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# Digitalization and Smartification of Urban Services to Enhance Urban Resilience in the Post-Pandemic Era: The Case of the Pilgrimage City of Makkah

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**Abstract:** The COVID-19 pandemic has significantly disrupted human socioeconomic activities, leaving an everlasting impact on urban systems. As a result, there is a growing scholarly focus on exploring how urban planning strategies and tools can help create resilient cities. In Saudi Arabia, the pilgrimage city of Makkah, which has always faced the challenge of managing crowds during the annual pilgrimage, was left deserted due to lockdowns and social distancing measures. To quickly revive socioeconomic and pilgrimage activities in the city, a set of digital tools and communication technologies were deployed to manage crowds and enforce social distancing to minimize the spread of the COVID-19 virus. This study examines the role of digitalization and smartification in reviving the city and the importance of context in building urban resilience. This study used desktop research and case study analysis to highlight the transformation to the new normal and the development of future smart technologies for the city. Smart solutions provided valuable support in reducing the impacts of the pandemic and restarting Makkah's economy. Although most activities have been restored, some facilities and services are still operating below capacity. Digitalization and smartification of urban services could play a major role in improving service delivery and urban resilience.

**Keywords:** digitalization; smart city; pilgrimage; COVID-19; mass gathering events; post-pandemic resilience



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## 1. Introduction

The World Health Organization declared COVID-19 as a pandemic on 11 March 2020, which by the end of 2022 resulted in at least 651.918 million confirmed cases, including over 6.657 million mortalities worldwide [1]. To combat the spread and enhance monitoring of the virus, smart technologies such as wearables, robots, drones, and AVs that utilize the Internet, GPS, and Bluetooth technology have been utilized for telemedicine and tracking infected patients while minimizing the need for human contact [2]. Smart solutions, such as artificial intelligence (AI), have helped in real-time tracking of the transmission of the virus and identifying patients at high risk. Patients' past medical histories have also been used to forecast their likelihood of becoming seriously ill or dying. Using population monitoring, medical aid, warning, and infection control advice, AI can aid in reducing the spread of the virus, and crisis management at every level, from disease detection and prevention to intervention and recovery, and research [3,4]. Smart technologies have been used to collect and analyze data to stop the spread of the virus and several other essential applications, such as early detection, contact tracing and monitoring infected people, case projection,

developing drugs and vaccines, reducing healthcare workers' service, and overall virus prevention [5]. Care for COVID-19 patients and diligent monitoring of their health are among areas where technology can help lessen the severity of the pandemic's effects.

Although the pandemic has been declared over, the current literature has increasingly focused on the lasting implications of the pandemic on the nature and location of human socioeconomic activities [6,7], how people access basic urban services such as healthcare, education [8–10], and the overall urban planning and governance systems [11–13]. Differentiated efforts for digitization between developed and developing countries were revealed by the pandemic, demonstrating how unequally developed cities are from the perspective of modernization and the transition to smart cities. Thus, the potential for the smartification of city services to increase urban resilience to pandemics is crucial. In the current view of economic resilience, "smart cities resilience" refers to the accomplishment and triumph over social, economic, and cultural performances as a new developmental balance founded on the association of factors and resources on another growth pattern, capitalizing on past experiences (both positive and negative) and rebuilding subsystems (through creative disruption, for example), resulting in a strong and sustainable recovery and smart development [14]. It is a new way of thinking about development wherein economic resilience is seen as a goal of human progress rather than purely technical. As a result, a smart city is a socially, economically, and environmentally sustainable place to live. Public services, technological and social infrastructure, high levels of security, and attention to the environment and green spaces all contribute to the welcoming atmosphere of a "smart city", which promotes sustainability [15,16]. Digital connectivity, fostering the transformation of at-risk areas into smart, sustainable communities; implementing digital transformation in business; increasing future-focused, transformative, and innovative research; funding a more inclusive, future-proof education system; e-governance with targeted services for businesses and the public; e-health transition and cross-system collaboration; and e-health transition and cross-sector collaboration are all critical components of a resilient city with an integrated vision [14]. In this approach, the idea of SDG-11, smart cities, and digital infrastructure opens the door to making cities more resistant to pandemics. However, there is little literature in the Global South focusing on how social distancing and quarantine policies resulting from the pandemic have altered service delivery, mobility, and working patterns and impacted the entire urban system and the role of urban planning strategies and tools in creating resilient cities in the post-pandemic era.

To address this research gap, the present study investigates the role of digitalization and smartification in fostering urban resilience to the threat of natural disasters such as the pandemic in the Saudi Arabian holy city of Makkah (Mecca). Saudi Arabia hosts one of the world's largest public events every year, where 2–3 million Muslims from over 180 countries gather annually to make the Hajj pilgrimage [17]. The cancellation of the Hajj and the Umrah in 2020 due to the pandemic has significantly affected the national economy, individual livelihoods, and public morale because over 12 billion dollars were lost in that year alone [18]. However, the economic loss was preferred over the risks of pilgrims getting sick or dying from respiratory infection during the Hajj because of the high concentration of people in confined spaces [19,20] and the difficulty in crowd management [21]. As such, one thousand pilgrims were chosen randomly from among 160 different nationalities to complete the Hajj rituals in 2020 [7]. Therefore, the city became deserted due to lockdowns and social distancing measures, and the city administrators are now searching for strategies and technologies to mitigate the impacts of the pandemic and allow the city's religious and socioeconomic activities to bounce back.

To improve passive surveillance of symptoms through self-reporting and guarantee monitoring compliance to post-Hajj quarantine procedures, the SMART Pilgrim city of Makkah program was established. The program required all pilgrims to keep using the Tetamman application and wear their electronic tracking bands during and even after Hajj rituals were completed. Pilgrims were not just monitored through the app; they also received regular phone calls asking about their symptoms. As a result, there were

no confirmed instances of COVID-19 during the 2020 Hajj. When pilgrims came to the Grand Mosque in Makkah for Hajj 2021, they were guided by four-wheeled robot guides that could speak 11 languages [22]. These robots helped human cleaners sanitize the site, assisted in the cleaning process, and distribution of bottled water to pilgrims, dramatically reducing the risk of cross-contamination. The government promised to use cutting-edge technologies like smart apps, smart cards, and electronic platforms designed to improve the pilgrimage experience [23,24]. At the Holy Mosque, those with impairments and the elderly have access to 2000 electric vehicles [23]. As a result, over half a million worshippers could pray in the courtyards of the Prophet's Mosque in a comfortable atmosphere, thanks to digital technologies that operate over 250 electric umbrellas, fans, and air conditioners that sprayed light droplets of water into the air with minimal congestion. The program has also developed these methods and measures to highlight the importance of smart systems and the good effects technology use has in the fight against pandemics [25]. Through the increased use of AI and other digital technologies, the country has become a leader in crowd management and a role model in this area, particularly during the recent COVID-19 pandemic [26]. Similarly, Saudi Arabian health officials have successfully optimized and maintained a strategy to reduce the transmission of the COVID-19 virus using a variety of digital technologies. From 2020 to 2022, it took all required safety steps to ensure that pilgrims would not be harmed.

However, there is a need for researching how smartification can enhance the resilience of pilgrim cities. Alghamdi et al. [27] and Felemban et al. [28], among others, highlight the rapid digital response of Saudi Arabia in supporting and considering individuals and technology factors to limit the spread of the COVID-19 virus using various digital technologies. Others have highlighted the use of digital technology and how it helped cities get through the pandemic [29]. They attempted to include all digital solutions and tools utilized during the COVID-19 outbreak in Saudi Arabia. Public health strategies to combat the pandemic were also considered by other authors [7,13,30]. There is, however, a gap between the studies and the work that needs to be done to sustain digital technology and investigate the experience of AI in leading smartification for increasing the resilience of pilgrim cities in the future. There is a need for a more in-depth examination of how smart city development and urban resilience improvement strengthen urban centers' capacity to withstand pandemics. Thus, this study examines the role of digitalization and smartification in reviving a pilgrimage city and the importance of context in building urban resilience.

## 2. Review of the Literature

### *2.1. Enhancing Resilience to Pandemic Using Smart Technologies*

The emergence of coronavirus in late 2019 brought severe disruption to the global economy and livelihood, resulting in the death of millions of people and causing major social and economic changes in many countries. While the COVID-19 vaccination program broke down the outbreak in many countries, and these countries have been returning to normal life, there are some countries with instability in prevention and control measures where the pandemic may still knock back, and new infection waves may resurface [31]. Although this pandemic affected all aspects of our lives and communities, like other natural disasters, most people did not anticipate such instability and unpredictability in the control and immunization of pandemic outbreaks among countries, even developed ones [32]. The use of smart technologies in enhancing the resilience of communities has shown remarkable results. However, the application of these technologies poses some challenges, such as data accessibility and privacy, legal issues, data security, technological issues, and citizen management [33,34]. The pandemic has led to an increasing interest in the smart city approach, given the potential use of its solutions for addressing the crisis. The COVID-19 outbreak in the techno-driven era may have precipitated this new adoption because of high-tech initiatives in urban areas. However, lifestyles have been shaped by large connections and mobility for social interactions, education, leisure, and economic purposes at local and

regional levels. The result was that urban communities and cities were one of the hotspots for COVID-19 transmission.

Thus, most government efforts taken to break the COVID-19 transmission chain emphasized social distancing, shutting down activities, and lockdown orders in different countries [35]. Nevertheless, it was obvious that fear of COVID-19 and isolation led to a wide range of significant disruptions from mental health to attitudes and from social connections to walking abilities [36]. Subsequently, most governments applied conventional and unconventional policies and measures to enhance social and economic resilience and prevent sudden, inconceivable, damaging, sensitive impacts on communities [37]. Moreover, social resilience was also emphasized by several governments in terms of individuals, social interactions among people, and the relationship between people and institutions [36]. To enhance social resilience, a range of strategies and policies have been applied, including persistence to deal with a sudden shock, adaptability to deal with a changed situation and condition of risk, and transferability to engage people in decision-making processes with a view to fostering the future [37]. Based on the results of implemented policies over the past two years, countries with weak service delivery systems have made fewer achievements. As a result, many developing countries' attempts failed to improve resilience due to a lack of familiarity with technology in their infrastructure. The COVID-19 pandemic emerged in an era of technology and is becoming prevalent in many cities, but the pandemic demonstrated the need to upgrade traditional systems with digital technologies and transform the public sector to become more inclusive and resilient [38].

### *2.2. Role of Digitalization and Smartification in Improving the Resilience of Pilgrim Cities*

In recent years, there has been a significant growth trend toward religious tourism [39]. This trend has been significantly contributing to the revenue of many countries due to the interest and growth of lay people in religious travel [40]. Pilgrimages and religious tourism will play an increasing role in the configuration of commodity-dependent economies in the future [41], but COVID-19 has highlighted how this dynamic and growing industry may be affected and damaged by a natural crisis like the pandemic [42,43]. Due to COVID-19 transmission mode, it appears to have had a more significant impact on the tourism industry than other diseases or natural disasters. While event tourism has been affected more than other segments of the tourism industry, scholars and researchers have been discussing the negative impacts of COVID-19 on the tourism industry only and almost overlooking this segment [44,45]. To break the COVID-19 transmission chain, social distancing measures caused all kinds of events to be canceled or held via the internet [46], but the decision-making process for changes to religious events was incredibly difficult. On the one hand, some major religious events involve mass religious gatherings at a specific place and duration that cause a significant issue in terms of the spread of infection [47]. On the other hand, a significant number of foreign tourists participate in religious events, which may contribute to the outbreak and its early spread [48]. Also, mass religious gatherings must be conducted according to certain rituals, and some are non-negotiable, such as Umrah rituals during Hajj. Therefore, implementing proactive measures against COVID-19 outbreaks has been challenging, if not impossible [49]. It is always challenging to organize large-scale events, but it is especially difficult during an ongoing crisis or pandemic, such as COVID-19, which has many restrictions, extra-checking processes, and monitoring [50]. Since local communities can add substantial value to urban development through their lifestyles and environmental, cultural, and traditional factors, all efforts related to mass events management should look beyond maintaining events and focus on preserving the destination's existence [51].

From the review of the literature, it appears that pilgrims' desire to go on a journey was not reduced by COVID-19, because their resilience was inspired by faith [39,52,53]. Furthermore, faith plays an influential role in enhancing resilience, which in turn encourages pilgrims to participate in religious events [53,54]. Nevertheless, multi-dimensional resilience is needed to address the fear of a pandemic or potential health risks among

pilgrims and the local community with a host of additional benefits, services, and perhaps even higher profits [55]. Smart innovations support urban managers in providing and facilitating all types of tourism activities that strengthen urban competitiveness as they integrate relevant aspects into the governance and management of urban areas [56,57]. Accordingly, smartification of cities is based on a techno-driven approach and strategic management of information where human capital, social capital, traditional communication infrastructures, and digital network infrastructures are integrated to achieve sustainable economic development and a higher quality of life through proper resource management [33,58]. Despite this situation, it seems counterproductive to achieve enhanced resilience if you make a place more dependent on technology as technology adoption can introduce new kinds of vulnerabilities to a place [56,59,60].

### *2.3. Digital and Smart Tools for Enhancing Urban Resilience*

Urban planners have conceptualized smart city ideas as a major chance to combine technological progress and urban sustainable goals [61–63]. The smart city solutions adopted by many cities is one of the strategic urban development notions that aims at improving the work and living condition of urban communities through infrastructure and services digitalization as well as the use of modern ICT solutions, Internet, and big data analytics [63,64]. Research by Marbouh et al. [65] revealed how blockchain technologies can potentially deal with the challenges during a pandemic. Chamola et al. [66] analyze how the adoption of technologies such as AI, IoT, and unmanned aerial vehicles (UAVs) can lead to better management of the COVID-19 crisis through improvement in diagnosis, surveillance, and treatment. Naseem et al. [67] discussed solutions that can effectively identify, monitor, and trace COVID-19 cases. Similarly, Dong et al. [68] utilized the GIS application to collect locations and numbers of new cases, deaths, and cred cases and generate real-time epidemic maps to find the source of an outbreak. Nevertheless, hundreds of cities tried to manage the COVID-19 outbreak through strategies like lockdowns, patient tracing, social distancing, and citizens' movement limitations, but only those cities that utilized technological advancements were successful [69]. Initially, smart initiatives did not incorporate non-physical aspects, such as people, institutions, knowledge economy, etc.). It is now recognized that these non-physical dimensions and components are critical to smart initiatives (e.g., people, institutions, knowledge economy, etc.) [33].

Generally, approaches and methods that focus on enhancing resilience have emphasized the characteristics and features that enable a system to recover from and adapt to changes and shocks. Thus, resilience can be defined as the capacity of a system to perform four functions in the face of adversity: planning and preparation; absorption; recovery; and adaptation [33,70]. Many urban processes can be made smart, like infrastructure systems, security surveillance, mobility and transport systems, city buildings, energy grids, education, health, and public services. Table 1 and Figure 1 below illustrate the different smart solutions and technologies in urban planning and resilience strategy. Sharifi et al. [33] stressed that urban digital transformation could develop the capacity to predict epidemic patterns, facilitate an integrated and timely response, minimize supply chain disruptions, and provide a solution for optimizing the normal operation of cities in the state of the epidemic. Urban resilience is the key element in helping cities recover rapidly when an emergency occurs [71]. Amirzadeh et al. [72] proposed a framework of three principles for mapping the requirements of making cities pandemic resilient. The principles include health requirements, environmental and psychological principles, and general resilience principles. Similarly, Fan et al. [73] highlighted the importance of urban form, infrastructure, and urban governance in building resilience. They projected a future of planning practices that integrates decisions at all levels and addresses inequalities and vulnerabilities with an emphasis on social infrastructure [73]. To promote social resilience, planners should consider long-term adaptation measures and the well-being of the population [74]. The planning process should be open, participatory, and inclusive of the disadvantaged city dwellers to build resilient future cities [75].

**Table 1.** Global classification of smart solutions used to control and prevent COVID-19 outbreaks (Source: Adapted from [33,66]).

| Resilience Sub-Category | Smart Solution | Applied Measures in Different Contexts |
| --- | --- | --- |
| Planning | • City monitoring<br>• 5G technology<br>• Promoting digital platforms<br>• Big data analytics and visualization<br>• Blockchain technology<br>• Internet of Things (IoT)<br>• AI<br>• Big data<br>• Machine learning<br>• GPS devices<br>• Wearable devices<br>• CCTV camera | • Extensive surveillance coverage<br>• Tracing and tracking (positive cases and contact persons)<br>• Real-time monitoring<br>• Telemedicine<br>• Supply chain management<br>• Self-isolation<br>• Fast medical services<br>• Diagnosis<br>• Integrated COVID-19 management<br>• Identifying COVID-19 risk factors<br>• data sharing<br>• Forecasting, prediction warning potential risks<br>• Recognizing hotspots<br>• Smart ventilation |
| Absorption | • AI<br>• Wearable devices<br>• Applications<br>• Drones<br>• Intelligent Cameras<br>• Machine Learning<br>• Smart robots<br>• Smart helmets<br>• Face detection<br>• Voice Detection<br>• Ultraviolet-C radiation<br>• Automated systems<br>• Telemedicine<br>• 3D printing<br>• Smart phones<br>• Bluetooth<br>• QR codes<br>• Facial recognition<br>• GPS<br>• Credit Cards<br>• Space monitoring<br>• Digital media networking | • Diagnosis<br>• Early detection of disease<br>• Supply medical equipment<br>• Social distancing<br>• Apply contactless policies<br>• Tracking and tracing<br>• Identifying and removing misinformation<br>• Information dissemination<br>• Improve communities' social capital<br>• Indoor air quality and ventilation monitoring |
| Recovery | • Smart distribution and Delivery system<br>• IoT<br>• AI<br>• 3D printing<br>• Digital platforms<br>• Application<br>• Ultraviolet-C radiation<br>• Smart robots<br>• Machine learning<br>• Wearable devices<br>• 5G internet service<br>• Augmented Reality (AR) technology | • Supply chain management<br>• Service delivery<br>• Social distancing<br>• Supply medical equipment<br>• Continuity of research and educational activities<br>• Maintaining SMEs<br>• Disinfect objects and places<br>• Immediate action to replace resource shortage<br>• Predicting the surge in service demand<br>• Speeding treatment efforts<br>• Test and feedback of existing and new generations of drugs<br>• Telemedicine<br>• Telesurgery |

**Table 1.** *Cont.*

| Resilience Sub-Category | Smart Solution | Applied Measures in Different Contexts |
|---|---|---|
| Adaptation | • Automated system<br>• Teleworking<br>• 5G internet service<br>• Telemedicine<br>• Blockchain<br>• E-tourism<br>• Streaming services<br>• Big data<br>• Digital platforms | • Maintaining industries operation<br>• Maintaining business<br>• Work–life balance<br>• Facilitate sophisticated functions in hospitals<br>• Improving all groups' accessibility to healthcare service<br>• Addressing users' privacy and security concerns<br>• Realizing the full potential of smart initiatives<br>• Forecasting, prediction, and warning of potential risks<br>• Improving transportation system operations |

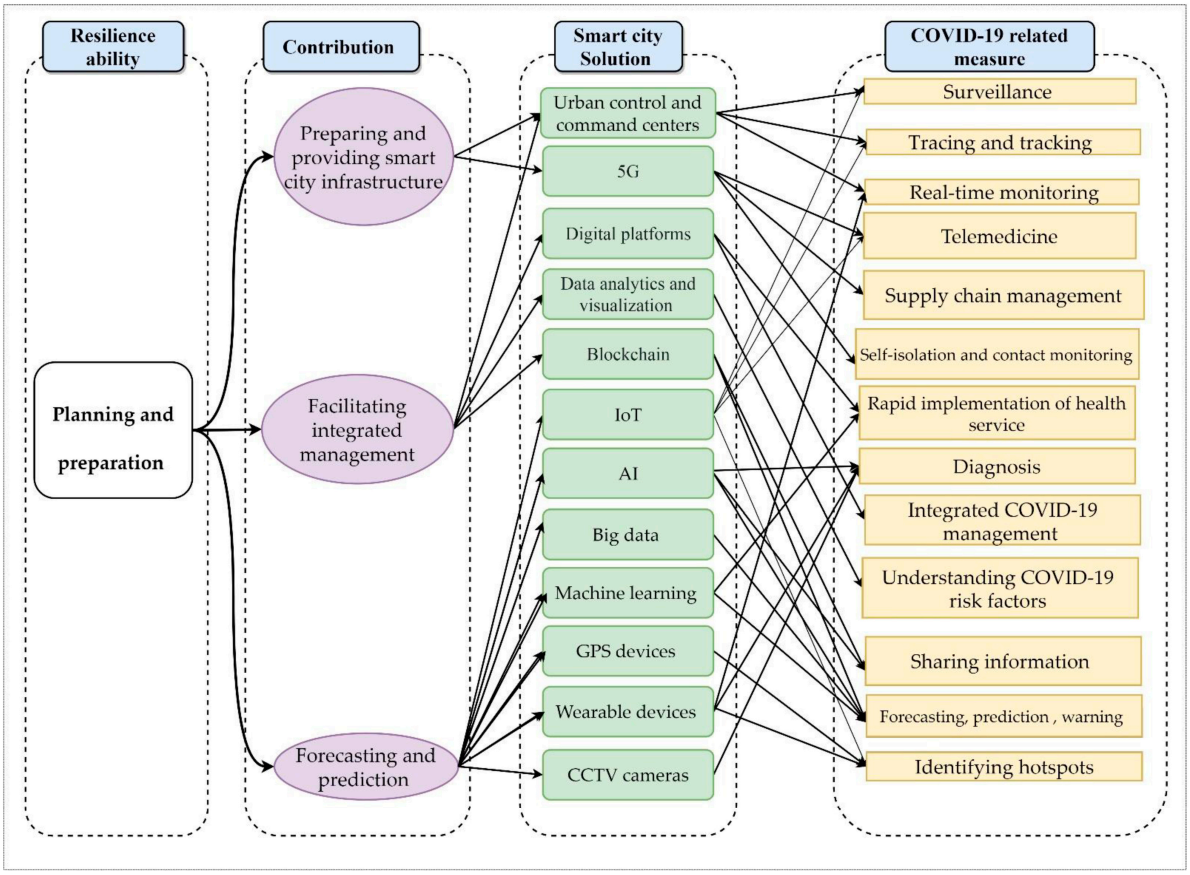


**Figure 1.** Contributions of different smart solutions and technologies in urban planning (Source: [33]).

Many scholars have studied digital technology applications in the post-pandemic era. Regarding digital technology applications, scholars raised the importance of handphones as the most widely used digital tool in blocking the spread of COVID-19. Handphones are not merely for collecting user movement trajectories but are also a significant carrier for remote medical treatment, remote education, and disclosure of epidemic information [76]. In addition, social media and mobile media provide people with a virtual environment and platform for communicating health issues, allowing the dissemination of epidemic information and social communication to be further expanded [77]. Studies conducted by Shen et al. [78] revealed that digital platforms build more resilient public service systems for cities by promoting inter-organizational coordination, public entrepreneurship, and citizen co-production of public services in the state of the COVID-19 emergency. Meanwhile,

Sarker et al. [79] in their study stressed that smart approaches via urban digital transformation could improve the speed and effectiveness of linkages between disaster information and system responses, help to mitigate the risks and impacts of urban socio-ecological vulnerabilities, and improve the recovery of cities from disasters. As such, it is important to investigate how digitization can help religious cities adapt and bounce back after disasters.

## 3. Materials and Methods

### *3.1. Study Area*

Saudi Arabia, the largest and most populous country in the Middle East, has a population of 34,110,821 people according to 2021 official estimates. The country spans about 2,150,000 square kilometers, with 85% of the population residing in urban areas and nearly half (48%) below the age of 30 years [80]. Saudi Arabia shares borders with Iraq, Kuwait, Bahrain, Jordan, Qatar, Egypt, United Arab Emirates, and Yemen. It is home to the two holiest mosques of Islam, located in Makkah (Mecca) and Madinah (Medina). With a GDP per capita of USD 44,300, Saudi Arabia holds about 17% of the world's proven oil reserves and is a leading producer of petroleum and natural gas, accounting for 90% of export earnings as of 2020 [81].

Over the past two decades, the population has been increasingly exposed to digital tools through the Internet, personal computers, and smartphones. According to World Development Indicators, the Internet penetration rate has more than doubled from 41% to 98% of the population between 2010 and 2020. Coupled with 126 mobile phones for every 100 residents and an adult literacy rate of 97.6% as of 2020, this wide diffusion of ICT tools indicates a promising future for digitalization and smartification of urban services in the country [82]. People use ICT for a wide range of urban activities, such as disaster risk communication, accessing healthcare services, online shopping, flight reservations, banking and finance, virtual education, and social media communication. Saudi Vision 2030 promotes digital technologies to create smart cities and transform the country into an information society by 2030 [83]. The existing high-quality ICT infrastructure, including 5G and fiber optics, coupled with high smartphone ownership and Internet penetration rates, can enable municipalities to deploy smart tools to enhance urban resilience during the post-pandemic era.

### *3.2. Data Collection and Analysis*

The present study employs the desktop research method of identifying, gathering, and analyzing relevant data from secondary sources and the existing literature through the Internet. This approach is gaining popularity because it is fast, inexpensive, and supports collaboration, and because of the existence of a vast amount of data online [84]. It involves three iterative stages: (a) scoping, (b) collection of relevant documents, and (c) data analysis (Figure 2). The scoping stage involved understanding the research problem and setting the study objective and boundary. The objective of the present research was to explore the extent of digitalization and smartification of urban services during and post the pandemic era and critically analyze how they can help foster urban resilience, with Saudi Arabia and Makkah city as the study boundary.

The second stage involved identifying and gathering relevant documents from online sources. Some relevant keywords in Table 1 in the literature review section were used to search and identify peer-reviewed academic works (journal articles, conference proceedings, and books) and gray literature (such as datasets, technical reports, newspaper articles, statistics, and website contents from local government agencies and international development organizations) using Google Scholar and Scopus because they are among the most comprehensive databases of academic works (Table 2). Documents that satisfied three inclusion criteria were identified and downloaded: (a) they are related to the study objective, (b) in the English language; and (c) have been published within the last twenty years, although some old documents about established concepts and approaches were also accessed.

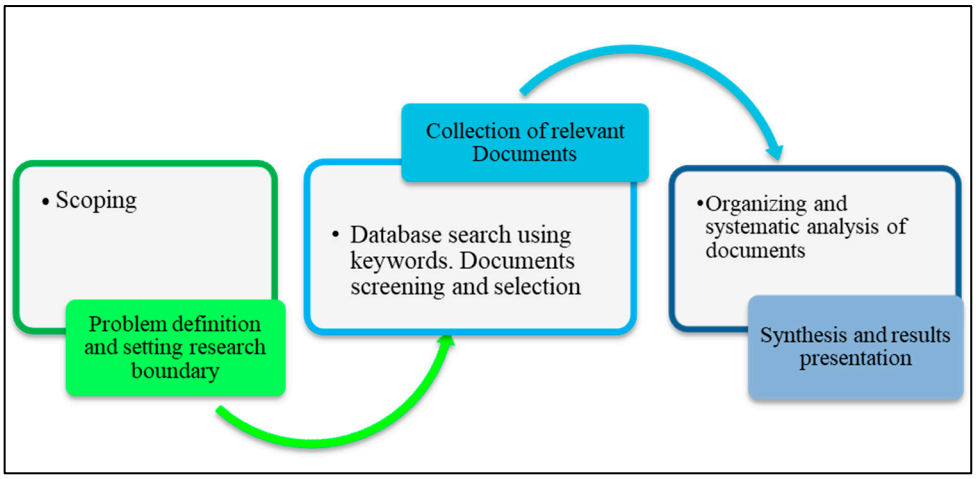


**Figure 2.** The flow chart of the research method (adapted from [84]).

**Table 2.** Key sources of peer-reviewed and gray literature utilized in the present study (Sources: Compiled by authors).

| Peer-Reviewed Literature | Grey Literature |
|---|---|
| • Abalkhail and Al Amri [26]<br>• Aina [85]<br>• Alabdulkarim et al. [21]<br>• Alahmari et al. [86]<br>• AlFattani et al. [30]<br>• Alghamdi et al. [27]<br>• Almutairi et al. [50]<br>• Alzahrani et al. [19]<br>• Atique and Itumalla [87]<br>• Basahel et al. [88]<br>• Binsawad and Albahar [89]<br>• Champlin et al. [74]<br>• Doheim et al. [90]<br>• Ebrahim and Memish [91]<br>• Economou [36]<br>• Fan et al. [73]<br>• Felemban [28]<br>• Goni et al. [20]<br>• Hashim et al. [17]<br>• Jokhdar et al. [7]<br>• Korstanje et al. [41]<br>• Kummitha [69]<br>• Mubarak and Zin [49]<br>• Nguyen et al. [5]<br>• Said et al. [92]<br>• Sarker et al. [79]<br>• Shambour and Gutub [93]<br>• Sharifi et al. [33]<br>• Takefuji [94,95]<br>• Zumla et al. [18] | • Arab News: https://www.arabnews.com/<br>• Alarabiya News: https://english.alarabiya.net/<br>• Islam Channel: https://www.islamchannel.tv/<br>• The National News: https://www.thenationalnews.com/<br>• Saudi Gazette: https://saudigazette.com.sa/<br>• Saudi Press Agency: https://www.spa.gov.sa/<br>• CIA, The World Factbook: https://www.cia.gov/<br>• Makkah Live: https://www.makkahlive.net/<br>• Makkah Municipality: https://www.makkah.gov.sa/<br>• Makkah Region Development Authority: https://www.mrda.gov.sa/<br>• Saudi Vision 2030: https://www.vision2030.gov.sa/<br>• General Authority for Statistics: https://www.stats.gov.sa<br>• Ministry of Hajj and Umrah: https://www.haj.gov.sa/<br>• Ministry of Interior: https://www.moi.gov.sa/<br>• Makkah Chamber of Commerce and Industry: https://mcci.org.sa/ (All accessed on 1 July 2023) |

The last stage involved organizing, analyzing, and synthesizing the collected data. First, the downloaded documents were organized according to the similarity of topics, even though some fit into more than one group. Then, each document was thoroughly studied, and themes related to the study's objective were collated, synthesized, and harmonized. Finally, the themes were summarized in Tables and discussed. Implications and recommendations of the findings were then highlighted. Desktop research is a valuable and cost-effective method for gathering information and analyzing data. However, there are limitations to this approach compared to field research, including a lack of control over data quality and accuracy, an inability to test hypotheses directly, and limited generalizability. Despite these limitations, desktop research remains robust and valid due to the triangulation of data from multiple sources. This approach has been adopted by several studies published in high-impact journals, such as a recent study by Abubakar and Alshammari [96].

## 4. Results and Discussion

### *4.1. Smart City Development in Makkah during the Pandemic*

Based on a review of some of the top mass religious events in different parts of the world, Hajj is the most diverse mass religious event and is performed annually in Mecca, Saudi Arabia [49]. In this vein, approximately three million pilgrims will arrive in Saudi Arabia from 180 countries and stay for several weeks in Mecca and Madinah cities during Hajj. Reports indicated low levels of adherence and implementation of preventive measures against diseases [91]. Accordingly, respiratory infections had a long history even before the COVID-19 outbreak began [49]. Consistent with the findings, some studies have found poor awareness, poor availability of information, poor coverage, and poor coverage among pilgrims. These factors are contributing factors to weak adherence to preventive measures [97–99]. For this reason, it is necessary to employ a smart and comprehensive tool for monitoring and controlling people participating in mass events to avoid falling into a human disaster. In general, Saudi Arabia uses a variety of approaches, methods, and techniques during the Hajj. Based on technology, these activities and measures have been classified into spatial computing, crowd simulation, mobile applications, and big data analytics [28].

Further to the Hajj event, in response to COVID-19, Saudi Arabia implemented several preventive measures aligning with WHO guidelines. The COVID-19 pandemic has accelerated the smart city development in the holy city of Makkah due to the rising demand for smart solutions to curb the spread of the COVID-19 virus. The global pandemic has led to the suspension of Hajj and Umrah rituals in 2020 to safeguard the health of pilgrims, following the World Health Organization's recommendations [100]. The suspension has led to groundbreaking research in the field of AI to develop several smart initiatives and smart infrastructures to safeguard the well-being of the pilgrims. Several smart and digital tools have been commissioned by the government, in collaboration with several government agencies such as the Communications and Information Technology Commission, the Saudi Data and Artificial Intelligence Authority, the Ministry of Health, the Ministry of Hajj and Umrah, and the Saudi Telecommunication Company.

To achieve the smart initiatives, over 5900 telecommunication towers and over 11,000 Wi-Fi access points were provided in the two holy cities of Makkah and Madinah [101]. Similarly, there was a 41% increase in deploying 5G towers within the holy cities, which amounted to over 2600 towers to facilitate the fastest connections [101]. In addition, 25 hospitals were equipped with 5000 smart beds and a medical team of 1141 personnel to provide physical and virtual healthcare services in the two holy cities. Similarly, over 140 mobile clinics, 142 healthcare centers, and 86 medical field teams were provided within strategic places in the holy sites [26]. The deployment and growth of smart solutions have resulted in the stave-off of the pandemic among pilgrims and worshipers in the two holy cities [102].

### *4.2. Digitalization and Smartification of Urban Services in Makkah City*

Saudi Arabia has developed several recent digital tools in AI to contain and minimize the spread of the COVID-19 virus and enhance urban resilience (Table 3). This study categorized the deployed smart tools into shared and personalized access. Both covered areas include health, crowd management, sanitation, guidance, religious learning, navigation, tracking, security, transportation, and environmental monitoring. The shared access smart infrastructures include smart robots, Holodoctor services, and thermal cameras, whereas the smart initiatives with personalized access, such as smart bracelets, smart cards, and those used as smartphone applications, are primarily individualized, as shown in Table 2. The intelligent smart robots were deployed to serve many purposes, such as sanitizing the holy sites, guiding, advising, and answering religious questions, dispensing Zamzam water, distributing the holy Quran, delivering sermons, and calling for prayers, and enforcing the social distancing instruction to prevent the spread of the COVID-19 virus. In addition, the smart robots were equipped with barcodes to enable the pilgrims to download services on their smart cell phones (Figure 3). Also, pilgrims can press the instructions button on the smart robots to access prayer-related information such as prayer times, muezzins, imams, and weekly calendars. For instance, the security robots were designed to facilitate strict following of the Ministry of Health's precautionary measures. Furthermore, through AI techniques, the robots could measure body temperature, monitor the adherence to wearing the face mask, and provide round-the-clock purification and sterilization of the holy places. Moreover, guidance robots were deployed to help pilgrims and worshipers during the Umrah rituals. The robots can advise and answer 100 to 150 questions daily [103]. The most common users interacting with the guidance robots are pilgrims from Saudi Arabia, Syria, India, and Pakistan [103]. Also, fleets of guidance robots were deployed to assist female worshippers in answering their questions in 11 languages, allowing them to connect with Islamic scholars [104].


**Figure 3.** Automated sanitization robots at the holy places (Source: [105]).

**Table 3.** Digital tools deployed in Makkah city to contain the spread of the COVID-19 pandemic (Sources: Compiled by authors).

| Smart Tools | Description | Type of Services | Mode of Delivery | Access |
|---|---|---|---|---|
| Holodoctor | Provides medical services to pilgrims | Healthcare | Stationary video conference devices | Shared access |
| Smart robots | Offers various services to pilgrims | Dispensing sanitizers, monitoring indoor air quality, distributing Zamzam water, providing guidance and religious information | Stationary via physical contact | Shared access |
| Thermal cameras | Scans body temperature to detect influenza infections and track population data | Disease tracking and diagnostics | Stationary cameras and computers | Shared access |
| Smart bracelets | Provides integrated services for pilgrims including health and personal data | Personal data and health information | Smartphone-based application | Personalized access |
| Smart cards | Offers access to various services including health, e-transactions, and navigation | Health and personal information, e-transaction services, navigation and tracking, and detecting illegal pilgrims. | Near-field communication devices | Personalized access |
| Virtual reality | Allows pilgrims to experience touching the Black Stone in virtual reality to avoid physical contact | Ritual-related and historical services | Virtual reality devices | Personalized access |
| Tawakkal-na | Provides health-related services, personal information, and booking services | Health-related services, Hajj and Umrah booking, and crowd management | Smartphone-based application | Personalized access |
| Tabaud | Offers detection and notification services for COVID-19-infected persons and those in contact with them | Detection, tracking, and alerting services | Smartphone-based application | Personalized access |
| Sehhaty | Offers access to virtual clinics for medical consultations, examinations, and prescriptions | Health-related services via audio and video conferences | Smartphone-based application | Personalized access |
| Eatamarna | Provides Hajj and Umrah booking servers, entry to the Grand Mosque, and transportation services | Crowd management, Hajj and Umrah booking, and transportation services | Smartphone-based application | Personalized access |
| Kollona Amn | Provides e-services for reporting incidents | Pandemic cases, disasters, accidents, crime, and emergency reporting | Smartphone-based application | Personalized access |
| Watani | Allows pilgrims to assess, rate, and offer suggestions for improving public services | Public services evaluation | Smartphone-based application | Personalized access |
| Mecca Cleanliness | Offers cleaning services of the holy mosque and allows people to report littering or violations | Sanitation services, navigation, and tracking | Smartphone-based application | Personalized access |
| Fazaah | Enables the verification of incident reporters' geographical location | Navigation, tracking, and incident reporting | Smartphone-based application | Personalized access |
| Almutawaf | Provides pilgrim services, including the location of sites, rituals, and times | Guidance and religious learning, navigation, and tracking | Smartphone-based application | Personalized access |
| Asafny | Enables users to file emergency reports, detect incident locations, support victims, and record medical history | Disaster, accident, and emergency reporting, navigation and tracking, and healthcare | Smartphone-based application | Personalized access |
| Turjuman | Translates rituals and health-related instructions or signs into major global languages | Guidance and instruction for pilgrims | Smartphone-based application | Personalized access |

Similarly, smart thermal and imaging cameras were deployed at all the major entrances of the holy site to scan and detect likely infected individuals. Each camera can scan 25 people simultaneously [106] These cameras have an advantage over conventional cameras due to their scanning, counting, tracking, and detecting features [92]. Moreover, there are eHealth smart initiatives where several innovative smart solutions were deployed in the holy city of Makkah to serve and safeguard pilgrims. For example, the Holodoctor initiative for medical consultation was developed to offer modern medical services to pilgrims through video conferences with Seha Virtual Hospital, Riyadh (Figure 4). The Holodoctor smart initiative provides several healthcare services to pilgrims and worshipers, such as investigation, diagnosis, and disbursement of medications through direct contact with the Seha Virtual Hospital [107]. Other eHealth initiatives include personalized access applications such as Tawakkalna, Sehhaty, and Tabaud, among others (Table 2). Among the smart solutions used in containing and preventing the spread of the pandemic is the radio frequency detection chips developed in the form of a bracelet. It is an IoT device capable of providing an array of information related to the pilgrim, such as health status, including measuring blood oxygen and pulse, emergency and security assistance requests, and receipt of messages [89,93]. In the 2021 pilgrimage, 5000 smart bracelets were distributed to pilgrims to facilitate the strategized precautionary measures to prevent the pandemic's spread among pilgrims [26]. Similarly, internet-free smart cards were developed and distributed to pilgrims. The smart cards served as electronic wallets to the pilgrims, enabling electronic purchases, navigation, and tracking services.

**Figure 4.** Holodoctor virtual services for medical consultation (Source: [107]).

Another smart initiative is launching a virtual reality experience to enable pilgrims and worshipers to experience the touching of the Black Stone due to the COVID-19 pandemic that restricted physical contact with the Black Stone (Figure 5). The Black Stone is a holy stone located in the eastern part of the Kaaba, in the Grand Mosque of Makkah. It symbolizes the beginning and endpoint of the Tawaf ritual. Virtual reality brought an additional digital and temporary solution that allows pilgrims to connect spiritually with the holy sites. Likewise, pilgrims can explore the other sacred sites visited during the pilgrimage, such as Mount Arafat, Muzdalifah, and Mina [108].

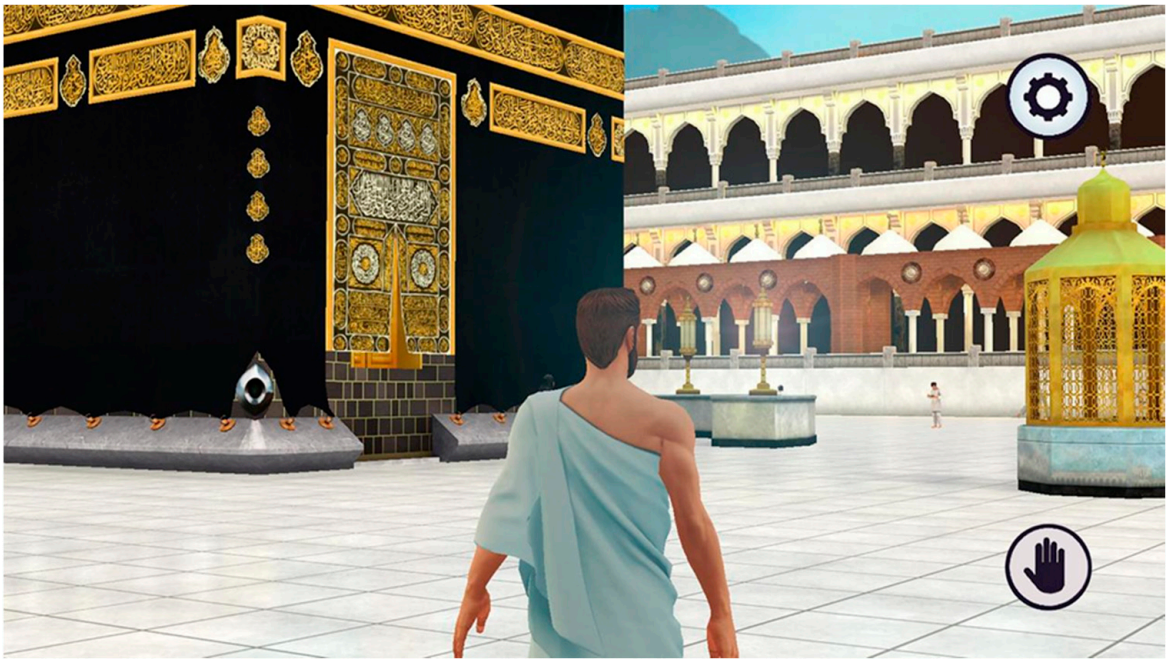

**Figure 5.** Muslim 3D virtual reality Demo (Source: [108]).

### *4.3. Improving Makkah's Resilience through Smartification*

The pandemic posed socioeconomic and religious challenges to Saudi Arabia. As a mass gathering event, the Hajj was regarded as a potential spot for the high rate of COVID-19 spread [87]. On the other hand, the pilgrimage economy is valued at over USD 12 billion yearly [18]. It accounts for about 7% of Saudi Arabia's GDP [109]. Therefore, the government faced the challenge of protecting pilgrims against infection while maintaining the city's economy. The number of pilgrims leading to the pandemic was around 2.5 million in 2019 (www.stats.gov.sa/en/news/340 (accessed on 1 July 2023)), dropping to 1000 during the lockdown, threatening socioeconomic and religious activities. Before the pandemic, a strategic plan had been established to make the city smarter and more sustainable [90,110]. The plan included Makkah Metro, an autonomous rail system to reduce traffic congestion and pollution [110]. In addition, the National Digital Transformation Unit (NDU) made a proposal in 2019 to embark on projects for smart Hajj [111]. The pandemic outbreak led to an increasing interest in using technology to enhance the resilience and sustainability of the city. Due to technology and other measures such as crowd management and smart mobility increased, the number of pilgrims from 1000 in 2020 to 60,000 in 2021 and around 1 million in 2022 [112]. Alahmari et al. [86] and Basahel et al. [88] found no increase in the spread of COVID-19 during the Hajj, unlike the recorded increase in cases during other mass gatherings events. However, the returning pilgrims from Iran to Pakistan caused a spike in the cases of COVID-19 in Pakistan [113]. Similarly, about one-third of new coronavirus infections in Malaysia were traced to a mass gathering event [114].

The recovery and improvement in the resilience of Makkah city can be explained by adopting the conceptual framework for urban resilience [72]. The triple dimensions of the framework are used to highlight efforts made in making Makkah more resilient. Table 4 shows how the city meets the requirements of pandemic-resilient cities. Most of the measures highlighted in Table 3 will continue to maintain the city's resilience. For example, the platform for getting permits to visit the holy sites has been upgraded to be used as an application for registering for Hajj and other pilgrimage-related activities such as hotel booking. The platform will offer about 100 services to pilgrims both individual and organization [115]. In addition, the Saudi authority has started an initiative of carrying out immigration process at pilgrims' home countries [115]. About 26,000 Pakistanis participated in the program and it is expected to be extended to more countries [115]. Apart from

facilitating the quick movement of pilgrims to Saudi Arabia, the initiative provides a digital fence for screening pilgrims as biometrics and other information will be taken at the immigration point. The assessment by Takefuji [94,95] showed that robust digital fences as practiced by Saudi Arabia are an effective strategy for mitigating the pandemic and building resilience.

**Table 4.** Fulfillment of pandemic-resilient city's principles by Makkah (Sources: Compiled by authors).

| Category | Actions Taken | Planned Actions | Reference |
| --- | --- | --- | --- |
| Pandemic-related health requirements | Technology for crowd management in Makkah city includes health surveillance, restricting access to holy sites using digital fences, smart mobility through smart bracelets, HEWS for health early warnings, and What3words for accurate location data. | Increase capacity to host 5 million pilgrims in the 2030.<br>Open the new Hajj platform (Nusuk) to pilgrims.<br>Establishing immigration desks at pilgrims' home airports | [93,111,112,115–117] |
| Environmental, psychological principles | The Saudi green initiative includes smart mobility projects to reduce greenhouse gas emissions. Visa for pilgrims to visit other Saudi cities for social networking and tourism. | Eco-friendly projects.<br>Integration of Hajj with green tourism.<br>Al-Faisaliah City Project with solar power plant. | [90,118–120] |
| General resilience principles | Adaptable and flexible technologies that maintain connectivity between holy sites via Haramain railway, Makkah Metro, and Makkah bus project.<br>The creation of Makkah Region Development Authority for the planning of Makkah region. | Transformation of Makkah into a financial and business hub.<br>Completion of Makkah Metro's remaining lines<br>Decentralization of governance. | [121–125] |

Moreover, the Saudi green initiative and smart mobility projects will reduce greenhouse gas emissions and make the city more sustainable [85,118,119,126]. Smart mobility, such as Autonomous Vehicle Location (AVL), is being explored in Saudi Arabia [127]. El Hanandeh [128] estimated the carbon footprint of Hajj as 60.5 kg $CO_2$-eq per pilgrim day. Exploring eco-friendly options can lead to a reduction in the carbon footprint. The Makkah Bus project, which is served by about 400 buses covering 12 routes, at its first trial carry about 100,000 passengers around the sacred sites [123]. Passengers can plan their route on their mobiles and track the movement of the buses (Figure 6). The digital information collected from users can be explored for contact tracing and crowd control. The project enhances the provision of the multimodal transport system in Makkah by supplementing the Makkah Metro and the Haramain railway. The high-speed train transported about 750,000 passengers during the 2023 Hajj, mainly between cities of Makkah and Madinah [125]. The Al-Faisaliah city project was planned to reduce the urban population pressure on Makkah and thereby create multiple urban centers [109]. The new city is expected to accommodate about 6.5 million people in 2050 [90,109]. The development of multiple urban centers might help in building a city's resilience due to the reduction in the concentration of high population [73]. The solar project of the city will contribute towards urban sustainability in Makkah.

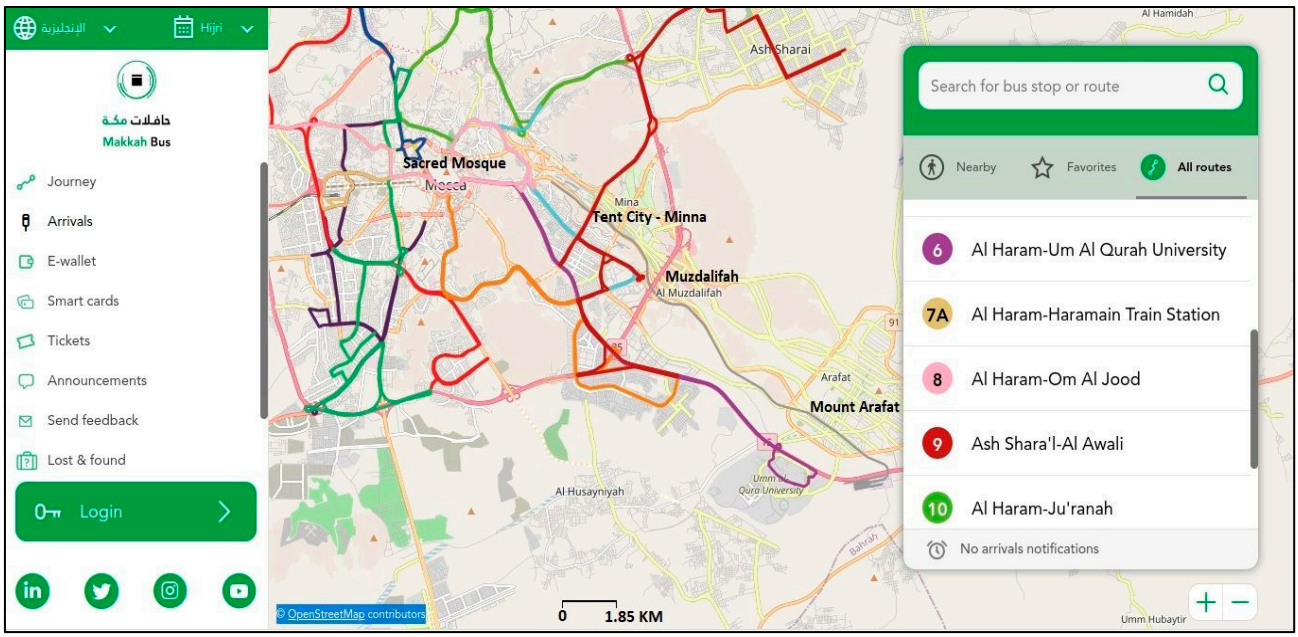


**Figure 6.** Makkah bus interface showing bus routes and Hajj sites—Sacred Mosque, Minna—Tent city, Muzdalifah, and Mount Arafat (adapted from [129]).

### *4.4. Limitations of the Smartification*

Despite notable achievements in using technology to improve the resilience of Makkah city during the pandemic, there are still some drawbacks. Incidents of overcrowding have occurred, which could lead to the spread of COVID-19 or stampedes [26]. Additionally, some pilgrims have struggled to use the available technology due to a lack of knowledge and skills [26]. There are reports of inadequate Wi-Fi and mobile internet coverage in some hotels and crowded public places [130]. Furthermore, the city has not fully recovered from the impacts of the pandemic. Hotel occupancy rates are still lower than in the pre-pandemic period [131], and the number of pilgrims is significantly lower than the licensed capacity, despite approaching pre-pandemic numbers [124,132]. Additionally, the value of the economy during the current pilgrimage season is only about half of the pre-COVID-19 value [124].

Aina et al. [121] and Alajmi and Memon [133] highlighted the challenge of funding some Saudi mega projects, which are often affected by fluctuations in oil prices. Felemban et al. [28] emphasized the need to improve crowd management through data analysis with innovative methods for more efficient and timely results. Takefuji [95] suggested that technology alone is not sufficient for building resilience. Policymakers need to consider policies and disaster preparedness in addition to technology [95]. Thus, while technology has played a significant role in improving the resilience of Makkah city during the pandemic, there are still challenges to address. Overcrowding and lack of technology skills among some pilgrims remain concerns. The city also needs to fully recover from the impacts of the pandemic, and funding for Saudi mega projects remains a challenge. Policymakers should consider disaster preparedness and policies in addition to technology to build resilience and improve crowd management. By addressing these challenges, Makkah city can continue to improve its resilience in the face of unexpected challenges.

## 5. Conclusions

The pandemic presented a great challenge and an opportunity for cities that host mass gathering events. The challenge is how to continue to host many people without being a great spreader of the disease. The opportunity is provided by cutting-edge technologies to recover from the pandemic and improve the resilience of cities. However, the contexts of different cities dictate the path to follow in building resilience as there is no one-size-fits-all

digitalization and smartification strategy. Nevertheless, there are principles and conceptual frameworks that can serve as lessons to many communities. This article reviewed relevant documents to extract various smartification approaches and principles for pandemic-resilient cities based on the use of technologies. Thereafter, based on documents and secondary data analysis, the paper highlighted how the COVID-19 pandemic changed how the city of Makkah hosts mass gathering events, and the smartification and digitization tools deployed to recover from the pandemic and enhance the city's resilience. The city has begun a speedy recovery by restoring the religious events using technology in verifying the health status of visitors, restricting access to Hajj to only authorized pilgrims, and facilitating safe conduct of religious and other socioeconomic activities.

While some digitization tools have the potential for improvement, several are not currently in use or are facing technical difficulties. To address this, the government should secure additional funds, potentially through public–private partnerships, to implement pending digitization projects. The recent funding of smart mega projects such as NEOM and Red Sea Projects through private investment may indicate a shift towards a new era of funding for Makkah city projects. In addition to investing in digital solutions, disaster preparedness and policies should be explored to recover from the pre-COVID-19 period and improve upon it. Future studies can investigate how digital solutions can integrate with traditional planning and design methods to create more resilient urban systems. However, it is important to note that cities should not rely solely on digital solutions to build resilience. Instead, digital solutions should be integrated with traditional planning and design methods to mitigate the spread of a pandemic. This may include redesigning public spaces, increasing outdoor areas, and improving ventilation systems. Data-driven decision-making can inform policy and planning decisions, while smart technologies can improve the efficiency of urban services and reduce virus spread. Building resilience requires a multi-disciplinary approach involving stakeholders from various sectors to ensure that solutions are feasible, sustainable, and responsive to the community's needs. Equitable access to resources and services for vulnerable populations is critical, and digital solutions can improve access to essential services.

Moreover, sustainable urban planning and design strategies are necessary to control the spread of the virus and reduce environmental impact. Green infrastructure and sustainable transportation strategies can mitigate the urban heat island effect and improve air quality. Digital tools can monitor environmental conditions and improve service efficiency. Finally, cities must ensure that pandemic control measures and building resilience are economically viable and financially sustainable. Smart technologies can reduce costs, and public–private partnerships and innovative financing mechanisms can finance pandemic control measures and build resilience. Engaging with stakeholders and communities is crucial to ensure that solutions are economically viable and financially sustainable. The involvement of stakeholders in the design and implementation of these solutions is crucial in ensuring that they meet the needs of the city and its residents and are flexible and adaptable. Therefore, building resilient urban systems that can adapt to unexpected challenges is crucial. It requires integrating digital solutions with traditional planning and design methods, engaging stakeholders from various sectors, and implementing sustainable urban planning and design strategies. These efforts can create more resilient urban systems that can address future challenges.

This study has improved the understanding of the practical applications of digitization and smartification tools and strategies to build resilience and enhance better urban systems in the post-pandemic new normal. The digitalization and smartification of urban services in Makkah have improved the city's resilience to pandemics and other crises. This experience can serve as a model for other pilgrim cities worldwide, where the deployment of smart technologies can aid in safeguarding the safety and well-being of both pilgrims and residents. To improve the efficiency, efficacy, and safety of urban services, reduce the risk of disease transmission, and enhance the capacity of cities to respond to crises, digital transformation using smart technologies such as AI, IoT, and big data analytics is essential.

However, deploying smart solutions requires close collaboration between several public agencies to mobilize resources, expertise, and innovation effectively. Continuous monitoring and evaluation are also crucial for the sustainability, optimization, and continuous improvement of smart technologies. This ensures that they remain aligned with the city's goals and objectives and can respond adequately to changing circumstances and emerging threats. Therefore, by embracing digital transformation and smart technologies, cities can improve their capacity to respond to crises, enhance the safety and well-being of their residents, and create more efficient and effective urban services. Makkah's experience can serve as an excellent example for other cities worldwide seeking to improve their resilience to crises and enhance the quality of life for their residents. To address the limitation of the lack of field research, future studies can provide more empirical evidence through field surveys and further explore the long-term implications of these digital solutions for urban planning and management in the post-pandemic era.

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