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Review

The Need for Smart Architecture Caused by the Impact of COVID-19 upon Architecture and City: A Systematic Literature Review

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Abstract: The recent pandemic era of COVID-19 has shown social adjustment on a global scale in an attempt to reduce contamination. In response, academic studies relating to smart technologies have increased to assist with governmental restrictions such as social distancing. Despite the restrictions, architectural, engineering and construction industries have shown an increase in budget and activity. An investigation of the adjustments made in response to the pandemic through utilizing new technologies, such as the internet of things (IoT) and smart technologies, is necessary to understand the research trends of the new normal. This study should address various sectors, including business, healthcare, architecture, education, tourism and transportation. In this study, a literature review was performed on two web-based, peer-reviewed journal databases, SCOPUS and Web of Science, to identify a trend in research for the pandemic era in various sectors. The results from 123 papers revealed a focused word group of IoT, smart technologies, architecture, building, space and COVID-19. Overlapping knowledges of IoT systems, within the design of a building which was designed for a specific purpose, were discovered. The findings justify the need for a new sub-category within the field of architecture called "smart architecture". This aims to categorize the knowledge which is required to embed IoT systems in three key architectural topics—planning, design, and construction—for building design with specific purposes, tailored to various sectors.

Keywords: smart architecture; pandemic; internet of things; smart technologies

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Citation: Park, S.-J.; Lee, K.-T.; Im, J.-B.; Kim, J.-H. The Need for Smart Architecture Caused by the Impact of COVID-19 upon Architecture and City: A Systematic Literature Review. *Sustainability* **2022**, *14*, 7900. https://doi.org/10.3390/su14137900

Academic Editor: Miguel Amado

Received: 21 April 2022
Accepted: 21 June 2022
Published: 28 June 2022

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1. Introduction

A pandemic, the spread of a disease across continents, is a natural disaster that humans have been facing since records began. The most recent severe pandemic was COVID-19, with 427.5 million cases and more than 6.6 million deaths reported by the end of January 2020. The seriousness of this pandemic has had a major impact on corporate and social structures in major cities [1]. The impact of these changes has involved adaptation to developing technologies which have assisted our survival of the pandemic. Within the last century, rapid evolution of information and communication technology (ICT) has facilitated an increase in the production of effective devices and systems for assisting in various industries, such as business, government, healthcare, education, and tourism and transport.

Faster computing power and near-instantaneous communication between devices has led to the beginnings of the fourth industrial revolution (Industry 4.0), facilitating the emergence of the internet of things (IoT). Industry 4.0 is a collection of several technologies and concepts that defines the fourth industrial revolution. These technologies were initially implemented to assist in industrial manufacturing and economic growth. The success in the adoption of technologies and concepts from Industry 4.0 within the industrial sector, such as IoT, shows that it can be implemented in other applications [2].

The IoT describes devices with sensors that collect, process, and exchange data within a system [3–5]. A standard initiative began with the aim of raising awareness of the IoT, which led to the establishment of a new study group that began at the international telecommunications union (ITU) called SG20 [6]. Since then, from the increasing numbers of smart cities, it has become a significant agenda of governmental bodies across the world, with global applications for the IoT increasing since 2015 [7]. Cities that have joined the initiative through ITU for implementing IoT to improve four main attributes of a city have called the project "smart city". In 2015, when the initiative began, a few selected cities that could afford the development led the way for other cities to follow [8].

The development of smart cities was focused on four main attributes of a city: sustainability, quality of life, urbanization, and smartness [9]. Sustainability is the main contributor in establishing smart cities. Assistance and data gathering advantages from practical application of IoT have proved to be of major influence in controlling non-renewable resources [10]. For example, by using the internet as a networking strategy, energy-related devices can be connected through the network that combines devices, people, and cloud services to facilitate application tasks [11]. In this instance, information regarding energy can be conveyed efficiently to the user and has an additional advantage of being stored by cloud services. This assists in critical decision making concerning energy consumption for a building; where stored data are used for further analytical purposes. However, devices and methods are still being studied and implemented in service by a few governments that follow the initiative [12]. In other words, further development is required to fully realize the end goal for smart cities.

This is particularly crucial in preparation for a pandemic event. IoT devices have been utilized in various industries for collecting data. For example, healthcare has adopted the technology for monitoring patients with COVID-19 symptoms. Smart healthcare, where medical devices are connected over a network, is able to provide services to staff and patients [13]. It has a particular advantage of monitoring and treating patients remotely, thus reducing the chances of infection by upholding social distancing. Social distancing is a measure suggested by the world health organization (WHO) that was conducted by governments worldwide for reducing the spread of a disease, in this case, COVID-19 [14]. For this purpose, IoT devices are being used and researched by major industries to monitor this measure.

A common area of study that relates the major industries, including business, healthcare, education, tourism and transportation, is architecture. Furthermore, there is a need for specifying smart development for individual industries that heavily involves architecture. Traditionally, architecture includes the design, construction, and maintenance of a building. Buildings with a specific purpose that are related to a specific industry require the design best suited to their function. To reach the end goal of creating an architectural industry that is truly smart, inclusion of IoT devices should be considered in all stages of architecture. However, studies regarding actual application of IoT for specific industries are focused on achieving similar aims, such as social distancing. Therefore, in order to bridge the knowledge gap, a collective area between the IoT and architecture is required, which can be referred to as smart architecture.

This paper aims to justify the need for research that combines the study of Industry 4.0 with the study of architecture, namely "smart architecture". Section 1 includes background information regarding the application of Industry 4.0 technology to cities that aim to become smart cities. Section 1 also includes the global reaction to the recent pandemic, COVID-19. Section 2 presents a systematic literature review from two peer-reviewed academic literature databases: Web of Science and SCOPUS. Section 3 presents the findings from the literature databases and is focused on the common areas of research found within the academic literature. Section 4 details case studies relating the IoT to architectural projects within the pandemic era of COVID-19. The conclusion is given in Section 5.

1.1. Pandemic Era

A classical definition of a pandemic is a spread of an infectious disease across a large region, typically across continents. Some of the most notable pandemics include since 1977 are smallpox, black death, tuberculosis, cholera, AIDS, and most recently COVID-19. COVID-19, a novel coronavirus SARS-CoV-2, has spread from Hubei province of the People's Republic of China at the end of 2019. Within January of 2020, the WHO issued a global health emergency regarding the disease and, by the beginning of March, it was declared a pandemic [15]. Data concerning the number of confirmed cases and deaths are collected in a data repository at Johns Hopkins University, where data are updated automatically.

Figure 1 shows the data of COVID-19 cases including confirmed cases, deaths, and recoveries between 2020 and 2022. It shows a steadily increasing rate from when WHO issued the national health warning and declared the pandemic. The number of confirmed cases rose steadily as governments issued restrictions as an attempt to keep the numbers low. There was a sharp spike in the approach to 2022 that reflects the emergence of a variant called omicron. Although governmental bodies globally had upheld the social distancing initiative set by WHO, the levels of social distancing have varied by country [16]. Many of the measures, including closures of schools, workplaces, and public transport, with additional restrictions of the size of gatherings, internal movement, and international travels, reflect the collective initiative of social distancing [17]. Enhancing control for the spread of a disease can be realized with the aid of IoT devices.

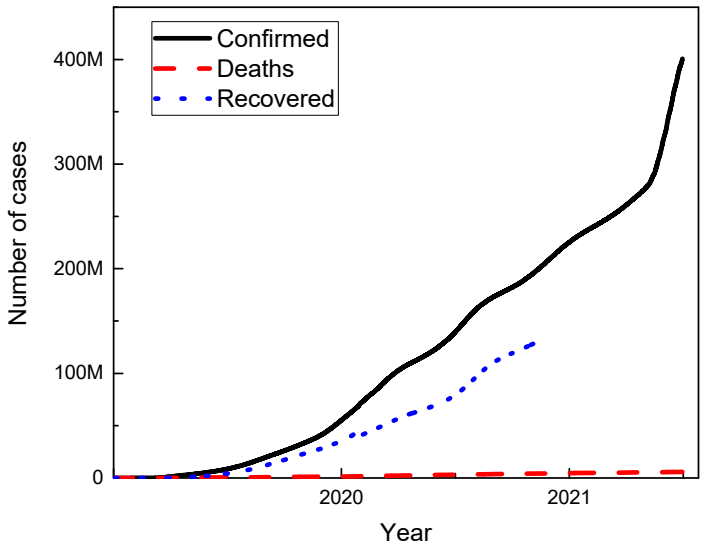

Figure 1. COVID-19 confirmed cases, deaths, and recovered cases between 2020 and 2022.

1.2. Smart Cities and the Internet of Things

IoT has been described as a system that integrates sensors, smart mobile devices, and intelligent devices [18] in a network for collecting and analyzing data. Services and applications provided by IoT technology can be divided in to 14 service domains within 4 application levels [19]. The application levels for the service domains are: infrastructure level, organizational level, individual level, and all-inclusive level. The smart city service domain is included in the infrastructure level, where IoT technology assists the government in improving city planning [3].

Smart cities are an integration of IoT into cities, gathering data and providing services, with implications ranging across major industries. For smart cities, four factors contribute to conventional cities: electronic device application, transforming way of life, data for government, and innovation and knowledge [20]. Moreover, the fundamental idea of smart cities is to assist in six functions of a city: economy, people, governance, mobility, environment, and living [21]. A review of pilot project smart cities showed an approach

in which cities differ according to the specific needs of a given city [7]. In order to satisfy the requirements for a city to be considered a smart city, networking between devices to transfer data—the internet of things—is essential [22].

According to the smart city index 2021, provided by IMD business school [23], 118 cities are moving toward being smart cities. Table 1 shows smart city rankings in 2021 and a smart city ranking from 2020.

Table 1. Smart city ranking 2021 and 2020 according to the smart city index.

City	Smart City Rank 2021	Smart City Rank 2020
Singapore	1	1
Zurich	2	3
Oslo	3	5
Taipei city	4	8
Lausanne	5	New
Helsinki	6	2
Copenhagen	7	6
Geneva	8	7
Auckland	9	4
Bilbao	10	24
Vienna	11	25
New York	12	10
Seoul	13	47

The index shown is based on a questionnaire survey analyzing attitudes toward smart cities. According to the index analysis, the development of a smart city is a unified cooperation between the government and citizens of a given place. In detail, comparing the highest and lowest smart city rankings shows that respondents' scores for trust in authorities were 48.8% and 75.3%, respectively. The development by the authorities showed the biggest difference where 5 categories of health and safety, mobility, activities, opportunities, and governance reflected the smart city ranking. In this study, the five categories mentioned are reworded according to the industrial sectors of transportation, tourism, environment, business, education, and governance that reflect the six functions of a smart city.

2. Literature Review

2.1. Review Methods

A systematic literature review was conducted to analyze the current trend in research by proposed guideline [24] for studies relating to the post-COVID-19 era. The objective of the review was to find the current research trends where research questions were established relating to IoT and smart applications for various fields. From the results, a common topic between the fields was identified. Key search words were extracted from the research questions where the results were filtered according to the fields. Two academic peer-reviewed journal databases, SCOPUS and Web of Science, were used in this study to search for smart-applications- and IoT-related journals for various fields: architecture, business, construction, education, environmental, government, healthcare, tourism, and transportation. SCOPUS and Web of Science were chosen as reliable sources of academic journals, because they contain significant amounts of peer-reviewed papers from multiple organizations [2].

The keywords used to cover the topic of IoT, COVID-19, and smart applications were categorized for specific disciplines. The Boolean operator of AND was used for the keyword "COVID-19" to include it for all searches, and OR was used for keywords "IoT" and "smart" to broaden the range of the search. Additionally, as the review was focused on architecture, "building" and "space" were also added to the search. Table 2 shows the search criteria for the systematic literature review. As one of main areas of interest was COVID-19, search for literature was conducted from 2019 onward. The results of the keywords from the two search databases were filtered according to the various fields of study. The papers were

collected and combined, and the titles, abstracts, and keywords were extracted. A word cloud was created using python, based on the most frequently mentioned words from the extracted words. Additionally, a network using VOSviewer was used to find related topics.

Table 2. Electronic database search criteria.

Keywords	"Internet of things" OR "smart" OR "IoT" AND "COVID-19" AND "architecture" and "building" and "space"
Covered period	2019–2022
Covered sectors	business, healthcare, tourism, transportation, architecture, and education
Database	SCOPUS and Web of Science

2.2. Research Questions

Research questions were created based on the main topic of IoT and smart technologies. Additionally, questions covering various fields surrounding the main topic were considered.

RQ1. What are the recent research topics for IoT and smart technology?
RQ2. How has COVID-19 affected research trends for IoT and smart technology?
RQ3. Which IoT and smart technologies are applied in various fields?
RQ4. Is there a common topic between various fields?

RQ1 refers to the scope of the study, uncovering recent research trends for IoT and smart technologies. RQ2 allows us to observe the impact that COVID-19 had on research directions for Industry 4.0 technologies. Due to the differences in applications of IoT and smart technologies, RQ3 was asked to uncover research directions in various fields. RQ4 was asked to identify a common topic among the various fields where IoT and smart technologies might be applied, in order to assist the respective fields. Expanding on RQ3, listed in Table 3 are the existing technologies that were considered for the literature review. The table is organized as guided by the framework of Industry 4.0, including devices, networks, and servers. The devices are applied for data acquisition purposes, including real-time data. Network applications enable the transference of data between devices, servers, and end-users. Servers are tools for analyzing procured the data that require high-speed processing to reduce any form of delay or error.

Table 3. Industry 4.0 technologies considered for literature review.

Topic	Technologies	Application
Device	Thermal sensors, RGB cameras, wearable devices, smart phone, near-field communication (NFC) tags, smart lights, smart heating ventilation, and air conditioning (HVAC), QR, micro dust sensors, microphone	Data acquisition
Network	Bluetooth, WiFi, 4G network, 5G network, ZigBee, NFC, global positioning system (GPS)	Networking between users and analysis by servers
Server	Machine learning, artificial intelligence, convolutional neural network (CNN), artificial neural network (ANN), support vector machine (SVM), deep autoencoder, deep-learning-based hierarchical neural network, natural language process (NLP)	Processing and managing procured data

2.3. Screening and Filtering

In total, we found 1245 papers on Web of Science and SCOPUS combined. From these search results, repeated papers were eliminated and only papers relating to the academic topics of business, healthcare, tourism, transportation, and architecture were chosen. From the filtering process, Web of Science and SCOPUS were left with 61 and 62 papers, respectively, for a total of 123 papers published since 2020. The time limit was

chosen as it relates to the adoption of technologies in response to the recent pandemic. In addition, articles relating to smart technologies were found to grasp an idea of what type of smart technologies are available for public use. The papers related to impacts during the pandemic era were then categorized within the mentioned fields. Table 4 shows some of the papers that implements Industry 4.0 technologies, including IoT, in the specific fields.

Table 4. Papers chosen after screening and filtering.

Topic	Authors	Aim
Business	M. Andronie et al.; M. Brown; H. P. Nguyen et al.; S. K. Sasikumar; S. Segkouli et al.; O. Svatoš; G. M. Abbas and I. G. Dino; A. Bahmanyar et al.; Y. Hou et al.; A. Kylili et al.; W. Leal et al.; M. Ryu et al.; D. Susandi et al.; H. Rafsanjani & A. Ghahramani; K. Furdik et al.; J. Patel et al.; T. Vafeiadis et al.; S. Yi & X. Liu; A. D. Dubey & S. Tripathi; A. Purwanto et al.; T. Kaur & P. Sharma; J. Morley et al.	Workspace modification for reducing spread of disease and business modification using Industry 4.0 technologies. [25–46]
Healthcare	A. S. Al-Ogaili et al.; D. C. Anderson et al.; H. K. Bharadwaj et al.; P. Chatterjee et al.; S. P. Dash; Y. Dong and Y. D. Yao; M. Elpeltagy and H. Sallam; A. J. G. L. Franca and S. W. Ornstein; F. Hussain et al.; M. Iqbal et al.; N. A. Jasim and H. T. S. Alrikabi; E. Leila et al.; M. Nasajpour et al.; M. Nazayer et al.; N. Pathak et al.; Y. Siriwardhana et al.; S. K. Udgata and N. K. Suryadevara; M. Umair et al.; B. Ç. Uslu et al.; R. Xiao and X. Liu; A. Zielonka et al.; A. Abed; A. Alhasan et al.; A. Amerio et al.; M. K. Anser et al.; M. Arlotti and C. Ranci; R. Gupta et al.; Y. K. Juan et al.; J. Li et al.; Y. H. Li and L. Y. Xu; H. L. Zhao et al.; S. Nagaranjan et al.	IoT application methods including reviews for specific cities. Machine learning applications for identification of diseases. Facility modification, adopting machine learning and IoT technologies. Adaptation of IoT in response to the recent pandemic. Development of robotics in medical environment. [47–78]
Tourism and transport	I. Ahmed et al.; G. De Luca et al.; E. Elbasi et al.; K. Gautam et al.; K. Hodor et al.; S. R. Reza et al.; M. Singh et al.; S. Thilagavathi et al.; Y. Yin et al.; T. Bayrsaikhan et al.; V. Bodolica et al.; T. Campisi et al.; A. Cheshmehzangi et al.; J. F. Jiao and A. Azimian; V. A. Joshi and I. Gupta; F. Khozaei et al.; M. H. Luo et al.; M. Madziel et al.; T. S. Martynenko; N. Nasir et al.; Nizetic; M. Z. Pakoz et al.; Bojan et al.	Consequences of overtourism. Development of geospatial platform for planning. IoT adaptation for response in pandemic. Machine learning adaptation for social distancing. [79–102]
Architecture	A. A. Alraouf; E. Antonini et al.; A. Cheshmehzangi; D. G. Costa et al.; U. Emmanuel et al.; H. M. K. K. M. B. Herath et al.; K. Herman and L. Drozda; C. L. Lin et al.; N. A. Megahed and E. M. Ghoneim; R. Mumtaz et al.; B. V. D. Nguyen et al.; T. Peters and A. Halleran; C. Riratanaphong; M. Shorfuzzaman et al.; W. S. Wang et al.; Z. Yue et al.; A. A. Alhusban et al.; A. X. I. Cenecorta; M. G. Kang et al.; N. Megahed and A. Hassan; M. R. S. Melone and S. Borgo; G. A. Merli and G. S. Graciano; I. Mironowicz et al.; T. Peters and A. Halleran; F. Rahal et al.; L. Rice; F. Sierra; P. Valizadeh and A. Iranmanesh; C. T. Wai et al.; J. Xie et al.; M. Perez; Y. Lu et al.; A. T. Xu et al.; Y. Li et al.	COVID-19 impact on architecture and homes. Design strategies for infection prevention and control. Green infrastructure and social distancing. Framework for immersive cross-reality. Implication of IoT and machine learning. Accommodation strategies and privacy security. [103–136]
Education	A. Eltawil et al.; A. Millán-Jiménez et al.; M. Mircea et al.	Accommodation design strategies and mental healthcare for students by implementing Industry 4.0 analytical techniques. [137–139]

Figure 2 shows the research papers categorized into topics: business, healthcare, tourism, transportation, architecture, and education. Additionally, research papers that were focused on the recent pandemic and specific development of IoT technologies were

left uncategorized. It was found that the majority of the research papers were related to architecture and healthcare with a combination of 52.04%, while studies relating to education comprised the minority, with only 2.44%.

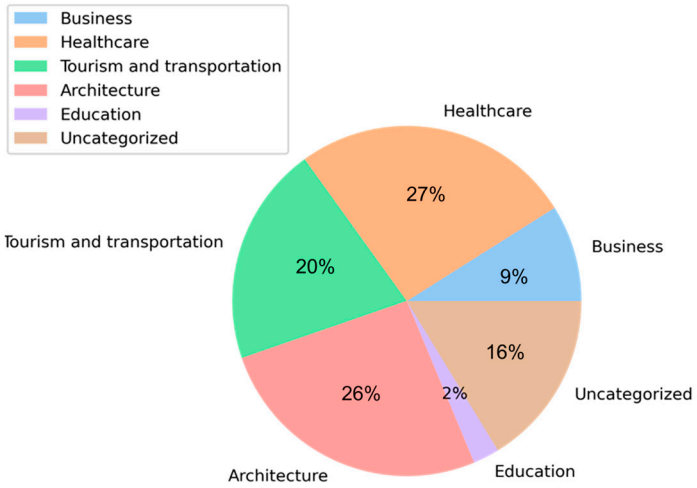

Figure 2. Research papers categorized into topics of interest.

2.4. Academic Paper Analysis

In order to visually analyze the found papers, a word map was created to find the most-used words within titles, abstracts, and keywords from the journals. Python coding was used to create the word map, and the built-in stop-word package was used to eliminate words that were irrelevant. Additionally, search words used for searching for the journals, such as COVID, pandemic, impact, and study, are used as stop words.

Figure 3 shows the most common words within all categories of papers: "architecture" and "IoT" from SCOPUS; "design", "building", "space", and "urban" from Web of Science. The word clouds show the clear connection between the Industry 4.0 techniques which were used in reaction to the pandemic within all the topics.

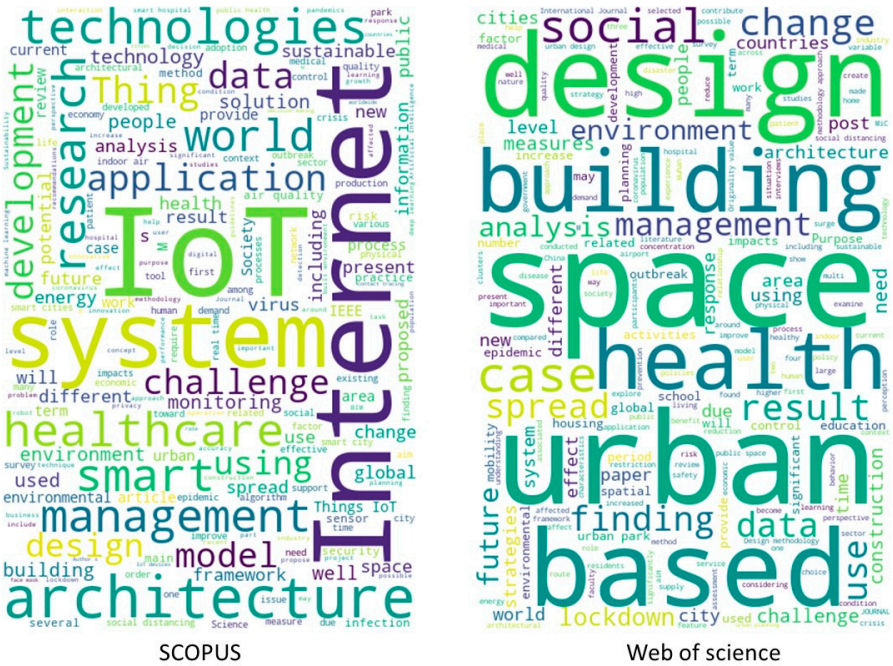

Figure 3. Word clouds produced in python.

The frequent mentioning of keywords within the academic fields shows the necessary creation of a new category of smart architecture: the field of architecture with the implementation of Industry 4.0 techniques. Figure 4 shows a network diagram from the combined text of SCOPUS and Web of Science. The significant words that were linked to most of the papers are highlighted. It was found that "IoT" and "smart city" had the most significant relation with other words, since these were the keywords used for the searches in the electronic databases. Aside from the technological words, such as "smart" and "IoT", words relating to architecture, such as "accommodation strategy", "planning", and "urbanization" were found to be profoundly common as highlighted in Figure 4. The networking diagram shows that there is a significant number of studies deriving from the field of architecture that apply concepts from Industry 4.0.

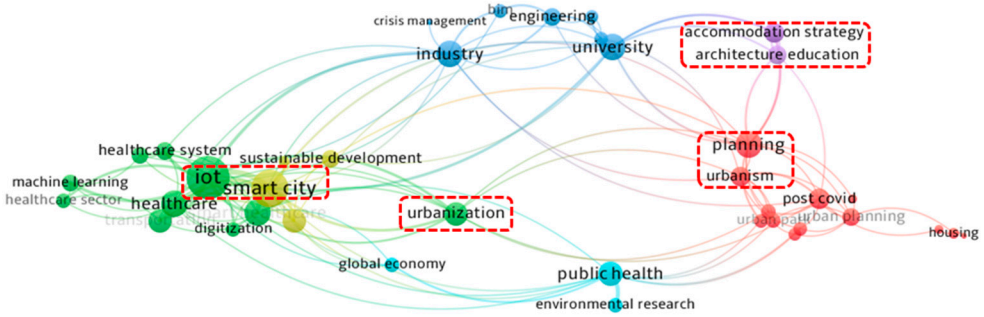

Figure 4. Network diagram produced in VOSviewer.

The requirements of architecture, with a focus on the pandemic era, were defined from the COVID-19 example. In terms of healthcare, temporary hospital units and converted existing buildings were utilized to accommodate the overwhelming increase in the number of patients. These units and conversions required extensive architectural planning to keep the patients and users comfortable and free from possible external contamination. For the business sector, internal planning for office spaces that utilized IoT was found where the majority of studies were conducted to maintain social distancing and create a clean environment. Similarly, tourism and transportation implemented artificial intelligence to identify crowded places and individuals without masks. Railway and aerospace industries also used artificial intelligence along with IoT devices for similar aims. Studies also developed route recommendation technologies for avoiding crowded places, which used the same technologies. Within education, student accommodation planning and controls for indoor environments were also researched using the same technologies. A pattern emerged for various sectors, where a combination of IoT devices with machine learning and artificial intelligence was implemented to create "smart" environments. This gives a clearer understanding of what makes something "smart". Commercial applications are described in more detail with examples in the next section.

3. Review Results

This section covers information found in the papers surrounding applications of IoT and Industry 4.0 technologies. It covers the five topics chosen from the search: business, healthcare, tourism and transportation, architecture, and education.

3.1. Business Sector

IoT technology can be applied to businesses in two key areas: internal and external activities. In other words, internal activities of businesses consider human resources and management, and external activities consider planning, operation, and customer services [25]. The general beneficial traits of IoT technology, such as data collection and networking, have allowed it to be adopted in two areas within business. Internally, a local network can be used to provide numerous services for the employees. For example, a smart office can provide services to the employees for a particular scenario within their

day [36]. A typical office has two spaces: personal space and shared space. IoT devices can be applied for providing information to employees related to parking spaces, energy, and comfort [37–39], to name a few. Externally, market trends and customer preferences can be analyzed by using machine and deep learning techniques [40,41]. Natural language processes (NLP) and word classification techniques are used search engines on online stores with the purpose of auto-finishing sentences or words [42]. These techniques were especially useful during COVID-19.

The recent COVID-19 pandemic has had significant consequences for businesses. Governmental social distancing restrictions led to nationwide lockdowns for numerous countries, where employees were forced to work from home [43–45]. Public spaces, including department stores and local shops, had restricted entry for customers. In these cases, IoT technologies were applied to create smart businesses and smart stores. For day-to-day business processes, IoT companies, such as Zoom and Google, solved some of the issues related to working through remote meetings and defining boundaries between work and personal life [45]. In South Korea, entry to public spaces was only granted upon scanning a QR code to assist in COVID-19 contact tracing [46].

3.2. Healthcare Sector

The healthcare sector is a key area in the development and application of IoT technologies. With the outbreak of COVID-19, researchers utilizing Industry 4.0 technologies, such as artificial intelligence and IoT devices, conducted studies for identifying symptoms and preventing spread of the disease. Some of the literature found for healthcare was based on frameworks and review. The application of the same technologies, such as IoT devices and artificial intelligence, was researched for specific countries, including South America, India, Malaysia, Iraq, Italy, and China [47,49–53,55,60,61,66,137]. Some of the IoT devices that have been studied include thermal detection devices, surveillance networks, healthcare delivery services, and tracking and tracing. Devices are connected to a network that integrates machine learning technology for classification purposes. The application of the technologies benefits diagnosis, prognosis, spread control, monitoring, and logistics. Due to the depth of study, this area of research and technology has been identified as the healthcare internet of things (H-IoT) or the internet of health things (IoHT). Key factors of H-IoT and IoHT include accuracy and networking efficiency to minimize misdiagnosis and contain emergency situations. Studies relating to error and time have also been performed [78].

Technological studies considering the design of healthcare-related spaces, such as nursing homes, accommodation, and hospitals, have been performed [48,57,64–67,71,72,94]. The design of these spaces was related to the routes recommended for patients and staff to avoid crowded areas, with the primary aim of reducing the spread of disease. Moreover, studies related to designing spaces which are specific to the needs of patients have been conducted [48,70,120]. There have also been studies conducted in the past related to the renovation of vacant spaces into hospitals [74]. This type of research set precedent that was particularly practical during the COVID-19 pandemic due to the spike in numbers of patients. Other studies regarding healthcare have involved identifying symptoms using artificial intelligence and IoT devices, faster networking within hospital environments, and software development for identifying contact between patients [53,56,58,60,62,73].

The number of studies conducted for actual applications of Industry 4.0 technologies were found to be much fewer than those for the design of spaces, a topic which is closely linked to architecture. Smart technologies that include machine learning and IoT are planned and designed similarly to those of systems which are included in buildings, such as mechanical, electrical, and piping (MEP), and heating ventilation and air conditioning (HVAC) systems. For healthcare, the combination of collecting data from devices and performing analyses using machine learning techniques on a high-speed network exists. In this field, studies to identify appropriate machine learning methods have been performed [78].

3.3. Tourism and Transportation Sector

Most cities practicing smart city movement have shown IoT adoption within the traffic and transportation, government, and education industries, with the unified aim of improving the quality of life of citizens. A survey from 2010 [3] showed the open research issues that are being solved by academics and researchers in industries. For example, in the public transport industry, conventional methods of tracking and searching for a printed timetable to estimate the time of arrival are eliminated with the use of IoT. Transport vehicle locations are tracked with GPS sensors where the information is shared on a network. The uploaded data are calculated with the distance remaining to the next stop, where time is calculated and the data are shared with bus stops and individual smart devices [102]. In South Korea, as a response to COVID-19 pandemic, Seoul has developed a smart shelter service, where information relating to transportation, micro-dust, time, and temperature is provided near bus stops [140]. The smart shelter is equipped with UV lamps for disinfecting purposes and can only be entered after an automatic temperature sensor, where the user must be less than 37.5 °C.

Figure 5 shows a smart transportation strategy from Seoul city council. It shows the transferring of data between the transportation units and a smart shelter that is connected to the control center.

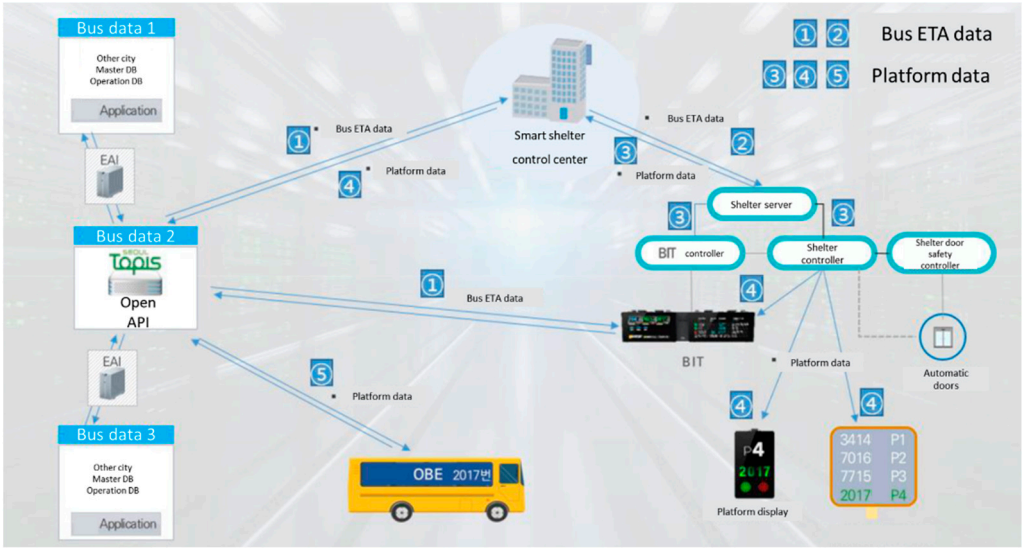

Figure 5. Seoul smart transportation strategy.

For tourism, we found studies that implemented IoT devices and machine learning techniques to identify high-risk areas for potential contact with COVID-19, i.e., crowded spaces [80,82,86,87,93,94,99]. In upholding social distancing, smart retail was studied for a potential change in the retail experience paradigm. Deep learning techniques were implemented to detect face masks in unavoidable crowded spaces. Geospatial platforms were found to be a significant topic for tourism planning.

3.4. Architecture Sector

Despite the rising numbers in confirmed cases in the Republic of Korea, the construction and civil sectors are on a continuous rise in construction activities and demand, as shown in Figure 6. The rise in construction is inevitable, as it is the construction and civil sectors that are required to build infrastructure in preparation for the pandemic era.

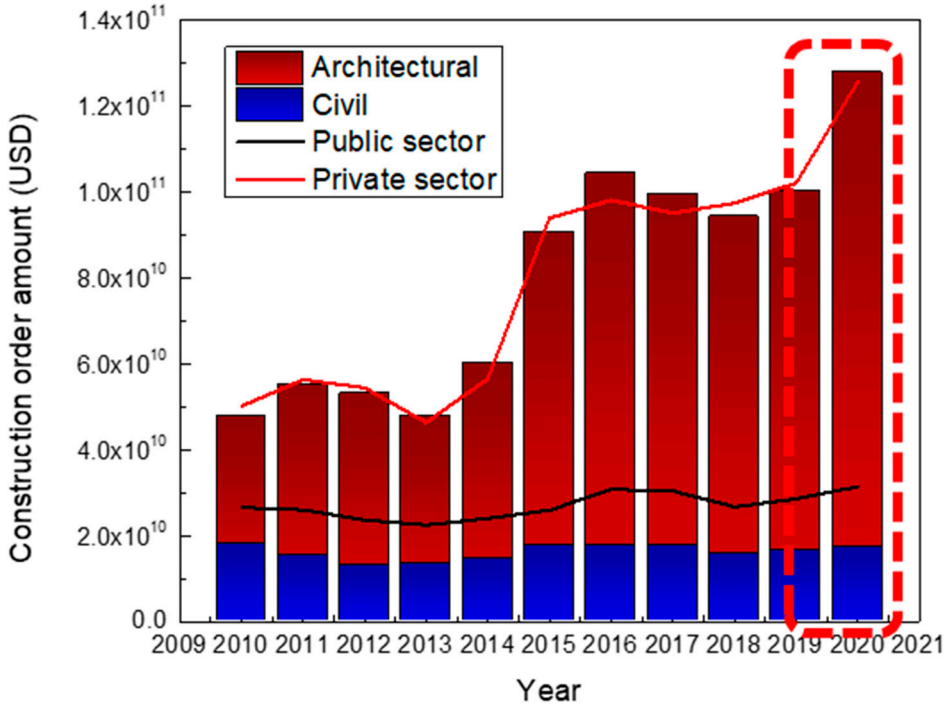

Figure 6. Rise in public and private construction status despite COVID-19.

From the case studies, the necessity to accommodate for the sudden rise in patients is one of the most significant factors to consider in the pandemic era. According to case studies, from an industrial point of view, temporal or permanent solutions are insignificant. By the time this paper is published, the release of vaccines and the settling of COVID-19 will show that a temporal solution is preferred to a permanent solution. Nonetheless, preparation is required for a potential occurrence of another pandemic in the future.

In general, papers found for the architectural sector can be divided into categories of indoor space, outdoor space, and architectural education. For indoor spaces, research papers tend to focus on social distancing and air quality [79,109,113,114,116,117,123,126,133]. Social distancing was considered as one of the primary aims to consider when designing a new space. This was seen crucial during the time of COVID-19, because reducing contact with other individuals where possible was a known method for reducing the spread of diseases. Indoor environments were another factor to consider, with two primary aims: air quality in terms of dust and purifying the air of contaminants, including COVID-19. These key aims were considered to be significant during the design stage of a sensitive environment such as hospitals and nursing homes.

Outdoor spaces included subtopics: smart cities, urbanism, and green infrastructure [35,50,51,70,72,79,84,85,97,111,117,125,135,136]. Studies relating to smart cities and the impact of COVID-19 blended with healthcare subtopic as it included designs of smart hospitals and responses by emergency vehicles. Urbanism was a frequently occurring keyword, where the design and maintenance of urban parks and accommodation strategies were studied. Investigation of the current trend and of recommendations on how to stay safe during the pandemic was the primary aim for the majority of the studies.

The impact of COVID-19 was prominent during the search. We found studies conducted for the implementation of IoT, with a focus on the attempt to uphold social distancing [27,59,79,111,119,123,129]. Within this, the usage of building information modelling (BIM) for special design of hospitals, nursing homes, and accommodation was explored.

3.5. Education Sector

The literature review for the education sector resulted in the lowest number of papers published in peer-reviewed journals. Studies conducted regarding the education sector

were focused on campus design for sustainability, student welfare during COVID-19, and the impact of IoT [134,137,138].

4. Smart Architecture

Section 4 explores the idea of smart architecture and the necessity thereof. It was found from the systematic literature review that many of the topics covered within the business, healthcare, tourism and transportation, architecture, and education topics also included common subtopics relating to space, design, and planning. Space, design, and planning are significant factors for architects to consider when starting a building project. Therefore, this section covers the potential implementation of IoT technologies and Industry 4.0 techniques for specific phases of smart architecture: planning, design, and construction. Based on the systematic literature review, the lessons that have been learned from the technologies applied in various sectors that are also applicable to the three mentioned phases of architecture are listed in Table 5. It lists the potential devices, networking methods, and analysis methods that were derived from the studies reviewed in Section 3. Further explanation of how smart architecture can be implemented presented through the individual phases in this section.

Table 5. Smart architecture list.

Topic	Devices	Networking	Server
Planning	Microphone, RGB camera	Bluetooth, WiFi, 4G network, 5G network	NLP, SVM, deep autoencoder, deep-learning-based hierarchical neural network.
Design	CAD, BIM, augmented-reality (AR) devices	WiFi, 5G network	Numerical optimization, CNN, ANN, simulation.
Construction	RGB cameras, NFC tags, thermal cameras, smart phones, wearable devices, QR, mixed-reality (MR) devices	Bluetooth, WiFi, 4G network, 5G network, GPS, NFC	CNN, ANN, SVM.

4.1. Planning Phase

The planning phase of an architectural project identifies the needs and requirements of a specific building. It also considers how a built space will be used and the preferences of the users. For this purpose, surveys and interviews are commonly conducted with clients, including users. To this end, conventional time-consuming methods of text mining and statistical processes can be improved with machine learning and deep learning techniques. The planning phase of smart architecture processes should consider the lifetime of a building and the potential emergency situations that could occur, such as future pandemics. The lessons learned from COVID-19 and previous emergencies should be taken into consideration when planning for a building project.

4.2. Design Phase

The introduction of BIM for architecture is reshaping the architectural sector yet again after the development of computer-aided design (CAD) techniques. There is an exploratory need to implement new techniques, such as machine learning and deep learning, for the design phases of smart architecture. These Industry 4.0 techniques may assist the conventional numerical optimization methods in designing a space. For example, user route estimation and room placement are generally performed by the standards set by similar projects or numerical optimization methods. Classification and neural network techniques of machine and deep learning may assist architects in improving conventional methods.

The design of new buildings in preparation for future pandemics by implementing IoT devices should adjust well to smart architecture. This was prominent in the systematic literature review, since the unexplored areas are vast, with enormous potential for research topics. Along with IoT devices, machine learning techniques for assisting users is an area

of interest along with the development of smart cities. In addition, installation of these techniques is possible for existing buildings during renovation.

4.3. Construction Phase

There are far more studies concerning IoT and machine learning techniques implemented in the construction phase of a building project when compared with the amount of research performed for the planning and design phases of architecture. This is mainly a response to the number of accidents and deaths which occur within construction environments. Moreover, the cost of construction covers most of the budget for a building project. Therefore, keeping construction workers safe whilst constructing with minimal construction errors is crucial in a successful building project.

One of the implementations of machine learning and IoT devices for construction workers is the identification of hardhats that are to be worn at all times by law for most construction projects.

In the safety sector, to detect hardhats, researches has been performed for feature extraction and classification using a convolutional neural network (CNN), a deep learning technique [136]. Project managers and construction managers planning to implement new techniques can be considered an element of smart architecture, as an aid to smart construction.

Other techniques that could be implemented during the construction phase include the improvement of 3D scanning techniques and the analysis thereof. Moreover, with the development of automation and robots, a new paradigm of construction could be realized.

Inclusion of scanning devices in construction projects is on the rise as this reduces manual labor of ground surveying and the time consumed performing these actions. Combining scanning devices with robots provides access to potentially dangerous areas for workers. These are just a few potential benefits that could be achieved when these technologies are developed for commercial use.

5. Conclusions

This study explored the impact that COVID-19 had in the respective sectors of business, healthcare, tourism and transportation, architecture, and education. We focused on the applications and research topics relating to IoT and Industry 4.0 techniques. The combination of these two topics within the respective sectors characterizes their responses to the pandemic.

A systematic literature review was performed according to the procedure presented by Kitchenham [24]. Research questions were created to give direction to the searches. The findings from the literature review were as follows:

(1) Most of the recent research topics for IoT and smart technologies for the respective sectors were found to be related to upholding social distancing, as per RQ1. Machine learning and deep learning techniques have been studied for various purposes. It was found that many of the peer-reviewed articles studied smart technologies and IoT devices derived from the Industry 4.0 concept. Devices collect real-time data that are analyzed by machine learning processes, and these involve artificial intelligence and are connected via high-speed networks. The application of this framework varied across sectors, and the framework can be applied in preparation for future smart cities with the primary aim of sustainability [141].

(2) Investigation following RQ2 and RQ3 led to studies being found in the business, healthcare, tourism and transportation, architecture, and education sectors. Two aspects of business—retail and offices—were found to have been studied for the implementation of smart technologies and IoT. Smart retail has been studied to maintain social distancing and assist customers. This has a knock-on effect of increasing revenue, with additional preparation for future pandemics. Smart offices were studied to identify crowded spaces and mask identification using machine learning and deep learning techniques, reducing chances of contamination. For healthcare, identification

of symptoms relating to COVID-19 was studied along with identifying crowded places, allowing patients and staff to be recommended an appropriate route to maintain social distancing. In addition, the potential application of 5G networks to increase efficiency in communication between staff within a healthcare environment has been studied. In design, ventilation and layout for nursing homes and smart hospitals have been studied. The impacts of COVID-19 have been analyzed for transportation, including the railway and aerospace industries. Implementation of IoT and smart technologies were found to be mostly related to tourism, maintaining social distancing. Urbanism for indoor and outdoor spaces fell under the category of architecture, as most of the studies considered the design of spaces for users. Studies relating to architecture were focused on the three aspects of architecture—planning, design, and construction—with an additional focus on architectural education. Research on smart technologies since 2020 has focused on preventing COVID-19 contamination; this will influence the designs of buildings, spaces, and urban areas in preparation for future pandemics.

(3) In regard to RQ4, the systematic literature review showed that studies within the various sectors had the following overlapping aims: maintaining social distancing, preventing contamination, and redesigning the space. These can all be achieved within the architectural sector.

From the research findings, it was found that all the study areas implementing smart technologies in various sectors had architecture in common. Social distancing became a common aim between the various sectors as a response to governmental restrictions related to COVID-19. The aims of the researched and developed technologies were similar in that the purpose was tracking and maintaining social distancing. Other aims included the monitoring of individuals for temperature. The application of technologies for the purpose of transferring data should be considered in the planning, design, and construction stages of architecture. Smart architecture is necessary for transferring data, similarly to MEP and HVAC, which transfer essential utilities such as gas, electricity, and water. However, the problem arises when the study area becomes uncontrollable due to the sheer depth of the topic. To properly organize the area of study, a new subtopic of architecture is required, namely smart architecture. Smart architecture can be described as including the traditional architectural aspects of planning, design, and construction, with the inclusion of concepts and technologies from Industry 4.0. The new subtopic is necessary to categorize the ever-deeper and complex nature of architecture. As supported by this systematic literature review, architecture is related to the various sectors studied in this paper. The expected implications for smart architecture involve the provision of assistance in future studies for categorizing overlaps in knowledge that will continue in the future with the continuing development of technologies. This categorization is especially useful for academics, researchers, and practitioners. Among academics, building the knowledge of smart technology upon a firm foundation of classical architecture will assist the careers of students. Researchers and practitioners with a sound understanding of smart architecture are thought to have an important role in the development towards future smart cities, which are prepared for forthcoming pandemics.

In this paper, the need for smart architecture is identified through a systematic literature review; however, further research is still necessary. There is a need for an appropriate method of categorization and organization that can match the pace of technological advancement. Research is needed to investigate appropriate methods of effectively imparting difficult concepts and technical knowledge to students and individuals who are not specialists within the field of smart technology and engineering. There is also a need for quantifying methods that show the effect of applying smart technologies to architecture, beyond a means-to-an-end approach [142]. Further research would benefit the development of future smart cities, with the added benefit of being prepared for future pandemics—going beyond Industry 4.0 technologies.

Author Contributions: Conceptualization, J.-H.K. and S.-J.P.; methodology, S.-J.P. and K.-T.L.; software, S.-J.P.; validation, S.-J.P., K.-T.L. and J.-B.I.; formal analysis, S.-J.P. and J.-B.I.; investigation, S.-J.P.; writing—original draft preparation, S.-J.P. and J.-H.K.; writing—review and editing, S.-J.P., J.-B.I. and J.-H.K.; visualization, S.-J.P. and J.-B.I.; supervision, J.-H.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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