Title

A scoping review on the use, processing, and fusion of geographic data in virtual assistants

Carlos Granell, Paola Pesántez-Cabrera, Luis Vilches-Blázquez, Rosario Achig, Miguel Luaces, Alenjandro Cortiñas-Álvarez, Carolina Chayle, Villie Morocho-Zurita

Abstract

Virtual assistants are a growing area of research in academia and industry with an impact on people's daily life. Many disciplines in science are moving towards the incorporation of intelligent virtual assistants in multiple scenarios and application domains, and GIScience is not external to this trend since they may be connected to Intelligent Spatial Decision Support Systems. This article presents a scoping review to indicate relevant literature pertinent to intelligent virtual assistants and their usage of geospatial information and technologies. In particular, the study was designed to find critical aspects of GIScience and how to contribute to the development of virtual assistants. Moreover, this work explores the most prominent research lines as well as relevant technologies/platforms to determine the main challenges and current limitations regarding the use and implementation of virtual assistants in the geospatial-related fields. As a result, this review shows the current state of the geospatial applications regarding the use of intelligent virtual assistants, as well as reveals gaps and limitations in the use of spatial methods, standards, and resources available in Spatial Data Infrastructures to develop intelligent decision systems based on virtual assistants for a wide array of application domains.

Keywords

Scoping review, virtual assistant, geographic data, processing, fusion, decision support

1 Introduction

Amazon's Alexa, Apple's Siri, Google's Assistant and Google Home, and Cortana are well-known examples of intelligent virtual assistants created by big technological companies with a high market penetration (Mennicken et al., 2018). A recent study about these assistants has estimated that 111.8 million people in the U.S. use them for various routine activities such as work commuting, cooking, and searching on the Internet (Petrock, 2019). Therefore, it is clear that voice-activated assistants, also known as intelligent virtual assistants, are a growing area of research in academia and industry with a significant impact on people's daily life. In the geospatial-related fields, these kinds of assistants are recently receiving attention from the GIScience community, including them in future roadmaps on the interaction of geospatial and Artificial Intelligence (AI) (Janowicz et al., 2020; UN, 2020); thus, virtual assistants in conjunction with location can be definitively connected to Intelligent Spatial Decision Support Systems.

From a technical viewpoint, a virtual assistant is a natural language processing pipeline that includes automated speech recognition, natural language understanding, natural language generation, and text-to-speech methods to improve the interaction experience with users through questions and answers. Moreover, these assistants can incorporate search, knowledge graphs, agent back-ends, and agents of different platforms (Mennicken et al., 2018). Thereby, they can fit many different purposes. As an example, a user can initiate an intelligent virtual assistant by voice commands to perform an action (such as searching for suitable services/data, interacting with existing services) for which the standardization and protocols, as well as the processing and/or fusion of geographic information, are crucial. The results can be displayed in the form of a map, contextualized in a virtual world, sound, text, or even a combination thereof. For example, rest spaces on the route by car from Valencia to Madrid can be represented on a map, in the form of a virtual tour in a virtual globe, orally communicated, or even sent as alert messages to mobile devices. In short, virtual assistants can use machine learning and other AI techniques to extract and process knowledge from spatial data.

In this context, the IDEAIS project (Bernabé et al., 2019) pursues the creation and consolidation of an Ibero-American collaboration environment to undertake the design, exploration, and development of a new generation of virtual assistants that facilitate the access, recovery, processing, and visualization of geographic information available in Spatial Data Infrastructures (SDI) (Schade et al., 2020), geospatial cyberinfrastructure (Yang et al., 2010; Wright and Wang, 2011), and Digital Earth systems and platforms (Morales and de By, 2013; Alderson et al., 2020). As many science disciplines are moving towards the incorporation of intelligent virtual assistants in multiple scenarios and application domains (health, tourism, etc.), a scoping review has been performed to analyze the current relevant literature pertinent to intelligent virtual assistants in relation to the geospatial information and technologies. In particular, the scoping review was designed to find which key aspects of GIScience and how these contribute to the development of virtual assistants. These key aspects include the type of applications, services, and scenarios in which virtual assistants are used in conjunction with the access, processing, and fusion of geographic information, as well as the application of geospatial-related standards and protocols to develop virtual assistants. In addition, this study seeks to explore the most influential research lines as well as the key technologies and platforms employed in the found developments, in order to determine the main challenges and current limitations regarding the use and implementation of virtual assistants from the GIScience perspective.

Despite scoping reviews are a common method to search for literature in health-related fields (Mitton et al., 2009; Bazzano et al., 2017), they are gaining increasing notoriety as a means of summarizing literature in diverse topic areas such as education (O'Flaherty and Phillips, 2015) and psychology (Davis et al., 2015). In the field of GIScience and Geography in general, scoping reviews are yet scarce even though the scoping review method is widely accepted in multidisciplinary works (often health-related) in which a facet(s) of GIScience plays an important role (see for example Fritz et al., 2013; Makanga et al., 2016; Vasilyeva et al., 2018; Boyda et al., 2019; Manda et al., 2020). According to Colguhoun et al. (2014), a scoping review is defined as "a form of knowledge synthesis that addresses an exploratory research question aimed at mapping key concepts, types of evidence, and gaps in research related to a defined area or field by systematically searching, selecting, and synthesizing existing knowledge." Therefore, a scoping review turns out to be an appropriate synthesis instrument to make visible what has/is been/being done in the academic literature regarding the combination of virtual assistants and GIScience, which includes the processing, fusion, and use of geographic information and geospatial technology. While chatbots and virtual assistants have recently drawn much attention in other fields such as healthcare and mental health (Bendig et al., 2019; Abd-alrazaq et al., 2019; Vaidyam et al., 2019), nothing similar has yet been done in the field of GIScience.

The results of this scoping review may inform future applications of spatial research regarding the use of intelligent virtual assistants, as they can reveal: 1) gaps and limitations in the current use of spatial methods and standards and 2) the vast amount of geospatial resources available in SDIs for developing intelligent decision systems based on virtual assistants for a wide array of application domains.

The remainder of the article is structured as follows: Section 2 presents the methods used for performing this scoping review. Section 3 describes the obtained results, highlighting search results as well as the studies and virtual assistants considered. Section 4 provides a discussion, focusing on challenges, limitations, and future recommendations for the GIScience community. Finally, Section 5 outlines some conclusions.

2 Methods

The review methodology followed is the "PRISMA extension for scoping reviews (PRISMA-ScR)" and, therefore, the article is strictly organized according to the methodological steps defined in a scoping review (Tricco et al., 2018). This section describes the inclusion criteria for selecting the set of eligible papers, including the information sources and the eligibility process. Next, the items of information or variables extracted from each article will be explained. These items are the basis for the analysis of the results in the next section.

2.1 Inclusion Criteria

The inclusion criteria (eligibility) are as follows:

- (IC1) Language: English.
- (IC2) Type of documents: peer-review journal papers and conference papers.

- (IC3) Temporary window: from 2010 to 2019. Although research on virtual assistants dates back to the beginning of AI, the first modern virtual assistant on a smartphone (Siri) was launched in 2011. Therefore, the review has been limited to the last decade to get the most significant results.
- (IC4) Documents should focus on the use of virtual assistants for integration, fusion, and, ultimately, the use of geographic information. Therefore, a document will be excluded if it talks about a virtual assistant, but it does not consider geographic information or spatial methods.
- (IC5) Given the criterion IC4, documents can describe specific applications, conceptual designs, requirements analysis, etc. That is, it is not necessary that a virtual assistant has been developed for a document to be eligible.
- (IC6) If standards for geographic information are not mentioned in a document, this is not an exclusion criterion as long as the paper meets IC4.

2.2 Selected information sources and bibliographic search

To collect the largest pool of relevant documents, bibliographic searches were conducted in three scientific literature databases that are among the largest and most common multidisciplinary repositories: SCOPUS, EBSCOhost, and Web of Science. An extensive search in these three scientific databases was performed, covering the last ten years from 2010 to 2019 and executing queries that combined search terms related to the virtual assistants (e.g., chatbot, conversational, and agent) and the geospatial dimension (e.g., spatial, location, and geoinformation) using logical operators. Search terms were selected through an interactive refinement process against the scientific literature databases, adjusting the boolean and wildcard operators to mitigate false positives in the resulting records. The complete reference query was:

(TITLE-ABS-KEY("virtual assistant" OR chatbot OR (conversational AND (system* OR chatbot* OR agent*))) AND DOCTYPE(ar OR cp) AND PUBYEAR > 2009) AND (TITLE-ABS-KEY(geograph* OR spati* OR geoinformat* OR geo-informat* OR GIS OR location OR locali?at*) AND DOCTYPE(ar OR cp) AND PUBYEAR > 2009)*

All database-specific queries were semantically equivalent but formulated using the different syntaxes and technical support of the respective search engines. The queries were launched on September 18, 2019, covering results from 2010 until September 2019 and relaunched in December 2019 to include the full year of 2019.

2.3 **Study selection**

All resulting publications were downloaded, and duplicates were removed. All papers were equally divided among four multidisciplinary groups of two members. Publications were initially screened based on the IC, using *title*, *abstract*, and *keywords*. Subsequently, the documents that passed the screening phase were thoroughly reviewed to check their eligibility using the same IC. Both during the initial screening and full-text screening for eligibility, the two members of each reviewing group examined independently all the papers assigned to them and discussed their observations before making a final decision. In case of disagreement, a third reviewer was assigned, and a final decision was made collaboratively. Finally, the reference list of the selected papers was reviewed to identify relevant documents that were overlooked in the previous phases but met the inclusion criteria.

2.4 Data items and methods for data extraction

To identify the data to be extracted and define a homogeneous data extraction process, a pilot test was carried out on five of the included articles. As a result, a standardized form for data extraction was defined. The extraction process was performed by four groups of two reviewers each, being the same as in the eligibility phase. However, the groups extracted data from documents that were not reviewed by them in the previous phase, so that all groups could examine as many different documents as possible and minimize biases in the selection and extraction of data.

Regarding the extracted data items, bibliographic data (e.g., year of publication, journal/conference, etc.) and a series of variables were extracted from each of the articles that successfully passed the eligibility process. These variables are broadly divided into two groups: those exclusively related to virtual assistants, and those related to standards, use, integration, and fusion of geographic information by the virtual assistant.

The variables on virtual assistants were:

- The purpose of the virtual assistant: tourism, construction, education, guided tours (museums), emergency management, etc.
- The development phase as reported in the document: requirements, design, prototype, operational implementation.
- The name of the virtual assistant: if it appears in the document.
- The place where the virtual assistant was tested: if mentioned in the document.
- The technical approach: cloud-based, web-based, mobile-based, device-based (e.g., Pi, Arduino), agent-based, etc.
- The platform in which the assistant was built: Alexa, Google Assistant, Cortana, Siri, robot, etc.
- The research areas of the virtual assistant: Natural Language Processing (NLP), voice recognition, Machine Learning (ML), Augmented Reality, Virtual Reality, etc. as indicated by the document's authors.

With respect to geographic information (GI), the extracted variables were:

- The primary use of the GI in the virtual assistants: navigation, route calculation, data access, visualization, etc.
- The type of geographic data used: LiDAR, vector, raster, 3D model, etc.
- How the user asks for geographic data: text, voice, sound, maps, visual (e.g., images, touch screen, etc.), etc.
- How the resulting geographic data are displayed: text, voice, sound, maps, visual, etc.
- Which GI standards are used: if any (e.g., Open Geospatial Consortium (OGC), International Organization for Standardization (ISO), etc.).
- Whether there is any type of processing and/or fusion of geographic data to carry out the task demanded by the user, and the type of spatial analysis method or service employed: if any (e.g., calculation of routes, distances, recognition of geographical entities, classifiers, etc.).

2.5 Methods for the synthesis of results

The extracted variables were processed and analyzed using R scripts. All data supporting this publication, except for the set of eligible papers because some are subject to restrictive licenses, are available on Zenodo (Granell, 2020). The computational workflow is provided as a GitHub repository at *https://github.com/cgranell/ideais-scopingreview-2019* and archived in (Granell, 2020). The repository also includes instructions in the README file. The scripts produced the figures and tables in Sections 3.2 and 3.3. For Table 2, which summarizes the main characteristics of the eligible studies (see Section 3.2), the information was grouped according to some of the main variables extracted. Section 3.3 will present the proposed classification of virtual assistants narratively and describe them based on the exploratory questions posed in the introduction.

3 Results

This section presents the results concerning the scoping review performed. Thus, we detail the search results, present included studies, and characterize different virtual assistants considering multiple aspects, such as application domains, geographical purposes, technologies, platforms, among other elements. In addition, we highlight some of the most relevant research areas of the collected studies.

3.1 Search results

As Figure 1 shows, 358 documents were initially retrieved for the screening phase. After removing duplicates, 229 were screened. During the screening, 153 records were excluded as follows: 124 (IC4 and IC5) were irrelevant due to the review topic (not GI, virtual assistants for other applications), 28 (IC2) for the type of document (editorial, short papers, posters, etc.), and 1 (IC1) was not in English. The final number of documents that passed to the eligibility phase was 76. After the eligibility phase, 36 articles were definitely included, and 40 documents were excluded (2 for IC1, 4 for IC2, and 34 for IC4 and IC5). Finally, an additional article was included through the inspection of the reference list of eligible documents. Consequently, a total of 37 studies were considered in the synthesis phase.

3.2 Description of included studies

Most of the studies were published as conference articles (24/37, 65%), while the rest were articles in academic journals (13/37, 35%). Research on the use of geographic data in virtual assistants is accepted in an ample range of academic journals and conferences (Table 1). However, this results in a lack of a dominant scientific community that concentrates much of the research on the topic. Eligible papers to date have been published in a total of 22 unique conferences and 13 journals. Only two geography conferences and three geography journals appear in Table 1, suggesting the low impact of the GIScience community in the large and multidisciplinary research area of virtual assistants.

Based on the temporal distribution of the studies, illustrated in Figure 2, two-thirds of the studies were published during the last two years, 2018 and 2019 (25 out of 37). The only research published in 2020 refers to the publication date of the conference proceedings since the conference took place in 2019 (specifically in June 2019 at the AGILE conference). For the rest of the years, the number of studies is two or one, except for 2014 without publications and 2017 with three.

A fundamental analysis of the words stems that appear in the abstracts of the eligible articles revealed that “informat,” “system,” “user,” “interact,” “data,” and “convers” are among the most frequent word stems (see the left side of Figure 3). The derived terms (i.e., information, interactive, conversational, etc.) are not specific to the GIScience domain but are generally applicable to any areas of knowledge related to informatics and computer science, including the field of virtual assistants. Only two word stems in the top 15 (see bar chart on the right side of Figure 3), “navig” and “locat,” are directly connected to GIScience. Only five word stems most closely related to GIScience beyond the top 15 were found: “spatial” (ranked 18), “geograph” (31), “map” (43), “rout” (89), and “gis” (100). Overall, only 7 of the 100 most frequent word stems in all abstracts are relevant to the field. Although the eligible documents were searched taking into account geospatial aspects (Section 2.2), the low frequency of geospatial terms in the abstracts is another source of evidence, in correlation to the scarcity of geography journals/conferences found in Table 1, that the integration of geospatial aspects in virtual assistants is not seen *yet* as a research line of interest by the GIScience community.

3.3 Description of virtual assistants

This section describes the virtual assistants found in the eligible articles according to the initial research questions, which are: 1) type of application domains in which virtual assistants are used in conjunction with geographic information, 2) technologies and platforms employed in the found developments, 3) support for geographic integration and geospatial-related standards, and 4) the most influential research areas. Table 2 describes each virtual assistant of the eligible articles in function of its main application domain or scenario, geospatial usage, the application description, relevant geospatial data sources and/or methods used, and the involved research areas in the development of the virtual assistant.

3.3.1 Application domains and geographical purpose

The articles can be classified into two groups whether or not they address a particular application domain (see Table 2, leftmost column). The first group relates to articles that target specific application domains such as education and tourism, and the reported virtual assistants are used to meet the requirements of these application domains. The other group contains articles that attempt to improve specific features or aspects of virtual assistants, such as conversational features or place recognition in unstructured texts, without having a concrete use case in mind (i.e., not indicated at least in the study). The first group accounts for 73% (27/37) and the second group for 27% (10/37).

The virtual assistants that are part of the first group are, in general, applied to a few application domains. Tourism-related scenarios clearly stand out (10/27, 37%). A large proportion of these cases utilize geoinformation resources for user positioning (Chen et al., 2019; Ali et al., 2019; Massai et al., 2019; Klopfenstein et al., 2018; Grazioso et al., 2018; Garrido et al., 2017) to identify places of interest (POIs) near the user (i.e., traveler, tourist, etc.). Navigation (Bartie et al., 2018; Abate et al., 2011) is also a key feature in the reported tourism-related virtual assistants in order to guide users in outdoor spaces and help them with route selection. Navigation is complemented with the use of question-answering techniques (Janarthanam et al., 2012) in which the assistant exploits contextual data to answer personalized questions to guide users. Related to personalization, contextual geoinformation, and maps, Signoretti et al. (2015) enabled a personalized experience about the places being visited by tourists.

Articles in the first group broadly acknowledge recommendation (Sardella et al., 2019; Anelli et al., 2019; Reis et al., 2019; Acer et al., 2019; Ronzhin et al., 2019; Atreja et al., 2018; Agarwal et al., 2017; Sánchez-Pi et al., 2010) as a critical use case in which virtual assistants are valuable (8/27, 30%). Again, user' positioning is used for recommendation activities such as searching for near restaurants (Sardella et al., 2019), local information (Acer et al., 2019), business (Agarwal et al., 2017), as well as recommending contextualized services depending on where a traveler is in an indoor space (e.g., airports - see Sánchez-Pi et al., 2010). Other scenarios are, for instance, virtual libraries to recommend resources based on how close (geographically) they are (Anelli et al., 2019), summarization (Reis et al., 2019), and citizen support on civic problems in urban contexts (Atreja et al., 2018). To some extent, recommendations of touristic places, for example, can also be interpreted as a form of decision-making support, so the line between tourism-related applications and recommendation applications is sometimes fuzzy and depends on each particular study. The point is that there is an apparent intensification on the development of virtual assistants in conjunction with user positioning in which tourism and recommendation are central since both together account for two-thirds of the articles of the first group (18/27, 67%).

A third application domain is education (Eiris-Pereira & Gheisari, 2018; Cai, Yu & Chen, 2013; Klopfenstein et al., 2018; Doumanis & Smith, 2015), often combined with entertainment or gamified aspects (Klopfenstein et al., 2018; Doumanis & Smith, 2015). The use of geoinformation resources is varied ranging from space-time immersion in a Building Information Modeling (BIM) environment (see Liu et al. (2017) for a general description of BIM in geospatial scenarios) to improve communication skills in a construction scenario (Eiris-Pereira & Gheisari, 2018), to better understand the concepts around spatial operations (Cai et al., 2013), to gamified assistants to promote code-literacy as a treasure hunt game (Klopfenstein et al., 2018), and to improve the learning of cultural narratives through embodied conversational agents (Doumanis & Smith, 2015).

Healthcare is also a target application domain (González-Medina et al., 2019; Bandara et al., 2018; Gintner et al., 2018; Santos et al., 2016). Here, two articles focus on assistance to elderly and disabled people in indoor environments (González-Medina et al., 2019; Bandara et al., 2018) and one on helping blind people for outdoor navigation (Gintner et al., 2018). Another article (Santos et al., 2016) focuses on data collection (location, heart rate, etc.) in patient health monitoring. It is worth noting that a large body of research is increasingly focusing on the ecological and momentary tracking of patients through active and passive data collection methods using mobile devices, wearables, and chatbots (Weisel et al., 2019; Miralles et al., 2020). In particular, the review by Miralles et al. (2020) concluded that the use of location and location analysis is still testimonial and that chatbots or virtual assistants on health-related scenarios focus primarily on replacing therapists to provide help and psycho-educational content to patients instead of taking advantage of location and geoinformation resources to improve patient monitoring and/or intervention.

The second group of articles (27%) attempts to improve specific areas or aspects of virtual assistants, in which authors do not explicitly address an application domain. Relevant fields are linguistic, navigation, and conversation. Linguistics refers to articles that explore text similarities such as identifying place entities (Gupta et al., 2018; Thenmozhi et al., 2018; Zhu, 2017) and spatial relationships (Prendergast & Szafir, 2018) in unstructured texts. Improving navigation is vital for location-aware virtual assistants, be in indoor contexts (Subramani & Deepika, 2019; Dobnik & Pulman, 2010) or outdoors spaces (Antrobus et al., 2019; Cuayáhuitl & Dethlefs, 2011). Finally, improving the conversation and understanding the subtle emotions in the communication between humans and assistants (Portela & Granell, 2017) is a primary research line regardless of the target application domain. In this context, Hamzei et al. (2020) explore structural patterns of questions related to places and their human-generated responses, and Margue & Rudnicky (2019) investigate conversational interfaces between a human operator giving navigational instructions to a team of robots.

Figure 4 complements Table 2, focusing on the interaction of the group, application domain, and main geospatial usage or purpose of the virtual assistants. Not surprisingly, positioning is the most popular geospatial use regardless of whether or not a virtual assistant targets a particular application domain. Likewise, the use of mapping plays a prominent role, as it connects various application domains. In general, positioning and mapping are widely used in virtual assistants, which show a clear interest in geospatial aspects but, at the same time, indicate a limited perception of location and spatial analysis potential.

Finally, of the total studies analyzed, only twelve (12/37, 32%) name the virtual assistant (e.g., SpaceBook, CitiCafe, MIRob, or PeopleBot). Among these twelve named virtual assistants, only four (SpaceBook (Bartie et al., 2018), Paval (Massai et al., 2019), TITERIA (Garrido et al., 2017), and Trip 4 All (Signoretti et al., 2015)) have to do with tourism-related activities, followed by recommendation or decision-making support (Loki (Ronzhin et al., 2019) and CitiCafe (Atreja et al., 2018)), healthcare (MIRob (Bandara et al., 2018) and PeopleBot (González-Medina et al., 2019)), and education (CAGA (Cai et al., 2013) and TreasureHuntBot (Klopfenstein et al., 2018)). Finally, Diana (Tsai et al., 2019), which is related to disaster management, and Satnav (Antrobus et al., 2019), which explores relationships between driver workload and environmental engagement associated navigation systems, are categorized differently even though they still could be seen under the recommendation-related application domain.

3.3.2 Employed technologies and platforms

Based on the development status of the virtual assistants reported in each study, the vast majority is implemented as a prototype application (26/37, 70%), and only five studies (5/37, 14%) have performed an operational version, that is, the virtual assistant has been validated in real situations with users (SpaceBook, Paval, TITERIA, Loki, TreasureHuntBot). The remaining studies are yet in early development stages, such as in the definition of requirements and/or design (6/37, 16%). This aspect reveals that the field is still in its beginning, as the number of operational virtual assistants is scarce.

Figure 5 shows the relationship between technical approaches for implementing virtual assistants and their state of development over time. In line with Figure 2, many developments are concentrated in the last two years (2018-2019). As for the technical approach, there is no clear pattern. A slight trend based on agents appears in the first years (2010-2013) since developments in other technologies and platforms were practically non-existent. As of 2017, the development of virtual assistants based on the web, mobile, or the combination of both predominate. There is no clear evidence on the best technical approach since recent developments are fully diversified.

Both commercial and open-source intelligent virtual assistants such as Google Assistant, Cortana, and Telegram are popular in the review. Among the articles that specify an existing platform for the development of virtual assistants (18/37, 49%), eight are based on such platforms, either to use them directly in order to employ and take for granted their conversational experience and natural language process capabilities (e.g., voice-activated commands), or to create new “skills” functionalities (White, 2018) on top of them. Other platforms are a minority, including robots, agents, kiosks, and less popular systems such as Ambro, Atrv-jr mobile robot, Line, Satnav, and Teamtalk.

3.3.3. Support for geographic integration and geospatial-related standards

The lack of relationship between the proposed approaches of virtual assistants with the norms and standards related to geographic information, or even with the use of existing geographic information sources, is evident. This is probably due to the origin of the proposed approaches, which mostly correspond to the Artificial Intelligence (AI) community and, therefore, the integration of geospatial sources and standards in the virtual assistants is often superficial. Despite this, there are attempts to support geospatial-related standards in some articles, among which the study presented by Ronzhin et al. (2019) stands out due to its use of knowledge graphs, for the government of The Netherlands, following the best practices for spatial data on the Web (see *https://www.w3.org/TR/sdw-bp/*) and the use of GeoSPARQL, an OGC standard that provides building blocks to formalize the geospatial semantics in the data and enabled geospatial reasoning in SPARQL (*https://www.ogc.org/standards/geosparql*).

Some kind of geospatial processing and spatial analysis is present in 40% (15/37) of the articles, corresponding mainly to tourism and recognition of places, in similar percentages, as determined in Section 3.3.1. Leaving aside user’s positioning, the types of spatial methods and geospatial services include route calculation and selection (Subramani & Deepika, 2019; Anelli et al., 2019; Antrobus et al., 2019) geoparsing and geocoding (Massai et al., 2019), reverse geocoding (Gintner et al., 2018), distance to points of interest (Sardella et al., 2019; Anelli et al., 2019), searches for shortest paths, and optimal routes (Bartie et al., 2018). A few articles combine various geospatial methods. Gintcher et al. (2018) improve a reverse-geocoding service by gathering additional location information (e.g., heading from embedded sensors in a mobile device) to determine which sidewalk a blind person is walking on. Massai et al. (2018) put together gazetteers and geocoding/geoparsing processes to suggest local points of interest and services to a given user on the move. The majority of articles, though, use one's position based on the GPS coordinates of the mobile device and associated point-based analyses as the only significant geospatial method in practice.

Only three articles out of fifteen that use some form of geospatial processing are dedicated to more complex tasks such as geoinformation modeling and fusion (Grazioso et al., 2018; Bartie et al., 2018; Reis et al., 2019). Grazioso et al. (2018) combined LiDAR and Linked Open Data to create 3D representations of heritage buildings for guided tours, Bartie et al. (2018) integrated a virtual surface model based on LiDAR with social media geodata to compute the visibility of places of interest from the tourist’s position, and Reis et al. (2019) created meteorological narratives (summarization) for blind people requesting data from remote meteorological models.

The remaining 60% (22/37) of the articles use circumstantially geospatial information for providing context, for example, to access vector data, maps, and places of interest (POIs) related to the user's location. The most common geographic sources are OpenStreetMap (Bartie et al., 2018; Janarthanam et al., 2012) and Ordnance Survey (Bartie et al., 2018). Usage of widely employed geospatial tools, frameworks, and spatial databases (e.g., PostGIS) is also residual: SpaceBook (Bartie et al., 2018) utilizes PostGIS and the pgRouting library for outdoor navigation and routing guidance, and CAGA (Cai et al., 2013), whose authors employ ArcGIS to support training in spatial analysis operators. Overall, even though multiple GIS tools (ArcGIS or QGIS, among others) have matured over the years to integrate with mobile and web platforms seamlessly, almost none of the articles reviewed take advantage of them.

3.3.4 Influential research areas

The most relevant research areas of the studies (see the rightmost column in Table 2 and Figure 6) are linked to the interaction with the proposed or implemented platforms, such as NLP (9%), conversational agent (9%), and speech recognition (8%), which are traditional subfields of AI. Next, it follows knowledge base methods (knowledge graphs, 4%), named entity recognition (3%), and broader terms such as Artificial Intelligence (3%), emphasizing the pivotal role of AI-related approaches and techniques in the reviewed articles. The rest of the identified areas have lower percentages (2%) and cover areas such as AI techniques, methodologies for semantic information management, use of algorithms for understanding, among others. The *Others* category comprises research terms or areas mentioned once (1%) like augmented reality and indoor spaces modeling. Consequently, as mentioned before, geospatial-related research areas are scarcely considered.

4 Discussion

This section summarizes and conveys each of the findings to provide an overview of what is currently known about the use and integration of geographic information and resources in virtual assistants and draws attention to research and practice recommendations from the perspective of GIScience to lead to geographic or geographically-explicit virtual assistants and agents.

4.1 Summary of evidence

In the analyzed decade, it can be seen that the use of location and geographic information integrated with virtual assistants has become increasingly popular. The number of developments in the last two years (2018-2019) has significantly raised in comparison to the previous eight years. This suggests a similar amount or even a substantial and meaningful increment in geographically-explicit virtual assistants in the coming years. However, the variety of spatial methods used is still quite limited and there is no indication that this aspect will change in the coming years. Amongst the spatial methods and geographic usages, navigation is one of the most recurring purposes in the studied virtual assistants, followed by basic spatial methods that are solely aimed to calculate the distance to points of interest and to compute the shortest paths and routes based on the user's position. The use of sophisticated spatial methods is rare; nonetheless, Bartie et al. (2018) make a remarkable exception by employing a more sophisticated visibility engine that combined a virtual surface model based on LiDAR to reveal which places of interest are visible from the tourist line of sight. The best evidence for the use of geoprocessing related to virtual assistants is presented by Ronzhin et al. (2019), in the municipal project of the Netherlands. There, language processing has been coupled with a basic SDI to obtain cadastral data. Although it is based on a written interface and has very few understandable commands, it already makes it possible to identify difficulties to be overcome regarding the integration of geographic information with intelligent virtual assistants.

The state of spatial methods in the analyzed literature reveals that location is simply a source of additional information for the current scenario of intelligent virtual assistants. Therefore, it adds little to the complexity of analyzing and understanding the causes of spatial phenomena. As we mentioned before, we believe this is due to the approaches' origin mostly correspond to the AI community.

When it comes to geospatial-related standards and protocols, the usage of OGC/ISO geospatial standards is shallow. Gazetteers are sporadically used for searching points of interest, but that is where the exploitation of standards-based geoinformation resources and services often ends. Consequently, the link between virtual assistants and SDIs is merely non-existent. Based on the articles in the review, these two areas, geographically-explicit virtual assistants and SDIs, run in parallel, without apparent connection and communication between them. The lack of synergies is, to some extent, surprising since a large proportion of virtual assistants are targeted to tourism-related applications, a domain that has been traditionally well connected with geographic resources in SDIs.

Although the articles in this scoping review encompassed a relatively low range of application domains (tourism, recommendation/decision support, education, and healthcare), it is remarkable that vital application domains such as disaster management are not yet under the radar of virtual assistants when it comes to using geographic information. In particular, disaster management is a well-supported area by the GIScience community, with vast amounts of spatial data deployed in SDI nodes and Digital Earth platforms. Indeed, virtual assistants for improving responsiveness and management of disaster situations and emergencies can be a fascinating domain to prove the benefits of adding geospatial data and methods, as well as consolidated standards and protocols from GIScience into such intelligent virtual assistants.

As demonstrated by the articles included in this review, the study of virtual assistants is a multidisciplinary and diversified research area where machine learning, NLP, and conversational agents dominate. Due to these advanced functionalities, a significant part of the articles is highly influenced by commercial chatbots (e.g., Alexa, Google Assistant, etc.) to build customized assistants/applications on top of them. It is unclear whether this factor will have a positive or negative impact on how virtual assistants are developed or in which application domains will be applied. Hence, it remains an open question. Nevertheless, it is clear that spatial characteristics such as location are increasingly gaining more importance to create sophisticated, more personalized assistants in order to improve question answering and contextual recommendations for decision-making support. Therefore, in the coming years, geoinformation and spatial methods are expected to play a pivotal role in intelligent virtual assistants, even though there is currently a gap between spatial data availability and advanced spatial methods and their usage in such virtual assistants. In this line, these assistants will be able to identify, interact, fusion, or treat with geospatial information through complex spatial methods (Gibbons et al., 2015), which will play a crucial role in determining the nature of these interactions and in the development of other algorithms.

4.2 Recommendations for the GIScience community

Based on the results obtained, it can be concluded that there is a significant lack of knowledge about the geographic information standards for the use, access, and integration of geospatial information in the implementations of the analyzed virtual assistants. Therefore, there is a crucial need to put together a series of research and practical recommendations to make the virtual assistant research community aware of the benefits of applying geographical standards to future implementations of virtual assistants, when geographic information is of particular relevance in such developments. In fact, the personal level of the assistants could have greater potential by taking advantage of spatial characteristics. In short, geographic data and resources accessible from existing SDIs should not be ignored when creating the next generation of virtual assistants where the location is a critical context factor.

Synergies with standardization bodies related to geospatial information are strongly advisable. On the one hand, the OGC has as its purpose the definition of open and interoperable protocols within the GIScience community and, as such, it is well-positioned to reach an adequate interrelation and real use of geoinformation with AI, accompanied by national initiatives such as the National Catalog of Geographical Objects in Ecuador (National Council of Geoinformatics, 2013) for the identification of projections and parameters in the representation of geographic information. Adhering to established standards would definitely increase interoperability and integration of geographic information, with greater or lesser understanding at the level of data or a basic semantic level.

On the other hand, the Foundation of Intelligent Physical Agents (FIPA) is an international non-profit organization, establishing a common and generic framework for agents and multi-agent systems. FIPA has recommended a set of software specification protocols for heterogeneous and interactive agents and agent systems admitted to IEEE in 2005. An open-source framework for implementing these indicators constitutes the Java Agent Development Framework (JADE). In general, JADE's basic levels have its own architecture. However, in higher levels, as in the case of the semantic component, there is a trend towards the use of standards. Therefore, an interaction that correlates with each level can be proposed.

In order to achieve this correlation between geoinformation and AI standards, a discretization is required between the levels of interoperability and integration, where advances in geographic information parameters have made specific advances. The most visible results of this interoperability occur on SDI platforms where integration from different spatial data sources is achieved. Therefore, correspondence at these levels is necessary with the artificial intelligence algorithms used in virtual assistants. This would allow handling by interoperability layers, even a higher level with semantics and virtual assistants. Works referred to these are the basis for current developments without the relationship with assistants (Morocho et al., 2003).

Furthermore, it is worth mentioning the OGC Artificial Intelligence in Geoinformatics discussion working group, (OCG 2019), which works in close collaboration with other ongoing initiatives such as the IEEE Global Initiative for Ethical Considerations in Artificial Intelligence and Autonomous System (April 2016), ITU committees on the development of AI standards since 2016 (e.g., ITU-T Y.AI4SC for Artificial Intelligence and IoT, and ITU-T Y.qos-ml, for the requirements of machine learning based QoS assurance), and the ISO/IEC JTC 1/SC 42 on Artificial Intelligence (April 2018), which works on the JTC1's standardization program on Artificial Intelligence; and provides guidance to JTC1, IEC, and ISO committees developing Artificial Intelligence applications.

In this review, despite the recent creation of these working groups by different standardization organizations, the standardized relationship that would be expected as a result of the above initiatives has not been identified. Therefore, the initial steps are yet pending to consolidate the standardization and organization of geospatial-related functionalities within the AI domain for the development of geospatial-explicitly virtual assistants that will leverage the full potential of the GIScience field.

4.3 Limitations

Concerning the used method, we are aware that it has some limitations. Firstly, the scoping review concentrates on three search engines (SCOPUS, EBSCOhost, and Web of Science) that are among the largest and most common multidisciplinary repositories available. Nevertheless, only the articles collected from the mentioned repositories are considered. Secondly, works based on a set of keywords were gathered. Hence, virtual assistant articles without these keywords may have been omitted in this review. Thirdly, due to the selection criteria, other types of investigations (other than journal articles and conferences papers) with results in this discipline may have been excluded. In this way, although these issues may mean that the present scoping review is not exhaustive, it definitely provides reasonable insights about the state of intelligent virtual assistants concerning geospatial information and technologies.

As much of the recent development and explosion of virtual assistants has come hand in hand with the industry (Siri, Cortana, Alexa, etc.), technical developments and innovations in this area have been mainly protected by patents, instead of being published in articles in academic journals and conferences. Therefore, there was the option of expanding the information sources with ESPACENET (https://www.epo.org/), a free reference database on world-wide patents, developed and maintained by the European Office of Patents, with more than 110 million patent documents at the time of writing. Thus, the chance to include ESPACENET as an information source for the scoping review was explored. However, the same search query (see Section 2.2) was launched over ESPACENET, resulting in approximately 10,000 patent records. Taking into account this volume of results, the final decision was to exclude ESPACENET due to lack of training in the revision of patent documents and due to time constraints, since differentiating patents that are important from “noisy” ones is a time-consuming task. Additionally, many companies often publish hundreds of patents on the same subject to intentionally hinder the task of identifying the relevant patent(s).

5 Conclusions

This review revealed that there is a gap between the current developments of virtual assistants that use or rely on geospatial information and the extent to which they leverage the spatial dimension. While some articles use sophisticated geospatial sources (LiDAR, knowledge graphs, etc.), the status quo is to rely primarily on vector data (POIs, routes, or region), especially for application domains related to tourism and/or recommendation/decision support. Thus, the use of several geographical sources in one virtual assistant is almost absent (except Bartie et al., 2018). The work presented by Ronzhin et al. (2019), allows visualizing the integration potential of a virtual assistant with geoservices. Although, it is not described as an internal process, especially when the integration into the basic SDI is achieved. The result is encouraging to be able to propose a greater push by the Geo and AI communities together, for real citizen use. Thus, the advances of each one should provide a consolidated product that adequately handles the different levels of interoperability, from standards to the real integration of data sources in an SDI with understanding. Despite the occasional use of gazetteers, none of the articles rely on commonly geospatial resources deployed or accessible in SDIs. Although most developments are mobile- or device-based, typically in the form of mobile applications, all sensors but GPS are underutilized. Other complementary sources, such as geo-referenced social data, are testimonial too.

Despite this panorama, we seek to start conversations and discussions with and between the new working groups and committees associated with various international organizations to put forward initiatives to combine AI, and more specifically, virtual assistants, with research lines and resources of the GIScience field. Moreover, as mentioned earlier, some voices are calling for greater engagement of the GIScience community to this growing area of research, both in academia and industry. Therefore, we are sure that the described scenario will change shortly.

References

Abate, A. F., Acampora, G., & Ricciardi, S. (2011). An interactive virtual guide for the AR based visit of archaeological sites. *Journal of Visual Languages & Computing*, *22*(6), 415–425. doi: 10.1016/j.jvlc.2011.02.005

Abd-alrazaq, A. A., Alajlani, M., Alalwan, A. A., Bewick, B. M., Gardner, P., & Househ, M. (2019). An overview of the features of chatbots in mental health: A scoping review. *International Journal of Medical Informatics*, *132*, 103978. doi: 10.1016/j.ijmedinf.2019.103978

Acer, U. G., Van Den Broeck, M., & Kawsar, F. (2019). On hyper-local conversational agents in urban settings. *Proceedings of the 5th ACM Workshop on Mobile Systems for Computational Social Science*, 1–4. doi: 10.1145/3325426.3329949

Agarwal, V., Khan, O. Z., & Sarikaya, R. (2017). Remembering what you said: Semantic personalized memory for personal digital assistants. *IEEE International Conference on Acoustics, Speech and Signal Processing*, 5835–5839. doi: 10.1109/ICASSP.2017.7953275

Alderson, T., Purss, M., Du, X., Mahdavi-Amiri, A., & Samavati, F. (2020). Digital Earth Platforms. In H. Guo, M. F. Goodchild, & A. Annoni (Eds.), *Manual of Digital Earth* (pp. 25–54). Springer Singapore. doi: 10.1007/978-981-32-9915-3_2

Ali, G., Le, H.-Q., Kim, J., Hwang, S.-W., & Hwang, J.-I. (2019). Design of seamless multi-modal interaction framework for intelligent virtual agents in wearable mixed reality environment. *Proceedings of the 32nd International Conference on Computer Animation and Social Agents*, 47–52. doi: 10.1145/3328756.3328758

Anelli, V. W., Di Noia, T., Di Sciascio, E., & Ragone, A. (2019). Anna: A virtual assistant to interact with puglia digital library (discussion paper). *Proceedings of the 27th Italian Symposium on Advanced Database Systems*, *2400*.

Antrobus, V., Large, D., Burnett, G., & Hare, C. (2019). Enhancing Environmental Engagement with Natural Language Interfaces for In-Vehicle Navigation Systems. *Journal of Navigation*, *72*(3), 513–527. doi: 10.1017/S037346331800108X

Atreja, S., Dumrewal, A., Aggarwal, P., Basu, A., Mohapatra, P., & Dasgupta, G. B. (2018). Citicafe: An interactive interface for citizen engagement. *23rd International Conference on Intelligent User Interfaces*, 617–628. doi: 10.1145/3172944.3172955

Bandara, H. M. R. T., Muthugala, M. A. V. J., Jayasekara, A. G. B. P., & Chandima, D. P. (2018). Cognitive Spatial Representative Map for Interactive Conversational Model of Service Robot. *27th IEEE International Symposium on Robot and Human Interactive Communication*, 686–691. doi: 10.1109/ROMAN.2018.8525778

Bartie, P., Mackaness, W., Lemon, O., Dalmas, T., Janarthanam, S., Hill, R. L., Dickinson, A., & Liu, X. (2018). A dialogue based mobile virtual assistant for tourists: The SpaceBook Project. *Computers, Environment and Urban Systems*, *67*, 110–123. doi: 10.1016/j.compenvurbsys.2017.09.010

Bazzano, A. N., Martin, J., Hicks, E., Faughnan, M., & Murphy, L. (2017). Human-centred design in global health: A scoping review of applications and contexts. *PLOS ONE*, *12*(11), 1–24. doi: 10.1371/journal.pone.0186744

Bendig, E., Erb, B., Schulze-Thuesing, L., & Baumeister, H. (2019). The Next Generation: Chatbots in Clinical Psychology and Psychotherapy to Foster Mental Health - A Scoping Review. *Verhaltenstherapie*, 1–13. doi: 10.1159/000501812

Bernabé, M. A., Estima, J., González, M. E., Granell, C., López-Vázquez, C., Luaces, M. R., Martins, B., Moctezuma, D., & Seco, D. (2019). IDEAIS: Smart Voice Assistants to Improve Interaction with SDIs. *ArXiv Preprint ArXiv:1910.04696*. https://arxiv.org/abs/1910.04696

Boyda, D. C., Holzman, S. B., Berman, A., Grabowski, M. K., & Chang, L. W. (2019). Geographic Information Systems, spatial analysis, and HIV in Africa: A scoping review. PloS one, 14(5), e0216388. doi: 10.1371/journal.pone.0216388

Cabrera, J., Mena, M., Parra, A., & Pinos, E. (2016). Intelligent assistant to control home power network. *2016 IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC)*, 1–6. doi: 10.1109/ROPEC.2016.7830531

Cai, G., Yu, B., & Chen, D. (2013). Modeling and communicating the conceptual intent of geo-analytical tasks for human-GIS interaction. *Transactions in GIS*, *17*(3), 353–368. doi: 10.1111/tgis.12040

Chen, C.-H., Wu, M.-C., & Wang, C.-C. (2019). Cloud-based dialog navigation agent system for service robots. *Sensors and Materials*, *31*(6), 1871–1891. doi: 10.18494/SAM.2019.2326

Colquhoun, H. L., Levac, D., O'Brien, K. K., Straus, S., Tricco, A. C., Perrier, L., Kastner, M., & Moher, D. (2014). Scoping reviews: Time for clarity in definition, methods, and reporting. *Journal of Clinical Epidemiology*, *67*(12), 1291–1294.

Cuayáhuitl, H., & Dethlefs, N. (2011). Optimizing situated dialogue management in unknown environments. *Twelfth Annual Conference of the International Speech Communication Association*, 1009–1012.

Davis, R., Campbell, R., Hildon, Z., Hobbs, L., & Michie, S. (2015). Theories of behaviour and behaviour change across the social and behavioural sciences: A scoping review. *Health Psychology Review*, *9*(3), 323–344. doi: 10.1080/17437199.2014.941722

Dobnik, S., & Pulman, S. G. (2010). Human evaluation of robot-generated spatial descriptions. *Proceedings of the Workshop on Computational Models of Spatial Language Interpretation*, *620*, 25–32.

Doumanis, I., & Smith, S. (2015). A Framework for Research in Gamified Mobile Guide Applications using Embodied Conversational Agents (ECAs). *International Journal of Serious Games*, *2*(3). doi: 10.17083/ijsg.v2i3.79

Eiris-Pereira, R., & Gheisari, M. (2018). Building intelligent virtual agents as conversational partners in digital construction sites. *Construction Research Congress 2018*, *2018-April*, 200–209. doi: 10.1061/9780784481264.020

Fritz, C. E., Schuurman, N., Robertson, C., & Lear, S. (2013). A scoping review of spatial cluster analysis techniques for point-event data. *Geospatial Health*, 183–198. doi: 10.4081/gh.2013.79

Garrido, P., Barrachina, J., Martinez, F. J., & Seron, F. J. (2017). Smart tourist information points by combining agents, semantics and AI techniques. *Computer Science and Information Systems*, *14*(1), 1–23. doi: 10.2298/CSIS150410029G

Gibbons, S., Overman, H. G., & Patacchini, E. (2015). Spatial methods. In Handbook of regional and urban economics, 5, 115-168. Elsevier. doi: 10.1016/B978-0-444-59517-1.00003-9

Gintner, V., Balata, J., Boksansky, J., & Mikovec, Z. (2018). Improving reverse geocoding: Localization of blind pedestrians using conversational UI. *8th IEEE International Conference on Cognitive Infocommunications*, *2018-January*. doi: 10.1109/CogInfoCom.2017.8268232

González-Medina, D., Romero-González, C., & García-Varea, I. (2019). Combination of Semantic Localization and Conversational Skills for Assistive Robots. *Proceedings of the 19th International Workshop of Physical Agents*, *855*, 56–69. doi: 10.1007/978-3-319-99885-5_5

Granell, C. (2020, August 31). Reproducibility Package for "A scoping review on the use, processing, and fusion of geographic data in virtual assistants" (Version v1). Zenodo. doi: 10.5281/zenodo.4009220

Grazioso, M., Cera, V., Di Maro, M., Origlia, A., & Cutugno, F. (2018). From linguistic linked open data to multimodal natural interaction: A case study. *22nd International Conference Information Visualisation*, 315–320. doi: 10.1109/iV.2018.00060

Gupta, A., Ayyar, M., Singh, A. K., & Shah, R. R. (2018). Raiden11@IECSIL-FIRE-2018: Named entity recognition for Indian languages. *Forum for Information Retrieval Evaluation*, *2266*, 174–186.

Hamzei, E., Li, H., Vasardani, M., Baldwin, T., Winter, S., & Tomko, M. (2020). Place questions and human-generated answers: A data analysis approach. In: Kyriakidis P., Hadjimitsis D., Skarlatos D., Mansourian A. (eds) *Geospatial Technologies for Local and Regional Development. AGILE 2019*. Lecture Notes in Geoinformation and Cartography. Springer, Cham. doi: 10.1007/978-3-030-14745-7_1

Janarthanam, S., Lemon, O., Liu, X., Bartie, P., Mackaness, W., Dalmas, T., & Goetze, J. (2012). Conversational natural language interaction for place-related knowledge acquisition. *International Workshop on Place-Related Knowledge Acquisition Research*, *881*, 33–38.

Janowicz, K., Gao, S., McKenzie, G., Hu, Y., & Bhaduri, B. (2020). GeoAI: spatially explicit artificial intelligence techniques for geographic knowledge discovery and beyond. *International Journal of Geographical Information Science*, *34*(4), 625–636. doi: 10.1080/13658816.2019.1684500

Klopfenstein, L. C., Delpriori, S., Paolini, B. D., & Bogliolo, A. (2018). Code Hunting Games: A Mixed Reality Multiplayer Treasure Hunt Through a Conversational Interface. *International Conference on Internet Science*, *10750 LNCS*. doi : 10.1007/978-3-319-77547-0_14

Klopfenstein, L., Delpriori, S., Paolini, B., & Bogliolo, A. (2018). X MARKS THE BOT: ONLINE CODING-BASED TREASURE HUNT GAMES FOR CODE LITERACY. *INTED2018 Proceedings*, 4867–4873. doi: 10.21125/inted.2018.0951

Liu, X., Wang, X., Wright, G., Cheng, J. C. P., Li, X., & Liu, R. (2017). A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS International Journal of Geo-Information*, *6*(2). doi: 10.3390/ijgi6020053

Makanga, P. T., Schuurman, N., von Dadelszen, P., & Firoz, T. (2016). A scoping review of geographic information systems in maternal health. *International Journal of Gynecology & Obstetrics*, *134*(1), 13–17. doi: 10.1016/j.ijgo.2015.11.022

Manda, S., Haushona, N., & Bergquist, R. (2020). A Scoping Review of Spatial Analysis Approaches Using Health Survey Data in Sub-Saharan Africa. International Journal of Environmental Research and Public Health, 17(9), 3070. doi: 10.3390/ijerph17093070

Marge, M., & Rudnicky, A. I. (2019). Miscommunication Detection and Recovery in Situated Human-Robot Dialogue. *ACM Transactions on Interactive Intelligent Systems*, *9*(1). doi: 10.1145/3237189

Massai, L., Nesi, P., & Pantaleo, G. (2019). PAVAL: A location-aware virtual personal assistant for retrieving geolocated points of interest and location-based services. *Engineering Applications of Artificial Intelligence*, *77*, 70–85. doi: 10.1016/j.engappai.2018.09.013

Mennicken, S., Brillman, R., Thom, J., & Cramer, H. (2018). Challenges and Methods in Design of Domain-specific Voice Assistants. *AAAI Spring Symposium Series*.

Miralles, I., Granell, C., Díaz-Sanahuja, L., Van Woensel, W., Bretón-López, J., Mira, A., Castilla, D., & Casteleyn, S. (2020). Smartphone apps for the treatment of mental disorders: A systematic review. *JMIR MHealth and UHealth, 8*(3)*:* e14897. doi: 10.2196/14897

Mitton, C., Smith, N., Peacock, S., Evoy, B., & Abelson, J. (2009). Public participation in health care priority setting: A scoping review. *Health Policy*, *91*(3), 219 – 228. doi: 10.1016/j.healthpol.2009.01.005

Morales, J., & By, R. A. de. (2014). Cyber-applications as gateway to data-rich Digital Earth systems. *International Journal of Digital Earth*, *7*(7), 576–593. doi: 10.1080/17538947.2013.788224

Morocho, V., Saltor, F., & Pérez-Vidal, L. (2003). Ontologies: Solving semantic heterogeneity in a Federated Spatial database system. *ICEIS 2003 - Proceedings of the 5th International Conference on Enterprise Information Systems*, *1*, 347–352.

National Council of Geoinformatics. (2013) National Catalog of Geographical Objects in Ecuador. Retrieved from https://sni.gob.ec/documentos-conage

O'Flaherty, J., & Phillips, C. (2015). The use of flipped classrooms in higher education: A scoping review. *The Internet and Higher Education*, *25*, 85 – 95. doi: 10.1016/j.iheduc.2015.02.002

OGC. (2019). *Artificial Intelligence in Geoinformatics DWG*. Retrieved from https://www.ogc.org/projects/groups/geoaidwg

Petrock, V. (2019). *US Voice Assistant Users 2019. Who, What, When, Where and Why*. Retrieved from https://www.emarketer.com/content/us-voice-assistant-users-2019

Portela, M., & Granell-Canut, C. (2017). A New Friend in Our Smartphone? Observing Interactions with Chatbots in the Search of Emotional Engagement. *Proceedings of the XVIII International Conference on Human Computer Interaction*. doi: 10.1145/3123818.3123826

Prendergast, D., & Szafir, D. (2018). Improving object disambiguation from natural language using empirical models. *Proceedings of the 20th ACM International Conference on Multimodal Interaction*, 477–485. doi: 10.1145/3242969.3243025

Reis, A., Liberato, M., Paredes, H., Martins, P., & Barroso, J. (2019). Creating Weather Narratives. *International Conference on Human-Computer Interaction*, *11573 LNCS*, 312–322.

Ronzhin, S., Folmer, E., Maria, P., Brattinga, M., Beek, W., Lemmens, R., & van't Veer, R. (2019). Kadaster Knowledge Graph: Beyond the Fifth Star of Open Data. *Information*, *10*(10), 310. doi: 10.3390/info10100310

Santos, J., Rodrigues, J. J. P. C., Casal, J., Saleem, K., & Denisov, V. (2018). Intelligent Personal Assistants Based on Internet of Things Approaches. *IEEE Systems Journal*, *12*(2), 1793–1802. doi: 10.1109/JSYST.2016.2555292

Santos, João, Rodrigues, J. J. P. C., Silva, B. M. C., Casal, J., Saleem, K., & Denisov, V. (2016). An IoT-based mobile gateway for intelligent personal assistants on mobile health environments. *Journal of Network and Computer Applications*, *71*, 194–204. doi: 10.1016/j.jnca.2016.03.014

Sardella, N., Biancalana, C., Micarelli, A., & Sansonetti, G. (2019). An Approach to Conversational Recommendation of Restaurants. *International Conference on Human-Computer Interaction*, 123–130. doi: 10.1007/978-3-030-23525-3_16

Schade, S., Granell, C., Vancauwenberghe, G., Keßler, C., Vandenbroucke, D., Masser, I., & Gould, M. (2020). Geospatial Information Infrastructures. In H. Guo, M. F. Goodchild, & A. Annoni (Eds.), *Manual of Digital Earth* (pp. 161–190). Springer Singapore. doi: 10.1007/978-981-32-9915-3_5

Signoretti, A., Martins, A. I., Almeida, N., Vieira, D., Rosa, A. F., Costa, C. M. M., & Texeira, A. (2015). Trip 4 All: A Gamified App to Provide a New Way to Elderly People to Travel. *Proceedings of the 6th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-Exclusion*, *67*, 301–311. doi: 10.1016/j.procs.2015.09.274

Subramani, B., & Deepika, S. P. (2019). A robust artificial intelligence: Smart indoor positioning system. *International Journal of Innovative Technology and Exploring Engineering*, *8*(10), 1393–1398. doi: 10.35940/ijitee.A1001.0881019

Sánchez-Pi, N., Mangina, E., Carbó, J., & Molina, J. M. (2010). Multi-agent system (MAS) applications in ambient intelligence (AmI) environments. *Trends in Practical Applications of Agents and Multiagent Systems*, *71*, 493–500.

Thenmozhi, D., Senthil Kumar, B., & Aravindan, C. (2018). SSN_NLp@IECSIL-FIRE-2018: Deep learning approach to named entity recognition and relation extraction for conversational systems in Indian languages. *Forum for Information Retrieval Evaluation*, *2266*, 187–201.

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., … Straus, S. E. (2018). PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Annals of Internal Medicine*, *169*(7), 467–473. doi: 10.7326/M18-0850

Tsai, M.-H., Chen, J. Y., & Kang, S.-C. (2019). Ask Diana: A Keyword-Based Chatbot System for Water-Related Disaster Management. *Water*, *11*(2), 234. doi: 10.3390/w11020234

Vaidyam, A. N., Wisniewski, H., Halamka, J. D., Kashavan, M. S., & Torous, J. B. (2019). Chatbots and Conversational Agents in Mental Health: A Review of the Psychiatric Landscape. *The Canadian Journal of Psychiatry*, *64*(7), 456–464. doi: 10.1177/0706743719828977

Vasilyeva, K., Widener, M. J., Galvagno, S. M., & Ginsberg, Z. (2018). Spatial methods for evaluating critical care and trauma transport: A scoping review. *Journal of Critical Care*, *43*, 265 – 270. doi: 10.1016/j.jcrc.2017.08.039

Walter, C. (2020). Future Trends in geospatial information management: the five to ten year vision - Third Edition (August 2020). Ordnance Survey of Great Britain and the UN Committee of Experts on Global Geospatial Information Management, http://ggim.un.org/future-trends. Unpublished manuscript. Retrieved from https://ggim.un.org/documents/DRAFT_Future_Trends_report_3rd_edition.pdf

Weisel, K. K., Fuhrmann, L. M., Berking, M., Baumeister, H., Cuijpers, P., & Ebert, D. D. (2019). Standalone smartphone apps for mental health—A systematic review and meta-analysis. *Npj Digital Medicine*, *2*(1), 1–10. doi: 10.1038/s41746-019-0188-8

White, R. W. (2018). Skill Discovery in Virtual Assistants. *Commun. ACM*, *61*(11), 106-113. doi: 10.1145/3185336

Wright, D. J., & Wang, S. (2011). The emergence of spatial cyberinfrastructure. *Proceedings of the National Academy of Sciences*, *108*(14), 5488–5491. doi: 10.1073/pnas.1103051108

Yang, C., Raskin, R., Goodchild, M., & Gahegan, M. (2010). Geospatial Cyberinfrastructure: Past, present and future. *Computers, Environment and Urban Systems*, *34*(4), 264 – 277. doi: 10.1016/j.compenvurbsys.2010.04.001

Zhu, W. (2017). Using knowledge graph and search query click logs in statistical language model for speech recognition. *Proc. Interspeech 2017*, *2017-August*, 2735–2738. doi: 10.21437/Interspeech.2017-1790

Tables

Table 1. Conferences and journals. Number of articles per conference/journal in square brackets (nothing means 1). Geography ones are highlighted in bold.

Type	Year	Source
Conferences (65%)	2010	Proceedings of the Workshop on Computational Models of Spatial Language Interpretation; Trends in Practical Applications of Agents and Multiagent Systems
	2011	Annual Conference of the International Speech Communication Association
	2012	**International Workshop on Place-related Knowledge Acquisition Research**
	2015	Proceedings of the International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-exclusion
	2017	IEEE International Conference on Acoustics, Speech and Signal Processing; Proc. Interspeech 2017
	2018	International Conference Information Visualization; International Conference on Intelligent User Interfaces; IEEE International Symposium on Robot and Human Interactive Communication; IEEE International Conference on Cognitive Infocommunications; Construction Research Congress 2018; Forum for Information Retrieval Evaluation [2]; INTED2018 Proceedings; International Conference on Internet Science; ACM International Conference on Multimodal Interaction
	2019	International Conference on Human-Computer Interaction [2]; International Workshop of Physical Agent; Italian Symposium on Advanced Database Systems; International Conference on Computer Animation and Social Agent; ACM Workshop on Mobile Systems for Computational Social Science
	2020	**The Annual International Conference on Geographic Information Science (AGILE)**
Journals (35%)	2011	Journal of Visual Languages & Computing
	2013	**Transactions in GIS**
	2015	International Journal of Serious Games
	2016	Journal of Network and Computer Applications
	2017	Computer Science and Information Systems
	2018	**Computers, Environment and Urban Systems**
	2019	ACM Transactions on Interactive Intelligent Systems; Engineering Applications of Artificial Intelligence; Information; International Journal of Innovative Technology and Exploring Engineering; **Journal of Navigation**; Sensors and Material; Water

Table 2. Applications domains and scenarios of the eligible articles. The "geo goal" column summarizes how geographic information is used in the virtual assistants.

Group	Main domain	Geospatial usage	Reference	Virtual Assistant application description	Relevant Geospatial data sources and/or methods used	Research areas
Specific application domains	Disaster management	Mapping	(Tsai, Chen & Kang, 2019)	Disaster management (floods)	Georeferenced maps with layers of relevant information	Fuzzy search algorithms, Knowledge graphs
	Education	Spatial operators by concepts	(Cai, Yu & Chen, 2013)	Conversational interface for the use and access of geospatial functions	Spatial data analysis	Conversational agent
		Mapping	(Eiris-Pereira & Gheisari, 2018)	Education (in communicative competencies) in construction environments	Space-time Immersion in a BIM environment	BIM environments, Conversational agent, Game engines
	Education; Entertainment	Positioning	(Doumanis & Smith, 2015)	Gamified mobile guide applications	Efficiency improvement for gamification-based location	Embodied conversational agents, Gamification
		Mapping	(Klopfenstein, Delpriori, Paolini & Bogliolo, 2018)	Chatbot for multiplayer game	Promote code-literacy through a multiplayer game	Code literacy, Messaging bot, Mixed reality
	Healthcare	Positioning	(Santos et al., 2016)	Health	Monitoring of health parameters in patients through their location	Cloud, IoT
		(Object) positioning	(Bandara, Muthugala, Jayasekara & Chandima, 2018)	Assistance robot for the elderly and disabled	Identifying spatial relationships between objects within an environment	Assistive robotics, Human-robot interaction, Speech recognition, Uncertain term interpretation
		Navigation	(Gintner, Balata, Boksansky & Mikovec, 2018)	Outside navigation for blind pedestrians	Outdoor navigation	Conversational agent
		(Object) positioning	(González-Medina, Romero-González & García-Varea, 2019)	Assistance robot for the elderly and disabled	Search for objects based on the recognition of their characteristics within an indoor environment	Assistive robotics, Human-robot interaction, Speech recognition, Uncertain term interpretation

	Recommendation	Positioning	(Sánchez-Pi, Mangina, Carbó & Molina, 2010)	Customization of services depending on the position and user data (e.g., check-in at an airport)	Indoor positioning and navigation	Conversational agent, Multi-agent system
		Positioning	(Agarwal Khan & Sarikaya, 2017)	Information consultation and recovery	Treatment of queries with location information of POIs (business)	Artificial intelligence
		Mapping	(Atreja et al., 2018)	Citizen support for the solution of civic problems in the city	Presentation of relevant information and registration of complaints in specific locations	Continuous learning, Conversational agent, Crowd sourcing, Intent classifier, Natural language processing, Proactive interaction
		Positioning	(Acer, Van Den Broeck & Kawsar, 2019)	Get local information from conversational agents embedded in a local neighbourhood, complemented with navigation	Outdoor positioning	Conversational agent, Multi-agent system
		Positioning	(Sardella, Biancalana, Micarelli & Sansonetti, 2019)	Restaurant recommendation	Outdoor positioning	Recommender systems, Similarity algorithms
		Proximity	(Anelli, Di Noia, Di Sciascio & Ragone, 2019)	Information search system in digital libraries	Localization of digital resources in digital libraries through geospatial queries	Knowledge graphs, Linked open data, Natural language processing
		Summarisati on	(Reis, Liberato, Paredes, Martins & Barroso, 2019)	Weather narration for blind people	Data access to meteorological data	Natural language processing
		Place recognition	(Ronzhin et al., 2019)	Chatbot with location recognition	Chat panel with a map viewer for access to geospatial information	Government open data, Knowledge graph, Linked data, Location-aware chatbots, Semantic enrichment
	Tourism	Question answering	(Janarthanam et al., 2012)	Tourism	Navigation based on questions-answers	Speech recognition, Text-to-speech responses

		Mapping	(Signoretti et al., 2015)	Tourism	Multimedia and personalized experience about places visited	Gamification, Natural language processing
		(Object) positioning	(Grazioso, Cera, Di Maro, Origlia & Cutugno, 2018)	Guided tours	Identification of the object that the user looks at; 3D reconstruction of heritage buildings; data access	Semantic annotation, Speech recognition
		Navigation	(Bartie et al., 2018)	Tourism	Visibility of places of interest from the point of view of the tourist (pedestrian); route guide; outdoor navigation	Speech recognition, Text-to-speech responses
		(Object) positioning	(Ali, Le, Kim, Hwang & Hwang, 2019)	Guided tours	Identification of the object that the user looks at	Conversational agent, Mixed reality, Speech recognition
		Positioning	(Massai, Nesi & Pantaleo, 2019)	POIs recommendation	Estimation of the need for information and possible geographical references expressed by users	Artificial intelligence, Knowledge graphs, Natural language processing, Ontologies, Semantic queries
		Positioning	(Chen, Wu & Wang, 2019)	Outdoor navigation for touristic guides	Outdoor navigation, route planning and place guides	Artificial intelligence, Natural language processing
	Tourism; Cultural heritage	Navigation	(Abate, Acampora & Ricciardi, 2011)	Tours in archaeological sites	A tour to a set of exhibits located within a cultural heritage site by means of an avatar	Augmented reality, Automata, RFID
		Positioning	(Garrido, Barrachina, Martinez & Sero, 2017)	Smart tourist information points with travel information organized in ontologies	Regions of interest organize knowledge base, POIs location	Affective computing, Animation engine, Embodied conversational agents, Ontologies, Speech recognition
	Tourism; Entertainment	Positioning	(Klopfenstein, Delpriori, Paolini & Bogliolo, 2018)	Education, tourism, entertainment	Physical location of objects and solving puzzles	Conversational agent, Deep-linking, Natural language processing

Specific features or aspects of virtual assistants	Conversation	Navigation	(Margue & Rudnicky, 2019)	Conversational interface between a human operator and a team of one or more robots	Detection and recovery of human-robot communication	Human–robot communication, Language grounding, physically situated dialogue, Spoken-dialogue systems
		Question answering	(Hamzei et al., 2020)	In situ conversational search and assistance system	Structural patterns of questions related to places and their human-generated responses using the MS MARCO V2.1 data set	Named entity recognition, Question answering
	Linguistic	Place recognition	(Zhu, 2017)	Automatic speech recognition for place entities	Recognition of words that define places in dialects and regions of interest organized in a knowledge base	Entity relation, Knowledge graphs, Speech recognition
		Reasoning on spatial relations	(Prendergast & Szafir, 2018)	Recognition of spatial relationships in text	Establishment of spatial relationships between objects in a scene	Machine learning, Natural language processing
		Place recognition	(Gupta, Ayyar, Singh & Shah, 2018)	Conversational system for Indian languages	Identification and classification of words that denote places or location	Linear models, Named entity recognition, Neural network
		Place recognition	(Thenmozhi, Senthil Kumar & Aravindan et al., 2018)	Automatic text recognition for place entities	Recognition of places in unstructured text	Deep learning, Entity relation, Named entity recognition, Neural machine translation
	Navigation	Space modelling	(Dobnik & Pulman, 2010)	Evaluation of routes generated by a robot (indoor maps)	Indoor space modeling	Modelling of indoor spaces, Natural language description of indoor spaces
		Positioning	(Cuayáhuitl & Dethlefs, 2011)	Conversational learning agent	Navigation through complex and challenging space environments	Conversational agent
		Positioning	(Subramani & Deepika, 2019)	Indoor navigation	Indoor positioning and navigation	Natural language processing

		Positioning	(Antrobus, Large, Burnett & Hare, 2019)	Driver workload and environmental engagement associated with ‘active’ and ‘passive’ navigation systems.	Route selection	Natural language interfaces, Vehicle navigation systems

Figure legends

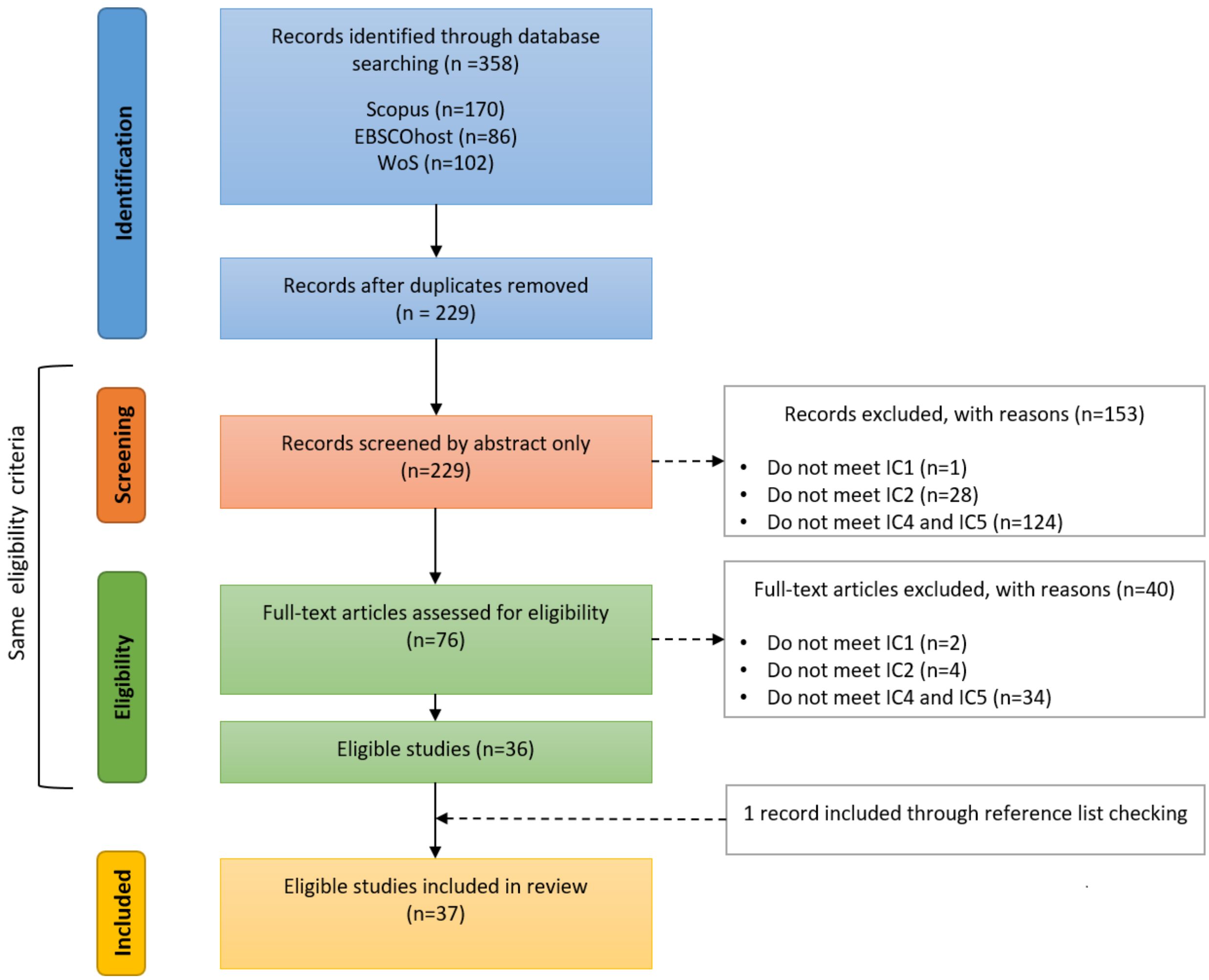

Figure 1. Flowchart of the eligibility process according to the PRISMA methodology.

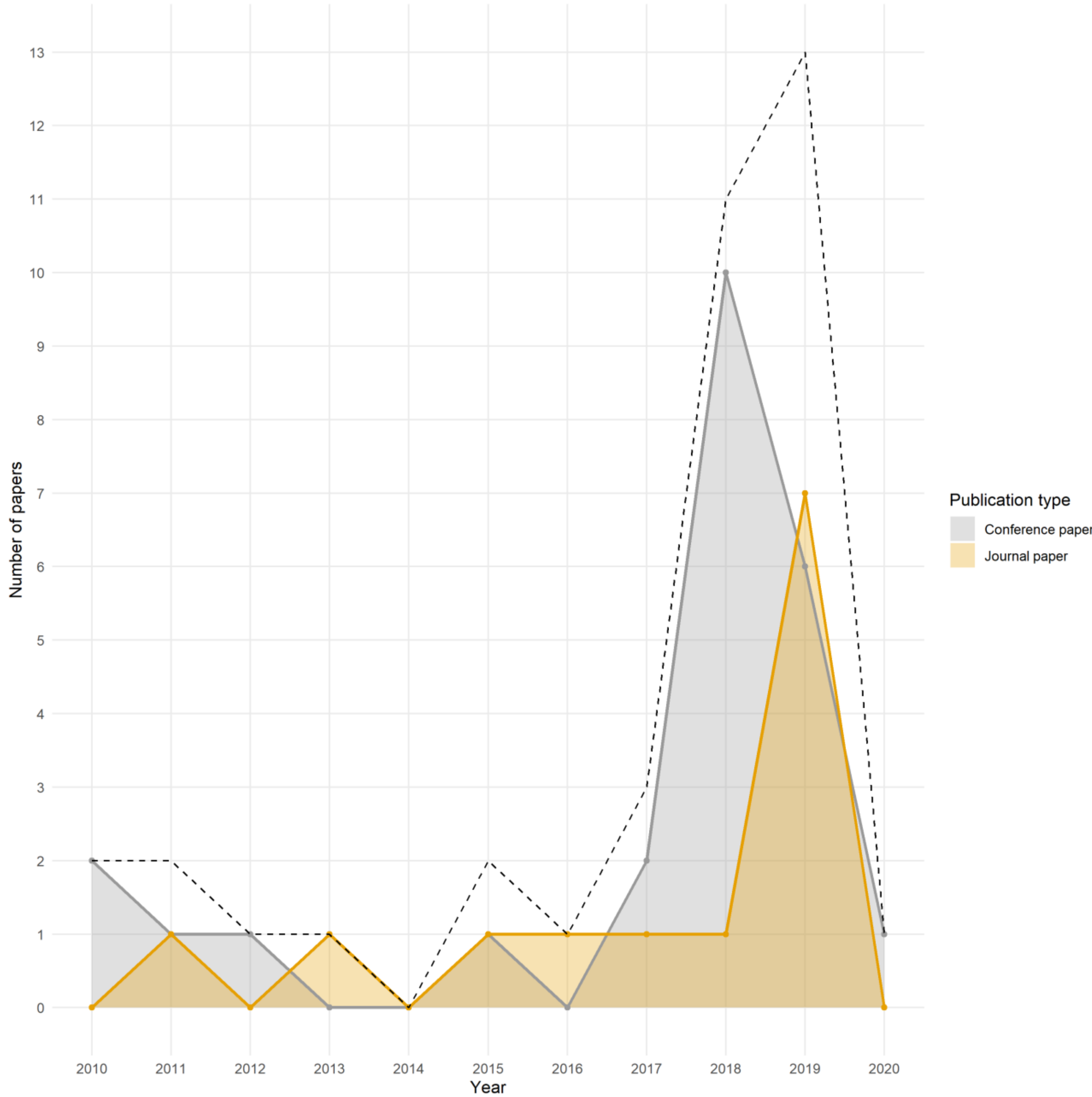

Figure 2. Temporal distribution of eligible papers. Note that the article in 2020 was presented in 2019, but the publication date (publisher) is 2020. The dashed line denotes the sum of journal papers and conference papers per year.

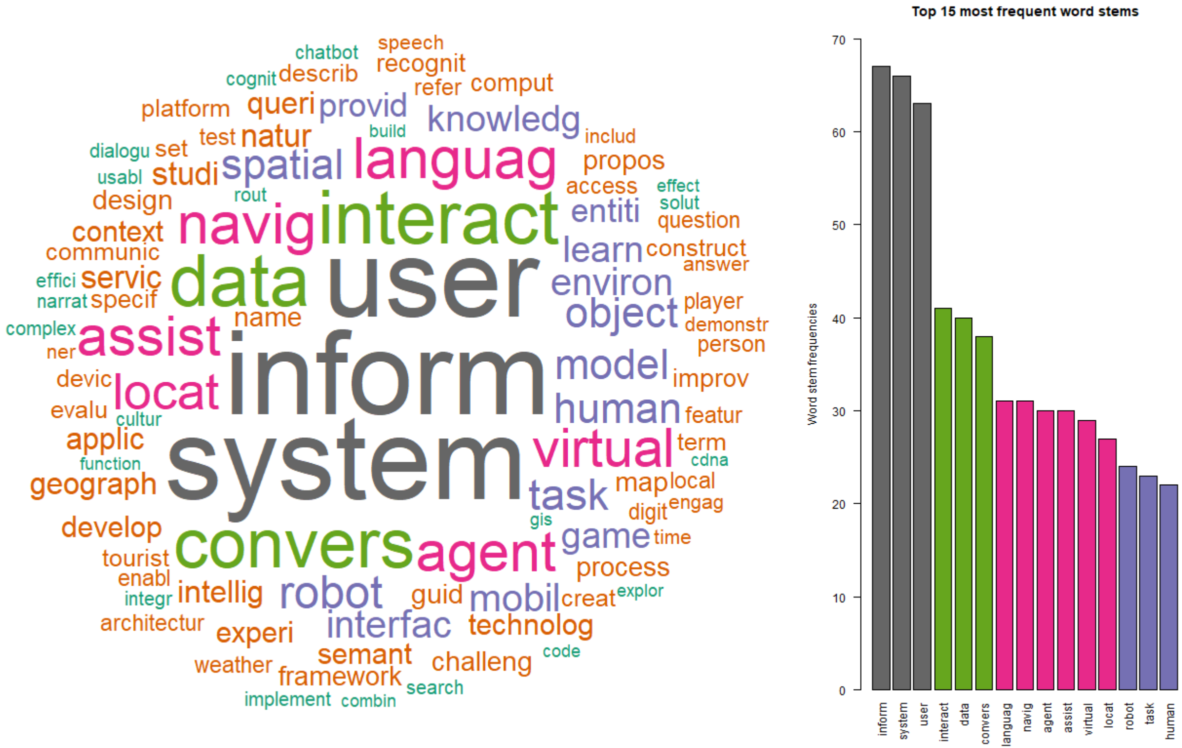

Figure 3. The left side shows a word cloud of the most frequent word stems (minimum 5 occurrences) in all abstracts after removing stopwords. The right side shows a frequency bar chart of the top 15 word stems.

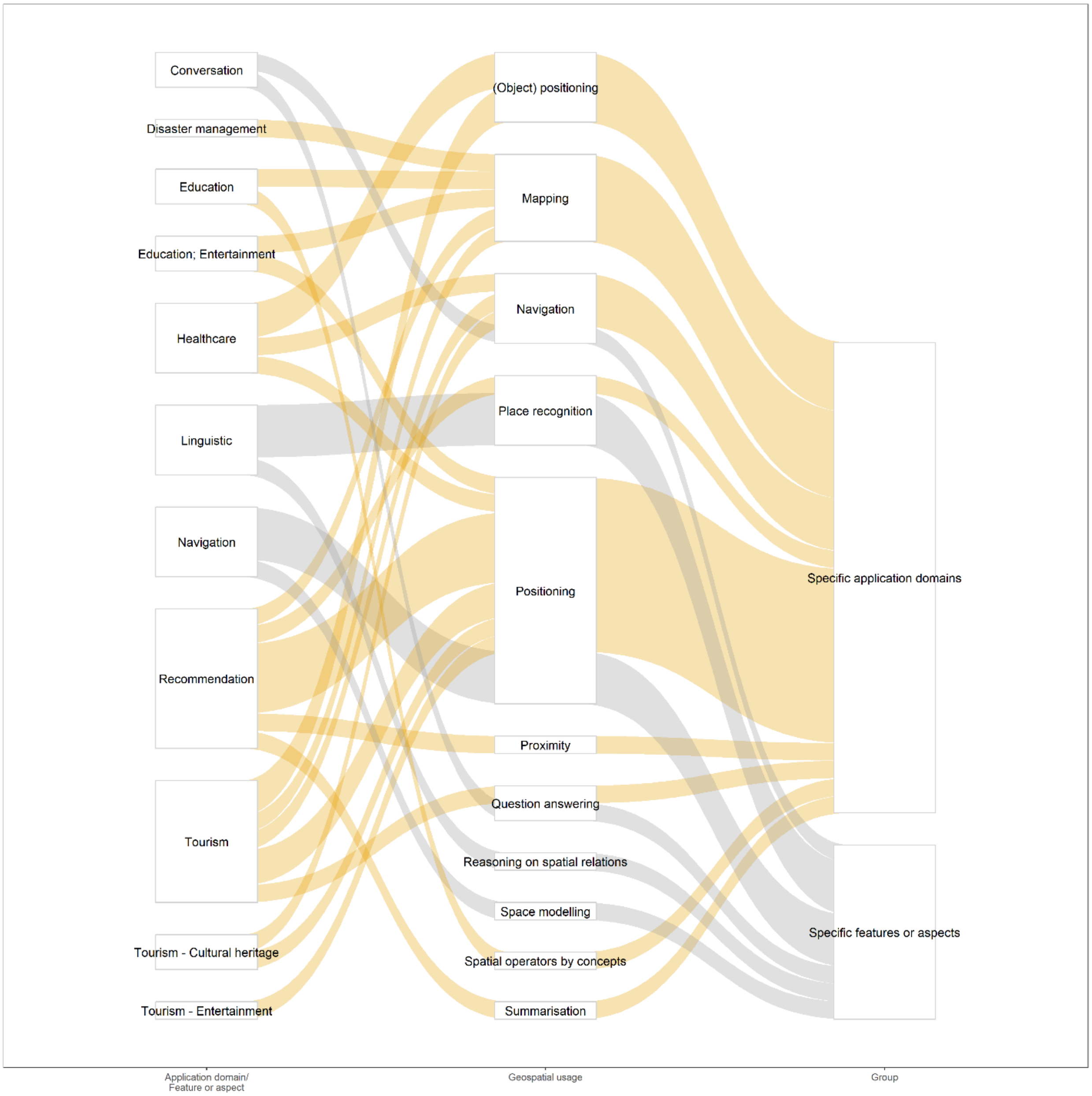

Figure 4. Interaction between the group, application domain/feature, and geospatial usage of the virtual assistants.

Figure 5. Temporal distribution of the virtual assistants according to their technical approach and development status.

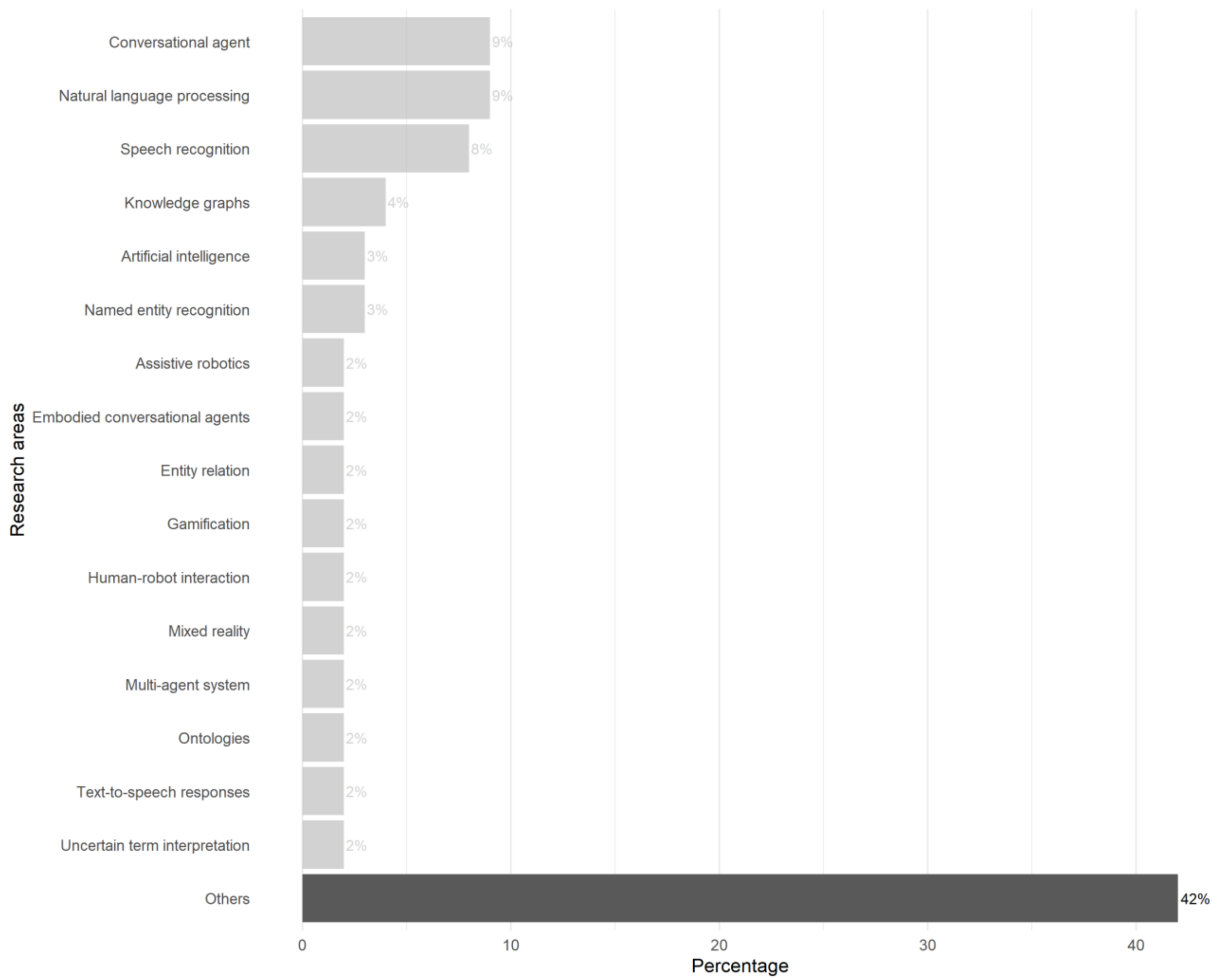

Figure 6. Percentages of the research areas identified in the reviewed papers.