate with external elements (building-to building, Or building-to-infrastructure).
3	Facility management	Preventive maintenance and organized operation and control of building facilities and equipment to reduce operations and maintenance time and cost.	Establish communication between building's equipment and devices
4	Indoor occupant comfort	Optimize ambient environmental conditions according to occupants' preferences for improving health and productivity.	Understand occupants' behavior pattern.

5.4. 5G use cases

5.4.1. Artificial intelligence (AI)

Artificial intelligence in smart building management will become a necessity in coming years with providing 5G technology to make buildings more adaptive and not just automated, according to a new survey of smart building tech facility managers and other end users. Smart cities generate a vast amount of data. However, to be valuable and provide important information, this data must be analyzed. In AI, data produce via machine-to-machine communications in smart cities is processed and analyzed. Machine learning and deep-learning technologies can significantly help with making predictive and preventive decisions and obtaining a holistic understanding of intra-and-inter system settings [14]. Currently, a smart building management system is capable of locking and reopening entrance doors during non-operating and operating hours, respectively. With the introduction of artificial intelligence (AI), in cases of emergency during non-operating hours (for example, a fire) in any area of the building, the system has the capacity to automatically open doors. If motion sensors are also a component of a state-of-the-art system, it can inform emergency services about the location of victims or wrongdoers. On a daily basis, a smart building systems' temperature control can be set to switch on air conditioning (AC) at a specific time prior to the operating hours, thereby facilitating a comfortable temperature for employees, customers, etc. on arrival. Enhancing such a system with AI equips it with the ability to monitor weather forecasts in real-time and gather supplementary information from sensors so as to determine the probable conditions on any given day. In the case of a large glass building face, this would mean that the AC could be adjusted accordingly. According to Green, whilst AI is undeniably an additional expense that typically recurs as new applications are introduced with the growing industry and end-user knowledge, the exciting aspect is that with the increased system connections and feeds, the system becomes more potent, thus generating greater cost-savings and advantageous outputs in the long-run.

5.4.2. Intent of things (IOT)

Information and communication technologies play a fundamental role in achieving the requirements of a smart city [36,37] because they enable data to be effectively communicated and analyzed. Moreover, they can be used to implement strategies designed to ensure that the smart city functions efficiently and safely. The most crucial aspect of smart city applications is IoT (Fig. 5) because it generates vast quantities of data [13]. It is incredibly challenging to identify and select the most suitable and efficient activities when such vast amounts of big and complex data are involved. The analyze big data in the most effective manner, advanced methods such as Artificial intelligence (AI), Machine learning (ML), and Deep Reinforcement Learning (DRL) should be used. This can play a vital part in ensuring that the best decision is made [14]. Such methods take into account long term objectives in order to determine the best possible control decisions [15]. Moreover, increasing the amount of training data can heighten the accuracy and reliability of these methods by reinforcing their learning capabilities and thus improving their abilities to make optimal automated decisions [16]. The researchers in [17] found that the development of smart cities has occurred simultaneously with the advancements to big data analysis methods. The use of technologies such as IoT, Blockchain, AI, ML, unmanned aerial vehicles (UAVs) and DRL-based methods in the field of smart city development is still in its infancy, but it looks extremely promising for the future.

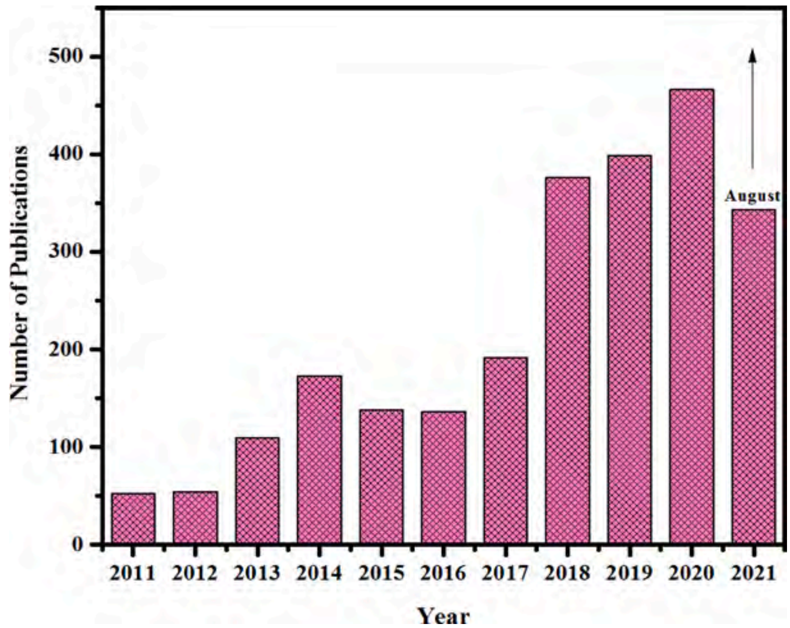

Fig. 5. IoT applications for smart city.

5.4.3. Machine learning

Due to recent developments in mobile computing, communication technologies and wireless sensing, cities have become increasingly modernised. Nowadays, various smart sensors and digital devices that operate through the internet have been installed in roads, vehicles and building to facilitate machine-to-machine communication. Essentially, this has created something called 'the internet of things' (IoT) [38]. Through this, our cities have become smarter and now have enhanced capacities due to the incorporation of cyber-physical systems that allow humans and machines to interact. "Smart environment" is a term that can be used in various fields, including smart buildings, precision agriculture and smart transportation, infrastructure and resource management. Through Machine learning (ML), computers learn how to react to things based on data collected during previous events. In instances where writing programs specifically to resolve problems is not possible, learning is the next most suitable option. In such cases, a solution is not yet known, and thus the solution must be developed based on existing data or experiences. This often occurs in instances where there is no human expertise, or when expressing human expertise is too difficult. Some examples of more conventional ML applications include speech/face recognition, spam filtering and language processing. With regard to the building industry specifically, there are several problems that cannot be addressed using traditional programming. For example, predicting the actions and preferences of residents, and predicting energy demands. Thus, to address these issues, solutions must be learned from data. The application of ML in developing industries (such as smart-building) is a topic that has become an important focal point for research communities in various disciplines, such as architecture, computer science, civil engineering, electrical engineering and power engineering.

5.4.4. Robotics

One of the most apparent differences in contemporary property development is arguably the availability of new materials, methods, and strategies that optimise efficiency and cost, and encompass technology for the future. A smart building enmeshes this remotely controllable and accessible technology from the outset. It has the potential to operate in conjunction with several disparate apartment groups, or even comparable style buildings. Generally, buildings and structures are being constructed accounting for the future, with the ability to be remotely controlled and interconnected for environmental and other reasons. However, how does this look on a lower level; for instance, in an individuals' daily life? The last several years have seen significant focus on the 'Internet of Things' (IOT) concept, and the types of products that are within its scope are beginning to become more common in homes. Some examples are smart LED light bulbs, speakers, CCTV cameras, and smart heating solutions. The benefits are that these and similar products connect to the home Internet in a hive mind, which is consequently far simpler to navigate. It could be considered an AI pillar for the whole house. Robotic technologies for building construction represent a significant departure from conventional construction approaches. The use of robots is likely to bring a host of opportunities that transform the way we design and construct buildings [39].

5.4.5. Blockchain

Over the past few years, smart cities have emerged to provide residents with high-quality services through the dynamic enhancement of city resources. They can play a significant role in improving the lives of citizens in a variety of ways, including healthcare, education, energy consumption and transportation. Nonetheless, despite the potential future benefits, the concept of 'smart cities' is still in its infancy. Moreover, there are significant security issues that must be addressed. Given the favorable features of Blockchain technology, such as its transparency, immutability, decentralization and auditability, it is likely to play a vital role in the development of smart cities [40]. As opposed to more conventional methods, blockchain technology allows digital assets to be shared between peers, with no intermediary parties being involved [41]. What's more, it is a decentralized and immutable shared database that is widely available to the public. It has thus revolutionized the ways in which individuals make payments, interact and monitor transactions by removing peers automate payments, interact, trace and track transactions by completely eliminating the central authority who would previously oversee the transactions. Before this, smart city devices would store their collected data on a central server, which could be used in future. However, there are several issues associated with the use of central servers, including a vulnerability of the unencrypted server being hacked, the possibility of revealing of sensitive information and the need for multiple management authorities to monitor the process at all times [42]. The privacy issues related to the development of smart cities have been explored by Sookhak et al. [43]. Moreover, the application of blockchain technology in smart cities and the different process models involved in ensuring safe transactions were investigated by Aggarwal et al. [44]. A review of the different attacks that could be experienced by IoT systems was conducted by Sengupta et al. [45], who also identified the key advantages of combining blockchain technology with IoT for industrial purposes. Additionally, Moniruzzaman et al. [46] carried out two case studies to explore recent advancements to the use of blockchain in smart homes. Blockchain can potentially be used in a wide variety of settings and can effectively identify solutions to problems in a variety of fields, including governance, supply chains, identity management, healthcare, voting and the distribution of energy resources. This technology can also be applied in many different industrial processes, financial services and key government functions. It facilitates data sharing and autonomous peer-to-peer connectivity between IoT devices. With regard to smart cities specifically, blockchain technology can help to ensure that data is transparent, robust, immutable and secure. Blockchain systems thus have huge potential within the field of smart city development [47].

5.4.6. Video and image analytic

With the popularity of surveillance HD cameras and the maturity and improvement of intelligent video analysis technology, more and more industries are increasingly demanding intelligent video analysis. The application scenarios are broader and more detailed than ever. Chemical. For some common functions of intelligent video analysis in monitoring, we analyze the application of some scenarios of intelligent analysis from the aspect of intelligent building. Video analytics involves image processing, tracking technology, pattern recognition, artificial intelligence, digital signal processing (DSP) and many other fields. The main intelligent analysis products are concentrated in the front-end and back-end categories. The front-end intelligence is to transplant some video analysis algorithms into the camera, and realize real-time video analysis and inspection in the camera.

5.4.7. Predictive maintenance

Fundamentally, smart buildings provide greater levels of control of their environment and operations. In terms of facility management, maintenance benefits significantly from increased control. It is a complex undertaking to achieve the optimum balance in maintenance strategy. For instance, while the hasty replacement of parts that possibly remain viable could be considered a financial and time waste, not replacing parts until they break could cause critical operational or process delays or discomfort within the building. Hence, predictive maintenance within a smart building provides increased control of maintenance processes, thereby facilitating an enhanced balance with less waste and expensive delays or interruptions. One highly effective maintenance technique that can be used to significantly lower the operational costs of public, industrial and commercial areas is predictive. This process is intricate and largely data-driven and attempts to predict the states of company assets in the future. It requires all components to be condition-monitored using a machine and collected data to be fully integrated with other information management systems. In an age of digitization and the emergence of big data science, the future of smart monitoring and predictive maintenance systems looks very promising [48].

5.4.8. Traffic analysis

Urbanization is causing a significant number of challenges, with vehicular traffic management being a prime example. It has largely impeded smooth traffic flow, as well as causing long road delays and threatened road safety. Furthermore, urbanization has had significant implications for the economy, environment, public health and other essential services. For the most part, traffic mismanagement is caused by the dynamic nature of the traffic and insufficient legacy systems that simply cannot interpret dynamic data in real-time. The Edge-Cloud based data analysis services that are used in technology systems within city settings can provide robust, smart solutions to urbanization problems in real-time [49]. To predict the inflow of traffic, the phase times of traffic movement can be adjusted accordingly. This means that congestion at intersections can be eliminated. Smart navigation allows traffic to be distributed through various alternative routes, which ultimately enhances road safety, especially at crossroads and intersections. To make predictions regarding the inflow of traffic, baseline classifiers are employed. Statistical analysis methods incorporate the J48 Decision Tree to ensure prediction efficiency. To enhance smart navigation systems in vehicles, Edge Computing is employed. This enables optimal traffic load balancing to be performed in real-time. Additionally, optimal traffic load balancing can significantly improve road safety at intersections. Research findings have thus shown that smart navigation systems can improve traffic load balancing and road safety.

5.4.9. Energy management

Energy-efficient construction is a topic that has received a wealth of research attention since buildings constitute 40% of global energy consumption. However, when creating a smart building, it is vital that residents' comfort and convenience is not disrupted. There is thus a need to find a solution which is energy efficient but does not compromise the comfort of residents. Several commercial Building Energy Management Systems (BEMS) have been developed to monitor and optimize energy consumption in buildings. Typically, such systems rely on the installation of non-intrusive meters at electric circuits, which send data about energy consumption to managers and users. Nonetheless, there is still huge room for improvement in this regard. There must be specific requirements that smart buildings must fulfil. However, a high level of context awareness is necessary to achieve this. Thus, the resident and the environment are both key factors in determining the operation of a smart building. For instance, the HVAC system should operate based on the number of individuals present in the room. Moreover, the light intensity external to the building should be monitored so that the indoor lighting can be adjusted accordingly. It is possible to accomplish this using IoT, as many researchers have found.

The statistical relationship between energy use, environmental factors, occupancy status and heating/cooling energy consumption was initially investigated by Pan et al. [50]. They concluded that, despite buildings being designed to be 'green', significant energy was still be wasted. To address this, they proposed a location-based automated energy control model which involved the use of cell phones with installed GPS location sensors and various other auxiliary services. Additionally, the model required the use of Wi-Fi. Location information was stored by the system to enable the distance between the building in question and the cell phone to be calculated. An energy policy plan will be then be created, provided that the distance does not exceed the specified threshold. This plan, for example, may include the automatic turning off of air-conditioning in order to save energy. The results were tested using an electricity meter, after which the test was carried out in a variety of settings to determine the effectiveness of the IoT-based model.

Viswanath et al. [24] created a system intended for use in residential buildings. This system incorporated aspects of IoT with specific software designs. Developed a system with IoT elements deployment and software designs on residential buildings. Several sensors, smart plugs, actuators, smart meters, and a universal home gateway (UHG) were used in the testing of each unit. The UHG facilitates communication between devices and the cloud server when information is collected and processed. This system enables building systems to be modified in line with demand, which ultimately means that peak times can be avoided. Thus, the load control is more balanced. Moreover, the system offers other services to users, such as home automation, security and energy monitoring. When presented with dynamic pricing information, users may set low load-consuming tasks as their system preferences.

IoT allows for a smart grid to be developed that can manage energy consumption at a macro-level. The smart grid is made up of various computer networks and a power infrastructure which work collaboratively to monitor energy consumption [51]. Conventional electric grids can effectively manage fluctuating energy demands. Mutual communication between utility provider and energy user is facilitated through the smart grid, which ensures that both energy and information can be transferred efficiently. A smart meter is a key feature of smart grids and plays a pivotal role in facilitating this two-way communication. As an advanced energy meter, it can measure energy use in real-time, as well as providing other important information including frequency, voltage and phase angle. Additionally, there are capable of communicating with and transferring diagnostic information to other smart meters [52].

The development of energy-efficient buildings is becoming a matter of increasing importance across the globe, and many countries worldwide have established targets to achieve this. For instance, the United States Environmental Protection Agency (USEPC) aims to decrease energy consumption in commercial buildings by 20% between 2020 and 2030. Moreover, the Taiwanese government has set a target for a 33% reduction by 2025. IoT will significantly help industries to achieve these goals, which will eventually lead to vast resource savings and global environment improvements throughout the world.

5.4.10. Digital twin

Designed with Smart Estate principles in mind, Smart Estate Solution Architecture enables Smart Estates to collect live data with Internet-of-Things (IoT) sensors built into all assets. These sensors feed into the estate's digital twin model, generating insights on maintenance issues, space utilization patterns, and simulations to forecast building performance. Such integration is beginning to increase in adoption through platforms such as digital design and construction company Willow's software, which performs data integration, management, and analysis. Digital Architecture, which utilises dynamic geospatial intelligence of the surrounding estate environment, generates models of traffic flows and activity patterns in different parts of the estate. This allows Digital Architects to make design decisions which are informed by the interaction of key parameters. Design scripting, supported by Artificial Intelligence applications, help achieve design breakthroughs. Collected data can also be integrated with other buildings in the estate of the future, where Artificial Intelligence is applied to improve on subsequent designs to better suit clients' needs, maximising space while not compromising the user experience. The combined power of sensor integration and analytics will optimise building operations beyond the current capabilities of Digital Twin technology.

5.4.11. Safety and security

Many different systems are involved in the functioning of smart buildings, and thus it is imperative that effective safety and security measures are also implemented. The importance of installing effective fire safety, home invasion and access control systems has been highlighted by smart building providers, who define them as the most important features of smart buildings. Security solutions must evolve with smart technology developments to ensure that building systems are safe and provide optimal experiences for residents. The most effective security systems work collaboratively with other building systems to generate a combined value that far exceeds the value of individual parts. By integrating important safety systems with other building systems, risks are lowered but building productivity and efficiency are maximised. Different business systems must be coordinated to create an energy-efficient building. Nonetheless, this can be a challenging task. There are several advantages of integrating facility-wide systems, including the optimization of systems, software and network infrastructure, lower technology-related costs, the capacity to draw in and retain workers, tenants and students, enhanced communications, heightened productivity and the development of a strong infrastructure with sufficient flexibility to accommodate change and modifications in line with future technological developments and changing communications needs.

5.4.12. Waste management

The new paradigm called 'the Internet of Things' has led to significant transformations with global industries. Business management teams are investing increasing amounts of money and time in transforming their services to reap the advantages of IoT [53]. For example, in the field of public waste management, decision-makers want to keep up with the crowd. However, creating an effective waste management system that operates in real-time is very difficult. Some waste management systems adopt IoT approaches which enable discarded waste placed in smart bins to be monitored at all times using sensors that measure how full each compartment is. The data is processed using IoT middleware and sent to waste management teams so that they can collect it promptly. Research carried out by Pardini et al. [54] found that residents can use a mobile app or website to find information about the public refuse collections. A prototype of the smart container and a mobile application for waste management have already been created. Moreover, a real-scale experiment has been performed to assess the system. The research findings indicate that the proposed system will largely change how individuals manage their waste whilst simultaneously optimising economic and material resources.

5.4.13. Facilities management

The operation stage is the longest phase of a building's life cycle. For this reason, facility management is a key objective of smart building construction. This involves organizational activities designed specifically to support the running of efficient and effective services. In facility management (FM), preventive maintenance and the identification of malfunctions in building equipment must be carried out swiftly to ensure that the facility runs to optimal standards. There are several issues associated with traditional FM, including low data quality, longer notification time, and delays in performing necessary operations and maintenance. However, IoT overcomes these issues by offering staff members flexible access to building facilities in real-time. As shown in Fig. 6, there are many advantages associated with efficient FM. These include significant health and comfort improvements for residents, high-quality services within the facility, reduced energy costs, efficient planning and effective distribution of resources.

D'Elia et al. [22] developed a smart-building maintenance system consisting of several different context-aware applications which monitored different variables (including humidity and temperature) using environmental sensors. This system provided automatical report feedbacks. For instance, the system can identify the location of a faulty HVAC system if a "temperature-out-of-range" message is received. It is will transfer this information to the person operating the system via a personal device. What's more, the system can provide recommendations for corrective measures to the tenant and operator so that they can initiate the repair process. This platform may be applicable to all building systems inside a smart building and may facilitate automatic monitoring of the entire building. Srinivasan et al. [55] and Nirjon et al. [56] are working towards the development of an acoustic-based HVAC maintenance system which uses the internet to transmit audio signals, after which the data signals are processed and the audio signature is matched with the corresponding HVAC system-related data.

6. 5G technology for smart buildings in Singapore

6.1. Singapore as a smart nation

In 2014 the Singapore government introduced Smart Nation. This is a national attempt to create tech-enabled solutions for and with information communication technologies, network, and big data. Singapore's evolution into a Smart Nation generates greater productivity in their businesses, which creates new opportunities within both the digital economy and for collaboration with other countries working towards a global solution. Considering the growing trends of global tech disruption, the subsequent stage of Singapore's nation-building being a smart

Fig. 6. Smart home facilities management [22].

nation is key to preserving the countries' significance. As shown in Fig. 7, the optimum approach is to be prepared and support an entirely digitised economy. As the prior 4G LTE network does not have the capability to support the transmission of crucial information from current sensors within the market, 5G technology makes a vital contribution. 5G technology was first introduced in Singapore in 2020. It enables networks to support up to 1000,000 devices per square kilometer, including embedded traffic sensors. Overall, the potency of 5G facilitates more rapid speeds, greater bandwidth capacity, and reduced latency, which is essential for growing technologies such as AI, AR, and even VR. In Singapore, there are several Proptech brands that could find the benefits that 5G generates advantageous; for instance:

- Artificial Intelligence (AI): The concept of humanoid robots is no longer simply the plot of a sci-fi movie. NTU and AIA have collaborated to develop customer service humanoid robots called Nadine and Pepper. Their programming is intended to place them in customer service roles within the insurance industry in Singapore. This state-of-the-art robotics technology, merged with the low latency 5G network, signifies robotics of an intelligence and intuitive level that is capable of world dominance.
- Virtual Reality (VR) Property Viewing: Originally, VR headsets were primarily used for gaming purposes. Now they have evolved to where they can be used in virtual house viewings. House hunters are now able to view properties by taking an immersive 360° tour via VR headset, meaning they do not have to be present at the location. An example of a product such as this is the Keppel Land Live by Keppel Land, which is under the umbrella of the Keppel Corporation. With the increasing demand for this VR tool, it is essential that the network improves, strengthens, and expands its scope. Singapore is leading the implementation of 5G technology, thus, it is clear why this small red dot could potentially become the most technology advanced city in Asia. This is another factor as to why Singapore is an excellent location for start-up companies, particularly those falling within the Proptech range.

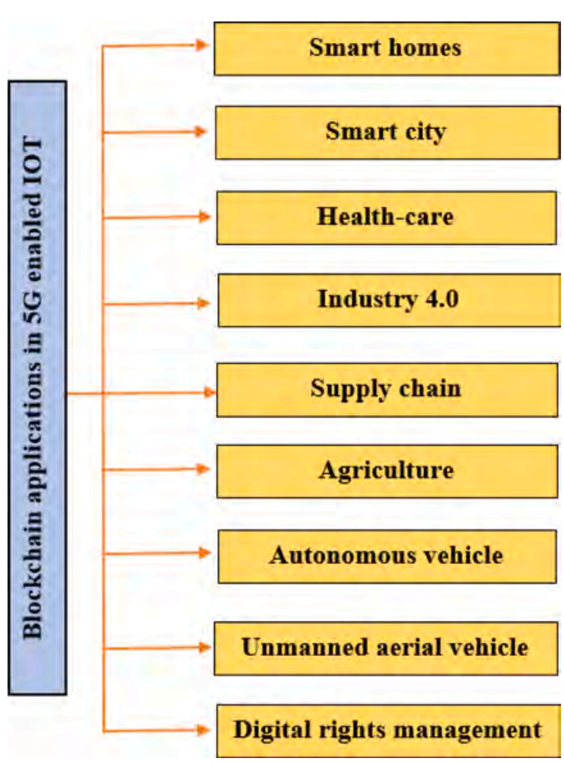

Fig. 7. Key milestones for strategic national projects.

6.2. 5G strategies and early investing in Singapore

Singapore is a leading city for technology. In fact, in terms of technology, it is ranked fourth in the world. Everything in Singapore revolves around technology. Its impressive fiberoptic network spans the entire island, and there are, on average, three mobiles devices per every two residents. It even has robot hospitals (with both human employees and robots), autonomous taxis, and vertical gardens/agricultural land that are temperature-controlled through the absorption and dispersion of heat when collecting rainwater. Singapore is famous for being very technologically advanced, and thus it is one of the smartest cities that exist. The Smart Nation program was established in the country in 2014 and required many sensors to be installed throughout the city. The sensors collect huge amounts of information regarding the daily lives and actions of residents. As Fig. 8 shows, the sensors measure everything, from the level of cleanliness in a specific area to the crowdedness of an event. This allows the government to observe what's going on around the city in real-time. However, the key factor that sets Singapore's smart city project apart, is that it is not centrally-housed with an individual company, but instead with the government.

In response to the Singapore government's call for industry transformation, several companies extending its 5G, Cloud and AI capabilities to local government agencies, SMEs, and Institutes of Higher Learning,

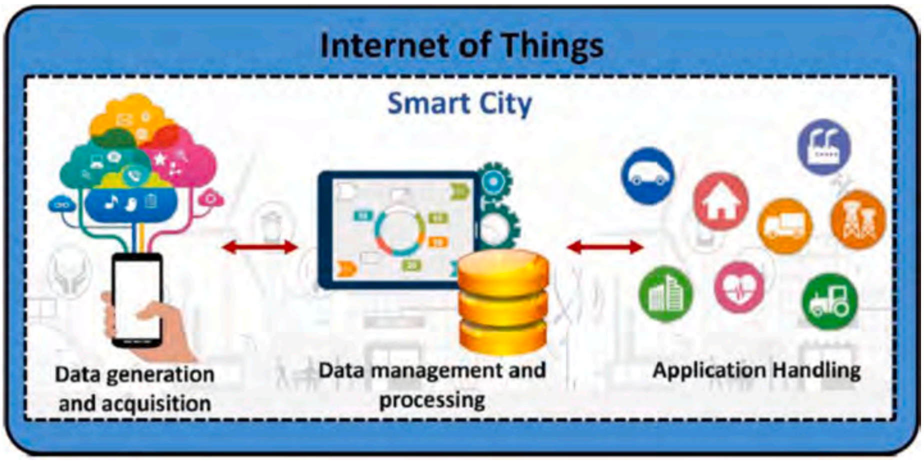

Fig. 8. Smart technology for smart Singapore.

to help accelerate Singapore's 5G application and nation-wide intelligent transformation. 5G is widely believed to be the next step in the future of mobile communications. Experts believe that it will generate new and innovative business models and advanced applications, as well as promoting business innovation and ultimately enhancing economic growth. The transformative effects of 5G are likely to be beneficial for communities, businesses and industries. Singapore has earmarked S$40 million to build an open, inclusive 5G ecosystem, where the funds will be used to support 5G tech trials for enterprise use, create new open test beds and for R&D in areas like cyber security for the next-generation mobile network, across six strategic clusters. The 5G strategic choices and policy issues illustrated in Table 4 below. However, the projected 5G penetration in east Asia (2025) present in Table 5.

Table 5
Projected 5G penetration in East Asia (2025).

No.	Country	%
1	Singapore	56.89
2	Malaysia	39.81
3	Thailand	33.00
4	Indonesia	27.24
5	Brunei	17.10
6	Myanmar	16.99
7	Philippines	14.77
8	Vietnam	6.31
9	Laos	5.44
10	Cambodia	3.18

6.3. Applications of 5G technology in Singapore

Singapore has identified several key verticals for 5G adoption including healthcare, manufacturing and maritime, and has set aside SG $40 million to develop the necessary supporting infrastructure and ecosystem (Fig. 9). The engineering teams at the National University of Singapore (NUS) and Singapore Technologies (ST) have signed upon a $6.6 million multi-year research program deal to create a "people-orientated smart Singapore" in the near future. The two parties released a statement, in which they stated that the research will have implications for "Singapore, and beyond", thus suggesting that the research will serve as a framework that other cities and countries will follow. The key focus of this research will be on smart city technologies, and specifically on maintenance, repair, and the restructuring of urban infrastructure and services. The ins-and-outs of civic operations will be explored from a digital perspective, and the research will be centered around five key aspects, namely: "prescriptive analytics; optimizing resources and scheduling; decision and sense-making; reasoning engine and machine learning; and digital twinning." The Engineering group ST Engineering have stated that, to begin with, the money will be invested in two fundamental research projects which will pave the way for the future of industry 4.0. An innovative enterprise digital platform (EDP) will be developed to serve as the backbone of connected city services and operations. Additionally, an algorithm-based urban traffic flow management system will be created to ease (and prevent) traffic congestion. The founders have defined EDP as a flexible artificial intelligence (AI) platform that will allow for data from various sources and internal/external systems to be synthesized. It will also enable cross-vertical data, as well as the opinions of customers and partners, to be collected. ST Engineering revealed that a common AI system stored within the EDP will be created and will integrate all AI models within the system, which will allow for future re-use. The new traffic management scheme will rely on AI technologies to perform traffic data analysis following a "smoothening approach". Table 6 presents examples of actions that this system will perform, which include the predicting of traffic status and the implementation of strategies to effectively control and manage traffic. This system will develop and grow with advanced innovative 5G technology, machine technologies, and the emergence of autonomous vehicles.

Table 4
5G strategic choices and policy issues.

Strategic choices	Key targets	Coordination measures	Policy issues/ challenges
Being at the forefront of the 5G developments, thriving with 5G, Having at least two operators for 5G networks	The coverage of 5G SA networks will exceed >50% of population within 24 months from the obtaining of the 3.5GHz spectrum right and the mmWave spectrum will bein use within 12 months from its assignment	The coverage of 5G SA networks will exceed >50% of population within 24 months from the obtaining of the 3.5GHz spectrum right and the mmWave spectrum will bein use within 12 months from its assignment	Choice between SA and NSA in the first phase of 5G deployment; The optimal allocation of 3.5GHz bands

6.4. Singapore 5G innovation use-cases

Singapore wants to be a world leader in 5G technology. To do this, they need a thriving 5G innovation ecosystem and a strong, secure, resilient and high-performing 5G infrastructure. The country's

Fig. 9. 5G development in Singapore.

government thus strongly support innovation efforts made by national companies. In 2016, IMDA set up a 26,000sqf PIXEL facility in the One-North innovation district to expand the innovation community and reinforce the Infocomm media (ICM) industry. 5G technology will be used to enhance PIXEL by promoting industry-wide efforts to develop innovative 5G solutions and to improve technical capabilities. In December 2020, the Living Lab@PIXEL 5G testbed will be opened, which will give companies (including SMEs) a great opportunity to test new 5G technologies. Virtual Reality (VR) and Augmented Reality (AR) will be key focal points here, as they play a significant role in developing personal experiences. This is even more relevant now as an increasing number of remote activities and events are being carried out to support industries that have suffered due to the COVID-19 pandemic, such as retail and construction. Additionally, PIXEL will further develop their programs to create an open environment in which ICM users to discuss and experiment with new 5G technologies. Table 7 highlights the significant contributions made towards the development of 5G technology by different companies.

The application of 5G in maritime operations can have many advantages. The Port of Singapore is one of the world's busiest ports and plays a vital role in the country's trading activities. 5G technology is vital in the automation and remote operation of the port and ultimately gives it a competitive edge. IMDA and PSA announced a Technology Call in 2019, in which they requested that 5G technology be trialled at the Pasir Panjang Terminal in March 2019. They called upon M1 and Singtel to experiment with the use of 5G in Automated Guided Vehicles (AGV) and Automated Cranes (see Fig. 10). The tests taking place in the largely-digital port area (which has presented many difficulties in the past for other mobile technologies like 3G and 4G) have shown positive results. Thanks to the high bandwidth, low latency and high reliability of 5G technology, high-definition video feeds can now be used by crane operators which means that operators no longer have to physically scale the cranes to use them. Not only does this improve productivity, but it significantly enhances the safety of workers. Through PSA's AGV operations, the need to manual operate prime movers has been eliminated. Furthermore, the high reliability of 5G technology has minimized the occurrence of momentary stoppages caused by connectivity issues. Such stoppages largely interrupt port activities; whereby port operators often have to carry out troubleshooting tasks to restart the AGVs.

6.5. 5G smart buildings in Singapore

6.5.1. Singapore's first 5G-enabled net-zero energy building in NUS

A Memorandum of Understanding (MOU) was signed by the National University of Singapore (NUS) and StarHub on the 12th December 2019. The aim of this was to promote joint innovation efforts in the fields of virtual reality (VR) and artificial intelligence (AI) using StarHub's 5G network located in the NUS' net-zero energy building at the School of Design and Environment (SDE). This partnership is the start of an intense process to facilitate the use of 5G (Fig. 11). The two collaborating parties will work together to apply 5G in a multitude of use cases and to provide solutions which will significantly improve education, enhance cutting-edge research and address industry needs and challenges.

A brand new 5G laboratory located in the NUS SDE4 building has been created specifically for the research activities to take place. Incidentally, this laboratory is the net-zero energy building in Singapore. It is essentially a living laboratory in which technology solutions aimed at promoting sustainable development can be developed in a human-oriented manner. Moreover, this environment also enables green building technologies to be test-bedded and developed (Fig. 12).

In the SDE4 building, 5G serves as the primary enabling technology. Thus, the building is an excellent research area that is devoted to the development and testing of practical VR and AI solutions designed to improve person-environment wellness through a sustainable ecosystem. StarHub's 5G network powers these 5G concepts at the laboratory, which are broadcast via a 3.5GHz trial spectrum. 5G provides ultra-reliable low-latency communications and enhanced bandwidth performance, which are the two key features that are necessary for VR and AI solutions to run seamlessly. At present, NUS SDE and StarHub have just begun their preliminary investigations for two key projects incorporating 5G technology, which are as follows:

(a) Mixed-Reality in Education - MILES (Measurement Immersive Learning Engagement System) incorporating 5G technology for purposes of Facilities Management:

5G AR and VR are utilized in this education and training scheme to facilitate interactive, immersive classes. Ultimately, the education process is completely digitalized by implementing technology into teaching, which improves learning outcomes. With existing network technology, a

Table 6
The sectors, cases and goals developing by several companies using 5G technology.

No.	Company/ partnered up	Sector	Cases	Goals
1	BM/ Singaporean local mobile carrier M1/ South Korean vendor Samsung	manufacturing sector	Artificial intelligence (AI) and augmented reality (AR)	To enhance a number of business operations like video analytics, predictive maintenance.
2	IMDA, Razer and Singtel	Cloud Gaming	–	Through a technology trial, 5G's capacity to fulfil cloud gaming demands will be evaluated. Moreover, this trial will also investigate the design of low latency cloud gaming hardware and how this impacts the quality of gaming experiences.
3	CapitaLand partnered Navinfo Datatech and TPG Telecom	Urban Mobility and Smart Estates	–	CapitaLand is tasked with leveraging the ultra-high-speed and ultra-low latency capacities of standalone 5G networks in these areas, where they will implement and test new, advanced estate-level solutions. At present, the company are testing a 5G-enabled Cellular Vehicle-to-Everything (C-V2X) technology designed to facilitate mobility in Smart Estates located in commercial spaces.
4	IMDA-Microsoft MOI	development environment	–	In line with Microsoft's Center-to-Center Collaboration Program, this site is linked to PIXEL to promote the development of new 5G applications and services.
5	M1 and the Nanyang Technological University (NTU)/ A*Star, NRF and the Singapore Economic Development Board.	Urban Mobility	–	Through this project, NTU will be allowed to expand their current C-V2X communications trials and thus to test the use of 5G technologies in the domains of traffic infrastructure, autonomous vehicles, and unmanned aircraft systems. Moreover, companies are allowed to create and test innovative connected mobility solutions on the campus-wide testbed.
6	IMDA, M1, IBM and Samsung	Industry 4.0	AI	The project intends to generate a more profound understanding of the advantages of 5G in industry 4.0 so as to highlight the transformative effects that 5G can have on companies and ultimately, to push forward Singapore's digital economy.
7	Singapore's Agency for Science, Technology and Research's (A*STAR) Advanced Remanufacturing and Technology Center (ARTC), JTC and Singtel	Industry 4.0	–	To develop Industry 4.0 solutions based on 5G technology.
8	NUS, StarHub, Huawei, ZPMC and ST Engineering and SG Tech	Smart buildings	virtual reality (VR) and artificial intelligence (AI)	Solutions in a Net-zero Energy Building

Table 7
List of companies have contributed to develop 5G technology in Singapore.

No.		
1	Serl.io	A local start-up company supported by PIXEL are in the process of developing an immersive platform which enables users to create, use and manage collaborative mixed-reality experiences. They intend to create a prototype of a holoportation feature that will facilitate real-time collaboration between different 5G networks.
2	Hiverlab	Hiverlab is also a company specializing in technological innovation and VR content. They have developed the Storyhive solution, an immersive VR-based communication platform. Additionally, the company has started to focus on developing solutions for mobile-based AR broadcasting between 5G networks so as to make future online communications easier for users. The 2020 Chingay Broadcast is a great example of their work.
3	UCCVR	VooX, a platform facilitating the development of 5G-based spatial and AI solutions to enhance front-line productivity is currently being created by UCCVR. In terms of monitoring and diagnostic tools. It incorporates various remote AR-based video collaboration tools, a simple industry-specific checklist platform, a Building Information Model (BIM) and digital twins.

Fig. 10. Since announced in June 2019, a total of five 5G innvoation use-cases supported by IMDA along with 5G Living Lab.

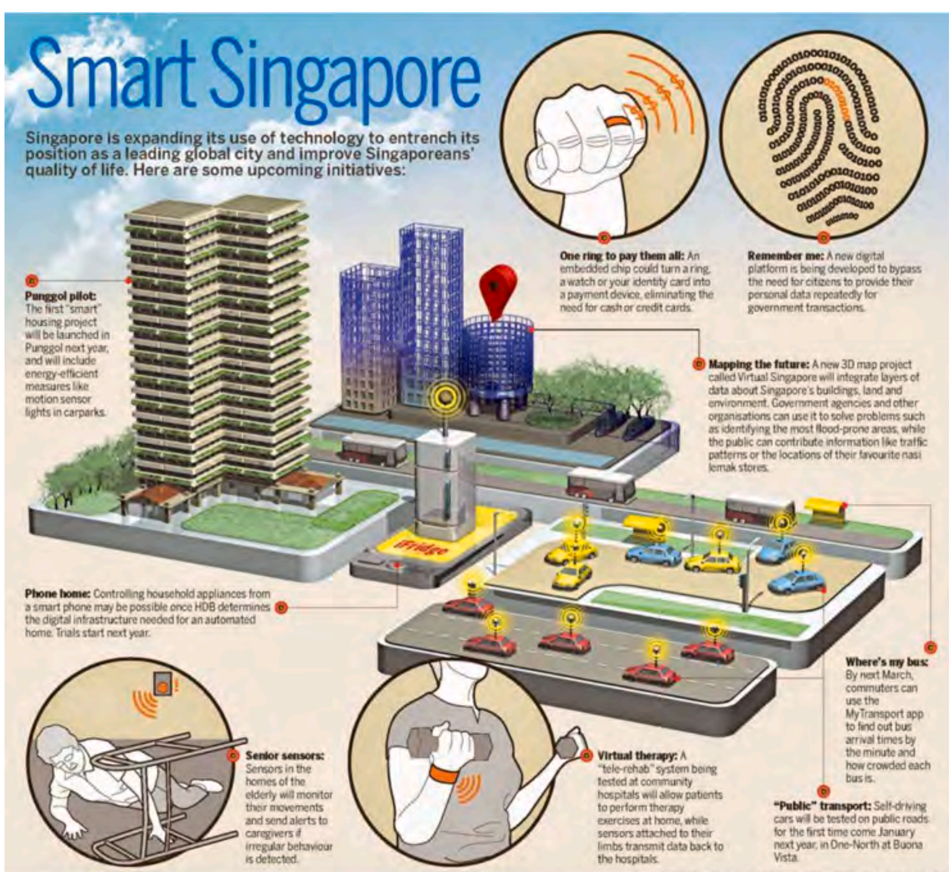

Fig. 11. Singapore's first 5G Net Zero Energy Building, National University of Singapore.

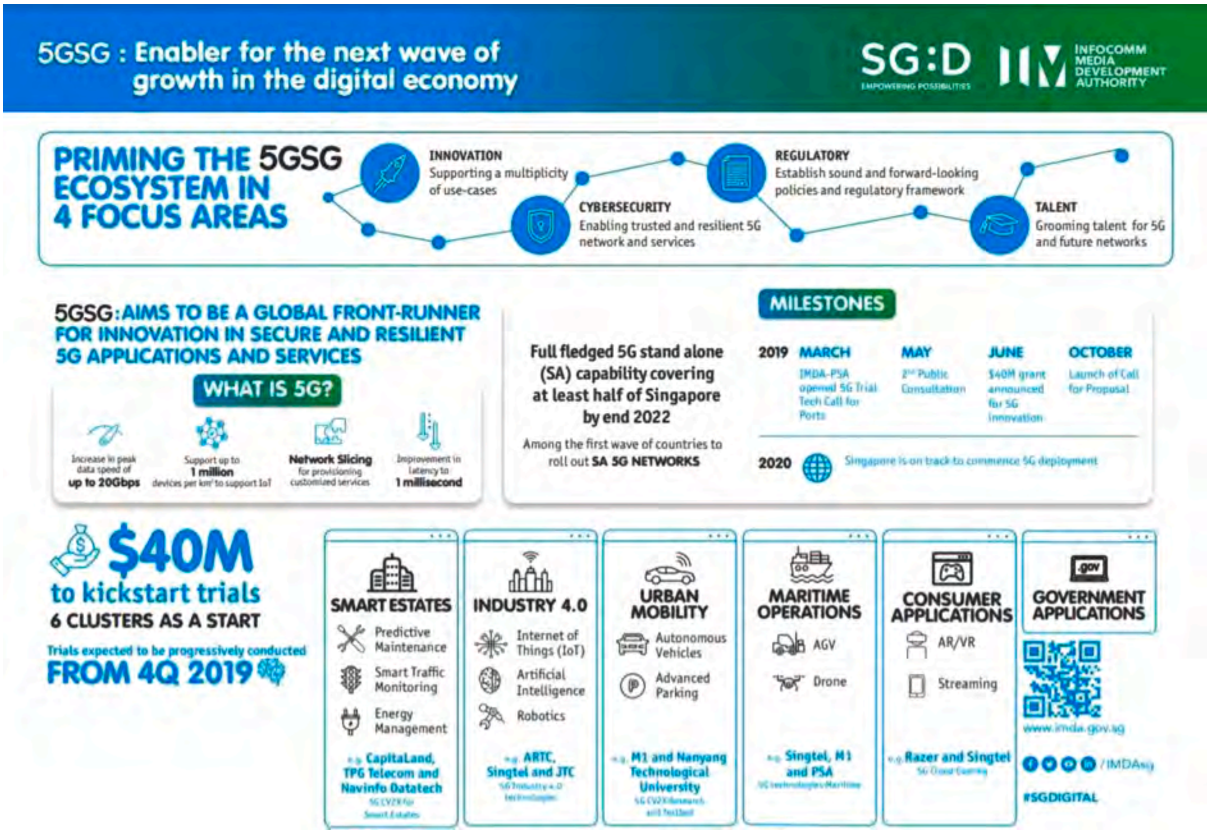

Fig. 12. NUS' 5G lab smart facilities management buildings.

maximum of five participants can join a virtual classroom. What's more, students must be in the same location to join the VR environment, and this is largely restricted due to limitations of hardware and network speed. By using 5G technology, NUS SDE may be able to facilitate classes of up to 30 students by employing next-generation VR tools. Students may even be able to partake in classes remotely (i.e. from home or a library). The proposed solution may also support the development of powerful cloud-based services, which will ultimately reduce expensive hardware costs (such as the cost of PCs and servers). The use of VR and AR in providing interactive classes is being investigated by the Department of Building in NUS SDE (Fig. 12). By implementing VR and AR, students can become part of an immersive learning environment within a virtual building. This can help them to understand the basics of measurement in building features and facilities (Fig. 13).

(a) The use of 5G-powered AI and drones to develop a facade inspection system

This objective of this scheme is to create a prototype of a drone-based facade inspection system that operates in real-time and records digital images and videos through a drone-based camera. Once the images/videos have been recorded, they will be sent to a remote AI-based defect

Fig. 13. Benefits of VR and AR in Education.

detection system via 5G to be analyzed. This innovation will completely overhaul conventional manual inspection systems. Not only will this improve the safety of those working at heights, but it will also enable more comprehensive inspections to be carried out. In turn, this will generate major changes to workflow and operational effectiveness throughout the building inspection industry (Fig. 14).

Table 8 summarized the theoretical benefits of 5G technology compared to previous WIFI in zero energy building and 5G lab in National University of Singapore.

Table 8
5G vs WIFI (existing NUS Leaseline-Wifi).

No.	WiFi (Limitations)	5G (Theoretical Benefits)
1	Longer wait due to latency, lag, and the application getting stuck at regular intervals	Low latency, High network speed, No lag
2	Interference on WiFi connection	No interference in 5G connection
3	Connectivity issues (varied connection strength, intermittent disconnection)	Steady, consistent, and high speed connection strength
4	No end-to-end control	Can be customized specifically to AR/VR needs
5	Less scalable to high device requirements	Scalable to high devices requirements
6	Unavailability of consistent high speed network for remote learning. Fixed to space	Network speed can be available for all location with consistency. Does not have to be confined to a pre-determined space
7	Cannot support cloud based VR with high efficiency	Can support cloud based VR
8	Inconsistent speed leads to high end PC requirements in VR for local rendering	High speed will help in using all in one wireless devices (lightweight with mobility) and removing PC with cloud server.
9	No efficient method for locating and resolving Wi-Fi performance issues	Can be customized for VR experience
10	Signal interference, signal attenuation, and mutual influence of services	No issues in 5G connection.
11	AR application is restricted to WiFi space and availability	No restrictions to mobility in AR applications
12	AR applications need high consistent bandwidth and very low latency which cannot be supported by WiFi	High band width and Low latency is provided by 5G

6.5.2. 5G AR VR BIM remote educational/training

As the nation progresses towards industry 4.0, Big Data, Internet of Things, Augmented Reality (AR), and Virtual Reality (VR) will become increasingly prominent throughout all industries (Fig. 15). In order to actualize Singapore's vision of becoming a leading digital economy, Institutes of Higher Learning (IHLs) play an extremely crucial role in cultivating and nurturing future leaders to build a competitive workforce that is augmented by technology.

Taking into consideration the nation's vision and IMDA's aims of nurturing the growth of 5G use-cases to understand and derive learning for future 5G development, we believe that a seamless education platform developed using VR and AR technologies, that utilizes 5G network for faster and remote device rendering, to conduct immersive and interactive classes would be able to digitize and revolutionize education as a whole, thereby ingraining technology into teaching while enhancing the effectiveness of learning.

Building quantities measurement skills are a significant part of the skill set of any successful student pursuing the Project and Facilities Management (PFM) program. Measurement is where the students' ability to understand basic construction methods, materials, and processes is applied. Lacking proficiency in measurement skills puts the students at an implacable disadvantage in the later stages of their course and the early stages of their work career. However, the problem in teaching the building measurements is that the students are unable to read and visualize the 2D hardcopy drawings and thus making them unable to take-off quantities of building works correctly. For students to take-off quantities of building works, they must be able to read the 2D hardcopy drawings and visuals in 3D. Beside, students also need to have construction technology skills to understand the building construction process. To make the situation worst, most students do not have technical knowledge/background of construction before joining NUS.

NUS have developed better educational tools and techniques to facilitate more effective teaching and learning methodologies for measurement and construction technology (taught by the Department of Building, School of Design and Environment, National University of Singapore). Using 5G, AR and VR environments to engage students in an immersive experience to better learning and pick up the fundamentals of measurement and construction technology more effectively. Such integrated applications include a virtual building environment where students can interact to aid in visualizing various building elements and forms as well as running quantity take-off at the ease of students' gestures and interaction with their environment. This provided about new levels of learning and understanding the various augments of reality through first-hand user experience. This project brought about greater learning experience to students through interactivity in a 3D virtual world, cultivating better memories and faster learning skills and

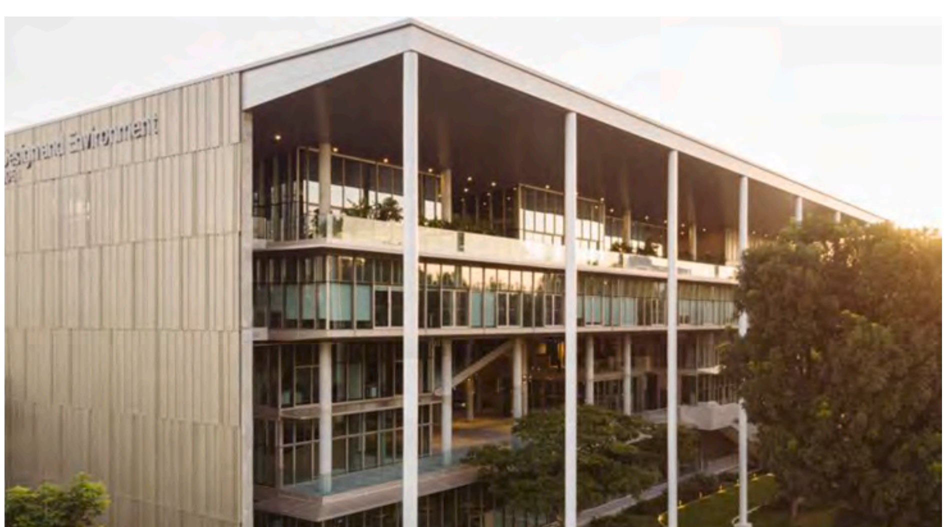

Fig. 14. Workflow of a 5G-powered Façade Inspection System using AI and Drones.

Fig. 15. Industry 4.0 Framework- Digital Education Technologies.

methodologies throughout their coursework.

AR and VR contents and videos require high bandwidth and low latency to perform optimally. 4G struggles to maintain the traffic required for AR and VR experiences. Some challenges are mainly related to motion sickness for the user experience and the lack of mobility. The application of an integrated array of AR and VR applications in the context of building measurement and teaching construction technology is only achievable using high-speed, low latency networks such as 5G

VR in education and training provides an opportunity for students to interact with each other in a virtual three-dimensional (3D) environment. Intuitive sense can be enhanced while students interact with various objects, related messages, and information in the virtual environment. Different from the conventional education and training approaches, such as the utilization of static pictures or two dimensional (2D) drawings, VR's visual representation allows more degrees of freedom (DoFs) to be integrated.

There is currently some VR/AR-based software in the market. Some examples are Enscape, Unity VR, IrisVR are among the leading players who are BIM-based applications. However, these platforms are limited to their functionalities and are mainly used for visualization of BIM models in the 3D VR environment. Even though these platforms provide architectural visualization, they are not suitable for teaching purposes beyond visualization. Various researchers have highlighted that the future directions for VR based Construction Engineering Education and Training (CEET) are Integrations with Emerging Education Paradigms and VR-Enhanced Online Education. There is a need for the development of customized solutions catered to the pedagogical environment and aligned with the current teaching practices. This will help students to get a better understanding of the current subject areas. In this project, NUS want to harness these gaps to develop a VR based Remote Educational/Training - MILES (Measurement Immersive Learning Engagement System) using 5G networks" for Facilities Management. In addition to these, the current VR run over the 4G network has high latency leading to dizziness, motion sickness, and blurriness. With 5G, we expect that a

Fig. 16. Graphical representation of the implementation architecture.

Fig. 17. Workflow of a 5G-powered Façade Inspection System using AI and Drones

Fig. 18. Industry 4.0 Framework- Digital Education Technologies

low latency solution can be developed which can address these issues. Students can participate from anywhere with Internet access (Fig. 16).

7. Challenges, recommendations and future works

The 5G technology applications have shown promising results, as evident from the existing literature of smart cities. The challenges, recommendations and future works following:

1 The concept of smart city is continuing to evolve and only developed countries are engaging in experimentation and its implementation. Singapore is leading the way with regards to employing citywide sensor data to monitor daily life. Singapore's Smart Nation programme encompasses current technology infrastructure to create an online connection for all communities. There are wide-ranging and numerous advantages to smart cities that can be applied in any urban area. Hence, future studies on cost-effective design and implementation are essential to increase the focus on the smart city approach globally. It is also vital to include renewable energy sources so as to safeguard the viability of city operations and to address scarcity issues for non-renewable energy sources.

2 Future smart cities should comprehensively examine the big data analytics of existing smart cities.

3 In connected environments, it is critical to safeguard the security of sensitive data. If there is any doubt about this, citizens will typically just not utilise the ICT platforms, thereby decreasing the city operations' viability and reliability. Hence, a key area for future research is the implementation of collective security measures in smart cities.

4 Another area requiring more in-depth investigation is how to optimise the advantages of diverse devices. Smart cities amalgamate a range of subsystems at the application layer in order to provide reliable and efficient services. At this point, aggregation is worth further analysis. Due to its universal accessibility, the web inspired WoT concept is considered an ideal element to amalgamate diverse applications. Consequently, smart city constituents will be capable of intercommunication, regardless of any conflicting components in their communication technologies or operational platforms.

5 Researchers and industry experts can concentrate on the gaps in the literature that can successfully employ the AI, ML, and DRL approaches based on 5G technology to increase smart cities' efficiency levels.

8. Conclusions

The conclusions following:

1 The growth of advanced technologies and their inclusion in diverse elements of daily life have created opportunities for enhancing service performance in buildings communities and cities.

2 A brief study of the fundamental concepts of use cases such as AI, ML, and DRL techniques using in smart city and high improved by using 5G technology have been discussed.

3 As a range of technologies have been introduced, Singapore has supported the smart city 5G technology. Increasingly, meeting the

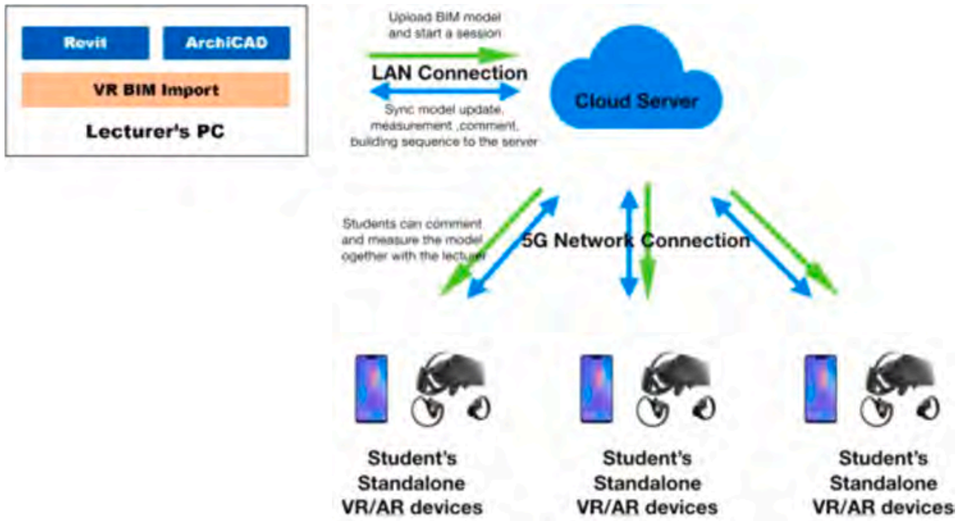

Fig. 19. Graphical representation of the implementation architecture.

requirements of the public for aspects such as comfort within buildings, energy efficiency, environmentally friendly, and intelligence, is becoming a priority. Furthermore, in the future, intelligent buildings will become more significant in the context of large buildings.

4 Singapore applies 5G communication technology to intelligent buildings in order to accomplish the most cost-effective system. Essentially, the goal is to achieve the greatest performance possible with the lowest investment possible.
5 Lower rise institutional buildings and schools have the potential to achieve zero or positive energy target first.
6 Singapore has committed to reducing its emissions intensity by 36% from 2005 levels by 2030. Buildings sector, which is responsible for more than one-third of the country's total electricity consumption, holds a major role in reduction of carbon footprint to mitigate climate change.

Declaration of Competing Interest

The authors whose names are listed immediately below certify that they have **NO** affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.egyai.2021.100116.

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