

## Article

# Evaluating the Roadmap of 5G Technology Implementation for Smart Building and Facilities Management in Singapore

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**Abstract:** The concepts of smart building (SB) and smart facilities management (SFM) are crucial as they aim to uplift occupants' living standards through information and communication technology. However, the current network possesses several challenges to SFM, due to low bandwidth, high latency, and inability to connect a high amount of IoT (Internet of things) devices. 5G technology promises high-class network services with low latency, high bandwidth, and network slicing to achieve real-time efficiency. Moreover, 5G promises a more sustainable future as it will play a crucial role in reducing energy consumption and shaping future applications to achieve higher sustainability goals. This paper discusses the current challenges and benefits of implementing 5G in various use cases in SFM applications. Furthermore, this paper highlights the Singapore government rollout plan for 5G implementation and discusses the roadmap of SFM use case development initiatives undertaken by 5G Advanced BIM Lab (Department of Building, National University of Singapore) in alignment with the 5G implementation plan of Singapore. Under these 5G SFM projects, the lab seeks to develop state-of-the-art 5G use cases in collaboration with various industry partners and developed a framework for teaching and training to enhance students' learning motivation and help mid-career professionals to upskill and upgrade themselves to reap multiple benefits using the 5G network. This article will serve as a benchmark for researchers and industries for future progress and development of SFM systems by leveraging 5G networks for higher sustainability targets and implementing teaching and learning programs to achieve greater organizational excellence.

**Keywords:** 5G technology; smart building; smart facilities management; BIM; AR/VR; AI; drone

## 1. Introduction

In recent years, the concept of intelligence, digitalization, and smartness of buildings has gained significant attention. A smart city is a concept based on the use of information and communication technology (ICT) to sense, analyze, and integrate core systems' key information in running cities [1]. While the term intelligent building has been in use for some time [2], "smartness" is a more recent term introduced by the *Energy Performance of Buildings Directive (EPBD)* to increase the energy efficiency in building usage [3]. Ghaffarianhoseini et al. [4] highlighted that the terms "intelligent" and "smartness" have a complementary meaning in terms of building as both aim to optimize the building performance. On the other hand, Albino, Berardi, and Dangelico [5] differentiated intelligence and smartness by highlighting that smartness goes beyond ICT and includes people's and communities' demands and needs.

A smart city (SC) is composed of several components such as smart homes (SH), smart buildings (SB), smart grids (SG), and smart meters (SM) [6–8]. Le, Nguyen, and Barnett [9] highlighted five feature of SBs as:

- Automation: The capability to handle automatic devices and undertake automatic functions.
- Multi-functionality: Allow more than one optimization function in a building.
- Adaptability: The capability to adapt to the needs of users based on learning, prediction, and variables.
- Interactivity: Allow interaction between users in a building.
- Efficiency: The ability to achieve energy and other efficiencies promoting time and cost-saving.

Kiliccote et al. [10] stressed that SBs are self-aware and grid-aware. SB interacts with SG based on real-time demand response. Cook and Das [11] highlighted that responsiveness, adaptability, and flexibility are the three key features that differentiate an SB from previous generation buildings. McGlinn et al. [12] highlighted that it is necessary to have adequate information and knowledge about its inhabitants and surrounding environment for SBs' efficient functioning. This will help in increasing the inhabitants' experience in an SB customized to the surrounding environment. Moreover, an SB is in itself an entire system rather than a collection of small environments. Being so, the spaces inside an SB can interact and provide a more coherent environment.

Sinopoli [13] suggested that the SB concept revolves principally around integration, both of the building's system and the way the building is designed and implemented. The author also highlighted the need for vertical and horizontal integration of information to be utilized by facilities managers and individuals residing in the building. Buckman, Mayfield [14] defined SBs as "buildings which integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at the core, in order to meet the drivers for building progression: energy and efficiency, longevity, and comfort and satisfaction." Furthermore, an SB is not about how the building is being designed but it is about how the building functions in its operation stage. To achieve a real SB, it is necessary that the building performs to its intended task and adapts and deviates from its intended design as per user's requirements. Therefore, efficient facilities management (FM) plays an essential role in achieving SB goals because O&M accounts for around 60% of the total cost incurred to owners [15].

Therefore, the backbone of the SB goals lies in adopting smart facilities management (SFM). The smart facilities management leverages new-age advanced information technology and equipment to achieve smart building goals. Driven by the adoption of building information modeling (BIM), Internet of things (IoT), artificial intelligence (AI), digital twin (DT), augmented reality (AR)/virtual reality (VR)/mixed reality (MR), Construction Operations Building Information Exchange (COBie) and data analytics technologies, SFM is empowering owners and occupants with greater visibility, actionable insights, and cost-saving [16–22]. Most of these technologies require high bandwidth, low latency connection, and leverage cloud computing for better output. However, the current wireless networks (e.g., Wi-Fi, 4G, 3G) that support these functions pose various challenges for the broader adoption of these new-age technologies. The following are some critical challenges:

- **High bandwidth requirements:** With a greater emphasis on integrating BIM with FM, the future SFM will use BIM as the primary visualization and information source model. Additionally, the adoption of new technologies in FM such as AR/VR/MR, image analytics, drones, computer vision, cloud computing requires high bandwidth to support seamless real-time analysis. The current wireless networks are not consistent enough to provide high bandwidth on the go [23].
- **Low latency:** Latency is the time that passes from the moment information is sent from a device until the receiver can use it. Low latency is a must for future cloud-based systems, AR/VR/MR, drones, and computer vision. The current wireless networks cannot support very low latency requirements [24].

- **Cybersecurity:** The current wireless networks pose huge cybersecurity risks when millions of devices are connected using IoT. Current networks cannot transact with large amounts of encrypted data at a time [25].
- **Customized networks:** The current wireless networks lack supporting customized networks for various applications [25,26].
- **Supporting a large volume of devices:** There will be a gradual increase in IoT devices as SFM adoption increases. It will be difficult for current wireless networks to support such a large volume of devices in a defined radius [26].

To support SFM with greater efficiency and in real-time, these identified challenges with current wireless networks must be addressed. 5G network can potentially address all these identified issues. 5G network promises a high bandwidth, low latency network, that can be customized using network slicing, with enhanced cybersecurity and capability to cater to millions of devices in an identified radius. Moreover, 5G network promises to be more energy efficient. When integrated with IoT, it will spur technological deployment in ways that will promote long term sustainability through energy consumption reduction, reduced emission, and better predictive technologies implementations in varieties of industrial verticals such as building, transportation, agriculture, marine, healthcare, and manufacturing [27].

This paper aims to analyze how 5G network can help overcome the challenges posed by current wireless networks in implementing SFM solutions. The paper starts with a literature review that discusses the SFM, 5G network, and the drivers of SFM that can benefit from the 5G network. The vision, implementation roadmap, ongoing solution development of Singapore's Smart Nation initiative, followed by Research and Development (R&D) conducted in National University of Singapore's "5G Advanced BIM Lab" are discussed.

## 2. Literature Review

### 2.1. Smart Facilities Management (SFM)

Facility management (FM) has been typically driven by cost-centric rather than value-driven priorities [28]. However, new-age customers are more demanding concerning space experience and connected services. This has led to more tech-driven FM in the industry. The built space has a direct impact on workplace productivity and occupant wellbeing. This has led to property value enhancement which provides a more holistic user experience [29], as well as an evolution to create and modify existing spaces by adopting and leveraging on tech-enhanced services to attract a premium for their facilities [28]. Additionally, it brings an overall cost and time saving through multiple automated functions [30].

SFM is an emerging technology that uses smart sensors, computer intelligence, and wireless networks to help buildings achieve their SB goals [31]. Under the SFM, the data collected by various sensors, cameras, and other IoT devices are analyzed to perform various tasks such as energy efficiency, security, space management, indoor air quality (IAQ), and maintenance management [32]. SFM aims to achieve more significant savings through automating various functions inside the building and predicting future faults in buildings through data analytics and artificial intelligence [33].

Fairchild [31] highlighted that SFM is driven by three different needs, i.e., energy efficiency, environment functionality, and space optimization. Armstrong, Brambley [34] stressed that interoperation control systems, sensors, automated diagnostics, and IoT devices are some standard components required in SFM. Meanwhile, as the facilities are getting increasingly complex, the umbrella of activities under SFM is getting bigger. Table 1 shows various functions under the SFM umbrella, describing the functions' target and the technical requirements to achieve those functions. SFM can be categorized into (1) smart energy management, (2) smart maintenance management, (3) smart indoor occupant comfort management, (4) smart space management, (5) smart traffic management, (6) smart security management, and (7) smart document code and transaction management.

**Table 1.** Smart facilities management (SFM).

No.	Function	Target Descriptions	Technical Requirements
1	Smart energy management	<ul style="list-style-type: none"> <li>• Increase energy efficiency.</li> <li>• Targeting to achieve net-zero goals.</li> <li>• Reduce cost.</li> <li>• Conserve resources.</li> </ul>	<ul style="list-style-type: none"> <li>• Establish the connection between building elements and the surrounding environment.</li> </ul>
2	Smart maintenance management	<ul style="list-style-type: none"> <li>• Pre-emptive maintenance</li> <li>• Preventive maintenance.</li> <li>• Predictive maintenance.</li> <li>• Demand-based maintenance management.</li> </ul>	<ul style="list-style-type: none"> <li>• Connected equipment data using IoT devices.</li> <li>• Digital twin.</li> </ul>
3	Smart indoor occupant comfort management	<ul style="list-style-type: none"> <li>• Optimize ambient environmental conditions according to occupants' needs.</li> <li>• Improving health and productivity.</li> </ul>	<ul style="list-style-type: none"> <li>• Understand occupants' behavior patterns.</li> </ul>
4	Smart space management	<ul style="list-style-type: none"> <li>• Identify and optimize space usage.</li> <li>• Customize space use based on user needs.</li> <li>• Promote collaboration, innovation, and productivity through workplace customization.</li> </ul>	<ul style="list-style-type: none"> <li>• Establish zones occupancy and modify spaces as per need.</li> </ul>
5	Smart traffic management	<ul style="list-style-type: none"> <li>• Smart car parking and traffic control systems will enable users to find parking efficiently in large facilities.</li> </ul>	<ul style="list-style-type: none"> <li>• Establish connections between cars (users) and parking sensors.</li> </ul>
6	Smart security management	<ul style="list-style-type: none"> <li>• Identification and neutralization of security threats.</li> <li>• Visitor control systems.</li> </ul>	<ul style="list-style-type: none"> <li>• Access control network, face recognition system, and security threat notification cameras.</li> </ul>
7	Smart document code, and transaction management	<ul style="list-style-type: none"> <li>• Storage of data in common data environment.</li> <li>• Automated checking of code compliance in post occupancy stage.</li> <li>• Automated payment system based on smart contract.</li> </ul>	<ul style="list-style-type: none"> <li>• Common data environment.</li> </ul>

The technical requirements of these categories must be managed in a timely and cost-effective manner, and hence robust networks are considered essential ingredients for SFM.

## 2.2. Importance of 5G Network

### 2.2.1. 5G Network

5G is the fifth generation of mobile network. It is designed to connect virtually everyone with everything such as machines, objects, and devices. 5G network aims to provide high bandwidth data (multi Gbps speed), ultra-low latency, better reliability, high cybersecurity, and connection to high number of devices per square kilometer. It also aims to provide a much better and uniform user experience [35]. To reduce interference, 5G is based on OFDM (orthogonal frequency division multiplexing) that modulates digital signal across different channels [36]. 5G uses wider bandwidth technologies such as sub-6 GHz and mmWave [37]. To provide better flexibility and scalability, 5G NR (new radio) air interface enhances OFDM [38]. This means that more people can have access to 5G for

various use cases like gaming, VR/AR, video streaming, analytics, and so on. Moreover, 5G brings a much wider bandwidth to 100 GHz and beyond that of 4G [39]. The flexibility to operate in both bands, i.e., lower band (e.g., sub-6 GHz) and mmWave (e.g., 24 GHz and up), gives 5G more capacity for high throughput and low latency [35]. 5G will provide a much better experience compared to 4G LTE in providing services from mission critical activities to connecting IoTs [38,39].

### 2.2.2. Expected Benefits of 5G Network

5G focuses more on elevating the mobile broadband experiences to a larger variety of use cases compared to 4G LTE, or 3G [38]. 5G is designed to support all kind of spectrums such as licensed, shared or unlicensed and multiple bands. It can also be used for wide range of deployment models such as traditional macro-cells to hotspots. Furthermore, it provides new ways to interconnect such as device-to-device and multi-hop mesh [35]. Using advanced technologies, 5G claims to be significantly faster (up to 20 Gbps) than current wireless networks such as 4G, providing ultra-low latency, 100x increased traffic capacity and efficient network [37,40,41].

Table 2 summarizes the limitations of Wi-Fi/4G and the theoretical benefits of 5G, which can help overcome these limitations [42–48].

**Table 2.** Theoretical benefits of 5G which overcome the general limitations of Wi-Fi/4G.

No.	Wi-Fi/4G (General 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 Wi-Fi/4G 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 end-to-end needs.
5	Less scalable to high device requirements.	Scalable to high devices requirements.
6	Unavailability of a consistent high-speed network for remote learning. Fixed to space.	Network speed can be available for all locations with consistency. Does not have to be confined to a pre-determined space.
7	Inconsistent speed leads to high-end PC requirements in VR for local rendering.	High speed enables the use of all in one wireless device (lightweight with mobility) and replace PC with a cloud server.
8	No efficient method for locating and resolving Wi-Fi performance issues.	Can be customized for VR experience.
9	Signal interference, signal attenuation, and mutual influence of services.	No issues in 5G connection.

### 2.2.3. Sustainable Future with 5G Network

5G plays a leading role in broad ICTs (information and communication technologies) to achieve sustainability goals through reduced energy emission [49]. With billions of devices connected to the cloud, 5G will play a crucial role in reducing energy consumption and shaping new processes and applications, leading to better energy efficiency [50]. With 5G, new functionalities can be developed to detect environmental changes in real-time, which can aid in the disaster recovery effort. By supporting enhanced automation and digitization, from manufacturing to buildings to transportation to agriculture, 5G promises to reduce energy, resource, and material consumption [27]. Technological advancements such as smaller chipsets are reducing the power consumption and hardware footprint, leading to high energy efficiency [50]. The next generation 5G hardware is designed with energy efficiency in mind, with power-saving features and functionalities. For example, British Telecom (BT) predicted that 5G could reduce CO<sub>2</sub> emissions by 1.5 gigatons by 2030 [51].

Sustainability strategies in the ICT sector are setting high targets for carbon emission reduction [52]. Such targets are challenging as, in the future, more devices will be connected and IoT based. 5G will

play a crucial role in addressing this challenge, as it can support more data usage requirements across various sectors, which provide increased energy efficiency through flexible operations [51]. The current network's ability to make other industries more energy efficient is known as the "enabling effect." Some of the enabling effects of the 5G network will be [52]:

- Smart energy management across various sectors through the smart meter and grid system, IoT based monitoring, and AI-enabled analytics.
- Remote working, incorporating new-age technologies like AR, VR, work from home, leading to reduced office space and travel.
- Low wastage and proactive planning leading to just-in-time efficiency in broader processes.
- Intelligent movement management of people and goods leading to reduced journey time.
- Smart building management through effective real-time systems.
- Empowered agriculture sector through predictive and sensor-based technology leading to reduced food waste.

### 2.3. Drivers of Smart Facilities Management

#### 2.3.1. Internet of Things (IoT)

IoT is a rapidly growing ICT allowing rapid connection, transmission, and data exchange between various devices through embedded sensors and wireless network technologies [53]. Radio-frequency identification (RFID) is considered enabling technology for IoT, comprising four essential components, i.e., a tag, a reader (antenna), software, and a computer network [54]. These tags aim to automatically capture and interface with remote systems for inventory management and tracking [55]. The accurate environmental parameter measurements such as temperature, humidity, light, and so on can be done with networked RFID devices paired with physical sensors [54].

RFID and sensor systems provide great potential for SFM and its related processes such as energy controls, document management, space efficiency, occupancy control, logistics management, and building security [30,56]. IoT-based location detection recognition of facilities items have great potential for increasing maintenance management efficiency [57,58]. Similarly, Dong and Lam [59] highlighted that IoT could help in accurate building occupancy detection that can lead to better decisions for building services delivery and energy control.

The current wireless networks pose a great challenge to tap onto the benefits of IoT devices. With the number of IoT devices going to increase manifold in the near future, current wireless networks cannot securely connect a huge number of IoT devices [25,26,30]. 5G network provides multiple benefits that can take IoT device function to greater heights. 5G network provides high bandwidth, very low latency, and possibility for network slicing to help significantly increase the number of device connections (a million per square km) [60]. Moreover, as the number of devices increases, most of the functions in future will be conducted in the cloud. 5G provides low latency to tap on cloud computing capabilities for real-time experiences. 5G also allows us to implement virtual networks (network slicing) and create subnets to provide connectivity more adjusted to specific needs [37].

#### 2.3.2. Artificial Intelligence (AI)

Artificial intelligence (AI) concerns building smart machines that can perform and process human-like tasks and learn over time to adjust tasks to gain more accuracy and efficacy [61,62]. With the advent of smart buildings, the role of AI has increased manifold. The data captured from various sources such as sensors, cameras, LIDAR, AR/VR need to be processed faster to achieve real-time analysis and provide sensible information in respect of threat detection, predictive maintenance, energy optimization, space optimization, and the like [63–66]. AI's role is to automate processes and help buildings adapt to the users' needs and the surrounding environment [67]. The enormous amount of data generated by a smart building is worthless unless analyzed to derive sensible and valuable

information. AI facilitates the processing and analysis of the data generated from machine-to-machine communication in a “smart” setup [68].

Nevertheless, the primary requirement for conducting AI in SFM is to have powerful machines that can conduct real-time analysis and provide feedback [66]. The communication channel between the sensor, AI algorithm, and the user should all be done in a real-time environment [68]. With the advent of cloud computing, most of the future programs will be hosted in the cloud, posing a huge challenge to the current wireless networks with the need to handle such high bandwidth, low latency, and cybersecurity requirements [26]. 5G network promises to support these kinds of real-time applications.

### 2.3.3. Augmented and Virtual Reality (AR/VR)

Augmented reality (AR) enhances perception with the overlaying of the virtual environment onto the real world. In contrast, virtual reality (VR) creates a virtual environment to let users feel the real-world scale [69]. Using headgear, key information can be overlaid within the visual field during an inspection [70]. This simplifies maintenance tasks and building system modifications while making work safer [71]. Similarly, virtual reality (VR) can help FM personnel visualize facilities in detail before conducting an actual visit to the site using a BIM model [72]. By leveraging BIM information, maintenance officers can visualize the exact location of pipes, cables, and other information overlaid on their view as they move around the building [73]. Sensors in the walls and throughout the building can also add real-time information not immediately visible to the human eye [74]. AR-enabled maintenance has been shown to be able to significantly improve accuracy and productivity [69], minimizing cost and disruption and downtime [75].

AR and VR contents and videos require high bandwidth and low latency to perform optimally. The current wireless network struggles to maintain the traffic required for AR and VR experiences [42]. Some challenges are mainly related to motion sickness for the user experience and the lack of mobility [76]. Applying an integrated array of AR and VR applications in SFM will require a high bandwidth connection for various activities such as stream videos for remote maintenance or BIM model loading [46]. Similarly, AR/VR will require ultra-low latency to reduce motion sickness and perform on the go AR applications [77]. Again, 5G network promises to solve problems faced by AR/VR in SFM.

### 2.3.4. Digital Twin (DT)

Digital twin is a replica of physical identity that can think (obtain conclusions), sense (in real-time), and act (suggest optimizations) [78]. It shares some similarities with BIM. A BIM models on a building's design and construction, whereas a digital twin models how people interact with built environments. It is a widely used concept in manufacturing and marine engineering. The digital representation uses sensors to monitor devices' operation and lives throughout lifecycle [79]. Digital twin uses a series of integration with IoT, AI, machine learning, and software analytics [80]. Through the amalgamation of various technologies, digital twin continuously learns and updates itself [81]. It is hence the foundation of SFM, with a digital system integrating all devices to help achieve building smart building goals. A digital twin is based on a huge amount of data flowing from various systems, sensors, and software. Qiuchen Lu et al., [82] highlighted that digital twin poses huge data management challenges related to integrating data from various autonomous, disparate, and heterogeneous sources such as real-time sensors, building management systems, cloud services, and asset management systems.

The digital twin applications need high-speed connectivity to perform various tasks in real or short processing time. The current wireless networks cannot support integration with various devices, sensors, processing, and output in real-time. 5G network can address problems faced by digital twin in SFM by providing massive data connectivity with security and cloud processing in real-time.

### 2.3.5. Video and Image Analytics

With the growing popularity of surveillance HD cameras and intelligent video analysis technology, SFM demands intelligent video analysis [83,84]. Video analytics involves image processing, tracking technology, pattern recognition, artificial intelligence, digital signal processing (DSP), and many other fields [85]. The main intelligent analysis products are concentrated in the front-end and back-end categories. The front-end intelligence requires transplanting some video analysis algorithms into the camera and realizing real-time video analysis and inspection [86].

Using artificial intelligence (AI), video analytics can turn high-definition camera streams into actionable information [87]. AI-dominated video analytics requires higher bandwidth, consumes considerable CPU/GPU resources for processing, and demands larger memory for caching [87]. Only 5G can support the increasing density of cameras, with the uplink bandwidth and quality of service that 4K and 8K video require [88]. With 5G, one can benefit from the freedom and flexibility of wireless communications. Monitoring and inspection services can be carried out by drones equipped with high-definition cameras, with 5G enabling low-latency feedback and control in real-time [88].

However, with the increase in video and image analytics techniques, privacy concerns have increased manifold. With current data being stored on devices primarily used in passive form (i.e., analysis after a security breach has happened), the risk of privacy breach has increased manifold. With the current limitation of bandwidth and connectivity, reliance on advanced technologies such as object recognition, behavior recognition, event recognition, scene analytics has been limited and negligible [89]. There is always a concern about the storage of sensitive data either on cloud or locally [90].

5G network also promises to address the privacy issues associated with video and image analytics. With technologies like scene analytics, anomaly behavior can be detected while masking the people in real-time [90]. Such a technique reduces the storage space as it analyzes and stores only the anomalous event while discarding the rest [91]. 5G will support edge computing and distributed cloud architecture, which helps process and analyze video streams locally on 5G edge clouds rather than remotely [92]. This will help in processing videos near the camera, meaning that the software will carry out the decision-making without human intervention. Processing near the camera will ensure that video surveillance and anomaly detection will keep people safe while addressing privacy concerns [92].

### 2.3.6. Drones

Building façade and rooftop inspections of tall buildings are of high risk and time-consuming. Specialized scaffolds or mechanized lifting equipment are often needed to access hard-to-reach areas [93]. With the introduction of flying drones, building inspections can now be done efficiently in real-time by specialized persons remotely [94]. Armed with a high-resolution camera, the drones can record and relay 'live' footage to the operator on the ground. Assessment using AI for anomalies can be done live with important decisions such as whistleblowing for public safety. Rectification strategy can be devised instantly shortening the response time needed before actual repairs are carried out [95]. Using drones for other similar maintenance activities will be a game changer for SFM.

When compared to 4G, 5G offers greater speeds, lower latency, and a broader range of frequencies that allows for supporting more devices while lowering interference from other channels [26]. The most significant advantage of using 5G for drones is that there is no longer the need for long and complicated reconnection protocols while moving across cells [96]. This means that new network areas covered by different masts will not halt the movement of drones to a distant location. This enables remote operators to easily monitor drone data in real-time, while they are not required to be present at a specific control center [96].

## 2.4. Singapore's Roadmap for 5G Technologies Implementation

### 2.4.1. Singapore Smart Nation Vision

Singapore's government introduced the smart nation initiative in 2014 to promote large-scale information and communications technologies (ICTs) to resolve complex urban issues and develop supporting industries around these solutions [97]. The initiative is controlled by the Smart Nation Program Office (SNPO) under the Prime Minister's Office (PMO) [97]. This initiative is a culmination of various previous efforts by the Singapore government to digitalize various services used for public delivery [98,99]. The efforts for digitalization started in the late 1980s through various programs such as the "Civil Service Computerization Program," in the 1990s followed by the "IT2000" strategic plan and e-Government Action Plans of the early 2000s, and the iGov 2010 initiative. Nevertheless, the previous efforts in digitalization differ from the smart nation initiative. The previous digitalization efforts were more focused on raising productivity and efficiency in public service delivery using various digital platforms. The smart nation initiative is more aligned with various digitalizing facets of urban life through involvement of citizens, industry, private sector, and government [100].

At its inception, the smart nation initiative focused on five key domains: transport, home and environment, business productivity, health and enabled aging, and public sector services. These domains have since been expanded, particularly with the recent emphasis on artificial intelligence. Digitization in these various domains is achieved through a set of "enablers" [100]:

- Research institutes and industry collaboration for test-bedding,
- A data portal for open exchange of government data,
- Research and development (R&D) investments,
- Laboratories for the development and piloting of technological solutions,
- Promoting start-ups and innovations,
- Safeguarding data, systems, and networks through enhanced cybersecurity measures,
- Building computational capabilities among citizens through educational programs at various levels, including young children, secondary-school students, and working professionals.

### 2.4.2. NUS Department of Building (DoB) Smart Nation Research Initiatives

Virtual Singapore and Smart Nation is about transforming through technology powered with digital innovation. NUS Department of Building (DoB)'s 5G Advanced BIM Lab has been actively researching the smart national initiative's two verticals, as shown in Figure 1. The lab has collaborated with various government agencies, private sector, industry partners, and overseas institutions. One such example under the "piloting" vertical supporting SFM is the as-built BIM modeling efforts undertaken by DoB in collaboration with the town council. The lab has collaborated with the town council to develop as-built BIM models which are used by the town council for future facilities management. The BIM modeling of the whole town will help the town council to manage their properties better and get more accurate costing for maintenance work like painting or façade enhancement works, etc. [101].

Similarly, another project under the "Virtual Singapore" vertical is an ongoing collaboration with a government agency to develop a BIM integration with their existing mapping system to provide more accurate building data. This will bring other government agencies to tap on this platform to conduct their analyses. Furthermore, new developments can tap on this map to develop user-centric facilities.

### 2.4.3. Infocomm Media Development Authority (IMDA)'s 5G Roadmap

Infocomm Media Development Authority (IMDA) is a statutory board of the Singapore government, under the Ministry of Communications and Information. In response to the Singapore government's call for industry transformation, several companies are extending their 5G, cloud, and AI capabilities to local government agencies, SMEs, and institutes of higher learning, to help accelerate Singapore's 5G application nation-wide intelligent transformation [102] Globally acknowledged to be

the next big leap in mobile and wireless communications, 5G technology is widely touted to develop new business models and advanced applications, fostering business innovation and spurring economic growth. Communities, businesses, and industries are expected to benefit from the transformative impact that 5G enables. 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 testbeds, and for R&D in areas like cybersecurity for the next-generation mobile network across six strategic clusters (Figure 2) [103]. The projected 5G penetration in Southeast Asia (2025) is tabulated in Table 3 [104]. This means that institutions of higher learning (IHLs) need to lead the way in developing adequate use cases, guidelines, and frameworks that can be adopted in future 5G commercial applications.

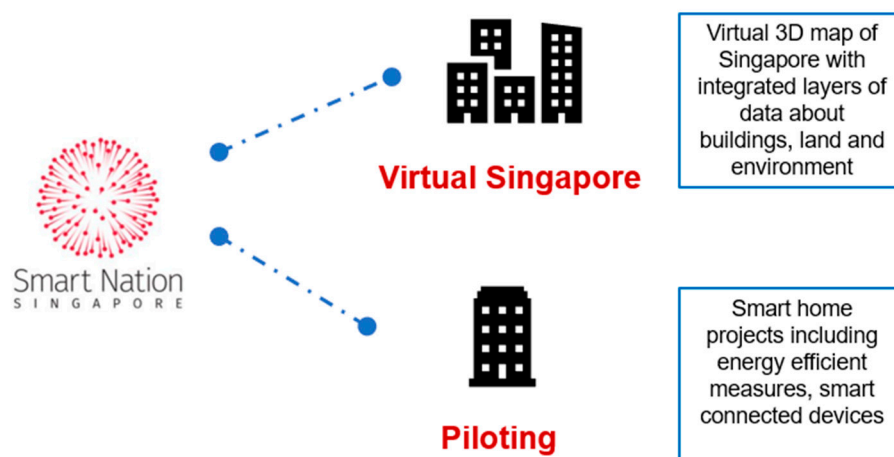


Figure 1. Verticals of smart Singapore supporting smart facilities management (SFM).

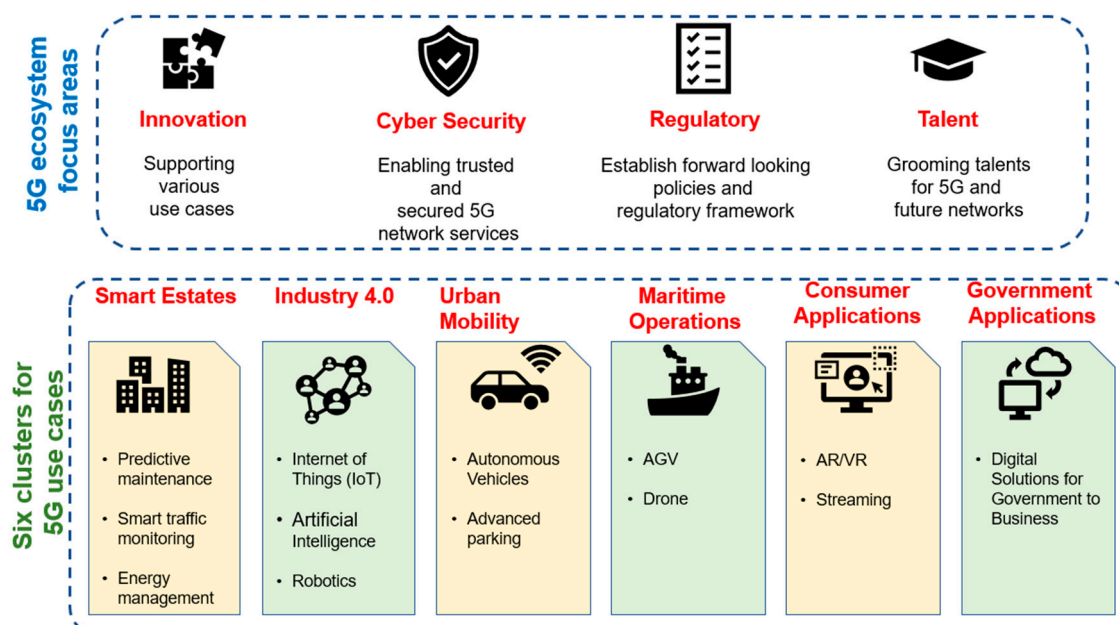


Figure 2. 5G development in Singapore [103].

**Table 3.** Projected penetration of 5G in South East Asia by Year 2025 [104].

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

#### 2.4.4. Department of Building's 5G Advanced BIM Lab

The roadmap for DoB's 5G Advanced BIM Lab for SFM aims to transform the way people design, deliver, and manage built environments through bridging disciplines, innovating solutions, and managing processes. It targets to influence the state-of-the-art research in new developing areas of FM sectors adopting AR, VR, mixed reality (MR), drones, computer vision, LIDAR, BIM, and so on. It intends to innovate through high-impact research, transform construction education with the intervention of new-age technologies, and collaborate with industry stakeholders to enable more effective adoption of research into practical applications for SFM. The objectives of DoB's 5G Advanced BIM Lab are to collaborate with the construction industry partners to achieve productivity improvement and solve real-life problems for SFM using 5G technologies. This delivers greater value to the industry in saving time, achieving high quality, and aligning with new-age technologies backed by research.

The focus of 5G Advanced BIM Lab is to concentrate on three broad areas: research, industry, and education (RIE). Under the "research" area, the 5G Advanced BIM Lab works on multiple SFM research projects in fields such as BIM, AR, VR, mixed reality, digital twin, LIDAR, computer vision, artificial intelligence, drones, and the like. Under the "industry" area, the lab collaborates with various industry partners to develop customized solutions backed by innovative research. Industrial collaboration helps in solving real-life problems faced by the industry. Under the "education" area, the lab partners with the industry to develop customized training solutions for the workforce. Such training activities in collaboration with industry partners enhance the workforce's skillset and align them with construction industry transformation map. It helps in associating research with practical solutions. The lab develops course content for Project and Facilities Management students using new-age technologies to prepare them for the SFM sector upon entering the workforce.

With the 5G network rollout in Singapore, the 5G Advanced BIM Lab has collaborated with telecom partners to set up the 5G trial spectrum provided by Infocomm Media Development Authority (IMDA) for research and development purposes. In alignment with the smart nation's vision, the lab has been working on various use cases under the different clusters identified by IMDA. These use cases also align with the four verticals under which the lab works. Figure 3 shows the various core areas under which the lab is currently working and projects under development. Figure 3 also shows the various use cases alignment under 5G trials with IMDA's various clusters.

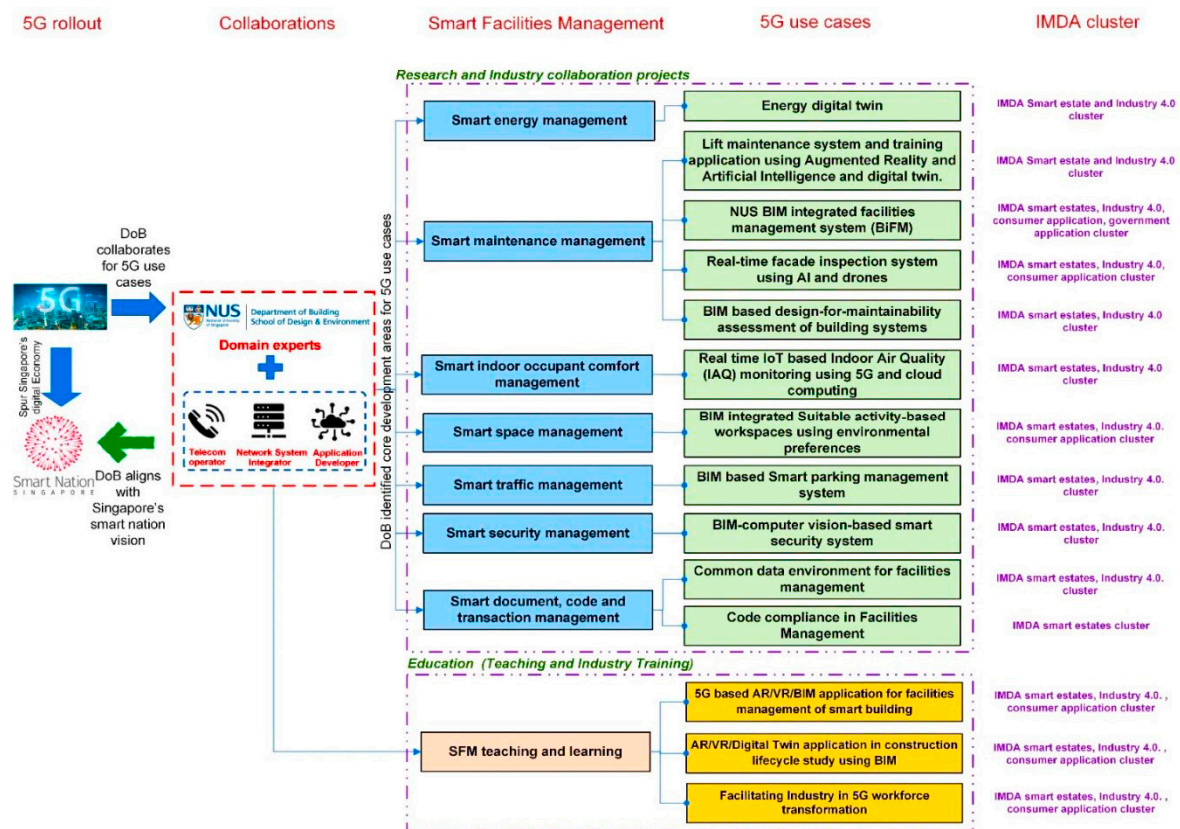


Figure 3. Department of Building's (DoB) 5G Advanced BIM Lab initiatives for SFM.

### 3. 5G Use Cases in Department of Building (DoB), NUS

This section discusses the various 5G use case projects undertaken by DoB's 5G Advanced BIM Lab (Figure 3). The Sections 3.1–3.3 show a brief description of the various projects and the role of 5G in facilitating the various use case projects. The concept of DoB's 5G Advanced BIM Lab training framework in response to 5G adoption is shown in Figures 3 and 4.

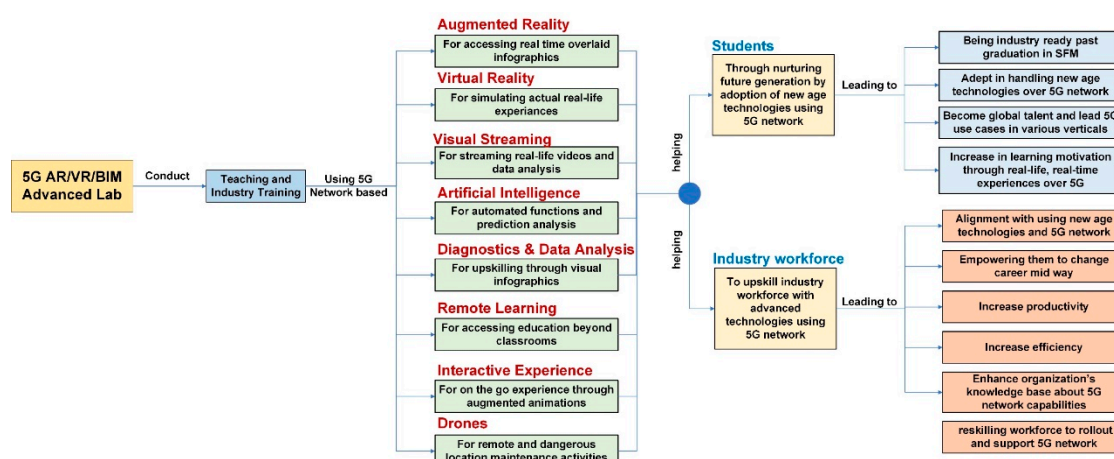


Figure 4. DoB's 5G Advanced BIM Lab training framework in response to 5G network adoption.

### 3.1. Research and Industry Collaboration Projects

#### 3.1.1. Smart Energy Management: Energy Digital Twin

With the emergence of the Internet of things (IoT), it has become cost-effective to implement a digital twin of a building's operation that continuously learns and updates itself using information from building energy management systems (BEMS) and BIM. The creation and calibration of energy models is a labor-intensive and time-consuming process. This study aims to develop an information exchange infrastructure to help create realistic physics-based models of major energy-consuming HVAC components. The models would also be automatically calibrated continuously to ensure reliability over time. The aims of this ongoing study are:

- Real-time performance monitoring of building systems against design specifications.
- Real-time optimization of a building's operation to achieve improved building performance and indoor environmental quality.
- Integration with machine learning algorithms for automated fault detection and diagnostics.
- Solar photovoltaic (PV) energy output analysis for automated correction to maximize output.

The role of 5G network in this use case is to address the need to support multiple IoT device support in a small radius area. It will also help in data analysis over the cloud to achieve real-time information from various IoT devices. Low latency 5G network will ensure a more real-time analysis of data.

#### 3.1.2. Smart Maintenance Management: Lift Maintenance System and Training Application Using Augmented Reality and Artificial Intelligence and Digital Twin

This project aims to analyze the proposed first-in-Singapore universal AR platform for training new lift technicians, comprised of AR training contents, AI diagnostic, and remote guidance tools in enhancing learning motivation. This project's basic idea is to create digital AR training contents and AI tools based on existing PCP training programs augmented with AR technology and AI power tools and test its effectiveness. Singapore's Professional Conversion Program (PCP) are training programs that help mid-career professionals to change career path and move to a new field [91].

This project development collaborates with Singapore's town council and estate managing consultants/agents. The estate managing agents of residential, commercial, and industrial estates development in Singapore operate, inspect, and maintain a wide range of complex lift transportation systems with many highly interrelated components.

This project aims to develop the following applications used by the industry to train the next generation of lift trainees. They are:

- a) AR platform development: The AR platform development will connect lift technicians with the AR cloud-based centralized system for AR experience, automated work orders, job notifications, and building animated repair sequences to guide technicians through specific lift checking and maintenance tasks.
- b) AR content for lift training: AR content development for lift training ready-made lesson plans covers a wide range of lift maintenance topics. The easy, intuitive AR platform allows experienced trainers to create virtual 3D infographics to share their maintenance and troubleshooting sequences with trainees' recorded scenes.
- c) AI diagnostic tool: AI diagnostic tool will help to identify the most common lift faults and their causes. This will also help in fostering the predictive maintenance technologies in the lift maintenance system.
- d) AR remote guidance tool: AR remote guidance tool will allow simple and quick remote guidance from a team of subject matter experts who can resolve issues and perform diagnostics without incurring any travel expenses and have a higher rate of first-time fixes.

The role of 5G in this use case will be to address the need for high bandwidth and low latency requirements of AR function. Moreover, live video streaming over the 5G network for remote location maintenance will be enhanced using the 5G network. Accessibility of AR content over the 5G network will ensure seamless access to cloud content on the go.

### 3.1.3. Smart Maintenance Management: NUS BIM Integrated Facilities Management System

NUS BIM integrated management system (BiFM) is an effort to integrate various functionalities of estate management activities under a unified application. The prototype application has been developed to engage the town council, estate managing agents, and residents in a unified application. The application is unified with the BIM model to help all stakeholders visualize their data more coherently. The application has variable access rights depending on user type (town council, managing agents, or residents). The features of this ongoing development are:

- A BIM integrated system to manage town for town council, managing agents, and residents.
- A comprehensive all in one platform to create and manage defects, reporting, booking of facilities, and performance management.
- A powerful tool to integrate BIM with FM for better visualization.
- Powered by data analytics to gain detailed insight into facilities.
- Integration with GIS with more updated building outlines, information about government services and urban mobility.
- Collaborate with industry partners to integrate their application inside BiFM such as washroom management, smart control of devices, smart security, smart hand sanitation, and BIM object library.

With the integration of BIM and GIS, high bandwidth requirements will be needed for multiple devices at the same time to access more BIM-based features over the mobile devices. 5G will provide greater bandwidth to various devices in any localized area. Moreover, the IoT devices installed for various monitoring of facilities will be analyzed over the cloud using cloud computing and sent back to mobile devices in real-time which will be fulfilled by 5G network's ability to process data from large number of IoT devices.

### 3.1.4. Smart Maintenance Management: Real-time Facade Inspection System Using AI and Drones

This initiative aims to build a prototype of a real-time, drone-based facade inspection system that will record digital images or videos using a drone-based camera. Subsequently, the recordings will be transmitted over 5G to a remote AI-driven defect detection system for analysis. This capability will transform traditional manual inspections. Besides ensuring work safety at heights, the use of AI and drones will yield more complete and detailed inspection results, resulting in significant changes in the building inspection industry's workflow, and operational effectiveness. The features of this ongoing project are:

- Drone-based camera to capture and analyze façade defects using AI.
- Real-time analysis by remote qualified personal for better operational efficiency.
- Cloud-based AI-powered system on conducting faster processing.

The current system requires a facilities manager to analyze data later due to network issues. 5G will ensure that real-time analysis will be done while monitoring facilities inspection. The drones will use a 5G network to send data to the cloud where the data will be processed, and results will be sent to the facilities manager in real-time.

### 3.1.5. Smart Maintenance Management: BIM-Based Design-For-Maintainability Assessment of Building Systems

This project reports on developing a building design assessment system that predicts the maintainability impacts of design alternatives. A mixed-method approach will be used in this

study. Multiple DfM benchmarks from national and international building standards were analyzed qualitatively to identify benchmarks relating to 123 critical building defects. Five Bayesian belief networks (BBN) were developed using five-year defect data and expert judgments from case buildings. Monetary quantification of results was carried out, indicating the complex relationships between DfM benchmarks and building defects to great effect. The project is further developed to integrate this maintainability assessment of the building system with a BIM model. This will help facility managers to analyze buildings in a 3D environment and make a better-informed decision. This will also be used to analyze future building defects using AI to make a better design. The aim of this ongoing research is to develop:

- Methodology for a design for maintainability assessment system for building designs using BIM.
- Novel and flexible assessment system for maintainability with global applicability.
- Building design decision support with forecasting expected maintenance cost integrated with BIM.
- Established variable dependence between maintainability benchmarks and defects.
- Knowledge and evidence-based hybrid approach to building Bayesian belief networks integrated with BIM.

The role of 5G network in this research is to support high bandwidth requirements for facilities inspection for maintainability issues while facilities manager can move around using a handheld device to monitor, assess, and apply decision support.

### 3.1.6. Smart Indoor Occupant Comfort Management: Real-time IoT Based Indoor Air Quality (IAQ) Monitoring Using 5G and Cloud Computing

Under this project, an IoT based indoor air quality monitoring platform will be developed. The platform will be connected to air quality sensors through a web server. Through the use of web server and IoT devices, data about the indoor air quality (IAQ) can be monitored anywhere, anytime. The use of 5G will promote real-time analysis and AI powered remedial action when IAQ goes below threat levels. A new device will be designed which will be composed of a 5G model, pollutant detection sensors, and microcontrollers. In this research project, the device will be designed to measure and monitor various air quality parameters. The device will be designed following the prescribed procedure from the National Environmental Agency (NEA). IAQ analysis requires huge amount of data analysis, which will be done on cloud using cloud-based computing. This project aims to develop precise monitoring sensors for indoor air quality using the advantages of the 5G network. The features of the proposed development are:

- It utilizes IoT for efficient monitoring of real-time data.
- It also uses the adoption of cloud computing for real-time analysis of indoor air quality over a 5G network.
- A one-stop web-based portal to access real-time data from anywhere, anytime.
- An AI-powered analytics tool to find fault inside the existing system and propose a solution.
- An AI-powered automated system to trigger safety functions in the event of IAQ falling below dangerous levels.

The role of 5G network in this use case is to address the need to support multiple IoT device support in a small radius area. It will also help in data analysis over the cloud to achieve real-time information from various IoT devices. Low latency 5G network will ensure a more real-time analysis of data. A real-time low latency system can ensure safety functions to run automatically.

### 3.1.7. Smart Space Management: BIM Integrated Suitable Activity-Based Workspaces Using Environmental Preferences

This project aims to develop a BIM-IoT based smart space management integrated with environmental preferences for a better user experience. IoT helps to deliver an unprecedented

space utilization possibility backed by AI. This becomes one of the core pillars of SFM. The smart occupancy sensors will enable next-generation wireless technologies powered by 5G to capture and communicate with the facilities manager automatically. By marrying IoT sensor data with advanced analytics, this project aims to bring better user experience and help organize spaces efficiently with better thermal and IAQ comfort and promote demand-based facilities management and maintenance activities. This ongoing project aims to develop:

- Optimized space planning and utilization using data from IoT sensors.
- Enhanced energy efficiency and reduced energy wastage based on sensor data.
- Occupancy behavior model-based lighting and HVAC control.
- Improved user experience with better-customized space matching experience.
- BIM-based visualization and data integration.
- Demand-based facilities management and maintenance activities.

The 5G network will be used to support occupancy behavior model-based lighting and HVAC control in real-time. Moreover, the 5G network will be used for demand-based facilities management and maintenance activities.

### 3.1.8. Smart Traffic Management: BIM-Based Smart Parking Management System

This project aims to develop a BIM-IoT integrated parking management system for parking spaces' accessible location in a metropolitan area. Integrating BIM with parking sensors will help users navigate better in large parking spaces in less time. This will help in reducing the time to find the right parking spaces. Moreover, users can decide and plan their mobility based on parking space availability, leading to more uniform traffic distribution. This project aims to:

- Develop a 5G and IoT based parking system to effectively locate parking in metropolitan areas.
- Connect sensors monitor whether parking spaces are occupied, enabling drivers to use the app to see in real-time where they can park.

The 5G network will support and connect to large IoT devices in a small radius area to find parking spaces. Moreover, the 5G network will provide better connectivity, even in underground spaces, to get more accurate data which lacks currently in Wi-Fi and 4G network.

### 3.1.9. Smart Security Management: BIM-Computer Vision-Based Smart Security System

This project aims to integrate BIM with computer vision to develop a more advanced smart security and access control system. The need for automated person identification is growing for multiple applications such as surveillance, access control, and smart interfaces. With the COVID-19 pandemic outbreak and social distancing becoming norms, computer vision will help automate many processes that are not efficiently carried out due to workforce shortage. This project will develop a more advanced BIM-computer vision-based security system to automate and prevent smart facilities from security threats. This proposed project aims to:

- Develop a computer vision and BIM-based smart security system to automatically prevent security threats and provide better location mapping of threats.
- Use the system to implement the crowd management system in the event of communicable disease outbreaks like COVID.
- Implement automated access control measures using computer vision to prevent security threats to high-security zones.

The role of 5G network will be to support cloud computing and processing of camera-based feeds. Distributed AI will be supported on the 5G network that can use simple cameras to perform complex tasks. The distributed cloud in 5G would help in analyzing the video close to the camera and only transmit the results preventing privacy issues in special cases.

### 3.1.10. Smart Document, Code, and Transaction Management: Common Data Environment for Facilities Management

This project aims to develop a common data environment for facilities management to easier store, process, and retrieve data using the BIM model as a base. This project aims to develop an integrated system to store data from a variety of sources, automatically process, and analyze the data. This project uses computer vision for hazard identification and automated action, LIDAR-based as-built BIM model creation, AI and analytics-based anomaly detection and recommendations, and development of product data templates for structured information storage about equipment and facilities for better analysis. This ongoing project aims to develop following in phase one development:

- Computer vision-based safety hazard identification.
- LIDAR/drone-based productivity enhancement and as-built BIM modeling with greater accuracy.
- AI and analytics-based anomaly detection techniques for FM.
- Product data templates for automated data capturing, analysis of whole life cycle, and progress payment during maintenance activities.

The 5G network will help to gather data from a variety of sources such as facilities camera, drone, IoT sensors to process data over the cloud and perform anomaly detection and safety hazard identification based on computer vision. It will also help to process video analytics near to the camera, thus promoting faster read time analysis. The use of drone with 5G network will help for site managers to conduct real time progress monitoring.

### 3.1.11. Smart Document, Code, and Transaction Management: Code Checking for Facilities Management

This is a BIM-based system to check statutory compliance and code checking at facilities management stage. While facilities are in use, there are various code compliances such as fire safety or statutory compliance, including health and safety or confined spaces regulations, that need to be followed. This project aims to create automated code and statutory compliance checking for facilities using BIM. This will give facility managers a better insight into their facilities and help them manage their managing agents or contractors for maintenance works.

- Development of a BIM-based system for automated code compliance checking for FM stage.
- The system will be able to automatically check statutory compliance for various spaces.
- The system will help facilities managers to analyze building with building code requirements in post occupancy phase.

The 5G network will be used for high bandwidth and cloud computing. The entire system will function on cloud and provide access to web-based platforms.

## 3.2. Education (Teaching and Industry Training)

Figure 4 presents the teaching and training roadmap of the 5G Advanced BIM Lab for 5G network adoption. Being housed in higher learning institutes, the lab will train students using new-age advanced technologies such as AR/VR and digital twin designed over the 5G network. This will ensure that the new technological interventions can be designed using the 5G network to provide students with new learning motivations. Similarly, industrial training will help the industry workforce upskill themselves with the use of new technologies designed for the 5G network. This helps them to align with Singapore's smart nation vision and increase their productivity and efficiency.

### 3.2.1. 5G AR/VR/BIM Application for Facilities Management of Smart Building

Regarding the MOE's (Ministry of Education) latest direction on augmenting digital capabilities into current teaching methods to create a more robust learning environment in a post-Covid-19

Singapore, this AR/VR project aims to test and showcase the possibility of new technology such as 5G to accelerate the digital transformation in this area, with reference for other industries' adaptation in the near future. The project covers remote location access to illustrate real-time, interactive virtual learning across different locations, which will require a reliable and high-performance mobility ecosystem.

The purpose of this ongoing research project is to develop better educational tools and techniques to facilitate more effective teaching and learning methodologies for facilities management. The project looks at the feasibility of incorporating AR and VR environments to engage students in an immersive experience to learn better and pick up facilities management fundamentals. This ongoing research shall bring about new learning levels and understanding of reality's various augmentations through first-hand user experience. This project's success will bring about more significant learning experience to students through interactivity in a 3D virtual world, cultivating better memories and faster learning skills and methodologies throughout their coursework. Some state-of-the-art features of this ongoing development are:

- This is the first of a kind project in Singapore and ASEAN countries in construction education, which combines various technologies into a single solution for the customized need. There is no existing solution that combines AR/VR, BIM, 5G, cloud computing, and remote teaching/learning experiences using wireless on 5G.
- This is the first of a kind project which aims to study high data required BIM model upload and download requirements using 5G over the cloud and powered by cloud rendering to feed on wireless devices.
- Almost all the current VR BIM solutions require a wired network [105]. This is the first project where we want to conduct trials for AR/VR BIM for wireless solutions to delimit the boundaries of educational space and bring it home.
- This is the first a kind project which wants to expand the teaching and learning classroom size, up to 30, to avoid repetition of course content to small groups of students.
- This is the first of a kind research study aiming to amalgamate different verticals (construction space, education space, advanced technology space) into a new vertical, opening new research and development verticals in the future.
- Unlike other AR/VR projects, this project is being developed by a joint venture between a telecom partner, AR/VR developer, and buildings domain experts (Department of Building). The network is customized for an enhanced user experience that is not viable with other such development.

The 5G network will be used to provide low latency, high bandwidth requirements put forth by BIM and AR/VR. Since the system will be supported on the cloud for BIM rendering, the cloud processing part will be conducted using the 5G network. By using 5G network, we are developing a cloud-based architecture whereby the rendering of BIM model is done on cloud using high processing graphical processing unit (GPU) which was not possible using 4G or Wi-Fi network.

### 3.2.2. AR/VR/Digital Twin Application in Construction Lifecycle Using BIM

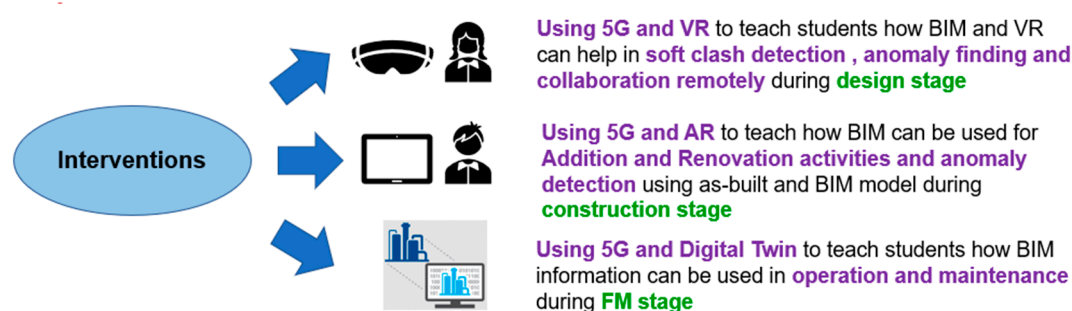
As Singapore progresses towards industry 4.0, big data, Internet of things, augmented reality (AR), virtual reality (VR), and digital twins become new research areas and need to be introduced in teaching and learning in order to prepare students to be future-ready. The ongoing project entails applying an integrated array of AR, VR, and digital twin applications in the context of teaching building information modelling. It proposes teaching the extended application of BIM coupled with new-age technologies such as AR, VR, and digital twin to enhance students' learning experience and align pedagogy with the industry 4.0 framework. The digital twin is a replica of physical identity, that can think (obtain conclusions), sense (in real-time), and act (suggest optimizations). Under Singapore's Construction Industry Transformation Map (ITM), one of the thrusts is digital revolution enabled by building information modelling (BIM). Integrated Digital Delivery (IDD) fully integrates processes

and stakeholders along the value chain through advanced info-communications technology (ICT) and smart technologies.

This project aims to teach students new-age info-communication and smart technology in the construction industry using BIM during the design, construction, and FM stage over the 5G network. This project's intent is to:

- Use AR/VR/digital twin application to teach students BIM usage in the entire life cycle.
- Increase learning motivation through intervention of new age technologies in BIM teaching.
- Transit BIM learning from BIM modeling to BIM application using advanced technologies.

In the ongoing project, three proposed interventions have been proposed. Figure 5 shows the proposed three interventions.



**Figure 5.** Interventions to enhance learning motivation in BIM module teaching.

In this project we aim to utilize 5G network to provide low latency, high bandwidth requirements put forth by BIM and AR/VR. Since the system will be supported on the cloud for BIM rendering, the cloud processing part will be conducted using the 5G network.

### 3.2.3. Facilitating Industry in 5G Workforce Transformation

5G training will reshape future workplaces. The training and development have an important impact on trainees' work performance and productivity. Through acquiring new digital skills (such as AR, VR, BIM, AI, robotics, machine learning, etc.), workers are able to pick up multiple-disciplinary skillsets. NUS (DoB) collaborate with telecom partners and industries together to lead and oversee learning and development of Singapore's 5G workforce capabilities across diverse economic domains and functionalities. The aim of such industrial training is to:

- Upskill in the areas of 5G network, cybersecurity, and solution engineering.
- Train workers to be future-ready before the commercial rollout of 5G.
- State of the art lab to support industry training. The lab is equipped with AR/VR devices, drones, high-power customized PCs, LIDAR equipment, servers, AR glasses, interactive whiteboards, robots, holographic projectors, a computer lab, etc.

DoB is emphasizing the following training areas:

- 5G-enabled smart facilities management

SFM is about adopting and integrating smart, disruptive digital technologies into FM systems (5G technologies, digital twinning, autonomous robotics, digital twin, drones, AR, VR, cloud computing, etc.), people, and intelligent processes to enhance a building's facilities management system (forb management, cleaning, safety and security, carpark, M&E, logistics), lessen response time, reduce costs and manpower, and raise productivity, thereby driving better outcomes in the management of a building's facilities, optimizing facilities through technology and data-driven decisions.

- 5G-enabled smart building and smart estates

Smart building technologies help developers, building owners, building managers, facilities managers to save time and money on property management, bring about greater welfare and healthier environments to building occupants, improve employee wellness and productivity. Our 5G use cases and case studies will be based on smart building technologies such as 5G technologies, digital twinning, AI maintenance, autonomous robotics, drones, IoT sensors, intelligent M&E systems, asset tracking, crowd management, equipment monitoring, IAQ monitoring, climate control, centralized management, intelligent carpark monitoring, safety and security systems, autonomous robotic cleaning, smart energy systems.

- Managing 5G future built environment

This area aims to train for managing future built-environments by leveraging on smart future-proof technologies such as 5G connectivity, digital twins, autonomous robotics, intelligent building management systems, cloud-computing, AR, VR, IoT, and artificial intelligence to improve building uptime and enhance operational efficiency, while reducing manpower and energy, streamlining work processes, adopting ultra-fast 5G connectivity, intelligent centralized building management systems, and advanced robotics to reduce energy waste and increase energy savings. Future-proof building designs will be safer, pandemic-proof, equipped with AI robotics for crowd monitoring, intelligent cleansing and auto-disinfection systems, and clean air systems.

### 3.3. Future Challenges for 5G Uses

5G promises to be a breakthrough network technology designed to virtually connect everything and everyone from objects, machines, and people. However, 5G network utilization is still new, as various use cases are still in development. While undertaking various use cases around 5G, it is necessary to understand the challenges that lie ahead. Some of the future challenges for 5G use cases are outlined as follows:

1. Many 5G use cases for SB and SFM are still evolving and under different stages of research experimentation and pilot-testing. Actual commercialization of 5G hardware products are still in progress and 5G devices such as 5G chipsets, 5G VR headsets, 5G laptops, 5G sensors, and 5G smart AR glasses are still under product development as 5G telecommunications protocol race for global standardization.
2. Test-bedding of many 5G use cases are taking place within institutes of higher learning and largely limited within the physical boundaries of Singapore. Trans-boundary deployments and global scale 5G use cases are few, especially in developing ASEAN countries.
3. Studies on cost-efficient 5G design, adoption, and implementation is necessary to attract any building developers and private industry to adopt any new expensive telecommunication protocol. Achieving the best cost-effective system to achieve optimal performance with minimal investment is a major concern for companies.
4. Minimizing the energy consumption of energy-intensive 5G network infrastructures while incorporating alternative renewable energy sources into smart buildings is another concern to maintain low running costs and sustainability of operations.
5. Preserving security of sensitive data is demanded in any connected environments. Building occupants must be convinced about the security of sensitive data, otherwise they will simply tend to avoid using ICT platform of smart buildings. Introducing stringent security measures is an essential necessity that requires further investigation.
6. Integrating heterogeneous devices and proprietary software applications is necessary to fully exploit the benefits of open source platforms and devices, so as to ensure universal inter-operability and allow different devices to inter-communicate with each other without

restrictions. Universal accessibility entails removing incompatibilities between multiple operational platforms and monopolistic protectionism at all levels of 5G implementation.

This section discusses the various use case projects and educational and industrial training ongoing and proposed in DoB under the SFM leveraging over the 5G network. With 5G promising to be high bandwidth, low latency network which can support a million devices per square mile area, various SFM projects will see a more dynamic change in the software architecture, hardware support, and user connectivity. With these ongoing projects, DoB is aiming to develop future-ready prototype applications under SFM designed especially for the 5G network. The outcome and learning from these projects will be shared in our forthcoming papers and through white papers, best practices guides for wider community reach. However, the 5G network is still in the trial license, and its wider applicability still needs to be commercially tested. As the 5G network will be rolled out commercially in the near future, we perceive a more mature development in various applications. Thus, in Section 3.3, we have highlighted some of the future challenges for 5G use cases development.

#### 4. Conclusions

This paper introduced DoB's 5G Advanced BIM Lab as a forefront research and industry application-oriented living laboratory which fosters research and solves practical industry problems. The 5G Lab has a dedicated 5G infrastructure set up in collaboration with telecom and network service providers to research and develop 5G network-based use cases in collaboration with the industry. The 5G Lab has several ongoing research and development projects which aim to develop successful 5G network use cases in three core development areas: research, industry, and education (RIE).

This paper analyzes various SFM drivers and identifies the current network-related challenges that hinder real-time and intensive memory-hungry applications. The paper illustrated the necessity of high bandwidth, low latency, and a customizable network that can support various network-related requirements in the case of an SFM, that cannot be fulfilled with the current networks. 5G's multiple features such as low latency, high bandwidth, and network slicing will enable future changes in processes and behaviors to facilitate industries in achieving higher sustainability goals. 5G also promises to mitigate the current challenges with mobile networks to empower next generation sustainability applications using AI based analytics, virtualization, IoT, edge computing, and cloud technologies.

Furthermore, this paper also analyzed the 5G network implementation for smart building and smart facilities management in Singapore. The rollout of 5G in Singapore aligns with the smart nation vision. IMDA, the government body which manages the spectrum allocation, has identified four focus areas, i.e., innovate, cybersecurity, regulatory, and talent grooming for 5G rollout. Under these four focus areas, six clusters have been identified: smart estates, industry 4.0, urban mobility, maritime operations, consumer applications, and government applications. The paper studied the alignment of smart nation Singapore and IMDA's 5G implementation plans and discussed the various state of the art projects undertaken under the SFM initiative by DoB's 5G Advanced BIM Lab. These use case projects aim to improve efficiency and productivity and redefine SFM applications to achieve higher sustainability levels through reduced energy consumption and real-time monitoring and actions while expanding RIE's horizon through the advanced state of the art technologies in implementing SFM. The paper further discussed a 5G based training framework adopted by the lab with holistic training goals for wider 5G adoption and future 5G challenges. These use case projects and teaching and training framework intend to provide for Singapore's vision of a smart and sustainable nation.

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