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 (ICT). The construction sector is one of the largest sectors of industry. Most of the tasks associated with this sector are carried out in worksites that are defined by their dynamism, decentralization, temporality and by 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 ICT. 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. Then, the main characteristics of 5G that address these use cases are identified. Finally, a global framework for the application of 5G technology to construction industry is proposed.**

I. Introduction

Nowadays, the world is facing a new industrial revolution marked by the rise of Information and Communication Technologies (ICT) 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 the ICT in it has been less than in other industry sectors such as logistics or manufacturing. Most of the activity in construction industry takes place on worksites. These are very dynamic environments, in many cases outdoors, characterized by the intervention of different companies as well as by a large number of workers during the different stages of the construction process. In addition, the use of heavy machinery such as trucks, cranes or loaders and hazardous materials such as chemicals or heavy materials, make these environments arduous, where tasks of control, planning and safety are often difficult to handle. In this context, the emergence of new ICT technologies that allow the monitoring of workers and resources, the remote operation of machinery, and the automation of tasks in worksites will help to obtain a more sustainable and efficient construction, as well as to improve the safety in worksites and to accelerate the constructive processes.

The particular needs of the construction industry are a challenge for the implementation of ICT. First, worksites are distinguished by their distributed and, in some cases remote locations. Depending on the location of the construction work, the conditions of the environment can notably change, this situation highlights the need to use a technology that presents good levels of coverage and capacity in different locations. Second, construction projects are time-limited and tightly planned, thus, the time and resources invested in the implementation of ICT for a particular worksite are usually limited. Third, on construction sites there are a lot of 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 to provide a great bandwidth to allow the monitoring by means of high quality video. 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 remote control of of heavy machinery in worksites, very low latency communications and high reliability and availability of services are essential.

During the last few years, the incorporation of ICT 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 in worksites, leaving aside aspects such as improving efficiency, productivity, or sustainability at work. In this sense, in [2]–[5] several applications of the Internet of Things (IoT) to safety in construction sites are presented. In [2] a framework for monitoring risk areas on the worksite and locating workers and machinery is described. Authors in [3] propose a worker location system to alert of access to unauthorized areas. A system to avoid workers from being run over on worksites is proposed in [4]. In [5] a system for sending personalized safety instructions to workers is presented. IoT platforms for the collection of worksites information in real-time are presented in [6] and [7]. In these works, wireless technologies such as WiFi, General Packet Radio Service (GPRS) or the Fourth Generation (4G) of mobile networks are 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 [8].

Despite the great benefits that 5G networks bring to the monitoring, control, and automation of the construction sector, today 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, [9] proposes a system for the prevention of accidents on worksites based on 4K cameras. 5G networks has been also proposed in [10] to perform machinery remote control. In [11] an overview of how 5G could impact construction management applications is provided. However, that reference does not address the complete problematic of the construction industry. The authors focus on the use of IoT applications, not taking into account the complete automation of the sector. Moreover, although the main advantages of 5G are presented, the authors do 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 in terms of automation are clearly and jointly established. In this sense, several use cases are defined specifying the requirements, characteristics and limitations of each one of them in relation to the application of technologies for their automation. In addition, the main characteristics of the new 5G mobile network technology are established in order to respond to the challenges introduced by these use cases.

II. Construction use cases

In order to tackle the challenge of automating the construction industry by means of a digital transformation, this section defines different use cases that include those aspects related to the construction process that may benefit from the use of 5G. In this way, five use cases have been identified.The following subsections define each of these use cases, providing for each of them an analysis of the requirements and challenges they present for ICT.

A. 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 to worksites. These elements collect information from their environment such as video images or physical parameters through the use of sensors in real-time and perform certain actions based on that information. In the case of autonomous objects, the making-decision process should be normally made by the machine itself, while in the case of remotely-controlled machinery, that decision can be made by an operator. The use of this type of machinery in worksites prevents the exposure of workers to dangerous situations and environments, allowing the operators to control the machines from safe positions, without the need to go inside the machine itself in case of using remotely-controlled machines, and eliminating human errors in the case of autonomous elements. In addition, the use of autonomous objects helps to increase productivity, efficiency at work, facilitating the coordination of different processes and speeding up the development of different tasks, and sustainability via energy savings.

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 that should be at least 10^{-6}, and the need of a secure link. In those cases where the data collected by the machinery are video, there is also need of a high bandwidth, being at least a data rate of 10 Mbps per connected machine required [12].

B. Health and safety on worksites

Precisely monitoring high-risk areas and workers and giving helpful advertises may lead to a safety worksite. The main idea of this use case is the creation of a digital twin map of the construction site in real-time in which the high-risk areas are correctly identified, as well as the use of location techniques that allow workers and machinery to be positioned 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 struck by machinery or objects. This use case also includes the use of wearable capable of measuring the vital signs of workers and alert in case of fatigue as well as the use of sensors in safety equipment (hard-hats, boots, harnesses, etc.) that allows detecting if workers are making a correct use of it. This technology can be also 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 wearable) 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 done with low latency between 5 and 10 ms [12].

C. 3D models

This use case refers to the use of Augmented Reality (AR) and Virtual Reality (VR) to provide on-site view of the building drawings and its combination with Building Information Modeling (BIM), thus allowing the visualization of the building plans during the different construction phases in three dimensions (3D) and providing additional information such as tasks planning, materials costs or characteristics of the different construction elements. 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 associated with the need for high bandwidth, around 25 Mbps per device [13], to be able to transmit high-quality real-time video and a latency

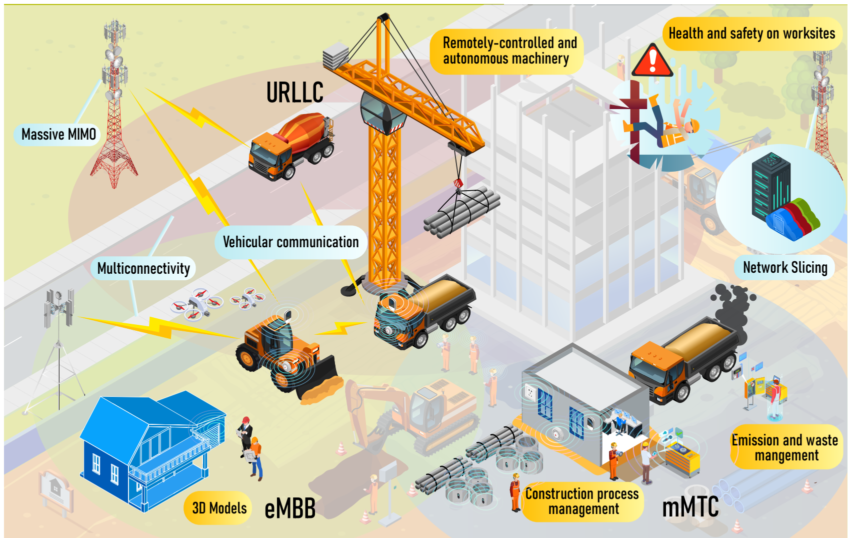

Fig. 1: 5G at a worksite

lower than 10 ms [12], in order to provide AR and VR users with a sense of reality.

D. Construction processes management

This use case focuses on the digitization and automation of construction processes management with the aim of improving the efficiency and the effectiveness of the tasks involved in these processes. In this sense, this use case includes all those applications intended at automating the collection of information on-site and controlling construction processes, such as concrete setting or welding execution that have a great impact on the final result of the work. 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 and increasing productivity and the quality of the final result, 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, ordering material on time and reducing delays in the original planning of tasks. Finally, this type of monitoring can also be useful in preventing theft of materials and equipment.

As in health and safety on worksites use case, to meet the requirements of this one, it is necessary to provide connectivity to a large number of devices on the worksite. Moreover, in this case, it will also be required to have a large bandwidth, around 25 Mbps per device [13], to be able to transmit the video images with very high quality and very low latency, between 1 and 10 ms to drones remote control [12].

E. Emissions and waste management

This use case is oriented to sustainable construction. Thus, it includes all those applications aimed at controlling and managing greenhouse gas emissions and waste in those activities related to the construction process. 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, being necessary to allow them to transmit data even when they are out of the worksite, as for example it would be the case of the sensors placed in the trucks to control the gases emitted by these during their trips.

III. 5G AT CONSTRUCTION

As described in previous sections, construction is a very dynamic environment, in which it is also necessary to provide communication to elements such as workers or machinery, which are in constant movement. In this type of scenario, the use of wireless communications is essential . Different wireless technologies have been proposed for IoT implementation in the construction sector such as WiFi, ZigBee and LoRA. However, these technologies are not able to respond to all the requirements of this sector. On the one hand, although WiFi technology supports large bandwidths, due to the use of the unlicensed spectrum, it cannot guarantee a certain quality of service and therefore a high reliability [14]. In addition, WiFi has a maximum coverage range of approximately 300m, being considered a short-range network. Thus, the use of WiFi in large worksites could lead to coverage holes in some areas. On the other hand, technologies such as ZigBee or LoRA that allow serving a large number of devices transmitting at a low data rate, would only be compatible with IoT related applications, not providing enough bandwidth for high quality video transmission (achieving a maximum data rate of 250 kbps and 50 kbps respectively) nor the latency and reliability needed for critical applications [15]. Finally, legacy cellular generation such as GPRS and 4G have been proposed to address IoT in construction environment. 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) connection [8]. In this way, 5G is able to support the requirements demanded by the use cases identified in the construction sector.

The key characteristics of 5G that make it possible to meet the requirements of the construction sector are the definition of three service categories as well as the addition of new features, Fig. 1.

A. 5G service categories

Third Generation Partnership Project (3GPP) has defined three service categories that present different requirement and characteristics. Each service category is intended to cover different type 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. Thus, eMBB increments the capacity of the new mobile network by adding some new features such as the increase of the range of code rates, code lengths and modulation orders, the consideration of new frequencies as millimeter waves (mmWave) that allow increasing the bandwidth spectrum and massive MIMO. 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 low volume of traffic. IoT networks is the most important example of use of this type of service. IoT networks are constituted by a large number of devices that send information to a management center. In the construction industry, many sensors and other devices such as cameras or wearable 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 use cases related to construction process management or workers safety.
- **Ultra-Reliable Low-Latency Communications**. URLLC may provide latency values of 1 millisecond while assuring the 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 use cases related to construction industry, URLLC services will provide the capacity to remotely control drones or manage machinery in worksites in addition to others.

B. 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 as a multi-service network which provide service with different requirements in a vast dimension of verticals . Such variety of requirements is complex to be addressed by the same network. Network slicing is the 5G functionality that provides the capability to cope with services that present so different requirements. This feature allows defining several logical networks (slices) based on the same physical network elements. In this context, Software Defined Networking (SDN) becomes an essential tool, providing independence between services by virtualization. This functionality is essential in a construction scenario since different use cases present different requirements and have different priorities. 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 an application with high priority and stringent requirements of latency and reliability. However, the use of high definition video cameras for the management of construction processes is an application that demands high throughput but does not have significant requirements in terms latency and reliability. For that reason, these two applications should be managed independently, by the definition of two different slices.
- **Multi-Connectivity**. MC, allows UEs 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: one node (carrier aggregation), two nodes (dual connectivity) or a number from one to more than two nodes (MC). 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 specially important for eMBB services and 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 on reliability. This option is usually used with URLLC services and applications such

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 on 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

TABLE I: 5G solutions for construction industry use cases

as remotely-controlled and autonomous machinery. In both cases, the several links from the UE to the network provide more robustness to the UE connection assuring the data transmission.

- **Massive MIMO**. Massive MIMO is usually associated with arrays with a high number of antenna elements. These multiple antennas may be used with different objectives. Thus, massive MIMO allows increasing the cell capacity when different antennas are used to connect different UEs. In addition, one UE can have more than one connection improving the 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. Beamforming is specially 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 industry, 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 is referred to the communication between vehicles and other elements, that is vehicle-to-everything (V2X) communications. 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). 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 industry, this kind of communications allows machinery to act autonomously, improving the efficiency of construction processes.

Table I summaries the possibilities of 5G technology to address the main challenges of the digitization and automation of construction industry.

IV. System architecture

This section presents a high level architecture of the integration of 5G in the construction industry, Fig.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 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.

A. *Sources of information*

The proposed system will use information gathered from different information sources. This different sources are related to the different elements that can be found in a worksite and are involved in the use cases. Thus, the possible sources of information that can be found in 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; wearable to assure workers safety; 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.

B. *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 allows addressing the main challenges presented by the use cases in construction industry. One of these functionality is network slicing, which is shown in Fig.2. This paper proposes a specific slices definition based on the use cases defined and the applications identified for each use case. Thus, the first slice is

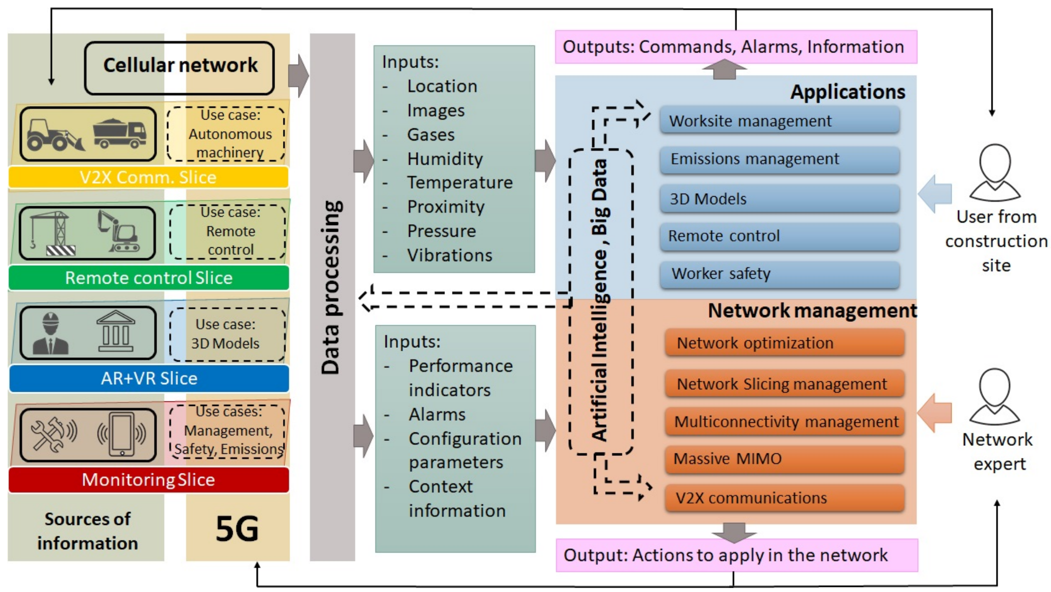

Fig. 2: System architecture for 5G at construction

intended to V2X communications. This kind of communications present restrictive requirements in terms of latency, reliability and throughput as well as an important accident risk so it is essential to assure the communications availability. The second slice is defined for remote control of machinery and drones. Although these applications present similar requirements to the previous ones to guarantee the reserve of resources and a correct optimization of the network, it is proposed the use of a second slice centered in the category of service URLLCC, with the addiction of video control services. 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 implementing use cases such as health and safety, emissions and waste management and 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 III such as MC or massive MIMO.

C. Data processing

Once all the information from the different sources are collected, a data processing must be applied, given the diversity of such information. First, the data provided to subsequent stages in the system architecture must have the same structure so it 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 algorithms defined in the system. The use of Artificial Intelligence (AI) and big data techniques will be essential in this data processing.

D. Application

This block includes all the applications defined for the automation, digitization and improvement of the different processes in construction industry. There are many inputs to this block. Location of workers and high-quality video images may be used for worker safety application, in addition to information about gas concentration, humidity or temperature. This information can be also used for construction processes management application. Accurate location information and high-quality images are also used in applications such as remote control. These applications may also produce some outputs. Some of them may be applied to elements of the construction site, such as commands generated by remote control application or alarms from workers safety application that should alert workers of an imminent danger. AI techniques may be used for the implementation of these applications.

E. 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 AI techniques for the implementation of these applications allows them to automatically adapt to the changes of the worksite. For instance, 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, number of machinery and equipment, specific use cases needed, etc. As a result of the applications execution, a set of outputs are provided. These outputs represents the actions to be applied to the network in order to optimize its performance.

V. Conclusions

The particularities of the construction industry, as well as the limitations of the ICT existing so far, have led this sector to present a low level of automation and digitization. The emerging 5G technology is 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 is presented. In this way, first, different use cases referring to the automation and digitization of this sector have been defined, identifying for each one the challenges that they present regarding the implantation of ICT. Next, the main characteristics of 5G networks that respond to the needs of the construction industry have been presented. These characteristics refer, on the one hand, to the service categories defined by 3GPP: 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. Finally, a general high-level architecture for the integration of 5G technology in this sector has been proposed.

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