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A Survey of Cloud-Enabled GIS Solutions Toward Edge Computing: Challenges and Perspectives

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ABSTRACT Geographical Information System (GIS), as an Information System (IS), helps public/private organizations represent changes in natural/human context and discover patterns/relationships for social and economic progress through the examination of spatial/non-spatial data. In GIS applications, like smart communities services, rapid updating of great amount of data and expenditure of resources (hardware, human, financial) are significant, making traditional analysis on a single computer impractical due to computing limitations. Over the years, GIS has transformed from a tool that merely visualizes data to one that can model future scenarios. So, at first Cloud Computing (CC) emerged as an Internet-based paradigm offering dynamic and scalable solutions. Then, a new ecosystem has been defined Multi-Access Edge Computing (MEC), enabling CC capabilities and Information Technology (IT) services environment to the edge of the network, running applications, and performing related processing tasks closer to the customers. In this way network congestion is reduced and applications perform better. Therefore, a transition from CC to MEC is recommended for GIS. In this survey we provide a clear and structured overview of GIS applications proposed to date, who is using GIS and for what, to take advantage of its capabilities from integration with emerging technologies, CC first and MEC later, critically considering the problems, strengths and challenges inherent in these approaches, to support intelligent resource management and to fully grasp the opportunity offered by fifth-generation (5G) connectivity. The survey concludes by presenting some recommendations and future research directions.

INDEX TERMS Cloud, MEC, GIS, cloud-edge computing, smart communities, survey.

I. INTRODUCTION

TECHNOLOGICAL innovation is playing a role in several areas, from the digitization of public administration to citizen services and welfare. Today the "Science of Where" applies a data-driven approach that uses geography to unlock understanding of our world, through GIS. We "think spatially" every day and we regularly ask spatially-related questions all the time [1]. The adoption of GIS as a decision support tool is becoming increasingly popular because it can help store, explore, manage and visualize large volumes of data combining different aspects (geographic and non-geographic) [2], [3], [4] to make informed decisions in a wide range of issues in order to increase economic viability and social welfare and maintain environmental quality [5], under the banner of a sustainable development approach as envisioned by the United Nations' Agenda 2030 [6]. Furthermore, in 2007 Toronto Mayor Miller stated "cities are where change is happening the fastest and we must seize the opportunities we have been presented with to make that change significant and permanent" [7]. Cities have a chance, it is up to them.

In Khanna's global strategic view [8], "connectography" offers a promising vision for the future. In fact, migration, mega-cities, Special Economic Zones, communications and climate change are reshaping planetary geography: States are no longer defined by their borders, but by the flows of people and financial, commercial and energy ties that flow through them on a daily basis [8]. The goal of using GIS is to arrive at a better understanding of the relationships and patterns that exist in the world around us between the dynamic daily activities that occur on Earth. The ability to run a variety of queries and analytics on GIS data means experts can evaluate how new projects will fit in with existing ones and meet regulatory demands. When British mathematician Clive Humby declared in 2006 that "data is the new oil", he meant that data, like oil, isn't useful in its raw state [9]. It needs to be refined, processed and turned into something useful; its value lies in its potential.

This has made Geographic Information Science and Technology (GIST) useful for businesses, governments, non-profits, industries, and others, minimizing the impact while maximizing the benefits to the community [10], [11]. For example, GIS is used by: retailers to help locate sites for new stores; insurance companies to support the underwriting and pricing of insurance policies; banks to target new customers for credit cards or checking accounts; transportation and logistics companies to route their fleets more efficiently; utility companies leverage the location of smart sensors to track energy usage by neighborhood and mitigate outages from bad weather; governments in a variety of ways from urban planning to tax collection; cities to plan for road repairs, remove snow after storms, pick up waste from streets or find the optimum location for schools; public safety departments, both fire and police, to deploy resources according to the need to protect citizens from fire and crime, respectively [12].

This work is organized as follows. Section II highlights the purpose and novelty of this work. Section III provides the technological context taken into consideration. Sections IV and V present the research questions and the methodology adopted to pursue them, respectively. Then, Section VI analyse the and discusses the results. Finally, Section VII discusses the limitations of our research while Section VIII draw the conclusions and future directions.

II. NOVELTY AND RESEARCH CONTRIBUTION

The novel contribution of the work consists of a classification for use cases of GIS applications in the real world, which does not exist to date and instead may be useful for any decision-maker who is considering adopting GIS technology in their processes. Moreover, the integration of GIS with other technologies not only enhances its usefulness but is also a driver of innovation.

Aim of the work is to review the current state of GIS applications since 1995 and to examine GIS-related works and their evolution. The selected papers are those that best fit the research questions the authors are interested in solving and can be classified into use cases, which are not mutually exclusive, but the same papers could be included in multiple cases.

III. BACKGROUND

GIS technology has evolved over its 50-year history, and the theoretical framework is based on the properties of GIS [2] and its integration with new technologies such as CC [13] and MEC [14] that give rise to Cloud-GIS and MEC-GIS solutions, respectively.

Given the central and supportive role that big data plays in the development of smart cities and for intelligent resource management in general, (capacity-constrained) devices at the edge of the network require low response times for compute-intensive applications (such as health monitoring, disaster management, and smart homes), mindful of energy consumption. CC and MEC environments, by decentralizing processing, storage and services between data centers and end users, come to the rescue [13], [14], [15], [16]. Particularly, MEC seems to be able to address the challenges that need to be overcome to realize the potential of 5G technology [17], [18], [19], and this is attracting considerable interest.

The technologies that form the framework of this work are presented below.

A. GEOGRAPHICAL INFORMATION SYSTEMS

Starting with the Babylonians, Greeks and Phoenicians (2300 and 350 B.C.), maps have traditionally been used to explore the Earth and exploit its resources, to trade and to conduct wars, and, more recently, for tourism. Technological development in the early 20th century led to a shift from paper-based mapping to computerized mapping leading to a revolution in Geographic Information (GI) management. GI has been defined as "the information, which can be related to a location (defined in terms of a point, area or volume) on the Earth, particularly information on natural phenomena, cultural and human resources" [20], [21].

In 1962, Roger Tomlinson, a.k.a. the father of GIS, developed the first version of a computerized GIS called Canadian Geographical Information System for storing, analyzing, and manipulating data collected for Canada Land Inventory: this was an initiative to determine the land capacity of rural Canada by mapping information on soils, agriculture, recreation, wildlife, forestry, and land use at a scale of 1:50.000 [22], [23]. The "Big Book of GIS" [24] includes an entire chapter on the history of GIS, the other book on the history of GIS [25] appeared in early 1998, and many texts [2], [20], [26], [27], [28], [29], [30], [31] include short histories. Rather than attempting to summarize, the emphasis is on its functionalities and capabilities, which integrated with other advanced technologies, are useful for our application context.

Several definitions of GIS exist in literature [2], [3], [4], [5], [26], [28], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [31], [41], [42], [43], [44], but they have overlaps that allow us to identify its basic characteristics: as a geography-oriented information technology, GIS has the ability to process geographic (or spatial) data and associated descriptive (or non-spatial) data, integrate them with each other, and transform them into information by returning visualizations accompanied by reports [29]. The acronym GIS itself gives an idea of what it is [45]:

- G = Geographical, implies an interest in the spatial identity or location of certain entities on, under or above the Earth's surface (i.e., spatial data);
- I = Information, implies the need to be informed in order to make decisions. Raw data or facts are interpreted to create information useful for decision-making;
- S = System, implies the need for personnel, hardware and procedures, capable of producing the information necessary for decision-making, i.e., data collection, processing, and presentation.

When information is in digital form, it is much easier to manipulate and share it. GIS essentially performs five tasks, i.e., input, manipulation, management, query and analysis, visualization [24], [46], and integrates five components, i.e., hardware, software, data, people and methods [20], [47]. Maguire advocates three possible visions of GIS, i.e., as an automation tool, as a database, as an information tool [30].

Precursors of GIS were in France in 1832 and in England in 1854, when Charles Picquet [48] and John Snow [49] created cartographic representations of the cholera that struck Paris and London, respectively. This already underlines that GIS is not a stand-alone science, but integrates with other sciences [20], [24], [25], [50] finding application in various public and private sectors [51], [52], [53]. Therefore, GIS is considered as a Management Information System [2], [36], [54] and some scholars [27], [55] proposed "Geographical Information Studies" to indicate that social, legal, economic and ethical issues are embraced.

Also, GIS improves organizational integration through the ability to link dataset together based on geography, facilitating information sharing across departments [56]. In addition, GIS enables scholars to conduct analysis and propose solutions for resource and asset management (e.g., networks) and land-use planning (e.g., utilities) [23] and could lead to new insights for the development of smart cities.

B. WEB GIS

GIS was developed for stand-alone users, but the World Wide Web has transformed everything, and GIS is no exception [57]. The Web Geographic Information System (WebGIS) [58] is an advanced form of GIS available on Web platforms serving desktop and mobile clients [59]. WebGIS allows users to dynamically access, manipulate, and share data, but is dependent on server and Internet availability.

WebGIS, as a type of Service-Oriented Architecture (SOA), is based on the integration of interoperable and loosely coupled services that are invoked and consumed remotely across a network [60]. This mode allows companies to gain significant benefits, such as increased agility and efficiency, better utilization of existing resources, and flexibility [61]. Several WebGIS applications are available, both commercial (e.g., ArchGIS [62]) and free (e.g., GeoServer [63], OpenLayers [64], Quantum GIS (QGIS) [65]).

C. CLOUD COMPUTING

In the last decade, CC has emerged as a new enabling technology with disruptive effects in many societal domains [13], [66], [67], [68], [69]. National Institute of Standards and Technology (NIST) declares "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [13]. Weinman [70] uses the acronym C.L.O.U.D. to describe the fundamental characteristics of CC: Common infrastructure, Location independence between providers and users, Online accessibility meant as broad network diffusion, Utility pricing in the sense of cloud as a utility service of the 21st century, and Demand resources that are configurable according to the needs of users in a pay-per-use logic. Benlian et al. [71] underline how the "transformative and value-creating capacity of cloud computing".

CC is characterized by properties (i.e., on-demand self-service, ubiquitous network access, resource pooling, rapid elasticity, measured service), by delivery models (i.e., Software as a Service, Platform as a Service, Infrastructure as a Service, Data as a Service, Information as a Service, Business Process as a Service), and by deployment models (i.e., Private cloud, Public cloud, Community cloud, Hybrid cloud, Multi cloud) [13], [72], [73], [74].

Moreover, a distinction is made between Internal (or corporate) and External cloud [75].

The benefits of using a cloud-based service over an on-premise one include the following:

- dynamic possibility to scale up and down the digital infrastructure and initial solution [76], [77];
- economics in process management [78];
- organizational flexibility [79], [80];
- energy efficiency [15];
- cost reduction in terms of servers, back-ups and licenses [77], [79], [81]. At the same time, new (additional) costs for training staff [79] and set up operations [82];
- on-demand access to shared digital resources that extend the scale and speed of business strategies for cloud service users [80], [83];
- expand the scope of digital business strategies involving third parties in the exchange of digital resources and capabilities [83], [84];

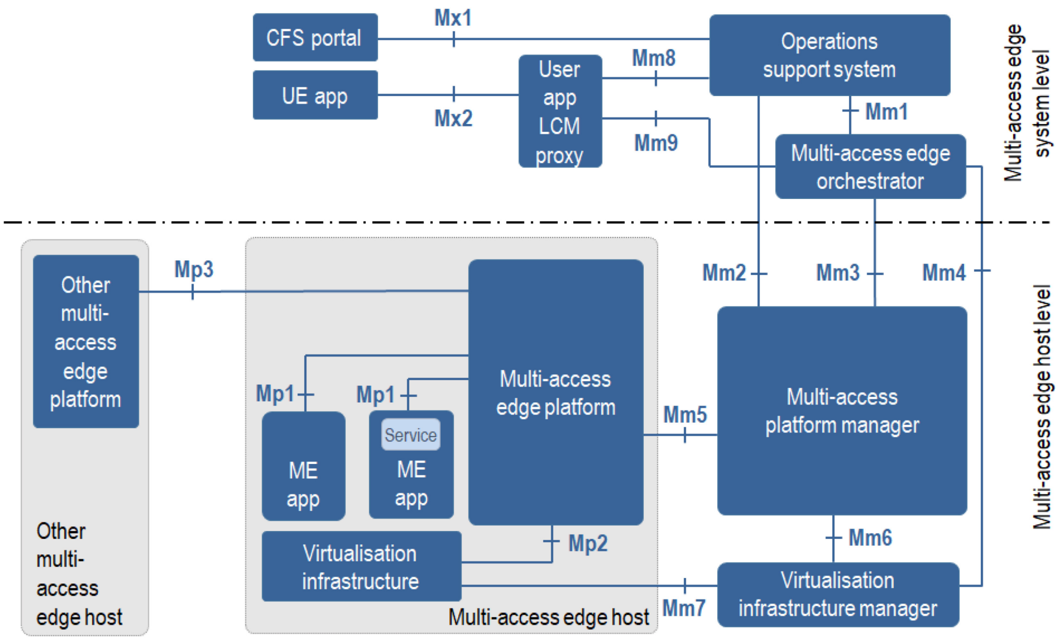


FIGURE 1. Overview of ETSI's MEC reference architecture.

- possibility to balance workload and ensure failure safety, providing business continuity and resilient service delivery [76], [81], [82].

Issues that may be raised include data control by different actors, as data objects must be protected from privacy, intellectual property, and security threats [85], [86], and data as a means of exerting control over other actors [87], [88].

D. MULTI-ACCESS EDGE COMPUTING

The term "edge computing" is not new [89], [90], [91], but only in 2009 Satyanarayanan et al. placed basis for today's edge computing concept [92]. Since then, the paradigm gained momentum as [16], [93], [94], and in 2014 the European Telecommunications Standards Institute (ETSI) proposed Mobile Edge Computing for global standardization [14], as a means of extending intelligence to the edge of the network along with higher processing and storage capabilities [95]. From 2017, ETSI renamed it to MEC, since the benefits of MEC technology have extended beyond mobile to fixed access technologies and Wi-Fi [96]. The underlying principle of MEC is to extend cloud computing capabilities to the edge of cellular networks, and ETSI defines it as "provides IT and cloud-computing capabilities within the Radio Access Network (RAN) in close proximity to mobile subscribers" [14] proposing the architecture depicted in Figure 1.

By leveraging the RAN, MEC improves latency - by bringing computing services closer to the network edge (i.e., proximity) - and bandwidth utilization, reducing network congestion and optimizing overall performance, improving the user experience [16], [17], [19], [97]. Through interoperability, MEC can benefit from the high real-time data transfer and processing speed offered by the 5G network [18], [98]. The integration of MEC and 5G also improves network reliability and security for better quality of service [17], [18], also safeguarding data from cyber threats. In addition, scalability and cost reduction allow companies to expand or contract services without incurring high costs [89]. As the use of Internet of Things (IoT) devices [99], autonomous driving and critical applications increases [100], the above aspects become stringent [19], [101].

IV. OBJECTIVES

The purpose of this work is to present an overview of the current state of the art of GISs, from the use of traditional GIS to its evolution with integration with new network architectures (such as Cloud-GIS and MEC-GIS) to exploit their features.

The research activity was motivated by the wide use of geodata in various operations and numerous applications, that relate to: engineering, planning, management, transport/logistics, insurance, telecommunications, and business. Traditionally, cartography has been used to represent the Earth's surface and gain comprehensive knowledge of the territory. GIS has evolved over time by integrating location data (where things are) with all kinds of descriptive information (what things are like at that location), that goes beyond digital cartography and paves the way for the study of terrestrial human and natural phenomena. This GIS key feature has begun to open up new avenues for scientific studies. For example, if we consider a scenario in which the geographic map is enriched with information representing jurisdictional boundaries, land ownership and designated use: the result is a thematic map, produced with GIS software, that aids decision-making processes in urban planning in a cadastral office.

We define our research questions as:

- *RQ1 Who uses GIS?*
- *RQ2 Why is GIS used?*
- *RQ3 How is GIS used?*

The ultimate goal of the survey is to provide a novel research contribution consisting of the classification of GIS use cases - which currently does not exist in literature - useful to all decision makers who are considering adopting GIS technology in their processes or are already using it in their operations and want to improve its performance. Hence, this work conducts a comprehensive survey of GIS applications in the real world and their functionalities. Through the listed use cases, we explore the possible benefits of integrating GIS with cloud-edge computing (moving from CC to MEC) and 5G connectivity, highlighting strengths, weaknesses, and challenges for the future.

V. RESEARCH METHODOLOGY

A. SEARCH PROCESS

An extensive search process, combining automated and manual searches to increase coverage, was conducted to identify peer-reviewed papers published (or available online) up to 02 2022. The search process used search engines and indexing systems such as ACM Digital Library, IEEE Xplore, Scopus, Science Direct, SpringerLink and Google Scholar. Search was also conducted on Conference Proceedings and ResearchGate's scientific network. In addition, the bibliographies of all selected papers were scanned for additional papers. The search terms used were (GIS OR Cloud-GIS OR MEC-GIS) AND (survey OR systematic review OR literature review OR structured review OR overview of existing research) AND (use cases OR applications OR sectors). Adjustments were made to accommodate the syntax of the search engines used.

B. INCLUSION/EXCLUSION CRITERIA

Publications were included if they:

- reported GIS or Cloud-GIS or MEC-GIS adoption and were written in English;
- were published in, or submitted to, an international conference or journal or were technical report or book chapter. Articles related to the following were excluded:
- Masters and PhD studies not published in refereed conferences or journals;
- informal literature surveys (no defined search questions, no search process).

C. PUBLICATIONS SELECTION

We evaluated the papers resulting from the automatic and manual searches and, after considering the title and abstract, discarded all those that were not relevant. After also reading the conclusions of the selected papers, and based on the inclusion and exclusion criteria, we obtained 51 publications considered appropriate to be included in our study.

D. DATA EXTRACTION

The answer to the initial question is determined by the specific discipline from which the georeferenced attributes originate, such as health care, agriculture, industry, logistics, tourism, and others. The motivation behind the use of GIS is shared by all disciplines and, as mentioned above, revolves around understanding geographic relationships and context to improve decision making by decision makers, regardless of sector. The last question is about the technical aspects of the GIS, which include how to use the GIS and how to deploy it, whether through a conventional (local) client-server architecture or a distributed cloud-based approach. There is currently no predefined standard for GIS, as the development phase, software selection, and deployment approach depend on specific use cases. Each use case has different requirements in terms of latency, Quality of Service (QoS), reliability and scalability, which can be met by carefully choosing a network architecture that supports the computational processes underlying GIS. This research work used this criterion, classifying papers according to the entities using GIS and differentiating their areas of application. Table 1, which presents the classification of 51 scientific publications, serves as a guiding model for organizations wishing to adopt GIS in their processes or improve in the use of GIS.

Table 1 offers the following insights:

- given an authority, it highlights the domains in which GIS can be applied;
- given a scope, it outlines the various network architectures that can be implemented.

Since there are no predefined standards, all information was analyzed according to:

- Type of scientific contribution (see Figure 2)
- Type of work (i.e., suggestive - applied)
- Technology (i.e., model - software)
- Solution (i.e., proprietary - open source)
- Use case (see Figure 4)
- Geographical reference area (see Section VI-B)

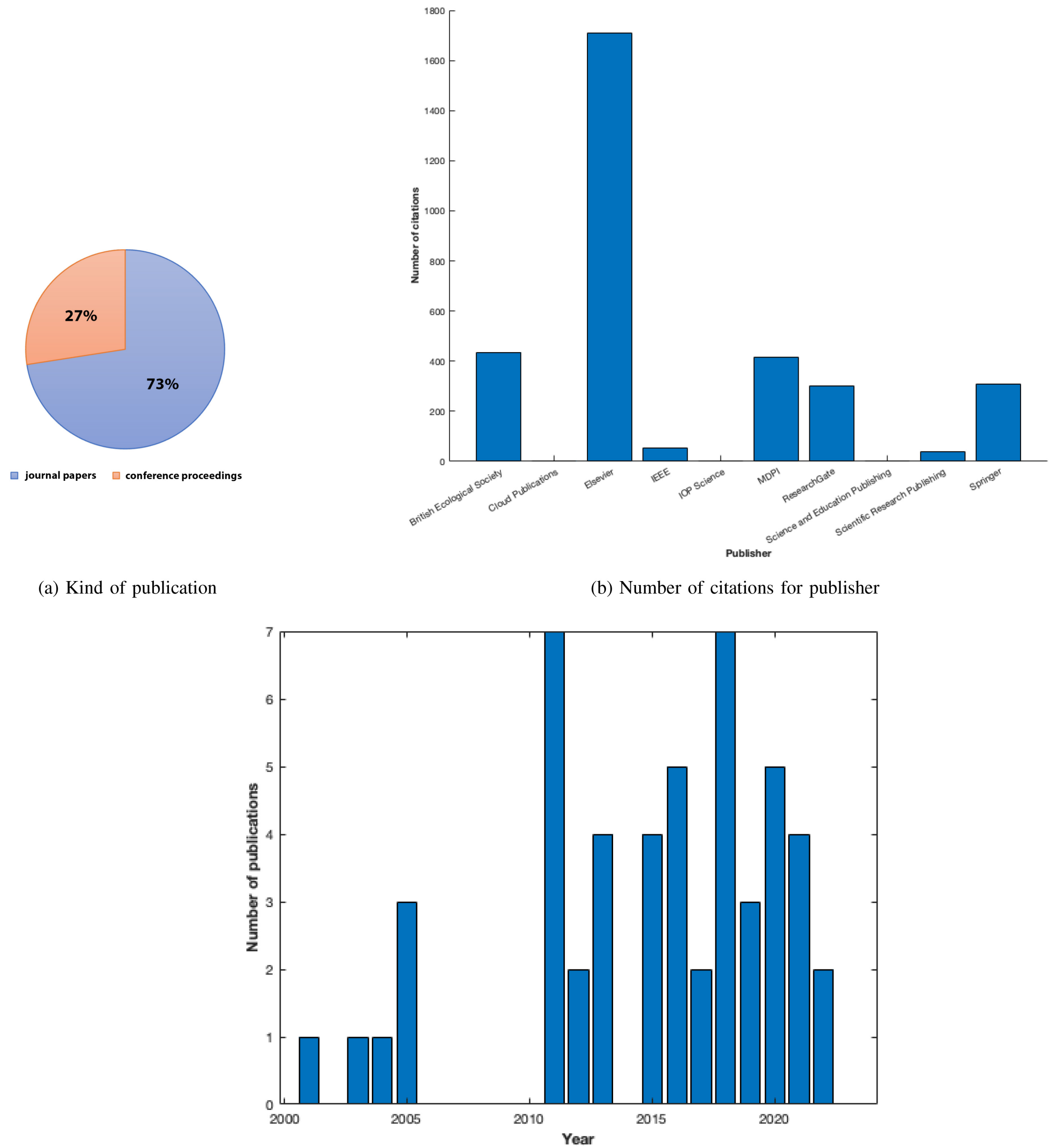
To facilitate the analysis of the data obtained from this research work and to enable a comparison between different papers, Table 1 was constructed, in which each paper examined is labeled with the topics covered.

VI. DATA ANALYSIS

A. TYPE OF SCIENTIFIC CONTRIBUTION

Figure 2 reveals scholarly interest in GIS technology in conjunction with the widespread adoption of CC. The papers reviewed dating back to the early 2000s focused mainly on methodology, while applications in different sectors gained momentum in the second half of the 2010s. Development of experimental solutions is ongoing. Specifically, three main factors were considered in Table 1 for the selected papers:

- *Kind of publication* is split into papers published in journals, which account for the majority, and the remaining 27 percent are papers presented at conferences or book chapters, as in Figure 2(a).



(a) Kind of publication

(b) Number of citations for publisher

(c) Year of publication

FIGURE 2. Type of Scientific Contribution.

- *Year of publication* provides an overview of the evolution of interest, studies, and developments in the area of GIS. Figure 2(c) illustrates the distribution of papers over the years, showing an increase in WebGIS related publications since 2011, peaking in both 2011 and 2018.
- *Number of citations* varies depending on the access source, as in Figure 2(b).

B. GEOGRAPHICAL REFERENCE AREA

The "Geographical area" column in Table 1 shows the countries that contribute to Cloud/MEC-GIS research through publication of papers. Figure 3 illustrates that China and African countries are the main contributors, each with 21.7 percent of publications. This is followed by India with 13 percent of the reviewed papers, with the rest coming from institutions in Greece, Turkey, Saudi Arabia, Malaysia, Brazil, England, Norway and Jordan.

C. USE CASES

Review of the selected papers revealed that GIS technology is used on a daily basis to address various problems and improve processes. According to the Figure 4, the categories

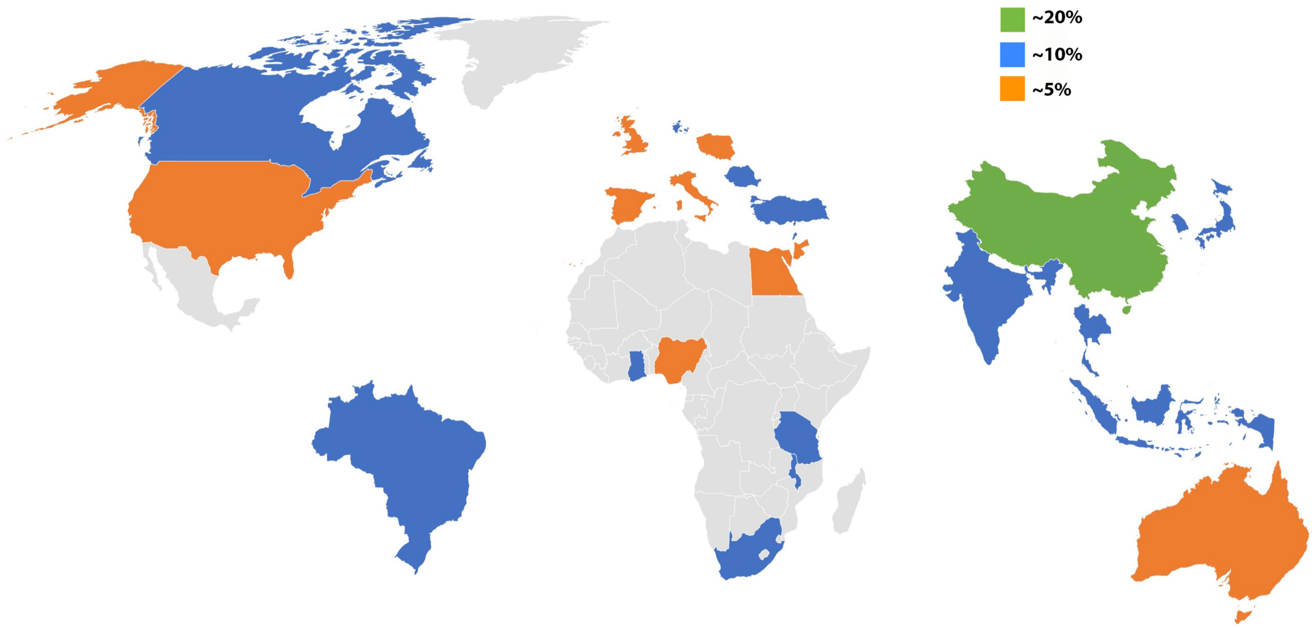


FIGURE 3. Distribution of papers by country.

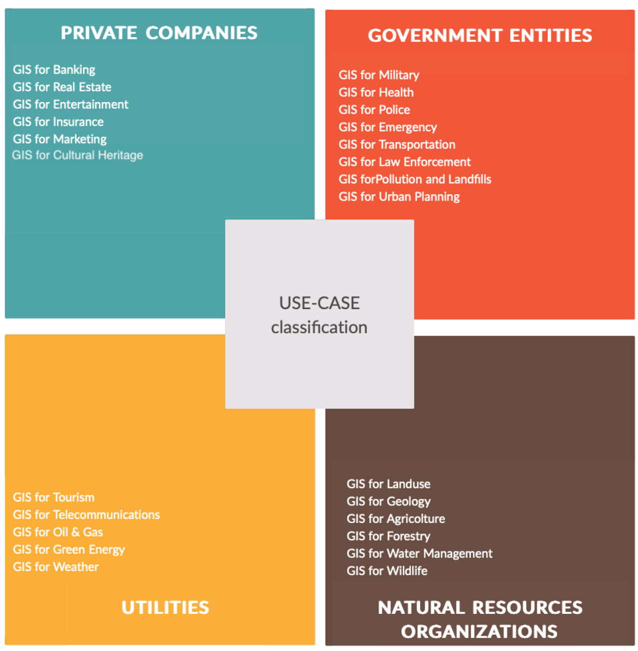


FIGURE 4. Use Cases classification.

of users who benefit from GIS are: (1) Government Entities; (2) Private Companies; (3) Natural Resource Organizations; and (4) Utilities.

1) GOVERNMENT ENTITIES

Government Entities use GIS in various areas. Examination of these papers reveals a common goal: to improve the well-being of citizens, encompassing both socio-cultural and environmental aspects. To achieve this goal, GIS is used to quickly analyze complex scenarios, leading to the identification of the following areas of application, as observed in the analyzed papers.

- *GIS in Health:* In tropical countries such as Ghana, malaria-related health problems have become a significant concern. The disease is transmitted by different species of mosquitoes, and its prevalence is influenced by environmental factors such as humidity and latitude. To address this problem, researchers have used GIS technology to map areas at high risk of infection, with the goal of improving malaria control and health care delivery [102].
  Similarly, in Egypt, the implementation of a comprehensive strategic health plan was facilitated by the integration of a GIS system. Previously, the absence of a unified health platform had led to inefficiencies in the collection of spatial health information, resulting in inadequate allocation of resources. With the help of GIS [103], a network route map was created to efficiently serve health districts, identify locations for new hospitals in underserved areas, and optimize drug delivery services.
- *GIS for Defense:* GISs are widely used in defense forces because of their data integration capabilities, analytical tools and decision support in essential functions. The system's ability to ensure a constant exchange of data between headquarters and the individual agencies using the service is particularly crucial, as it enables rapid decision making and implementation of actions. Access to GIS software and availability of geospatial data have become key requirements for the armed forces. However, the development and operations of police

departments in developing countries are hindered by the lack of GIS and Global Positioning System (GPS) infrastructure, mainly due to the high costs associated with purchasing proprietary software licenses, training personnel, and infrastructure hardware components.

The application of GIS in police departments is covered in "Ducks 7/8". For crime mapping, a cost-effective decision support software solution is proposed that can be accessed from any computer connected to the Internet. The software uses Google's cloud and GIS technology to combine spatial data from GoogleMaps with non-spatial data captured through Really Simple Syndication (RSS) feeds from various news websites, enabling crime analysis and crime prevention strategies tailored to specific locations without the need for GPS support.

In the military, accurate geographic information is critical to mission success. While proprietary software GIS is commonly used, paper [104] analyzes the feasibility of open-source software such as QGIS as a cost-effective alternative. The research, conducted in South Africa, involved a Military Operations Other Than War (MOOTW) military operation simulating a cholera outbreak. The results indicated that the results of QGIS and ArcGIS (which is proprietary software instead) were equivalent for mission planning, suggesting that open-source software is a viable solution, especially for operations with budget constraints and limited notice.

For forensic investigations in police departments, digital evidence often has a geospatial component. Paper [105] proposes tailored Forensic GIS software designed to meet the specific needs of investigators. The paper presents the components and system architecture of the proposed software, along with implemented and tested use cases.

Emergency services rely heavily on GIS to manage the risks of environmental damage and simplify rescue operations. Paper [106] explores the combined use of GIS and Building Information Modeling (BIM) for flood management. By combining the large-scale representation capabilities of GIS with the comprehensive building details of BIM, a detailed analysis of the impact of flooding on individual buildings can be made. This improves the sensitivity and accuracy of flood damage assessments, helping decision making to increase resilience against flood impacts.

Resource allocation in response to environmental disasters is discussed in paper [107]. The paper proposes a framework based on GIS that facilitates the allocation of support equipment. Through mobile devices, field personnel can request resources and the geospatial database supports a resource repository. Using GIS, the framework optimizes resource allocation by determining the optimal path, thus improving the efficiency of rescue operations.

- *GIS for Transportation:* The accessibility of transportation services, such as streetcars, subways, and railways, plays a vital role in society by providing access to vital services such as jobs and health facilities. It also facilitates tourists' travel to explore various attractions. The choice of transportation mode also has a significant impact on the sustainability of urban areas. Paper [108] proposes a GIS system, tested in London, that calculates accessibility based on users' costs for various travel options: public transport, private cars or sustainable means such as bicycles. In addition, the system helps authorities make informed decisions on investments in new sustainable infrastructure to reduce CO_2 emissions and ensure accessibility to a wider range of users.
- *GIS for Pollution and Landfills:* A city achieves sustainability when the waste management chain functions seamlessly, meeting the needs of both citizens seeking adequate waste disposal facilities and municipal authorities responsible for efficient collection and timely intervention in case of complaints.

  In this context, the Government of India, as mentioned in [109], has made available a system GIS to citizens and waste officers. This system allows for reporting, monitoring, and visualizing the location of solid waste. Citizens can file complaints using a geo-locator to locate the area that needs attention, while municipal employees can efficiently coordinate action based on accurate information, exceeding what a telephone complaint could offer.

  Another crucial responsibility of government agencies is to ensure healthy air quality for citizens by monitoring and regulating pollutant levels within legal limits. The main sources of pollutants are vehicle exhausts and factory emissions, particularly nitrogen oxides. In Thailand, for example, where industrialization is at its peak, a pollution monitoring system is still lacking, but in [110] a system is proposed GIS for real-time air quality mapping. The Department of Pollution Control (PCD) uploads data from high-pollution areas in real time, making it accessible to ordinary citizens through a simple browser. Similarly, in Korea, a framework presented in [111] leverages cloud computing platforms for air pollution mapping.
- *GIS for Urban Planning:* Urban planning is a discipline concerned with designing and organizing urban areas to create sustainable, functional and quality communities. Its main goal is to meet the needs and aspirations of residents, workers and visitors. Through strategic planning, urban planners seek a balance between the social, economic and environmental aspects of a city or area. They analyze demographics, social trends, local economies and other factors to understand community needs and challenges. Based on this information, they develop plans and strategies for future development, including

the location of housing, public services and mobility improvements. Urban planning is also concerned with environmental protection, heritage conservation, risk management and sustainable development.

Over the years, urban planning has evolved from the separation of urban functions (residential, commercial, industrial zones) to an integrated approach that prioritizes people's quality of life. This is where systems GIS play a crucial role in decision making.

In [112], a study focused on optimizing the location of satellite cities in rapidly changing urban areas using the Saaty model and features GIS. Suitability maps were also created for water, power lines, roads, communication lines, elevation, slope and land use.

Authors in [113] explored groundwater flow systems and their connection with the distribution of chemical facies, with the support of GIS. This approach offers significant advantages, such as separating drinking water from non-potable water and managing groundwater for various uses through understanding the chemical composition of water.

2) PRIVATE COMPANIES

The use of GIS by private companies offers numerous benefits, ranging from business planning to resource management, from competitive analysis to identification of new investment opportunities, from market analysis to customer segmentation. These advantages enable private companies, including museums, banks, gambling houses, and others, to make strategic decisions, customize offerings for customers, and improve marketing and general business operations.

- *GIS in Entertainment*: Using GIS in the entertainment industry offers several benefits, such as improving event planning, enhancing the customer experience through personalization, optimizing venue management, and making location-based decisions to increase the success of entertainment initiatives. However, current systems GIS provide only two-dimensional representations, limiting the immersive entertainment experience. To solve this problem, it is necessary to switch to 3D image representation.

  In [114], a system for automatic construction of 3D road networks is proposed. It combines a traditional GIS, which provides two-dimensional maps, with a 3D visualization system that builds objects from real images. The integration between the GIS and Virtual Reality (VR) systems is tested, where the former provides maps from elevation data, satellite images and 2D road median data, while the latter transforms them into three-dimensional representations.

  Although GIS integrated with VR equipment operates on a three-dimensional spatial plane, it lacks the temporal component usually provided by Temporal Simulation Systems (TSS). To address this challenge, a group of Swedish researchers seeks to model, analyze, and visualize landscapes in all three dimensions [115].
- *GIS in Insurance*: GIS and insurance are closely interconnected in the forestry sector. With GIS, valuable information such as the distribution of forest resources, high-risk areas, and geographic features can be visually represented. This allows for more in-depth analysis, significantly improving risk assessment, planning of forestry activities, and policy underwriting.

  The study described in [116] focuses on creating a GIS specifically designed to identify optimal insurance policies in the forestry sector. The developed model includes three modules: the first calculates economic damages, the second evaluates the annual probability of environmental disasters (e.g., flood, fire), and the last module calculates the policy price for potential underwriting based on forest site characteristics.

  To assess the reliability of the GIS, the researchers conducted tests by analyzing potential insurance contracts at the regional and national levels in Italy. The results obtained validated the effectiveness of the system in generating meaningful insights for forest insurance.
- *GIS for Marketing*: Companies can gain numerous advantages by incorporating GIS into their operations, as these systems provide a geographic perspective of business information. This contributes significantly to improved business operations and strategic decision making, ultimately leading to a substantial competitive marketing advantage.

  The use of GIS enables companies to operate in a variety of ways. For example, they can conduct market analysis and planning, efficiently manage resources and operations, analyze potential locations of new facilities, effectively manage infrastructure, assess risks, optimize transportation and logistics, conduct demographic studies, conduct market research, and more. In [117] the authors specifically address some of these applications of GIS in the business context.
- *GIS for Banking*: The use of GIS in the banking sector presents numerous opportunities to improve operational efficiency, enable location-based decision making, and provide personalized services to customers.

  In [118], one of the analyzed use cases of GIS concerns risk management and fraud prevention in the Kenyan banking sector. When a customer applies for a loan, they offer real estate and/or land as collateral, which the bank can seize if the borrower fails to repay the loan.

  The bank GIS tested in Kenya aims to display the location of bank assets and assess their corresponding collateral value. This system streamlines the paperwork processing process. Without the use of this GIS, the required documents and files are paper-based, increasing the risk of loss and human error. In addition, verifying the authenticity of documents and checking defaulting clients at other financial institutions is time-consuming.

By integrating this system with other databases of information from different branches and departments, the bank can verify the identity of customers, evaluate the collateral offered, and speed up the decision-making and paperwork associated with these files.

- *GIS for Cultural Heritage (CH)*: Advances in technologies have had a significant impact on the cultural sector, playing a key role in the preservation and promotion of cultural heritage. A specific goal is to replace traditional paper-based methods of management and documentation used in archaeological sites and museums with a more sustainable and efficient solution. Poland has implemented a noteworthy approach, as described in [119], where a comprehensive GIS is used to manage the cultural heritage of the Wilanow Palace. This information system comprises eight modules, each of which houses distinct data, including room plans, archaeological artifacts, scans of historical maps, and documentation of objects through 3D images. The GIS incorporates a monitoring system for cultural heritage protection. This system integrates data collected from sensors scattered around the area, such as temperature, humidity, and the presence of dust, which are then stored and displayed on the Wilanow building map.

3) NATURAL RESOURCES ORGANIZATIONS

Natural resource organizations, such as environmental agencies, nature conservation organizations, National Parks, forestry companies, and water management companies, find great value in GIS. It offers a holistic view of environmental conditions, aiding planning and resource management and facilitating public communication. Adoption of GIS enables more efficient and sustainable management of natural resources, promoting conservation and protection of ecosystems.

- *GIS in Land Use:* The GIS is used to understand land use patterns, assess the suitability of areas, identify conflicts, and involve the public in decision-making processes. In a specific study conducted by [120], the GIS was used to identify flood-prone areas around the M'Boyci River in Brazil and irregular urban settlements. The analysis incorporated census data, orthophotos, and topographic maps to define the boundaries of the affected area. Houses within the protected areas were identified, and the region was divided according to risk levels. The use of GIS facilitated planning for relocation of residents from high-risk areas and safeguarded conservation areas from human impact.
  A similar issue is addressed in [121], which involves the use of GIS to plan the development of new urban areas while preserving surrounding green spaces. Economic growth, including the expansion of factories, has driven the population to migrate to urban centers such as the city of Trabzon in Turkey. The resulting increase in population density has led to changes in land use, with housing development extending from the city center to its suburbs, including the conversion of formerly green areas for other purposes.
- *GIS in Agricolture:* GIS for agriculture is a technology that combines geographic data and agronomic information to help agricultural professionals make decisions. It is used for land resource management and agricultural planning, enabling farmers to optimize practices, increase productivity and minimize environmental impact.
  The integration of data from various sources, such as satellite imagery, weather, soil information and crop data, into GIS for agriculture creates digital maps. These maps enable farmers to analyze spatial and temporal patterns, providing a comprehensive understanding of agricultural conditions and identifying areas that need attention.
  Benefits of GIS in agriculture include resource management, monitoring crop development, crop planning, and optimizing product distribution by identifying areas of demand and optimizing transportation.
  For example, in [122], water resource optimization is addressed by combining edge computing and data GIS to create a forecasting model for irrigation areas. This model helps identify the optimal location, quality and quantity of water resources for sustainable development. The proposed model ensures quality water supply by taking into account water conditions, conservation projects and specific demand requirements.
  In [123], image processing and the capabilities of GIS, especially ArcMap, are used to dynamically generate the spatiotemporal situation of Land Use/Land Cover (LULC). These data are then used to assess the suitability of land for agricultural purposes.
- *GIS for Wildlife:* In the context of wildlife, GIS plays a crucial role in collecting, organizing, and analyzing data on habitats, species distribution, migratory movements, protected areas, and other factors that influence wildlife life and behavior.
  The authors in [124] demonstrates the use of predictive models for the bustard in central Spain. These models use satellite imagery Advanced Very High Resolution Radiometer (AVHRR), along with mapped features represented as data layers GIS.
- *GIS in Geology:* GIS plays a key role in geology, enabling scientists to efficiently collect, analyze, and visualize geological data. It finds diverse applications in the field, including soil and natural resource analysis, detailed geological mapping, examination of geological structures such as faults and folds, assessment of natural hazards such as volcanic events, landslides and earthquakes, and mineral resource management. As a result, GIS significantly improves scientists' understanding of geologic features, natural resources, and associated hazards, enabling effective resource planning and management.

In [125], one of the case studies focuses on creating workspaces for field surveys at a limestone mining facility in Poland using ArcGIS online and collector for ArcGIS.

In [126] the authors present the implementation of a WebGIS support system to explore the integration of Spatial Multi-criteria Analysis (SMCA) and Fuzzy Structure Modeling (FSM) to identify an ambiguous preference structure in the creation of livable environments. This system has interactive user interfaces that facilitate the manipulation of spatial and statistical information.

- *GIS in Forestry:* The application of GIS technology to forest management enables a comprehensive understanding and effective use of forest resources. It involves a variety of tasks, from creating maps to visualize forest extent and cover types, to assessing tree health, detecting diseases or pest infestations, and analyzing factors affecting forest growth. Urban forests are particularly important because of their ability to absorb atmospheric CO_2 through photosynthesis, storing carbon in trunks, branches and soil. An example of the application of GIS in forestry can be found in [127], where a GIS application was developed to monitor and protect green areas. This application uses a database containing information on all plant species and their spatial attributes, enabling forest management administrators to optimize green areas to provide environmental services to citizens.
- *GIS for Water Management:* The primary goal is to ensure equitable, sustainable and efficient use of water resources to meet current and future needs. GIS plays a key role in achieving this goal by enabling the creation of maps that visualize the spatial distribution of water resources, including rivers, lakes, watersheds, and groundwater. In addition, GIS facilitates the integration of data from different sources to monitor the status of water resources in real time, such as available water quantity, river levels, and water quality. For example, an GIS approach was proposed in [128] to identify areas at risk and estimate water collection within rock cavities in western Lebanon. Remote sensing was combined with GIS, allowing better extrapolation of details and faster updating of information.
- *GIS in Maritime Sector:* In the context of the Maritime Spatial Planning (MSP), the GIS is used to manage and plan activities in maritime spaces. Managed data include information on use zones, jurisdictional boundaries, biological resources, fisheries, shipping lanes, and protected areas. The study in [129] focuses on improving collaborative MSP using GIS. It consists of five steps: identifying the shortcomings of current GIS for collaborative MSP, defining the requirements for an effective Collaborative GIS (CGIS) (Collaborative GIS) in MSP, developing a prototype CGIS called Baltic Explorer, testing the system, and evaluating the results. During a workshop on MSP, Baltic Explorer demonstrated its ability to facilitate discussions and collaboration. It also identified new areas of research, such as using spatial data in a collaborative MSP and integrating model-based geospatial analysis into CGIS.

4) UTILITIES

With GIS for utilities, which cover water, gas, electricity and telecommunications supply management, organizations can gain a spatial perspective of their assets, facilitating better planning, management and maintenance of infrastructure. It also supports network performance analysis, enabling monitoring and evaluation of operational efficiency and service reliability. For example, it can identify energy-intensive regions or optimize network routing to minimize water or gas leaks.

- *GIS in Oil & Gas Sector:* GIS plays a key role in the oil and gas industry by facilitating the integration and analysis of geological, topographical, and geospatial data to identify and evaluate potential areas for oil and gas exploration and production. It also helps plan drilling sites and analyze ground, landscape, and water conditions. The geospatial information acquired enables well-informed decisions on the location of production facilities, transportation networks, and necessary infrastructure. As a result, the GIS significantly improves the efficiency and accuracy of oil and gas extraction operations, promoting optimized resource management and reducing negative environmental impacts. The authors in [130] use a remote sensing system that collects data and maps it through a GIS system.
- *GIS for Green Energy:* With the application of GIS for green energy, specific information on renewable energy resources, such as solar irradiance, winds, and water resources, can be visualized through interactive maps. Energy operators can use these maps for a variety of purposes, including identifying suitable sites for renewable energy facilities, planning the layout of such facilities within an existing energy grid, analyzing the environmental impacts associated with renewable energy projects, monitoring the efficiency and performance of existing facilities, and more.

  In [131], the focus is on providing energy access to underserved populations, with Nigeria as a reference case. The GIS was used to determine the optimal electrification strategy. The results revealed clear advantages in managing electrification strategies when such a system is adopted.

  In [132], on the other hand, the authors studied the use of a GIS for planning wind energy projects in Poland. The study involved the analysis of available sites according to the criteria of spatial and ecological regulations.
- *GIS for Tourism:* GIS proves to be a powerful tool in the tourism industry, enabling the management and analysis

of geographic data to present a comprehensive and integrated perspective of a particular region's tourism resources. By combining maps, satellite imagery, spatial information and socio-economic data, informed decisions on planning, development and promotion of tourism destinations can be made.

These systems play a crucial role in identifying and evaluating a region's tourism resources, including natural attractions, cultural sites, tourism infrastructure, and tourist routes. This information is invaluable for planning new attractions, developing existing resources sustainably, and effectively managing tourism offerings. In addition, the GIS facilitates the analysis of demographic data, travel trends and visitor behavior, helping to identify profitable market segments and enabling adaptive marketing and promotion strategies for tourism destinations. This, in turn, increases the ability to attract tourists.

Recent developments in the field of GIS, such as WebGIS and Cloud-GIS, are increasingly providing tourists with geographic data relevant to their decision making. These technologies enable tourists to make well-informed and personalized choices when planning their trips.

For example, the paper [133] shows the increasing use of GIS systems to provide tourists with geographic data relevant to their decision making. Similarly, the paper [134] focuses on the development of a Web- and mobile-device-based GIS for Place of Worship Information (GPWI), which facilitates Muslim tourists in locating mosques and other tourist attractions in Bukittinggi, an Indonesian city. The system allows tourists to search for mosques based on specific criteria and provides detailed information on their location, route, and available transportation.

Reference [135] explored the use of spatially explicit participatory planning to manage visitors in protected areas, focusing on cyclists frequenting national parks in northern Sydney, Australia. Public Participation Geographic Information Systems (PPGIS) or Participatory GIS (PGIS) devices and GPS were used to monitor cyclists' activities. Data collected through PPGIS showed a strong correlation with GPS location results, illustrating how cyclists' route choices are influenced by their geographic location and specific reasons for their route choice.

- *GIS in Telecommunication:* The paper [136] presents Net2Plan-GIS, an open-source extension of Net2Plan, a network planning tool. This extension allows importing data from databases GIS to address network planning problems concerning city infrastructure. The authors present a case study using this extension to analyze GIS data (managed with QGIS software) from Cartagena, Spain. The analysis involves estimating traffic demand and antenna locations for the preliminary sizing of a 5G backhaul segment. For this purpose, the sizing problem is formulated as an Integer Linear Programming (ILP) problem, using infrastructure data as input and optimizing cost reduction within the constraints of the scenario in question.
- *GIS in Meteorology & Weather Forecasting:* GIS plays a key role in meteorology and weather forecasting, benefiting climate scientists and meteorologists in several ways. First, it enables the collection of weather data from such diverse sources as weather stations, satellites, radar, and numerical weather prediction models. This data is then organized and georeferenced for analysis and visualization in a spatial context, leading to the creation of more accurate forecast models. The resulting interactive maps help forecasters and end users make informed decisions based on weather forecasts.

  Another vital function of GIS is conducting spatial analysis of weather data. Climatologists and meteorologists can identify precipitation patterns, compare historical data with real-time information, and evaluate wind patterns in specific regions. This spatial approach deepens the understanding of atmospheric phenomena and their connection to geography.

  In addition, the GIS proves indispensable in the management of climate-related emergencies. During extreme weather events such as hurricanes, floods, or fires, it facilitates monitoring of changing weather conditions, identification of high-risk areas, evacuation planning, and coordination of relief efforts.

  A notable application developed in this area is HydroShare GIS. It offers a cloud-based visualization of spatial data from HydroShare, a Web-based system for climate and water data management. The design and technology infrastructure that support HydroShare GIS are described in [137], and its effectiveness has been examined in depth.

D. TECHNOLOGY

1) TRADITIONAL GIS

Traditional GIS are closed, centralized systems that incorporate interface, programs, and data. Each system depends on the platform and application. Each element is embedded in the traditional GIS and cannot be separated from the rest of the architecture. The traditional GIS functions as a standalone system.

2) CLOUD-GIS

With regard to Cloud-GIS, the main focus is on clarifying the different delivery models inherent in cloud services. The benefits of this approach are considerable. This methodology enables the delivery of services to enterprises on a scale that can expand significantly, dramatically shortening implementation time. With CC, customers can leverage pre-existing infrastructure for application deployment, saving them the complexities of managing hardware (machines and network configuration) and software (operating systems, databases and software). These infrastructures are provided by vendors

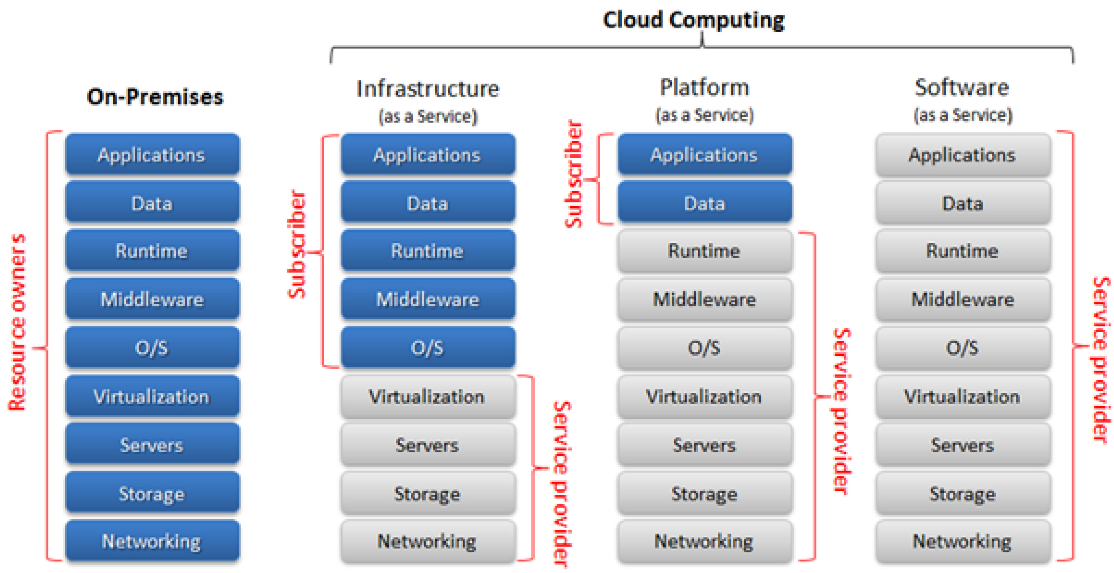


FIGURE 5. Cloud services delivery models [138].

whose specifications are in line with customer requirements. These attributes consequently influence the financial aspects of the services provided. In addition, these characteristics determine the division of the infrastructure into three distinct categories [13], [138], as illustrated in Figure 5:

- *Infrastructure-as-a-Service (IaaS):* In this model, the vendor assumes responsibility for the hardware, as in the case of AWS and Azure. Customers are in charge of machine configuration, which includes security considerations (e.g., setting up firewalls), operating system selection, software selection, database configuration, and technical specifications necessary for seamless application deployment.
- *Platform-as-a-Service (PaaS):* This model presents a dynamic platform adaptable to customer service needs. It is complete with Operating System (OS), software stack, programming languages, server and database. In particular, developers enjoy a significant advantage in software deployment. Their focus is on proprietary Application Programming Interfaces (APIs) designed to run within specially designed hosting platforms. As a result, customer outlay for purchasing and administering hardware and software is greatly reduced. Their responsibilities are primarily directed toward application configuration (e.g., encapsulation within a Docker container) to enable their application to be exposed on the network.
- *Software-as-a-Service (SaaS):* This model directly involves the distribution of software through Web services, accessible through a browser without the need for installation. Illustrative examples include online storage providers (such as Dropbox), Microsoft 365 suite, online banking services, and webmail providers (such as Gmail). Such services allow users to interact with mailbox management software through a browser interface.

Further differentiation can be established based on the nature of the distribution [13]:

- *Public Cloud:* In this scenario, the cloud service provider oversees the infrastructure and offers it to multiple (universally accessible) companies or users. These users are charged based on the services they use, according to a pay-per-use model.
- *Private Cloud:* The service provider supplies the customer with exclusive and secure access to the necessary on-premises cloud infrastructure, which the customer can tailor to his or her specific needs.
- *Hybrid Cloud:* This deployment method combines elements of both types mentioned above. For example, a customer can deploy its application in the private cloud and, when faced with a sudden increase in user demands, seamlessly expand computing resources by deploying them in the public cloud as well. This approach ensures flexibility and responsiveness to varying levels of demand.

The choice of cloud deployment model is determined by the desired level of control and scalability. For example, a private cloud is chosen to ensure maximum security for the customer, while a public cloud is chosen when multiple instances of the service need to be deployed to handle a substantial increase in connection requests.

3) MEC-GIS

Modern smart community related services generate various types of geospatial data in real time. These data, collected through physical and social sensing, together with modern remote sensing technologies, collectively contribute to what is increasingly referred to as the urban “digital twin”, playing a key role in the development of smart communities.

TABLE 1. Classification of Selected Papers.

#	Authors	Publication details			Work type		Technology		Solutions		Use case	Area
		Editor	Year	Citations	Suggestive	Applied	Model	Software	Proprietary	Open Source		
1	Mayunga et al. [112]	Scientific Research Publishing	2018	3		✓					GIS for Urban Planning	Tanzania
2	Nur et al. [113]	Scientific Research Publishing	2012	27		✓		✓	✓		GIS for Urban Planning	Nigeria
3	Ankrah et al. [102]	Scientific Research Publishing	2016	0		✓					GIS in Health	Ghana
4	Chikumba et al. [143]	Science and Education Publishing	2018	1		✓					GIS in Health	Malawi
5	Singh et al. [109]	Cloud Publications	2016	2		✓		✓		✓	GIS for Pollution and Landfills	India
6	Helmi et al. [103]	Elsevier	2018	35		✓	✓				GIS in Health	Egypt
7	Singh et al. [144]	ResearchGate	2012	13	✓			✓	✓		GIS for Law Enforcement	-
8	Henrico et al. [104]	ResearchGate	2020	3		✓		✓	✓	✓	GIS for Law Enforcement	South Africa
9	Neteler et al. [145]	Elsevier	2011	830		✓		✓			GIS in Health	Italy
10	Ford et al. [108]	MDPI	2015	190		✓		✓			GIS for Transportation	UK
11	Tillekens et al. [105]	IEEE	2016	17		✓		✓			GIS for Police Departments	-
12	Pummakarnchana et al. [110]	Elsevier	2005	49		✓					GIS for Pollution and Landfills	Thailandia
13	Amirebrahimi et al. [106]	ResearchGate	2015	60		✓		✓			GIS for Emergency Services	Australia
14	Chen et al. [107]	Elsevier	2011	101		✓		✓			GIS for Emergency Services	USA
15	Park et al. [111]	IEEE	2011	12		✓		✓			GIS for Pollution and Landfills	South Korea
16	Franchi et al. [146]	IEEE	2019	12	✓		✓				GIS for Emergency Services	-
17	Gattulli et al. [147]	IEEE	2022	7		✓	✓				GIS for Emergency Services	-
18	De et al. [120]	Scientific Research Publishing	2016	2		✓					GIS In Land-use	Brazil
19	Li et al. [122]	ResearchGate	2021	4		✓					GIS in Agricolture	China
20	Osborne et al. [124]	British Ecological Society	2001	435		✓		✓			GIS for Wildlife	Spain
21	Nowak et al. [125]	Elsevier	2020	65		✓		✓			GIS In Geology	Polonia
22	Sakamoto et al. [126]	Springer	2004	48		✓		✓			GIS In Geology	Japan
23	Aymen et al. [123]	Elsevier	2020	58		✓		✓			GIS in Agriculture	Jordan
24	Tasoulas et al. [127]	Elsevier	2013	2		✓		✓		✓	GIS in Forestry	Greece
25	Koski et al. [129]	ResearchGate	2021	8		✓		✓			GIS for Water Management	-
26	Selccuk et el. [121]	ResearchGate	2003	60		✓					GIS in Landuse	Turkey
27	Shaban et al. [128]	Springer	2005	260		✓					GIS for Water Management	Lebanon
28	Huang et al. [130]	IEEE	2021	0	✓			✓			GIS in Oil & Gas Field	-
29	Mentis et al. [131]	Elsevier	2015	170		✓		✓		✓	GIS for Green Energy	Nigeria
30	Jovanovic et al. [133]	ResearchGate	2013	8		✓		✓			GIS for Tourism	-
31	Sliz et al. [132]	Elsevier	2011	113		✓		✓			GIS for Green Energy	Polonia
32	Afnarius et al. [134]	MDPI	2011	194		✓		✓			GIS For Tourism	Indonesia
33	Romero et al. [136]	IEEE	2018	13		✓		✓			GIS In Telecommunication	Spain
34	Crawley et al. [137]	ResearchGate	2017	8		✓	✓	✓	✓		GIS in Weather	USA
35	Wolf et al. [135]	Elsevier	2015	101		✓		✓	✓		GIS for Tourism	Australia
36	Wang et al. [114]	IOP Science	2021	0		✓	✓				GIS In Entertainment	China
37	Isenegger et al. [115]	Elsevier	2005	11	✓			✓			GIS In Entertainment	-
38	Sacchelli et al. [116]	Elsevier	2018	18		✓					GIS in Insurance	Italy
39	Azaz et al. [117]	ResearchGate	2011	14	✓						GIS for Marketing	-
40	Kuria et al. [118]	ResearchGate	2011	0		✓					GIS for Banking	Kenya
41	Tobiasz et al. [119]	MDPI	2013	1		✓	✓				GIS for CH	Denmark
42	Menccik et el. [148]	ResearchGate	2022	1	✓		✓	✓	✓		-	-
43	Al et al. [149]	ResearchGate	2017	10	✓		✓		✓	✓	-	-
44	Guo et al. [150]	MDPI	2020	28	✓		✓	✓	✓	✓	-	-
45	Ujang et al. [151]	Scientific Research Publishing	2013	5	✓						-	-
46	Zhang et al. [152]	MDPI	2019	4		✓	✓				-	China
47	Evangelidis et al. [153]	Elsevier	2013	140	✓						-	-
48	He et al. [154]	IEEE	2020	2		✓	✓	✓		✓	-	China
49	Alfaqih et al. [155]	ResearchGate	2016	3	✓		✓				-	-
50	Bhat et al. [156]	ResearchGate	2011	107	✓		✓	✓	✓	✓	-	-
51	Al et al. [157]	ResearchGate	2018	3		✓					-	Jordan

Urban data falls under Big Data - which has been described as "the mother lode of disruptive change in a networked business environment" [139] - and has the characteristics of volume, variety, veracity, speed, and value [140] that make traditional analysis on a single computer impractical due to memory and processing capacity limitations [141]. Thus, the capacity of the system is expanded by interconnecting numerous locally distributed computers through different high-speed communication networks, creating what is called MEC. This solution allows substantial portions of big data to be distributed among various computing nodes for task execution or data partitioning. In addition, analytical tasks can be partitioned into smaller tasks, which are executed in parallel on these nodes, improving the overall geoprocessing speed.

However, to achieve real-time visualization and analysis of urban data, a GIS must transcend conventional data analysis, in which data size takes precedence and batch processing is critical. Instead, a real-time GIS requires high throughput and minimal latency in receiving, storing, and managing streaming data arriving in real time. Throughput addresses the challenges of "speed" and "volume" in real-time big data, ensuring that the system can handle large amounts of data at high speed. Latency is concerned with the timeliness of geo-processing; a low-latency GIS quickly performs spatial queries/analysis, providing results in a short time. As a result, NoSQL (non-relational) databases and streaming architectures have emerged as cutting-edge solutions for real-time geoprocessing.

Above the real-time storage layer is the streaming architecture for real-time data processing. In [142] the authors propose a MEC-based service that can act as an exploitable Decision Support System (DSS) through GIS technology.

Another promising aspect of the multilayer architecture concerns its fusion with Machine Learning (ML) and spatio-temporal data mining to improve real-time intelligence and responsiveness in urban analysis. In a supervised learning context, the time-consuming model training phase can take place in the batch layer, followed by loading the well-trained model into the speed layer for real-time or near real-time predictions on incoming data. On a broader scale, the future of smart cities will increasingly rely on Artificial Intelligence (AI) and real-time processing for automation and improvement of urban service delivery, fostering better city governance, equity and sustainability.

VII. STUDY LIMITATIONS

This study is limited to exploring those aspects that are exclusively relevant to the adoption of MECs for GIS applications. To this end, the work specifically focuses on papers that delve into MEC architecture features directly relevant to GIS applications. This implies the exclusion of models exclusively associated with pure CC and papers that discuss MEC without any GIS context. The search for relevant papers was limited to a selection of major scientific databases, including ACM, Google Scholar, IEEE, Science Direct, Elsevier, and Springer.

Ultimately, the intent of this work was to respond to research questions and provide an overview of the current literature on the application of MEC in GIS.

The scope of this study is based solely on scientific papers, without exploring commercial or high-tech solutions.

VIII. CONCLUSION AND FUTURE OUTLOOK

The needs of contemporary society have led to the growing trend of adopting CC, which is playing a key role in enabling next-generation services, while GIS is proving its ability to handle geospatial data. As a result, the convergence of distributed computing and GIS is poised to give rise to smarter and more rational designs. This work undertakes a comprehensive review of studies related to Cloud/MEC and GIS, guided by two primary objectives: (1) to explore the individual and combined contributions of each technology, categorizing the studies into specific application domains, and (2) to examine the involvement of GIS in the Cloud-Edge architecture. The ability of GIS to manage geospatial data and attributes, coupled with real-time data collection and monitoring, makes it an appropriate solution to address many challenges.

The original contribution of this work, i.e., the use-case classification of GIS applications - hitherto unavailable - may prove invaluable to public and private decision-makers who are considering adopting GIS technology in their operational processes (including saving costs, a relevant aspect of public action) or who are already using it and want to improve its use, by integrating it with MEC technology to distribute and decentralize the service (optimizing performance in terms of effectiveness, efficiency, and transparency). The intent was to provide an overview of GIS applications to date, highlighting their possible benefits, and to show the growing interest of the scientific community in conducting research on GIS technology and its MEC integration to produce positive and innovative impacts on society.

There are four key areas that deserve attention for future research. First, the identification of new target areas that can benefit from an integrated system that simultaneously employs Cloud/MEC and GIS capabilities. Second, a concentrated effort on exploiting the full potential offered by Cloud/MEC and GIS to improve existing systems, making them more efficient and reliable. Although the integration of Cloud/MEC and GIS offers many advantages, it is crucial to thoroughly analyze the challenges posed by these new integrated systems.

The demand for geospatial data affects various fields, as shown by the papers analyzed in this survey, because they can lead to new insights, fostering progress. Those who decide to exploit GIS's capabilities must confront the specifics of geoinformation and the geoprocesses that generate it. Also, these specifications must meet the needs of the telecom network domain to leverage the benefits of the Cloud/MEC environment.

Finally, it is worth noting that temporal data, which represent states over time, have not been fully explored by previous authors. Therefore, it is recommended that future studies consider this type of data along with or in parallel with real-time data collection.

APPENDIX

A. ABBREVIATIONS AND ACRONYMS

ACRONYMS

AI	Artificial Intelligence
AVHRR	Advanced Very High Resolution Radiometer
BIM	Building Information Modeling
CC	Cloud Computing
CGIS	Collaborative GIS
DSS	Decision Support System
ETSI	European Telecommunications Standards Institute
FSM	Fuzzy Structure Modeling
GI	Geographic Information
GIS	Geographical Information System
GIST	Geographic Information Science and Technology
GPS	Global Positioning System
GPWI	GIS for Place of Worship Information
IaaS	Infrastructure-as-a-Service
ILP	Integer Linear Programming
IoT	Internet of Things
IS	Information System
IT	Information Technology
LULC	Land Use/Land Cover
MEC	Multi-Access Edge Computing
ML	Machine Learning
MOOTW	Military Operations Other Than War
MSP	Maritime Spatial Planning
NIST	National Institute of Standards and Technology
PaaS	Platform-as-a-Service
PGIS	Participatory GIS
PPGIS	Public Participation Geographic Information Systems
QGIS	Quantum GIS
QoS	Quality of Service
RAN	Radio Access Network
RSS	Really Simple Syndication
SaaS	Software-as-a-Service
SMCA	Spatial Multi-criteria Analysis
SOA	Service-Oriented Architecture
TSS	Temporal Simulation Systems
VR	Virtual Reality
WebGIS	Web Geographic Information System.

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