Adaptive Ontologies for Multimedia Maps

M.G. Fugini, J. Finocchi, and E. Rossi

***Abstract*—**The paper illustrates a web-based framework linking geographic elements with geo and temporal-referenced multimedia contents. Among the key features, - multimedia content integration, time management and self-adaptivity to different application contexts are the most relevant ones. A hybrid approach to classify stored contents combines a Machine Learning (ML) technique for text classification with the intervention of human experts. A dynamically configured ontology-based navigation is proposed based on the adaptivity of the tool to dynamic classification of contents. Adaptive navigation is supported by a general world and by a domain-specific ontology. The approach is presented in a framework and prototype named Multimedia Adaptive Geographic Information System (MAGIS), an extension to Geographic Information Systems (GIS) devised as a common foundation to be adapted to different domain-specific implementations. A demonstration of the web-based MAGIS prototype is provided for Cultural Heritage (CH) events.

***Index Terms*—**Georeferenced Data, Text Analytics, Adaptive Systems, Multimedia Content, Cultural Heritage.

I. Introduction

Among the most recent aims of geographic-based applications, the aim of enriching maps with georeferenced content is prominent, allowing one to explore selected areas and run thematic, multilevel analyses [1].

In existing applications, some features are still lacking or awkward in highly dynamic contexts, where contents vary in real-time and in a seamless way. An example is citizen journalism, where news arrives in real-time and need to be integrated and analyzed in a seamless way and at various levels of interest and zoom levels: from the largest one, enriching navigation by accessing more linked content, to the narrowest one, focusing on details of interest.

This paper proposes MAGIS, a framework to associate structured and unstructured multimedia data to geographic maps, creating a web environment that can be navigated both geographically and temporally. The framework is instantiated into domain-specific implementations via dynamic layers obtained classifying content items according to application-specific tags, interconnected through a domain-specific ontology.

The adoption of an ontology facilitates the exploration of associated knowledge, by considering correlations and logical connections between content items.

MAGIS performs dynamic filtering and aggregation of content items based on semantic properties of knowledge, namely location, time and topic:

- Location aggregation is implemented by spatial clustering, a technique typical of geographical maps;
- Time aggregation is based on a calendar hierarchy;
- Thematic topics aggregation is based on a domain-specific ontology and is implemented through *layers*.

The integration of structured data into geographic maps is a target achieved by various applications, which address for instance map thematization and choropleth maps [2]. Usually, navigation is carried out by applying filters on measurable values, while data analysis is performed via statistical and analytical tools typical of business intelligence.

Our proposal aims at integrating cartography with unstructured data, which appears as a less established area [3]. Unstructured contents typically include multimedia elements (images, videos, texts, or document files) together with a set of metadata describing the content item. Georeferenced multimedia is particularly important in fields like Cultural Heritage (CH), which brings together heterogeneous types of content, like textual posts, pictures or video, audio recordings, and event information related to happenings in museums, theatres, or city areas.

Our framework was tested by developing a prototype called MAGIS (Multimedia Adaptive Geographic Information System), an extension to existing GIS that allows for semi-automatic classification of contents by combining a Machine Learning (ML) technique for text classification with the intervention of human experts. Other features regard the capability to handle temporal information and to dynamically adapt the user navigation according to the dynamic classification of the content.

The addressed problems are as follows.

1. *Reducing information overload*.
2. *Adapting knowledge to specific application-related context automatically,* via ML algorithms (adaption of knowledge). Human intervention by an expert is required to tune the knowledge to the specific requirements of a user or of an application.
3. *Dealing with highly dynamic realities*, like News or CH events. These emerge and disappear quickly, as happens in the “Piano City” event, a piano marathon in Milan, Italy, that has a huge quantity of associated knowledge accumulated by social media. Such knowledge has to be acquired, maintained, verified, publicized, stored for

This work was partially supported by the European Union’s Horizon 2020 research and innovation program under grant agreement No. 826232, project WorkingAge (SmartWorking environments for all Ages) and by the “Seamless” Project - Area Smart Living, Regione Lombardia.

future years, inherited from previous editions for reuse, and so on.

The solution we propose in MAGIS is to link contents to both spatial (in Piano City, areas of the town, buildings, etc.) and chronological references (date and time of events). MAGIS manages the spatial dimension via Points of Interest on the maps, and the temporal dimension via temporal tags. The user can display the chronological placement of contents and the related multimedia items over time. For example, using the general ontology, it is possible to retrieve the content associated with a geographical area in a certain time period or to inspect how an element has evolved over time (e.g., in CH, pictures documenting variation of style of a building through interventions).

By instantiation of MAGIS knowledge, designers of a multimedia-based geographic information system can develop an application in a specific domain context. In fact, a key feature of MAGIS is its adaptability to different application domains, or contexts, such as history, architecture, CH, digital twinning of artifacts and buildings, and so on.

The paper is organized as follows. In Section 2, related work is presented. In Section 3, the MAGIS approach to enriching maps with knowledge is explained. In Section 4, a demonstrative prototype shows how the framework has been implemented. In Section 5, the conclusions are drawn.

II. Related Work

Many geographic-based tools and applications have been proposed in the literature in different contexts, where maps are used either as exploration tools or as professional tools for advanced analyses. Geographic applications are still a widespread object of study. Developers are implementing many different solutions that combine geo-referenced information related to a map, ending up with maps that can be used either as general interest exploration tools or as professional tools for advanced analyses purposes. Among the most common applications, Geographic Information Systems (GIS) are software platforms specialised in gathering, managing, and analysing geo-referenced data.

GIS can reveal deeper insights into data, such as patterns, relationships, and events, helping users in taking smarter decisions [4]. Some examples of GIS platforms available today are ArcGIS by ESRI [5], GISMaker by ProgeCAD [6], and PostGIS, the special database extender for the open-source object-relational database PostgreSQL [7]. MAGIS is to be considered – under this viewpoint – a GIS frameworkor a portion thereof, which can lead to the development of components to be eventually incorporated in a commercial product as add-on components.

Differently from traditional GISs, which manage *static* data, MAGIS is designed to manage *dynamic* data coming from real-time data sources, including crowdsourcing, participatory news and social media.

Over years, developers have also implemented Temporal GIS [8]. Temporal information has been incorporated into spatial data models of GIS by time-stamping layers (the snapshot models [9]), attributes (space-time composites [10]), and spatial objects (spatiotemporal objects [11], [12]).

Historic Atlas tools illustrate the evolution of historic events and phenomena characterising different geographical areas in a certain era. One example is GeaCron [13], an interactive Global Historic Atlas from 3000 B.C.

Other GIS platforms focus on map-based tools to run specific data analyses, especially exploiting Big Data and making use of ML and Data Mining algorithms. [14] introduces ML models and their potential applications to geospatial data, with a focuson artificial neural networks and statistical learning. [15] proposes Picterra [16] as a tool to upload images where users can train an algorithm to find objects of interest. In [17], some socio-economic indicators (i.e., residents, unemployment, migration, and elderly) were predicted based on OpenStreetMap (OSM) using ML algorithms. Recently, multimedia GIS (MM-GIS) [18] can collect, analyse and store data in unstructured formats, i.e., text, images (pictures) and graphs as well as audio (sound), animations and video (moving pictures). Current examples of MM-GIS on the market are ArcGIS Insights and ArcGIS StoryMaps by ESRI [19].

Existing geographic-based applications seem to be focused on a certain aspect, e.g., time dimension, or multimedia management, while it is difficult to find a combination of the different aspects in a way that they are all dynamically managed. For example, the *Russia-Ukraine Monitor Map* [20] is an interactive map of georeferenced multimedia contents built to monitor the conflict in Ukraine; contents are taken from Twitter and other social media and are uploaded by citizens who can navigate the map via a menu listing all the content items grouped by topic. Here, contents are manually uploaded and tagged, one by one, without an automatic classification.

Compared to existing solutions, MAGIS natively provides a link among the spatial, temporal, and semantic dimensions: contents can be referenced in all the three aspects so that the user can easily access and select elements by multiple criteria.

The user interface is another aspect of GIS where further improvements are still needed. Some research has highlighted the need for more dynamic and adaptive map layers, as in [21]. MAGIS interface is built into dynamic layers where contents are structured into groups of related topics; a topic-specific ontological structure at the basis of MAGIS framework is used to logically organise contents and create a dynamic interface.

An innovative theme currently investigated regards semantic analysis tools, typically based on an ontology, supporting logic/probabilistic deductions from a base of geo-referenced data. To improve the quality of noisy and ambiguous data of OSM caused by its simple and open semantic structure, [22] proposes an OSM Semantic Network tocompute semantic similarity through co-citation measures, providing a novel semantic tool for OSM and GIS communities. The exploitation of semantic meaning to facilitate content navigation is often assisted by an ontology, as in [23], whose support is beneficial in the specialisation of concepts within each context, such as in the CH domain described in [24]. This is also managed in MAGIS, where a *meta-ontology* is built to generally define the key concepts of the framework, and a *topic-specific ontology* is designed to structure the specific contents of a defined knowledge domain.

III. Adding Knowledge to Maps

The objective of MAGIS is to enable a generic knowledge model to be instantiated onto different contexts via self-adaptation, based on automatic content classification. This issue is one innovative feature of our approach. Its purpose is to automatically adapt the navigation interface to the available contents, to mitigate the information overload that would occur when showing all the content items at the same time.

To allow users to focus on the subset of contents of their interest, MAGIS introduces dynamic aggregation criteria and reduces the multitude of objects that can appear on the map. Selection and aggregation are based on spatial navigation (map panning and zooming) on items chronology and, especially, on thematic tags. The selection and aggregation criteria are dynamic, namely, they depend on the available contents and on their classification.

MAGIS performs dynamic filtering and aggregation of content items based on three semantic properties, namely location, time, and topic as follows: i) Aggregation by geographic locations, obtained via spatial clustering (a technique typical of geographical maps); ii) Time aggregation, based on a calendar hierarchy, and iii) Aggregation by thematic topics, based on a domain-specific ontology and implemented through layers.

An ontology supports context-adaptive presentation. It is used also to achieve a language-independent content navigation, which often represents an issue in geographic systems [25]. The navigation of multimedia content is organized in layers representing different topics. The basic layer is the map itself where cartographic objects are visualized, while subsequent layers are automatically created to display topic-specific contents. Layers are dynamic (not predefined), based on the available content and user preferences. The definition of layers requires contents be classified: the classification must be specific to the application context, making use of a context-specific set of tags.

Classification is performed in MAGIS by a *mixed approach* that combines Artificial Intelligence (AI) with human expertise. First, a domain expert defines an ontology that includes domain-specific semantic categories, then manually classifies a training set of contents. Afterwards, the contents gradually collected during the MAGIS lifecycle are automatically classified by the ML algorithm, associating each content to an ontology node.

In order to import contents from massive existing archives with no need formanual classification of contents, automatic classification is extremely beneficial, particularly if it can be performed at run time.

Manual classification can take place as a fallback solution when a training set cannot be provided or no textual metadata is available. The human expertcan also intervene on-demand when some confidence indicators about automatically classified data are lower than a given threshold.

The MAGIS ontology supports content selection and dynamic granularity of aggregation criteria. For instance, if the number of items available for a given content topic is too limited, the navigation layer is built on the upper hierarchical level topic. Conversely, if too many items are retrieved, the navigation layer is split into a lower-level hierarchy. This dynamic granularity approach is a novelty of our proposal.

A. MAGIS Functional Architecture

MAGIS is a geographic-based framework involving multimedia data management, namely: acquisition, representation, analysis and visualization [4]. MAGIS architecture is shown in Fig.1. Users are both individual citizens and professional users or Public Administrations. Each user category authenticates separately and is granted access to different contents and functionalities according to their needs and roles.

The *Storage* area contains a spatial database for cartographic data, and a database storing information about contexts and multimedia data. The User Profiles module manages data accesses and users' preferences, which is important for selective navigation and recommendation. The Ontology module is the core of MAGIS: it organizes multimedia contents for content classification and retrieval.

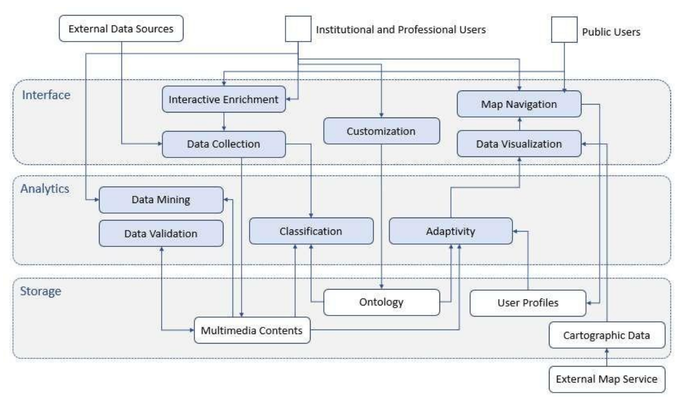

Fig. 1. MAGIS components

The Analytics area contains the key algorithms performing analyses and data aggregations. The Classification module implements the grouping of contents based on thematic tags and manages their connection with ontological classes. The Adaptivity module uses the context-specific ontology to organise the presentation and navigation of content on the map. The Data Validation module assesses the quality of data acquired from external sources and contributors, while Data Mining will allow – in a later development stage – qualified users to conduct more complex analyses by combining structured data with multimedia content.

Interface area uses information about users' profiles and data types to discriminate access to multimedia. A public (open access) set of data allows people to navigate themap and enrich it with their multimedia content. A private set is for registered professional users who can customise their view on the map, by defining their classification ontology. The Data Visualisation and Map Navigation modules aim at reducing information overload by presenting to users an adaptive content organisation,driven by the context-specific ontology, and implemented by dynamic clustering and filtering.

B. MAGIS Data Model

The general ontology is a meta-structure of concepts that is valid for all domain contexts and plays the role of an abstract reference from which the data model is derived. To adapt to different contexts, the data model is generic and extendable. This structure is then required to be made concrete into a domain-specific second-level ontology according to the application field. The ontology represents both the geographic elements that constitute the map layer and classes representing media contents, organised into different thematic topics, and including their metadata, as shown in Fig.2, with two main areas (enclosed into dotted-line frames).

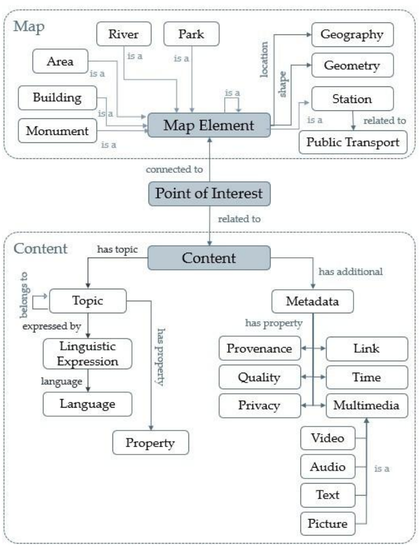

Fig. 2. The general ontology

On the top, the classes related to the management of cartographic data are placed. The central class is the Map Element, representing the generic item that constitutes a certain portion of the map layer. It is defined with its geographic coordinates and can represent a single point (e.g., a monument), a line (e.g., a street) or a polygon (e.g., an area).

The bottom part of the figure is related to the content items managed by the framework. Content is surrounded by a set of other classes and subclasses that represent its attributes and properties. A group of classes deals with the nature of the content item including the temporal dimension. The media element is managed as a link so that potentially any type of document or unstructured dataset can be managed. A central role is also played by the Topic of the multimedia, which is the key for the classification phase.

The link between the two branches is the class *Point of Interest (POI)*.

Fig.3 represents the time dimension of content. Time has different levels of granularity and different aspects that can be associated with it. For instance, it can map the date when a web article was written or published, when a picture was taken, or when a document was edited. It can also represent the moment when the subject of the content item (e.g., an event) takes place, like the date of a theatre performance or the time window of a museum exhibition.

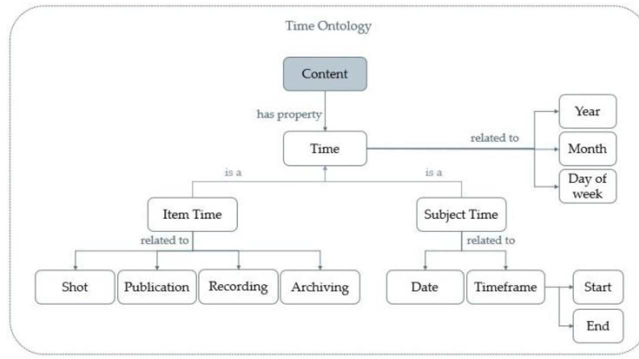

Fig. 3. The time dimension in the ontology

Declining this structure according to different temporal units of measure, the ontology can classify the uploaded data according to temporal tags, like the day of the week, the month, or the year, or to assign a time instant or a time interval allowing the user to investigate time-related queries. The representation of a time hierarchy facilitates information retrieval rather than a single timestamp.

Another qualifying aspect of this data model is the integrated management of aspects related to the origin or provenance of contents. Issues related to data privacy, ownership, licensing, and reliability [26] are included by design to distinguish data sources that are authoritative, trusted, voluntary, or institutional to various degrees.

Multimedia items, as well as being associated with a POI and a chronological label, are classified based on their topics. A *two-level ontology* is defined: the general ontology represents the generic concepts of topic and their *semantic properties and relations*, which are then expanded into a domain-specific ontology, finally instantiated by the single pieces of content.

In our ontologies, besides semantic relations describing connections between concepts, linguistic relations are added, to define the connection between a concept and its linguistic expression in different languages. This linguistic knowledge can have a dual function: on one hand, it enables the translation of the navigation interface into different languages, creating a language-independent topic navigation; on the other hand, it helps to manage synonyms (i.e., two linguistic expressions referencing the same topic).

C. Data Analysis and Content Classification

To classify content topics, MAGIS relies on *textual metadata* associated to multimedia items, which are typically a textual title or a short description (e.g., a title or a caption from a picture), a post on social media, or a text taken from a blog, a forum, or an online newspaper.

Directly analysing the media could be an option, but many different algorithms would be needed according to the type of content (e.g., texts, pictures, videos, audios) and this approach is currently excluded from MAGIS.

The data analysis stage is focused on processing the metadata associated with the contents and in particular on the techniques of Text Extraction and Text Classification, exploiting ML and AI methodologies, such as Natural Language Processing (NLP). Text extraction, based on Entity Recognition algorithms, is used to index data, recognise POIs and generate temporal attributes or semantic tags to enrich the content item properties. Text Classification is aimed to Topic Analysis, through a supervised ML algorithm that can recognise the most relevant topics in a text.

For automatic classification, among the solutions available online, the supervised Short Text Classifier developed by MonkeyLearn [27] has been identified as a suitable candidate for this analysis. Once data have been collected, semantic tags describing their topics must be assigned, starting from available metadata. Domain-specific tags describe contents according to the topic ontology specified by experts at system definition time, or during the application life. Semantic tags will form the basis of domain-specific knowledge navigation tools, such as layering (subdividing contents based on sub-topics or other properties), filtering and faceted search [28] (selecting only a subset of contents) or clustering (grouping contents based on some user-defined criteria), in combination with the time dimension, when available.

The role of the domain expert in this process is to define the most relevant concepts to be included in the domain-specific ontology and how they are interconnected, and then to classify a training set of content items, labelling them with thematic tags. These tags are used to structure contents according to the domain ontology and to allow the navigation interface to show filtered contents.

Overall, the intent is to obtain a *dynamically adaptive system*, designed to adapt not only to different thematic contexts but also to contents that vary over time, therefore not entirely available in advance.

IV. Sample Use of MAGIS Prototype

The MAGIS prototype is a pure demonstrative implementation. Geographic data constituting the base map layer have been taken from OpenStreetMap, an open-source platform available on the web [29] and applied to a piano event from "Piano City". From this source we draw some georeferenced data to populate the prototype, in order to verify the role of the domain-specific ontology and to test the feasibility of the automatic classification tool. Possible open data sources can be exploited for multimedia content fetching, e.g., considering local social media pages (e.g., the Facebook page 'Eventi Milano' [30]), municipal websites (e.g., 'Comune di Milano' [31]) or local online newspapers (e.g., Milano Today). Once collected and stored, content items have been assigned to defined points of interest through an interactive assignment to their map location.

Following the approach described above, we developed a specific ontology for this context, instantiated by the event related contents and made use of it both as a basis for the automatic classification of contents and to dynamically generate the presentation layer. The website of the prototype can be found at the following web address [32]. Fig.4 shows an overview of the user interface, generated from data from the Piano City website, where points of interest are depicted by markers on the map. When clicking on a marker, a list of associated content items is shown aside the map.

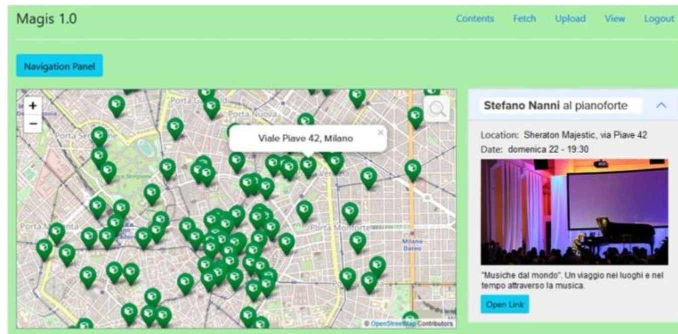

Fig. 4. MAGIS user interface example for Piano City content.

By using the "Navigation Panel" section, the user can filter contents based on the topics, their relations and properties, and the time span selected. The topic tree is dynamically generated starting from the ontology and the contents collected for each topic category.

The maps integrated into the official Piano City web application do not allow users to view multimedia content, which could be related to either the current or previous edition. The automatic analysis and classification of the contents could allow you to retrieve comments in real time from blogs, local news or even from social media.

In the filter panel of the Piano City website, the selection by topic takes place through the classification of contents according to their musical genre. The topic navigation is not language independent, but is only possible in Italian, even in the English version of the interface. Furthermore, the topics are just a flat list, without exploiting neither hierarchies nor other relationships between topics. These limitations are due to the fact that the topics are not organized in a network of semantic and linguistic relations and therefore suggest the usefulness of an ontological approach, such as the one provided by MAGIS.

Another example of MAGIS is given on the case of Citizen Journalism (CJ) [33].

We have compared different ML algorithms, including the Support Vector Machine, Naive Bayes and Artificial Neural Networks, to select the most effective in classifying contents on the basis of their metadata. Some cloud ML services and pre-trained algorithms available online can be used as a starting point for the text classification step. Among these, we have selected the Monkey Learn [27] Topic Classifier and their Keyword Extractor.

V. Conclusions and Future Work

In this paper, the MAGIS prototype is described, a dynamic adaptive system, designed to adapt not only to different thematic contexts but also to contents that vary over time, therefore not entirely available in advance. This is achieved via self- adaption, based on automatic content classification and a set of semantic tags. A hybrid approach combining human intervention and ML algorithm is used to classify contents into topic ontologies that lay the foundations of a layer-based organisation. The navigation interface is equipped with adaptive filtering based on the topic ontology, which helps retrieve contents of interest and reduce information overload.

The geographic data constituting the base map layer has been taken from the OpenStreetMap [29], a platform available on the web.

Two contexts are being considered as examples to develop a prototype, namely CH and journalism, possibly on restricted geographical areas. Possible input content can be thematic collections of pictures shared by professional users, contents from thematic groups about art, sculpture, design, etc. on social media, or media items that can be downloaded from open collections such as Wikimedia Commons [34].

Acknowledgment

This work was partially supported by the European Union's Horizon 2020 research and innovation program under grant agreement No. 826232, project WorkingAge (SmartWorking environments for all Ages - https://www.workingage.eu/) and by the "Seamless" Project - Area Smart Living, Regione Lombardia.

References

[1] C. D. Cobb, "Geospatial Analysis: A New Window Into Educational Equity, Access, and Opportunity", *Review of Research in Education*, 44(1), pp. 97-129, 2020. https://doi.org/10.3102/0091732X20907362
[2] L. McNabb, R. S. Laramee, and R. Fry, "Dynamic choropleth maps – using amalgamation to increase area perceivability", in *22nd International Conference Information Visualisation (IV)*, pp. 284-293, IEEE, 2018. https://doi.org/10.1109/iV.2018.00056
[3] C. Zhou, H. Wang, et al., "Geoscience knowledge graph in the big data era", *Science China Earth Sciences*, 64.7: pp. 1105-1114, 2021. https://doi.org/10.1007/s11430-020-9750-4
[4] S. Gordillo, and R. Laurini, "Conceptual Modeling of Geographic Applications", *Advanced Geographic Information Systems, Encyclopedia of Life Support Systems (EOLSS)*, 2008.
[5] ESRI, https://www.esri.com/en-us/arcgis/about-arcgis/overview, last accessed: 2022/04/12.
[6] P.U.S.P. Italia, "GISMaker, programma per l'elaborazione e la manipolazione di dati geometrici georeferenziati", *GEOmedia*, vol. 19, no. 4, 2015.
[7] PostGIS, http://postgis.net/, last accessed: 2022/03/28.
[8] M. Yuan, "Temporal GIS and spatio-temporal modelling", in *Third International Conference on Integrating GIS and Environmental Modeling*, Santa Fe, NM, 1996.
[9] M. P. Armstrong, "Temporality in spatial databases", in *GIS/LIS 88 Proceedings: Accessing the world*, pp. 880-889, 1988.
[10] G. Langran, and N. R. Chrisman, "A framework for temporal geographic information", *Cartographica*, 1988. https://doi.org/10.3138/K877-7273-2238-5Q6V
[11] M. F. Worboys, "A model for spatio-temporal information", in *5th International Symposium on Spatial Data Handling*, 1992.
[12] W. Siabato, C. Claramunt, S. Ilarri, and M. A. Manso-Callejo, "A survey of modelling trends in temporal GIS", *ACM Computing Surveys (CSUR)*, 51(2), 1-41, 2018. https://doi.org/10.1145/3141772
[13] GeaCron, http://geacron.com/home-it/, last accessed: 2022/03/28.
[14] M. Kanevski, L. Foresti, C. Kaiser, A. Pozdnukhov, V. Timonin, and D. Tuia, "Machine learning models for geospatial data", *Handbook of Theoretical and Quantitative Geography*, Faculty of Geosciences and Environment, University of Lausanne, Switzerland, pp. 175-227, 2009.
[15] M. Altaweel, "Machine Learning and Object Detection in Spatial Analysis", *GIS Lounge*, 2020. Available: https://www.gislounge.com/machine-learning-and-object-detection-in-spatial-analysis/, last accessed: 2022/02/12.
[16] Picterra - Geospatial cloud-based platform, https://picterra.ch/mission/, last accessed: 2022/03/28.
[17] D. Feldmeyer, C. Meisc, H. Sauter, and J. Birkmann, "Using OpenStreetMap Data and Machine Learning to Generate Socio-Economic Indicators", *ISPRS International Journal of Geo-Information*, 2020. https://doi.org/10.3390/ijgi9090498
[18] S. T. Rahim, Z. Kougen, T. Saidu, and P. Yunhe, "Capabilities of Multimedia GIS", *Chinese Geographical Science*, vol. 9, no. 2, pp. 159-165, 1999. https://doi.org/10.1007/BF02791367
[19] ArcGIS StoryMaps - Digital Storytelling with Maps, https://www.esri.com/en- us/arcgis/products/arcgis-storymaps/overview, last accessed: 2022/02/12.
[20] Map Hub: The Russia-Ukraine Monitor Map, https://maphub.net/Cen4infoRes/russian-ukraine-monitor, last accessed: 2022/02/11.
[21] M. J. Lobo, C. Appert, and E. Pietriga, "MapMosaic: dynamic layer compositing for interactive geovisualization", *International Journal of Geographical Information Science*, 31(9), pp. 1818-1845, 2017. https://doi.org/10.1080/13658816.2017.1325488
[22] A. Ballatore, M. Bertolotto, and D. C. Wilson, "Geographic Knowledge Extraction and Semantic Similarity", *Knowledge and Information Systems*, vol. 37, pp. 61-81, 2013. https://doi.org/10.1007/s10115-012-0571-0
[23] T. Sobral, T. Galvão, and J. Borges, "An ontology-based approach to knowledge-assisted integration and visualization of urban mobility data", *Expert Systems With Applications*, 150, 2020. https://doi.org/10.1016/j.eswa.2020.113260
[24] M. B. Ellefi, P. Drap, O. Papini, D. Merad, J. P. Royer, M. M. Nawaf, and F. Castro, "Ontology-based web tools for retrieving photogrammetric cultural heritage models", *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42(2/W10), pp. 31-38, 2019. https://doi.org/10.1016/j.eswa.2020.113260
[25] T. Blaschke, H. Merschdorf, P. Cabrera-Barona, S. Gao, E. Papadakis, and A. Kovacs-Györi, "Place versus space: from points, lines and polygons in GIS to place-based representations reflecting language and culture", *ISPRS International Journal of Geo-Information*, 7(11), 452, 2018. https://doi.org/10.3390/ijgi7110452
[26] S. Castano, M. G. Fugini, G. Martella, and P. Samarati, *Database Security*, Addison – Wesley, 1995.
[27] MonkeyLearn, https://monkeylearn.com/ , last accessed: 2022/04/19.
[28] M. N. Mahdi, A. R. Ahmad, R. Ismail, H. Natiq, and M. A. Mohammed, "Solution for Information Overload Using Faceted Search - A Review", *IEEE Access*, vol. 8, pp. 119554-119585, 2020.
[29] OpenStreetMap, https://wiki.osmfoundation.org/wiki/Main_Page, last accessed: 2022/04/19.
[30] Eventi Milano - Facebook page, https://www.facebook.com/eventimilano.it, last accessed: 2022/03/28.
[31] Comune di Milano - Home page, https://www.comune.milano.it/, last accessed 2022/03/28.
[32] MAGIS 1.0, http://www.mixmap.it/magis/home/, last accessed: 2022/05/12.
[33] M. G. Fugini, J. Finocchi, and E. Rossi, "Semantic Adaptive Enrichment of Cartography for Intangible Cultural Heritage and Citizen Journalism", in: *Future of Information and Communication Conference*, pp. 173-185, Springer, Cham, 2022. https://doi.org/10.1007/978-3-030-98012-2_14
[34] WikiMedia Commons, https://commons.wikimedia.org/wiki/Pagina_principale, last accessed 2021/07/26