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Review article

Smart cities and disaster risk reduction in South Korea by 2022: The case of daegu

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ABSTRACT

Smart cities have been introduced globally. It involves technical development and economic, social, and environmental objectives. In response to the Fourth Industrial Revolution (Industry 4.0) and global trends, Korea has prepared legal and institutional measures for smart city composition. This study reviewed the importance of key documents and agreements in Daegu Metropolitan City to reduce disaster risk for the vulnerable in the context of smart cities. 25 research studies were critically and systematically reviewed from the perspective of disaster risk reduction in smart cities. In its disaster safety areas, Daegu Metropolitan City aims to reduce property damage and casualties that may occur because of physical events such as collapse, water-related disasters, and heatwaves by up to 20%. Smart disaster mitigation involves data collection, sharing, and propagation. The entire process is handled on a safety platform called Data hub. According to the Daegu Metropolitan City government, solving social problems and managing disasters is key to a smart city, and it is striving to improve the efficiency of other cities. However, Daegu has limitations because it is a service-oriented smart city, and it is necessary to engage citizens to participate, raise awareness of the smart city, and educate them on the platform. The study results recommend future research that focus on disaster risk reduction and resilience in smart cities worldwide.

1. Introduction

The smart city concept has emerged as a solution for rapid urbanization worldwide. Smart cities involve technical development and include economic, social, and environmental goals [1–5]. The demand for smart cities is likely to expand alongside rapid population growth [6–11]. Representative examples of smart cities include Columbus (Smart City Challenge) in the United States, Toronto in Canada, Hangzhou (Yunqi Cloud Town) in China, and Fujisawa (a sustainable smart city) in Japan [12–18]. In Hangzhou, the city government has begun to implement a city platform using environmental data. Similarly, Quayside in Toronto has promoted the construction of a pilot city using the entire city as a representative model [13,16]. City authorities in Columbus (Ohio) are keen to reinforce the participation of business organizations and citizens through the Smart City Challenge project [19].

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Overall, consistent with the massive shift to Industry 4.0 technologies and global trends, Korea has established legal systems and three plans to establish smart cities [20–23]. Three plans related to smart cities have been established in Korea [20]. The first plan (2009–2013) includes building a ubiquitous city under the vision "realization of a high-tech information city that enhances citizens' quality of life (QoL) and city competitiveness." Four major strategies and 22 national tasks have been established [20]. The second plan (2014–2018) is the vision of realizing a safe and happy high-tech creative city and includes four major strategies and ten tasks [21]. In the third plan, which is currently underway, the original "Ubiquitous City Plan" has been transformed into the "Smart City Comprehensive Plan" [21,24].

Although the concept of a Ubiquitous-City (U-City) has expanded smart infrastructure by combining information and communication technology (ICT) with cities such as Busan, it has exposed various limitations of a top-down approach led by the government [20,25,26]. Therefore, a bottom-up policy model was established to create a citizen-led smart city, and programs such as the Living Lab, in which citizens actively participate, are being promoted [27–31]. During the first and second promotion plans, the budget was invested in some new cities, and policy reorganization was conducted to expand the existing cities into the third Smart City Comprehensive Plan. Table 1 presents the details of this major comprehensive plan for promoting smart cities in Korea [20,28–30,32,33].

The rapid development of this smart city provides three main reasons for conducting a systematic review. First, we summarize the smart city policies and technologies of the previous government. Second, we explore and criticize the policy and technological direction of the smart city that the city is aiming for through reviews. Third, major businesses in smart cities are classified, and limitations and improvements are presented. Analyzing systematic reviews based on these three reasons can ultimately contribute to achieving the goals of providing a better quality of life for citizens, and interaction between citizens and cities.

Despite these active movements, it is difficult to find research on the types of projects executed in Korea's smart cities. It is necessary to summarize the trends in smart city policies in Korea and organize various problems that can be solved at each stage of the smart city. This study presents an overview of smart cities in Korea, focusing on the implementation of the Daegu Smart City. Finally, the advantages and disadvantages of smart cities and future research directions are discussed.

Referring to the 2021 Smart City Index, Daegu Metropolitan City is located lower than Seoul or Busan; however, it is one of the two cities where R&D projects are taking place. It is a representative city where research and technology development are taking place together, and it is a traditional metropolitan city representing the Gyeongsangbuk-do region of Korea; thus, it is worth examining the changes in the city and the application of smart city technology. Living Lab, Daegu Metropolitan City's representative smart city service model, focuses on solving the problems of traditional cities, and reviewing Daegu Metropolitan City's smart city-related literature will be a good benchmarking case for other large cities that are shrinking.

2. Literature review

Studies on the following major cities worldwide are comprehensively analyzed in this section: Barcelona, Singapore, Shenzhen, and others.

The most recently published case study of a smart city is that in Shenzhen, China. Currently, Shenzhen is experiencing dramatic growth and has emerged as a model for high-tech growth led by two telecommunications giants, namely Huawei and Tencent. These two companies play a pivotal role in China's smart city movement and are actively expanding their global business [15,34–37]. Shenzhen has established its identity as a Chinese smart city and uses technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI), all empowered by Huawei and Tencent. However, this study is limited in that the actual cases in operation are not discussed in detail ([15]; Stores et al., 2018).

Barcelona aims to provide an integrated urban development model and strengthen the cooperation between citizens and experts [38–41]. The Barcelona Smart City model comprises four categories: smart governance, smart economy, smart living, and smart people [39,42–44]. More importantly, the Barcelona smart city model promotes both public- and private-sector organizations. In addition, more than 1500 new companies have been established, housing prices have lowered, and new jobs have been created. Moreover, cultural heritage and tourism potential influence the development of smart cities [44–46]. However, while dealing with the Barcelona

Table 1
Development of the smart city comprehensive plan in Korea.

	Stage 1 (2009–13)	Stage 2 (2014–18)	Stage 3 (2019–22)
Objectives	Convergence in construction, information, and communication industries	Low-cost, high-efficiency services	City problem-solving Innovative ecosystem
Information	Vertical data integration	Horizontal data integration	Multiple data integration
Platform	Closed platform	Closed platform and opened platform	Expansion of closed platform and opened platform
Policy& Plan	Ubiquitous City (U-City) Law First Ubiquitous City Comprehensive Plan	U-City Law 2nd Ubiquitous City Comprehensive Plan	Smart City Act 3rd Smart City Comprehensive Plan
Leading	Central Government (Ministry of Land, Infrastructure and Transport)	Central government and local government	Central government, local government, and citizens
City	New city	New city and old city	New city and old city (extended)
Business	Integrated operation center, building communication network, infrastructure	Establish public integrated platform, secure compatibility, and promote standardization	Building a national pilot city Various public offering projects

smart city strategy, studies by Kuyper [44] and Trencher [45] did not provide a solution for Barcelona smart city's main task, that is, providing better quality public services and did not empirically explain the content of the Barcelona smart city well.

Singapore has made constant efforts to build smart cities since 1999. In particular, it aims to improve QoL in the city as there are no natural resources [47]. Singapore was also ranked as the top smart city by ABI Research in 2018, achieving the highest score for innovation [48]. Singapore has also used the innovative paradigm of freight as a service (Faas) and mobility as a service (Maas) to solve structural problems [49]. A recent study on Singapore's energy policy described the energy conservation measures implemented through smart home technologies. The study explains in detail remote healthcare sensing and monitoring technologies that are available for elderly people who require medical help, such as elderly alarm systems, and home appliance control using sensors and motion detectors. Moreover, after the implementation of a home energy management system (HEMS), energy consumption was reportedly reduced by 20% [50].

Sidewalk Labs, an urban innovation company, created a smart city plan on 12 acres of Toronto's waterfront [16]. Toronto introduced an urban-data trust to address public concerns regarding personal data collection [51]. Sidewalk Lab's data collection initiatives and projects have been rated as innovative [52]. However, the project has been abandoned caused by economic uncertainties following the outbreak of the COVID-19 pandemic and lack of citizen participation [53].

A smart city was created in Kitakyushu, Japan to increase environmental sustainability [54,55]. Kitakyushu's smart city uses micrgrids, smart meters, and home/building energy management systems to reduce the city's overall carbon emissions [56].

A study examining the Korean cases of Gimpo and Namyangju explained the strategies of each smart city. Using an ICT platform, Gimpo provides services to prevent social disasters and accidents. In addition, the public–private partnership (PPP) strategy is being used to pursue cooperation between the public, citizens, and businesses. Namyangju integrates four smart-city platforms into its operations: big data analytics, IoT, drones, citizen participation, and integrated services. This study focused on improving transportation problems and seasonal epidemics [22,57–59]. It is evident from previous studies that, even under the same national policy, policies and services being locally promoted are different, depending on the goals pursued by the city. This justifies the need for a detailed evaluation of the policies and cases of each city.

In the case of Pohang, two target strategies were established with the goal of "building a data-sharing platform and improving QoL through the construction of a safe and intelligent smart city" [60–62]. First, the main focus is to build a city safety system through smart cities; second, to pursue the strategy of building new growth engines through smart cities [63,64]. The most important characteristic of Pohang (Korea), unlike Shenzhen in China, is that it is focused on small and medium-sized enterprises, and smart technology is deployed to build themed tourism cities.

Busan aims to become a water city where an innovative ecosystem is created by leveraging the city's coastline and nurturing industries such as robotics ([25,65]; Stores et al., 2018). To promote the industry, five clusters have been created ([65,66]; Stores et al., 2018 [67]). Essentially, the technology developed in these five cluster spaces combines water management and robotics and presents the vision of digital, augmented reality (AR), and automatic robotic city ([65]; Stores et al., 2018 [67]). In addition, smart parks and smart water systems are being introduced, consistent with the Green New Deal project announced in Korea [68–71]. In addition, smart parks and smart water systems are being introduced, consistent with the Green New Deal project announced in the Moon Jae-in administration in Korea [68–71].

To conduct a review with a technical focus, one may resort to the methods of reliability, availability, maintainability, and safety (RAMS) or failure modes, effects, and criticality analysis (FMECA) [72–75]. RAMS and FMECA are predominantly key elements of systems engineering. They play a crucial role in system design and operation, contributing significantly to the analysis of faults and failures.

Petritoli et al. [76] applied RAMS analysis in the development of the expansion of smart street pilot sites. Their study was a comprehensive consideration of reliability analysis and FMECA, providing a holistic perspective to enhance system performance and preempt potential flaws.

In another instance, Ghoshal et al. [77] applied the FMECA method to smart manufacturing, contributing to improved equipment design and the mitigation of failure factors. By systematically identifying potential failure modes and assessing their impact, they were able to develop more robust and reliable systems.

Overall, both RAMS and FMECA approaches not only facilitate better understanding and control of system performance but also provide insight into potential weaknesses. Thus, they serve as valuable tools for technical review in numerous engineering contexts, from smart street systems to advanced manufacturing.

Upon examining recent smart city review papers, various systematic analysis methods are being applied. Among them, the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method, a type of systematic review, is representative [78,79]. Cortese et al. [80] utilized the PRISMA protocol to review literature related to energy sustainability in smart cities, and Reis et al. [81] used the PRISMA protocol to unearth key terms such as dimensions of smart cities, digital transformation, sustainability, and resilience. Alshuwaikhat et al. [82] also utilized the systematic review technique to analyze the trends, impacts, and contributions of computing implementations in smart cities. Reis & Melão [83] employed the PRISMA technique to identify six dimensions and seventeen categories related to digital transformation.

In the process of reviewing smart cities, statistical methods are occasionally employed. Hosseinzadeh et al. [84] used statistical techniques to analyze research articles in the IoT clustering field, and Rozario et al. [85] suggested the need for a holistic approach to smart cities using statistical data analysis. Depending on the case, the narrative literature review method is also used for smart city analysis. A narrative review is a methodology that explains the knowledge of research papers published so far related to the research topic [86–88].

Most previous studies do not provide details of projects that are being implemented in smart cities. In addition, because the goals of smart cities vary, it is necessary to examine the characteristics of each city in detail. Therefore, Daegu Metropolitan City, a smart city implemented in Korea, was selected as the target site, and the details of various projects were evaluated [68,89–91]. This study detailedly examines the goals of the smart city that Daegu Metropolitan City aims to build and discusses the various projects.

3. Methodology

This study adopted the PRISMA protocol to systematically review practical policies focused on disasters in Daegu Smart City

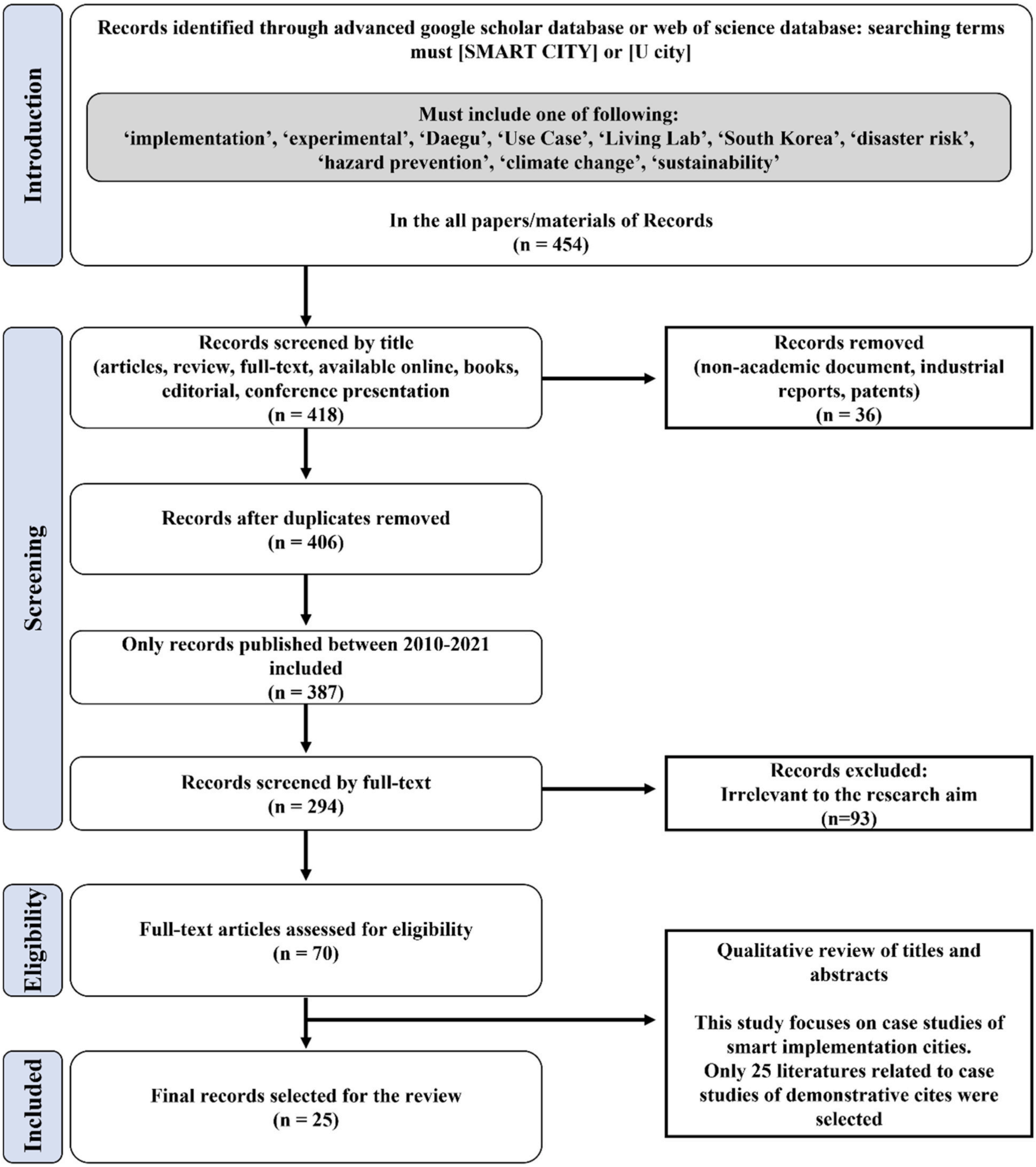

Fig. 1. The PRISMA selection process of relevant literature.

Table 2
Analysis of articles related to "Smart City".

Main Content	Smart City Dimensions	Type of Literature	Author	Title
Presenting a master plan and blueprint for creating a Ubiquitous City (U-City) in Korea. Enactment of comprehensive laws for ubiquitous urban planning.	Overall preparation steps for the creation of a U-City including laws and regulations.	Report	Ministry of Land, Infrastructure and Transport, The 1st Ubiquitous City Comprehensive Plan (2009–2013), Seoul, Korea, 2008.	First Ubiquitous City Comprehensive Plan (2009–13)
National spread of U-City and construction of urban infrastructure. Establishment of a practical application plan of U-City. Strategies for entering the global smart technologies business.	Spread steps to build U-City. Technology-oriented top-down approach to build a U-City.	Report	Ministry of Land, Infrastructure and Transport, The 2nd Ubiquitous City Comprehensive Plan (2014–2018), Seoul, Korea, 2019.	Second Ubiquitous City Comprehensive Plan (2014–18)
Based on global trends and implications, and evaluation and reflection on Korean U-City projects, the seven city innovation changes for future policy initiatives. Proposal of key challenges for use case and living labs across Korea.	The transition from U-City to Smart City. Design of master plan considering people, technology, and the environment.	Report	Ministry of Land, Infrastructure and Transport, The 3rd Smart City Comprehensive Plan (2019–2023), Seoul, Korea, 2020.	Third Smart City Comprehensive Plan (2019–23)
Improving the image of a high-tech smart city in Daegu Metropolitan City. Enhance QoL for citizens and foster the local economy, based on the Fourth Industrial Revolution.	Development of human-oriented smart technology. Disaster risk reduction using smart technology.	Report	Daegu Metropolitan City [1] Daegu Smart City planning (2021–2025)	Daegu Smart City planning (2021–5)
Conceptualizes ubiquitous computing by illustrating U-City projects to provide socio-technical insights.	Socio-technical changes due to the U-City.	Research article	Shin and Kim [23]	Enabling the smart city: Progress of U-City in Korea
Study of the resilience of smart cities. Improving carrying capacity, disaster resistance, and development capacity through smart cities.	The resilience of smart cities. Technological and distribution effects.	Research article	Zhou et al. [37]	Achieving resilience through smart cities? Evidence from China
Identifies the framework, challenges, and trends of smart city IoT and use case for the smart street, highlighting the importance of the proposed structure.	IoT services and use case of a smart city.	Research article	Ahmed and Rani [97]	A hybrid approach Smart Street use case and future aspects for Internet of Things in smart cities
Critical analysis of ubiquitous eco-city in Korea and discussions to develop a sustainable and ideal city model.	Ubiquitous technologies, infrastructure, services, management systems, and policy changes.	Research article	Yigitcanlar and Lee (2019)	Korean ubiquitous-eco-city: A smart-sustainable urban form or a branding hoax?
Overall trend analysis of smart city research using text mining. Smart city–related policies and technology applications in Korea and other countries.	Understanding and advancing research on a smart city.	Research article	Lim et al. [4]	Understanding the linkages of smart-city technologies and applications: Key lessons from a text mining approach and a call for future research
Evaluation of thermal comfort by utilizing the demolition program of shrinking areas in the smart city of Daegu.	Thermal comfort and environmental evaluation in a smart city.	Research article	Jang and Kim [89]	Are decline-oriented strategies thermally sustainable in shrinking cities?
Case study of crime prevention and a traffic control management system in Korea using cutting-edge ICT technology and video surveillance systems.	Linkage and convergence of information and systems of a smart city.	Research article	Leem et al. [27]	Linking data and converging systems for smarter urban services: Two cases of U-City services in Korea
Address strategies, models, and the motivation behind smart cities by analyzing two smart city project cases in South Korea: Gimpo and Namyangju.	Examples of smart city projects in South Korea.	Research article	Myeong et al. [22]	Smart city strategies-technology push or culture pull? A case study exploration of Gimpo and Namyangju, South Korea

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Table 2 (*continued*)

Main Content	Smart City Dimensions	Type of Literature	Author	Title
Smart city initiatives in South Korea, examining the recent history of smart city policies.	Overall policies of smart cities in South Korea.	Research article	Choi et al. [20]	Smart City evolution in South Korea: Findings from big data analytics
Analysis of energy consumption using a real-world dataset obtained from Songdo a smart city in South Korea.	Energy consumption analysis in the smart city.	Research article	Carrera et al. [32]	Meta-regression framework for energy consumption prediction in a smart city: A case study of Songdo in South Korea
Examining the development processes of the IoT using the Living Lab frame in South Korea.	IoT services for the smart city in South Korea	Research article	Shin [98]	A living lab as a socio-technical ecosystem: Evaluating the Korean living lab of internet of things
Understanding the tendency of smart city service development and its application.	Smart city service, development, and application in South Korea.	Research article	Kim and Jung [21]	Current trends in smart city service application in Korea
Determinants of smart cities and their priorities through an analytic hierarchy analysis.	Hierarchical process analysis of a smart city in South Korea	Research article	Myeong et al. [99]	A study on determinant factors in smart city development: An analytical hierarchical process analysis
Significance of citizens' adoption of smart urbanism for sustainable living. Concept of smart equity among citizens.	Smart Urbanism and citizens' adoption. Human-centric viewpoint.	Review article	Han and Kim [100]	A critical review of the smart city in relation to citizen adoption toward sustainable smart living
Acceptance of the U-life services as part of a citizen's household. Songdo city residents' perception of U-City.	Citizens' awareness level and consensus on the ubiquitous city.	Publication	Ilhan et al. [101]	Citizens' acceptance of U-life services in the ubiquitous city of Songdo
Overall changes in the Korean government's smart city policy, accomplishments, and limitations.	Evaluation of South Korea's smart city policies.	Publication	Lee and Chang [33]	The evolution of smart city policies of Korea
Smart city technology is used to track COVID-19 patients in South Korean cities. Data collection method based on Data hub technology developed by Daegu Metropolitan City.	Review of social disaster reduction system based on Data hub and Massive IoT.	Editorial	Sonn et al. (2021)	Smart city technologies for pandemic control without lockdown
Scenario-based crowdsourcing for improving various problems of the city. Collecting and monitoring diverse road environment information reported from mobile situations for civic participation. Cases of Daejeon and Daegu.	Smart transportation using crowdsourcing.	Conference presentation	Choi et al. [102]	The service scenario of road environment improvement based on crowd sourcing for the smart city
Implementation cases and obstacles of U-City in major cities in Korea. Five types and models of the U-City.	U-City's policies and implementation examples in South Korea.	Conference presentation	Shin et al. [24]	Policy alternative to solve problems and issues for U-City implementation in Korea
Implementation of a global smart parking use case that employs data from Santander and Busan.	Use cases of a smart city in Spain and South Korea.	Conference presentation	Sotres et al. [103]	Smart city services over a global interoperable internet-of-things system: the smart parking case
Basic data for the policy on energy demand and management of a U-City. Guidelines for environment-friendly urban architecture planning and assessment of energy consumption in the city.	Energy policies and management in the U-City	Research article	Lee et al. [104]	A study on energy consumption and management of a U-based city considering the characteristics of building energy in a city focused on the Daegu·Gyeongbuk Area

[92–94]. To analyze the application of smart technologies in Daegu Metropolitan City (smart city), this study comprises the following four major processes. The theoretical part summarizes the smart city project of Daegu based on the literature and analyzes the content of the published documents. In the first phase of the literature review, Google Scholar and Web of Science databases were used as search engines to find articles, reviews, reports, and conference papers related to smart cities. In addition, industrial reports, patents, or non-academic documents were excluded, and only documents publsihed between 2010 and 2021 were listed. This was slightly modified based on the criteria in "Guidance on conducting a systematic literature review" by Xiao and Watson [95,96]. The combinations below helped identify articles with titles with smart cities as their key focus. The following keywords were mentioned in the title or abstract of each study and formed the core content of the literature.

- "smart city" or "U-city" + "implementation city" or "implementation"
- "smart city" or "U-city" + "experimental city" + "experimental"
- "smart city" or "U-city" + "Daegu City"
- "smart city" or "U-city" + "use case" or "use case service"
- "smart city" or "U-city" + "living lab"
- "smart city" or "U-city" + "South Korea"
- "smart city" or "U-city" + "disaster risk" or "disaster risk reduction"
- "smart city" or "U-city" + "hazard prevention" or "hazard"
- "smart city" or "U city" + "climate change" or "climate adaptation" or "climate mitigation"
- "smart city" or "U-city" + "sustainability"

The most important source was the report of the Smart City Innovation Growth Engine Project, the largest national R&D project in South Korea. Fig. 1 presents the selection process for the systematic review studies following the PRISMA model. The literature review process began in February 2019, and approximately 450 documents were reviewed, of which 70 documents related to "Smart Implementation City" or "Smart Experimental City" were examined and 25 studies that focused on smart cities for implementing new smart technology in Korea were reviewed. Table 2 presents the contents and details of the major documents.

In the second stage, a qualitative research method was applied for document analysis. This study reviewed the key documents and agreements for Daegu Metropolitan City in relation to disaster risk reduction for the vulnerable in a smart city. Such document analysis determines various global trends related to smartness and, in turn, can determine how disaster mitigation and adaptation policies work for the vulnerable in the city. The qualitative analysis focused on the goals, actions, and evaluation of disaster reduction services in smart cities.

The third stage focuses on various policies and cases used for disaster risk reduction. During this stage, this study analyzed disaster risk reduction services that are being specifically used and their impact on the urban environment. In the fourth stage, through discussion, we evaluated Daegu Metropolitan City, the third smart city project in Korea that is currently close to completion, and discussed the various issues it is experiencing.

4. Daegu Metropolitan City's smart city plan

The smart city project in Daegu started in 2020 and is targetted for completion in 2025. Daegu Metropolitan City is striving to build smart mobility that optimizes the transportation sector in urban areas and reduces economic, environmental, and time costs through the use of real-time data, information, and communication technology. Representative examples include smart road operation (smart crosswalk signals, emergency vehicle priority signal systems, school zones) and smart public transportation (consumer-responsive transportation services, autonomous driving shuttle buses)/smart parking (reservation of parking lot location and free space information)/environment-friendly (electric buses, two-way charging system for electric vehicles) [102].

Another major issue is the disaster safety convergence service using new ICT technology, which is provided along with services such as ICT technology, big data, unmanned aerial vehicles (UAVs), social media, AI, AR, and virtual reality (VR). Typically, natural disasters include typhoons, heavy rains, floods, and strong winds, and social disasters include incidents of crime and fire in urban areas. The Daegu Metropolitan City video surveillance Control Center is being operated for integrated management, and a total of 11,541 video surveillances and 500 operation/control personnel are deployed. In addition, disaster management systems, modernization of rainwater pumping stations and smart control systems, and smart flood management systems are in operation.

In the energy sector, massive efforts are being made to create a smart city, which is related to the Korean government's Renewable Energy 3020 Implementation Plan. The Moon Jae-in government set the target of renewable energy generation to 20% by 2030 considering power system safety, supply conditions for domestic companies, and potential capacity. The plan is to supply more than 95% of the newly installed capacity with clean energy, such as solar and wind power. To this end, a roadmap for revitalizing the hydrogen economy has been presented, including the operation of hydrogen cars and hydrogen charging stations, production of 6.2 million hydrogen cars by 2040, construction of 1200 hydrogen charging stations, and development of hydrogen-based energy sources, such as fuel cells and electric power generation.

In addition, smart technology has been widely applied for the welfare of underprivileged (vulnerable) people. Daegu City promotes the development of IoT home appliances and smart home core service technology through life care services and supports it for the underprivileged.

5. Objectives of Daegu's smart city innovation growth engine and R&D

The Smart City Innovation Growth Engine R&D is a representative project related to smart cities in South Korea. This project aims to build a data-based innovation model to improve citizens' QoL and promote sustainable growth. The project has three core objectives.

First, the smart city model and base technology project aims to develop a "Data hub model" for integrated operation and management of information generated through base technologies such as Data hub, massive IoT, and digital twins. Second, the Daegu Metropolitan City was used as the implementation city, called the use case. Daegu Smart City focuses on service discovery and development verification to solve problems raised by citizens, such as transportation, safety, and city administration. The third core comprises a Living Lab city for urban growth and regeneration, solving environmental, energy, and welfare problems in Siheung, Gyeonggi-do. In the case of Daegu Metropolitan City, the infrastructure is well established while Siheung is a newly implementated city. The first core serves to integrate data from the other two and provides services to citizens.

Among these services, disaster reduction in Daegu Metropolitan City is related to the two core tasks and sub-task 1–2. In particular, it has great relevance to sub-task 2–2, and the biggest goal is to "develop urban disaster safety and social safety emergency rescue technology through data sharing." In addition, as an implementation task to reduce natural (collapse of slopes and floods) and social disasters (accidents and incidents of fire), services are divided into stages such as the use of case-based technology development, implementation, verification, and stabilization.

Sub-task 2–2 aims to reduce property damage and casualties that may occur due to collapse, water-related disasters, and heatwaves through use case services for each field by up to 20% in disaster safety areas. In the field of social safety emergency rescue, research is being conducted to achieve 80% of the accident site arrival rate within the critical "golden time" (Fig. 2).

Daegu Metropolitan City's safety service consists of three stages: data collection, data sharing, and data propagation. Information on slope collapse risk, urban flood risk, heatwave, fire incidents, traffic and fall accident, and disasters are collected via sensors. The received data are linked to the safety platform of sub-task 1–2 and information is transmitted to citizens through the city safety mobile app. Safety services are divided into the following three categories:

The first is a slope collapse prediction service. Compared to the existing prediction accuracy of approximately 40%, the project aims to improve the accuracy by 20% by developing a system to manage collapse risk factors. In addition, it aims to contribute to a 20% reduction in casualties and property damage through prediction and warning guidelines. Detailed services include an emergency message transition system.

The second is a mitigating service related to urban flooding, which aims to reduce flood damage by 20%. The goal of this service is to drive an urban flood situation awareness model using rainfall prediction and real-time water level information. It aims to achieve an 80% accuracy in predicting flood damage and improving the quality of urban-flood forecasting.

The third service of heatwave reduction contributes 20% reduction in the number of casualties caused by heatwaves. Developing heatwave reduction technology through data sharing can achieve a 10% reduction in temperature within the Daegu implementation area. Daegu Metropolitan City provides detailed services for each of the three goals. Details of the service are discussed in Section 6.

6. Use case service related to disaster risk reduction in daegu

6.1. Location-based water-related disaster forecasting and alarm services

6.1.1. Collapse prediction service

Collapse prediction and warning services secure technology to collect and manage risk factors for slope collapse. The sub-task is to invest in technologies such as massive IoT networks that can collect data such as soil porosity, moisture and water content, and water pressure, which can cause collapse.

In addition, the logical relationship between data and correlation is filtered in the development of data refinement technology for slope collapse risk factors. Complex event processing technologies can be applied to transportation and meteorology. Data purification

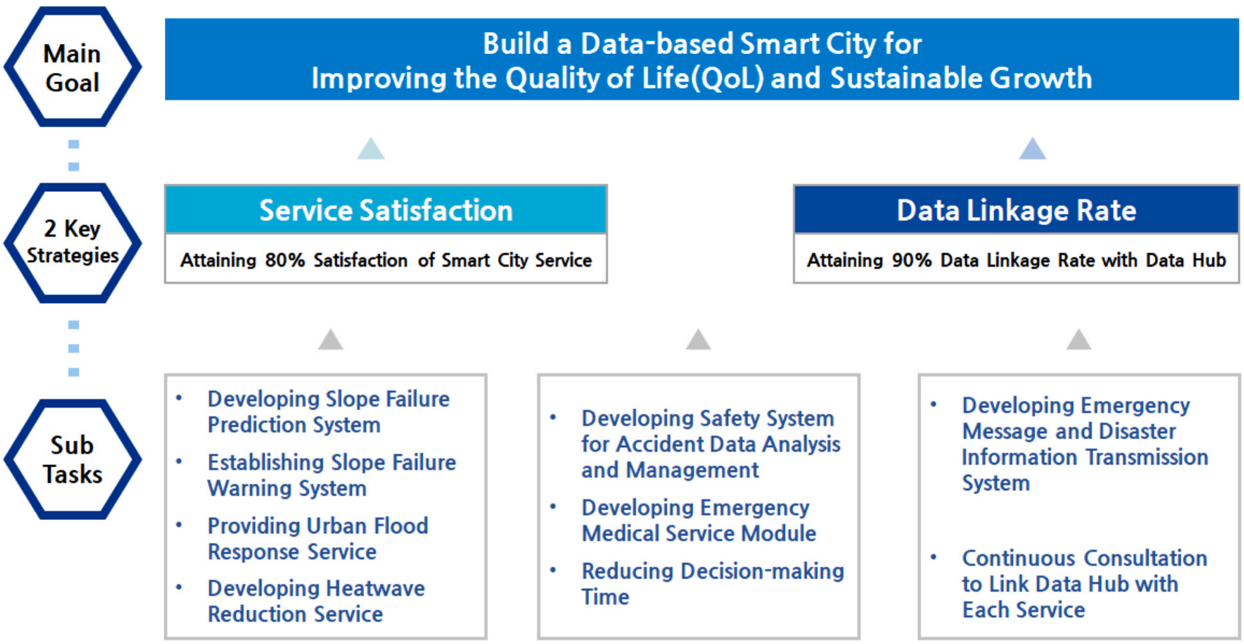

Fig. 2. Main goal of smart city innovation growth engine project and sub-tasks.

technology can improve data quality and increase the reliability of analysis results.

Although the steep slope collapse prediction system used in Korea was determined based on metrology or geological factors, a new prediction model that combines metrological data and geological factors have been developed to improve the accuracy using data sharing such as real-time slope, rainfall, and risk maps.

The slope collapse prediction system is deemed to reduce casualties by a scale of 20% compared to 46.2 billion won, which is the average annual cost of damage over the past ten years, by linking the location-based service (LBS). In addition, it is possible that the steep slope collapse prediction information comprises four stages: steep slope risk calculation, correction of risk calculation result, risk change prediction, and forecast warning information (Fig. 3). It is sent to citizens and municipalities to provide water-related disaster risk information and platforms.

Differentiation of the slope collapse prediction service is the automation of the data collection system. Earlier, the manager went directly to the place where the measuring instrument was installed to collect data, and this was performed approximately once or twice a month; therefore, the accuracy was low, and it was difficult to respond to an emergency. The new service can wirelessly collect and manage the data, and the system is capable of data management in multiple areas through filtering and complex event-processing techniques.

In the case of slope collapse prediction technology, ten test-bed sensors have been installed, and the slope collapse risk factor collection and management system has been verified. One of the differentiating points of the smart city innovation growth engine project is the use of the existing social infrastructure (SOC: Social Overhead Capital), which is defined as legacy data, and new data are defined as collected data. Representative legacy data include watersheds, pipeline networks, facility specification information, and meteorological agency rainfall (precipitation) radar. The collected data include surface displacement, moisture content, rainfall observation information, sewer pipe water level sensor, and river water level sensor.

6.1.2. Urban flood prediction information

Urban flood prediction services recognize urban conditions and provide a system that can promptly issue flood forecasts and warnings during flood damage. Urban flood prediction information aims to establish a preemptive flood response system. In the event of urban flooding, the system responds to climate change and improves citizens' ability to counter floods, secure a social safety net, and implement digital social welfare. Through this, data are used for urban infrastructure planning using flood maps based on convergence data, the establishment of disaster reduction plans, and disaster forecasts. This service aims to manage the vulnerable points of urban flooding using a flood analysis map (Fig. 4).

This service also aims to reduce personal and property damage caused by water-related disasters by 20%. Using the information on rainfall prediction and real-time water level, the urban flood recognition model is operated to secure 70%–80% accuracy in flood prediction information. Information on urban flood prediction comprises four stages: urban runoff analysis, two-dimensional flooding analysis, flood prediction, and production of forecast and warning information, eventually leading to flood hazard propagation risk mapping.

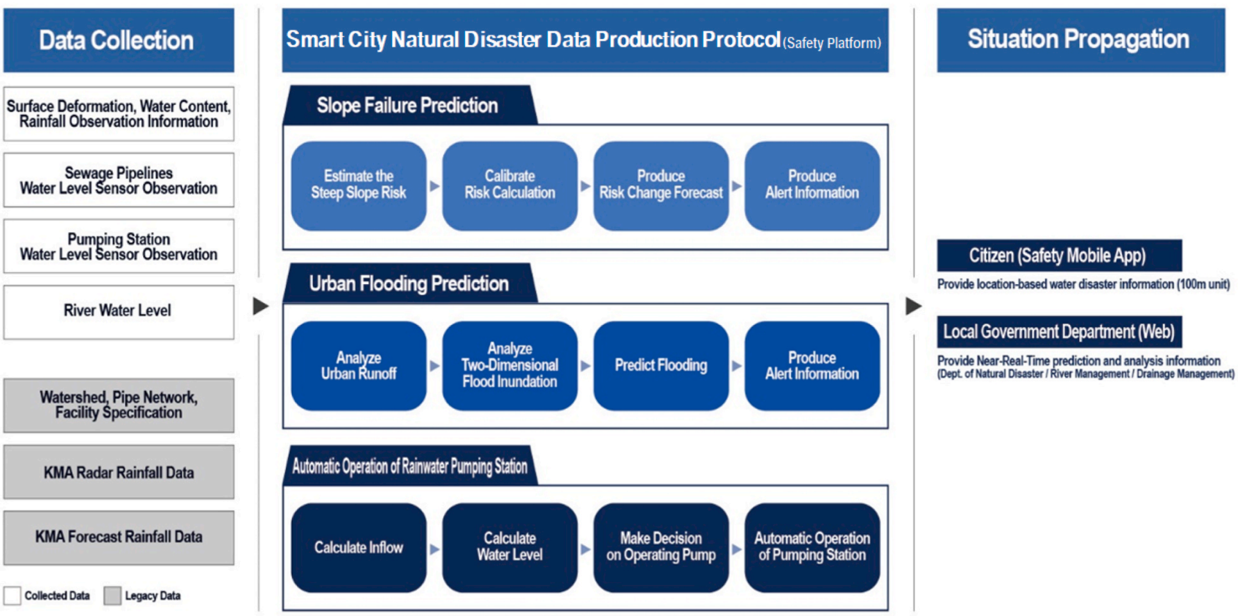

Fig. 3. Process of location-based water-related disaster forecast and warning service.

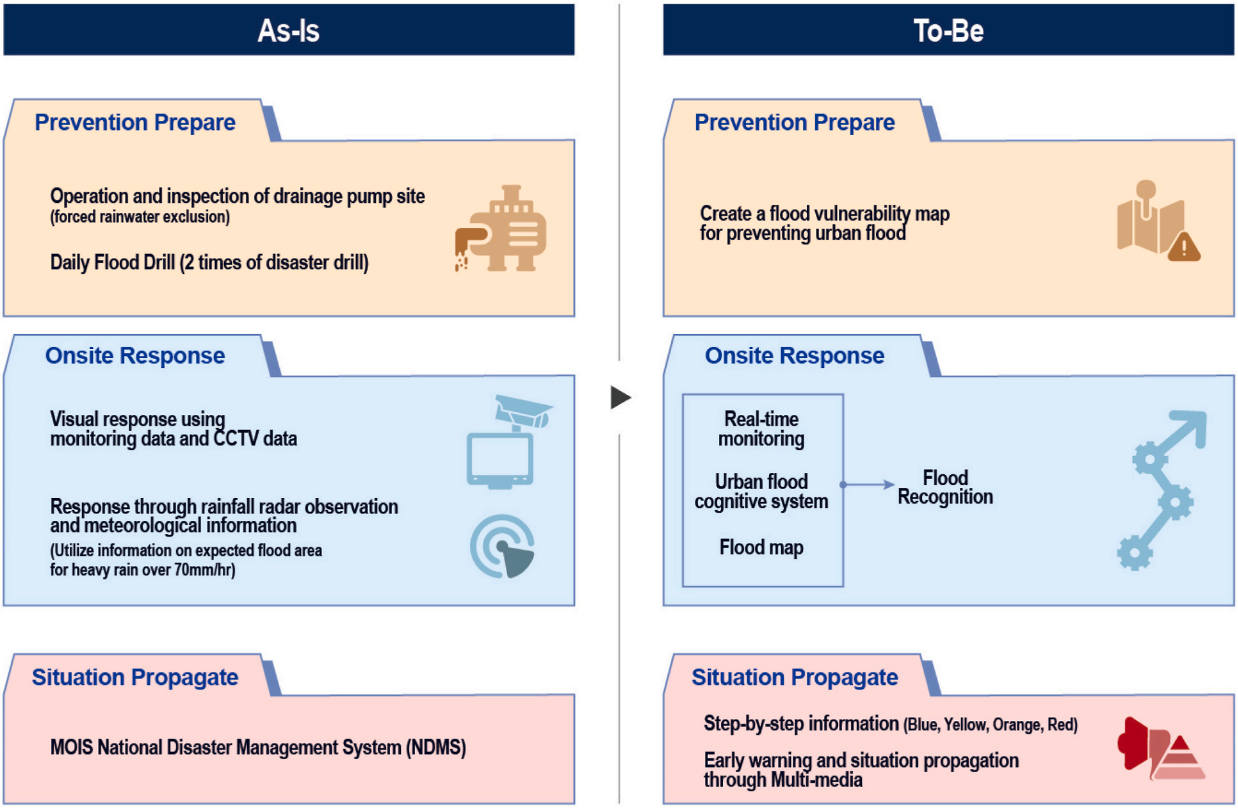

Fig. 4. Concept of providing information on urban flood forecasting.

6.1.3. IoT-based rainwater pumping station

The IoT-based automatic operation of the rainwater pumping station includes technology for predicting fluctuations in the reservoir water level through rainfall-runoff analysis. The IoT technology is applied to the rainwater pumping station, and a control system that integrates water level prediction technology and automatic operation technology is developed (Fig. 5).

This technology has been developed to reduce the risk of inundation of cities due to climate change and associated extreme weather events. Manual control and automatic control are simultaneously used to prevent malfunction and emergency operations. In addition, using PCs or smartphones, administrators can access sensor information and control pumps/sluice gates anytime and anywhere. Water level data are displayed in units of 1 min to recognize the situation inside and outside the reservoir in real time.

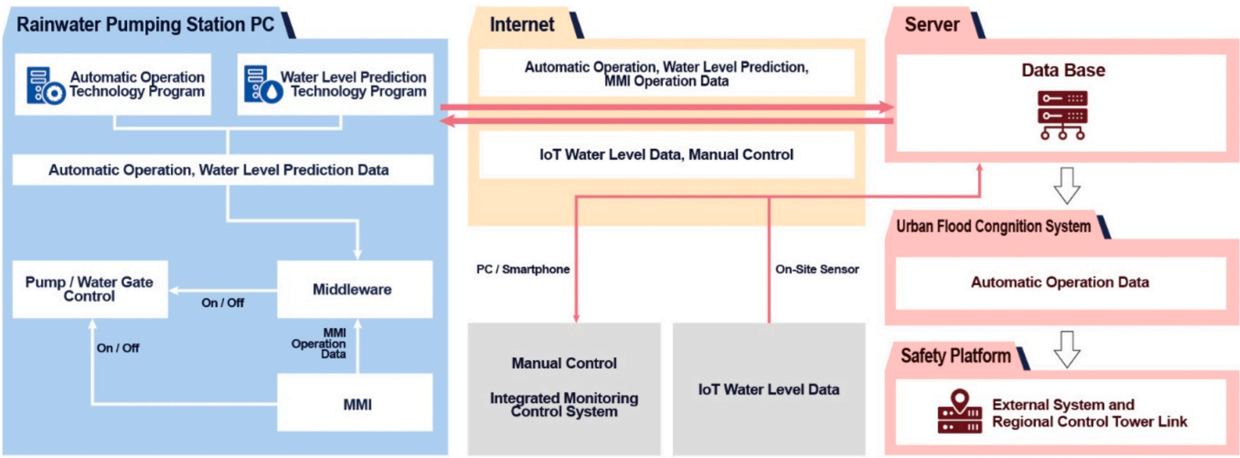

Fig. 5. IoT-based rainwater pumping station in Daegu.

6.2. Detailed heatwave information and reduction service

6.2.1. Real-time heatwave information and risk map service

The heatwave reduction service aims to collect real-time local weather information to provide information on utilization services. Heatwaves are natural disasters increasingly caused by intensifying climate change. Daegu Metropolitan City has one of the highest rates of heat strokes in Korea, and it is essential to provide heatwave adaptation services to the vulnerable. To mitigate the damage caused by heat waves, an alertness system has been developed, and decision makers can access information at an early stage.

The quantitative goal of this service is to contribute to a 20% reduction in the number of casualties caused by heatwaves. Daegu Smart City provides a safe living environment for citizens by creating a pleasant ecosystem and improving the city's air quality by mitigating heatwaves. In particular, it aims to contribute to the provision of environmental welfare that can be experienced by vulnerable groups (e.g., the elderly living alone, people with underlying diseases, and children). The heatwave information service is provided through four stages: establishment of heatwave information for each location, an analysis of information on heatwave vulnerability, a calculation of the heatwave risk, and creating a real-time heatwave risk area (Fig. 6).

Legacy data include the number of heat-related deaths and the number of elderly people living in Daegu. The collected data include information on temperature/relative humidity measurement, wind direction/wind speed measurement/fine dust measurement/ operation of heatwave reduction device.

Real-time heatwave information is supplied to citizens and local government departments. Citizens are provided heatwave risk information in the form of applications and kiosks, and heatwave reduction services are operated. Local government officials are provided information to efficiently operate these heatwave mitigation systems, and basic data are used for establishing heatwave countermeasures and performing damage reduction.

6.2.2. Heat reduction device control

The heat reduction device control system reduces the actual atmospheric temperature through a cooling fog that is provided via streetlamps. A real-time warning service based on heatwave data collection using massive IoT has been developed. Secondary services and processing data are provided by the construction and operation of the implementation complex and monitoring of heatwave data. The development of heatwave-reduction-technology service has achieved a 10% reduction in temperature in the Daegu Implementation Complex during a heatwave. The cooling fog uses both upper and lower mist; the upper part uses tap water, and the lower part uses rainwater to enhance the efficiency of water circulation.

The management of heatwave reduction systems involves four steps. First, it requires building a heatwave algorithm; second, heat warning management standards are analyzed; third, the operating conditions for heat reduction and control of heatwave reduction devices are analyzed. Simulations using computational fluid dynamics (CFD) were performed to determine the appropriateness of spraying cooling fog, and facilities were installed. Integrated environmental sensors, such as temperature/humidity sensors, which are the standard for operating an automatic control device, were installed, and the collected sensors are transmitted through massive IoT. A sensor called Beacon is also used to collect heatwave information, and it provides data to the server based on the individual's smartphone. Beacon is a type of Near-field NFC technology that utilizes Bluetooth 4.0 LE to support information with smartphones or smart tablets. This is the most representative Living Lab, in which a specific citizen installs an app and provides data to an integrated control server.

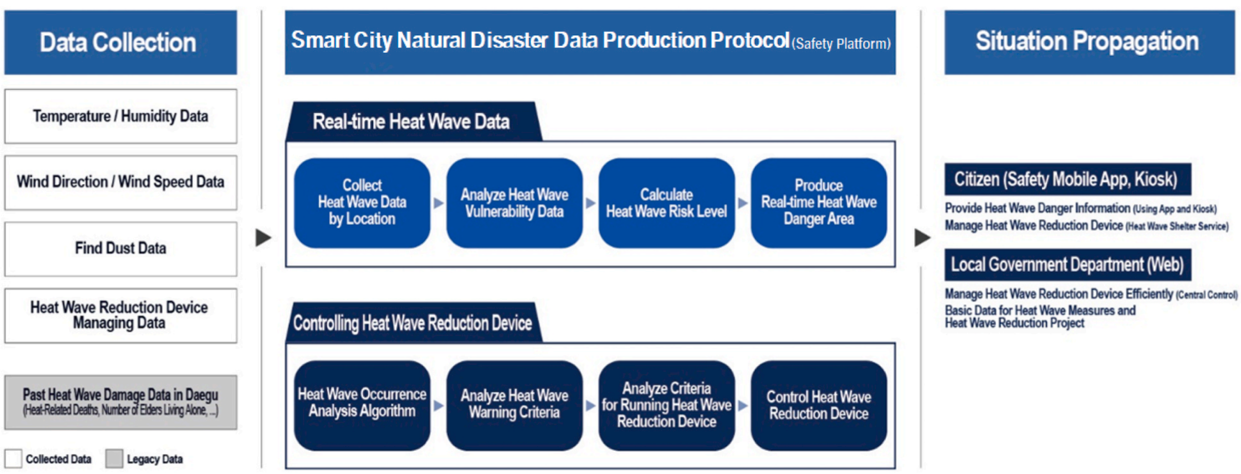

Fig. 6. Real-time heatwave information and risk map service.

6.3. Emergency rescue support service

6.3.1. Fire and accident information support services

Artificial intelligence-based technology to detect smoke and fire and accident information support services using video surveillance seeks to improve the risk detection performance of fire-related systems through image-based technology. By applying AI technology, it is possible to minimize the damage caused by fire and reduce the cost of restoration, thereby preventing and minimizing damage to human life and property. Image-based fire detection AI technology is the core technology of all smart cities and is being actively applied to smart cities in South Korea (Fig. 7). The developed AI-based fire detection technology was implemented through the development of artificial intelligence image analysis software that can detect smoke and fire in outdoor environments, and data are transmitted by linking the image analysis results with emergency rescue services. The interval is about 10 s, and with the ability to detect sparks of up to 40 × 40 pixels, it can detect sparks of about 0.01 m^2 at a distance of about 20 m. In addition, it provides a service that proposes an optimal evacuation route using learned fire detection technology, and if such a service is advanced, it can suggest an optimal evacuation route in densely populated areas, which can ultimately prevent events such as crowd crush in Itaewon on October 29, 2022.

The use of video surveillance technology can quickly and efficiently categorize fires in all indoor and outdoor environments and reduce civilian casualties and fire-related environmental pollution and accidents. An indoor IoT fire detector provides information on the entry location when firefighters are dispatched to the accident scene, and technological advancements can be used to extinguish a fire even in a large building.

The core technology is to improve the performance of the fire detection technology through the model called You Only Look Once, version 4 (YOLOv4) and the EfficientNet-based Convolutional Neural Network (CNN) algorithm. YOLOv4 and CNN are image learning algorithms used to automatically detect fire and smoke, and disaster are automatically recognized through surveillance cameras. In the case of YOLOv4 and CNN, it is a developed code that can detect 30 × 30 pixels of flame and 50 × 50 pixels of smoke when using the algorithm. However, Daegu City detected 40 × 40 pixels of flame and smoke up to 60 × 60 pixels at a distance of 20 m using a hybrid algorithm, and significantly reduced the error rate to less than 2%. YOLOv4 and CNN use object detection technology to detect fires. By developing high-quality object recognition technology and fire detection technology, it is possible to spread the fire situation quickly and immediately to rescue and emergency services. The fire data and analysis system aims to achieve an 80% arrival rate at the accident site within the golden time. Specifically, it aims to reduce the arrival time of medical and paramedics by 10% in vulnerable areas, determine the level of crisis alertness, and disseminate information about the emergency situation within 60 s. Fire accidents and information support services are provided to citizens in connection with the safety platform and the city safety mobile app.

6.3.2. Ambulance dispatch support information service

The ambulance dispatch support information service provides a module that utilizes indoor and outdoor spatial information and emergency vehicle-signal control equipment. It can reduce by up to 10% the time required for medical emergency services to arrive in vulnerable areas using software for indoor/outdoor geospatial linkage and a signal control equipment priority manual. The outdoor route instruction contacts the dispatch department and presents an optimal route through the use of the road network and reflection of

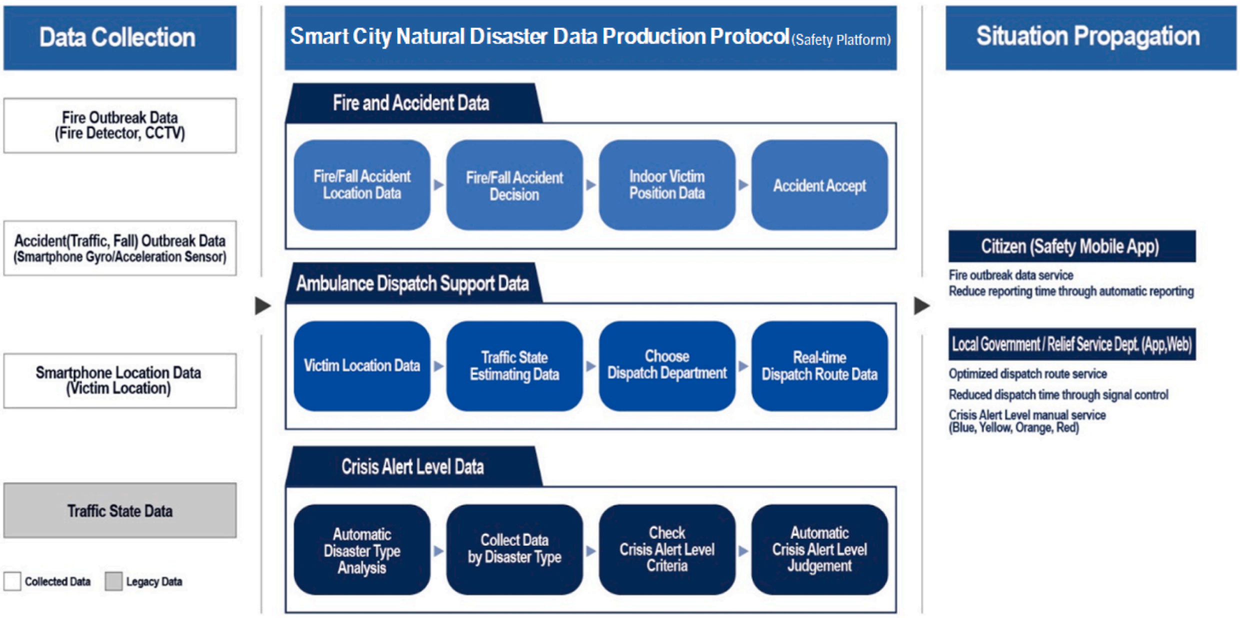

Fig. 7. Emergency rescue support service.

traffic conditions over time. In the case of indoor route instruction, the ambulance access road and entry point instructions are provided.

The ambulance dispatch instruction support service, which is based on the safety service platform, aims to give the dispatch route within 10 s of receiving the accident signal. In addition, the transit time of the ambulance signal section was reduced by more than 10%. A dispatch manual service module was developed and contributed to a 10% reduction in dispatch time.

6.3.3. Disaster alertness service

The existing disaster warning management system and decisions were developed by public officials by collecting information related to the disaster situation and considering warning standards. In an urgent disaster situation, it takes a long time for the person in charge to collect relevant information, make the right decision, and decide on crisis alertness. The new disaster warning service evaluates the level of crisis warning along with automatically collected information and disseminates it to concerned officials. (Fig. 8).

6.4. Smart city integrated safety platform

The Data hub platform is used to collect city data and deliver smart-city application services. The platform collects, stores, manages, analyzes, distributes, and visualizes data and enables data application programming interface (API) standards. The platform discloses open sources that can be utilized for sustainable development and private use, Korean local governments, and city construction Data hubs in other countries.

The core of a smart city is an integrated safety platform that builds a smart-city safety net by linking the various data sources mentioned above. Safety platforms are installed in cities, towns, and villages, and linked software and hardware are built to integrate them. The platform is developed as a data-sharing type based on big data and is provided as a mobile app that citizens can easily access (Fig. 9).

The safety platform and mobile app software implement the technology required for the safety field and large-scale, high-speed processing of data connected to the Data hub. As data is provided through various sensors, it aims to implement pattern-recognition-based technology through self-learning. It can contribute toward shortening the rescue time by constructing a base technology that improves the accuracy of accident judgment through self-learning, and reduces the social cost of damage repair. By linking independent safety technologies, cross-connections between technologies can be made, and the cost of system expansion or service combinations can be reduced. This enables the achievement of the fundamental goal of a smart city in that it provides services to all citizens, unlike the existing method in which services are provided to specific classes centered on managers.

7. Discussion and findings

The main discussions and finding obtained through this study are as follows. Based on various research reviews and case studies, this study demonstrated the importance of developing disaster mitigation technologies in the Smart City Innovation Growth Engine project currently underway in Korea. Disaster mitigation services along with smart mobility are important components in the smart-city concept and can bring a sustainable future to the city. Specifically, these services can influence the establishment of policies and technologies that can be adapted to safeguard vulnerable groups during the climate change era.

Citizens can receive accurate data through kiosks or mobile-platform-based data transmission services. Business organizations, experts, researchers, and innovators can support policymaking by collecting data on natural disasters. The Smart City Innovation Growth Engine project in Korea is significant because it provides services by reducing natural and social disasters by nearly 20%. In addition, based on the collected data, establishing a safety platform is important, and citizens can form a living lab using this framework. It plays a significant role in reflecting the design of communication methods and standards for collaboration between Data hubs and Korean telecommunication companies.

Massive IoT, developed by the Electronics and Telecommunications Research Institute, is a technology that can process large-scale data collected through this project in a batch. The most important aspect of Daegu Metropolitan City's disaster reduction efforts is the technology used to collect and share data. These projects are considered efficient because they collect data through tasks and comprehensively use legacy data. These projects also innovative in building sensing technologies and control systems that can be integrated.

The smart city of Daegu Metropolitan City is effective in dealing with natural disasters and urban problems such as lack of infrastructure, traffic congestion, and energy shortages. Several other countries are adopting the smart city concept to solve urban problems, and the smart city technology developed using ICT is being promoted to create innovative value [97]. Daegu Metropolitan City was also establishing large-scale implementation strategies that can support national development and safety net reinforcement, such as the Korean version of the New Deal Comprehensive Plan in Moon Jae-in administration.

A brief comparison between Daegu Metropolitan City and other cities shows that the other cities are focusing on energy efficiency and technology development, specifically, new and smart concepts, such as smart mobility and smart energy grids [13,36,37,50,71]. In contrast, Daegu Metropolitan City considers solving social problems, including disaster management, as the first step toward building a smart city while striving to improve energy consumption efficiency [104]. For this purpose, cutting-edge technologies, such as smart ICT and IoT, are being used. This is a point worthy of reference as the best practice for cities with existing infrastructure. The Itaewon crush incident, which occurred on October 29, 2022, could also have reduced the damage and casualties from the accident if these smart technologies were sufficiently applied. In the case of Itaewon accident, the biggest cause is the lack of manpower deployment, and if the smart city technologies mentioned above can be applied and operated well, the damage from the accident can be reduced. In

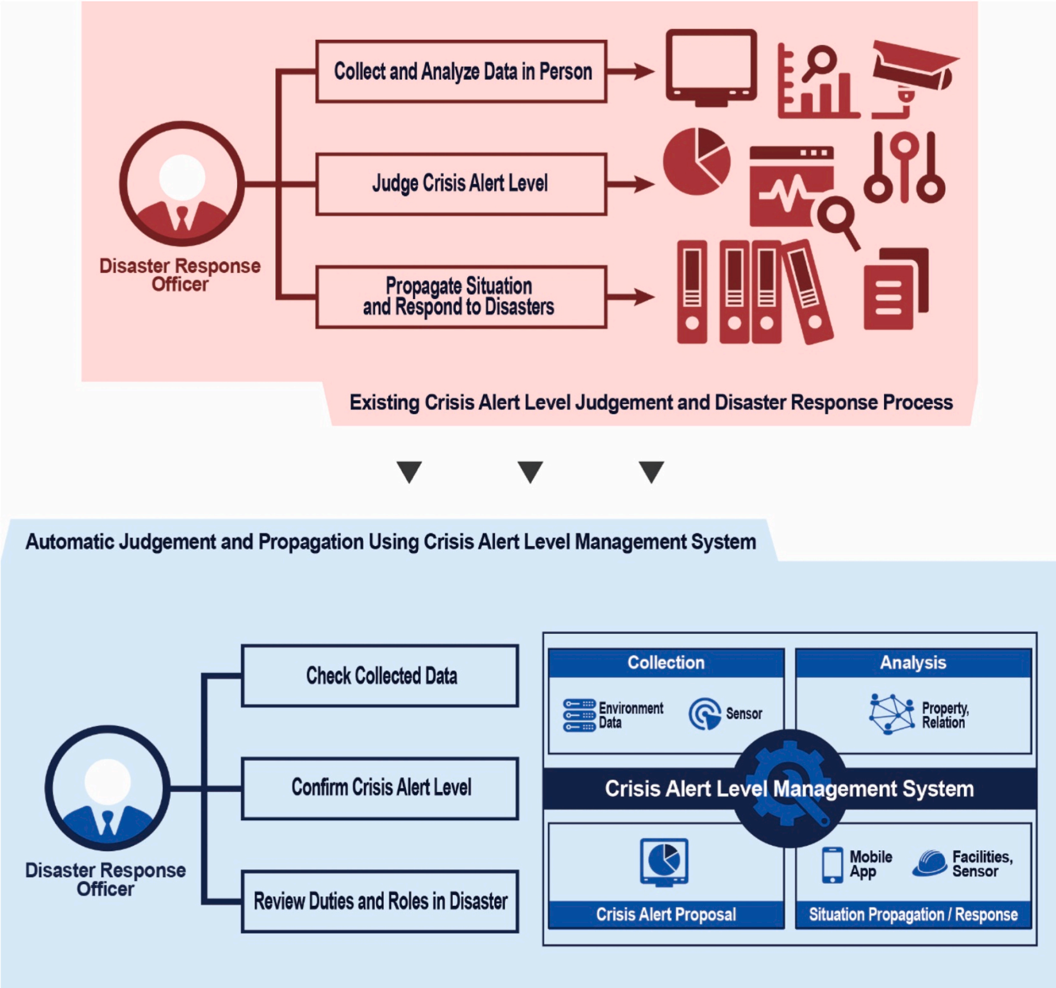

Fig. 8. System of a disaster alertness service.

particular, if the emergency rescue system was actively reflected, even if human casualties began, rescue personnel could have arrived faster and taken appropriate rescue measures. Although surveillance camera-based AI technology is currently limited to detecting fires in Daegu, problems such as crush can be solved by applying the current technology in the future. It is possible to prevent problems such as the Itaewon crowd crush by learning the degree of population concentration.

Nevertheless, Daegu Smart City must solve one task to efficiently adapt to climate change or pandemics. The task is to improve citizens' awareness of smart cities and provide opportunities for them to be continuously educated about smart techniques [101,105]. Smart disaster management services and citizen-based data provision do not have a positive impact on technology ([40]; Han & Kim, 2021; Jun et al., 2018 [61]). Specifically, as disaster adaptation plans and services target the vulnerable, citizens' level of awareness and education to use such services must be improved. Moreover, for citizen mobile platforms and sensor-based data collection, such as Beacon, problems related to providing personal information must be solved, and citizens' education and data collection techniques that can utilize it must be established. Overall, it is necessary to provide smart disaster management services and continuously use the benefits generated by these services to further enhance the advantages of the smart-city system. Newly developed technologies, data collection methods, and social services require continuous analysis and policy feedback for existing legacy services. In addition, an efficient approach and additional research are required through close cooperation between national R&D projects and local government projects.

However, this study systematically examined the disaster risk reduction aspect of Daegu Smart City using the PRISMA protocol. This was an important step in providing an in-depth understanding of a specific aspect of smart cities. Future research should conduct comprehensive reviews of smart cities that consider meta-analysis or statistical analysis methods; the integrated use of these different analysis techniques can strengthen the research findings and provide a broad understanding of the complex aspects of smart cities.

In addition, research should be accompanied by integrative reviews and thought processes that can comprehensively consider social, political, and civic aspects that have been overlooked. This can guide research in a direction that allows smart cities to operate more effectively within a social context, beyond being a mere technological solution. Therefore, this study can be seen as a first step in

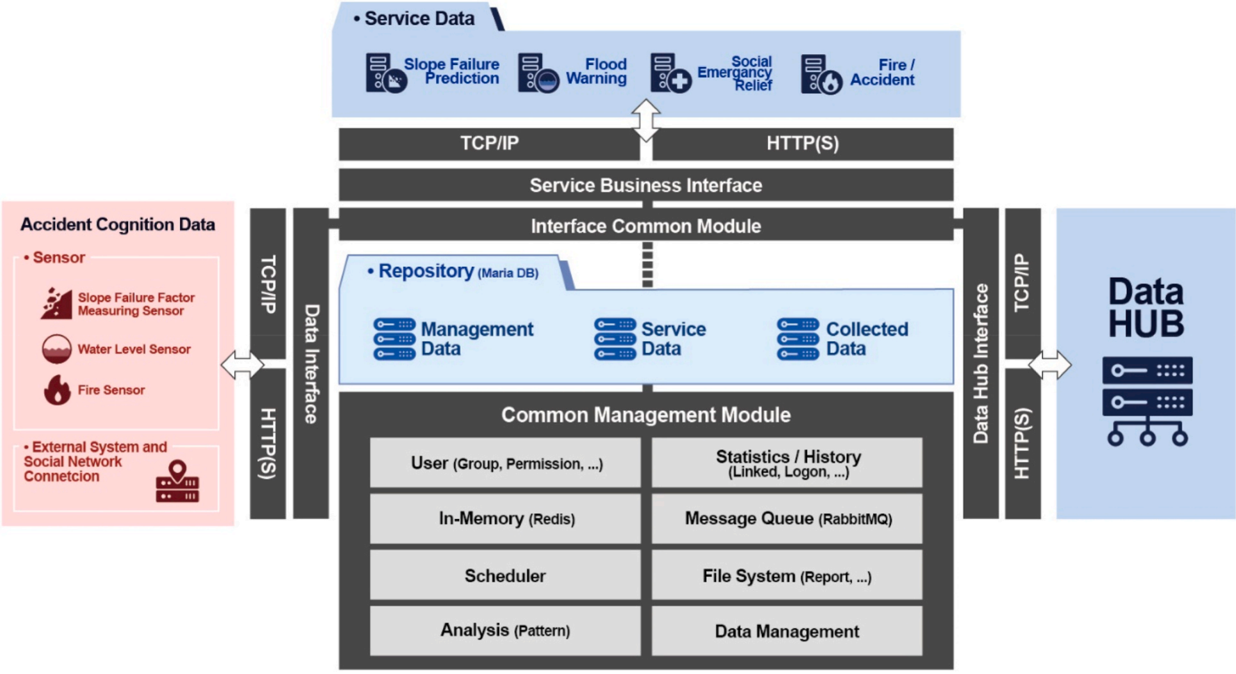

Fig. 9. Concept of a smart-city integrated safety platform in South Korea,[1,2,3] [1, 2, 3].

this direction, and it is expected that future research based on it will contribute to a more comprehensive and integrative understanding of smart cities.

8. Conclusion

Daegu Metropolitan City's smart city has proven to be a highly effective solution in managing natural disasters and addressing common urban heat islands, urban flooding and emergency rescue system. Daegu Metropolitan City places significant emphasis on addressing social problems, particularly in the field of disaster management, while making extensive efforts to encourage citizen participation and promote service provision. These goals are pursued through the adoption of cutting-edge technologies such as smart ICT and IoT. The establishment of a safety-focused smart city in Daegu Metropolitan City is significant, as it attracts attention from major smart cities around the world.

Through the processes of data collection, analysis, and service propagation, a hybrid decision-making system combining top-down and bottom-up approaches is being operated in Daegu Metropolitan Government. In the case of data hubs, the utilization of a high-capacity data processing technology called Massive IoT has enabled overall control of safety-related facilities within the city. Additionally, emergency rescue text message services and alarm services were provided to induce prompt and proactive responses from citizens. This study is significant in that it combines on-site case studies and literature research to understand the overall trends in Daegu Metropolitan City.

However, this paper is reviewing empirical studies on cities and does not cover research related to RAMS analysis or FMECA analysis [76,106,107]. For example, we can refer to the analysis of smart city lighting energy performance comparative cases by Petritoli et al. [108] and Leccisi et al. [109], or research on railway system maintainability improvement by Catelani et al. [110]. In future study, comprehensive reviews on the safety, availability, and reliability of smart cities technologies should be proposed, referring to studies such as those by Catelani et al. [111] and Leccese et al. [112].

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

Data associated with this study has been deposited at Corresponding Author's office under the accession number +8,228,804,872.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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[1] Collected Data: Data collected immediately through sensors (environment, traffic, image data, etc.).
[2] Management Data: Data managed on the safety platform, intermediate level data before service delivery.
[3] Service Data: Final service data provided to citizens (optimized evacuation route, thermal comfort information, water level control information, etc.).

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