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5G for Construction: Use Cases and Solutions

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Abstract: The world is currently undergoing a new industrial revolution characterized by the digitization and automation of industry through the use of Information and Communication Technologies (ICTs). The construction sector is one of the largest sectors of the industry. Most of the tasks associated with this sector are carried out at worksites that are defined by their dynamism, decentralization, temporality, and the intervention of a large number of workers, subcontractors, machinery, equipment, and materials. These characteristics make this sector a great challenge for the implementation of ICTs. In this paper, the benefits of the use of the Fifth-Generation (5G) of mobile networks in the construction industry are presented. To that end, first, the digitization and automation needs of the sector are jointly analyzed, establishing different use cases and identifying the requirements of each one. Second, the main characteristics of 5G that address these use cases are identified. Third, a global framework for the application of 5G technology to the construction industry is proposed. Finally, an overview of some directions for future work are provided.

Keywords: 5G use cases; construction industry; construction automation

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1. Introduction

Currently, the world is facing a new industrial revolution marked by the rise of Information and Communication Technologies (ICTs) in the industrial processes [1]. This new era of the industry is known as Industry 4.0. However, due to the special work conditions of the construction sector, the impact of ICTs on it has been less than in other industry sectors such as logistics or manufacturing [2,3]. Most of the activity in the construction industry takes place at worksites. These are very dynamic environments, in many cases outdoors, characterized by the intervention of different companies and by a large number of workers during the different stages of the construction process. In addition, the use of heavy machinery such as trucks or loaders and hazardous materials such as chemicals or heavy materials make these environments arduous, where the tasks of control, planning, and safety are often difficult to handle. In this context, the emergence of new ICTs that allow the monitoring of workers and resources, the remote operation of machinery, and the automation of tasks at worksites will help to obtain more sustainable and efficient construction, as well as to improve the safety at worksites and to accelerate construction processes. The integration of these new technologies in the construction sector opens the way to what is known as Construction 4.0 [4].

The particular needs of the construction industry are a challenge for the implementation of ICTs. In this paper, we focus on analyzing the requirements and limitations of the sector for the implementation of telecommunication networks. First, worksites are distinguished by their distributed and, in some cases, remote locations. Depending on the location of the worksite, the conditions of the environment can notably change. This situation highlights the need to use technology with a wide coverage in different locations.

Second, construction projects are time limited and tightly planned. Thus, the time and resources invested in the implementation of telecommunication technologies for a particular worksite are also limited. Third, at construction sites, there are many resources such as materials, equipment, or machinery and environmental factors that could be monitored. Therefore, a technology capable of serving a large number of devices is required. In addition, high bandwidth is required to enable high-quality video surveillance. Fourth, worksites are dynamic environments in which there are constant movements of people and machinery. Moreover, as the work progresses, the scenario may change drastically, going from a completely outdoor scenario to an indoor one. In this way, a robust technology capable of facing the changes in the scenario is needed. Finally, in order to automate tasks related to the remote control of heavy machinery at worksites, very low latency communications and high reliability and availability of services are essential.

During the last few years, the incorporation of ICTs in construction has been very limited; however, some works that address this issue can be found in the literature. Most of these works are focused on safety at worksites, leaving aside aspects such as improving efficiency, productivity, or sustainability at work. In this sense, in [5–9], several applications of the Internet of Things (IoT) to safety in construction sites were presented. In [5], a framework for monitoring risk areas at the worksite and locating workers and machinery was described. The authors in [6,7] proposed a worker location system that was used in [6] to alert workers of the need to wear hardhats and in [7] to alert about access to unauthorized areas. A system to avoid workers from being run over at worksites was proposed in [8]. In [9], a system for sending personalized safety instructions to workers was presented. IoT platforms for the collection of worksite information in real time were presented in [10,11]. This information was used in [10] to speed up the management of the industrialized construction and for automatizing the decision-making process in [11]. In these works, wireless communication technologies such as WiFi, General Packet Radio Service (GPRS), or the Fourth-Generation (4G) of mobile networks were used to transmit the information from the sensors and to send possible alerts to workers. Although these technologies are capable of covering some of the requirements of the sector, they fail to respond to all the requirements together. In this situation of blockage, a technology with the needed characteristics to solve the requirements of the construction industry arises, the Fifth-Generation (5G) of mobile networks [12].

Despite the great benefits that 5G networks bring to the monitoring, control, and automation of the construction sector, to date, there are only a few isolated works that address this issue. Moreover, these works focus on very specific 5G uses in construction, not providing a global solution to the problem. In this sense, Reference [13] proposed a system for the prevention of accidents at worksites based on 4K cameras. 5G networks were also proposed in [14] to perform machinery remote control. In [15], an overview of how 5G could impact construction management applications was provided. However, this work did not address the complete problem of the construction industry. The authors focused on the use of IoT applications, not taking into account the complete automation of the sector. Moreover, although the main advantages of 5G were presented, the authors did not propose the use of specific 5G features to cover the needs of the construction sector.

This paper proposes a complete framework of the benefits of using 5G technology in the construction sector. As far as the authors are concerned, this is the first time that the main aspects and use cases of Construction 4.0 have been clearly and jointly established. In this sense, the use cases of Construction 4.0 are first defined. For each use case, its requirements, characteristics, and limitations in relation to the application of telecommunications technologies are identified. The main characteristics and functionalities of the new 5G mobile networks that respond to the challenges introduced by these use cases are then highlighted. Furthermore, a high-level system architecture for the integration of 5G mobile networks in the construction sector is proposed. Finally, some of the challenges presented by the use of 5G networks in the built environment that need to be addressed by the research community are set out below.

2. Construction Use Cases

In order to tackle the challenge of automating the construction industry through digital transformation, this section defines different use cases. These use cases include those aspects related to the construction process that may benefit from the use of 5G. In this way, five use cases were identified: remotely controlled and autonomous machinery, health and safety at worksites, 3D models, construction processes' management, and emissions and waste management. The following subsections define each of these use cases, providing for each of them an analysis of the requirements and challenges they present for the integration and use of telecommunication networks.

2.1. Remotely Controlled and Autonomous Machinery

This first use case refers to the incorporation of autonomous machinery such as robotic operators or self-driven cranes and remotely controlled machinery such as bulldozers or excavators at worksites. These elements gather information from their environment such as video images or physical parameters through the use of sensors in real time. Based on the information collected, the actions to be performed by this machinery are decided. In the case of autonomous objects, the decision-making process is usually performed by the machine itself or by a control center. In the case of remotely controlled machinery, that decision is typically made by an operator. The use of this type of machinery at worksites prevents the exposure of workers to dangerous situations and environments by allowing operators to control machines from safe positions. The use of autonomous machinery avoids possible human errors. In addition, it contributes to increasing productivity and sustainability via energy savings and work efficiency, facilitating the coordination of different processes.

Remotely controlled and autonomous machinery are considered in the field of communications as mission-critical applications. In these types of applications, it is of vital importance to have a fast communication between the machinery and the decision-making entity. Fatal accidents may occur if the communication fails or if there are delays in the reception of the data. Thus, the main challenges posed by this use case are: the need to transmit and receive information at very low latency, between 1 and 10 ms, the high availability of the services, higher than 99.9999%, the reliability in the communication, which should be at least 10^{-6}, and the need for a secure link. In those cases where the data collected by the machinery are video, a high bandwidth is also needed, at least a data rate of 10 Mbps per connected machine being required [16].

2.2. Health and Safety at Worksites

Precisely monitoring high-risk areas and workers and giving helpful alerts may lead to a safe worksite. The main idea of this use case is the creation of a digital twin map of the construction site in real time. The map should identify high-risk areas, as well as the positioning of workers and machinery within the worksite. To monitor high-risk areas, it is necessary to deploy a network of sensors capable of measuring environmental conditions such as air quality, temperature, or noise. Real-time notification to workers at high-risk positions can prevent numerous accidents and deaths by reducing the number of falls and being struck by machinery or objects. This use case also includes the use of wearables, capable of measuring workers' vital signs and alerting them in the case of fatigue, and the use of sensors in safety equipment (hardhats, boots, harnesses, etc.), which allow detecting whether workers are using them correctly. This technology can also be useful for access control tasks.

To meet the needs of this use case, it will be essential to have a large number of devices (sensors and wearables) connected to the network. These devices are characterized by low data rates. In order to alert workers before their health is at risk, communication needs to be performed with low latency between 5 and 10 ms [16].

2.3. 3D Models

This use case refers to the use of Augmented Reality (AR) and Virtual Reality (VR) to provide an on-site view of project drawings. In addition, this use case considers the combination of these techniques with Building Information Modeling (BIM). In this way, it will be possible to provide additional information such as task planning, material costs, or the characteristics of the different construction elements to the animation generated by AR and VR services. This could noticeably ease the scheduling of building tasks and reduce the probability of making execution errors.

The challenges presented in this use case are firstly associated with the need to transmit high-quality video in real time. Thus, a high bandwidth of around 25 Mbps per device [17] is necessary. Secondly, to provide AR and VR users with a sense of reality, a latency lower than 10 ms [16] is required.

2.4. Construction Processes' Management

This use case focuses on the digitization and automation of construction processes' management. This use case aims at improving the efficiency and the effectiveness of processes that have a great impact on the final result of the work, such as concrete setting or welding execution. For this purpose, sensor networks that allow knowing in real time data such as the maturity of the concrete, the location of equipment and machinery, or the weather conditions, as well as IP cameras and drones to take 4K video images will be used. All this information will allow remote monitoring of progress and more informed decision-making, thus reducing time and costs, increasing productivity and the quality of the final result, and avoiding the appearance of problems in the short and long term. For example, in the setting of concrete, on the one hand, a too short waiting time can lead to later problems in the construction, such as the appearance of cracks. On the other hand, a too long waiting time leads to time loss and, therefore, to a less efficient construction process. In this scenario, sensors can help to measure not only the correct composition of the concrete, but also its setting state at any time. In addition, having greater control over existing resources and the status of the work can serve to optimize the supply chain. In this way, the information gathered could help to place material orders on time and to reduce delays in the original planning of tasks. Finally, this type of monitoring can also be useful in preventing the theft of materials and equipment.

To meet the requirements of this use case, it is necessary to provide connectivity to a large number of devices at the worksite. Moreover, to be able to transmit the video images with high quality, in this case, a high bandwidth, around 25 Mbps per device [17], is also required. Enabling remote control of the drones is necessary to have very low latency in the communication, between 1 and 10 ms [16].

2.5. Emissions and Waste Management

This use case is oriented toward sustainable construction. Thus, it includes all those applications aimed at controlling and managing greenhouse gas emissions and waste. For this purpose, the use of sensors is proposed to measure parameters such as the amount of waste accumulated or the levels of carbon dioxide or nitrogen dioxide in the environment. In this way, to cover the needs of this use case, it will be required to provide connectivity to a great amount of sensors. These sensors must be able to transit information even when they are outside of the worksite, as for example would be the case of the sensors placed in the trucks to control the gases emitted by these during their trips.

3. 5G in Construction

As described in the previous sections, construction is a very dynamic environment, in which it is also necessary to provide communication to elements in constant movement, such as workers or machinery. In this type of scenario, wired communications are not feasible, since they are not able to quickly adapt to changes and, furthermore, do not support the mobility of users [18]. Therefore, the use of wireless communications is essential in this environment.

Different wireless technologies have been proposed for IoT implementation in the construction sector. The proposed wireless technologies can be classified into long-range networks, short-range networks, and cellular networks [19]. However, these technologies are not able to respond to all the requirements of this sector.

Long-range networks such as LoRA [20] or SigFox [21] are characterized by providing low-power communications and a wide coverage radius, in the order of tens of kilometers. This type of technology provides the low power consumption of devices thanks to the efficient use of the bandwidth. As a consequence, the data rate achieved by these technologies is very limited, being approximately 50 kbps in the case of LoRA and 100 bps in the case of SigFox.

Short-range networks such as WiFi [22], ZigBee [23], and Bluetooth Low-Energy (BLE) [24] are characterized by a coverage range that goes from tens of meters, as in the case of BLE, to hundreds of meters, as in the case of WiFi and ZigBee. Thus, the use of these technologies at large construction sites could cause coverage holes in some areas. BLE technology only allows communication between two devices at the same time. This is a major limitation in situations where it is necessary to collect information from several devices at the same time, as is the case of worksites. In addition, this technology only achieves data rates of about 2 Mbps. ZigBee allows data rates of up to 250 kbps. Finally, WiFi supports a high throughput of up to 54 Mbps.

Long-range and short-range networks have in common that they both make use of the unlicensed spectrum. In this sense, these technologies cannot guarantee a certain Quality of Service (QoS), nor the latency and reliability required for critical applications. In addition, with the exception of WiFi, the aforementioned technologies do not provide sufficient bandwidth for real-time video transmission.

Finally, cellular networks such as 2G and 4G have been proposed to address the IoT in the construction environment. One of the main advantages of cellular networks over previous technologies is that they use the licensed spectrum, thus offering a higher level of security and QoS. In addition, unlike previous technologies, cellular networks support user mobility (handovers between cells in the same network) and roaming (handovers between different networks). In this sense, these technologies enable ubiquitous and seamless communications. Regarding IoT, EC-GSM-IoT [25], eMTC [26], and NB-IoT [27] features have been designed to coexist with both 2G and 4G networks. These technologies are designed to serve a massive number of devices, providing large coverage areas and efficient use of device batteries. However, both the latency and the throughput achieved by these technologies are limited, making them unsuitable for critical or high-bandwidth applications such as VR or AR. The new generation of cellular networks, 5G, improves the performance of previous generations, being able to provide a transmission rate 100 times greater than 4G, 1 ms of communication latency, 99.999% reliability, and a massive number of User Equipment (UE) connections [28]. Furthermore, the integration of 5G with Satellite Communications (SatComs), or Non-Terrestrial Networks (NTNs), following the Third-Generation Partnership Project (3GPP) nomenclature, [29], will bring benefits in terms of coverage extension and increased network availability. In this way, 5G is able to support the requirements demanded by Construction 4.0.

The key characteristics of 5G that make it possible to meet the requirements of the construction sector are the definition of three service categories: enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTCs), and Ultrareliable Low-Latency Communications (URLLCs), as well as the addition of new features such as network slicing, Multiconnectivity (MC), massive Multiple-Input Multiple-Output (MIMO), and vehicular communications. Moreover, the use of SatCom as a 5G access network will act as a transversal feature that, although not directly related to any of the Construction 4.0 use cases, will serve to cover both densely populated areas and rural or remote areas in which terrestrial 5G networks are not sufficient (see Section 3.3). Figure 1 shows a construction site scenario in which the different use cases defined in Section 2 are depicted. These use cases are represented by using yellow labels. In the figure, the different 5G service categories (gray labels) are also shown. Thus, the figure shows a division of the Construction 4.0 use cases among the 5G service categories. This division is further discussed in Section 3.1. Finally, the figure also shows the 5G features that are of major importance to meet the needs of Construction 4.0 applications. These 5G features are represented with blue labels. An overview of these features is provided in Section 3.2.

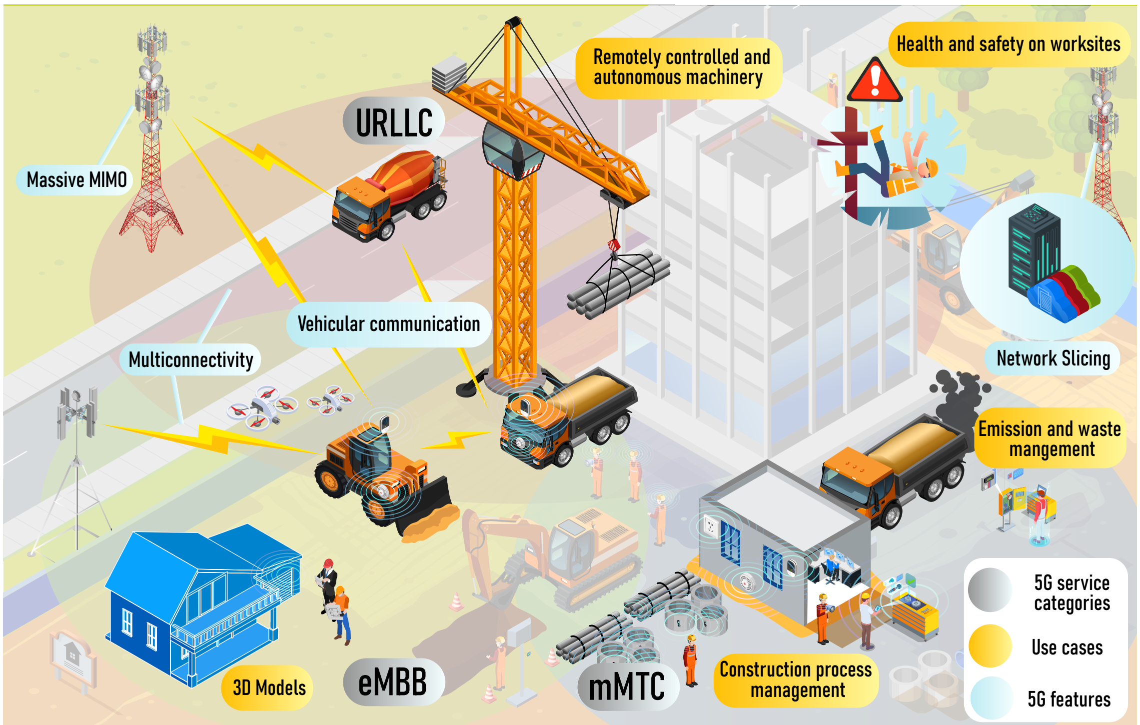

Figure 1. 5G at a worksite.

3.1. 5G Service Categories

The International Telecommunication Union Radiocommunication Sector (ITU-R) has defined three service categories (eMBB, mMTC, URLLC) that present different requirement and characteristics [30]. Each service category is intended to cover different types of applications. Thus, a 5G network will be able to address diverse scenarios and use cases with a global management framework. The service categories are:

- Enhanced Mobile Broadband. eMBB is related to applications that require high data rates across an extensive area. Some of the applications related to the construction industry that have strict requirements in terms of throughput and will therefore benefit from this category of service are the visualization of 3D models that make use of AR and VR services and the monitoring of worksites through the use of high-quality video cameras;
- Massive Machine-Type Communications. mMTC is characterized by the connection of an extremely high number of devices, which usually demands a low volume of traffic. IoT networks are the most important example of the use of this type of service. In the construction industry, many sensors and other devices such as cameras or wearables can be used to monitor the worksites. Sensors can be used to monitor the quality of the materials used in different stages of the construction process or the quality of the environment around the worksite. Thus, this type of service is essential in the use cases related to construction process management or worker safety;
- Ultrareliable Low-Latency Communications. URLLC may provide latency values of 1 ms while assuring an error packet rate below 10^{-5}. URLLC communications

have became a key element of critical applications where the reliability and latency requirements are very restrictive. Some of these applications are vehicular communications or remote monitoring. Regarding the use cases related to the construction industry, URLLC services will provide the capacity to remotely control drones or manage machinery at worksites in addition to others.

3.2. 5G Features

5G technology proposes new features that intend to address the restrictive requirements of the new services. Among the 5G features defined by the 3GPP, the more important ones to target the construction industry use cases are the following:

- Network slicing. 5G is conceived of as a multiservice network. Thus, 5G aims to meet the needs of a vast dimension of verticals with different requirements and characteristics (e.g., self-driving cars, smart homes, AR, voice, etc.). In order to meet the needs of all these services, the physical network is divided into multiple isolated logical networks (slices). Each of these slices will have different sizes and structures and will be dedicated to different types of services. This division of the physical network into multiple slices is known as network slicing [31]. In order to control and manage the different slices, the use of technologies such as Software-Defined Networking (SDN), Network Function Virtualization (NFV), or cloud computing becomes indispensable [32]. Network slicing is essential in a Construction 4.0 scenario due to the variety of requirements presented by its different use cases and applications. In each of the defined slices, the network configuration will be different in order to meet the requirements of the applications being served. For instance, autonomous machinery is a high-priority application with strict latency and reliability requirements. However, the use of high-definition video cameras for the management of construction processes is an application that, while demanding high throughput, does not have significant requirements in terms of latency and reliability. For this reason, these two applications should be managed independently, by defining two different slices. Network slicing management in industrial environments was recently discussed in [33];
- Multiconnectivity. MC allows UE to simultaneously aggregate radio resources from several network nodes. There are different MC approaches depending on the number of nodes with simultaneous connections with the UE: Carrier Aggregation (CA) [34], when only one node provides the several connections to the UE, and Dual Connectivity (DC) [35], when radio resources assigned to the UE belong to two different nodes. The concept of MC [36] can be extended to any situation where several connections are assigned to a UE from more than two nodes. This last definition is not yet included in the standard, although it has been discussed in several scientific fora. In any of the MC approaches, the information sent by each connection can be aggregated or duplicated. In the case that aggregation is applied, an increase of the UE throughput is the main benefit of MC. This is especially important for eMBB services and Construction 4.0 applications such as 3D models or monitoring of construction processes through the use of high-quality video. In the case of data duplication, the main benefit is an increase in reliability. This option is usually used with URLLC services. Construction 4.0 applications such as remotely controlled and autonomous machinery may benefit from this approach. In both cases, the several links from the UE to the network provide more robustness to the UE connection, ensuring the data transmission;
- Massive MIMO. Massive MIMO is usually associated with arrays with a high number of antenna elements [37]. Thus, massive MIMO allows increasing the cell capacity when each antenna is used to connect several UEs. In addition, one UE can have more than one connection, improving its experienced throughput. Extending these situations, in 5G networks, massive MIMO antennas provide the capacity to define different beamwidths for the antenna diagram, leading to beamforming functionality [38]. Beamforming is especially significant in mmWave. Finally, the high number

of antenna elements allows a large number of devices to have a simultaneous connection with the gNodeB, which is an important requirement for mMTC services. Regarding Construction 4.0, massive MIMO will be one of the key functionalities to be considered. It will be essential to have a large number of devices such as sensors for remote monitoring and to provide high throughput connections for services such as AR in the 3D models' visualization;

- Vehicular communications. Vehicular communications refer to the communications between vehicles and other elements, that is Vehicle-to-Everything (V2X) communications [39]. Depending on the type of elements involved in the communication, the information can be exchanged between vehicles (V2V), vehicle and pedestrian (V2P), vehicle and infrastructure (V2I), or vehicle and network (V2N). The 5G standard includes V2X communications as a key element of this mobile technology. The benefits of using this functionality go from avoiding traffic congestion, reducing environmental impacts, or even avoiding accidents. However, the requirements for such communications are very stringent in terms of latency, reliability, throughput, or accurate location. Regarding Construction 4.0, this kind of communication allows machinery to act autonomously, improving the efficiency of construction processes.

Table 1 summaries the possibilities of 5G technology to address the main challenges of Construction 4.0.

Table 1. 5G solutions for the construction industry use cases.

Use Case	Challenges	5G Solutions
Remotely controlled and autonomous machinery	Low latency (1–10 ms) High reliability ($<10^{-6}$) High bandwidth (>10 Mbps) High availability of services (>99.9999 %)	URLLC eMBB MC Network slicing V2X communications
Health and safety at worksites	Low latency (5–10 ms) Large number of devices	URLLC mMTC Network slicing
3D models	Low latency (<10 ms) High bandwidth (25 Mbps)	eMBB Massive MIMO MC
Construction processes' management	Large number of devices High bandwidth (25 Mbps)	mMTC eMBB Network slicing
Emissions and waste management	Large number of devices	mMTC

3.3. 5G–Satellite Integration

One of the main objectives of 5G is to achieve ubiquitous and seamless communication. In this context, SatCom will play a key role. The integration of these networks with 5G will support coverage in unserved or underserved areas. In addition, the use of satellites will reinforce the reliability of services by providing service continuity; improve availability, especially relevant in critical communications; and facilitate the scalability of 5G networks [29]. Thus, SatComs are considered one of the main enablers for 5G systems. However, the inherent characteristics of SatComs (e.g., Doppler shifts, delays, or large path loss) make this integration nontrivial. In this sense, one of the main aspects to be taken into account is how to guarantee the QoS of the traffic over SatCom. In general, this issue has been addressed in works such as [40,41], where an overview of different Satellite IP networks architectures is provided, taking into account different levels of the communication protocol stack. More specific to the integration of SatCom with 5G, Reference [42] propose solutions to physical and Medium Access Control (MAC) layer problems, such as: downlink synchronization, random access, and Hybrid Automatic Repeat reQuest (HARQ).

In order to meet the targets established in the integration of SatCom with 5G, both Geostationary Earth Orbit (GEO) and Low-Earth Orbit (LEO) satellites are considered [43], the latter being able to achieve lower latency, in the order of tens of ms [44]. In studies such as [45], communication latency reduction was achieved thanks to the use of MC between the NTN-based New-Generation Random Access Network (NG-RAN) and the terrestrial NG-RAN, although MC schemes between two different NTN-based NG-RANs are also being studied by 3GPP [46].

Regarding Construction 4.0, the benefits of integrating SatCom with 5G networks are not limited to a specific use case or application. Conversely, this 5G feature will be very useful to guarantee the QoS of Construction 4.0 applications in those environments that due to their characteristics lack sufficient 5G coverage (e.g., works in rural or remote areas, works in areas with a very high population density).

4. System Architecture

This section presents a high-level architecture of the integration of 5G in the construction industry (Figure 2). The main goal of this system architecture is to define a global framework for construction management that includes solutions for each use case described in the previous sections. This architecture is mainly composed of five components: sources of information, communication technology (5G), data processing, applications, and network management. In the following subsections, the different components of the network architecture are defined.

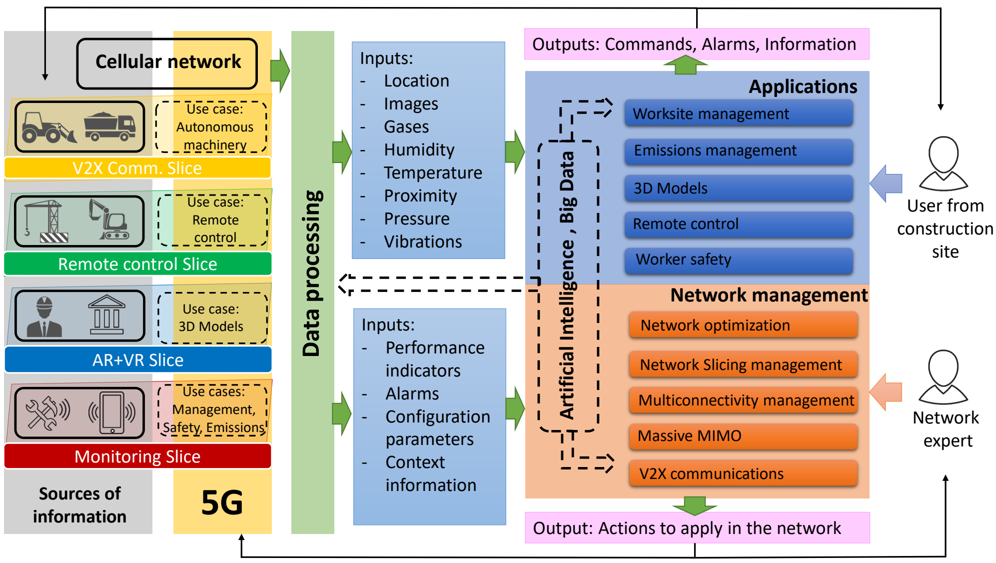

Figure 2. System architecture for 5G in construction.

4.1. Sources of Information

The proposed system will use information gathered from different information sources. These sources are related to the different elements that can be found at a worksite and are involved in the Construction 4.0 use cases. Thus, the possible sources of information that can be found at a construction site are sensors installed in vehicles, equipment, workers, machinery, etc.; cameras not only for the worksite surveillance, but also for vehicular communications or remote control of drones; wearables to ensure workers' safety; and devices for AR and VR for visualizing the BIM models of the building.

Finally, the 5G network itself is considered as a source of information since indicators gathered from network elements will be used in subsequent stages.

4.2. Communication Technology

Regarding communication technology, this system architecture is focused on the use of 5G networks. As described along the paper, this technology presents a set of key functionalities that allow addressing the main challenges presented by the use cases in the construction industry. One of these functionalities is network slicing, which is shown in Figure 2. This paper proposes a specific slice definition based on the use cases defined and the applications identified for each use case. Thus, the first slice is intended for V2X communications. This kind of communication presents restrictive requirements in terms of latency, reliability, and throughput, as well as an important accident risk, so it is essential to ensure the communication's availability. The second slice is intended for remote control of machinery and drones. Although these applications have similar requirements to the previous ones to ensure the availability of resources and proper network optimization, the use of a different slice to host these applications is proposed. Therefore, this second slice will be focused on URLLC services, which also need relatively high throughput to enable video control of machinery. The use case of 3D models will be addressed by the third slice. In this case, both URLLC and eMBB services are needed for applications such as VR and AR. Finally, the forth slice is mainly for mMTC services. This service category allows the implementation of use cases such as health and safety, emissions and waste management, and most of the construction process management use case applications.

In addition to network slicing, the 5G network should implement the main functionalities described in Section 3 such as MC or massive MIMO.

4.3. Data Processing

Due to the use of the different sources of information described in Section 4.1, a large amount and diversity of data are collected. In order to fuse the data from the different sources of information, it is necessary to apply data processing techniques. First, the data provided to subsequent stages in the system architecture must have the same structure so they can be combined in the different algorithms. In addition to diversity, the collected information may be too large to be efficiently used in the algorithms. In this case, dimensionality reduction techniques such as feature engineering should be applied. The main goal of this block is to achieve a set of inputs efficiently selected and processed for each algorithm defined in the system. The use of Artificial Intelligence (AI), data analytic, and big data techniques will be essential in this data processing.

Cloud, fog, and edge computing are considered for data processing. Cloud computing refers to the use of network resources. Cloud computing provides on-demand data processing and storage services with high availability. However, cloud computing, due to the distance of the processing and storage nodes from the data collection devices (information sources), has limitations in performing real-time processing functions. Fog and edge computing refer to performing data processing and storage tasks in a distributed manner on fog and edge nodes, respectively. In these types of approaches, the processing and storage nodes are located closer to the information sources. In the case of edge computing, the nodes will be located as close as possible, in some circumstances the same device that collects the data being the one that performs the processing tasks. In the case of fog computing, the nodes will be located somewhere between cloud and edge. In both edge and fog computing, it is possible to perform data processing in real time. However, in edge computing, the information that will be available to perform these tasks will be more limited, being in many cases the information collected by a single device. Thus, the combined use of the different approaches is proposed [47].

4.4. Application

This block includes all the applications defined for the automation, digitization, and improvement of the different processes in Construction 4.0. There are many inputs to this block. The location of workers and high-quality video images, in addition to information about gas concentration, humidity, or temperature may be used for worker safety applications. This environmental information may be also used for construction process management or waste management applications. Accurate location information and high-quality images are also used in applications such as remote machine control or AR. These applications will use these input data to perform functions such as automating decision-making, predicting the future state of the construction site, detecting and diagnosing problems, or generating statistics. To this end, these applications will make use of data analytic techniques such as regression and time series analysis and AI techniques such as machine learning, neural networks, or reinforcement learning. In this way, some of the outputs of these applications can be applied directly to elements of the construction site, such as commands generated by remote control applications or alarms regarding worker safety applications, which should alert workers of an imminent danger. In other cases, the outputs from these applications will support better management of the construction project and site resources. To perform these functions, applications may benefit from the use of cloud, fog, and edge computing. The use of these technologies will be especially relevant for those applications that need to handle large amounts of data or for those applications that need a high processing capacity.

4.5. Network Management

Finally, the system architecture includes a block for network management. The applications in this block should be managed by a network management expert. The main objective of these applications is the optimization of 5G functionalities in order to obtain the best results in construction automation. In addition, using data analytic and AI techniques for the implementation of these applications allows them to automatically adapt to the changes of the worksite. For instance, the network slicing management application might automatically distribute resources among all slices depending on the specific needs in each moment. These applications need a set of inputs including performance indicators and configuration parameters from the cellular network and context information related to the status of the worksite such as number of workers, the number of machinery and equipment, specific use cases needed, etc. As a result of the applications' execution, a set of outputs is provided. These outputs represent the actions to be applied to the network in order to optimize its performance. Network management tasks can also benefit from the use of cloud, fog, and edge computing technologies, which are necessary for tasks such as network slicing management.

5. Future Study Directions

This section discusses some possible lines of future work associated with the use of 5G networks in construction and the development of Construction 4.0. Thus, the directions for future work considered most interesting by the authors of this paper are as follows:

- Security and privacy. Throughout this paper, the benefits of using 5G networks for Construction 4.0 are discussed. However, the use of this type of network also implies the emergence of some problems related to network security and privacy. In 5G networks, most of the security and privacy issues are related to the virtualization of networks and the use of technologies such as cloud computing, SDN, and NFV [48]. The 5G standard contains some solutions to generally address the security issues of 5G networks. However, it is considered necessary to conduct studies in this direction, since some specific cases, especially those related to the use of low-power devices such as sensors, are not included in the standard [49];
- Limited capability devices. The automation and digitization of the construction sector involves, among others, the deployment of sensor networks in the construction site environment. These sensors, in some cases, may be devices with limited capabilities, i.e., devices with low-power, low-memory, or low-processing capacity. In these cases, integrating sensors into 5G networks may be a problem, as these devices lack the features needed to implement the IP protocol stack. To solve these problems, the Internet Engineering Task Force (IETF) has proposed a protocol stack that aims to

connect limited IoT devices to IP networks [50]. These protocols have been tested in ultralow-latency environments supported by 5G networks [51]. Thus, a possible line of future work would be to conduct studies analyzing the use of these types of protocols in other 5G environments;
- Development of new Construction 4.0 applications. Another line that future research can focus on is the development of new applications that promote the evolution of the construction industry. These applications will focus on improving the productivity, safety, efficiency, and sustainability of construction through the automation and digitization of processes. The use of cloud, fog, and edge computing for the development of these applications is also considered of interest, as well as the use of data analytics and AI techniques;
- 5G features management. Finally, the development of algorithms for the management of 5G networks is considered necessary. This is a field widely studied in the state-of-the-art. However, most of the scenarios studied present different characteristics from those of the construction environment. Thus, studies related to the management of these networks in Construction 4.0 environments are necessary. These studies should address the optimization of the different 5G features identified as key to the evolution of the construction sector: network slicing, MC, massive MIMO, and vehicular communications. In addition, studies related to 5G network fault management in this environment will also be considered of interest.

6. Conclusions

The particularities of the construction industry, as well as the limitations of the telecommunication networks existing so far have led this sector to present a low level of automation and digitization. The emerging 5G technology was presented as an enabler for the automation of the sector. This technology aims to accommodate a wide variety of services with very different requirements. In this paper, a complete framework of the benefits of using 5G networks in the construction sector was presented. In this way, first, different use cases referring to the automation and digitization of this sector were defined, identifying for each one the challenges that they present regarding the implantation of telecommunication networks. Next, the main characteristics of 5G networks that respond to the needs of the construction industry were presented. These characteristics refer, on the one hand, to the service categories defined by ITU-R: eMBB, mMTC, and URLLC, and, on the other hand, to the new 5G features that allow meeting the requirements established in the different construction use cases; these are: network slicing, MC, V2X communications, and massive MIMO. To enable the integration of 5G networks in the construction sector, a high-level network architecture composed of five elements (sources of information, 5G network, data processing, applications, and network management) was proposed. Finally, the main lines of future work were established. On the one hand, the problems that may arise from the use of 5G networks in construction environments were presented. These problems are mostly associated with the security and privacy of the networks and with the use of devices with limited capabilities. On the other hand, the need for the development of more applications that propose the automation and digitization of this sector and algorithms that allow a correct management of 5G networks in these scenarios was highlighted.

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References

1. Schwab, K. *The Fourth Industrial Revolution*; Crown Business: New York, NY, USA, 2017.
2. Alaloul, W.S.; Liew, M.S.; Zawawi, N.A.W.A.; Mohammed, B.S. Industry revolution IR 4.0: Future opportunities and challenges in construction industry. In *MATEC Web of Conferences*; EDP Sciences: Les Ulis, France, 2018; Volume 203, p. 02010.
3. Schönbeck, P.; Löfsjögård, M.; Ansell, A. Quantitative Review of Construction 4.0 Technology Presence in Construction Project Research. *Buildings* **2020**, *10*, 173. [CrossRef]
4. Munoz-La Rivera, F.; Mora-Serrano, J.; Valero, I.; Oñate, E. Methodological-technological framework for Construction 4.0. *Arch. Comput. Methods Eng.* **2021**, *28*, 689–711. [CrossRef]
5. Jiang, W.; Ding, L.; Zhou, C. Cyber physical system for safety management in smart construction site. *Eng. Constr. Archit. Manag.* **2020**. [CrossRef]
6. Zhang, H.; Yan, X.; Li, H.; Jin, R.; Fu, H. Real-time alarming, monitoring, and locating for non-hard-hat use in construction. *J. Constr. Eng. Manag.* **2019**, *145*, 04019006. [CrossRef]
7. Jin, R.; Zhang, H.; Liu, D.; Yan, X. IoT-based detecting, locating and alarming of unauthorized intrusion on construction sites. *Autom. Constr.* **2020**, *118*, 103278. [CrossRef]
8. Kanan, R.; Elhassan, O.; Bensalem, R. An IoT-based autonomous system for workers' safety in construction sites with real-time alarming, monitoring, and positioning strategies. *Autom. Constr.* **2018**, *88*, 73–86. [CrossRef]
9. Tang, N.; Hu, H.; Xu, F.; Zhu, F. Personalized safety instruction system for construction site based on Internet technology. *Saf. Sci.* **2019**, *116*, 161–169. [CrossRef]
10. Xu, G.; Li, M.; Chen, C.H.; Wei, Y. Cloud asset-enabled integrated IoT platform for lean prefabricated construction. *Autom. Constr.* **2018**, *93*, 123–134. [CrossRef]
11. Louis, J.; Dunston, P.S. Integrating IoT into operational workflows for real-time and automated decision-making in repetitive construction operations. *Autom. Constr.* **2018**, *94*, 317–327. [CrossRef]
12. 3GPP. *TR 38.913: Study on Scenarios and Requirements for Next Generation Access Technologies (Release 16)*; v:16.0.0; 3GPP: Route des Lucioles, France, July 2020.
13. Nozaki, D.; Okamoto, K.; Mochida, T.; Qi, X.; Wen, Z.; Tokuda, K.; Sato, T.; Tamesue, K.; AI management system to prevent accidents in construction zones using 4K cameras based on 5G network. In Proceedings of the 2018 21st International Symposium on Wireless Personal Multimedia Communications (WPMC), Chiang Rai, Thailand, 25–28 November 2018; pp. 462–466.
14. Xiang, Y.; Xu, B.; Su, T.; Brach, C.; Mao, S.S.; Geimer, M. 5G meets construction machines: Towards a smart working site. *arXiv* **2020**, arXiv:2009.05033.
15. Reja, V.K.; Varghese, K. Impact of 5G technology on IoT applications in construction project management. *ISARC. Proc. Int. Symp. Autom. Robot. Constr.* **2019**, *36*, 209–217.
16. 3GPP. *TR 22.804: Study on Communication for Automation in Vertical Domains (Release 16)*; v:16.3.0; 3GPP: Route des Lucioles, France, July 2020.
17. Akyildiz, I.F.; Nie, S.; Lin, S.C.; Chandrasekaran, M. 5G roadmap: 10 key enabling technologies. *Comput. Netw.* **2016**, *106*, 17–48. [CrossRef]
18. Flammini, A.; Ferrari, P.; Marioli, D.; Sisinni, E.; Taroni, A. Wired and wireless sensor networks for industrial applications. *Microelectron. J.* **2009**, *40*, 1322–1336. [CrossRef]
19. Akpakwu, G.A.; Silva, B.J.; Hancke, G.P.; Abu-Mahfouz, A.M. A survey on 5G networks for the Internet of Things: Communication technologies and challenges. *IEEE Access* **2017**, *6*, 3619–3647. [CrossRef]
20. Vangelista, L.; Zanella, A.; Zorzi, M. Long-range IoT technologies: The dawn of LoRa™. In *Future Access Enablers of Ubiquitous and Intelligent Infrastructures*; Springer: Cham, Germany, 2015; pp. 51–58.
21. SigFox. Available online: http://www.sigfox.com (accessed on 3 June 2021).
22. Khorov, E.; Kiryanov, A.; Lyakhov, A.; Bianchi, G. A tutorial on IEEE 802.11 ax high efficiency WLANs. *IEEE Commun. Surv. Tutor.* **2018**, *21*, 197–216. [CrossRef]
23. Farahani, S. *ZigBee Wireless Networks and Transceivers*; Newnes: Oxford, UK, 2011
24. Bluetooth Low Energy—It Starts with Advertising. Available online: https://www.bluetooth.com/blog/bluetooth-low-energy-it-starts-with-advertising/ (accessed on 3 June 2021).
25. 3GPP. *TR 45.820: Cellular System Support for Ultra Low Complexity and Low Throughput Internet of Things (Release 13)*; v:13.1.0; 3GPP: Route des Lucioles, France, November 2015.
26. Ericsson; Nokia Networks. *New WI Proposal: Further LTE Physical Layer Enhancements for MTC, RP-141660*; Technical Report for 3GPP TSG RAN Meeting: Edinburgh, UK, 2014.
27. Qualcomm. *Narrowband IoT (NB-IoT), RP-151621*; Technical Report; 3GPP TSG RAN Meeting: Phoenix, AZ, USA, 2015.
28. Peraković, D.; Periša, M.; Zorić, P.; Cvitić, I. Development and Implementation Possibilities of 5G in Industry 4.0. In *Design, Simulation, Manufacturing: The Innovation Exchange*; Springer: Cham, Germany, 2020; pp. 166–175.

29. 3GPP. *TR 38.811: Study on New Radio (NR) to Support Non-Terrestrial Networks (Release 15)*; v:15.4.0; 3GPP: Route des Lucioles, France, September 2020.
30. Series, M. IMT Vision–Framework and overall objectives of the future development of IMT for 2020 and beyond. *Recomm. ITU* **2015**, *2083*, 1–21.
31. Foukas, X.; Patounas, G.; Elmokashfi, A.; Marina, M.K. Network slicing in 5G: Survey and challenges. *IEEE Commun. Mag.* **2017**, *55*, 94–100. [CrossRef]
32. Barakabitze, A.A.; Ahmad, A.; Mijumbi, R.; Hines, A. 5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges. *Comput. Netw.* **2020**, *167*, 106984. [CrossRef]
33. Taleb, T.; Afolabi, I.; Bagaa, M. Orchestrating 5G network slices to support industrial internet and to shape next-generation smart factories. *IEEE Netw.* **2019**, *33*, 146–154. [CrossRef]
34. Nidhi; Mihovska, A.; Prasad, R. Overview of 5G New Radio and Carrier Aggregation: 5G and Beyond Networks. In Proceedings of the 2020 23rd International Symposium on Wireless Personal Multimedia Communications (WPMC), Okayama, Japan, 19–26 October 2020 pp. 1–6. [CrossRef]
35. Agiwal, M.; Kwon, H.; Park, S.; Jin, H. A Survey on 4G-5G Dual Connectivity: Road to 5G Implementation. *IEEE Access* **2021**, *9*, 16193–16210. [CrossRef]
36. Ravanshid, A.; Rost, P.; Michalopoulos, D.S.; Phan, V.V.; Bakker, H.; Aziz, D.; Tayade, S.; Schotten, H.D.; Wong, S.; Holland, O. Multi-connectivity functional architectures in 5G. In Proceedings of the 2016 IEEE International Conference on Communications Workshops (ICC), Kuala Lumpur, Malaysia, 23–27 May 2016; pp. 187–192. [CrossRef]
37. Chataut, R.; Akl, R. Massive MIMO systems for 5G and beyond networks—Overview, recent trends, challenges, and future research direction. *Sensors* **2020**, *20*, 2753. [CrossRef] [PubMed]
38. Molisch, A.F.; Ratnam, V.V.; Han, S.; Li, Z.; Nguyen, S.L.H.; Li, L.; Haneda, K. Hybrid beamforming for massive MIMO: A survey. *IEEE Commun. Mag.* **2017**, *55*, 134–141. [CrossRef]
39. Gyawali, S.; Xu, S.; Qian, Y.; Hu, R.Q. Challenges and Solutions for Cellular Based V2X Communications. *IEEE Commun. Surv. Tutor.* **2021**, *23*, 222–255. [CrossRef]
40. Matasaru, P.D.; Scripcariu, L.; Diaconu, F. An up-to-date overview on QoS for Satellite IP networks. In Proceedings of the 2017 International Symposium on Signals, Circuits and Systems (ISSCS), Iasi, Romania, 13–14 July 2017; pp. 1–4. [CrossRef]
41. Matasaru, P.D.; Scripcariu, L.; Diaconu, F. On the QoS for Satellite IP networks: A Follow-Up. In Proceedings of the 2019 International Symposium on Signals, Circuits and Systems (ISSCS), Iasi, Romania, 11–12 July 2019; pp. 1–3. [CrossRef]
42. Guidotti, A.; Cioni, S.; Colavolpe, G.; Conti, M.; Foggi, T.; Mengali, A.; Montorsi, G.; Piemontese, A.; Vanelli-Coralli, A. Architectures, standardisation, and procedures for 5G Satellite Communications: A survey. *Comput. Netw.* **2020**, *183*, 107588. [CrossRef]
43. Lin, M.; Huang, Q.; de Cola, T.; Wang, J.B.; Wang, J.; Guizani, M.; Wang, J.Y. Integrated 5G-Satellite Networks: A Perspective on Physical Layer Reliability and Security. *IEEE Wirel. Commun.* **2020**, *27*, 152–159. [CrossRef]
44. Leyva-Mayorga, I.; Soret, B.; Röper, M.; Wübben, D.; Matthiesen, B.; Dekorsy, A.; Popovski, P. LEO Small-Satellite Constellations for 5G and Beyond-5G Communications. *IEEE Access* **2020**, *8*, 184955–184964. [CrossRef]
45. Kim, J.; Casati, G.; Pietrabissa, A.; Giuseppi, A.; Calvanese Strinati, E.; Cassiau, N.; Noh, G.; Chung, H.; Kim, I.; Thary, M.; et al. 5G-ALLSTAR: An Integrated Satellite-Cellular System for 5G and Beyond. In Proceedings of the 2020 IEEE Wireless Communications and Networking Conference Workshops (WCNCW), Seoul, Korea, 6–9 April 2020; pp. 1–6. [CrossRef]
46. Thales. *NTN Multi Connectivity, R3-190177*; Technical Report for 3GPP TSG RAN WG3 Meeting: Athens, Greece, 2019.
47. Cao, H.; Wachowicz, M.; Renso, C.; Carlini, E. Analytics Everywhere: Generating Insights From the Internet of Things. *IEEE Access* **2019**, *7*, 71749–71769. [CrossRef]
48. Ahmad, I.; Kumar, T.; Liyanage, M.; Okwuibe, J.; Ylianttila, M.; Gurtov, A. 5G security: Analysis of threats and solutions. In Proceedings of the 2017 IEEE Conference on Standards for Communications and Networking (CSCN), Helsinki, Finland, 18–20 September 2017; pp. 193–199.
49. Varga, P.; Peto, J.; Franko, A.; Balla, D.; Haja, D.; Janky, F.; Soos, G.; Ficzere, D.; Maliosz, M.; Toka, L. 5G support for industrial IoT applications–challenges, solutions, and research gaps. *Sensors* **2020**, *20*, 828. [CrossRef]
50. Dong, L.; Li, R. A Survey on IETF Standardization for Connecting and Integrating the Low-Power and Constrained IoT Devices. In Proceedings of the 2020 International Conference on Computing, Networking and Communications (ICNC), Big Island, HI, USA, 17–20 February 2020; pp. 61–67. [CrossRef]
51. Nasrallah, A.; Thyagaturu, A.S.; Alharbi, Z.; Wang, C.; Shao, X.; Reisslein, M.; ElBakoury, H. Ultra-Low Latency (ULL) Networks: The IEEE TSN and IETF DetNet Standards and Related 5G ULL Research. *IEEE Commun. Surv. Tutor.* **2019**, *21*, 88–145. [CrossRef]