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5G Technology and the Future of Architecture

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Abstract

Architecture is the true expression of people's lives within a framework of different aspects, including socio-economic, cultural, traditional, spiritual, and technological. Throughout history, technology has a significant impact on the development of architectural forms and structures. Nowadays, the progress of advanced technology began to reach an unprecedented level in the age of the internet and its related technologies. Since the appearance of the wireless connectivity, architecture, and urban design began to take another dimension in the design process to adopt the new technology and integrated it within its envelope. At the beginning of the 21st century, new approaches began to take place in the city, such as the Internet of Things (IoT) and, more recently, the 4G and 5G wireless technology. However, the effectiveness of these advanced technologies depends on both the wireless signal coverage and the deployment of their equipment. In this context, these technologies impose a new challenge for architects, urban designers, and the construction industry to embrace them within the concept of the smart city. This study focuses on the analysis of 5G technology and highlighting its advantages and disadvantages, which impact the visual appearance and aesthetics of both buildings and the city. The study also intends to explore the various possible solutions to overcome the predicament of the wireless signal coverage and the penetration of buildings. However, this research aims to define a set of recommendations for the construction industry to take further innovative steps towards achieving advanced building materials that can adopt the 5G technology.

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Keywords: 5G Technology; Smart City; Architecture; Urban Design; Wireless Propagation; Building Materials

1. Introduction

Cities have a high potential to provide livable places where people can interact and share ideas. However, they are still facing various severe challenges, including the lack of economic opportunities, insufficient infrastructure, pollution, transportation, and the growth of the urban population. According to the report of the united nations in 2019, the global population is increasing exponentially to reach 7.7 billion in mid-2019, and 8.5 billion in 2030. It is also expected that the population of the world will reach 9.7 billion in 2050 and 10.9 billion in 2100 [1]. The world is also experiencing the phenomenon of rapid urbanization, where the majority of people prefer to live in cities. However, it is estimated that over 60% of the world population will be living in cities by 2030. Also, it is expected that low-income countries will face more urban population growth than higher-income ones. In addition, it is projected that the expansion of urban areas by 2030 will be higher than the collective urban growth in the history of humanity [2].

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Nevertheless, the world's numerous challenges need creative and innovative solutions, where technology can take place in achieving a better livable future for people. Throughout history, technology has played an essential role in shaping cities' architecture and urban environments. Since the industrial revolution in the mid-18th century and the advent of modern building materials and methods of construction, architecture responded significantly by creating a new architecture that expresses the spirit of the age. Architects introduced new forms and imposing architectural compositions that adopted the latest progress of the construction industry and coped with the modern lifestyle. Since the mid-20th century, several approaches, such as sustainability and green buildings, were introduced to solve the world's problems and combat climate change. By the end of the twentieth century, cities began to witness another age of digitization that depend on the technology of data-based solutions. Since the growth of the use of the internet and the ubiquitous wireless applications at the beginning of the 21st century, architecture began to reshape itself and create smart buildings that embrace the new technology. One of the latest technological approaches that affected architecture and urban design is the IoT that allows wireless connectivity to all the different devices in a building. However, over the last few years, the fourth generation (4G) wireless technology became a widespread use, and the introduction to the (5G) technology began to be witnessed and ready for a full rollout in 2020. This new trend of progressive technology that has ubiquitous wireless broadband connectivity coincides with the growing concern of countries to make cities smarter. However, this study aims to highlight the common problems of the wireless signal coverage in buildings to help the building industry in inventing smart materials that mitigate the signal penetration and improve the aesthetical value of the built environment.

2. The smart City

Throughout the twentieth century, cities have experienced substantial challenges that created several environmental, social, and economic crises. By the beginning of the 21st century, many cities worldwide began to initiate intelligent urban development concepts and approaches to improve the urban infrastructure, services, and wellbeing of people [3]. However, these initiative efforts were developed and introduced the concept of smart cities, which can be perceived as the successor of information city, digital city, sustainable city, and the intelligent use of digital information [4]. The United Nations report on smart cities and infrastructure in 2016 defined the smart city as primarily an innovative city that employs information and communications technologies and other resources to improve people's living conditions. The smart city also enhances the quality of urban operation and services, and reduce resource consumption, while meeting the essential needs of present and future generations within socio-economic and environmental aspects [5]. However, the smart city concept is not only limited to the application of technologies to cities but also provides different challenges and opportunities for different countries to meet the increasing pace of urbanization. In this context, as the complexity of the smart city is growing by the increase of things that need advanced technology to support them, the Internet of Things (IoT) approach can play a significant role in the global digital communication. Furthermore, the introduction of 5G technology announced a new age of technological progress that would open new frontiers for the wireless industry, and increase the complexity of mobile networks [6].

3. The fifth-generation (5G) technology

The world is changing fast, and the speed of innovation and the adoption of new technologies is increasing at an exponential rate. Although the fourth-generation 4G system was deployed in 2011 and offered broadband mobile services faster than the previous 3G, the race to achieve more advanced mobile traffic is still growing. However, the need for more sophisticated broadband services will push the standards of the current system beyond its limit to provide higher speeds of mobile communications. Nowadays, the evolution of fifth-generation 5G technology, which is expected to be widely deployed by the early 2020s, will offer more reliable and faster connections on smartphones and other devices. The 5G technology will provide an internet connection with an approximate speed of one Gigabit per second, which will bring a significant rise in the Internet of Things Technology IoT [7].

According to the Cisco corporate social responsibility report in 2019, the growth of 5G technology will increase the number of connected devices worldwide from approximately 29 billion networked devices in 2022 to 300 billion by 2030. Also, the number of users who will begin using the internet for the first time will increase by more than 3.5 billion people. This unprecedented evolution presents significant opportunities to deal with and solve essential global problems such as improving health, reducing pollution, and making cities smart [8]. 5G technology will be a substantial converged system that supports a wide range of applications, including multi-Giga-bit-per-second mobile internet, infrastructure communications, cloud computing, and public safety applications (Fig. 1). Moreover, it will support the smart grid application, which enables the electricity grid to operate more reliably and efficiently [9].

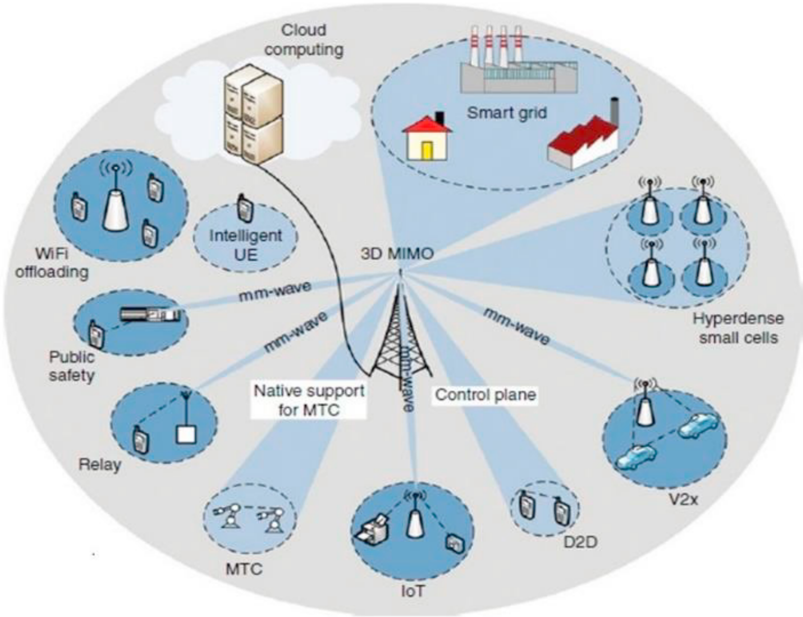


Fig. 1. 5G system architecture [9].

Although 5G technology has many advantages, including higher network speeds, lower latency, and 100 times faster broadband than 4G, the complexities of its technology present essential issues. These are the inability to penetrate building materials and the need for an enormous number of small antennas and cell towers [10]. Nevertheless, 5G technology has challenges in terms of the radio spectrum, which includes two different frequencies. One of these frequencies is similar to the current Sub 6 Gigahertz, which is exceptionally high-frequency millimeter wave (mmw) bands. However, the mmw band above 20 GHz requires an unobstructed and clear straight path to reach its destination. Consequently, buildings, mountains, trees, buildings, and even the human body, all block the 5G signals to varying degrees, particularly in dense urban areas [11]. Another disadvantage is that the air can absorb these waves even without any physical obstacles because they travel a distance less than a kilometer. Thus, they need many cellular base stations to be deployed at small distances, a matter which will affect the aesthetic value of the urban environment [12]. Consequently, buildings need to be equipped with cellular aids for reliable in-building coverage, as well as looking for new, innovative, and scalable solutions.

4. Building materials and the propagation of radiowaves

According to the energy-efficiency regulations by the European Commission in 2016, all new buildings should be practically zero-energy buildings by the end of 2020. However, as buildings account for nearly 40 % of the final energy consumption, governments and the construction industries set new construction regulations and principles to provide new building materials with better thermal insulation properties to improve the thermal performance of buildings and reduce energy consumption [13]. These new building materials include the metallic-coated materials, foil-backed plasterboard, insulation boards with an aluminum coating on both faces, low emissivity double-glazed windows. Although these new building materials meet the sustainable building regulations, they affect the transmission of wireless signals into and within buildings. However, an empirical study was conducted by Aegis Systems Limited in 2014 to examine the impact of modern insulating building materials on the propagation of radio waves with a relatively wide frequency range (6 GHz to100 MHz), in which (win1 and win2) indicate the fitment of different metalized windows and (FBP) of foil-backed plasterboard (Fig. 2). The results of the study have shown that these materials increased the levels of building entry loss when the radio signals enter or leave buildings [14].

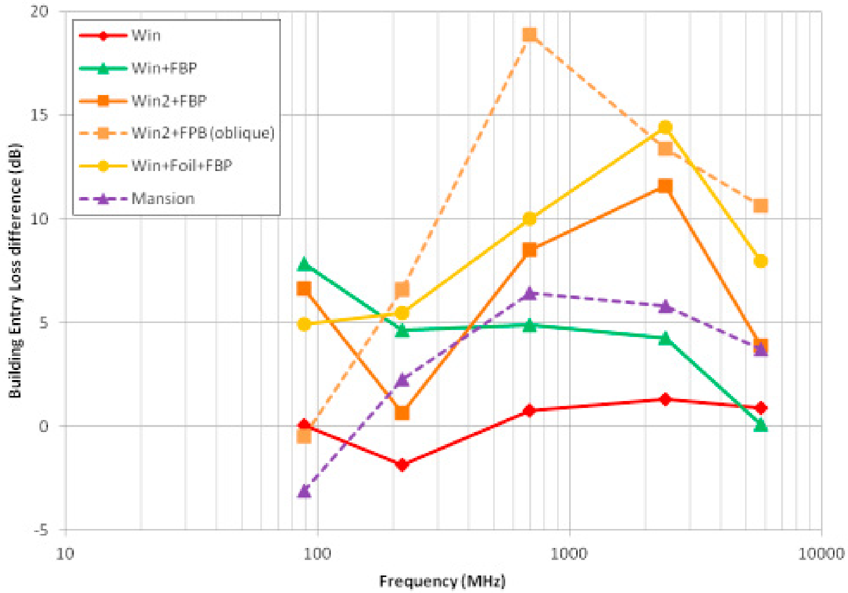


Fig. 2. Increasing levels of building entry loss as modern insulating materials are added [14].

For example, windows in the old building usually consist of thin glass and a wooden frame, while in modern buildings, windows are designed to achieve the requirements of the energy-efficiency regulations. However, the modern window is composed of more than one layer of panes of glass with inert gases between them to profoundly improve the insulation properties against the heat flow into or out of the house. The window frame is also made of a specific material to improve the window's insulating abilities, while the glass is covered with special coatings that create low emissivity and reflect heat and ultraviolet (UV) light [15]. However, these new modifications of the components of the window to meet the energies-efficiency improved its resistivity and imposed an impact on the attenuation of radio signals. Recent studies pointed out that the multi-layered energy-efficient glass presents a higher attenuation than the single-layer glass [16]. In the context of building material properties, each different material has a different effect on the wireless signal due to many factors including, reflection, refraction, diffraction, scattering, and absorption. Also, any given material can feature more than one of these factors, such as glass, which can both refract and absorb. Nevertheless, absorption represents the most common reactions of material against the wireless signal. Every material has a different absorption rate (Table 1); for example, wood and concrete can cause an enormous impact on wireless signal strength because of their high absorption capacity to the radio waves, while plasterboard and drywall have less impact on the signals. [17].

Table 1. Reactions of material against the wireless signal [9].

Material	Absorption Rate
Plasterboard / drywall	3-5 dB
Glass wall and metal frame	6 dB
Metal door	6-10 dB
Window	3 dB
Concrete wall	6-15 dB
Block wall	4-6 dB

Although building materials imposes predicaments to the wireless propagation, the wireless industry is inexorably moving towards realizing the 5G technology as the upcoming wave of wireless broadband connectivity. However, one of the most recent inventions that contributed a practical solution to the problem of wireless transmission through building materials is the Echo-5G-beamforming repeater. Recently, the Pivotal Commware Company invented the Echo-5G, which overcame the most significant difficulty of the fixed 5G wireless to penetrate buildings at millimeter waves by the Holographic Beam Forming (HBF) technology (Fig. 3). The company conducted a field experiment at 28 GHz that has successfully demonstrated 1.3 Gbps of throughput in the energetic 5G field using the HBF technology. However, the Echo 5G allowed connectivity to an indoor space by allowing the HBF to penetrate a double-paned glass at a 45-degree angle from an outside base station at a distance of 1,640 feet. Nevertheless, the low-profile and lightweight of Echo 5G allow the signal, both to and from the base station, to go through the window at any angle [18].

Fig. 3. Holographic Beam Forming Technology [18].

5. The potential of nanotechnology

This research has shown the strong relationship between the radio frequency engineer and the architect. Although the wireless technology engineer is the main actor in delivering the new technology to buildings and the city, the architect is responsible for designing the building spaces and the built environment that accommodates these new smart technologies. However, to overcome the problem of wireless signals propagating buildings, the cooperation of both the architect and the building construction industries needs urgent intervention to come up with the best possible solutions that mitigate the wireless signal's penetration loss. In this context, the architect should pay more concern to the arrangement of the building spaces during the design phase to reduce the wireless signals inside buildings.

Meanwhile, the building industries should also consider the invention of new building materials with appropriately modified properties in order to minimize the penetration loss of the new wireless technology and add to the beauty of buildings. This discussion of the issue of 5G technology is reminiscent of earlier debates over the emerging technologies of photovoltaic and its application in buildings in the 1970s. Looking back to the mid-19th century, the French scientist Edmond Becquerel discovered the photovoltaic effect, which refers to the process of converting light energy into electricity. However, the American scientist Charles Fritts developed Becquerel's findings and created the first solar cell, which was considered as the beginning of photovoltaic solar panel innovation. Nevertheless, in 1884, Fritts produced the first solar panels in New York and fixed it on the rooftop of a building (Fig. 4) [19].

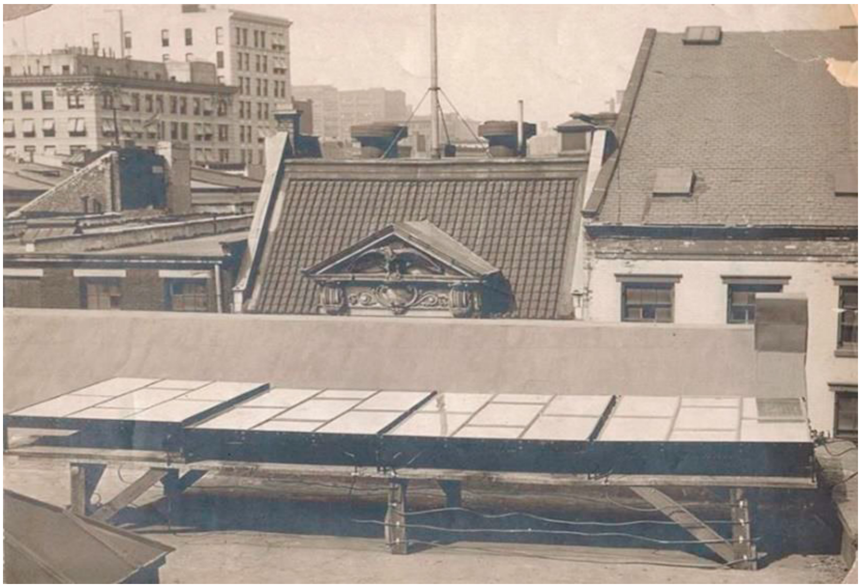
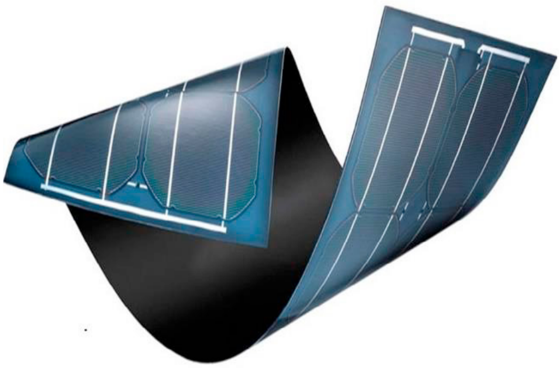


Fig. 4. The first solar panels in New York on the rooftop by Charles Fritts in 1884 [19].

Since then, photovoltaic panels have undergone a remarkable development in order to reduce cost, increase efficiency, and enhance its aesthetic characteristics. In 2015 the solar cells were aesthetically developed to become as thin as a paper sheet. Also, it can be manufactured using an industrial printer and made into products such as roof tiles or shingles [20]. The thin paper-like photovoltaic cells were significantly developed and produced as film flexible solar panels that can cover a whole building and give it a visually pleasing appearance (Fig. 5.a) [21]. The Office tower in Manchester, England, was built in 1962 and renovated in 2004 is a representative example of the revolutionized film flexible solar panels that covered the entire building and gave it a beautiful look (Fig. 5.b) [22].



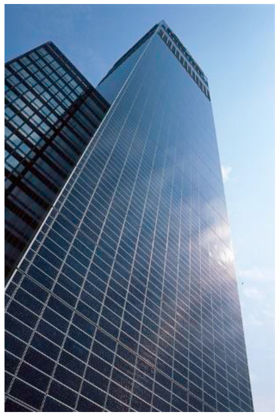


Fig.5. (a) Film flexible solar panels [21]. (b) Office Tower, Manchester [22].

However, in the context of the development of the photovoltaic material and its external shape to suit the aesthetical standards of buildings, a similar approach is required from the building industries in terms of the potential effects of new nano-building materials on wireless signal propagation. Nowadays, the construction industries should raise their awareness about the need for the development of new smart building-integrated materials that accommodate the new 5G antennas to be used in parts of the building envelope such as roofs, skylights, or facades. Today, the development of nanotechnologies would likely have a significant impact on buildings, people, and the environment. Nanotechnology has the potential to answer many of the problematic questions of architects and engineers and influence the future of architecture. However, the applications of nanotechnology in architecture and the building industry have taken the building enclosure materials, such as coatings, panels, and insulation, to outstanding levels of performance in terms of light, energy, security, and intelligence. Similarly, it is expected that nanotechnology would also offer a breakthrough generation of nano-building- materials with higher efficiency that allows the wireless signals to rapid and uninterrupted penetration [23].

As the use of nanotechnology in wireless communications introduced many advantages, including improved communication performance, reduced power consumption, and smaller size devices with new features, it also can produce new building materials with modified properties that serve the wireless signal propagation difficulties at a nano-scale [24]. Of course, there might be significant technical challenges to produce these new integrated-nanomaterials, but it may gain widespread commercialization and contribute to the beatification of the urban environment, especially in the high-density areas. However, nanomaterials could revolutionize both the construction and wireless industries by, either the way architects develop their imaginative ideas and accentuate the built environment, or the wireless engineers produce their products from integrated-building materials to avoid the deployment of the wireless equipment in the city.

6. 5G Antennas and the Urban Aesthetic

Cities are becoming more involved in decision-making about network infrastructure, as they support multiple new applications, as part of the smart city initiatives, for both mobile broadband and the Internet of Things (IoT). Nowadays, the 5G technology has been a controversial issue that concerns the world because of the different building materials and surfaces that significantly affect the propagation of the wireless signal through buildings and objects. The 5G network is characterized by increased high-speed bandwidth and the use of the millimeter-wave spectrum, which requires many smaller antennas deployment to carry signals. Consequently, it will suffer from congestion, particularly in the dense urban environment, and will interrupt the aesthetic of the built environment.

The aesthetic issues are not new for cities, as it has been common that sensors, cameras, monitors, and wireless antennas often look out of place, hard to blend into the surroundings, and may affect the beauty of the city. However, as there are many providers to the same new technology and all of them will install their equipment to cover the same area, the outcome would be unpleasant clusters of small cells that are visually unattractive. Another dilemma is the ground-mounted equipment accompanying some small cell facilities and obstructing a crowded city's rights-of-way [25]. Nevertheless, to control the 5G competitive race, some cities defined a set of regulations that require the wireless providers to satisfy including, working permission, fees, and aesthetic standards in an attempt to minimize the invasive effect of the equipment. For example, San Francisco issued rules, which reject mobile infrastructure if it detracts from the beauty of the city, and block scenic views [26]. However, the local authority of a city should review and control small cell deployments, not only to maintain environmental issues and public rights-of-way, but also the land use and the aesthetic values of the city. Besides, the city authority should manage the aesthetic elements of deployment to minimize any visual pollution caused by the number and size of the small cells [27]. Also, there should be design guidelines for the new small cell facilities, including height and size limits of the equipment, and rules that protect the street trees from any damage [28].

However, to overcome the problem of the significant number of antennas, small cells with massive multiple-input multiple-output (MIMO) antennas, were combined with increasing the coverage range. Nevertheless, it would be impossible to deploy all these small cells throughout the city without disrupting the cityscape. In this context, to encounter the challenges posed by the increased mobile network densification and small cells, current telecoms infrastructure began to develop site solutions to meet the predicted tenfold growth in global mobile data traffic by 2021. In 2016, Ericsson Company introduced solutions that address various expansion and installation possibilities, including Zero Sites, Street Furniture Sites, and Vault Sites. These solutions count on sharing site spaces in existing infrastructure to reduce costs. In conjunction with Philips, Ericsson developed the Zero Sites, which represent advanced street lighting systems that incorporate both small cells for better connectivity and LED street lighting to generate energy savings (Fig. 6.a). Ericsson small cells are also designed to be fully integrated into other different existing street furniture, including bus stops, information kiosks, and billboards (Fig. 6.b) [29].

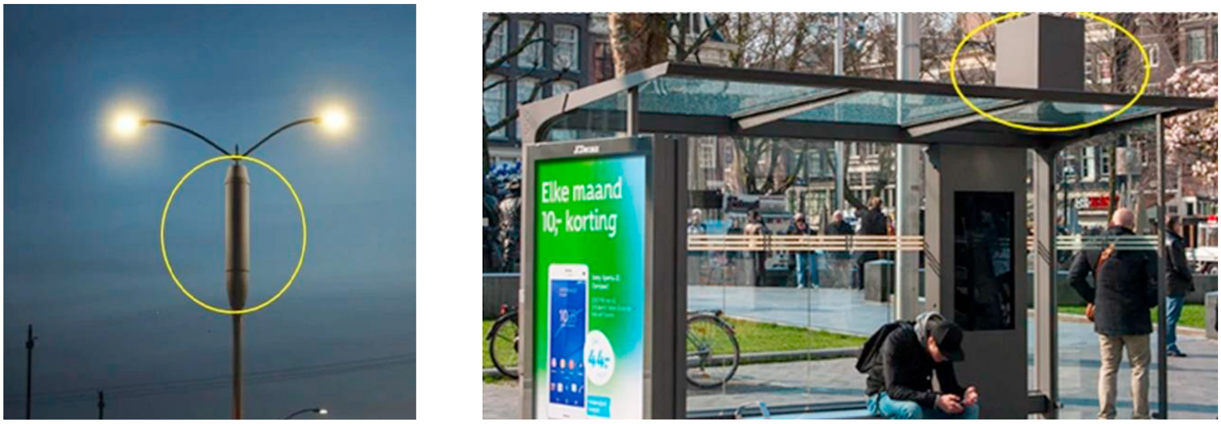


Fig. 6. (a) Street lighting includes 5G small cells [29]. (b) Bus stop incorporates 5G small cells [29]

However, one of the innovative solutions for deploying small cell antennas was produced by the cooperation of Ericson and telecom operator Swisscom. They introduced the Vault Sites approach, which house environmentally hardened radios in existing street maintenance-holes to improve the capacity of small cells even below street level (Fig. 7.a). Thus, this solution effectively addresses the needs of the city by the reuse of existing underground space, which already accommodates the fiber and power infrastructure [29].

Like Ericson, Vodafone, headquartered in the United Kingdom, has come up with a developed solution that makes the maintenance-hole cover work as antennas for mobile communications (Fig. 7.b). The 4G networks are currently using this strategy, but Vodafone believes that it could also be an appropriate solution for 5G networks. Nevertheless, the concept of using the maintenance holes provides a significant solution, especially in a dense urban context. It would also mitigate the traffic disruptions from street construction, and eliminates the awkward view of the antennas above buildings, which ruins the appearance of the city [30].

Fig.7. (a) Street maintenance holes [29]. (b) Maintenance-hole cover work as antennas [30].

Although, Ericson, Swisscom, and Vodafone introduced ingenious solutions that increased the small-cell coverage area of the 5G technology by using the existing infrastructure of the city, the search for more competitive solutions that can add to the visual beauty of the city is still ongoing. However, in cooperation with the T-Mobile parent, company Deutsche Telekom, the Covestro Materials Company, and the Swedish Umeå Institute of Design (UID), created two attractive 5G antennas. The first one takes the form of a bird, and the other is 24h5G clock, and both are serving as a millimeter-wave transmitting station and can be deployed every 600 feet (Fig. 8.a). Dr. Thomas Jansen, head of Deutsche Telekom small cell, believes that the companies succeeded in producing robust 5G solutions that can be harmoniously integrated into the cityscape. However, by contrast to the creative approaches adopted by Ericson and Swisscom, the Covestro/UID designs not only bring the highest-speed 5G service to millions of densely urban environment but also could contribute to the beauty of the city [31].

Besides, the inventive solutions presented by the wireless companies to mitigate the effect of radio towers, there are other creative solutions presented by the architecture students. One of the exciting proposals to enhance the unpleasant visual impact of the ubiquitous cell towers on the urban context is the wooden radio masts, a shading canopy in the city's open space (Fig. 8.b). The project was designed by the architecture students of the University of Kaiserslautern in Finland as a response to the predicament of the 5G cell towers. The project represents an environmentally-friendly telecommunications shading device made of wood to provide sustainability as well as aesthetic value to the surrounding context [32].

Fig. 8. (a) New attractive 5G antennas [31]. (b) Student design of wooden radio masts [32].

7. Intervention and recommendations

The building penetration loss varies significantly, depending on both the type of the material and frequency of the wireless signal. Thus, the architect should manipulate his designs in a way that concurrently maximize the desired signal power and minimize the interference signal power [33]. However, many useful recommendations that help the architect achieve the balance between the use of building materials and the signal penetration rates include:

1. The use of different building materials inside and outside buildings should be based on their penetration loss.
2. Consider the arrangement of the spaces and the choice of wall partition materials and their arrangements.
3. Use more glass and particle boards for the exterior surfaces.
4. In windows or openings, one-layer ordinary glass is recommended.
5. Fewer walls and partitions, more voids, and unobstructed corridors would allow the best propagation of the radio signal.
6. The open plan design concept for the interior would offer sufficient signal propagation.

Other recommendations that might help to integrate the 5G equipment into the existing context of a city and to pave the way for further research include:

7. Consider the requirements of 5G networking in the design and planning processes in order to maintain the aesthetic values of the public spaces.
8. Create novel design solutions to support smart technologies without disturbing the visual quality of the urban context.
9. Consider the surrounding landscape to reduce significant penetration loss through trees and plants.

8. Conclusion

As the urbanized world is continually growing and cities became significantly populated, digitalization plays an essential role in enhancing the well-being of economies and societies. Worldwide, governments are motivated to make their cities smarter by using digital technology to achieve efficient and livable urban environments. The market for IoT devices is exponentially growing as more "things" are connected to the Internet. Also, as the complexity of smart things increases, the technology to support them is being developed. However, the new 5G technology might not be able to provide all the infrastructural support for the increasing demands of the future, which will be global datadriven, hyper-connected, and progressively digitized. As 5G technology was maturing and began to be widely deployed to support global standardization, researchers initiated discussions on the development of 6G technology.

In this context, the world of buildings is becoming more progressed and smarter because of the advanced new technologies, which continually impose new challenges that need creative solutions. Consequently, the future of the architecture profession requires new design approaches that can maintain the continuity of the relationship between buildings and advanced technology. Moreover, as innovation will always be ongoing and the future still has possibilities of new generations of cellular technologies, architects, planners, construction industries, and vendors need to address the specific problems of the new wireless technologies, explore new affordable and creative solutions and have insights about what technologies might have of new challenges that affect the built environment. Within this perspective, cities should holistically define their urban problems before involving in new technology because not all smart technology solutions are appropriate for all different geographical regions. However, smart infrastructure approaches should be considered based on their applicability to local urban development needs, context, culture, economics, and the way of life of people. Thus, the use of 5G technology should be viewed within the context of each region's capacity to accommodate the required smart infrastructure and maintenance. Finally, we can say with certainty that the wireless industry has changed the way of designing the built environment in the world.

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