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GIS BASED WEB APPLICATIONS FOR TERRITORIAL ANALYSIS AND VIRTUAL ONLINE FRUITION OF COMPLEX DATASETS

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INTRODUCTION

In the field of territorial analysis, the use of GIS (Geographic Information System) based models is even more diffused. The possibility of integrating geospatial information with semantic information stored in database is now fundamental in several fields of research, offering the opportunity to integrate datasets provided by different sources (engineering, urban planning, transportation, business, security, etc.) (Goodchild, 2009; Zhan et al., 1998; Neteler et al., 2012; Cheng et al. 2007; Chainey et al., 2008). The applications based on GIS give the possibility to associate the geospatial representation of the studied entity with its corresponding semantic metadata description, overlaying and intersecting complex datasets according to geometric or semantic features. The world of GIS merges geospatial data management with computer and network technologies. The spread in recent decades of GIS platforms available on the web (WebGIS) and the spread of mobile internet connections have brought further importance to GIS, in a world where the geospatial information of any user has become fundamental for many applications (Figure 1).

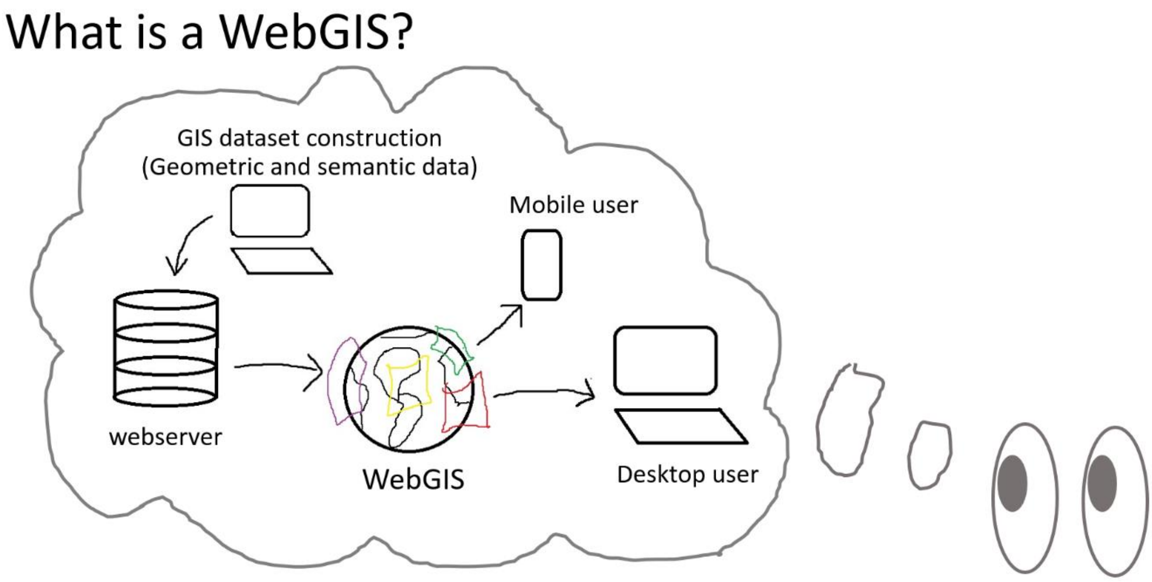

Figure 1. The sketch of the WebGIS structure.

As shown in Figure 1 the basic structure of a WebGIS is composed by online connected modules. The first module consists of the creation of the geospatial dataset, usually generated in a GIS software environment, where the vectorial and raster dataset is prepared. Then the dataset is stored on a geospatial webserver, that activates the WMS (Web Map Service) and the WFS (Web Feature Service) necessary for the web fruition of the information. The WebGIS visualization is generally generated in an .html module stored in a Webserver. Through the WebGIS .html page, employing proper JavaScript modules and libraries, it is possible to load and visualize the dataset previously stored in the geospatial server. In this way users can visualize the dataset on web and obtain detailed geospatial information with desktop and mobile devices.

In recent times the possibilities offered by WebGIS allowed to visualize tridimensional complex geospatial datasets inside a realistic globe representation of the world (Pirotti et al., 2017; Pispidikis and Dimopoulou, 2016). This technology merges the WebGIS capabilities of sharing semantic and geometric information with VR (Virtual Reality) visualization modules, allowing the online visualization of a 3D WebGIS model.

In reference to the origin of geospatial services, the core of GIS is the visualization and the fruition of geospatial datasets (vectorial and raster data) integrated with the corresponding semantic information located into a database (Zlatanova and Stoter, 2006). This is the base of GIS. Since its origins, it has been diffused a standard opensource protocol created by the OGC (Open Geospatial Consortium), that allowed the spread of this kind of technology, employing opensource software and JavaScript libraries to create and share geospatial information on web (Brovelli et al., 2012).

As mentioned before, to build a WebGIS application and prepare the hosting environment, it is necessary to configure a webserver and a Geospatial server. WMS and WFS services allow the fruition on web of the geospatial dataset, where the WebGIS environment is remotely connected to the Geospatial server (Michaelis and Ames, 2012). On the bases of the OGC protocol and WMS and WFS services, several opensource applications and libraries were created in recent years. Even considering the Globe based WebGIS platforms, programmers developed JavaScript opensource libraries that allow the web navigation of complex Globe-Based 3D datasets employing web browsers capabilities (Scianna and La Guardia, 2018). This solution could be customized according to the necessities of the programmer, editing the JavaScript libraries and the .html page.

Recent advances in the world of WebGIS allowed the integration of dataset elaboration modules on GIS software or on opensource remote operation modules developed in Python language. These calculation modules linked with the RDBMS (Relational Database Management System) allows a real-time territorial analysis of the geospatial dataset (Grippa et al., 2017; Shankar et al., 2018). The use of operational modules connected with WebGIS applications represents an important strategy to integrate geospatial analysis. It could be fundamental in a multidisciplinary approach considering that the use of geospatial datasets is necessary in many fields of research. (Koeva et al., 2021; Li et al., 2020).

The spread of internet connection, the use even more diffused of mobile devices as tablet, laptops and smartphones and the geolocalization of any device, led a further importance to WebGIS applications that share online geospatial dataset (Yang et al., 2005). This kind of applications allow the remote visualization of web maps, sometimes enriched with real time dataset integration, using GIS visualization tools (Su et al., 2000; Karnatak et al., 2012). The geospatial information standards diffused by OGC allowed the remote map visualization of territorial dataset (WMS service), and the possibility to load the features associated to the visualized dataset (WFS service) (Agrawal et al., 2017). The spread of GPS (Global Positioning System) geolocalization of common smartphones opened new scenarios for further dataset integrations on big data acquisition, employing WebGIS. In this way, the development of geospatial technologies led WebGIS applications to be fundamental in many sectors of research: accessibility and control of historical buildings (Vacca et al., 2018; Scianna et al., 2021), geolocalization of new power plants (La Guardia et al., 2021), study of pandemic expansions (Kieu et al., 2021), ecosystems analysis (Pisani et al., 2021), etc. Recent improvements on WebGIS technology also allowed the diffusion of collaborative

WebGIS platform, where every user joins to populate the geospatial dataset on web (very useful for the management and the monitoring on urban environment) (Herrera et al., 2021).

Considering the world of research on WebGIS applications and sensors integration (for real time dataset acquisition), it is relevant to underline the importance of studying new open standard solutions than the property software ones, because they allow to make experimentations for students, workers, and teams of researchers with few economic resources (avoiding the necessity to rent or by property software of commercial expensive solutions). At the same time, recent advances in IoT (Internet of Things) technology led researchers to focus the interest of geospatial integration of real time data acquired by networks of low-cost sensors.

Generally, we can say that recent advances in computer science grew on common users the need of sharing complex geospatial datasets employing smart solutions. The satisfaction of this requirement is not simple, because recent research highlighted many problems in accessibility and fruition of information. In fact, recent solutions adopted expensive property software to manage geospatial information, blinding to few researchers the possibility of making further experimentations.

The object of the work shown in this thesis analyzes different WebGIS Based applications developed with open-source solutions, aimed at the online fruition of complex datasets. The use of this kind of solutions is necessary to solve the problems related to the accessibility and the fruition of complex geospatial datasets information. The integration of WebGIS based applications is even more useful with the diffusion of desktop and mobile devices internet connection all over the world. The choice of study open-source integrations is connected with the idea of developing and testing new solutions easily replicable by researchers, students and common users.

The work of the thesis is divided in four different blocks that represent four cases of study that consider different territorial analysis solutions based on WebGIS opensource applications (Figure 2).

PhD research

WebGIS cases of study

Object	Technological solutions
P2G Plants Localization	MultiCriteria Analysis module integration
Touristic Web Monuments navigation	3D web navigation models integration
Globe based urban multiscale navigation	3D WebGIS platform with different LoDs
WebGIS monitoring platform	WebGIS and IoT integration

Figure 2. The cases of study of the PhD research.

These studies have been object of national and international collaboration with universities and centers of research and the results of the experimentations have been object of international publications. The four blocks are described below:

- Development of a WebGIS platform hosting an optimization model for the localization of PtG (Powet to Gas) plants in Sicily (Italy). In this work a Multi-Criteria Analysis module and a remote operation module have been integrated into a WebGIS opensource application. This work has been a contribution in a project in collaboration between the University of Palermo and the Institute of Advanced Technologies for Energy of the National Research Council of Italy (ITAE-CNR) institute of research.
- Creation of a touristic web navigation platform on the historic center of Palermo (Italy). This work integrates WebGIS opensource platform with the 3D web navigation of monuments, aimed at improving accessibility to Cultural Heritage (CH). This work was developed inside the I-ACCESS European Project in collaboration with the High-Performance Computing and Networking Institute of the National Research Council of Italy (ICAR - CNR) institute of research.

- Development of a Globe Based 3D WebGIS navigation platform that integrates different LoDs (Levels of Detail) of urban datasets. This work tests the urban dataset navigation on opensource 3D WebGIS platform, with different LoDs web visualization. This work was done in collaboration with the ITC Faculty Geo-Information Science and Earth Observation, University of Twente, Netherlands.
- Generation of a user-friendly solution to integrate IoT sensors acquisition and geospatial data management in WebGIS. This research was carried out in collaboration with the Kore University of Enna. In this work a WebGIS platform has been connected in real time with an IoT sensors network, using only opensource modules.

DEVELOPMENT OF A WEBGIS PLATFORM HOSTING AN OPTIMIZATION MODEL FOR THE LOCALIZATION OF PtG PLANTS IN SICILY

The results of human activity of the last century generated pollution and a complex natural scenario of primary importance for the health of the planet. The energy production represents one of the main processes involved in human activity that could be a risk for earth safety, considering the strong influences on CO_2 greenhouse gas emission that it has. The 2020 has been the year of the approval of the GND (Green New Deal) plan by the European Commission. The aim of the plan was the decarbonization of EU countries by 2050. Considering this goal, the development of alternative energy sources as RESs (Renewable Energy Sources) was a strategic solution to follow, with a particular focus on electric energy production from photovoltaic technology and wind power plants. At the same time, now the not predictable nature of renewable energy from wind and photovoltaic plants represents a strong limitation for a large diffusion of RES in electric energy production.

The PtG technology represents an interesting solution to the problem of the not predictable nature of renewable energy. This solution is based on the conversion of the excesses of electric energy, produced by RES plants and not predicted (otherwise curtailed), into hydrogen through electrolysis. The PtG solution, integrated with CO_2 caption technologies, offers the opportunity of gas methanation. At the same time the hydrogen produced could be injected into the gas grid or locally stored.

Considering the complexity of PtG application, the localization of the plants needs the study of an optimization model able to find the best localization of new possible RES facilities. For this reason, the research about new PtG plants localization needs a multidisciplinary approach to be solved, focusing the interest on technical, natural and territorial factors involved in the process.

The strategy followed in this research considers the application of MCA (Multi-Criteria Analysis) into a GIS structure, to find the best PtG localization in a studied territorial asset. This research takes into account the territory of Sicily (Italy) as a possible case of study.

This thesis shows in detail the development of a WebGIS platform hosting a geomatic semi-automated processing that allows to choose the best localization for new PTG plants in the territorial context of Sicily. The work is a contribution in a project in collaboration with the ITAE-CNR (National Research Council of Italy) institute of research. The developed platform is composed by several blocks based on opensource technology. The framework involves a Relational Database Management System (RDBMS), a Python data analysis module, a GIS opensource software, a geospatial server, and finally a WebGIS visualization structure. Every block of the platform is remote connected with all the others. The system allows to calculate the best PTG localization and to analyze on web the domain of possible localizations of PTG plants in Sicily, starting from a geospatial dataset. This system is useful for the management, the development and the study of hydrogen technologies, in order to link the electrical network and the gas network datasets with economical and infrastructural assets through GIS processing. In the future new factors will join in the process as policies on hydrogen take shape.

The next paragraphs of the chapter will introduce the world of renewable energies and then will come inside the core of PtG technology with reference to the associated RES technologies. After that, some examples of GIS integrations on localization of power plants will be shown, with a particular reference to PtG. In the end, the case of study will be presented, analysing the framework, the results, the conclusions, and possible open scenarios for further research in this field.

1.1 The Green New Deal and the world of renewable energies

The state of health of the plant was complicated by human activities since the last century. Now the Earth needs a revolution in human behaviour that involves the substitution of fossil fuels for energy production, considering their relevant role in CO_2 (the main greenhouse gas) production. The planet needs fast solutions in this field. The risk generated by pollution, global warming and fossil fuel limitation obliges to find a radical change of the route. This is the target outlined by 143 countries in the Green New Deal roadmap, with the conversion of the total amount of energy production in renewable energy sources, WWS (wind-water-solar), by 2050 (Jacobson et al., 2019). The emergency denoted by the IPCC (Intergovernmental Panel on Climate Change) outlined that the reduction of 45% on CO_2 emissions it is necessary to avoid the 1.5 C° increasing of temperature (IPCC, 2018). The spread of worldwide demand of energy is one of the main factors that causes this climate emergency. The result is the excessive exploitation of the main sources of energy that characterized the industrial revolution (oil, coal, and fossil fuels). The result of this process is the enormous environmental damage for the planet, considering the generated pollution and the CO_2 emissions. The strict relationship between the high percentages of anthropogenic greenhouse gas in the atmosphere and the global warming are confirmed by recent analyses (Kweku et al., 2018). In this scenario, the production of energy in territories with high density of population represents one of the main topics of study, where several research fields can give an important effort, such as policies, architecture, urban design, electronic engineering, economy, etc. (Keirstead et al., 2012).

Recently, several methodologies have been experimented around the world to reduce pollution and CO_2 emissions (Leung et al., 2014). Several studies conducted in many countries considered the development of RES for electric energy production (RES-E) (Krajacic et al., 2011; Kyriakopoulos et al., 2018; Haas et al., 2011; Glasnovic and Margeta, 2011). The policies conducted in last decades by the European Union indicated national targets to achieve step by step on RES electricity production. For instance, the Directive 2001/77/EC on electricity production, issued in 2001 by the European Parliament and Council, established the increasing of RES-E in total EU electric energy production from 12% (achieved in 1997) to 21% by 2010. In more recent times the target was the increasing in RES-E consumption in UE countries from 8,5% achieved in 2011 to the percentage of 20% to achieve in 2020. The recent growing interest on RES-E energy production allowed the spread of wind and photovoltaic power plants, that offered a great effort to avoid negative environmental impact caused by the growing total electric energy production (Beaudin et al., 2010; Cullen, 2013; Varun et al., 2009).

The problem of the employment of these technologies for electricity production is the not programmable nature of the electric energy produced, caused by the variable power generation of wind and photovoltaic plant that enhances risks of energy curtailment (Simonis and Newborough, 2017). The fast diffusion of wind and solar plants for renewable electricity production caused periodic excesses of electricity production (Bird et al., 2016) generated by the irregular and fluctuating nature of these sources (Zhou et al., 2018). In fact, many recent studies focused the research on finding alternative solutions to solve the problem of intermittent and not programmable electric energy production (Clegg and Mancarella, 2015).

Anyway, the diffusion of RES energy sources represents now one of the main approaches aimed at CO_2 emission reduction (Leung et al., 2014). Recent advances in this field have been carried out considering energy production from wind, solar and biological methanation. The first two options allow to obtain electric energy from not programmable energy sources, where the PtG solution represents an interesting opportunity to improve energy efficiency with a rising technology. In PtG, as will be shown in detail later, the electric energy allows to split water through an electrolyzer in oxygen and hydrogen. This last element could be used directly or combined with CO_2 through methanation process (Thema et al., 2019).

The possibility of combining the hydrogen with CO_2 reserves many advantages for multiple aims. In fact, the methanation grants to obtain the compatibility with the gas network and, at the same time, to catch CO_2 from atmosphere, reducing the pollution. The CO_2 gas could be extracted from several processes, and in these last decades multiple methods have been carried out by the scientists in this field of research. For instance, the diffusion of household anaerobic digesters allowed the natural caption of CO_2 in rural areas of the world granting the access to energy and avoiding the negative impact on the environment of traditional fuels (Garfì et al., 2016).

Another strategy recently adopted with the aim of reducing the levels of pollutions in the atmosphere is the abatement of CO_2 emission following Carbon Capture and Storage technologies (Wang et al., 2011). This approach is based on the separation of CO_2 from atmosphere and the next transportation and storage.

Hence, the integration of PtG plants with innovative solution of CO_2 caption could be an interesting and innovative approach to enhance the efficiency of not programmable energy sources and, at the same time, to reduce the amount of pollution in atmosphere. Obviously, the design of an integrated solution developed with this methodology results complex because there are natural, technical, economical, and territorial factors involved in the process to consider, that start from the electrical energy acquisition and finish with the methanization. For this reason, the complexity involved in this process needs a multidisciplinary research approach.

1.2 Power to Gas: an opportunity for a sustainable future

Recently, the relevant development of RES destined to the production of electricity has involved many countries and several studies considered this solution (Krajacic et al., 2011; Kyriakopoulos et al., 2018; Haas et al., 2011; Glasnovic and Margeta, 2011). As affirmed before, the fast diffusion of wind and solar power generation help to mitigate the negative environmental impacts of the total electric production (Beaudin et al., 2010; Cullen, 2013; Varun et al., 2009).

At the same time, this growing renewable electricity production determined a periodic excess of renewable energy caused by the not programmable nature of power production in wind and solar power plants (Bird et al., 2016). The recent research is, in facts, focused on the exploration of different solutions for using this excess of unused energy (Clegg and Mancarella, 2015). Another factor that strongly influences the quality of energy supply is the fluctuating and the intermittent nature of solar and wind energy (Zhou et al., 2018). The complicate combination of factors that influences the power production from wind and solar energy sources led scientists to study several strategies of scheduling (Liang and Liao, 2007). In the future this problem will be even more significant, considering that higher percentages of renewable power source are expected to be used for power supply in the world (Gahleitner, 2013).

In this scenario, the possibility of storing part of the electric energy produced by RES plant, producing hydrogen, allows to exploit the excess of energy production that in other ways would be lost (Buchholtz and Styczynski, 2014).

The Power to Gas (PtG) workflow represents a fundamental process for the future of the energy system. In fact, it allows the transformation of the excess of renewable electric energy into methane via electrolysis. The process consists of the link between the power grid and the gas grid, where the surplus power taken from non-programmable renewable energy plants is converted into a compatible gas through the H_2 production by water electrolysis. Then the H_2 could be combined with an external source of CO_2, producing CH_4 via methanation (Gotz et al., 2016) (Figure 3).

$$2\,H_2O \rightarrow 2\,H_2 + O_2$$

$$4\,H_2 + CO_2 \rightarrow CH_4 + 2\,H_2O$$

In particular, the hydrogen produced could be sent in low concentration directly to the methane pipeline or could be combined with an external source of carbon dioxide to be converted into SNG (Synthetic Natural Gas) (Gotz et al., 2016). Generally, the allowed limit of hydrogen concentration within natural gas distribution is 10% by volume.

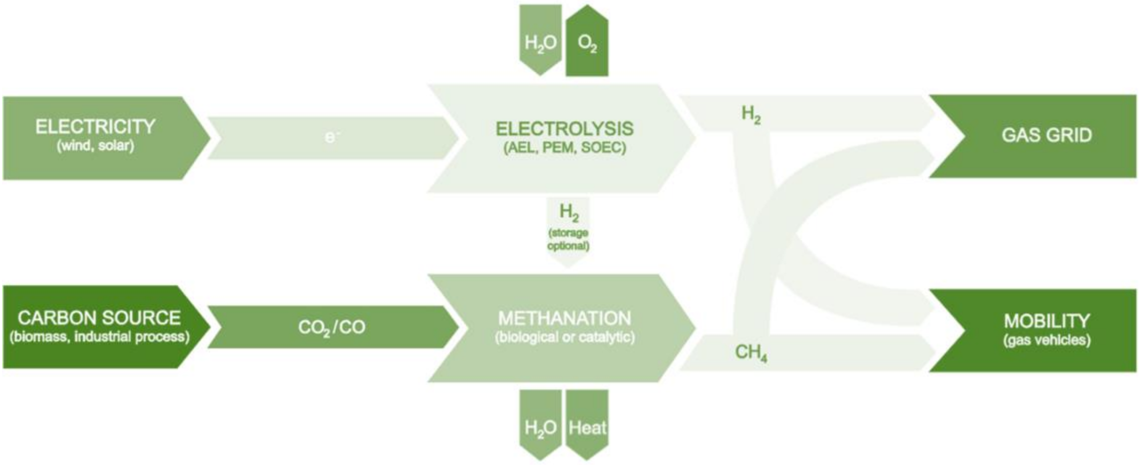

Figure 3. The Power to Gas process (Gotz et al., 2016).

Considering the gas consumption of towns and comparing it with the electricity demand and power availability of plants along days and months, there are a lot of mismatches of values in time (Figure 4). For instance, usually in summer evenings the electrical demand achieves high peaks, instead the gas demand is higher during daytime in winter weekends, when the use of heaters is widespread. Also, the non-programmable renewable energy source supplied by wind or solar plants is not well predictable (Simonis and Newborough, 2017). In this scenario the development of PtG systems allows to transform in hydrogen the excess renewable electrical energy.

If the amount of hydrogen is over the maximum value for the injection within the natural gas distribution, there are two possibilities: the reaction with CO_2, producing CH_4 (methanation), or the storage of the surplus of hydrogen. This last solution seems to be more dangerous, considering the high flammability level of hydrogen, and, for this reason, the costs involved for the introduction of hydrogen buffer systems into a PtG plants are relevant.

Instead, the reaction with CO_2 to produce SNG represents an interesting solution, because the product of the reaction is fully compliant with the natural gas composition, and therefore, ready to be injected into the gas network.

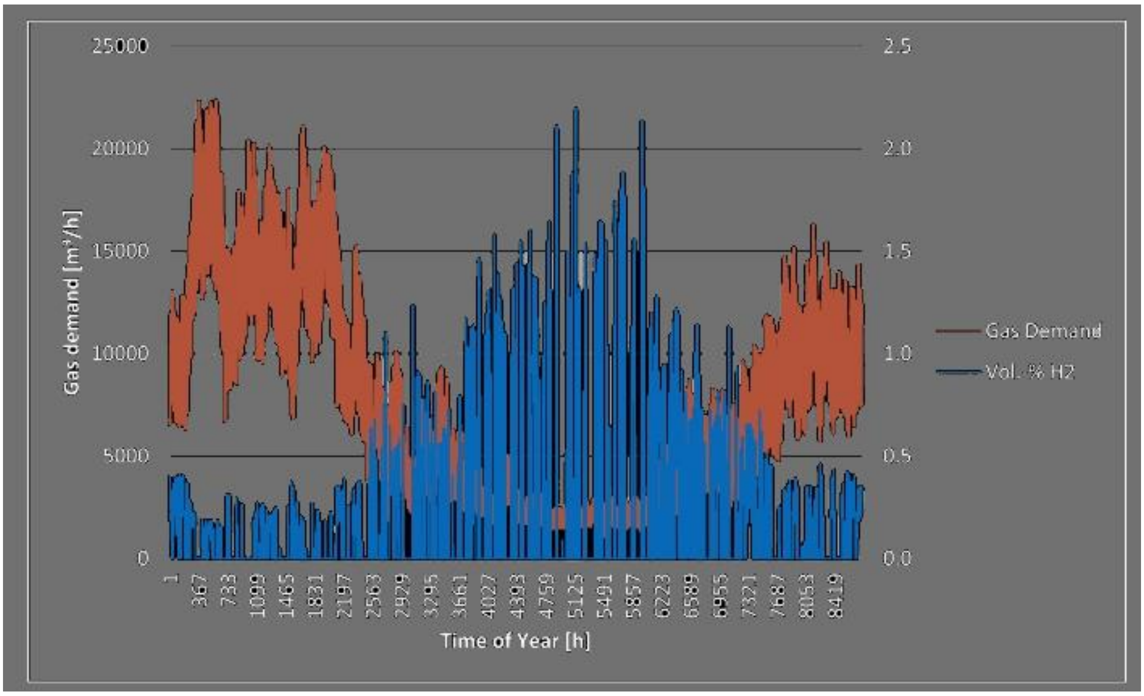

Figure 4. Annual variation of Gas demand (in orange) and hydrogen concentration (in blue), considering 1 MW PtG plant in 2020 (Simonis and Newborough, 2017). It's clear a relevant mismatch between the peak hydrogen production in summer month and the peak of Gas demand into the winter period.

1.2.1 The production of SNG

The extraction of CO_2 gas represents an important implementation to the PtG process. In fact, as affirmed before, the amount of hydrogen that can be introduced directly into the gas grid is limited. At the same time, the costs of hydrogen storages are relevant, and their dimension should be accurately designed in a preliminary phase. These technical constraints in the PtG workflow led to choose the methanation, to combine the excess of hydrogen with CO_2, to directly send SNG into the gas grid without limitations. Furthermore, considering the environmental pollution, today the CO_2 represents the main greenhouse gas in the atmosphere, and its concentration has deeply grown from the pre-industrialization period to the last decades, and is predicted to increase deeply in the future considering the current state of art. The fossil fuel-fired power plants represent the main source of CO_2 emission (Freund, 2003), but, at the same time, is still fundamental for the satisfaction of the energy demand. Considering CO_2 caption to produce synthetic methane, it's necessary to consider two solutions that could be better integrated into the workflow: the chemical CO_2 capture solution, from Carbon Capture and Storage (CCS) plants, and the biological CO_2 production, from Anaerobic Digesters (AD) plants (Figure 5).

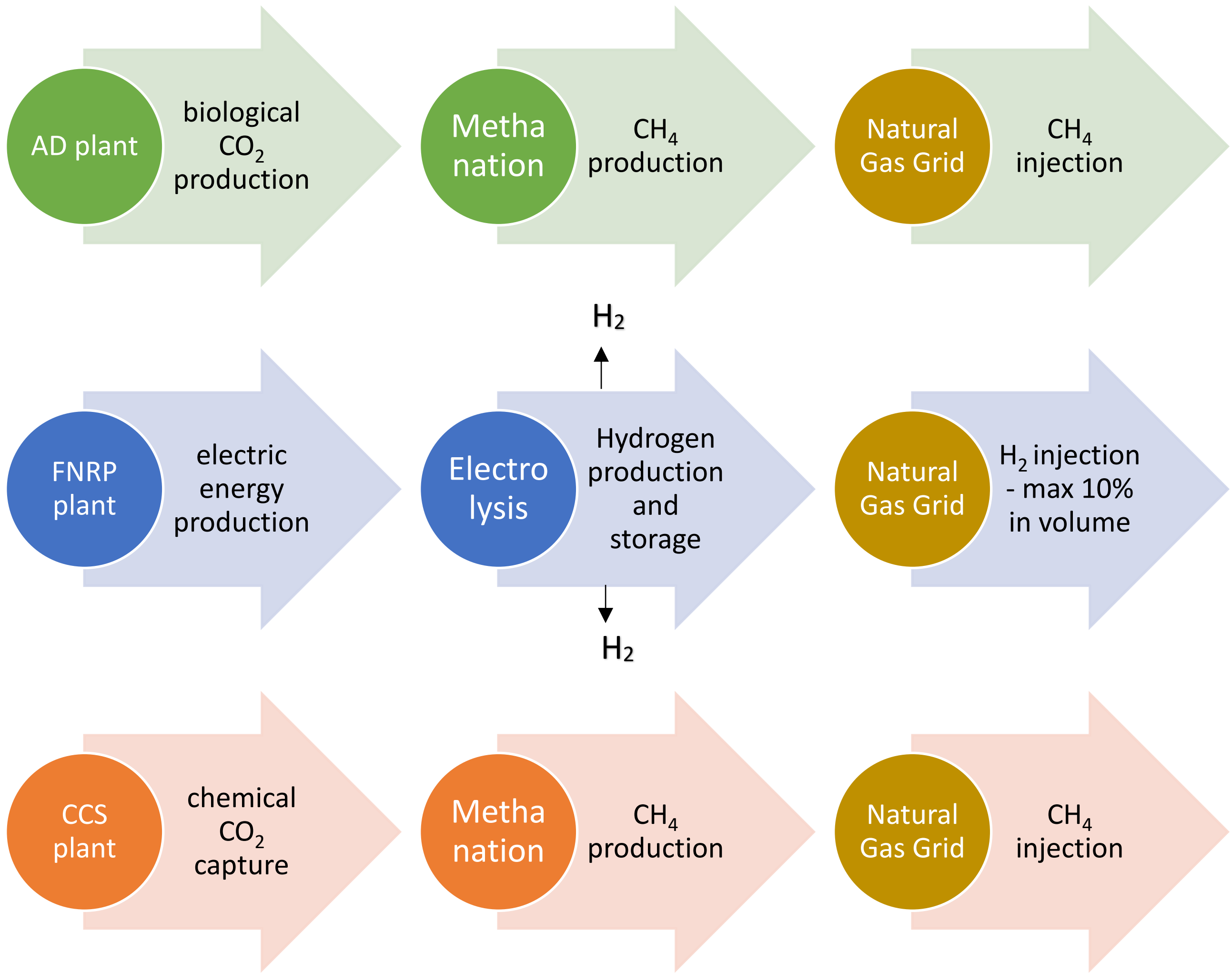

Figure 5. The possible solutions to consider in the PtG process.

1.2.2 The Carbon Capture and Storage solution.

As affirmed before, the necessity of CO_2 emission abatement strategies leads the research interest to the Carbon Capture and Storage (CCS) solutions (Metz et al., 2005). CCS process consists of the separation of CO2 from the atmosphere or from the industrial fumes and the next transport and storage for an isolation of long term. There are three different kinds of CCS solutions: post-combustion capture, pre-combustion capture and oxyfuel process (Metz et al., 2005).

Post-combustion capture solution represents some advantages respect the other CCS processes, because could exploit the existing combustion technologies without major changes. In fact, this strength helps the reuse of power plants to retrofit the existing structures. In this field there are different separation technologies useful to catch CO_2 with post-combustion capture: adsorption, physical absorption, chemical absorption, cryogenics separation and (e) membranes (Wang et al., 2011). Considering these technologies, the chemical absorption (Lawal et al., 2009) and adsorption could be considered the most mature CO_2 capture processes for post-combustion process (Yu et al., 2012).

At the same time, in the case of CCS technology, it’s necessary to consider that the installation of CCS into an existing power plant means a significant loss of power output. In particular, the decreasing of power efficiency is measurable considering different factors that play a key role in the extraction of CO_2 as the coal type, the power generation process and the CCS technology adopted. In the end, it’s possible to affirm that the loss of performance caused by the caption of CO_2 amount of about two thirds of the total energy process of the plant (Figure 6) (Goto et al., 2013).

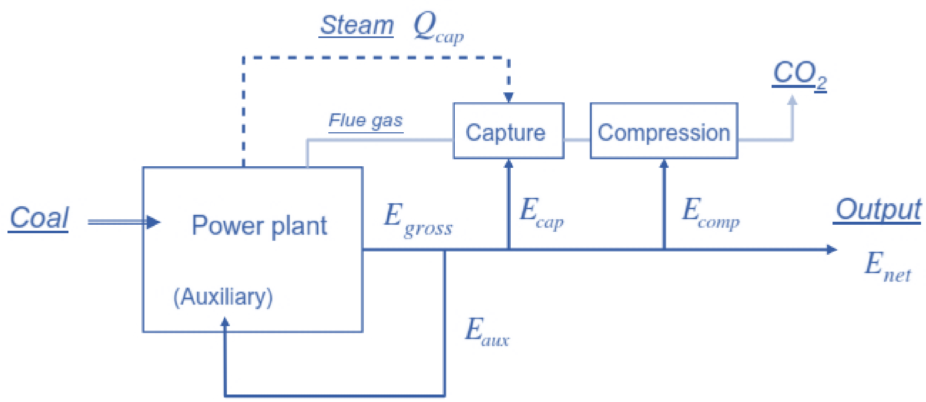

Figure 6. CO_2 post combustion capture process and the "efficiency penalty" determined by the CCS installation to the coal power plant (Goto et al., 2013).

1.2.3 The biological methanation.

The production of SNG needs the production of hydrogen from electrolysis (considering the PtG approach) and a necessary amount of CO_2 in any way extracted. In this field the biological methanation represents a renewable solution for synthesizing methane. The main role is played by the Anaerobic Digesters (AD), different groups of bacteria and methanogenic archaea involved into a biological process that converts various complex biomass and toxic wastes. This process consists in the transformation of organic biomass into "biogas" in the absence of oxygen. Biogas is mainly composed by methane (CH_4) and carbon dioxide (CO_2) with a less percentage of other contents. This conversion is carried out in four steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Laiq Ur Rehman et al., 2019) (Figure 7).

The biological methanation represents many advantages that make this process one of the main solutions for CO_2 capture. In fact, the possibility of producing biogas in a decentralized scale, considering farms and agricultural lands, makes this solution better suited than others. Furthermore, the necessary temperature of biological methanation is between 40° and 70°, is tolerant of gas impurities, unlike the chemical (catalytic) methanation (Simonis and Newborough, 2017), and it does not need external energy supplies.

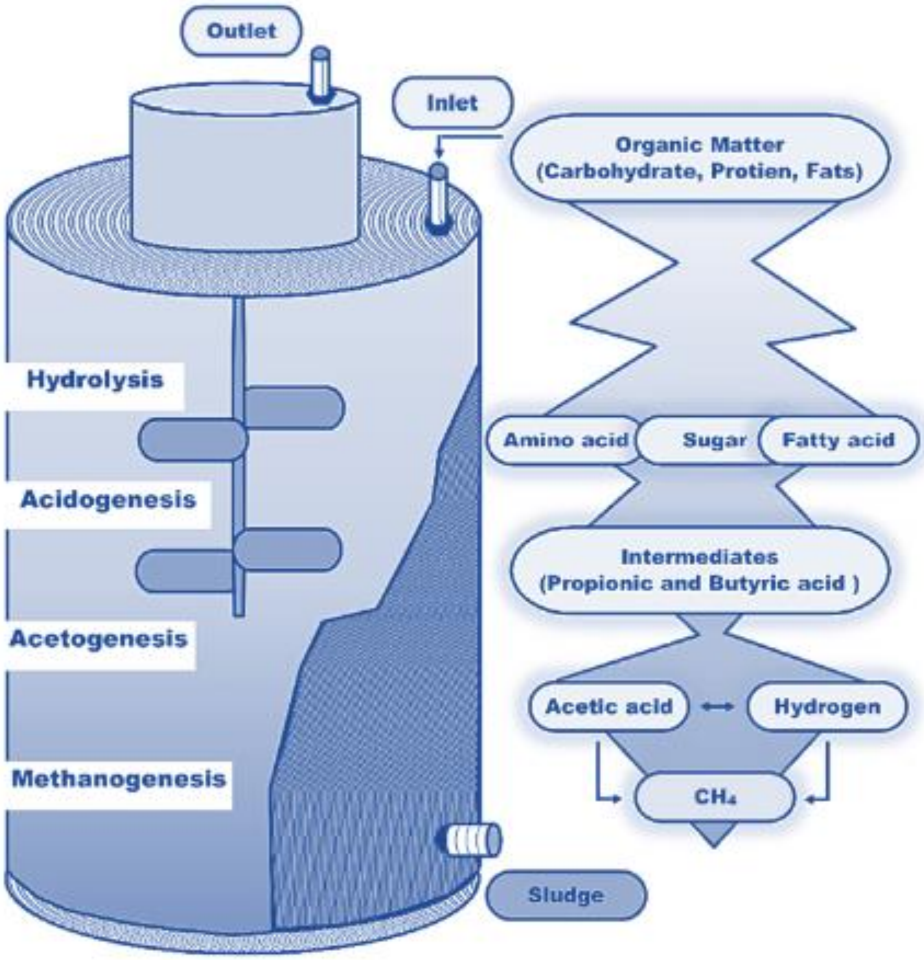

Figure 7. The Anaerobic Digestion process (Laiq Ur Rehman et al., 2019).

1.3 The integration between GIS and optimization models for the land energy sustainability

The study of renewable energy and the analysis of territorial asset in recent times even more involved Geomatics science, in particular GIS and spatial technologies as remote sensing (Calvert, 2011). Some years ago, first approaches have been carried out, starting from the division of the territory in a longitude-latitude grid. This solution offered the possibility to consider every single generated portion as an independent entity with proper semantic features stored in a RDBMS, allowing researchers to properly study the energy supply for every area. This method resulted very useful to study the world of RES (Sorensen and Meibom, 1999; Bunme et al., 2021; Mancini and Nastasi, 2020). The use of GIS tools allows to test simulations experimenting different possible scenarios of land exploitation, resulting a strategic for the study the localization of RES plants (Dominguez and Amador, 2007). In territorial analysis, it is necessary to study and insert criteria layers into the GIS platform to obtain useful results to discover possible land territorial suitability. In this process it is fundamental to employ the AHP (Analytic Hierarchy Process), that allow to properly set different weights for each variable involved (technical, economic, and environmental ones) (Asakereh et al., 2017). This optimization approach is the core of the mathematical model that gives the best solution to the problem, basing the operations on the dataset processed in the GIS platform.

This kind of approach, that merge Geomatics science and Optimization models, was, recently, followed in the research of the best localization of AD plants in a specific territorial asset, considering social, environmental, and economic factors.

This kind of strategy has been adopted in Tompkins County (New York) finding the best territories to install AD facilities (Ma et al., 2005). The best plant localization was obtained developing a LSM (Land Suitability Model) to the considered environment. The core of this model is the siting suitability index. This factor is integrated into a GIS platform and involves several variables and constraints that generate different geographic layers (Dominguez and Amador, 2007). The problem to solve considers that the final location should satisfy several environmental, social, and economic constraints and factors. For example, the minimum size of farms where associate an AD plant or the distance between AD facilities and the dairy manure themselves are possible factors that could determine a preference. The system considers the development of a LSM, necessary for choosing the best site solution (Figure 8).

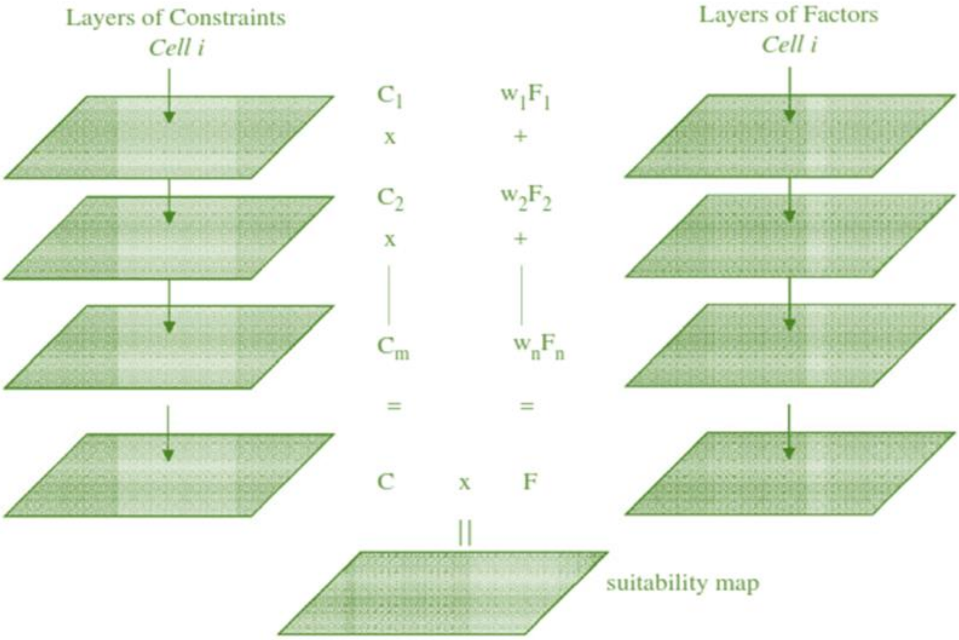

Figure 8. The Land Suitability Model obtained by the matching of both constraints and factors layers (Ma et al., 2005).

The LSM model approach is based on the siting suitability index, that considers both constraints and factors to implement different geographic layers mathematically integrated into a GIS environment. Considering the constraints, it's necessary to avoid residential areas, airports, and every sensitive zone, also calculating the appropriate buffering area (indicated as an offset of distance) for every constraint. The georeferred map is divided into a binary GIS grid, where a value of "0" or "1" is assigned to every cell, respectively inside or outside the buffer area. The LSM model considers also selective factors that help the choice of the best solution, considering different criterions of preference based on distances. Every factor has a different weight of influence, considering its relative importance. The Analytic Hierarchy Process (AHP) is the followed mathematical model (Figure 9).

It creates the decision problem building a hierarchy where the overall goal decision is the best solution. Once developed the model, the different site solutions are compared in pairs considering a matrix of multiple factors. The final land suitability grid is, then, generated matching the constraint map with the final factor map (Ma et al., 2005). The final overlap gives the suitability index for every cell and allows to find the best site solution for an introduction of an AD plant.

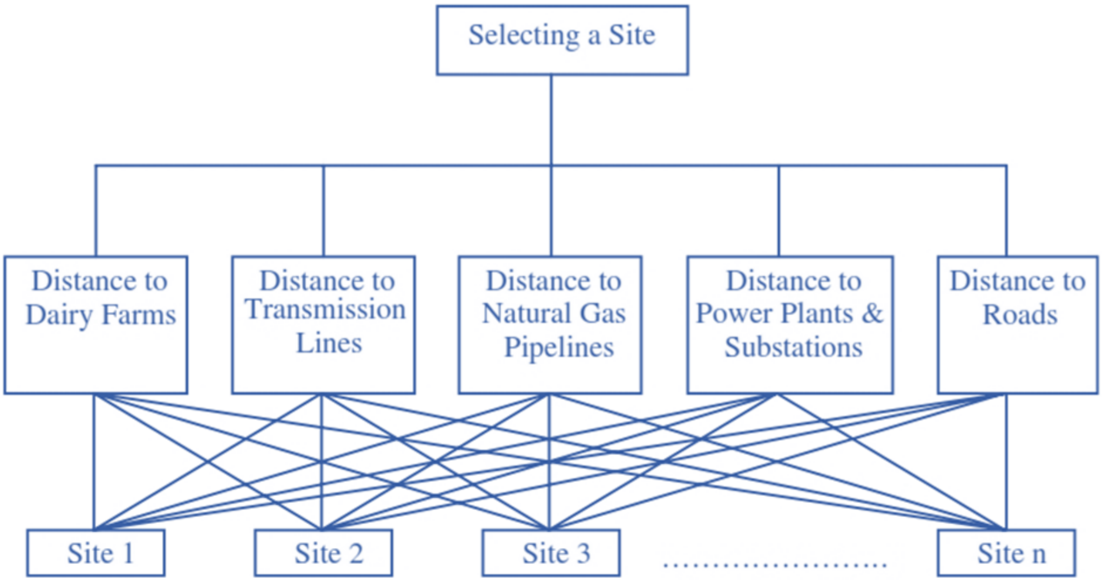

Figure 9. The Analytic Hierarchy Process necessary for the comparison on every site and based on different factors (Ma et al., 2005).

Ever in the field of the land exploitation finalized to energy production, another study involved in USA developed a dynamic model to produce bioenergy crops, comparing this possibility with the traditional agricultural use (Scheffran and BenDor, 2009). Bioenergy crops are a recent solution, that consists of an alternative soil use finalized for biomass and biofuel production. This solution results a possibility for the domestic renewable power production, useful for the improvement of the environmental quality. The analysis has been carried out in Illinois, where the weather conditions create a large variety of soil qualities. The system developed was a spatial dynamic model and the individual farmer was the agent that should consider different crop solutions (between corn, soybeans, miscanthus, and switchgrass). The global solution has been obtained using a dynamic, evolutionary game approach, considering different economic and environmental factors involved in the process. The considered options are respectively two bioenergy crops (switchgrass and miscanthus), and two classical agricultural crops (soybeans and corn). The developed system divides the considered area in a grid of different portions of terrain and calculates through a parameterized model for every cell if it's necessary to switch from agricultural production to bioenergy crops. The geographical data have been collected from different sources, to find the yield of every area in recently years, considering also different kind of costs (direct, power, and overhead costs). The agent-based model considers that farmers behavior moves like a network of agents, where the decision of everyone could alter the final solution of success (Scheffran and BenDor, 2009). The dynamic system is developed modelling different components like accumulations (stocks), changing vectors (flows) and variables, to obtain in the end the harvest for each simulated crop (Figure 10). The obtained data are then integrated with crop market prices and investment costs for each farmer. In the end the 'evolutionary game' adopted allows to find the best combination of crops for every farmer.

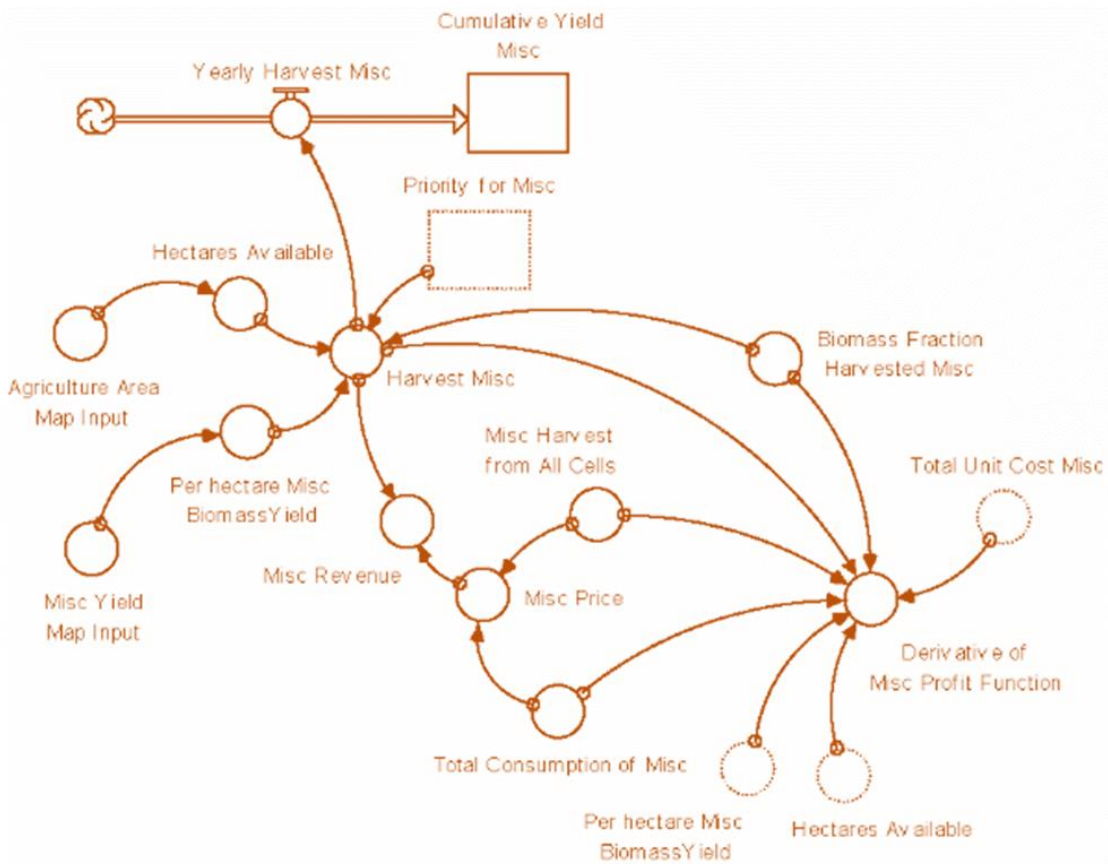

Figure 10. An example of a spatial dynamic model, here developed for the miscanthus production (Scheffran and BenDor, 2009).

At last, considering the world of Smart Grids (an automated model for the management and the control of the electrical grid) an interesting case of study has been developed, where a GIS information platform has built for sharing information between single agents (Monika et al., 2015). This solution has been followed to solve the system studied as an optimization game and considering all the different variables of electrical consumption. In particular, the possibility of sharing consumption information at microgrid level between the agents solved the Sub-game Perfect Nash equilibrium. The GIS platform has been developed considering three levels of design:

- The database were all semantic real time information data acquired have been stored in different tables.

- The business implementation, that represents the backbone of the system, where the operational code is developed.

- The presentation interface, that represents the environment visualization into a WEBGIS application.

The possibility of sharing electric power information through the WEBGIS platform developed the game structure from a no cooperative to a cooperative scenario. With this solution every considered agent is aware of each other behaviour. To consider the usage habits, it has been necessary to combine a matrix for every household and the possible appliances combinations considering different time periods. These data allowed to obtain each equation of sub-game perfect equilibrium. The possibility of users to visualize real-time energy information data allows to growth a new consciousness to develop better energy consumption strategies (Monika et al., 2015).

1.4 Optimization models and GIS analysis applied to the world of Power to Gas: State of art.

The PtG solution, hence, links the gas and the electric network. The choice of the best localization of this kind of plants should consider multiple factors that involve the process. These factors are related to the territorial relationship (Gahleitner, 2013) between the installation, the points of demands, the supply RES plants, the gas pipeline, the railway, and roads networks, etc.

The need to consider several factors related to heterogeneous datasets, led necessary the adoption of GIS-based models, where it's possible to overlap several georeferred layers, representing the multiple factors involved in the process, and to define the domain of possible solutions in the considered territorial asset. Geographic information systems (GIS) are massively adopted in public administration, industry, economy and many several disciplines, because they provide the integration of different datasets for positioning, data acquisition, analysis, and dissemination functions (Goodchild, 2009). The complexity of recent advances regarding the energy generation, storage and energy infrastructure design led necessary the integration of GIS to solve geospatial challenges in the renewable energy field (Resh et al., 2014). In fact, the diffusion of RES technology is strongly linked to the individuation of the most suitable lands for new RES plant localizations (Guo et al., 2020). The use of GIS based analysis in the field of RES localization has been recently adopted in many cases, for instance it is widely used for the localization of new wind plants (Miller and Li, 2014). GIS based models have been also exploited in the evaluation of available forest biomass residue useful to generate electrical and thermal energy (Viana et al., 2010), or in the localization of new biomethanation power plants (Brahma et al, 2016). At the same time, the choice of the best localization needs the development of an optimization model able to describe the process. In detail, the implementation of MCA analysis to define a proper optimization model it's required, considering the necessary criteria that allow to choose the best localization of the new power plant installations. This approach, that combines GIS-based models and MCA analysis, has been tested in recent years for wind power plant site selections (Atici et al., 2015), but also to find the best localization of solid waste incineration power plants (Feyzi et al., 2019) and solar PV power plants (Al Garni and Awasthi, 2017). The integration of MCA and GIS allows to solve site suitability problems with the possibility to combine data storage, geospatial analysis, geospatial decision support system and visualization (Albraheem and Alabdulkarim, 2021).

The management of the datasets related to geospatial information, where geometric and semantic data are combined, needs the implementation of RDBMS database, where it's possible to remotely share, analyze and modify the datasets involved in the system (Li et al., 2020). At the same time, the WebGIS visualization allows users to visualize the entire dataset and to analyze the solution of the localization problem, strictly connected with the geographical asset (Noskov, 2018).

Considering the optimization of the PtG power plant settlement, GIS analysis allows us to acquire and share the necessary geographic and semantic information involved in the operational research problem. To correctly manage all the variables involved in the process, it is necessary to follow a multidisciplinary approach for the construction of the model, where both Geomatics and Optimization play a key role. For instance, recent studies adopted this kind of approach for calculating the sizing and position of the potential pipeline network destined for hydrogen transmission in Germany (Baufumé et al., 2013). Other recent experiments started with data acquisition from a real PtG plant and then simulated the energy distribution by studying different territorial scenarios of application (Mazza et al., 2020). Scientific interest in this field is growing, and there is increasing experimentation on new PtG settlements. Considering the complexity of the variables involved in the process, the present work studies an innovative multidisciplinary approach where the localizations of new PtG installations are managed in a WebGIS system.

Taking in to account the recent experimentations of PtG technology, it's possible to affirm that the correct installation of a power to gas plant depends on its location, power requirements and load profile (Gahleitner, 2013). The experience of the projects involved in this technology teach us that it's necessary to pay attention to correctly size the power to gas system, because it strongly influences the efficiency, reliability, and economics of the plant (Simonis and Newborough, 2017; Gahleitner, 2013). Considering the design of a power to gas plant, the development of an automated chain results fundamental for optimizing the interaction of the PtG system with the power and gas grid, and, at the same time, the choice of the best location of plant installation result strategical for economic factors (Xing et al., 2018). The territorial analysis represents a fundamental requirement for the acquisition of geographical variables that strongly influence the optimization and the control of the PtG, and, in general, power plant settlement. In this field, GIS analysis allows to acquire and to share the necessary geographic and semantic information involved into the optimization problem.

Inside the localization process of PtG plants, it is necessary to take care about the impact of new PtG installations on the electrical transmission network and the gas grid. In fact, they represent the link between the two infrastructures. A possible strategy to follow is to model a PtG plant, integrating the process into the existing energy system, focusing the attention on the impact of the new plant on the electrical transmission and gas network (Clegg and Mancarella, 2015). In this case it's necessary to consider three different solutions of PtG plants, respectively located at gas terminals, at congested gas nodes, and at congested electrical nodes. In fact, choice of the best position of the power plant, in terms of distance from the electric transmission network and the gas grid, is crucial. For instance, the settlement of the PtG plant near gas terminals allow the possibility of direct production of H_2 into the gas network. On the other hand, the integration of PtG plant with a CO_2 source and the consequently generation of SNG, allows to locate the plant far from gas terminals, with the possibility to place it nearby congested gas or electrical nodes. In this example the integrated system has been analyzed with the Optimal Power Flow strategy, considering four consequently steps (Clegg and Mancarella, 2015) (Figure 11).

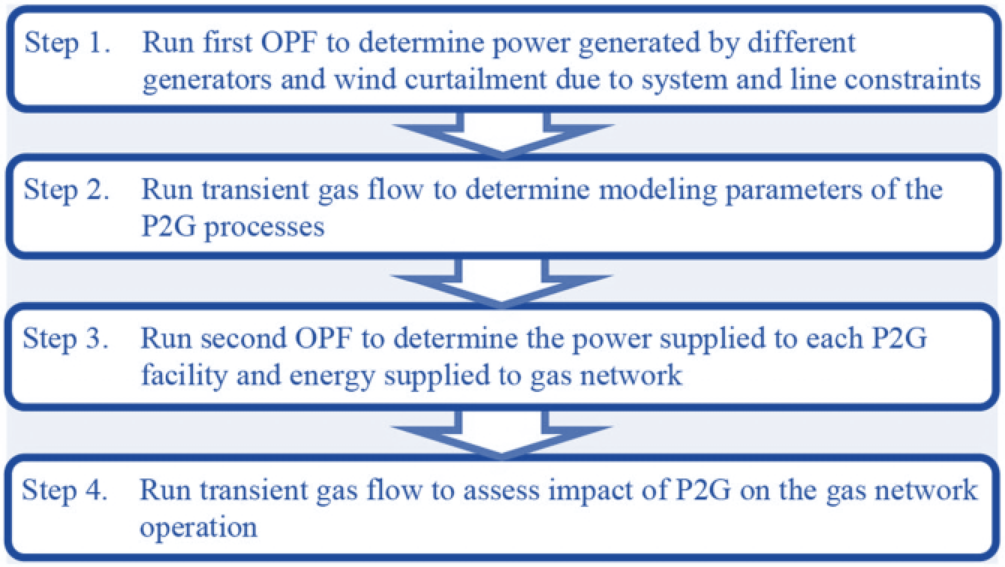

Figure 11. The Optimal Power Flow strategy applied to PtG plants (Clegg and Mancarella, 2015).

The first one considers the power generation of wind renewable energy plants and the possible curtailments caused by excesses of energy and line constraints. The second OPF model, starting from the results obtained from the first one, calculates the power injected into the PtG plants maximizing the yield and considering the position and the type of the considered facilities. The power involved into the PtG process is then transformed into hydrogen with the electrolysis process, and consequently, considering the power produced as volumetric unit (third step). Once produced the hydrogen, it is possible to start the fourth step, that consists of a second gas flow analysis, to study the injection of the hydrogen (or the SNG) into the gas network in a considered interval of time. The study case analyzed allowed to study all the aspects involved into the PtG plant design, considering economic, technological, and environmental implications, including the effects on the gas and electric transmission network. The results obtained from this analysis have shown that the use of curtailed wind energy for direct hydrogen injection to the Natural Gas terminal, or for SNG production, is possible with little disruptions of the gas flow into the grid.

1.5 Development of a GIS based optimization model for the localization of new PTG plants in Sicily.

The environmental features of Sicily (Italy) seem to be ideal for hosting RES power plants, particularly wind and photovoltaic facilities. The meteorological data collected along the island, such as solar irradiation (RS), air temperature (TA) and wind speed (VV), show high average values that led Sicily to be one of the best Italian regions for hosting wind and photovoltaic plants (Giallanza et al., 2018). In fact, the last few years have been characterized by a large diffusion of RES on the larger Mediterranean island. Wind energy has been considered one of the best solutions for producing clean energy in Sicily with a goal of sustainable development (Giuffrida et al., 2018).

In light of this, Sicily seems to be a strategic location for the future settlement of PtG plants, given the nonprogrammable nature of wind and solar energy, as well as a view of a sustainable future where hydrogen could play an even more dominant role in satisfying the territorial energy demand.

The work object of this thesis is englobed into a scientific collaboration between the University of Palermo and the ITAE Institute of the National Research Council of Italy. The scientific support consisted of a construction of a WebGIS platform useful for the optimization of new PtG plants localization in a proper land. The scientific experimentation carried out considered the territory of Sicily, due to its geographical attitude to host this rising of technology.

The workflow (Figure 12), followed in the construction of the case study, considers further steps. First, the mathematical model was developed and then the geographical dataset was acquired and appropriately clustered. Once the necessary starting information was prepared, the automated processing GIS model (based on Python programming language) was created using QGIS opensource software to obtain all the necessary information for the mathematical model.

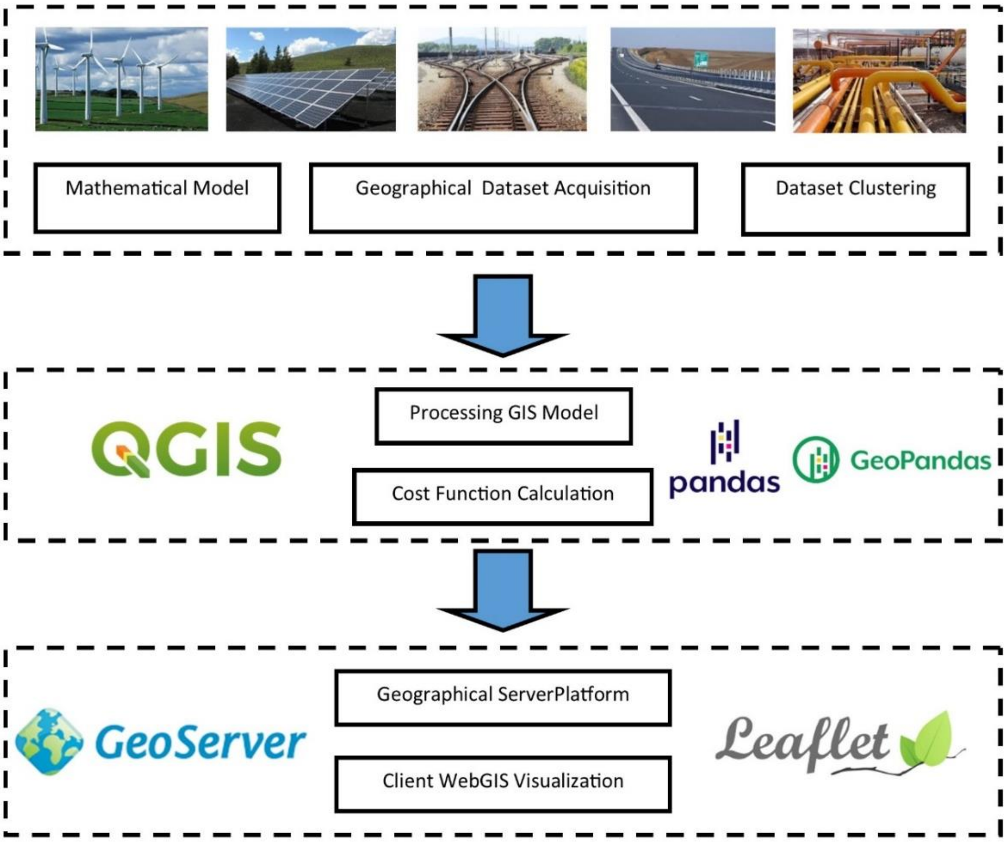

Figure 12. The workflow of the optimization GIS-based model.

The cost function, based on the previously developed mathematical model, was computed through the integration of remotely connected Python opensource modules (Pandas and Geopandas). In the end, the result, which gives the best localization of a possible new PtG installation in Sicily, could be available in a WebGIS online visualization model (based on Leaflet opensource Javscript libraries) for desktop or mobile devices, with the possibility of analysing the starting reference dataset.

1.5.1 The beams & nodes model.

The optimization model, able to select the best localization of a new PtG plant in the territory of Sicily, has been developed on the basis of operational research, the science that improves decision-making problems through mathematical optimization methods starting from existing relations of the real world. The relations should be integrated in a mathematical model able to solve the problem.

Every possible solution for the settlement of a new PtG plant is associated with a couple of geographical coordinates (Lon, Lat) inside the territorial environment of Sicily (La Guardia et al., 2022a). The first step, which is necessary for the definition of a domain of possible solutions to the problem, is the discretization of the space, where the surface vertical projection of the island has been divided in a regular grid of squares and every vertex represents a possible solution.

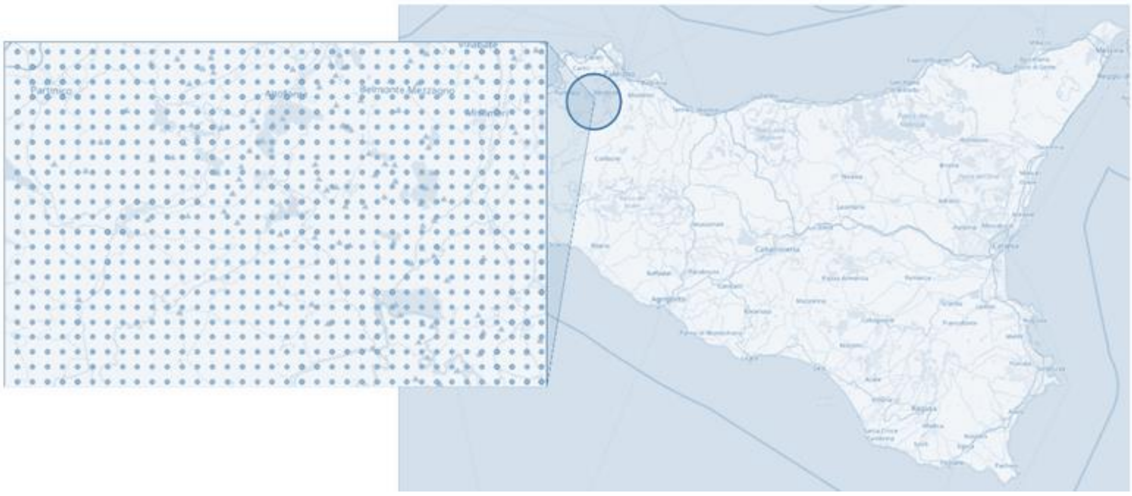

Figure 13. The grid thickening used in the model (La Guardia et al., 2022a).

The thickening of the grid is arbitrarily established and depends on the level of accuracy required. In this case, a grid of 1 km ×1 km squares was considered (Figure 13). In the choice of the density of the grid, it is necessary to find the true balance between the level of accuracy required and the number of calculations.

The considered model of optimization can be represented in this form:

$$\begin{cases} \min f(x) \\ x \in S \end{cases} \tag{1}$$

where f represents the objective function, which in our case is a cost function, and S is the set of alternative localization solutions inside the considered environment. The best solution that represents the best localization of the PtG plant inside the island will be the solution within S having the minimum cost function f(x) value. The selected mathematical model is a constrained continuous optimization problem. In fact, there are several geographical constraints that limit the domain of S because they reduce the possible solutions to consider in the cost function f(x). The presence of constraints reduces the calculation process, leading more quickly towards the optimal solution. The geographical constraints considered in the problem (Figure 14) are the following ones:

- proximity to the railway network.
- proximity to the road network.
- proximity to an existing photovoltaic or wind facility, avoiding those that already have an associated PtG plant.

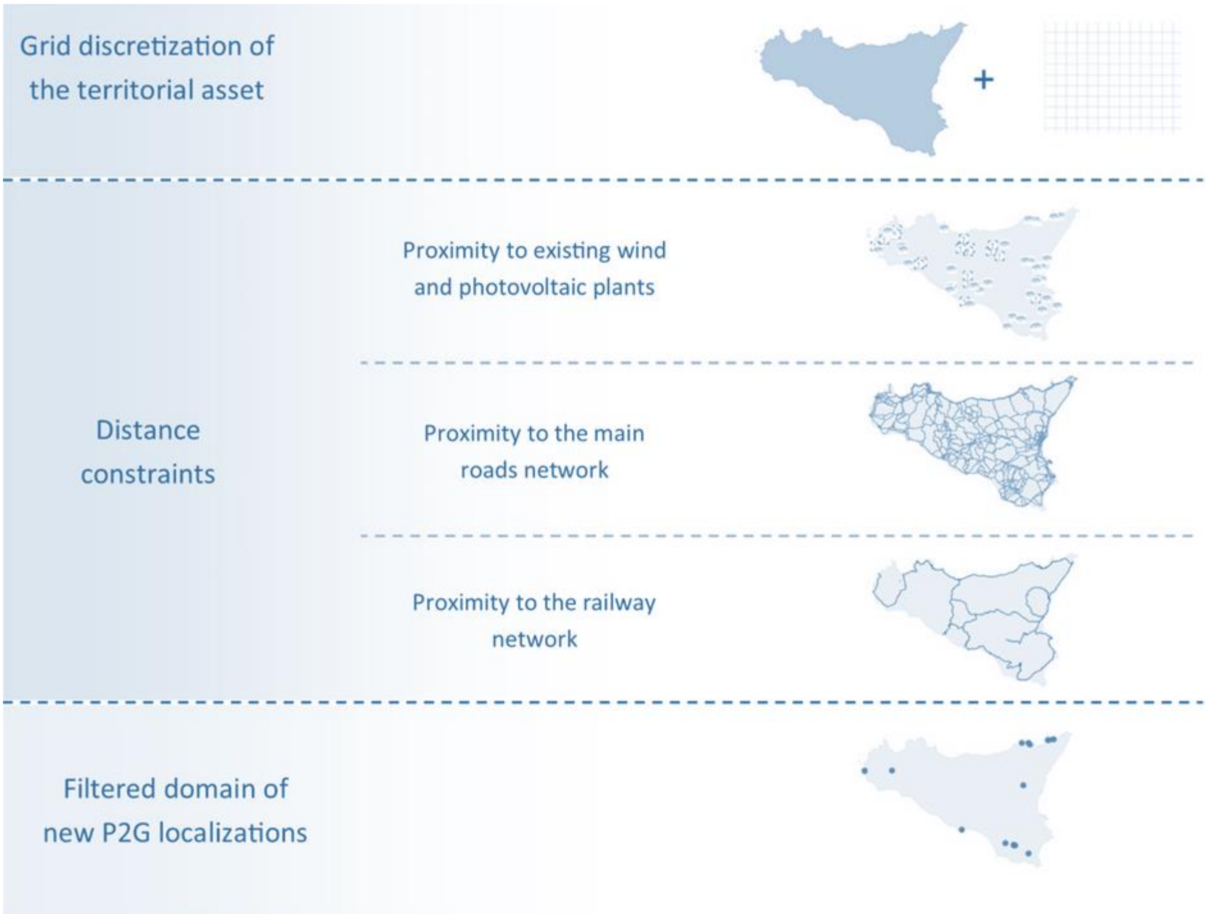

Figure 14. The geographical constraints considered to filter the original domain of possible PtG localizazions.

The first two constraints derive from the need for hydrogen transportation for the distribution and the satisfaction of the energy demand of the city centres. To visualize this model as a reference for future hydrogen transportation in the liquid and gaseous states, the proximity to the existing railway and road networks were considered mandatory constraints for the construction of the domain of the possible solutions.

At the same time, the localisation of the PtG plant near an existing wind or photovoltaic installation is necessary to exploit the amount of electric energy curtailed to avoid electric network overloads (caused by the nonprogrammable nature of these renewable energy sources). Operative GIS processing, which filters all the possible solutions inside the domain characterized by the considered constraints, will be described in the following paragraphs.

Once the set of possible new PtG installations is obtained and filtered by geographical constraints, the cost function f(x) considers all solutions extracted from the domain. For the construction of the cost function f(x), it is necessary to carefully choose the main factors involved in the process to represent the system in the best way, avoiding the use of unreliable variables. In fact, the datasets related to hydrogen production and its transport are subject to upheavals due to the continuous evolution of these technologies and the policies associated with them. The risk is the generation of misleading data that in a few years can become totally unusable due to continuous changes in the technological and economic field. To avoid these problems, the cost function considers factors that are readily available, which can be easily updated, to build the optimization model as an operational tool in the future. The data considered to be included in the cost function are:

- Hydrogen demand. This factor, considering the rapid diffusion of the technologies associated with the increasing use of this gas as a source of energy, such as power to fuel (transport fuel) and power to feedstock (raw material in industries), can be approximated as a quantity proportional to the number of inhabitants of the main inhabited centres. This factor, as will be described later, needs a clustering process to operate in the GIS environment to leave out towns containing a number inhabitants below a certain threshold. The hydrogen demand points, therefore, are assimilated as the centroids of the medium-large urban centres present in the region.

- Supply of energy from RES plants. This factor considers the existing photovoltaic and wind facilities settled in Sicilian land.
- Distances for the transport of hydrogen. These data, assuming the location of the hypothetical new PtG plants near the existing wind or solar plants, consist of the minimum distances between their localization and the hydrogen demand point (the medium-large urban centres). The distances to be considered are of three types based on the type of transport considered: road, rail or pipeline. Regarding transport by road and rail, it is sufficient to refer to the existing road network and the existing railway network, while regarding the gas pipeline, it is necessary to consider the minimum distance between the location of the plant and the natural gas network. This last factor considers, as explained before, the possibility of directly introducing hydrogen into the natural gas network in small quantities (10% by volume of the capacity within the natural gas network). In fact, in light of a new PtG installation, a possible connection via a hydrogen pipeline to the nearest natural gas network is assumed to be an additional transport route.

Hence, the model is based on a reticular network projected in the land surface in Lon-Lat coordinates (La Guardia et al., 2022a), called “beams & nodes” (Figure 15). The nodes represent the possible PtG installations (supply nodes) and the medium-large urban centres (demand nodes). The lines represent the minimum distances between the supply nodes and the demand nodes through the different forms of transport.

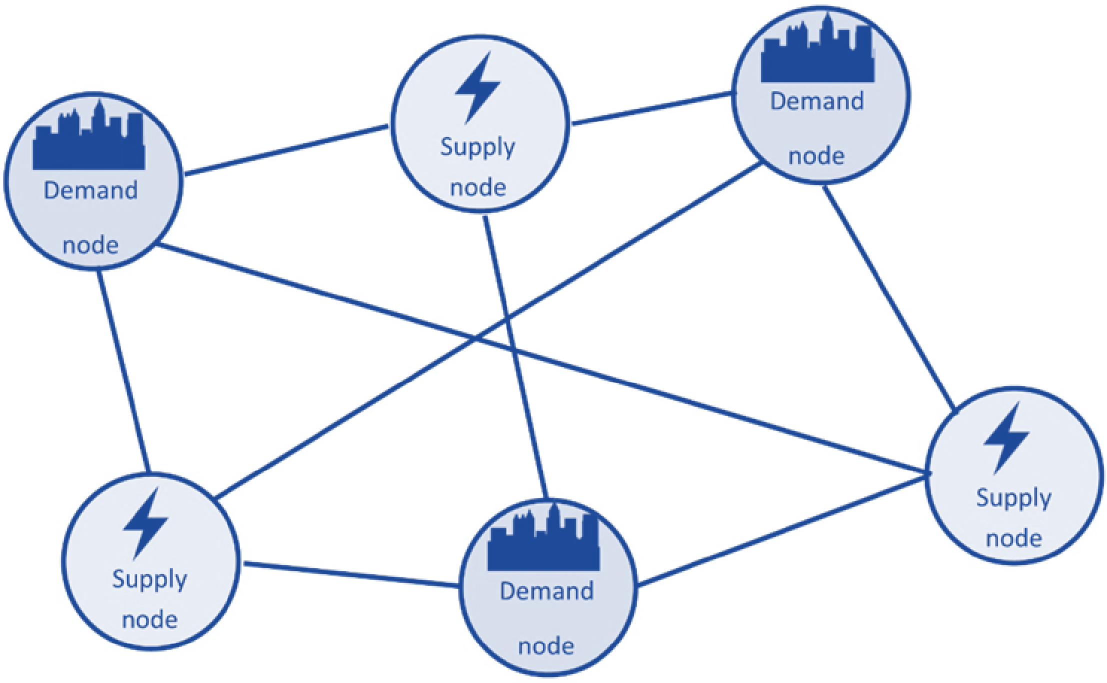

Figure 15. The "beams & nodes" schema (La Guardia et al., 2022a).

The cost function f(x) therefore considers all these factors, entered in a normalized form, and is calculated for each possible solution within the domain x ∈ S. It is necessary to underline that, for each type of variable, the values are normalized by scaling the standard deviation between the set of all the values taken into consideration.

The cost function f (x) is determined as follows for every i possible solution from 1 to n:

$$f(x_i) = (\sum_{j=1}^{m} \frac{DSN_{ij}}{AN_{ij}})/m + (\sum_{j=1}^{m} \frac{DFN_{ij}}{AN_{ij}})/m + DGN_i - PN_i;\ i = 1{,}2 \dots n; \quad (2)$$

Where:

- n = number of supply nodes.
- m = number of demand nodes.
- DSNij = normalized cost of the minimum distance between each supply node and every potential demand node through the road network.
- DFNij = normalized cost of the minimum distance between each supply node and every potential demand node through the railway network.
- ANij = normalized number of the inhabitants of the corresponding demand node for which the cost of minimum distance is calculated.

- DGNi = normalized minimum distance between the considered supply node and the natural gas grid.
- PNi = normalized production of energy of the RES plant associated with the considered supply node.

This cost function F(x) is calculated for every supply node (xi) inside the domain of constraints. The solution that obtains the lower cost function value represents the best localization of a new PtG plant installation in the territory of Sicily.

The next paragraph illustrates the operative steps that allow the construction of the WebGIS opensource platform applied to the case study of Sicily based on this mathematical theoretical model.

1.6 The WebGIS opensource platform: the dataset acquisition, elaboration and sharing of results.

1.6.1 The Semiautomated GIS processing chain

The study case presented in this work considers the localization of new PtG plants in the territory of Sicily (Italy). The WebGIS platform that hosts the system visualizes the dataset of the possible solutions loaded into an RDBMS database. The calculation of the set of possible solutions and the relative cost, as seen before, is the result of a process that involves both an MCA model and a semi-automated GIS processing chain.

In particular, the MCA model involved in the process (La Guardia et al., 2021) divides the framework in two parts (Figure 16). The first part consists of the definition of the domain of possible localizations, starting from a grid that considers the entire territory of the Mediterranean Island. The second part starts from this last domain and defines the final cost of every possible localization. This paragraph is focused on the first part, where a geomatic automated process is involved to define the domain of the possible solutions, considering specific territorial constraints.

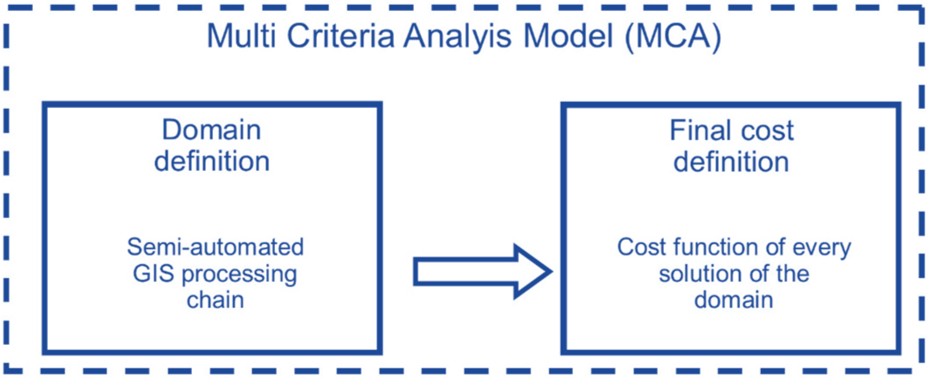

Figure 16. The structure of the MCA model (La Guardia et al., 2021).

The MCA model based on this processing assumes that the localization of new PtG plants follows specific criteria that define the constraints of the domain of possible solutions. These criteria are based on scientific reasons as the complexity of the production, the transport of hydrogen and the key role played by the PtG plant in the connection between electric and gas networks.

In fact, new PtG installations need specific requirements as the proximity with the road network, the railway network and with the existing photovoltaic or wind plants. There are also further parameters involved in the cost function to insert as attributes of possible solutions. In particular, as affirmed before, it is necessary to consider the nearness with the gas network and the cost of minimum distance between new installations and the main urban centers (filtering the centers with more than 50.000 inhabitants). The cost of minimum distance should be calculated considering both road and railway network. The semi-automated GIS processing model developed considers all these criteria and is structured in four different steps (La Guardia et al.; 2021): buffering, intersection, cleaning and cost of distance definition (Figure 17).

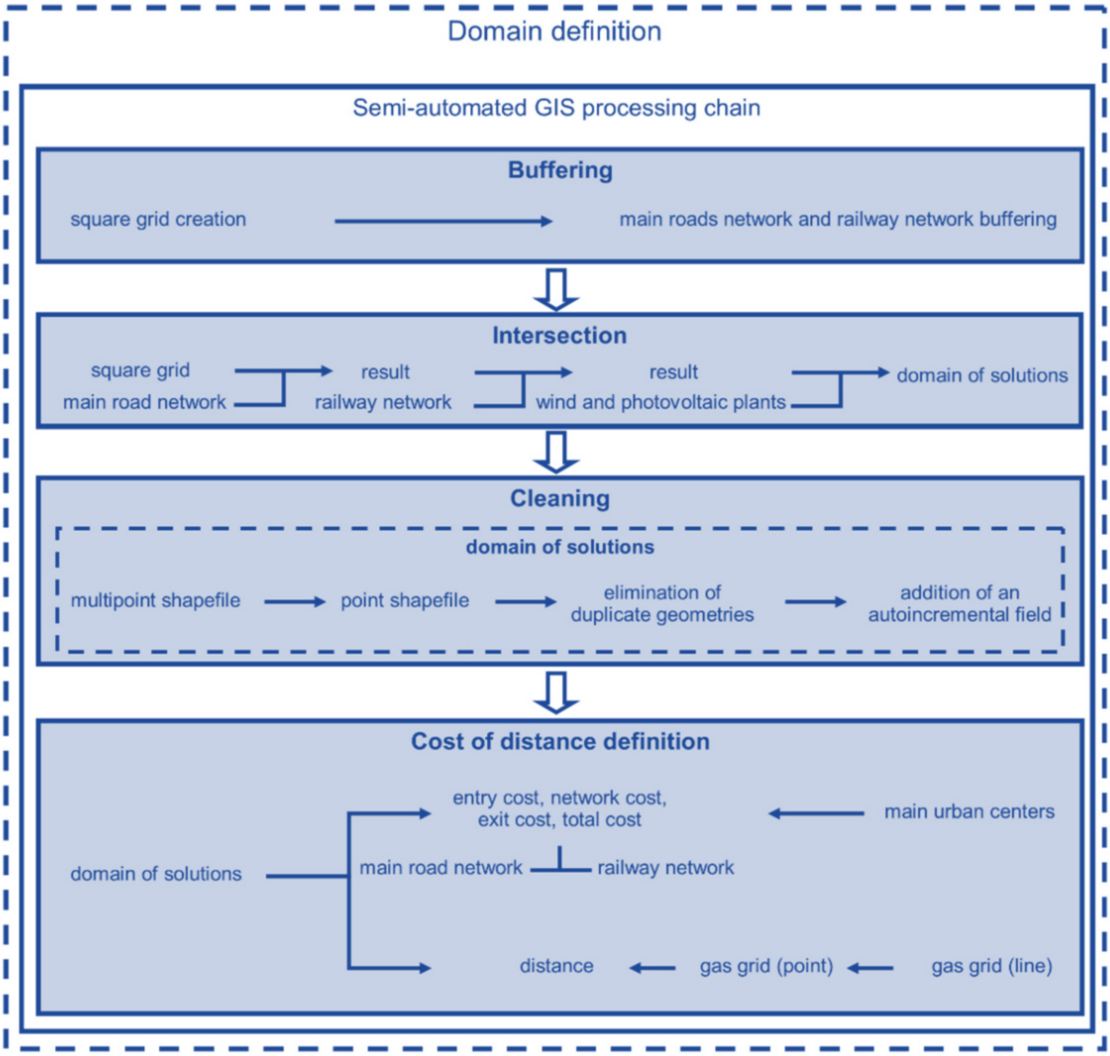

Figure 17. The framework of the Semi-automated GIS processing (La Guardia et al., 2021). Every step of the domain definition is handled manually in QGIS software, connecting each one with the previous and the next one. Once activated, it automatically works, performing the steps consecutively.

The result of every phase is the starting point of the next one in the processing chain. The involved process has been developed in QGIS opensource software, version 3.14.

The first phase starts from the environmental dataset composed by the square grid projected on the surface of Sicily (with a spatial resolution of 1x1 km), the railway network and the main road network of the Mediterranean island, and, in the end, the localization of the wind and photovoltaic plants (La Guardia et al., 2021). The entire opensource starting dataset is provided by ISTAT (National Institute of Statistics of Italy), ANAS (National Autonomous Company of Roads) and SNAM (National Pipeline Company), and considers the UTM WGS 84 EPSG 32633 reference system. Every step of the framework involves several datasets containing point, line and multipoint shapefiles (Table1).

Table 1. The shapefiles involved in every step of the framework (La Guardia et al., 2021).

Step	Shapefiles	Type
Buffering	square grid	point
	railway network	line
	main roads network	line
	wind and photovoltaic plants	point
Intersection	square grid	point
	railway network	line
	main roads network	line
	wind and photovoltaic plants	point
Cleaning	domain of possible localizations	multipoint
	domain of possible localizations	point
Cost of distances definition	domain of possible localizations	point
	main urban centers	point
	main roads network	line
	railway network	line
	gas network	line
	gas network	point

The square grid processing produces a shapefile containing a network of points, that will be next overlapped with the buffered layers of the considered networks and power plants. In particular, the line shapefiles of the railway and the main roads network have been buffered considering a thickness of 0,5 km, instead the point shapefile containing the localization of existing wind and photovoltaic plants has been buffered with a thickness of 1 km. The choice of the buffering thickness is strictly related to the local transportation network density and to the RES density.

The next step of the chain consists of the intersection of the square grid of points with the buffered layers, starting with the higher density shapefiles and ending with minor density ones. The first overlapping operation consists of the intersection between the square grid with the buffered main road network. The second is between the result of the previous one and the railway network. The last one is between the intersection with the previous networks and the buffer of existing wind and photovoltaic plants.

The result of intersection operations is a point shapefile, containing the domain of the possible localizations of new PtG installations. This shapefile needs to be cleaned due to the presence of multiple points and to be properly prepared for the cost function implementation. The cleaning step considers 3 subsequent operations that involve the shapefile of possible localizations of new PtG. The first one is the conversion of the shapefile from multipoint to point, necessary to make the further steps of the chain. The second consists of the elimination of duplicate geometries, in order to achieve unique geospatial results. The third step adds an auto-incremental field, necessary to correctly identify every solution in the cost function.

The last phase starts from the cleaned domain of possible new localizations of PtG plants in Sicily and defines the cost of minimum distance of every solution considering several factors, as introduced before. The minimum distance between every possible solution and the main urban centers through the main road network and the railway network has been calculated using the QNEAT plugin (Raffler, 2018). This plugin calculates the entry cost, the network cost, the exit cost and the total cost between two different point shapefiles through a specific line shapefile (the connection network).

Another considered factor is the minimum distance between every possible PtG localization and the network of the gas grid. This last operation is implemented in two steps. Firstly, the line shapefile of the gas network is converted into a point shapefile with an interval of 5 m between successive points. Subsequently the minimum distance between the point shapefile of the gas grid and the point shapefile of every possible localization is calculated, considering the minimum distance from the nearest node.

The four phases here described are implemented in a single processing chain (La Guardia et al., 2021) that automatically calculates consecutively every step starting from initial dataset (Table 2), in order to obtain the final domain of possible solutions with the relative costs of distance. The output of the GIS automated processing chain is the dataset that allows to calculate the final cost function.

The dataset included in the final cost function considers several factors that come into play in the localization problem:

- The hydrogen demand considered proportional to the population of the main inhabited centres.
- The supply energy from the existing photovoltaic and wind facilities settled in Sicily.
- The distances between the hydrogen demand nodes and every possible PtG localization considering different networks (main roads, railway and pipeline).

The cost function (described in the previous paragraph) is calculated for every possible solution within the domain of possible localizations.

Table 2. The Geospatial operations involved in the semiautomated GIS processing (La Guardia et al., 2021).

Shapefile	Type	Geospatial operation	Properties
square grid	point	grid creation	1x1 km ext.
railway network	line	buffering	0.5x0.5 km ext.
main roads network	line	buffering	0.5x0.5 km ext.
wind and photovoltaic plants	point	buffering	1x1 km ext.
square grid	point	intersection in order of density	
railway network	line		
main roads network	line		
wind and photovoltaic plants	point		
domain of possible localizations	multipoint	multipoint to point conversion	
domain of possible localizations	point	multiple geometries removal	
domain of possible localizations	point	auto-incremental field addiction	
domain of possible localizations	point	Origin-destination matrix (QNEAT)	Shortest path optimization
main urban centers	point		
main roads network	line		
railway network	line		
gas network	line	line to point conversion	5 m dist.
gas network	point	distance from the nearest node	

The calculation of the final cost was originally implemented in Matlab software, with a proper script that calls locally the dataset generated from the geomatic processing in QGIS ("Shaperead" function). The factors were then normalized in Matlab and each element of the final cost vector is calculated considering the hydrogen demand, the supply energy and the distances.

Once obtained the total cost of every solution (that represents every possible PtG plant localization of the domain), it was registered in a proper field of the shapefile and remotely exported from Matlab software into the RDBMS database ("Shapewrite" function).

1.6.2 The application of the cost function into the WebGIS platform

The first part of the geomatic framework works locally employing the QGIS processing chain. The second part of the chain regards the creation of the remote geospatial database (based on the results of the first part), the cost function operations, and the real time visualization of the solution on web browser. The first test regarding the application of the cost function was conducted in Matlab software. Then the entire construction of the WebGIS platform has been conducted employing only opensource technology and considering several remotely connected operational blocks (Figure 18).

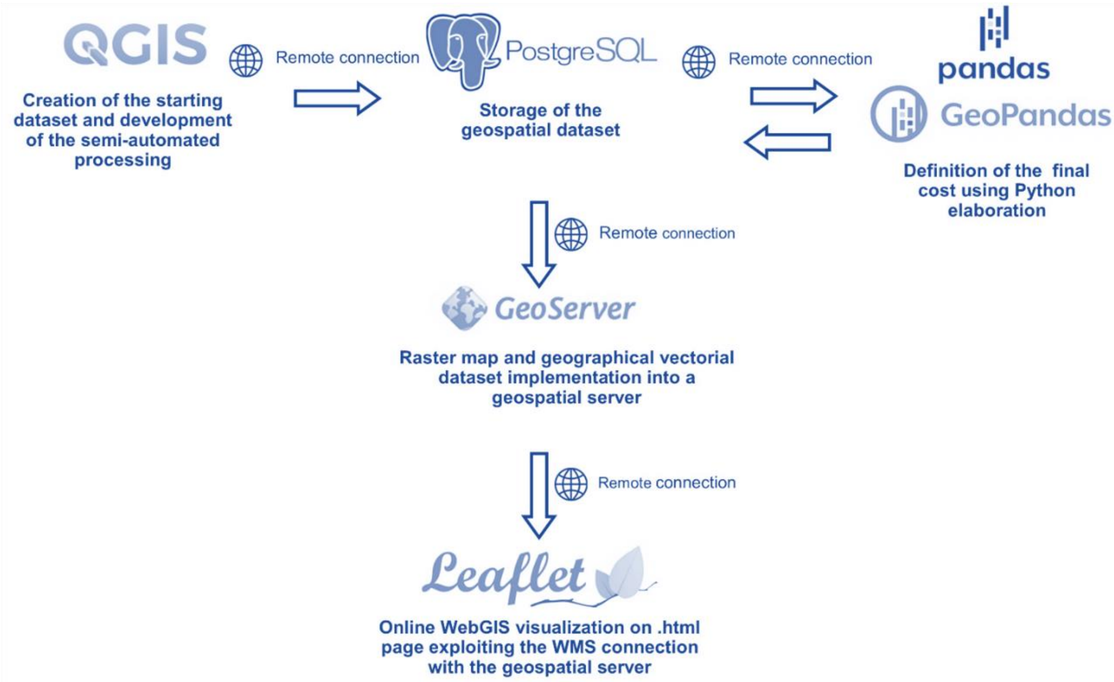

Figure 18. The structure of the WebGIS platform, that integrates all the blocks of the chain each other remotely connected.

Once defined the domain of possible solutions in QGIS, the obtained results are loaded into Postgres RDBMS opensource database employing PostGIS extension. PostGIS allows to load geospatial datasets in Postgres. In this way, the entire dataset is loaded into the relational database, considering geospatial dataset and the tables of costs. Here comes into play the Python data analysis opensource modules, necessary to elaborate the cost function (Table 3). Pandas and Geopandas are the Python modules selected for this operation. They are remotely connected to Postgres and allow to load the dataset, elaborate the cost function in DOS environment, and return the result to the database. It was necessary to use both Pandas and Geopandas modules because each of them owns necessary exclusive features. Pandas allows to employ specific operational modules that allow to make the necessary Python calculations, instead Geopandas preserves geospatial features in Python environment. In fact, it has been necessary to create a univocal identity column to join the Pandas results with Geopandas imported datasets.

Table 3: description of the Python modules used into the WebGIS platform.

Python modules	**Use**
Pandas	Remote data analysis and operation between columns of database tables in DOS environment
Geopandas	Remote geospatial data analysis and operation between database tables in DOS environment
Integrated Modules	**Use**
Psycopg2	shapefile remote download from Postgres database
Sqlalchemy	Normalization of columns

The Python strings are elaborated in DOS environment. In DOS the tables of costs of distances (considering the railway network, the main roads network and the gas pipeline) related to every possible solution are firstly normalized. The next step calculates the final cost of every solution, employing Pandas and loading the tables from Postgres through psycopg2 plugin. Hence the cost values of every possible solution are grouped into a table, following the order of the univocal identity column as reference. The table of the final costs is finally merged with the general geospatial dataset of the possible solution employing Geopandas opensource software and Sqlalchemy module using the univocal identity column as join element. The Python role finishes with the exportation into Postgres of the geospatial dataset with the addition of the final cost column.

The WebGIS online visualization of the geospatial dataset is created connecting the Postgres database with Geoserver, an opensource Geospatial data server. Geoserver allows to store geospatial raster or vectorial data and to generate WMS and WFS services for remote WebGIS connections. In this case, it has been configured a real time connection with Postgres database, to load the domain of possible PtG solutions (with the final cost calculated) and to share the results through WMS connection.

The online visualization of the dataset in the map is provided by Apache Server, creating a customized .html page, with inside JavaScript and CSS modules that create the WebGIS navigation interface. It has been used Leaflet opensource JavaScript module for WebGIS configuration, that allows the real time visualization and the queries of the features of the entire dataset, employing the WMS service.

1.6.3 Results

The WebGIS platform developed allows to real-time visualize the geospatial dataset through the map visualization on web browser. Users can navigate and visualize the dataset using desktop or mobile devices, to share the cost results of possible new power to gas localizations. The QGIS software dataset, the Postgres database, the Python data analysis module, Geoserver, and the WebGIS visualizer, are all remotely connected, allowing at the same time a smart management and a smart fruition of the dataset (Figure 19).

The experimentation described in this work involves a multidisciplinary approach where a GIS framework is applied to the problem of positioning new PtG plants into the territory of Sicily. The application of Geomatics procedures is necessary not only to build the cost function, but also to grow up the remote web platform, necessary for the acquisition, the management, and the final fruition on web of the dataset. This work is an example of how integrate Geomatics in a localization problem that combines different fields of research.

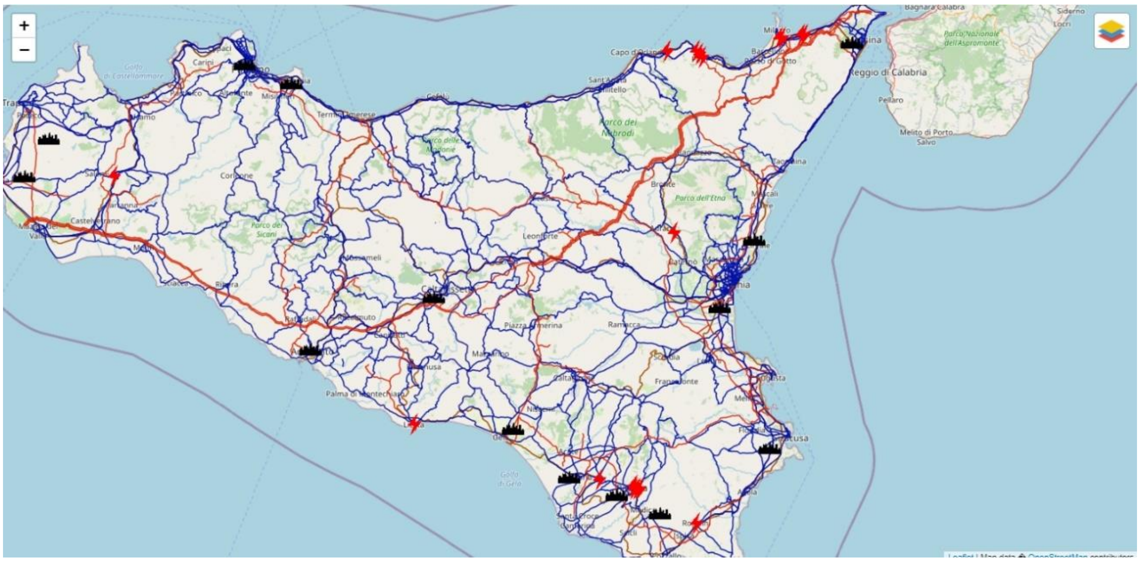

Figure 19. WebGIS visualization of the final dataset in web browser using Leaflet JavaScript libraries.

At the same time, the integration of Python modules is fundamental to elaborate operations into the geospatial dataset and to real time export the results in the relational database management system. The same structure could be extended in the future with the integration of real time energy acquisition from RES plants, to refine the cost function calculation. Furthermore, the framework studied in this experimentation represents a useful example considering the growing interest on hydrogen-based technology in the last years. In fact, the rapid spread of diffusion of PtG solutions in Europe, connected with the spread of photovoltaic and wind plants will focus the attention to this kind of strategies to optimize the localization of energy sources.

1.7 Discussion and open scenarios

The development of the WebGIS platform for the localization of new PtG plants, developed in collaboration with ITAE-CNR institute of research, involves a multidisciplinary approach where a GIS framework is applied to the problem of positioning new PtG plants into the territory of Sicily. The application of Geomatics procedures is necessary not only to build the cost function, but also to grow up the remote web platform, necessary for the acquisition, the management, and the final fruition on web of the dataset. This work is an example of how integrate Geomatics in a localization problem that combines different fields of research. At the same time, the integration of Python modules is fundamental to elaborate operations into the geospatial dataset and to real time export the results in the relational database management system. The same structure could be extended in the future with the integration of real time energy acquisition from RES plants, to refine the cost function calculation. Furthermore, the framework studied in this experimentation represents a useful example considering the growing interest in hydrogen-based technology in the last years. In fact, the rapid spread of diffusion of PtG solutions in Europe, connected with the spread of photovoltaic and wind plants will focus the attention to this kind of strategies to optimize the localization of energy sources.

In the future the same approach could be applied to several sector of research, and the same structure of platform could be replied by centres of research and municipalities to manage localization problems in a smart way, employing only opensource technology. Furthermore, the structure of the platform is ready to integrate IoT (Internet of Things) modules, to provide the real time acquisition of data from low-cost sensors networks, connecting the IoT modules to the relational database management system and providing the geospatial information.

CREATION OF A TOURISTIC WEB NAVIGATION PLATFORM ON THE HISTORIC CENTER OF PALERMO (ITALY)

This work regards the application of GIS systems and VR (Virtual Reality) to the enhancement of CH (Cultural Heritage). The advances achieved on the potential of these technologies are today increasingly promising. Even more interesting is the union of several technologies that, born in different contexts and for various purposes, allow users to achieve new levels of virtual fruition. Considering the field of territorial information services, the use of the GIS platform is almost widely diffused for providing the necessary information linked to the geographic position. It allows users to connect the geographic elements (points, lines and polygons) with semantic data stored in a Relational Database Management System (RDBMS) server (Zlatanova and Stoter, 2006). In fact, today the implementation on WEB of this kind of technology (WebGIS) is diffused in many sectors, allowing users to remotely connect their devices to GIS platforms through Web Map Services (WMS) and Web Feature Services (WFS). In this field, the collaboration between developers and researchers all over the world created a free and open-source standard protocol to share geographic information in free repositories distributed on the WEB (Brovelli et al., 2012). The implementation of this technology to CH allows to achieve a further level of accessibility to monuments and cultural sites, for touristic and scientific aims.

Advances in technologies related to photogrammetric reconstruction allow obtaining very accurate models both in geometry and in the application of realistic textures. The point clouds generated by the Structure from Motion algorithm (SfM) can be obtained today in a relatively short time and with a surprising quality using not expensive cameras. The use of low/medium range Unmanned Aerial Vehicles (UAVs) also offers new solutions in surveying and image acquisition operations, thanks to the possibility to acquire aerial nadir and oblique images with high-resolution cameras (Pepe et al., 2019).

The 3D data obtained by these means can then be used in various applications in the field of CH valorization, from monitoring and conservation purposes (Dominici et al., 2017, Aricò and Lo Brutto, 2022) to documentation (Guarnieri et al., 2017) or virtual representations finalized to virtual fruition (Scianna et al., 2020; Scianna et al., 2016). In Virtual Reality applications 3D models of architectural heritage can be freely explored by users from any point of view. This makes this technology, mainly applied to the world of video games, very captivating in a higher context such as the cultural one. Furthermore, virtual environments can now be accessed at any time and in any place, thanks to mobile devices such as smartphones and tablets. Just downloading a particular app or accessing a webpage it is possible to gain new levels of knowledge. The virtual exploration of an environment also allows eliminating, at least in part, some problems related to accessibility to CH. Many cultural sites are inaccessible today both due to problems associated with the disability of some users and because they are in impervious places or, more simply, because they are closed to the public. Another interesting aspect is, as mentioned previously, the possibility of sharing virtual reconstructions through the WEB. The WebGL libraries, based on the HTML5 standard, allow users to load three-dimensional virtual environments within .html pages that can be opened in the most common browsers. With a simple click, it is possible then to quickly access many visual information on CH. All these technologies together integrated allow to open new possibility of sharing CH information, useful for conservation, documentation and accessibility purposes (Dhonju et al., 2018; Themistocleous et al., 2015). In fact, recent studies focus the attention on the experimentation of the integration of augmented, virtual and mixed reality finalized to the improvement of CH accessibility (Bekele et al., 2018).

In the following sections of this chapter, therefore, the level of advancement and the potential offered by the technologies mentioned above, in the context of the CH, will be analysed. This will then be followed by the presentation of the case of study that regards the creation of a virtual path inside the historic centre of the city of Palermo. This work was developed within the I-ACCESS European Project in collaboration with the High-Performance Computing and Networking Institute of the National Research Council of

Italy (ICAR - CNR). In this work different technologies and different types of data were combined to offer a complete exploration of some architectural jewels present in the Historic Center of Palermo.

2.1 GIS and WebGIS finalized to fruition and conservation of CH

The fast diffusion of desktop and mobile electronic devices and the diffusion of portable internet connection enlarged the possibilities offered by GIS-based territorial services. In fact, if before the use of these technologies was almost limited to only specialists like architects, engineers and archaeologists, today GIS applications are commonly used by everyone simply through the activation of georeferencing of proper devices. Considering the world of CH, the development of GIS platform accessible by clients on the WEB, called WebGIS, strongly supported in recent times the accessibility of monuments and archaeological sites. Indeed, it's possible to connect the geographical localization of the place of interest with semantic documentation regarding history, conditions, and characteristics, connecting the GNSS positioning of the considered places with a proper relational database (Pelcer–Vujačić and Kovačević, 2016). This is the case of GIS, where specialists that came from different fields work together for the construction of a platform available through a WebGIS implementation useful for the fruition and the conservation of cultural goods (Vacca et al., 2018). The making of this kind of structure needs also the integration of different kinds of data to be acquired (Scianna and Villa, 2011). For instance, considering the archaeological sites it's necessary to connect raster and vectorial data, semantic RDBMS information and 3D models in the same system. The possibility of associating geometrical 3D datasets with semantic information stored in a proper database approaches the GIS structure based on CityGML (Geograph-ic Markup Language) standard with the BIM architecture based on IFC (Industry Foundation Classes). This affinity could result useful for developing multiscale methodologies for the territorial analysis (Noardo et al., 2020; Colucci et al., 2020).

Sometimes the use of SIS applied to the world of CH could be also strategic for the monitoring of monuments and archaeological sites threatened by anthropogenic hazards. In this case, the integration of remote sensing acquisitions integrated with GIS analysis is necessary (Agapiou et al., 2015). A similar approach could be used for discovering possible archaeological remains hidden by vegetation in impervious landscapes (Gennaro et al., 2019). Considering the GIS visualization, recent advances in computer graphics allowed specialists to develop 3D Globe platforms (Brovelli et al., 2013; Scianna and La Guardia, 2018), where every kind of data could be loaded and projected over the terrain surface. However, the 2D visualization for some applications remains more accessible and more user-friendly in navigation.

2.2 3D environment for CH valorization: VR and AR: State of art.

Today, the fast advances on the development of the technologies related to the architectural survey that allow the digital reconstruction of CH elements are surprising. An important strength is, in fact, the possibility of obtaining complete point clouds of an architectural complex with an adequate level of geometric accuracy. Digital photogrammetry has the great advantage of allowing rapid acquisition of images with not too expensive equipment. The scanned images acquired from different points and from different angles of view achieved a good level of quality and definition. This, combined with the automatic reconstruction based on the SfM algorithm, allows obtaining aligned point clouds of external and internal environments in a relatively accurate way. The use of high-quality images also guarantees a good result in the creation of textures to be applied to 3D models. Obviously, it is always necessary to consider the size of the object to be detected, the lighting conditions, the number of photos needed and the processing times. These are all elements that influence, in different ways, the result aimed at creating navigable virtual environments. The point clouds generated through digital photogrammetry procedures can be transformed into meshes and used in VR and AR (Augmented Reality) applications.

The use of VR, already widespread in various fields, has recently also involved the world of CH. Thanks to the availability of new media, the digitisation of CH qualifies as a new way of transmitting knowledge. It is, therefore, possible to provide information in different forms and for various purposes, quickly and with a user-friendly approach. In particular, the VR application to the world of CH has proved to be an interesting tool for the reconstruction, preservation and safeguarding of artistic works. Huge advantages can be obtained in the digital reconstruction of damaged parts or in supporting restoration interventions. Furthermore, three-dimensionality and virtuality are capable of transmitting emotions to the observer. For this reason, it has been experimented in museums to enrich the real experience (Carrozzino and Bergamasco, 2010). Moreover, the images enjoy a more immediate degree of understanding than reading. This makes visualization-based applications very effective in cultural dissemination and documentation (Koeva et al., 2017). Archaeological sites, museums, and art collections (Fineschi and Pozzebon, 2015) can also rely on these technologies to increase the involvement of the viewer, offering a further level of knowledge of what is observed in reality (Becattini et al., 2016). Interactive monitors, consoles with three-dimensional reconstructions and AR applications increase and renew interest in culture. By making use of virtuality, it is, therefore, possible to interact with objects in the collection even at a distance, thus involving a greater number of users, including the disabled and students. The new scenarios opened by the application of VR to the world of CH led researchers to produce several experimentations in the field of heritage education, coming proper in the world of serious games (Luigini et al, 2020, Skarlatos et al., 2016).

2.3 The virtual path through the La Loggia district of Palermo

Within the I-Access European Project, the choice to enhance the monumental heritage considering the part of the historical center of Palermo named La Loggia or Castellammare was inspired by the extraordinary cultural, artistic, and architectural value of the district (Scianna et al., 2021) (Figure 20). From the Norman period, the district became the favourite place of settlement for merchants of different origins. Genoes, Venetians, Pisans, Amal-fitans, Catalans built their lodges for commerce, their high houses, and their churches.

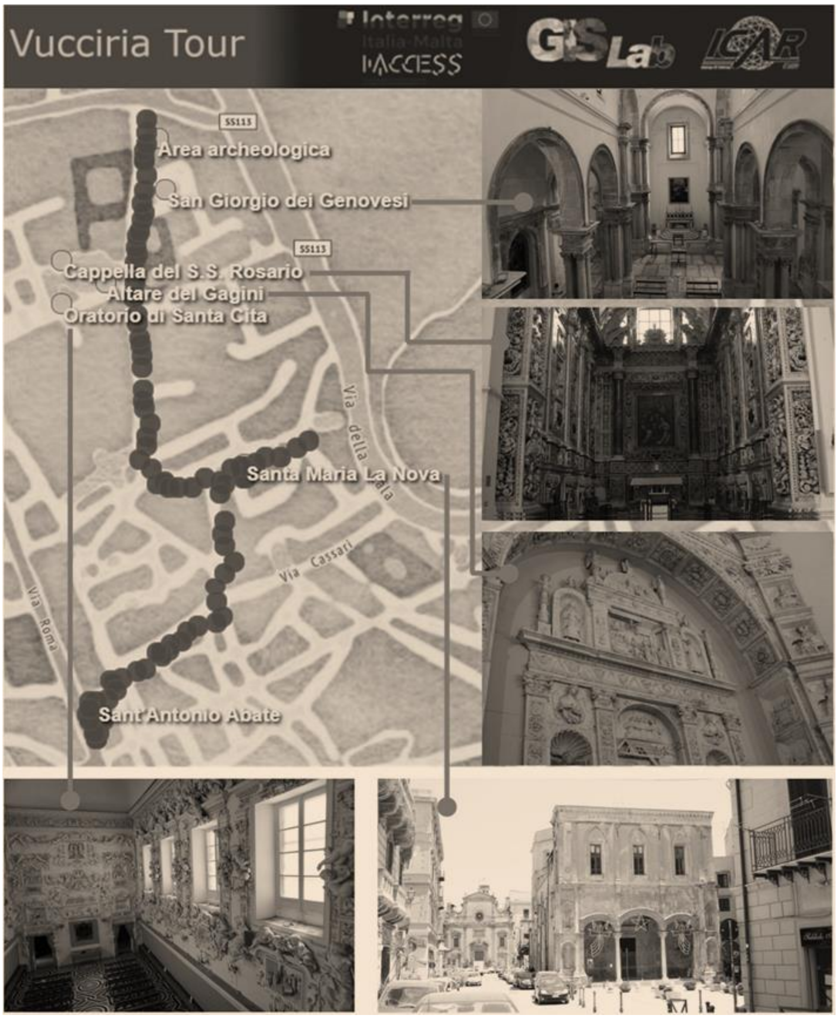

Figure 20. The cultural goods considered in the virtual tour of the historical centre of Palermo (Scianna et al., 2021).

With their decline, the craft corporations settled, and the heart of the district became the largest food market in the city, still known today with the name of Vucciria. The term comes from the French "boucherie" meaning butchery and in the Sicilian dialect indicates the confusion and shouts typical of the popular market.
In the minute and winding urban context of the shops, examples of monumental churches stand out. Most of these are the result of the political, economic and spiritual commitment of religious orders and confraternities. Rarely accessible to the public, these buildings constitute and preserve, within them, examples of significant artistic value that the virtual path aims to make accessible by the means of AR applications. Starting from the point closest to the sea, the route intercepts the church of San Giorgio dei Genovesi, an example of a sixteenth-century church on columns.
Its peculiarity consists in the tetrastyle pillars that divide the three naves, a characteristic that united the church to the cathedral of Palermo where these were replaced in the eighteenth century. The second step of the virtual path consists in the XVII century church of Santa Cita or Santa Zisa, severely damaged by the bombings of World War II and by carelessness; now restored and returned to worship (Di Natale and Brai, 1998). The church preserves one of the first works by the sculptor Antonello Gagini in Palermo, the external arc of the altar, sculpted in Carrara marble in 1504 and completed by the altar in 1516-17 (Nobile 2010; Di Natale and Brai, 1998).
On the right side of the apes opens the chapel of the SS. Rosario, burial place of the Brotherhood of SS Rosario, built between 1635 and 1641. The colourful marble inlays, covering its wall entirely, are an early example of this kind of decoration in Palermo, inspired by the chapel of Santa Rosalia inside the cathedral, and by some chapels in the Jesuit's church of Casa Professa. Attributed to Nicolò Travaglia and Gaspare Guercio the decoration was accomplished between 1696 and 1722 by sculptural reliefs of the ten Mysteries of the Rosary, realized by Giocacchino Vitagliano on models by Giacomo Serpotta (Piazza and Minnella, 2007).
The rich monumental site of Santa Cita also includes the oratory with the same name. It was entirely decorated at the end of the XVII century by Giacomo Serpotta, master in the creation of complex decorative sculptural patterns in white stucco, polished with

marble dust. The rectangular oratory features sculptures of personifications of the Mysteries and Virtues on the major sides, while the main theme is represented in the entrance wall: the battle of Lepanto, celebrating the victory of the Christian fleet over the Turkish fleet in 1571. (Serpotta and Palazzotto 2016; Viola, 2015).

Moving forward the market, the path intercepts another extraordinary example of baroque decoration with marble inlays, the church of Santa Maria in Valverde of the Carmelite nuns, work of the architect of the Senato of Palermo Paolo Amato. The decorative setting was structured by Amato articulating the walls with imposing and hyper-decorated marble altars, framed by giant Solomonic columns (Piazza and Giuffré, 1992). The sixteenth-century church of Santa Maria la Nova dominates a small square at crossroads between the via Giovanni Meli street and the Materassai street. The architect, Antonio Peris, designed a three naves basilica supported by columns with a large transept-sanctuary, basing on the example of the late-gothic Church of Santa Maria della Catena at the ancient port of Cala (Nobi-le, 2009). The facade, based on the same model, took inspiration from the fifteenth-century front porch with three arches of the cathedral of Palermo. Continuing towards the sea you can come across the baroque facade of the church of San Sebastiano, attributed to Gaspare Guercio. behind the facade hides a sixteenth-century church with characteristics similar to that of Santa Maria la Nova.

The project is modular, other partners must provide textual information through the general project website. Information hotspots present on facades of monuments call links to the project website pages. The information will be provided at different levels of detail depending on the users and their level of interest. The work described here is an accomplished part of the larger platform that will provide web services, geoservices, textual information and other multimedia information.

2.4 The Web interfaces

The first study of the work has been the choice of the best solution to guarantee user-friendly navigation of the considered historical path. The idea has been the creation of a reference map of the site, where it's possible to visualize the touristic path and the main monuments of the area. Navigating inside the map, users can click and navigate along the path or inside the cultural goods.

Hence, the proper virtual navigation starts, where users could make a virtual walk along the path, where it's possible directly to come inside the monuments and to read the related historical documentation. In this way, the tourist is immersed inside the environment such as a serious game and is motivated to continue the visit and discover new places. An important requirement of this platform should be the free and the simple access on the WEB from any kind of device, to be totally user-friendly.

2.4.1 The main visualization

In light of these requirements, the main visualization has been a 2D map of the considered area of the historic center of Palermo. This visualization is based on a WebGIS connected to the Open Street Map Site and to server folders, in order to load geospatial elements like maps, rasters and vectorial data. The coordinate system used in the platform is EPSG 4326 WGS 84. The main visualization of the map consists of a .html file, where an Open Layer structure has been set up through the implementation of JavaScript strings. In this way it's possible to insert in the map further layers called from remote servers through WMS service. The touristic path is indicated with a series of points, where each one is in correspondence with the spherical panorama associated with it. Users could start the navigation simply clicking on any point of the path. Along the path the main monuments are indicated with proper popups, allowing direct access to the virtual navigation models (Figure 21).

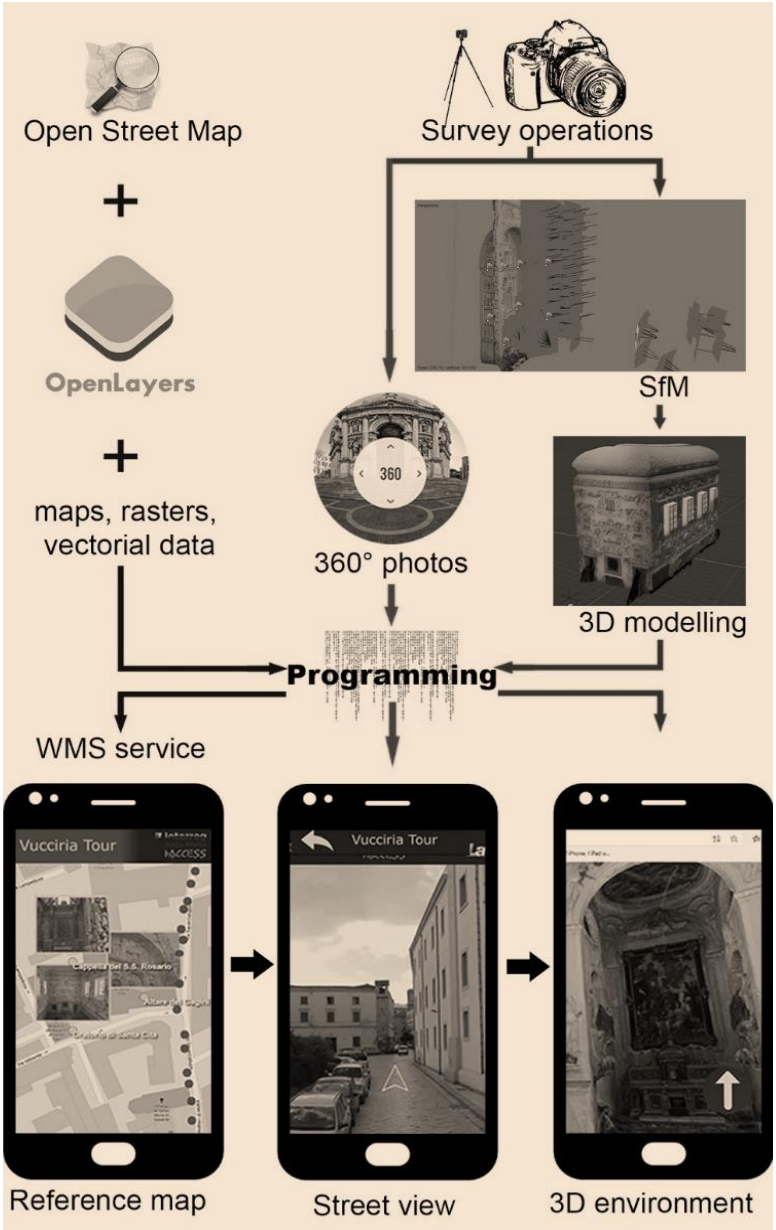

Figure 21. Application development workflow and structure of the platform (Scianna et al., 2021).

2.5 The virtualization of CH models: from survey operations to web-browsing

The process of virtualization of historical constructions is very complex. First, it's necessary to define the final use of the 3D representation. In this case, the final aim is to allow the online navigation of the 3D environments. Hence, it's necessary to find the true balance between the weight of the 3D models and the necessary level of detail and realism to achieve. In fact, to guarantee good performance on web-browsing of virtual monuments, it's necessary to limit the file extension of the models strongly. It's essential to take care of these requirements in all the phases of the process, starting from the survey. The monuments considered for the virtual navigation along the La Loggia district path of Palermo were chosen considering their historical relevance and their difficult accessibility. In particular, the selected monuments have been the church of San Giorgio dei Genovesi, the church of Santa Cita, considering the altar of Gagini, the chapel of SS. Rosario and the indoor environment of the oratory, the church of Santa Maria La Nova. Survey operations started with the geometrical acquisition of the environments with Terrestrial Laser Scanner (TLS) instrumentation and then to acquire several chunks of photos from different angles and with different cameras for the further photogrammetric reconstruction.

In particular, a Faro Focus 3D 150 laser scanner has been used for geometric acquisition. The photo acquisition has been obtained with three different instrumentations, a Single Reflex Camera (SLR) Canon EOS 550 D with 18 megapixels for shootings on the ground, an SLR Camera Sony Alpha 6000 with 24 megapixels for shootings taken with an extendable pole at different levels, and the micro-UAV equipment DJI Tello with 5 mpx camera for shootings on flight of not accessible surfaces. The digital photogrammetric reconstruction based on SfM algorithm has been carried out with Agisoft Photoscan software, creating the point clouds of the considered environment, and subsequently generating the 3D meshes.

The 3D models obtained from the photogrammetric processing have been properly simplified and refined in Blender, an opensource modelling software. In this phase, the geometric shape and the texture map have been modified to be loaded into a WebGL environment. Considering the strong limitation on geometric dimension to guarantee effective WEB navigation (15-20 MB), a good level of texture definition has been a fundamental requirement to obtain a realistic online virtual visualization. Once refined, the Blender file has been loaded into the Verge3D opensource application to proceed with programming the WebGL application. Verge3D, in fact, consists of two parts: a plug-in, in Blender, that allows the export of the project in .glTF format and an application that reads this file together with the original Blender file and allows it to be modified visually through a puzzle template.

To carry out the first-person navigation, a capsule-shaped object was created to which physical properties of a rigid body were associated. A camera was attached to it at a height corresponding to the human head. Physical properties of a rigid body have also been associated with church models (Scianna et al., 2021). This procedure, also used in the creation of the most common first-person video games, is necessary to prevent the user from going across the walls and objects of the 3D model. Through the Verge3D visual programming system, it was then possible to add movement to the capsule-shaped object which, moving, drags the camera with it following a specific input from the user (Figure 22).

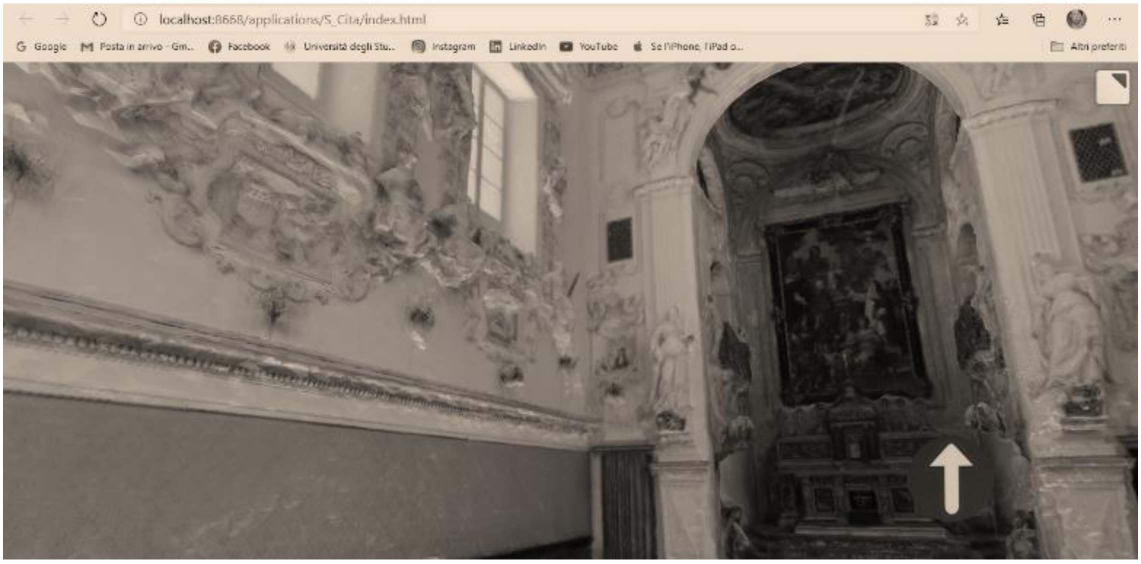

Figure 22. WebGL app visualization from the browser. Web visualization of the church of S. Cita (Scianna et al., 2022).

2.6 Results

This chapter describes an example of how digital technologies could be implemented in a unique structure for the development of a CH immersive experience. WebGIS implementation, 3D modelling, Virtual Reality and WebGL navigation are integrated for a unique goal: adding an advanced level of accessibility to a network of cultural goods. The created structure could be further enriched, adding semantic descriptions, 3D models, and linking AR applications connected to the main path. The project is promoted and publicized through public initiatives aimed at the various public and private stakeholders by the municipalities of Palermo and Valletta. The impact on users will be verified through some indicators by other project partners. The developed work allows simple navigation with the main browsers (Chrome, Firefox, Safari) for desktop and mobile devices, and is completely free. In this way, it's possible to freely navigate inside the path, visiting the considered monuments independently from any obstacle to their real accessibility. The virtual navigation grows not only the knowledge about cultural goods but also the interest and the desire to visit the real ones. In fact, the virtual tourist path is a complementary source of knowledge to the real visit of the monuments and couldn't be never seen as a substitute for it.

2.7 Discussion and open scenarios

The creation of the virtual navigation platform in the historic center of Palermo, developed in collaboration with ICAR-CNR institute of research, describes an example of how digital technologies could be implemented in a unique structure for the development of an immersive experience on CH. WEBGIS implementation, 3D modelling, VR and WebGL navigation are integrated for a unique goal: adding an advanced level of accessibility to a network of cultural goods. The developed work allows simple navigation with the main browsers (Chrome, Firefox, Safari) for desktop and mobile devices, and is completely free. In this way, it's possible to freely navigate inside the path, visiting the considered monuments independently from any obstacle to their real accessibility. The virtual navigation grows not only the knowledge about cultural goods but also the interest and the desire to visit the real ones. In fact, the virtual tourist path is a complementary source of knowledge to the real visit of the monuments and couldn’t be never seen as a substitute for it. The diffusion of this kind of applications could be strategic in the future to disseminate the CH knowledge embracing the interest of the new generations and, at the same time, offering a further opportunity of accessibility complementary to the real fruition.

DEVELOPMENT OF A GLOBE BASED 3D WEBGIS NAVIGATION PLATFORM THAT INTEGRATES DIFFERENT LODS (LEVELS OF DETAIL) OF URBAN DATASETS.

Recent advances in geospatial technologies allowed the visualization of a 3D complex environment on the WEB, exploiting realistic Globe reproduction of the real territorial asset (Pirotti et al., 2017; Pispidikis and Dimopoulou, 2016). This solution employs the features of GIS (Geographic Information System) for sharing online geospatial information (WebGIS). The last decades were characterized by the development and the diffusion of geospatial services based on the fruition and the visualization of vectorial and raster geo referred datasets connected with semantic information stored into a database (Zlatanova and Stoter, 2006). GIS development starts there. Then, the diffusion of a standard open-source protocol developed by the Open Geospatial Consortium (OGC) allowed the use of this technology to share online geospatial information using open-source local software or web applications developed with open-source technology (Brovelli et al., 2012).

To share the geospatial information online web server and Geospatial server implementation is needed. WMS and WFS allow sharing of geospatial information, connecting the WebGIS visualization module to the Geospatial server (Michaelis and Ames, 2012). Various open-source solutions and libraries have recently been developed based on web services. At the same time, recent research in this field developed JavaScript opensource libraries able to generate a Globe-based WebGIS visualization exploiting the capabilities of web browsers (Scianna and La Guardia, 2018). This kind of solution exploits the capabilities of web servers that can host the .html pages and the JavaScript libraries necessary to visualize the WebGIS environment.

In recent research, the integration of software calculation or open-source remote operation modules based on Python and connected with the WebGIS platform through RDBMS (Relational Database Management System) server improved these solutions by offering further possibilities for real-time territorial analysis (Grippa et al., 2017; Shankar et al., 2018).

Several research fields employ this kind of technology because the online fruition of geospatial analysis data is a strategic tool for many scientific aims (Koeva et al., 2021; Li et al., 2020).

In the field of 3D modelling, recent advances in computer science allowed finding immersive 3D visualization solutions, usable in many research sectors. The development of VR visualization technologies allowed developers to find new solutions for sharing different levels of information where the real fruition is not accessible (Bekele et al., 2018). Recent advances in VR tested many experimentations introducing AR, which integrates the real experience with the virtual one, offering users new levels of knowledge (Frontoni et al., 2018; Scianna et al., 2019). The recent spread of smart internet accessibility and the diffusion of fast internet connection allowed developers to test new possibilities to share online VR models. WebGL technologies emerged and allowed sharing complex environments on web. This open-source solution, based on Html 5 standard, exploits the capabilities of modern web browsers, allowing the visualization of complex 3D environments. These models are dynamically created inside Html pages (hosted in a web server) and integrated with JavaScript libraries, so-called WebGL libraries.

These developments in the last decade opened new opportunities in the field of VR, with the possibility to test and explore new solutions for complex 3D models navigation on the web for different purposes (Bian and Wang, 2020; Yuan et al., 2017). In this way, a complex 3D environment could be online navigable by users without installing any application on the device (pc, tablet, smartphone). This solution allows the employment of videogame technologies to create an interactive 3D environment on browser windows compliant with Html 5 standards (Scianna and La Guardia, 2020). WebGL technologies are used in many fields of research, from archaeological site exploration

(Vennaricci et al., 2021) to medical simulations (Min et al., 2018), from industrial robot kinematic analysis (Dey et al., 2016) to flood simulation (Kilsedar et al., 2019). This solution allows the online navigation of complex 3D environments, offering users real-time interaction with the visualized environment (Huixian, 2020).

Therefore, the research object of this chapter integrates the latest open-source achievements on WebGIS with the latest WebGL technologies to offer users information freely available on the WEB. This research has been developed in collaboration with the Faculty of Geo-Information Science and Earth Observation of University of Twente (The Netherlands).

In the next sections, state of the art in 3D WebGIS technology will be described, incorporating a variety of examples and applications. Then the structure of the integrated WebGIS platform will be shown, focusing on the WebGL environment integration. Afterwards, the results and the conclusions of this research will be presented, with a particular focus on the possible future integrations.

3.1 3D WebGIS solutions for the management of complex datasets: State of art.

The evolution in computer science allowed in recent years to integrate 3D building visualization in virtual urban environment models for territorial analysis (Noardo et al., 2020). The creation of digital open libraries of 3D buildings inside a geospatial Globe visualization by public entities allowed in recent times to acquire and share information about municipalities, giving the possibility to freely download specific parts of the datasets to make further analysis (Sun et al., 2019). The complexity of the geospatial information useful for urban planning and governing needs the development of spatial information systems to manage large extent of 3D spatial and non-spatial datasets (Zlatanova, 2000). Recent experimentation integrated urban spatial databases and non-spatial information (buildings, parcels, and property owners) to improve cadastral data management (Ostadabbas et al., 2021). In this field, the use of WFS, based on the OGC protocol, allows to load the shared dataset into GIS software and then store the semantic features of each building into an RDBMS server. Recent experimentations in WebGIS also considered the integration of automated workflows based on python modules that load the acquired geospatial dataset to generate and publish elaboration for territorial analysis (Binh et al., 2020; La Guardia et al., 2021).

The integration between 3D GIS globe navigation models and VR environment navigation is a solution that offers a variety of opportunities for web navigation, exploiting the capabilities of web browsers in the best way (Wang et al., 2015). Using 3D city models as a dataset source for further analysis by municipalities technicians needs more accuracy in management and data updating (Eriksson and Harrie, 2021). Recent applications in many sectors of research also tested the integration of GIS and VR 3D environments produced from SfM (Structure from Motion) modelling, allowing the virtual fruition of the territory for touristic and educational purposes (Antoniou et al., 2020; Scianna et al. 2021; Pepe et al. 2021). For these applications, integrating different types of 3D geospatial datasets used in various devices available on the market leads researchers to focus their interest on new solutions. Therefore, WebGL technology represents a smart and open-source solution to share geospatial dataset for research, fruition, and educational purposes (Buyukdemircioglu and Kocaman, 2018; Huixian, 2020; Zhu et al., 2019). In fact, this choice provides stable navigation and fruition of complex geospatial datasets exploiting the capabilities of the common web browsers (Lee and Jang, 2019).

The possibilities for 3D data integration on the WEB evolved a lot in recent years. The overall ambitions towards digital twinning incorporate the integration of models based on 3D complex and big datasets such as 3D point clouds generated from TLS (Terrestrial Laser Scanner) SLAM (Simultaneous localization and mapping) survey, BIM (Building Information Modelling) models, or also 3D visualization of real-time IoT (Internet of Things). Some of these tasks are still very challenging to achieve and are still in the exploration phase within the scientific community.

3.2 The integration of 3D datasets in a 3D WebGIS opensource platform

The research described in this chapter aims to develop a workflow to integrate different 3D data in a VR and 3D WebGIS navigation model with exclusive use of open-source libraries and software (La Guardia et al., 2021).

The selected case study is the city of Enschede, the Netherlands and more particularly the new building of the University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC). As visualised (Figure 23), the developed platform for web visualization integrates part of the 3D BAG open national geometric dataset with Image Based Model (IBM) and a Point Cloud Based Model (PCBM).

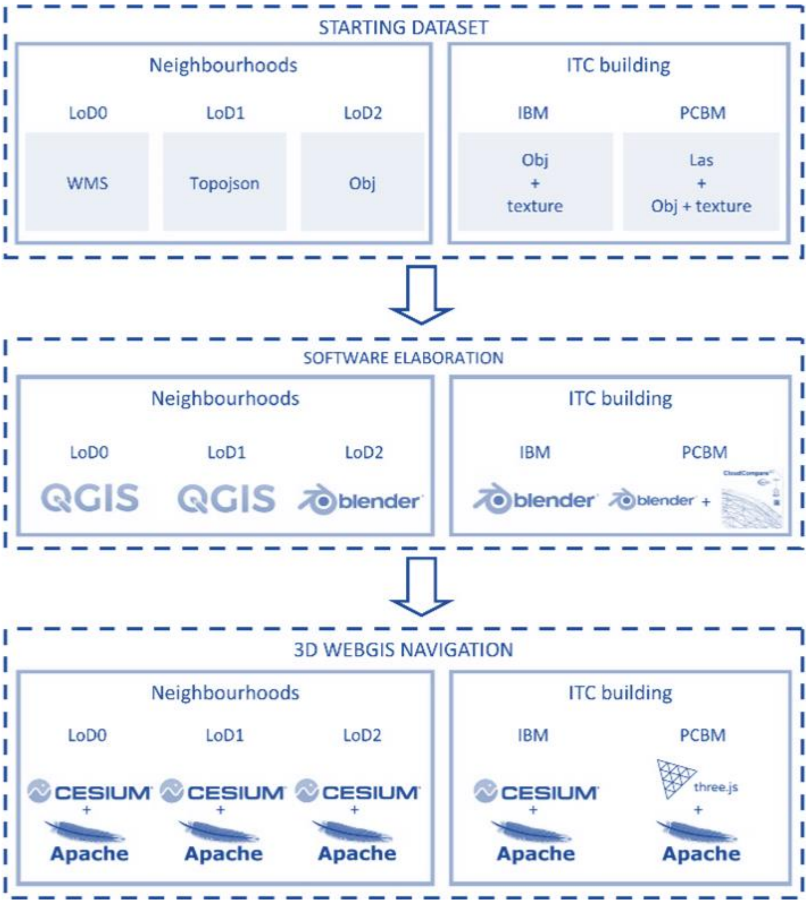

Figure 23. The schema of the dataset and the open-source solutions involved in the platform (La Guardia et al., 2022b).

The integrated datasets consist of 2D WMS maps, 2.5D topojson files, 3D textured meshes from photogrammetric reconstruction and 3D point cloud models. In addition, a comparison highlighting the strengths and weaknesses of these loaded datasets is made.

The general workflow for this research has been divided into a chain of steps to achieve the final web navigation of the platform (Figure 24).

Figure 24. The workflow (La Guardia et al., 2022b).

The first step consists of the generation of the WebGIS Globe-based platform. Configuring an open-source web server, such as Apache (https://httpd.apache.org/) that hosts the environment is necessary. Then, the globe visualization is built using Cesium.js open-source JavaScript libraries (https://cesium.com/platform/cesiumjs/), which allows configuring the 3D GIS environment inside a .html page. Then the input datasets were integrated, considering different kinds of data in correspondence of different LoD in the web visualization (Table 4). In addition, functionality has been developed for the users to switch between the different visualizations of the 3D WebGIS environment (Figure 25).

Table 4. Input dataset integrated into the platform (La Guardia et al., 2022b).

Input dataset	Type	Acquisition Format
2D buildings map	2D polygon	WMS
2.5D buildings map	2D extruded polygon	WFS
3D buildings model	3D model	OBJ
ITC building (Images Based Model)	3D textured mesh	OBJ
ITC building (Point Cloud Based Model)	3D point cloud	LAS

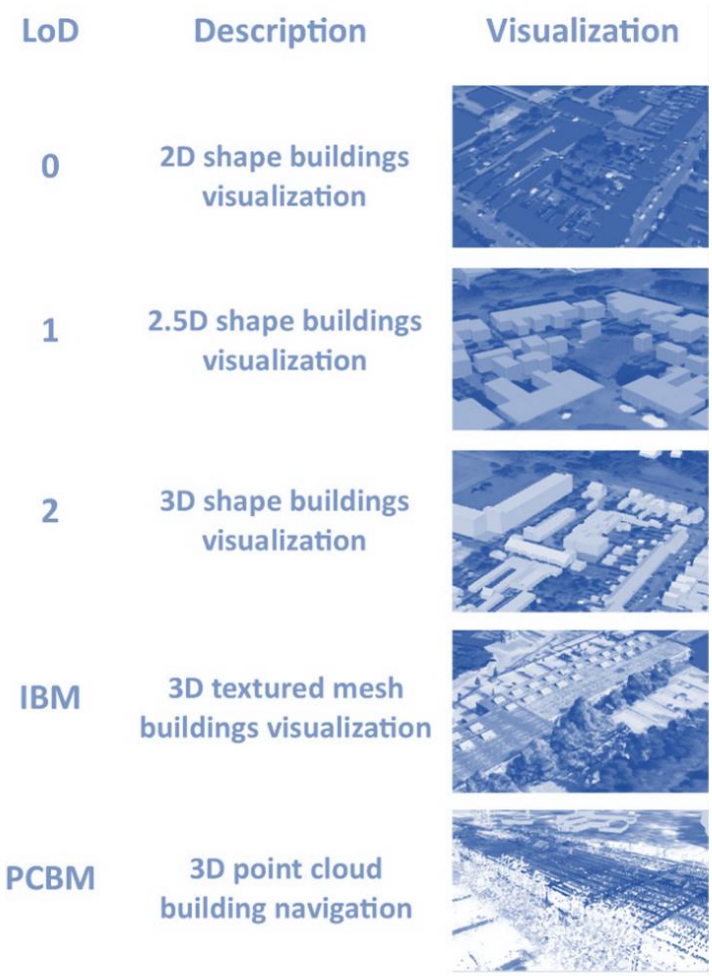

Figure 25. Description of the different LoDs (La Guardia et al., 2022b).

The 2D layer that represents the buildings of Enschede (LoD0) is real-time provided by the WMS service directly from the 3D BAG site (https://3dbag.nl/en/viewer). A script inside the Html page allows to activate the WMS service and visualize the WMS map containing the 2D information of the buildings on the browser navigation. If the WMS service is denied by CORS (Cross Origin Resource Sharing), it is necessary to configure the "access control allow origin" in the Apache configuration files.

The 2.5D topojson dataset (LoD1) is based on 2D polygon visualization extruded by the height value for each building. The base dataset is acquired by WFS in QGIS software. Then a QGIS plugin (https://plugins.qgis.org/plugins/topojson_writer/) converted the WFS extracted dataset into a topojson format. Then, the topojson dataset was loaded into the WebGIS platform, where the polygons were automatically extruded according to the height feature. The height of the represented structures has been considered a reference to automatically extrude the buildings on the WebGIS platform visualization (configured in the main .Html file).

The 3D models of the buildings of Enschede (LoD2) have been downloaded from 3D BAG choosing the corresponding tilesets available in the site (https://3dbag.nl/en/download). The tilesets have been downloaded in .obj format, with the maximum level of detail available on the 3D BAG dataset, showing the shapes of the buildings with the roof details. These tilesets have been merged and prepared for the WebGIS visualization using two open- source software solutions: Cloud compare (https://www.danielgm.net/cc/) and Blender (https://www.blender.org/). The first has been used to reset the localization of the datasets, the second has been used to define the boundaries of the focused area to visualize in WebGIS and to export the 3D model into Gltf. The final .Gltf file contained the colored surfaces of the buildings. It was loaded into the Apache web server, and then into the WebGIS platform (configuring the code on the main Html file to load and localize the 3D model).

Aiming at the complex 3D data integration, Imaged Based Model (IBM) and even the Point Cloud Based Model (PCBM) are tested in the current work. The 3D photogrammetric reconstruction (IBM) of the new ITC building visualized in the 3D

WebGIS environment was based on draping of the openly available Google imagery over the geometries. It is necessary to underline that the dataset acquisition used for the photogrammetric reconstruction represents only an example of possible dataset source to be inserted inside the 3D WebGIS platform and is not the focus of this paper. Structure from motion (SFM) based software was used to make the 3D mesh reconstruction of the ITC building, and then the textured models were simplified and exported in .obj format. The 3D mesh was finalized in Blender and then loaded into the Apache web server as a Gltf file. The 3D textured model was finally loaded into the WebGIS environment and located properly, scripting the code on the main Html file.

The last data integration experiment incorporates the VR visualization of 3D terrestrial laser scanning data acquired in April 2022 when the new ITC building was in construction. This 3D visualization of the PCBM was created in a WebGL environment where a 3D point cloud of the new ITC building was loaded inside the environment and properly aligned with the 3D model of the neighborhoods and the orthophoto base plan. The input dataset of the point cloud (in las format) was too big to be directly loaded into the WebGL environment. A strong simplification process in Cloud Compare software was necessary to obtain the final 3D point cloud (about 200 MB), which was finally converted in pcd format. The PCBM visualization was set up with orbit controls command and enriched with a fog effect to add a more realistic experience on web navigation.

3.3 Results

The structure of the WebGIS Globe platform is visualised on Figure 26. It integrates different data sources and different visualization environments connected by links to offer users a smart web fruition experience (La Guardia et al., 2022b). The current study used the new ITC building only as an example of data integration possibilities.

A JavaScript popup link connected the 3D WebGIS Globe with the PCBM environment in correspondence with the image-based model of the new ITC building (Figure 27). The link connects the Globe navigation with a popup window that show a preview of the building visualization, including a photo, a short text description of the building and a rotating zoomed 3D model visualization (created in WebGL). The structure of the window was created in JavaScript inside the main Html page.

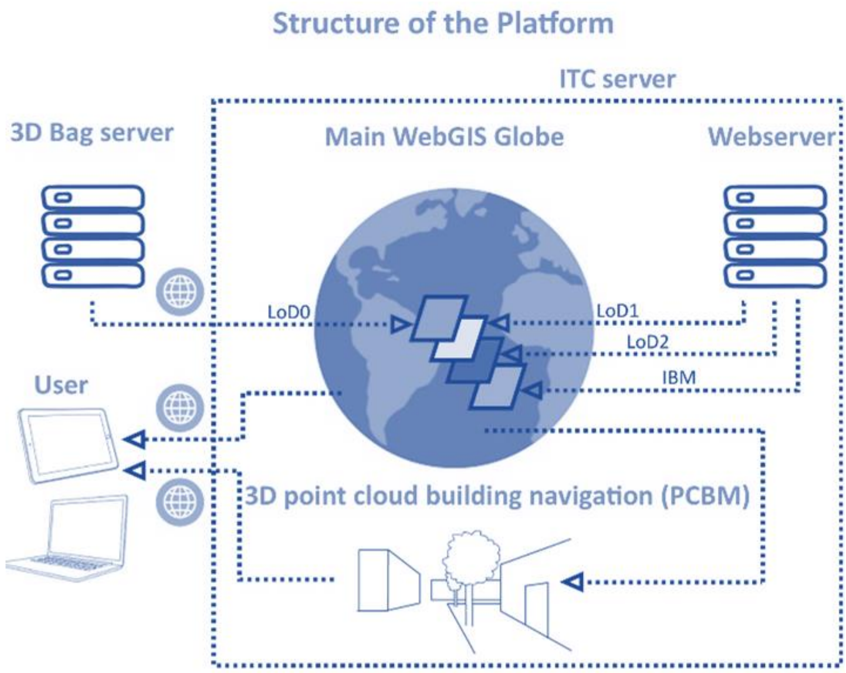

Figure 26. Structure of the platform and the connections between the different parts that involve the system (La Guardia et al., 2022b).

Figure 27. The popup link that connects the 3D WebGIS Globe with the VR environment of the new ITC building (La Guardia et al., 2022b).

The popup window is connected with the web navigation model of the new ITC building, allowing users to explore the selected building in an outdoor point cloud-based environment (Figure 28). This building's navigation model (PCBM) is developed using Three.js (https://threejs.org/) open-source JavaScript libraries, based on WebGL technology and fully compliant with HTML 5 standards. Every web navigation model is created inside an .Html page that hosts JavaScript codes. These scripts activate and customize the 3D web visualization on the web browser.

Figure 28. The VR web navigation (PCBM model) of the new ITC building (La Guardia et al., 2022b).

The process followed for the construction of the WebGIS platform employed exclusively open-source solutions. Cloud Compare, Blender 3D modelling software and QGIS application have been used to convert the loaded dataset properly for the integration on the interactive web visualization. At the same time, Cesium.js and Three.js JavaScript libraries have been employed and customized to create the Globe WebGIS environment and the VR navigation based on WebGL (Figure 29).

Different LoDs of the neighbourhoods' buildings can be visualized in the 3D WebGIS. We tested 3D data integration:

- The LoD0, that is based on the 2D visualization of the city buildings allowed by the WMS service.

- The LoD1 represents the 3D visualization of the buildings' volumes automatically generated by extrusion operations.
- The LoD2 represents the volumetric representation, including the roof shapes of the buildings.
- The IBM generated a 3D textured mesh visualization of the ITC buildings based on photogrammetric reconstruction.
- The PCBM, represents the point cloud visualization of the ITC buildings, allowed by the popup link connection with the virtual 3D navigation model.

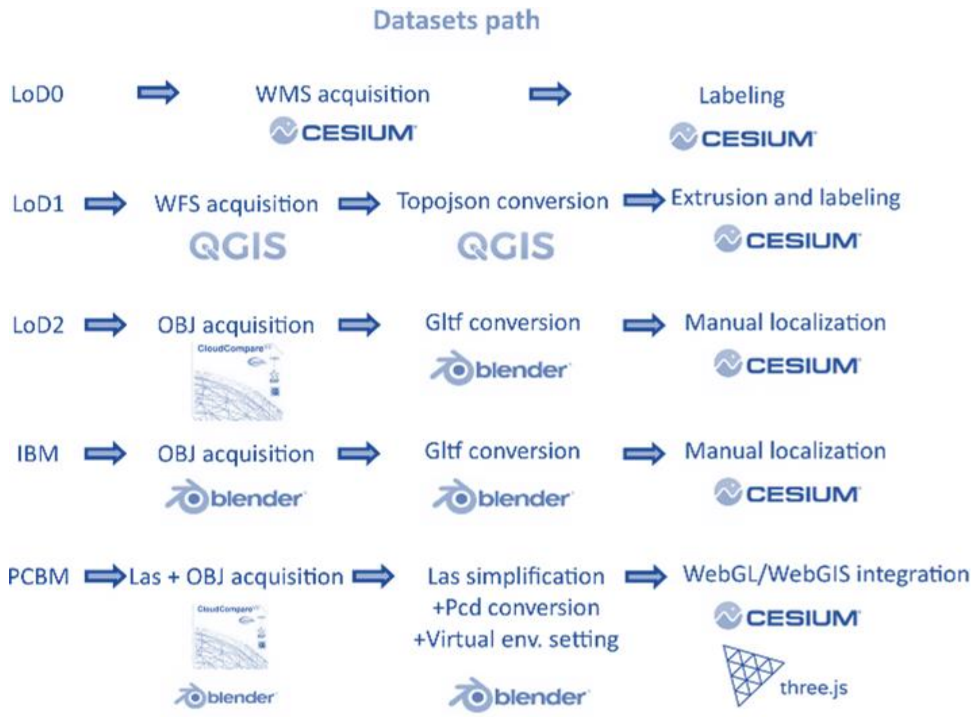

Figure 29. The description of the different elaboration paths of the datasets (La Guardia et al., 2022b).

The 3D WebGIS main environment is developed using an Html template connected with Cesium.js libraries, an open-source solution for sharing Globe WebGIS visualization on the WEB. For the current research, an Apache open-source web server was set up to host the necessary libraries and Html files to build the Globe navigation platform.

Comparing the different 3D model visualizations on web browsing tests, all of them appear whenever users activate them. On these tests, LoD1 environment is slower on loading, probably due to the real-time extrusion of the buildings' surfaces generated from the TopoJson file. The accessibility to the LoD0 strongly depends on the 3D BAG WMS connection. Instead, the LoD2 and the IBM are instantly loaded. The PCBM model takes more time to load the point cloud due to its dimension (about 200MB).
The system can be visualized and navigated using the main common web browsers (Chrome, Safari, Firefox), offering a smart solution for WebGIS navigation. Furthermore, it is working on different devices (pc, tablets, and smartphones) with perfect compliance and web navigation performances.

3.4 Discussion and open scenarios

The results regarding the development of the Globe Based 3D WebGIS navigation platform, in collaboration with the ITC University of Twente (The Netherlands), are useful for experts and users that want to share complex geospatial datasets, publishing sources at different scales and with different 3D input data models in a unique solution, avoiding the use of property software. Specialists can follow the developed workflow in the municipalities or private companies who want to build geospatial navigation models of complex scenarios accessible on the web. Future studies in this field of research could consider this work as an initial step for 3D data integration on the web. For instance, this solution allows integrating different datasets such as point clouds from TLS (Terrestrial Laser Scanner), 3D models from digital photogrammetric reconstruction, or also IFC models from BIM integration. Considering the spread of interest in the scientific field of Digital Twins, the shown solution represents a first step for the development of Digital Twins navigation models on the web. In fact, this infrastructure could be integrated in the future with the implementation of real-time IoT sensor information. This integration provides a smart solution to visualize and elaborate real time analysis, opening new scenarios for the management of structures and urban environments.

GENERATION OF A USER-FRIENDLY LOW-COST SOLUTION TO INTEGRATE IOT SENSORS ACQUISITION AND GEOSPATIAL DATA MANAGEMENT IN WEBGIS

The Cloud Computing is one of the more developed concepts in recent years in the world of computer science. Every kind of dataset can be hosted on the WEB (services, resources, data). The key features of Cloud Computing are elasticity, availability of on-demand services, remote access from everywhere, sharing of resources (Biswas and Giaffreda, 2014).

At the same time the possibilities offered by Internet of Things (IoT) recently emerged due to the possibility to connect smartphones, computers, actuators, cars, home appliances, and generally electronic devices to the Internet to share real time information. The integration of smart services connected to IoT lead the society to enhance sustainability, inclusion, economical aspects (Biswas and Giaffreda, 2014). IoT technology is considered as one of the most relevant technologies of the future, offering the possibility of creating a global network of interacting machines and devices (Lee and Lee, 2015). IoT systems rapidly diffused their integration in the “smart home” world, where users can remotely control the lighting of house environments (Phillips, 2022), receive alarm signals on their smartphones when smoke is indoor detected (Nest, 2022), real-time observe the activities of the kids (Dubey and Damke, 2019). The spread of this technology underlined new risks related to the possibility of attacks that can compromise personal safety, and it has been necessary to provide network security solutions (Sivanathan et al., 2016).

Recent experimentation employed IoT low-cost technology to analyze environmental conditions datasets (carbon dioxide, methane, carbon monoxide, rain, dust particulates, humidity, and temperature) useful to monitor the pollution of urban centers with a reduced cost (Khan et al., 2019). IoT technology has been also recently experimented in the field of agriculture to avoid wastes of water, developing a low-cost smart irrigation system including irrigation schedule estimation, neural based decision making and remote data viewing (Nawandar and Satpute, 2019). The integration of IoT systems allowed on recent research to employ low-cost technology for BIM (Building Information Modelling) and real time monitoring integration in the world of constructions on distinct phases of the life cycle of the structures (Scianna et al., 2022; Lee et al., 2012; Ding et al., 2013). The definition of smart building came properly from the integration of IoT technology (Kensek, 2014; Rabiee and Karlsson, 2021; Schuldt et al., 2021).

Considering the word of territorial analysis, last decades are characterized by the spread of GIS-based models, to make environmental geospatial operations in several fields of research, providing the integration of different kinds of dataset (transportation, security, business, terrain analysis, etc. (Goodchild, 2009; Zhan, 1997; Neteler et al., 2012; Cheng et al., 2007; Chainey and Tompson, 2008). GIS applications allow to work with large geographic dataset associating geospatial representation with semantic metadata description, merging spatial data with computer and network technologies.

The diffusion of mobile devices as laptops, tablet and smartphones and the continuous improvement of internet connection made even more useful to share geospatial dataset on the WEB, through the WebGIS (Yang et al., 2005). This solution allowed to share static web maps, to make real-time data integration, to access from different independent GIS analysis tools (Su et al., 2000; Karnatak et al., 2012). The OGC (Open Geospatial Consortium), the core of the open interoperability standards for geospatial information, provided the main services of map visualization, WMS, and the main services for loading geo-spatial features, WFS (Agrawal and Gupta, 2017). The diffusion of further technological solutions like GPS on smartphones offered new possibilities on geospatial dataset integration on WebGIS. With the evolution of geospatial technologies, the use of WebGIS opensource application has been implemented in many fields of research: historical buildings management and accessibility (Vacca et al., 2018; Scianna et al., 2021), power plants localizations (La Guardia et al., 2021), pandemic evolution (Kieu et al., 2021), study of ecosystems (Pisani et al., 2021), etc. Last years have been characterized by the diffusion of collaborative web platforms, useful to coordinate and manage environmental problems (Toro Herrera et al., 2021).

The development of low-cost facilities based on open standard solutions is more relevant in the research field than the high-cost ones, because it offers the opportunity of working with acquisition/elaboration/fruition of datasets obtained by networks of sensors to students, researchers, and teams with few economic resources. In fact, in this way it is not necessary to buy or rent property licences of hardware/software commercial solutions which can be prohibitively expensive.

The integration of IoT and WebGIS open-source solutions results strategic due to the wide range of possibilities of analysis offered by these technologies, and as will be shown, it represents a field of growing scientific interest. The solution shown in this chapter represents a smart ready to use equipment that integrates IoT and WebGIS technologies. This study has been developed with the scientific collaboration of the Kore University of Enna. The platform employs an automated process generating a chain of single modules based on containerization and virtualization. The components of the framework are totally opensource, and the costs for users are limited only to the IoT boards and sensors. The system allows users to run a real time dataset acquisition with a WebGIS browser visualization, with the possibility to download and share live and historical data. Users don't need any geospatial server, database, or IoT server configuration, because the automated process has packaged every component of the chain. The next paragraph will show the last advances and examples on IoT and WebGIS integration. Then, the deployment of the platform will be described, and, finally, the results will be shared, showing also possible future implementations based on this solution.

4.1 Iot technology in WebGIS applications: State of art.

As seen before, recent advances in IoT low-cost technology contributed to the diffusion of smart applications on several fields of research. IoT technology allows to collect data acquisition from remote sensors placed in any location, but to take the most of this solution, the dataset should be also georeferenced. In fact, sensors localization is necessary to integrate the monitoring with the contextual environment. In this field GIS integration offers new possibilities to IoT applications. Furthermore, the need to obtain a real time acquisition and to visualize it through remote connection lead necessary to integrate IoT systems with WebGIS. In fact, a WebGIS platform could integrate static geospatial information (provided by raster maps) and vectorial datasets (provided by remote databases) with real time dynamic information provided by IoT systems.

Last years are characterized by this kind of integration in many sectors, because IoT and WebGIS integration represents the basic smart solution for smart city evolution and infrastructure development (Miloudi and Rezeg, 2018). For instance, some researchers developed a spatial information infrastructure platform (PAMS) in precision agriculture integrating WebGIS and IoT, to monitor and manage the production of the soils (Ye et al., 2013). Even in the field of agriculture, this kind of integration has been experimented to evaluate the agricultural environment from on-farm sites to regional scales (Du et al., 2016), or to create a decision support system based on a close-range sensor-based data management platform (Adao et al., 2020). IoT based technology, as affirmed before, has been recently used for online monitoring in smart building applications. For instance, IoT solution integrated in a WebGIS platform has been used for Indoor Air Quality (IAQ) assessment analyzing radon gas values in indoor building environments (Lopes et al., 2019). In the field of mobility and transportation, IoT system has been used for monitoring traffics and for highlighting critical transport infrastructures integrated with WebGIS real time emergency management on road network (Du et al., 2015). Some years ago, considering the emergency caused by natural disasters, it has been developed and IT-based volcanic disasters response system simulating volcanic activity adopting proper scenarios with IoT GIS integration (Kim et al., 2014). Other applications considered the development of a WebGIS platform using Google Maps API (Application Programming Interface) services for data plotting of real-time flood monitoring, connecting in-situ instrumentation with the geospatial system (Kolios et al., 2018).

The development of an integrated GIS and IoT system able to improve current systems and to create more reliable solutions represents today one of the main areas of research (Safari-Bazargani and Sadeghi-Niaraki, 2021). Last advances on IoT and WebGIS integration considered possible open-source solutions for developing monitoring geospatial platforms aimed at real-time environmental survey (Pachoulas et al., 2021). This kind of solution is very smart but at the same time needs the management of configuration files and require programming skills by users. To create an open-source WebGIS framework, it is necessary to integrate several open-source tools with PHP MapScript programming languages, RDMS (Relational Database Management System) database and geospatial server (Sejati et al., 2020).

4.2 The construction of the platform

The overall framework is made up by two main parts, the hardware, and the software part (Figure 30). The hardware part, or mobile part, includes the electronic board with a WiFi microcontroller unit, the sensors (in this version humidity, temperature, and GPS) and the Lithium battery. The software part is made up by a cloud server infrastructure responsible to take account for data storage, computation, and results presentation. All the hardware and software components are supplied in an open-source way. Everyone with a little programming skill can customize the code to let the system fit its own goals.

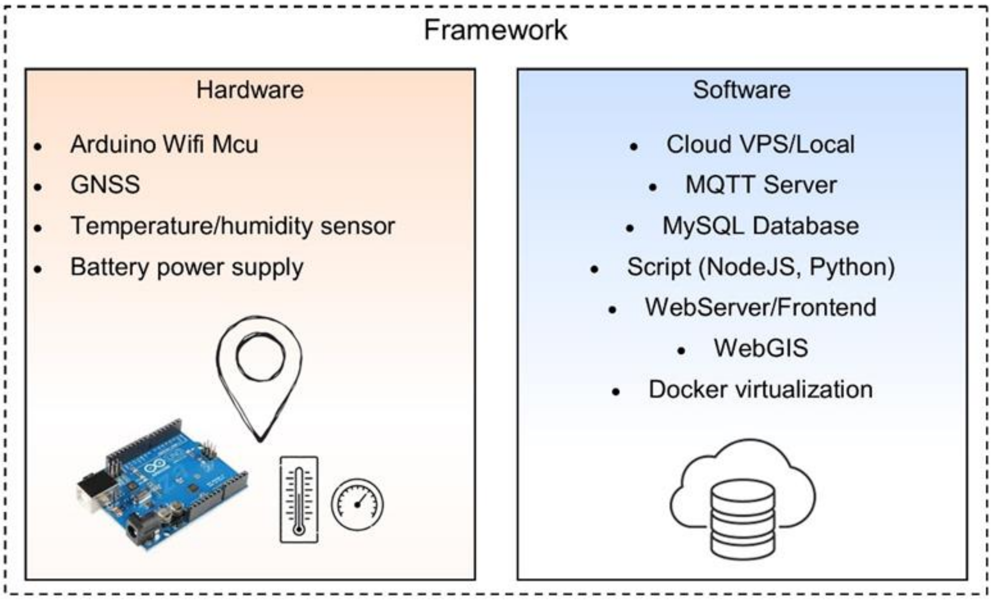

Figure 30. The overall framework composed by the hardware part and the software part.

4.2.1 The mobile module (hardware)

With regards to the mobile part, or hardware part of the project, it is built around a WiFi Arduino commercial board, the Wemos D1 that, in turn, is built on the ESP8266 Mcu (Figure 31). The final board is then equipped with sensors to acquire in real-time environmental data like temperature, humidity, and position coordinates and with a battery for mobile operations (Figure 32). The acquisition hardware equipment is internet connected and the data acquired with a sample rate defined in the project is instantly available, unless network latency times present on the Web-app in "Live data" mode (as will be described in the next paragraph). In detail, a digital DHT22 sensor is used to acquire temperature and humidity data via a I2C bus, while a GY-NEO6MV2 GPS module is used to acquire the georeferenced position. A custom firmware, built with the open-source Arduino IDE and Wiring C language, has been developed to perform a cyclic sensor read operation and to send data on the cloud through the WiFi interface.

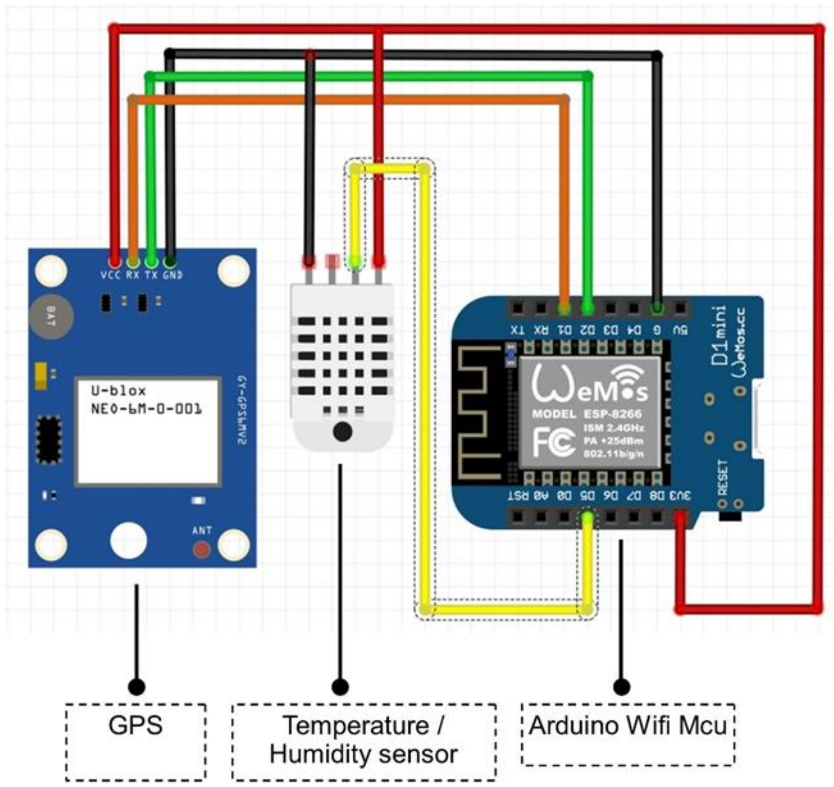

Figure 31. The mobile part, composed by the hardware integration of different modules.

In order to implement the ESP8266 firmware several open-source libraries (for sensor and connectivity interface) have been used from the Arduino open-source community. The firmware follows a quite simple flow. At startup the board in-put/output, digital bus and Wifi peripherals are configured in the so called "setup" procedures. Then, in a cyclic loop, whose interval has been set to 5 seconds (it is fully customizable), new sensor data are read and sent to the cloud through the WiFi interface by using the MQTTs protocol. The use of the MQTTs protocol instead of the standard MQTT one ensures that the communication through the mobile devices and the cloud infrastructure is secured with the cryptography TLS standard to ensure data consistency and avoid data sniffing.

The mobile board has been developed to be portable and replicable so one can build as many different cards as needed to log data from many scenarios. Each card is identified by its own unique MAC address stored, by factory, in the ESP8266 ROM and it is recognized by the system at the first connection to the cloud. The MAC address is also the unique identifier that allows to distinguish a board from the other ones. Other strategic peculiarities of the boards are the building with an open-source and open hardware paradigm. These features allow anyone that has a small confidence with the Arduino environment to expand the board capabilities by adding sensors and functionalities by simply modify the supplied code. To work, the board needs only an internet WiFi connection that can be supplied with an Access Point or by a smartphone with tethering capabilities. The WiFi configuration (SSID and password) are stored on separated header file so, each user, can edit them prior to compile the Arduino code to match its own net configuration.

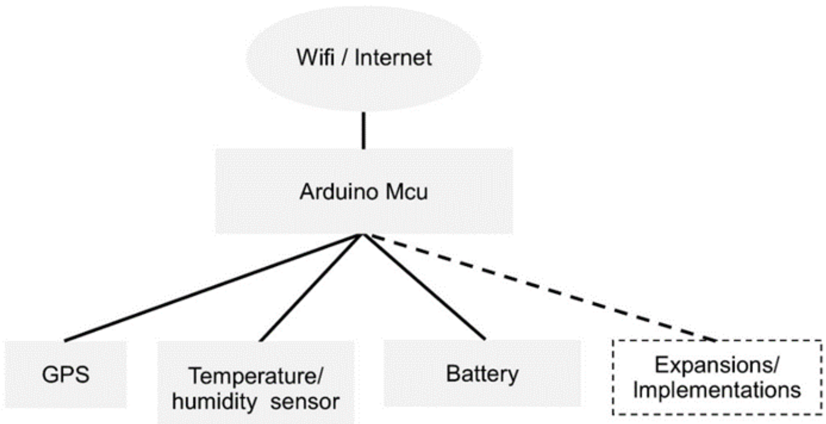

Figure 32. Operation scheme of the hardware connections that compose the mobile part.

4.2.2 The cloud server module (software)

With regards to the cloud server infrastructure, it is made by several software components built on top of a docker virtualized environment to facilitate the distribution and deploy of the code (Figure 33). The aim of this work is to allow the user to build its own infrastructure to work with data logging on a local environment. To get the same infrastructure work on a production environment the user should cover some other implementation aspects that are out of the scope of this work.

As early mentioned, the cloud infrastructure is built on top of a docker environment which is an open platform to develop, deliver and run applications in an isolated environment. In conjunction with the use of Docker, for this application, also the Docker-Compose utility has been used. Docker-Compose is a tool to define and share multi-container applications by defining them on a YAML file.

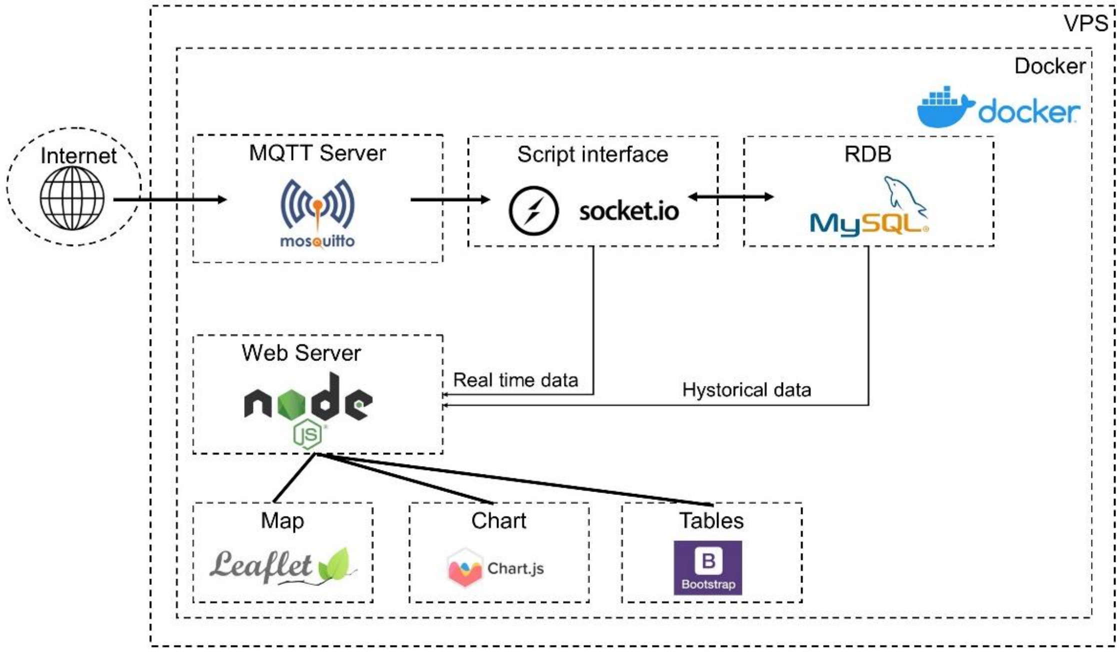

Figure 33. Operation scheme of the software part that represents the cloud server infrastructures with the main components.

The main advantage is that with a single click operation the final user can run the overall framework, composed by several components, instead to install and configure each service (web server, database, api, mqtt server) singularly. A Docker-compose file is supplied with this contribution with the source files to let the user build the overall framework with the smallest possible number of operations.

The framework is composed by these key services:

- MQTT broker/server
- NodeJS MQTT engine
- MySql Database
- Redis Server for queuing
- Express Webserver

As for the MQTT broker the Mosquitto server has been chosen. Mosquitto is a ligthweight open-source message broker that implements the MQTT protocol, and it is suitable for IoT applications. The MQTT server acts as an endpoint to receive the data coming from the Arduino board and offers websocket connectivity to interface with other software modules like the MQTT engine.

The MQTT engine is a custom software module, written in NodeJs, that listen for the incoming data packets from the MQTT server and adds two main services. The first one is the log of the data on the MySql database. Since every received packet is identified by the board MAC address, the MQTT engine firstly check if the device is present on the database devices table (adding it if not present) and then stores the new data on the values table adding the MAC address and timestamp references. The second service added by the MQTT engine is to instantiate a websocket connectivity to send data back to the webserver for real-time visualization.

MySql is an open-source relational database management system (RDBMS) that gives to the framework the capability to store data and device information to perform historical query on past data. In the following paragraph it will be shown that the front-end (the web server application) gives user the possibility to show real-time data and/or to query for historical data.

Redis is a simple open-source in-memory data store, used, in this application, to take account of asynchronous jobs computing. As for the other module no separate installation/configuration is needed. As will be shown in the implementation tutorial (https://iotgis.cyber-research.it/tutorial) the user will be able to deploy all the entire framework by simply launch the docker-compose command.

The Web server, namely the front-end, is the main software component that allow the final user to show real-time and historical data coming from the sensor boards. It has been developed on the top of the NodeJs Express that is an application framework providing a robust set of features for web and mobile applications. The frontend has been developed using Bootstrap components for the responsive graphics part in conjunction with some other open-source components to improve the user-experience. Data are represented on a map and on a chart and the user also has the possibility to download all the sensor data on an excel spreadsheet. About the map, data are represented through a clickable marker. When the user clicks on a marker on the map a popup containing sensor data, MAC address of the board and the timestamp are shown.

The map has been implemented using Leafleat, an open-source JavaScript library to develop interactive geographic map for WebGIS application. As early mentioned, data are also represented on a chart developed using ChartJS that is a free, open-source JavaScript library for data visualization.

The web application allows users to choose a device by the MAC address and then to select three way of data retrieve.

In the next paragraph the functionalities of the developed platform and the possibilities offered by the package to users will be described in detail.

4.3 Results

The web application integrates IoT and WebGIS technologies incapsulated in a Docker structure, as seen before. The first activity that user can do is to select an IoT device, that represents the source of the dataset to analyze.

After the device selection (it can be also a multiple choice) user is prompted to select one of the three different available query options. In detail, three mode options are (Figure 34):

- Live data.
- Historical + live data.
- Historical data.

In “Live data” mode the system starts with an empty map connected with a chart (Figure 35). When new data are available the map and the chart are filled in real-time. With the real-time measures available on “Live data” mode, it will be possible to obtain, with further integration in the future, virtual real-time replicas of physical resources (objects, sites, infrastructures) in the same web platform. This is the base to create, in fact, the so-called “digital twin”, that now represents a research topic of growing interest both in academic and industrial fields (Yuchen et al., 2021; Pylianidis et al., 2021; Ketzler et al., 2020; Ying et al., 2020).

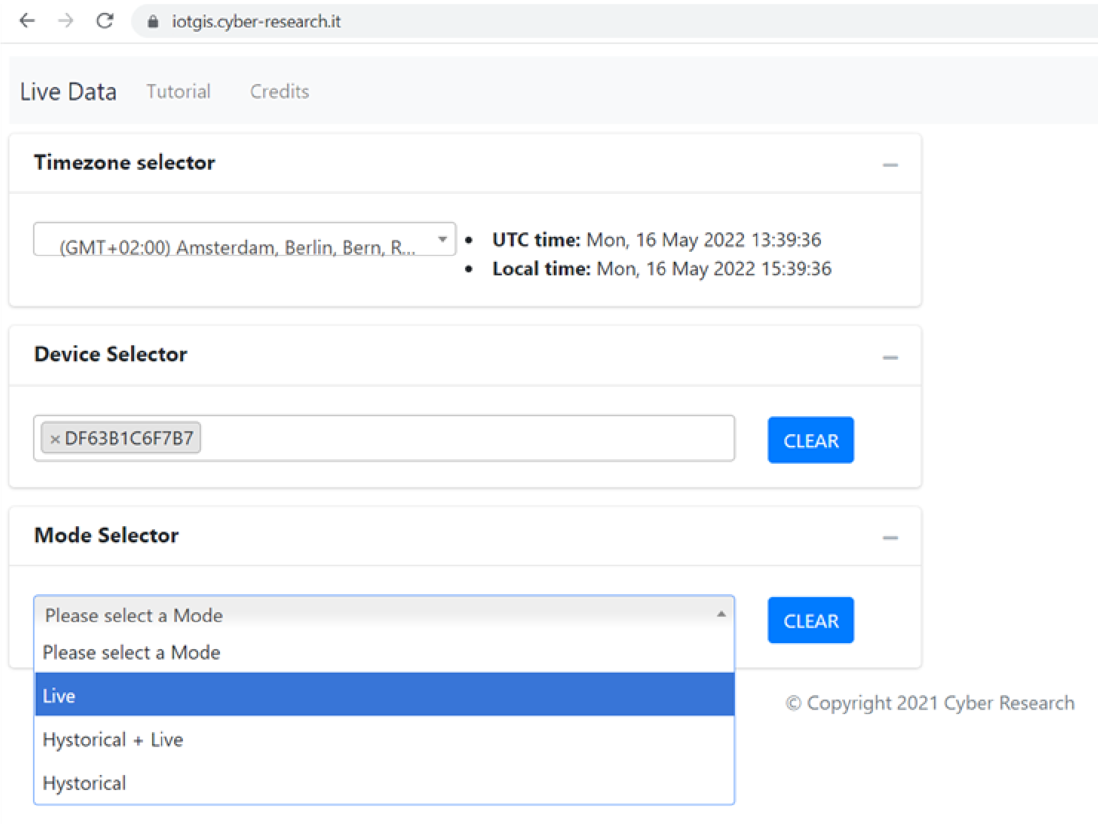

Figure 34. The main window of the web application with the device and mode selection forms.

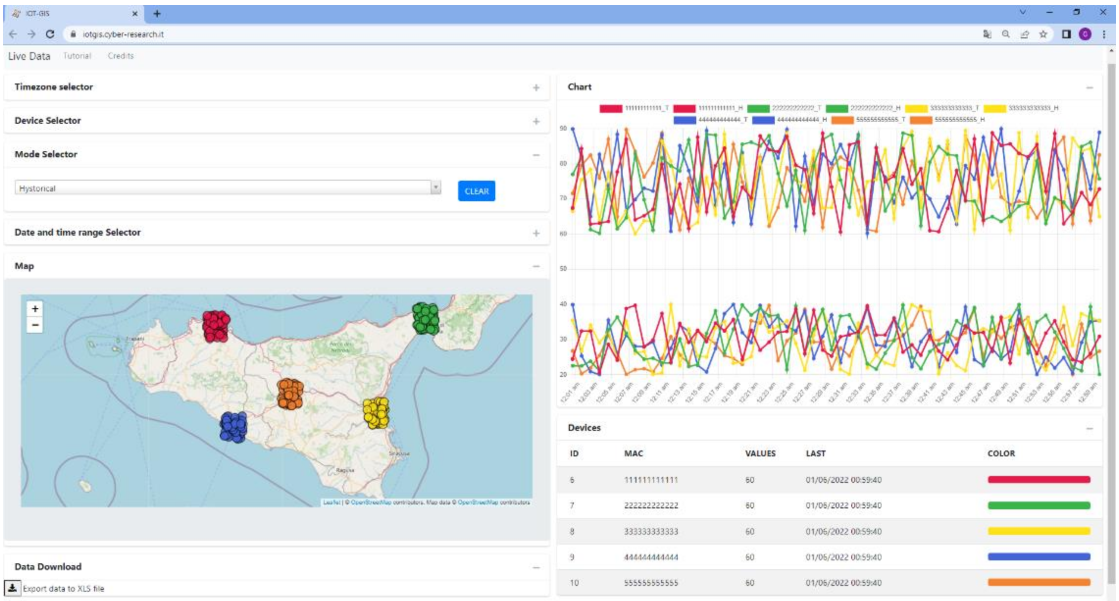

Figure 35. The real-time visualization of the platform, with the integration of a WebGIS map, the chart, and the possibility to download the visualized dataset.

In “Historical + live data” mode the user can select a start date/time for database data retrieving. In this case, if the database contains data from the selected start date, the map and the chart will be pre-filled with the queried data, then, real-time data will be added as they arrive.

The last mode, “Historical data” mode, has no real-time capabilities and allows the user to select a start and stop date/time, namely a range, to retrieve data from and to a specific date/time. No real-time data are added in this mode.

The web application presents also other pages that integrates the platform: the credits page and the tutorial page. In the credits page all the used software, modules, and libraries are listed and linked. In the tutorial page all the operations needed to build the sensor board and deploy the IoT framework are shown.

The platform is created to be employed by users for several integrations allowing two different possibilities of use: participatory and personal. The participatory use integrates the sensor dataset of users in the common online platform shared by the developers, where each user can visualize the datasets of everyone (like a participatory WebGIS). In the personal use, users can download the package provided by developers and then properly configure the personal hardware in a local environment. Then user can activate the docker opensource platform. In this case, it is possible to build-up the system creating a personal local version of the platform.

4.4 Discussion and open scenarios

The developed framework allows to create a smart monitoring system integrated with a WebGIS real-time visualization. The encapsulation of all the modules offers users the possibility to directly run the application, starting automatically, without the necessity of installing or configuring any software. Only the IoT hardware configuration is required. All the modules are opensource. Considering our choice of employing only opensource implementation, we wanted to openly share the platform to offer everyone the possibility of joining the platform. Our aim was to offer users the possibility to give the proper expertise to implement new functions, optimize the existing ones or simply customize the existing configurations for personal purposes, in a freely way, without the necessity of rewriting the entire code. The developed solution avoids the need of programming skills by users, offering a simple starting procedure, avoiding, at the same time, any cost of property software integration. In fact, electronic, telecommunication, informatics, and geomatics capabilities are normally requested to the user for implementing and configuring the entire toolchain (sensors dataset acquisition from different sources, storage of information into a relational database, online real time fruition through maps and charts) necessary to realize the entire IoT-GIS infrastructure. Our proposed solution offer user the opportunity to employ a ready to use framework that answers to these requirements (acquisition, storage, and fruition of the dataset), breaking down the barriers on the basis to reduce the effort in terms of man-hours. The provided link (https://iotgis.cyber-research.it/) offers the possibility to locally test the application. This solution makes the most of IoT and WebGIS integration offering a smart and opensource solution that could be employed by re-searchers, municipal technicians, planners, and software developers. In the future, further implementation could integrate other modules to real time online visualize and share monitoring results. The low-cost solution based on IoT-GIS integration represents an opportunity in the field of smart cities, where IoT integration is a crucial component. In fact, imaging a large diffusion of IoT application scenarios for building of complex datasets and for implementation of big data-based algorithms, it’s clear that, employing low-cost infrastructure and technology, it is possible to obtain a block of monitoring stations even more numerous than the network available using other monitoring solutions (considering the same economic expense). The developed IoT platform represents a base for next steps where 2D and 3D web visualization and analysis could offer a smart solution in the field of digital twin systems. In fact, this solution could be employed in the future on several fields of research integrating further web visualization modules based on WebGL technology and real time operation modules based on Python language. Building energy monitoring, civil structure monitoring, hydrogeological risk analysis, vehicle traffic analysis, are only some of the possible applications where the developed framework could be used and integrated. Following this strategy, integrating information technology, geomatics and computer science, the potential of IoT technology will continue to grow, opening ever new fields of applications.

CONCLUSIONS AND OPEN SCENARIOS

The four cases of study analyzed in this thesis highlighted the several opportunities offered by WebGIS integration in multidisciplinary cases of studies employing opensource technologies. The possibility to remotely integrate external modules (optimization module, 3D environment visualization, multiscale urban visualization, IoT sensors integration) allows to employ geospatial dataset integration in many fields of research, in a world almost dominated by the analysis of geospatial information datasets.

The followed path of research allowed to enhance the knowledge in this scientific sector also acquiring a multidisciplinary vision for every studied solution. In fact, the geomatic solutions were integrated in several fields of research: Energy, Optimization models, Cultural Heritage, City Planning, Information Technology. All the studied solutions are contextualized into the recent main concept of Smart Cities. It represents the set of strategies aimed at the optimization and the innovation of public services, combining, and organizing the infrastructures on the basis of emerging communication technologies.

Considering the solutions described in this thesis, a particular interest was given to the enhancement of accessibility and the fruition of territorial datasets. These strategies open new possibilities in territorial analysis, developing the first steps for the improvement of Digital Twins datasets at urban scale. Furthermore, this kind of solutions allow developers to freely create and manage complex geospatial datasets exploiting only opensource technology. These solutions could be employed in the future on several fields of research integrating further web visualization modules based on WebGL technology and real time operation modules based on Python language. Building energy monitoring, civil structure monitoring, hydrogeological risk analysis, vehicle traffic analysis, are only some of the possible applications where the developed frameworks could be used and integrated. Following this strategy, integrating information technology, geomatics and computer science, the potential of WebGIS solutions will continue to grow, opening ever new fields of applications.

PUBLICATIONS OF THE WORK

- D'Ippolito, F., Garraffa, G., La Guardia, M., Sferlazza, A. A low-cost, real-time and open-source framework for IoT and WebGIS integration. *Geographica Helvetica*, Under review.
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