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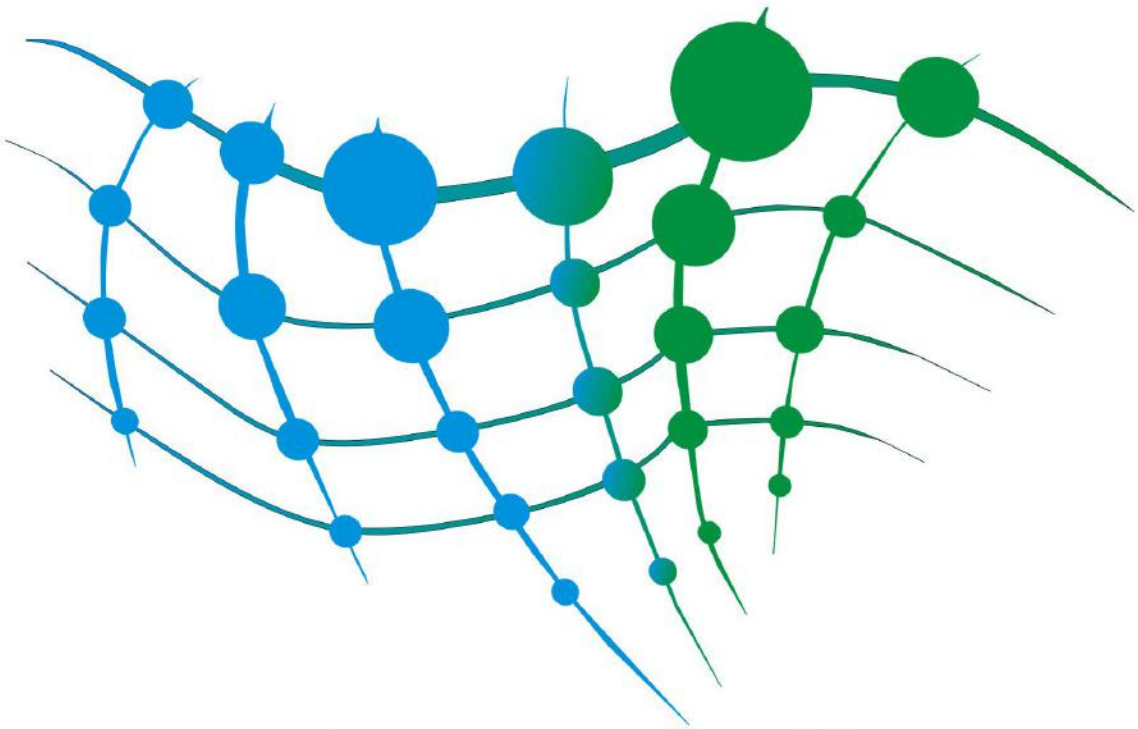

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USE OF UNIVERSAL ADDRESS TO ENSURE HIGH – QUALITY DATA

Abstract: The article describes how to ensure high quality of data previously processed in silos, i.e. separate databases and central registers. The concept of using a universal address was created in Poland in 2017, it was tested in practice and recommended for use in the annex to Resolution No. 28 of the Council of Ministers of February 18, 2021 on the Data Opening Program for the years 2021–2027 (Monitor Polski 2021, item 290). It is based on a specific complex data – created automatically and also automatically used, built from legally authorized codes – the so-called universal address. It is appropriate for solutions used in Poland because it is based on codes created by the Central Statistical Office and data structures of the Central Office of Geodesy and Cartography. It seems, however, that the concept is universal and could also be used in other countries and places where silos – not having a direct connection with each other – contain theoretically the same data provided with specifically defined identifiers. The practical usefulness of the described solution justifies an attempt to popularize it more widely and use it in various forms. The purpose of this article is to present this concept and to discuss it.

Keywords: data quality, open data, territorial codes, geodetic coordinate system, universal address, data integrity

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Introduction with analysis of the state of the problems

Data in legal circulation should be up-to-date and verifiable. Especially when it is data on which human safety depends (Wojsyk, 2019). The purpose of this article is to draw attention to the currently existing technical possibilities of detecting inconsistencies in address data contained in separate silos.

In Poland, as elsewhere, information silos are usually created in separate areas, managed by the minister or the head of the central office on the basis of separate legal provisions specifying in detail the scope, type and format of the collected data and the entities managing these silos. In this article, the possibility of capturing discrepancies between the same (theoretically) data stored in two different registers is shown.

Thanks to the use of linking territorial codes with geodetic data in the structure called "universal address", it is possible to automatically detect inconsistencies in data stored in the dictionaries of the Central Statistical Office (GUS) and in local resources created in communes, and then centralized in the Central Office of Geodesy and Cartography (GUGiK). Data inconsistency indicates an error made by a human (*errare humanum est*) manually entering data into each of these systems. Anyone using open resources (and these include both dictionary data provided by GUS and data provided by GUGiK) can create an appropriate, convenient solution for them, allowing them to determine which of the shared data are correct, consistent and which are uncertain and need checking.

The solution referred to in this article was created in mid-2017 (Wojsyk K., 2018, Adres …) as a response to the need to determine the real addresses of medical entities and pharmacies, in connection with the finalization of the creation of the healthcare information system (SIM), and in particular the system of electronic prescriptions. Prescriptions must contain the address of the medical entity where the prescription was issued – and it cannot be a non-existent (unverifiable) address. A universal address turned out to be a helpful solution.

The universal address is created automatically on the basis of territorial codes contained in the State Border Register (PRG) and dictionary data contained in the TERYT register. If the technical possibility of reaching into the silos and confronting the data contained therein is not created, the universal address will not be properly constructed. The essence of the concept boils down to creating the possibility of automatically generating reports of data inconsistencies, so that a human official can notice these inconsistencies and react appropriately.

The concept described in this article has been tested in Poland in practice: in the "*polska.e-mapa.net*" system, in the "*schematyzm.katolicki.pl*" application and in the so–called "address verifier" (available until December 9, 2022) at https://itia.pl/adres. It can be applied by others.

Material and methods

In 2017, the co-author of this article (K. Wojsyk), while working at the Center for Healthcare Information Systems (currently the e-Health Centre) in Warsaw, noticed the

phenomenon of the deterioration of the quality of data in medical registers (registers of pharmacies, entities performing medical activities, etc.). It was noticeable that the addresses of some of the above–mentioned entities (pharmacies, doctor's offices, clinics, etc.) entered in the register did not comply with the current address data, although the entities themselves did not physically change their location. Starting from January 3, 2021, every Saturday, K. Wojsyk was downloading data from the TERYT and PRG registers and comparing them using his own tools (programs written by himself) and Excel (used only for presentation), in order to detect data discrepancies in both registers. The question arose whether it was possible to create a mechanism to **automatically** update street names in other registers (information silos) based on the source of changes. This article is a result of the abovementioned weekly data analysis and practical experience in working on data quality and with data registers (Wojsyk K., 2021). Again, the problem of data incompatibility and the possibility of using a universal address in the practice of local government was described in the article *Universal Address in Practice* (Wojsyk K., 2022).

Results and discussion

A closer look at the various cases of changes in the addresses of entities' locations revealed that there are two types of address changes. One of them results from the actual change of the entity's location – moving it by the owner to a different geographical location – to a different street, to a different building number (e.g. to a newly created shopping mall). However, these were rare cases. A definitely more frequent case was the change of the name of the street as a result of the Act of 1 April 2016 on the prohibition of propagating communism or other totalitarian system by the names of organizational units, auxiliary units of the commune, buildings, public utility facilities and equipment, and monuments (Journal of Laws of 2018, item 1103, consolidated text). It should be noted that the change of, for example, the name of a street was made without any participation of the owner of the medical entity, however, it forced him to report changes to the relevant register.

I. Register of the official territorial division of the country (TERYT) – first data silo. Changing the name of the street by the Commune Council involved the owner of the entity in activities independent of him and completely unnecessary from the technical point of view. Since everything – the name of the entity, its address and all other data is stored in electronic registers, it is (technically) possible to create a situation where a change in data in one place (the source place) will automatically cause changes in all other dependent places. However, there was a problem of silosity and the inability to transfer these changes. Considering the simplest case – changing the name of a street requires the adoption of an appropriate resolution by the Commune Council and the publication of the resolution in the Provincial Official Journal. There is a problem: entrepreneurs or, for example, natural persons residing on a given street may not find out about the change at all in due time – reading the announced provisions of law is not a typical everyday activity – and if they finally find out, they have to undertake

notification activities (in various time and in various ways) about the change, towards any entities with which they enter into relations requiring providing the address of their business activity.

The contents of the resolutions on changing the names of streets (squares, parks, housing estates, etc.) announced in the Provincial Official Journals constitute the basis for the Central Statistical Office (GUS) to create a facility code if the given name does not yet appear in the register. GUS creates facility codes based on the provisions of a) the Act of June 29, 1995 on public statistics (Journal of Laws of 2020, item 443, as amended) and b) the Regulation of the Council of Ministers of December 15, 1998 on detailed rules for keeping, using and making available the national official register of the country's territorial division and the related obligations of government administration bodies and local government units (Journal of Laws No. 157, item 1031, as amended). Thus, we are dealing with the TERYT register – which contains (appropriately marked with the dates of entry into force and cancellation) the names of objects with their codes. It should be emphasized that the code is assigned to the full name of the street – along with its feature, i.e. the type of facility. This means that the difference of even one character in the full name – and not only in sound, but even in the case of the letter or feature of the object – results in assigning a separate code. It is worth noting that this approach allows to work only with object name codes, instead of just names.

If in any system the name of an object appeared, which did not correspond to the code assigned by the authority appointed for this purpose, it would mean that the given name is incorrect, legally unenforceable.

Table 1 shows examples of names of objects listed on April 15, 2023 in the TERYT register, whose patron is a person named "Chopin", and their codes. Subsequently, from the left, the table contains object codes, feature, part of the name used for alphabetical sorting, the remaining part of the name and the merged name.

The assumption was that the division of names into parts was to enable the alphabetical ordering of the names of objects in various intended for reading directly by a human. Name changes are made almost daily (names are removed, added, changed). Irrespective of the system containing current names, the Central Statistical Office keeps a register of changes, containing the names before the change, the name of the place where the name was changed, the name after the change, the date from which the new name is effective and the appropriate name codes.

Summarizing, there is a legally mandated, public central register containing all current and obsolete object names and unique codes of these names. If there is an error in this register (e.g. a so-called misspelling, transposition, omission or other defect), until it is noticed, it will be able to replicate itself in all places where the given name is retrieved.

Table 1. Examples of various objects with "Chopina" in their name

SYM_UL	CECHA	NAZWA_1	NAZWA_2	NAZWA_PEŁNA
55337	al.	Aleja Chopina		al. Aleja Chopina
44073	ul.	Aleja Fryderyka Chopina		ul. Aleja Fryderyka Chopina
60628	al.	Aleja Fryderyka Chopina		al. Aleja Fryderyka Chopina
02842	park	Chopina		park Chopina
02843	pl.	Chopina		pl. Chopina
02844	ul.	Chopina		ul. Chopina
02846	park	Chopina	Fryderyka	park Fryderyka Chopina
02847	pl.	Chopina	Fryderyka	pl. Fryderyka Chopina
02849	ul.	Chopina	Fryderyka	ul. Fryderyka Chopina
33732	ul.	Chopina	F.	ul. F. Chopina
49650	ul.	Chopina	Fr.	ul. Fr. Chopina
02850	ul.	Chopina Boczna		ul. Chopina Boczna
48894	ul.	Chopina Fryderyka		ul. Chopina Fryderyka
51745	ul.	Osiedle Fryderyka Chopina		ul. Osiedle Fryderyka Chopina
55123	ul.	Park Fryderyka Chopina		ul. Park Fryderyka Chopina
31905	park	Park im. Fryderyka Chopina		park Park im. Fryderyka Chopina
55905	park	park im. Fryderyka Chopina		park park im. Fryderyka Chopina
50575	park	park imienia Fryderyka Chopina		park park imienia Fryderyka Chopina
60832	pl.	Pl. Fryderyka Chopina		pl. Pl. Fryderyka Chopina
40873	pl.	Plac Chopina		pl. Plac Chopina
50857	ul.	Plac Chopina		ul. Plac Chopina
43037	ul.	Plac Fryderyka Chopina		ul. Plac Fryderyka Chopina
48033	pl.	Plac Fryderyka Chopina		pl. Plac Fryderyka Chopina
43918	rondo	Rondo Fryderyka Chopina		rondo Rondo Fryderyka Chopina
44531	skwer	Skwer Fryderyka Chopina		skwer Skwer Fryderyka Chopina

Source: TERYT

II. **State Border Register (PRG) – second data silo.** The PRG register is also an open, public central register, made available by the Head Office of Geodesy and Cartography (GUGiK). Access to data and specific services is possible via the website https://geoportal.gov.pl. The specificity of this register is the fact that it contains so much data allowing to depict on maps (many different – including topographic and orthophotomaps) objects such as buildings, roads, road infrastructure objects, etc., that its use (despite opening the data) can be very difficult for non–geodesists.

The PRG, containing data sent electronically from commune offices, also includes the names of the objects of territorial division of the country and codes of names (this is required by law – the executive acts to the Act of May 17, 1989 Geodetic and Cartographic Law: Regulation of the Minister of Development, Labor and Technology of

July 21, 2021 on the register of towns, streets and addresses and Regulation of the Minister of Development, Labor and Technology of July 27, 2021 on the register of land and buildings), but there is a problem whose solution – although it seems simple – is only in the initial phase.

The essence of the problem lies in the different ways of sending data to central registers, these information silos. In the case of the first silo (TERYT), the name of the facility is created in the commune, published in the Provincial Official Journal, entered into the TERYT register – and also published – this time not in the form of a resolution, but in the form of data in the register – as a name supplemented with a code.

In the case of the second silo (PRG), the name created in the commune, after being entered into the commune geodetic system together with the code assigned by GUS, is sent in a strictly defined structure to the central register (PRG). This is where the "weakness" of the system occurs: an employee of the municipality sending data to the central register may make a mistake, forget to enter new data, mistakenly associate the code with the name, etc. Such an error in the local system is almost undetectable. The only chance is to confront what is in the name register (TERYT) – that is, a data pair = code+name, with the data sent to PRG – that is, to compare theoretically the same values from two silos. Any difference in values will indicate not so much an error as a discrepancy. In order to determine which of the two compared values is incorrect (if they are different), a comparison should be made with the model, which is the entry of the name of the facility in the local law act – the resolution of the Commune Council.

In almost 100% of cases, the entry in the TERYT register is consistent with the wording of the entry in the resolution of the Commune Council. The figure below shows the place (Verifier) where one can compare data from two silos – and report any discrepancies.

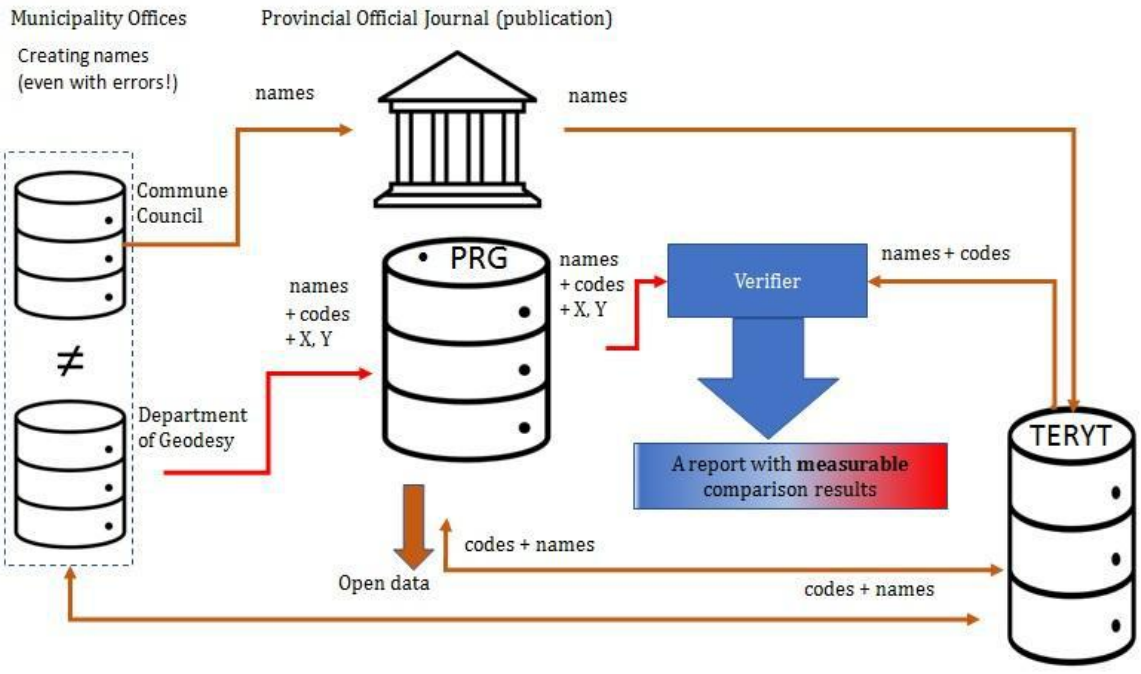

Figure 1. Confrontation of names and codes from two silos
Source: Kajetan Wojsyk, own chart

However, this does not fully solve the problem. There are cases (e.g. the capital city of Warsaw) where there are objects with the same names in the same city, but physically located in different places. Such locations are determined by the geodetic coordinates of the points – x, y in the rectangular system – and the above-mentioned legal provisions describe the method of determining them, e.g. for a building. Therefore, if there is a case of identically sounding addresses specifying different locations, then if they are associated with geodetic coordinates, it will always be possible to clearly determine which location is in question. However, such a solution is appropriate to be used for an IT system – people do not naturally transfer numerical coordinates to each other, they always use names. Therefore, it was necessary to create a solution that would contain something in a format suitable for human use, and something for a machine (IT system) – codes. Finally, as a result of the analyzes carried out, as well as taking into account various special cases, a structure was created that is constructed automatically, based on the TERYT dictionary and the x, y coordinates of the so-called address point (not to be confused with an address), additionally supplemented with a postal code.

According to the definitions given in the above-mentioned Regulation on the register of towns, streets and addresses:

address – an unambiguous description of the facility, carried out by indicating the town, postal code and street or square and the serial number at this street or square, and if there are no names for streets or squares in the town, the serial number in the town;

address point – address together with its spatial location expressed by flat rectangular x, y coordinates.

Therefore, the operation of coding an address point can be carried out by collecting in one specific structure TERYT codes (GUS), X, Y coordinates (GUGiK), the postal code appropriate for a given address point and finally the number of the building to which the description applies. It should be emphasized that since we are talking about a "point", it can mean the location of a lamppost, electrical substation, park bench, sewage well, fountain, bridge, tree, monument – anything that for some reason requires "addressing" for various purposes and visualizing on the map.

However, this structure, called the universal address, must be legible for humans in their human understanding. Therefore, it must be decoded – codes using the TERYT dictionary are "translated" into corresponding names, X, Y coordinates place on the map a specified point locating the object described with a universal address – and thanks to this operation, the location of the object becomes unambiguous.

But how does the encoding – the creation of a universal address – take place? If it is created by a man "by hand", he can do it in at least 2 ways:

1) Using an application based on dictionaries (updated daily) – selecting names from the list, from general to specific: voivodeship, city, street, building number. The choice of the county (*powiat*) is omitted because a person does not always have such a deep knowledge of the structure of the country's territorial division

to be able to distinguish, for example, the Częstochowa township (*powiat grodzki*) from the Częstochowa country district (*powiat ziemski*). However, when there is a situation of more than one town with the same name in a given province (voivodeship, *województwo*), the system will display a list of counties and communes (*gmina*) – and such a detailed list causes a moment of reflection – and then choosing the right town is easy. If there are no streets in a given town – then "none" is selected. After such selection, a list of formally existing, i.e. registered in the commune office, address points is displayed. If the number in question is not on the list, the situation requires clarification at the commune office.

2) By pointing to the map in a system that allows the so-called "reverse geocoding" a specific address point. The system – after clicking – saves the x and y coordinates of a point located on a specific street, in a specific town, in a specific commune (*gmina*), county (*powiat*) and province (*województwo*). This allows the code to be built automatically.

If the universal address is created by an IT system, it is done *en masse* on a national scale by collecting in a way suitable for direct use all universal addresses – in one file, containing also human-readable text data in the same record.

Below is an example of a record containing a postal code, territorial codes and rectangular coordinates of the location of the Monument to European Geodesy (*pomnik Geodezji Europejskiej*) at Theatre Square (*Plac Teatralny*) in Warsaw (see https://jbc.bj.uj.edu.pl/dlibra/doccontent?id=537965):

00077|146501|0918123|0918123|38515|488338|637132|, pomnik Geodezji Europejskiej|

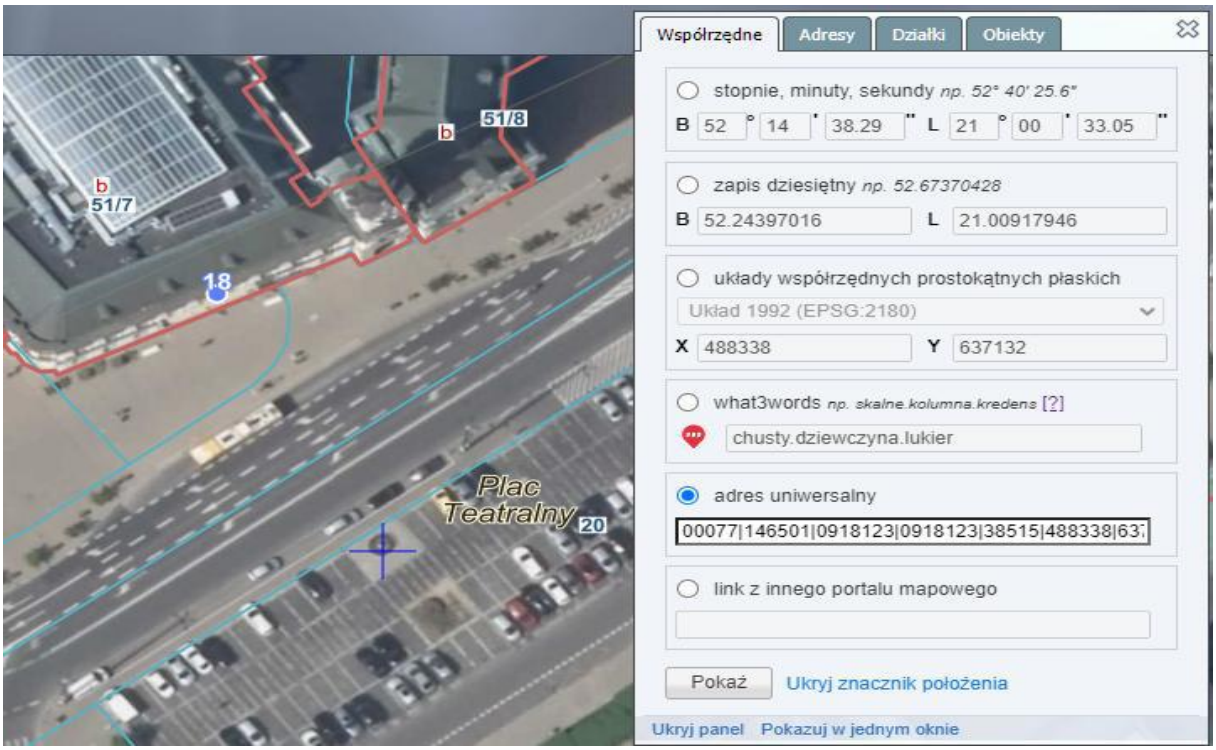

Figure 2. Converting a universal address to a human–readable address
Source: https://polska.e-mapa.net

The description of the structure and meaning of the elements of the universal address is provided on the website https://ezdrowie.gov.pl/portal/home/badania-i-dane/adres-uniwersalny.

More about the mentioned object can be found in Wikipedia at: https://pl.wikipedia.org/wiki/Południk_Warszawski.

The location of the facility can be easily visualized using the address verifier in Poland (https://polska.e-mapa.net).

The existence of an address in Poland in individual cases can be checked by using a dedicated application. It is enough to type in the data defining the address (city, street, number):

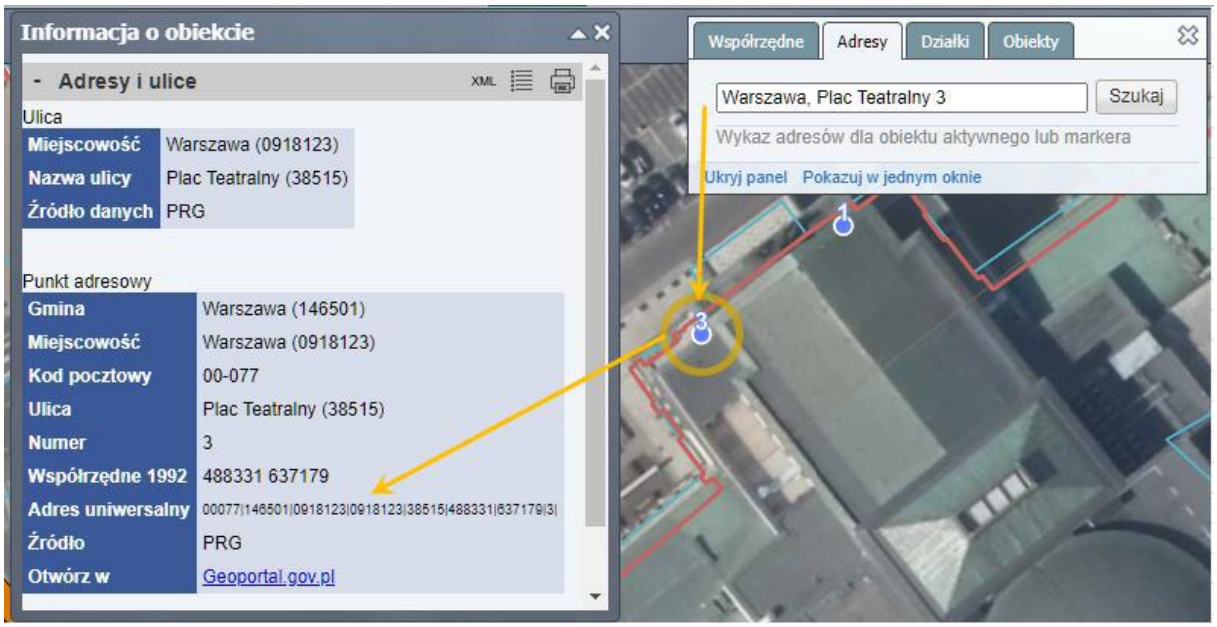

Figure 3. Verification of the existence of an address in the field
Source: https://polska.e-mapa.net

The practical importance of a universal address results from its role as a link between territorial codes and x, y geodetic coordinates, which are a kind of invariant of a place in the field. It should be noted that a change of address consisting in, for example, changing the name of a street will change the territorial codes assigned to specific geodetic coordinates x, y, but will not change the coordinates of this address point, defined in accordance with § 6 of the Regulation of the Minister of Development, Labor and Technology of July 21, 2021 on the register of towns, streets and addresses (Journal of Laws of 2021, item 1368).

The address https://itia.pl/adres ceased to be available after December 9, 2022. The authors are currently making efforts to launch similar functionality on other websites to enable anyone to check the existence of a specific address and determine its correct – lawful – record.

Below is an example of changing the street name from “ul. Dąbrowszczaków" into "ul. Prezydenta Lecha Kaczyńskiego” in Gdańsk. It is visible that apart from changing the

name and the code that is the identifier of this name, as well as the date of change, nothing has changed in this particular case – the ID is a combination of the city identifier and the street identifier – 12 digits define a specific street (alley, square, park, etc.) in a specific town. If there was a change in the territorial division of the country, which has already happened in the past, TerID would also change. If the street became an avenue, the feature would change and this would also change the street name identifier, however the x, y coordinates would not change. Thanks to the dates entered in the register of changes kept by the Central Statistical Office (GUS), it is always possible to determine the name of the object at different times (from December 31, 2006, from which the register is kept).

Table 2. List of some data included in the universal address

Data name	Before change	After change
ID	093301603694	093301642474
TerID	226101	226101
IdentyfikatorMiejscowosciPodstawowej	0933016	0933016
IdentyfikatorMiejscowosci	0933016	0933016
NazwaMiejscowosciPrzed	Gdańsk	Gdańsk
IdentyfikatorNazwyUlicy	03694	42474
Cecha	ul.	ul.
Wsp_x_PUWG_1992	728105	728105
Wsp_y_PUWG_1992	473798	473798
NazwaUlicyWPelnymBrzmieniu	ul. Dąbrowszczaków	ul. Prezydenta Lecha Kaczyńskiego
Stan	2017–12–22	2017–12–31

Source: own elaboration

The use of the character "|" (ASCII code 124) and x, y coordinates without decimal places in the universal address structure requires explanation. "|" character serves to protect against decomposition of the universal address during import/export to csv files, in which a comma, semicolon or tab is usually used as a separator, and rounding of coordinates to units from a practical point of view is sufficient, as it determines the location of a given address point with an accuracy of 1 meter. In addition, a strictly defined place of each territorial code in the universal address allows for easy localization of a given code and building the universal address structure in a format suitable not only for automatic decoding into a human-readable record, but also for a format suitable for automatic control of formal correctness.

In both confronted registers, the number of records changes almost every working day. As a result of removing obsolete street names, adding new names, and changing them from existing ones to new ones, the number of discrepancies also changes. This process is very dynamic. Below, for example, the number of various types of data discrepancies in 2021, 2022 and part of the current year, as at the end of the year and on the last day before submitting this article, is shown.

Tab. 3. Number of selected types of discrepancies

Year	A	B	C	D	Remarks
2021	131	3505	15698	259108	Whole year
2022	227	3395	15119	264504	Whole year
2023	114	3141	13972	266726	until May 20, 2023

Source: own elaboration

In the header of the table above, the individual letters mean:

A – The name of the street appearing in the PRG register is outdated (does not exist in any town).

B – The average of the number of unique identifiers, which are a combination of a city identifier and a street code in PRG that do not correspond to the name of the street entered in this register (code not related to the name of the street). This type of error most often occurs when the employee responsible for entering the street name into the register does not use the TERYT dictionary implemented in the geodetic system, but enters the name incorrectly manually or enters the wrong code.

C – The average of the number of unique records in which there is a literal discrepancy between the wording of the street name entered in the PRG and the wording of the street name in the TERYT register.

D – The number of unique identifiers that are a combination of the city identifier and the street code in PRG.

III. Croatian Register of Spatial Units – a potentially comparative case? In March 2023 an attempt was made to check whether a similar solution (application for verifying the correctness of addresses) exists in the Republic of Croatia, and if not, whether it could be created. The basic conditions for the creation of such an application are the openness of data and their non-requested availability, i.e. making them available in a way that allows for automatic comparison of dictionary data.

The State Geodetic Administration of the Republic of Croatia stated in March 2023 that it was responsible for the Register of Spatial Units in which data about spatial units were registered and maintained. All of registered spatial units have identification numbers and are linked to other spatial units in hierarchy. For example settlement “Murvica” with identification number 042510 is part of a municipality “Bol” with identification number 00272 and settlement “Murvica” with identification number 042528 is part of a municipality “Poličnik” with identification number 03450.

The State Geodetic Administration of the Republic of Croatia stated also that it currently does not provide a universal address structure similar to the one described in this article but it could be possible to build a similar structure because the Register of Spacial Units has all the necessary data:

country_code|county_code|city_or_municipality_code|settlement_code|street_code|E_coordinate_HTRS96/TM|N_coordinate_HTRS96/TM|house_number|

Regarding the payment for data, the State Geodetic Administration of the Republic of Croatia stated that it was planning to issue data free of charge soon, and that it should be contacted again in June 2023, as all necessary data is in the possession of the State Geodetic Administration of the Republic of Croatia, but not everything is yet possible to be fully opened and shared. Therefore, it will be possible to return to this topic only after obtaining information about the opening of resources containing appropriate codes and geodetic coordinates.

Conclusions

As it results from practical experience to date, the idea of using a universal address as a binding element in a strictly defined structure of object codes made available by entities appointed for this purpose can be an effective tool in data quality management, which for automatic processing is essential, and sometimes even crucial, especially when the safety of people depends on the quality of data.

The concept of universal address assumes that dictionary data from the TERYT register, i.e. name codes and names corresponding to these codes, are confronted with data from another register, but containing, among others, the same data, but in a different structure, also as codes with corresponding names recorded in this second register. Any difference in values in the corresponding pairs of both registers must be treated as a discrepancy requiring explanation. Thus, a similar concept – confronting (always in pairs, 1:1) theoretically the same data, but in different silos can be used for different data, not only addresses, but also for names of various products, names of entities, natural persons (when changing the name does not change ID of a natural person – e.g. Polish PESEL), comparing library statuses – however, there must always be some constant element constituting a reference. In the case of a universal address, these are the X, Y geodetic coordinates of a specific address point at a given time, in the case of an entity in Poland – REGON number, in the case of a natural person in Poland – PESEL number. The selection of registers for automatic comparison in order to detect discrepancies depends solely on the existence in these registers of data enabling the compilation of an unambiguous relationship and data constituting their counterparts.

The main reason for the occurrence of data discrepancies is the lack of mechanisms for updating data in time based on the source of creating these data and the lack of a mechanism for generating information about the occurrence of discrepancies. The authors of this article believe that all administrators of databases and registers under their management should analyze the occurrence of data in separate sets – and in the case of their repetition, create conditions for ensuring compliance (the same value of data at the same time in compared, different collections), and when it is not technically possible, provide an automatic non-compliance reporting system.

The previous experience (weekly downloading of data from PRG, TERYT and the register of changes in TERYT) allows us to conclude that any discrepancies in street names or building numbers can be found "manually" without much effort. Due to the proven effectiveness of the used universal address structure, it is postulated to create and introduce into practice automatic data verification on a daily basis through a system that downloads the appropriate central registers at night and collides data corresponding to the same geodetic coordinates. If discrepancies are detected, competent officials should take action to explain the reason for the discrepancy and correct the incorrect data on the next working day.

Since the "universal address" as a method of ensuring data consistency and good quality is possible to be used in Poland, one can try to apply it also in Croatia, which – as shown by the initial interaction with the competent institution – uses similar mechanisms (codes), and in other countries. Authors of this article will contact the State Geodetic Administration of the Republic of Croatia in June 2023 to follow up on the issue of opening the data collected in the Register of Spatial Units.

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CLIMATE CHALLENGES FOR HEALTH AND THE ENVIRONMENT – ON THE NEED FOR CHANGES TO POLISH SPA LAW

Abstract: The text present environmental and health challenges of climate changes. It refers to Polish medical spas and law regulating them. It begins with environmental aspects of climate changes and is followed with its health aspects. The scale of health problems caused by the quality of the environmental elements is increasing. This condition has not been improved by the covid-19 pandemic or the ageing population. All this poses challenges for the health system. The next part of the text places medical spa treatments and characterizes Polish spa law. The last part presents areas of spa law which seek for urgent change. The whole is finished with conclusions and list of resources.

Keywords: climate change, environmental health, environmental law, medical spa treatment, spa law

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Introduction

The first decades of the new millennium indisputably confirmed the changes in the Earth's climate that science had predicted, but which humanity was unable or unwilling to counteract sufficiently. The observed global warming has real social consequences, including economic ones, but also health consequences for entire societies. The scale of health problems caused by the state of the environmental elements is increasing. This condition has not been improved by the covid-19 pandemic or the ageing population. All this poses challenges for the health system.

One form of treatment developed in Europe since the Roman Empire is spa treatment. In the face of climatic and demographic problems, its role in the health care system is not diminishing, and the demand for rehabilitation and natural-healing treatments is still growing steadily. It is therefore worth looking at the Polish law regulating spas and spa treatment. Is it effective? Does it and how does it take into account the climate and other environmental elements, especially noise and air quality, among the conditions for running a spa? What can and how can and what must necessarily be changed in this legislation?

An attempt to answer these questions requires the application of a dogmatic-legal analysis to the currently binding regulations and, in order to gain a fuller understanding, of a historical-legal method to earlier regulations. The research problems outlined in this way determine the layout of the work.

It begins with environmental aspects of climate changes and is followed with its health aspects. The next part places medical spa treatments and characterizes Polish spa law. The last part presents areas of spa law which seek for urgent change. The whole is finished with conclusions and a list of sources. The study is based on national and international literature on environmental law, health law and spa law. Legal status on 31.05.2023.

State of a problem: environmental aspects of climate changes

The issue of climate change has become the single most important issue in international, EU and national environmental law. The impact of climate change on all aspects of life on earth is already widely discussed. Indeed, we are seeing the multidimensional economic effects of climate change.

Legal climate protection has been necessitated by the severe consequences of global climate change: rising temperatures, rising sea and ocean levels, reduction and loss of arable land, changes in the distribution and volume of waste, species migrations and extinctions, increases in atmospheric concentrations of greenhouse gases and increased frequency of extreme weather events (Ciechanowicz-McLean, 2016). These changes are already very pronounced. If climate change were to occur evolutionarily, the legal system would be able to respond to these changes in the typical manner of gradually adapting the law to the changes taking place. Rakoczy (2022) points that climate change is occurring faster than the legal system is able to absorb it through normal mechanisms. A feature of environmental law, not found on such a scale in other areas of law, plays an

important role here. Namely, this law, in the broadest and most comprehensive manner, must refer and react to the reality surrounding humans. For it is the law that must adapt to nature, not the other way around.

Hence, the climate law should be understood as a set of rules of international law, EU law and national law aimed at counteracting anthropogenic climate change and responding to the effects of such change already occurring. A term "Law of climate", often used in Polish legal doctrine (Ciechanowicz-McLean, 2016), where "climate" is a noun, should be understood as rules aimed at something or someone, in this case the climate, to which certain rights are given. It should therefore be understood as rules concerning the climate and the various activities related to or conducted in relation to it, including its protection. As Bojar-Fijałkowski (2022a) notes that climate law, on the other hand, should be understood as all pro-climate regulations addressed to the various actors whose activities affect the climate, who interact with it in various ways. Understood in this way, climate law is the rules for various activities aimed at benefiting the climate, taking into account the climate as a value in economic activities or the everyday activities of an individual, this is "climate impact law". It would include regulations for energy, transport, construction, industry or trade. In my view, 'climate law' is the narrowest concept, containing norms aimed at protecting the state of the climate as defined at some specific point in time. Law of climate, being a part of climate law, must define the scope of actions allowed and not allowed against the climate. Understood in this way, the law of climate is contained in climate law, which is the broadest concept (Bojar-Fijałkowski, 2022b).

Legislators are taking action to adapt to climate change, that is, to anticipate the negative consequences of climate change and take appropriate action to prevent or at least minimise the damage caused by it. These measures are being taken at all levels of government, from international to regional to national, and within them from the central to the lowest level – in Poland the municipal level. Today, this is a dynamic sector of the innovative economy and the direction of socio-economic change, as the expected environmental effects are strongly correlated with the economic effects.

State of a problem: health aspects of climate changes

Public health, identified with the actions taken by public authorities to maintain and improve it, is the health of the community as opposed to the health of the individual. Indeed, it is a feature of public health to see health problems from a population perspective. Public health is also defined in terms of activities and is then defined as action aimed at solving the health problems of the population.

Firstly, public health problems are not of an individual nature, but occur in a certain number in a certain area and have an epidemiological dimension. Secondly, such phenomena are regarded as undesirable, requiring action to remove or at least reduce them through organised action. The organisation of such actions is the task of the state. Thirdly, health problems of the population will be the result of factors of various nature, including economic, social, demographic, cultural, ethical but mainly environmental.

Fourthly, these phenomena can also be assessed in terms of their importance when juxtaposed with other tasks of the state, the speed of its response, the comprehensiveness of its actions or omissions. This allows particularly clear comparisons between public health and other spheres of state activity, including environment's protection and management.

The evolution of public health to the new public health has been from strictly sanitary measures and the control of infectious diseases to also include social, cultural and economic issues and their relationship to health. Hence, the new public health model focuses not only on issues limited to environmental hygiene, municipal hygiene or food and nutrition safety, but also on the consideration of all other determinants of health, in their interrelationships. The theory of the new public health is concerned with the health-promoting development of the environment surrounding humans in the context of sustainability in the broadest sense. The idea is that sustainable development should also have a health-promoting element (Haines et al., 2012). Indeed, social and material inequalities create inequalities in access and health. The new public health is a synthesis of classical public health with contemporary achievements of other sciences such as clinical medicine, psychology and sociology, epidemiology and demography, economics, management and law. Hence, the new public health can be seen as an all encompassing discipline. In this context, the issue of the state of the environment comes to the fore.

Environmental health, on the other hand, includes those aspects of human health, including quality of life, that are determined by biological, chemical, physical, psychological and social environmental factors. It also encompasses the theoretical assumptions and practice for assessing, eliminating and preventing the presence in the environment of those factors that may adversely affect the health of present and future generations. Accordingly, the concept of environmental factors is understood broadly. Elements of the definition of health, defined as full physical, mental and social well-being and not merely the absence of disease or infirmity, can be found in this formulation, as well as elements of the definition of sustainable development. Today, most threats to the health of individuals come from inadequate levels of quality of environmental elements, and climate change brings additional threats in this regard.

State of a problem: medical spa treatments

Medical spa treatment, which has operated in Europe for centuries and was highly developed in the former communist bloc countries, is a continuation of in-patient or out-patient treatment to help the patient recover from an illness or accident. Until the 1990s in Poland, it only operated with public funding and on a large scale. Currently, it is available, with some limitations but still widely, as part of the publicly funded healthcare system. In parallel, the same facilities often offer commercial services.

Medical spa treatment makes use of the curative properties of natural healing resources, climate and microclimate. The treatment is also very often accompanied by physiotherapy treatments. A patient who undergoes spa treatment if referred by

a doctor under the public insurance scheme may make use free of charge of diagnostic tests, medicines and medical devices that are necessary for this treatment.

Medical spa treatment is provided in spas by spa treatment facilities and outside the spa in hospitals and sanatoriums in underground mine workings. In spas, spa treatment is carried out in spa treatment facilities. Medical spa treatment facilities are health care institutions operating in the area of the spas, in which medical entities carry out therapeutic activities in the type of outpatient or inpatient and round-the-clock health care services. Patients can be treated or rehabilitated there. The establishments make use of the unique natural conditions of the spa in which they operate.

The types of medical spa treatment facilities are: spa hospitals; spa sanatoriums; children's spa hospitals and children's spa sanatoriums; outpatient spa clinics; natural health treatment facilities; hospitals in developed underground mine workings sanatoriums in developed underground mine workings.

Such treatment is carried out with the use of medical spa treatment facilities located in the spa area, such as: spa pump rooms; graduation towers; parks; exercise paths; arranged sections of the seashore; therapeutic and rehabilitation spa pools; arranged underground mine workings. In addition to technical equipment that can be delivered to any location, spa treatment relies on the special properties of the environmental elements: water, mineral resources and climate. Hence, it is indisputable that the state of the environment, including the climate, is fundamental to the possibility of spa treatment.

According to the Polish Central Statistical Office, at the end of 2021, there were 258 medical spa treatment facilities in Poland, which welcomed 600,000 patients during the year. There are 47 municipalities with spa status in the country.

The demand for this type of medical services is growing due to an ageing population, the still felt effects of the recent covid-19 pandemic and the negative health effects of climate change and the quality of other elements of the environment (Paszkowska, 2017). The deteriorating state of the environment correlates directly and positively with the demand for medical care. This is particularly evident in the area of air quality and long-term diseases caused by poor air quality in Poland.

Materials and methods: Polish spa law

Spa law sensu largo encompasses various legal norms influencing and shaping the operation of spas, spa facilities, procedures and processes for the provision of spa services, or patients' access to these services. The spa law defined in this way also includes, in addition to those already indicated, parts common to environmental law, including nature and climate protection, tax regulations as the spa commune has the right to charge an additional fee from tourists, public economic law, and in an important part regulations on access to medical services (Bojar-Fijałkowski, 2011).

Under the term “spa law”, strictly speaking, we should understand a set of norms of administrative law regulating the principles and directions of health resort treatment, supervision over this treatment, principles of granting and withdrawing from the areas, including municipalities, the status of a health resort or an area of health resort

protection together with the rights and obligations resulting from it. In the Polish legal system, the spa law is regulated by the Act of 28 July 2005 “on medical spa treatment, spa resorts and spa resort protection areas and spa communities” . This regulation replaced the Act of 1966, which designed a system of health resort treatment in a manner clearly different from current socio-economic doctrine. In contrast, the first Polish regulation of spas was the 1922 Act.

As assessed by Paczuski (2015), the 2005 Act is of high economic, social and environmental management significance, adequate to the goals and tasks of the idea of sustainable development, while respecting the constitutional principle of a balanced system, established in Article 5 of the Constitution of the Republic of Poland. Without questioning this view, it should and is worth considering to what extent its provisions are still relevant? To what extent, after almost two decades, are the procedures it provides for effective? Do the dynamic socio-economic changes which characterised Poland's development in the first two decades of the 21st century not require to be taken into account in the spa law? Certainly climate change needs to be taken into account in spa law.

Results and discussions – what to change in Polish medical spa law

The effectiveness of the spa law has also long been questioned by state control bodies. The Supreme Chamber of Control's 2016 report “Meeting the requirements set for medical spa” directly indicates that “Receiving and maintaining the status of a medical spa does not guarantee that spa resort have met and continue to meet environmental requirements and conditions regarding the therapeutic properties of the climate or the use of natural resources. None of the inspected localities met the requirements set for spas. Acceptable noise standards were exceeded in 10 of the 11 localities inspected, and a full range of climate surveys were not carried out in one. Air quality assessments did not reflect the actual level of air pollution. Despite the statutory obligation, the spa municipalities did not monitor the state of the environment in the resorts. In the opinion of the Supreme Chamber of Control, the lack of adequate care of the communes for the state of the environment may lead to the loss of the status of a health resort and, as a consequence, to the restriction of patients' access to health resort treatment".

The Minister of Health's supervision of spa treatment was ineffective. The Minister unreliably verified the fulfilment of the requirements set for spas, and did not monitor the preservation of therapeutic and environmental conditions in the area. He also failed to monitor the implementation of the recommendations contained in the spa decisions regarding the fulfilment of the required environmental standards and the use of natural resources in spa treatment.

At the stage of applying for or maintaining the status of a health resort, 10 of the 11 surveyed localities did not meet the requirements in relation to the environment, due to exceeding the permissible noise standards. On the other hand, in one locality, no noise as well as electromagnetic fields tests were carried out at all. For 10 localities, the

authorised bodies found that the permissible noise levels were exceeded and included recommendations for monitoring.

In the climate studies of five localities, the authorised entities formulated comments on the sanitary condition of the air, due to exceedences of 24-hour concentrations of PM10. In addition, for 10 localities, the authorised entities included recommendations for monitoring the sanitary condition of the air.

No action was taken to confirm that the spas complied with the requirements of the environmental legislation. The Minister of Health did not monitor the preservation of the therapeutic and environmental conditions for granting and maintaining the status of a health resort, although he has such a statutory obligation. Moreover, he did not monitor the implementation of the recommendations contained in the spa decisions to take measures to meet the required environmental standards, nor did he monitor the use of natural resources in spa treatment. On the other hand, the spa municipalities did not take measures to verify the fulfilment of the requirements in terms of, inter alia, permissible standards of air pollution, noise intensity and emission of electromagnetic fields.

The Minister of Health did not exercise effective supervision over spa treatment, including unreliably verifying that spa resorts complied with the requirements set out for spas and confirming the possibility to carry out spa treatment in all spa resorts at that time, even though they did not comply with the requirement set out for spas in terms of permissible noise levels. The Minister also failed to monitor the use of mud and therapeutic waters in spa treatment and did not use his authority to request the relevant services and inspections to inspect compliance with environmental regulations.

The report points to cardinal negligence in the control of spas, such as the erroneous designation of protection zones or the lack of their designation by municipalities in general. Important from the point of view of the quality of the spa law is also its enforcement. With the demonstrated inaction of the authorised state authorities, the failure to use even the existing, albeit ineffective, instruments, the question of respect for the law in force arises. In this case, negligence in the application of the law may result in the health of the citizens benefiting from spa treatment.

The Watchdog civic network, an active NGO, asked spa municipalities in a survey how they cared for air quality two years after the Supreme Chamber of Control report. One municipality did not fulfil its obligation to respond. The 35 municipalities that responded to the survey had not carried out any air quality monitoring in the past three years. Nine authorities, out of 42, only mentioned in their response the air monitoring station of the Regional Inspectorate for Environmental Protection located in the municipality.

The most common reason for commissioning studies is the need for the municipality to submit a spa operation. Such comprehensive studies to scientific institutions have been commissioned by 10 municipalities in the last three years. Only four municipalities mentioned air quality inspections involving checking boiler houses or businesses that emit harmful substances. The lack of enforcement of this obligation is a serious omission by the government.

In terms of external inspections, half of the spa municipalities had none in the last three years. A further eight indicated inspections by the Regional Environmental Inspectorate. 10 municipalities reported that such inspections had been carried out in their area. In response to questions about the results of air quality improvement studies, 26 municipalities did not provide any data. 16 of them do not have any stations, do not carry out measurements and do not use stations belonging to other entities.

Watchdog's monitoring shows that revenues from the spa fee range from a fraction of a percent of the total municipal budget to around 4 per cent. Some municipalities collect quite substantial amounts from the spa fee, for example Świnoujście – over PLN 8 million, Krynica Zdrój – PLN 4 million, Sopot – almost PLN 3 million. The money from this, however, goes to various purposes. Only one municipality, Goczałkowice-Zdrój, declared that it financed the 2018 emission reduction programme from the spa fee. As the authors of the survey conclude, many municipalities will have to face smog if they want to keep their spa status. For the time being, the first steps have been taken to diagnose the problem of polluted air in spas at all. Many spa municipalities have air quality measurement stations installed by provincial environmental inspectorates.

Despite the passage of several years, the actual state of affairs has not improved. According to Golba (2018), the spa resort regulations contain a multitude of imprecise, even conflicting legal norms, which lead to serious problems in their application, particularly as regards: the required conditions for obtaining the status of a health resort; numerous planning and spatial development issues. Including the cumulatively formulated, albeit without standardisation, conditions for obtaining spa status. The legislator has prescribed their cumulative fulfilment, moreover obligatorily, without derogations.

Particularly indefinite and difficult to interpret are precisely the requirements for “climate with therapeutic properties”, “requirements in relation to the environment” set out in the implementing provisions of the Regulation of the Minister of Health on the scope of tests necessary to determine the therapeutic properties of natural medicinal raw materials and the therapeutic properties of the climate, the criteria for their assessment and the model certificate confirming these properties. This regulation indicates in Annex 3 the elements to be assessed when verifying the medicinal properties of the climate. These are: air temperature; sunshine; cloud cover; relative humidity; atmospheric pressure and water vapour pressure; winds – strength and direction; precipitation; atmospheric phenomena: fog, thunderstorms, foehn and halal winds, snow cover, gloom. Some of these are unpredictable and almost independent of human activity, not including the impact of humanity on global warming, such as sunshine, precipitation, fog, temperature fluctuations, air humidity, wind strength. However, there are also those indicated, on the basis of the "Environmental Protection Law" of 2001, limits on harmful substances in the air, permissible noise levels, electromagnetic field levels, which are mostly the result of human activity and are subject to control. What is worth emphasising is that the levels of substances in the air set out in the 2012 Regulation are technical standards applicable to every locality in the country, but failure to meet them does not have any legal or factual consequences.

The 2005 law talks about localities in this respect, when the "Environmental Protection Law" and regulations talk about air quality in the area. Thus, it is possible to have a situation when there are documents in circulation confirming good air quality in a spa locality and, at the same time, another confirming bad air quality in the zone to which the locality belongs. Gobla (2018) calls for the creation of separate measurement zones for spa communities, or even spa areas or other areas of natural and tourist value.

The requirement to comply with environmental requirements is undefined. It is probably a matter of complying with general environmental law standards, but these apply to everyone, not just spas. They should be stated precisely and with an indication of the technical level limits, e.g. for noise, which, if exceeded in the limited time periods indicated, would result in the loss of the spa status.

Conclusions

The above study allows to the following conclusions and "de lege ferenda" postulates:

1. Law of climate must define the scope of actions allowed and not allowed against the climate. Understood in this way, the law of climate is contained in climate law, which is the broadest concept. Climate law is the rules for various activities aimed at benefiting the climate, taking into account the climate as a value in economic activities or the everyday activities of an individual, this is "climate impact law". In such a view, the phrase 'climate protection law' for the entirety of climate-related regulations, which is standard in Polish law doctrine, is inappropriate.
2. Environmental health, a concept of public health, includes those aspects of human health, including quality of life, that are determined by biological, chemical, physical, psychological and social environmental factors. Currently, most threats to the health of individuals and societies come from inadequate levels of quality of environmental elements, and climate change brings additional threats in this regard.
3. Medical spa treatment makes use of the curative properties of natural healing resources, climate and microclimate. In addition to technical equipment that can be delivered to any location, spa treatment relies on the special properties of the environmental elements: water, mineral resources and climate. Hence, it is indisputable that the state of the environment, including the climate, is fundamental to the possibility of spa treatment. The need for spa treatment is increasing in an ageing population. It is also increasing when the poor state of the environment worsens the health of the population.
4. Spa law sensu largo encompasses various legal norms influencing and shaping the operation of spas, spa facilities, procedures and processes for the provision of spa services, or patients' access to these services. Under the term “spa law”, strictly speaking, we should understand a set of norms of administrative law regulating the principles and directions of health resort treatment, supervision over this treatment, principles of granting and withdrawing from the areas, including

municipalities, the status of a spa resort or an area of spa resort protection together with the rights and obligations resulting from it.

5. The effectiveness of the spa law has also long been questioned by state control bodies. Acceptable noise standards are often exceeded and a full range of climate surveys are not carried out. Air quality assessments do not reflect the actual level of air pollution. Despite the statutory obligation, the spa municipalities do not monitor the state of the environment in the resorts. The Minister of Health's supervision of Polsih spas treatment is ineffective. The control also fails to monitor the use of mud and therapeutic waters in spa treatment and does not use its authority to request the relevant services and inspections to inspect compliance with environmental regulations.
6. This can also have financial implications. Spa municipalities can and do charge additional fees to tourists staying there. These are directly linked to the therapeutic conditions of the resort. With the unmonitored state of the environment, with frequent exceedances of the permissible noise and air quality limits, the municipalities run the risk of being held legally liable and having to pay back the fees collected as improper. A tourist or a patient paying a fee expects access to an environment of proper quality and the therapeutic properties of its elements. Obviously, if he or she does not get what he or she was offered, can demand a return of the payment. The most popular Polish health resorts collect millions, sometimes undue, on this account.
7. More control of the state of the environment in spa resorts by the government administration is needed. At the same time, the current structure of the Polish administration responsible for the environment, fragmented, with the division of competences into numerous institutions, contradicting the principle of comprehensiveness, definitely requires changes and reform. Effective control is not possible with the current structure of the government administration responsible for the environment. This is the primary problem, the ineffective implementation of this control is a secondary issue.

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DEFINED CYBERSECURITY THREATS IN UNDEFINED CYBERSPACE

Abstract: In the literature on the subject and international legal acts, there is no universal and common definition of cyberspace. Due to the above lack, countries are moving towards regional cooperation in cybersecurity. This descriptive-analytical research was conducted to illustrate cybersecurity threats (faced by countries and private individuals), the list of which, as a result of digital transformation, is constantly growing. The analysis results presented that a wide range of potential cyber-attacks may affect objects of a tangible and intangible character. This research suggests that in cyberspace, which is essentially intangible, non-physical targets (values) can also be an object of a cyber-attack.

Keywords: cyberspace, cybersecurity threats, cyber-attack, critical infrastructure

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Introduction with analysis of the state of the problems

It seems that nowadays, the prevailing view is that international law does not prohibit the state from regulating its "segment" of cyberinfrastructure, although this right should be implemented taking into account the principles of international law (Ivanova et al., 2022). Cyberspace is expanding in many directions without a clear teleology. This does not prevent us from theorising about the nature of cyberspace, but we should refrain from overly ambitious or deterministic claims (Lambach, 2019). At the same time, it still seems valid that cyberspace is not an apolitical sphere of non-state actors. On the contrary, it is a domain in which countries seek to exercise their sovereignty. As a result, managing cyberspace resembles a power politics game (Liaropoulos, 2017).

However, in the absence of an international, universal consensus regarding the legal status of cyberspace, countries are moving towards regional cooperation, primarily regarding the so-called cybersecurity, which is currently the main regulatory area of cyberspace (Wielec et al., 2023).

The purpose of this paper is to present key issues related to the issue of cybersecurity and the main threats to this security. The following questions were discussed (structure of the paper): 1) cybersecurity strategies of selected countries and their goals; 2) operational activities in cyberspace and cyber-attack; 3) cybersecurity threats; 4) the issue of critical infrastructure; 5) conclusions.

Material and Methods

This research was conducted in 2023. The research was based on legal acts of states and international organisations as well as on scientific and popular science literature. The research method used in the paper was a descriptive analysis (Portman, 1986) and interpretation of recent trends in the area of cybersecurity threats and operational activities in cyberspace. Based on the conducted research, it was possible to identify potential objects of a cyber-attack that may also be of an intangible character, i.e., values that create our "common good".

Cybersecurity

The concept of cyberspace is inextricably linked to the concept of cybersecurity, which at the most basic level can be understood as: 1) confidentiality - ensuring that unauthorised persons will not obtain information; 2) integrity - ensuring that information will not change its form in an unauthorised manner, for example, there will be no unwanted modifications; 3) availability – ensuring that the ability to use systems, data, information and resources will not be lost (Olejnik et al., 2022).

The definition mentioned above corresponds to the definition developed by the International Telecommunication Union, which reads as follows: "Cybersecurity is the collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment and organisation and a user's assets.

Organisation and a user's assets include connected computing devices, personnel, infrastructure, applications, services, telecommunications systems, and the totality of transmitted and/or stored information in the cyber environment. Cybersecurity strives to ensure the attainment and maintenance of the security properties of the organisation and user's assets against relevant security risks in the cyber environment. The general security objectives comprise the following: Availability, Integrity, which may include authenticity and non-repudiation, and Confidentiality" (International Telecommunication Union, 2023).

Countries refer to international cooperation in the field of cybersecurity (or more generally in the field of activities in cyberspace) in their National Cybersecurity Strategies (NCSS). Some countries only mention "international cooperation" in general terms. Some countries are a bit more precise and refer to "regional" or "multilateral" cooperation or cooperation within a "specific international organisation" or "bloc of states". Some countries refer to cooperation with "strategic partners" or "like-minded countries" (Serrano Iova et al., 2023). The most mentioned "country bloc" was the European Union-EU, with appearances in twenty-six individual NCSS, and the most mentioned organisations were the North Atlantic Treaty Organization-NATO, the United Nations-UN and the Organization for Security and Co-operation in Europe-OSCE, with eighteen, sixteen and thirteen mentions respectively (out of 194 countries analysed) (Serrano Iova et al., 2023).

The EU adopted (being still in force) Directive (EU) 2016/1148 of the European Parliament and the Council on 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union. This directive, among other things, made it mandatory for all EU Member States to adopt a national strategy on the security of network and information systems defining the strategic objectives and concrete policy actions to be implemented, set up a cooperation group to support and facilitate strategic cooperation and information exchange between EU Member States and to develop trust and confidence among them; established a network of computer security incident response teams (the so-called CSIRT's Network); established obligations for Member States to designate national competent authorities, points of single contact and CSIRT with tasks related to the security of network and information systems.

The Cybersecurity Strategy of the Republic of Poland for 2019–2024 distinguishes the main objective, which is to increase the level of resistance to cyber threats and increase the level of information protection in the public, military and private sectors, and to promote knowledge and good practices enabling citizens to protect their information better, as well as specific objectives, such as 1) development of the national cybersecurity system; 2) increasing the level of resilience of the administration's information systems; 3) increasing the national security potential; 4) building awareness and social competence in the field of cybersecurity; 5) building a strong international position of the Republic of Poland in the area of cybersecurity (Resolution no. 2 of the Council of Ministers of the Republic of Poland, 2019).

Odebade and Benkhelifa compared the NCSS contained in publicly available documents of ten countries in Europe (UK, France, Lithuania, Estonia, Spain and Norway), Asia-Pacific (Singapore and Australia) and the US region (United States of America and Canada) and came to the conclusion that common goals of the NCSS regarding network and information systems security strategy can be considered building a cybersecurity culture through education, fostering international cooperation, promoting research and development, promoting cyber awareness and creating an environment of trust in cyberspace where citizens, businesses and government can operate (Odebade et al., 2023).

At the same time, these authors indicated some unique goals in relation to the NCSS of the discussed countries. It is worth paying attention to the objectives contained in the Norwegian cybersecurity strategy, which mentions, among other things, that Norwegian companies will digitalise in a secure and trustworthy manner and be able to protect themselves against cyber incidents (Odebade et al., 2023). This is interesting because the document sets a goal for Norwegian companies, i.e., private entities, to be able to protect themselves against cyber incidents. In a government document, this type of task should be assessed positively. Ensuring cyber security for private entities or people cannot rest solely on the state and its authorities. Another interesting issue in this context is when an action in cyberspace aimed at a private company will cause the state and its authorities to react. Should a boundary be drawn, defining when a private company defends itself against cyber incidents and when the state and its authorities intervene? It seems that the answer to such a question should be negative, i.e., there should be no boundary defining when an attack on a private company will be covered by the state's and its authorities' intervention. The defined border, describing the circumstances in which the state and its authorities intervene, could be skilfully used by those launching attacks. Moreover, it could discourage private companies from taking action in the field of their own cybersecurity. Private companies exercise substantial autonomy over "their" territories (Lambach, 2019).

In the context of private companies, it is also worth mentioning that the cyber domain is based primarily on infrastructures created by global private companies (e.g., Microsoft, Cisco, Oracle), which are located in each country and are interconnected.

Also interesting is the goal included in the NCSS of the United States, which is to protect the American people, the homeland and the "American way of life" (Odebade et al., 2023). The latter should be understood as the values that stand behind a civilised nation, in which, among other things, civil rights and freedoms are respected. Undoubtedly, the purpose of protection formulated in this way sheds new light on concepts such as, for example, the concept of "common good". It also indicates that not only tangible goods are subject to protection, but also intangible ones, i.e., values.

Operational activities in cyberspace and the basic features of a cyber-attack

Four operational activities can be distinguished in cyberspace (Chmielewski, 2022):

1. Communications and Information Systems Infrastructure Operations-CISIO;

2. Cyberspace Intelligence, Surveillance and Reconnaissance Operations-CISRO; 3. Defensive Cyber Operations-DCO; 4. Offensive Cyber Operations-OCO.

Some argue that cyber capabilities are "one-time use": when a cyber operation exploits a certain vulnerability, it becomes known to the public and thus loses its usefulness. Knowing this, other potentially attacked can effectively defend themselves against a similar attack by installing appropriate software patches. Some argue that this is not the case and that it takes a long time for the appropriate patches to be installed and the vulnerabilities to be fixed (Smeets, 2022).

A cyber kill chain is the structure of a cyber-attack seen from the attacker's perspective. We can distinguish the following stages: 1) diagnosis; 2) armament; 3) delivery; 4) exploitation; 5) installation; 6) command; 7) implementation of goals (Olejnik et al., 2022). In other words, it is about finding a way in, finding a way back to your command and control server, and achieving exfiltration and cloaking capabilities (Perlroth, 2022).

A cyber-attack can be carried out by the so-called hacktivists, i.e., an informal group associated with some goal (social, political or any other) (Olejnik et al., 2022). Cybercriminals can also carry out a cyber-attack, i.e., usually organised groups focused mainly on profit (but also on behalf of state authorities) (Olejnik et al., 2022). We can also talk about people who work within state structures, the so-called cyber operators (Olejnik et al., 2022).

The basic features of a cyber-attack are 1) its virtual form; 2) no space limitation; the blurring of the traditional distinction between local and international conflict; 3) malware can travel in information resources and operates using network connections and not according to the rules of geography; 4) the "load" of weapons is also "intangible" - this software is the most direct cause of destruction; 5) causing damage requires a remote object – a controller – that can be manipulated, and the use of code using weapons can have consequences for the political and economic world; 6) the use of cybernetic weapons does not have to lead to physical destruction to constitute a serious threat to the state and its society (Chmielewski, 2022).

Results and discussion

If we assume – as above – that cybersecurity, at a basic, general level, can be understood as confidentiality, integrity and availability, then cybersecurity threats, also at a basic, general level, may lead to 1) lack of confidentiality, i.e. access to information by unauthorised persons; 2) lack of integrity, i.e. introducing changes to information in an unauthorised manner; 3) lack of availability, i.e. the inability to use systems, data, information, resources.

When it comes to the basic types of threats, we can therefore distinguish: 1) illegal access to the system (hacking) (Szpor et al., 2022); 2) breach of confidentiality of communication (sniffing); 3) data integrity violation; 4) destroying, damaging, deleting or changing IT data of special importance, e.g. for the defence of the country (computer sabotage); 5) preventing the use of systems, data, information, resources. Obviously,

many of these actions are reflected in the penal codes of the countries they are penalised.

When it comes to the basic methods of operation, we can distinguish: 1) malware – software or firmware designed to perform unauthorised processes that will adversely affect the confidentiality, integrity or availability of the IT system. A virus, worm, Trojan horse, or other code-based unit that infects a host. Spyware and some forms of adware are also examples of malicious code (Computer Security Resource Center, 2023); 2) ransomware – prevents or restricts users from accessing their system via malware. Ransomware expects you to pay a ransom through online payment methods to regain access to your system or data. Online payment methods often include virtual currencies, cryptocurrencies (the Commonwealth of Massachusetts, 2023); 3) Distributed denial of service (DDoS) attacks that render an online service unavailable because it is overwhelmed by excessive traffic from multiple locations and sources (the Commonwealth of Massachusetts, 2023); 4) acting with unsolicited, unwanted messages and emails (spam); 5) activities aimed at obtaining confidential information. Phishing attempts will look for information coming from a trusted person or company (phishing) (the Commonwealth of Massachusetts, 2023); 6) action, using all available techniques (e.g., baiting), consisting in persuading the victim to disclose certain information or perform a certain action for unjustified reasons (social engineering) (European Union Agency for Cybersecurity, 2023).

In addition to the above-mentioned basic methods of operation, it is also worth paying attention to the increasingly sophisticated cyber-attacks, including not only malware and phishing but also machine learning and artificial intelligence and others, which put the data and assets of corporations, governments and individuals at constant risk (Moore, 2023). It is worth remembering that cyber threats are changing rapidly. Attack tactics and methods change and improve every day.

Understanding the nature of the risks and threats facing the entity so that it can better prepare for them is dealt with by cyber intelligence, which can be considered a component of the entity's cybersecurity system. Cyber intelligence is used to identify a cyber threat. Cyber intelligence helps you understand attackers, their motives, actions and capabilities, and how they operate. It is more than data mining: it requires the ability to analyse what is happening in real-time. Cyber intelligence helps organisations make faster, more informed security decisions and shift their behaviour from reactive to proactive to combat attacks (EC-Council, 2023).

It is also worth pointing out that some also distinguish the concept of cyber-hygiene. Cyber hygiene differs from cybersecurity, but it relates to individuals rather than a group of organisations. While cyber-hygiene is the responsibility of an individual, cybersecurity is the responsibility of a group or organisation and applies only to their professional activities (Singh et al., 2020). An example of good cyber-hygiene practice is keeping your device and system software up to date (Singh et al., 2020).

Critical infrastructure

In the report of the Open-ended Working Group on Developments in the Field of Information and Telecommunications in the Context of International Security (the Group was convened by the resolution of the General Assembly of the United Nations on 5 December 2018) of 18 March 2021 stated, among other things, that activities contrary to obligations under international law, which deliberately damage critical infrastructure or otherwise impede the use and operation of critical infrastructure providing services to the population, may pose a threat not only to security, but also for the sovereignty of the state, as well as its economic development and livelihoods, and ultimately for the security and well-being of individuals (Report, 2021).

One of the basic obligations of states under international law is to refrain in their international relations from the threat or use of force against any state's territorial integrity or political independence. While cyber-attack techniques can and probably will evolve, shared values – such as peace – should remain the same. Therefore, it is not worth forgetting values when discussing cyberspace and cyber-attacks. Given what has been said, we can distinguish an object of a cyber-attack of a tangible or an intangible character. This distinction can be useful due to the aforementioned evolution of cyber-attack techniques and even the difficulty of identifying their existence. Sometimes only the effects will be visible, which can be tangible or intangible (non-physical) (like the whole of cyberspace).

A classic example of an object of a cyber-attack of a tangible character is critical infrastructure such as the electricity grid, the water supply network, the financial system, nuclear weapons, etc. (Sanger, 2021). Classically and quite broadly, the concept of critical infrastructure can therefore be understood as "(...) sensitive elements of state infrastructure, necessary for the functioning of the state and society (population)" (Olejnik et al., 2022).

An example of an object of a cyber-attack of an intangible character could be "values" such as peace. The electoral system can be considered a critical infrastructure of an intangible character. If the skeleton of democracy is the ability to conduct free and fair elections, then the state's electoral system can be considered an infrastructure of key importance to the state (Sanger, 2021).

Therefore, from the state's point of view, the most undesirable attacks will be those against elements of its critical infrastructure, both of tangible and intangible character. In addition, attacks on civilians (individuals – Internet users) and legal persons can also be distinguished.

Conclusions

Countries' activities in cyberspace may occur within specific types of operational activities in cyberspace. It can be said that currently, the main area of cooperation between countries in cyberspace is cybersecurity. This is due to the fact that there are several threats, the list of which – due to digital transformation – is constantly growing.

Cyber intelligence deals with identifying threats and understanding the motives of attackers and how they operate, which can be considered a component of cybersecurity.

Particularly important is the issue of cooperation between public authorities and private companies in the field of cybersecurity. Should a boundary be drawn, defining when a private company defends itself against cyber incidents and when the state and its authorities intervene? It seems that the answer to such a question should be negative, i.e., such a border should not be set. The defined border, describing the circumstances in which the state and its authorities intervene, could be skilfully used by those launching attacks. Moreover, it could discourage private companies from taking action on their own cybersecurity. Individuals should also comply with the so-called cyber-hygiene.

Due to the development of regulations in the field of cybersecurity, and the desire to protect goods that may become the object of attack, the concept of the common protective good is being extended. Cyber-attacks on tangible and intangible targets make us aware that the protected good can be of a physical or non-physical character. Such attacks on such tangible and intangible assets may affect the interpretation of such concepts as, for example, the concept of state security.

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COMPARATIVE CHARACTERISTICS OF GIS USING THE AHP METHOD

Abstract: The article discusses the methodology of comparative analysis of GIS class computer systems using the AHP method. Eighteen selected GIS systems that meet the criterion of completeness of all data required in the research were fully analysed. The proper comparative features were preceded by the recognition of the market situation in terms of the availability of GIS systems. Eight thematic groups of criteria were used in the research, on the basis of which GIS solutions were selected for comparison. The adopted system selection criteria carry out the selection of objects in a binary manner. The set of features and comparative criteria was created on the basis of our own experience and numerous consultations with specialists and field experts. The selected criteria are the most commonly used and most commonly accepted in the environments that systems of this class use on a daily basis. Both the functional scope (features, functions, properties, advantages and disadvantages) and the degree of fulfillment of subsequent criteria by the considered systems were defined and described.

Keywords: GIS, AHP, hierarchical methods

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Introduction

In the information society we are approaching, information and knowledge play an essential role. Despite the fact that they are intangible, they generate added value. Therefore, in times of such rapid development of knowledge and the related ubiquitous expansion of information, resulting in economic growth, GIS class systems were created on the basis of technology and business solutions, oriented on the use of information for comprehensive management of various types of entities, such as: economic organizations, companies, enterprises, systems, etc. GIS systems find practical application in many fields. Hence the diversity of terms for geographic information processing systems, such as geographic database information system, geographic data system, and spatial information system. Each of these terms approximates in some way the functions performed by individual systems. In practice, the most common are specialized systems, focused on a narrow group of applications, however, there are also multi-purpose general-purpose GIS.

The purpose of this article is to present a hierarchical comparative analysis of GIS enabling the selection of a properly tailored and effective GIS solution for a given enterprise, using the AHP (Analytic Hierarchy Process) method. The results obtained using this method can and very often constitute a kind of help, guidance and advice in decision-making, however, one should not base one's choice solely on it.

This article consists of six sections. The first section covers assumptions and key concepts. The second section contains the results of the literature review, on the basis of which GIS classes and categories were specified and then characterized for the purposes of comparative analysis. The third section presents the research methodology. The fourth section contains information on the problem analysis and research results. Finally, section five describes the conclusions and recommendations. The implementation of the topic was based on the possibly available bibliography specified in the chapters: "Assumptions and basic concepts" and "Overview of the studied GIS systems". In addition, numerous industry magazines of general circulation were used, concerning IT, outsourcing, design, problem and utility solutions related to GIS systems. Numerous consultations and meetings, e-mails and expert opinions from employees and experts from companies that produce and implement GIS class systems were also an invaluable source of data.

Assumptions and basic concepts

The concept of GIS and classification. GIS are the result of the revolution in geography taking place over the last dozen or so years, as well as, of course, the rapid development of information technology and database management methods (data collections). The creation of GIS is the result of a combination of works carried out in various fields: geography, cartography, geodesy, computer science, electronics. Geographic information system technology uses geographic concepts, applications and computer systems. A geographic information system is a tool that analyzes spatial relationships, patterns, and trends. This can be achieved by combining geography with

available data, making GIS more understandable in a geographic context. GIS includes both hardware and software systems. The geographic information system consists of several groups of programs (modules) performing separate functions. These are:

- procedures for entering and verifying input data,
- procedures for managing and processing within the database (database management system),
- procedures for processing and analyzing geographical data,
- output procedures: graphical, cartographic and textual presentation of data,
- user communication procedures.

GIS find practical application in many fields. Hence the diversity of terms describing systems that process geographic information, such as geographic database information system, geographic data system, spatial information system. Each of these terms approximates in some way the functions performed by individual systems. In practice, the most common are specialized systems, focused on a narrow group of applications, however, there are also multi-purpose general-purpose GIS. A wide group of GIS applications is presented in figure 1.

Fig. 1. GIS application areas
Source: https://www.educba.com/applications-of-gis/

The main areas of a GIS are creating geographic data, managing that data in a database, analyzing patterns to create, and visualizing it on a map. GIS provides a better understanding of spatial patterns and relationships. Thus, GIS technology combines database operations such as querying and statistical analysis with the unique visualization and geographic analysis offered by maps. GIS class systems or applications can be divided into the following types/models:

1. Four-dimensional GIS.
2. Multimedia or hypermedia GIS.
3. Internet GIS.
4. GIS Virtual Reality.

The characteristics of the above types of GIS are presented in table 1.

Table 1. Characteristics of GIS models

Type/Model	Characteristic [pos. literature]
Four-dimensional GIS:	It is designed to handle three dimensions of space and one dimension of time. Space-time representations can only support two dimensions of space and one dimension of time. (Bielecka, 2006; Chang and Kang-tsung, 2016; Fu & Sun, 2010; DeMers, 2009; Gaździcki, 2003; www.esri.com; Gotlib et al., 2008; Iwańczuk, 2016; www.mjcetce409.blogspot.com; Myrda & Litwin, 2005; www.wiki.osgeo.org; Szczepanek, 2017; Werner, 2004)
Multimedia /hypermedia GIS:	It allows the user to access a range of georeferenced multimedia data by selecting assets from a georeferenced image map database. A map that serves as the main index of multimedia data in a multimedia geographic representation is called a hypermap. Multimedia and virtual geographic representations can be stored in extended relational databases, object-oriented databases, or application-specific data stores. (Gaździcki, 2003; Iwańczak, 2016; www.pl.wikipedia.org; www.wseiz.pl; www.mjcetce409.blogspot.com; www.wiki.osgeo.org; Bolstad, 2019; Werner, 2004; Xuan & Zhu; 2016)
Web GIS:	Widespread access to the Internet combined with the use of web browsers and the explosion of geographic information enabled the development of new forms of multimedia geographic representations on the web. Many geomatic web solutions are web-based and are rapidly overtaking desktop GIS, and future trends are moving in the same direction. (Bielecka, 2005; Goodchild, 2010; www.pl.wikipedia.org; www.wseiz.pl; www.mjcetce409.blogspot.com; www.geoforum.pl; www.en.wikipedia.org; Bolstad, 2019; Szczepanek, 2017; Werner, 2004; Xuan & Zhu; 2016)
Virtual Reality GIS:	Virtual Reality GIS was developed to enable the creation, manipulation and exploration of geo-referenced virtual environments. For example, using Virtual Reality Markup Language (VRML) to experiment with different scenarios. GIS virtual reality can also be web-based. An example of the use of Virtual Reality GIS is a 3D simulation for planning in various scenarios. (Iwańczak, 2016; www.mjcetce409.blogspot.com; www.wiki.osgeo.org)

Source: own elaboration

Assumptions. Due to the large number of GIS systems on the market, it is impossible to obtain information about all products. The main difficulties were related

to the acquisition of the necessary materials. Therefore, for the purpose of comparison, the following rules have been defined, according to which the solutions operating on the market will be classified into the set of compared systems:

- the size of the considered set of studies consists of GIS systems selected from all available on the world market today,
- the selection of systems for comparison was based on the binary technique, in which the presence of any information in the aspect of eight thematic groups of criteria was detected,
- the vast majority of the GIS systems presented in the work are commercial products, although the earlier, preliminary environmental analysis also included "open source" systems,
- but to be a true GIS, the system must contain a significant group of components (Fig. 2).

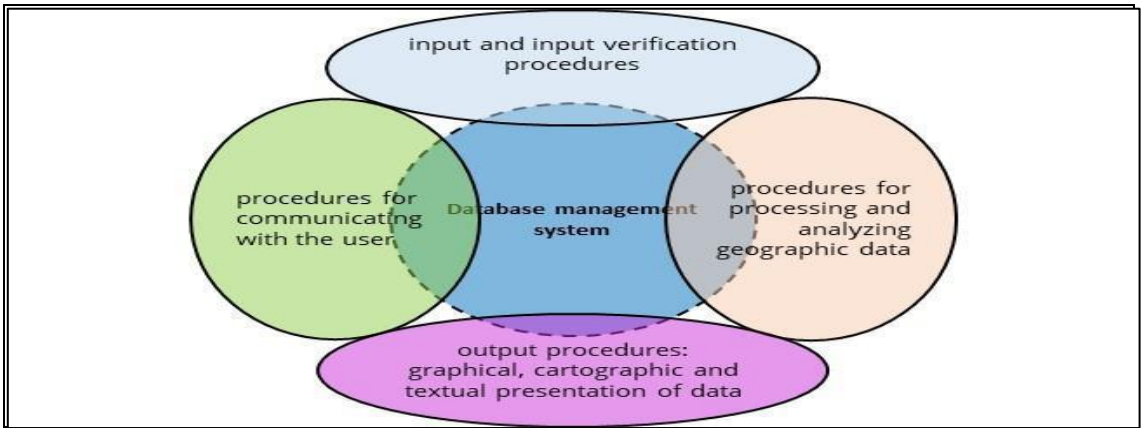


Fig. 2. Basic components of the GIS system
Source: own elaboration

Analytic Hierarchical Process (AHP). A methodology called AHP was used to prepare the proper ranking of the examined GIS class systems. The research was based, among others, on this strategy due to the fact that AHP, by representing the decision problem in a strictly hierarchical manner, ensures obtaining a more accurate, more representative solution, through the step by step technique of successive *actions*. Analytic Hierarchy Process ensures finding the optimal solution in a multi-criteria decision problem. AHP effectively supports the decision-maker in the decision-making process. This methodology allows for a hierarchical decomposition of the problem issue into individual, smaller units – actions to be considered. It can operate on archival or long-term data. The operating logic of AHP has the ability to detect inconsistencies contained in operational data. The AHP strategy allows for a convenient compilation of data, and thanks to the mechanism of mutual comparison of individual criteria in pairs, through association – assigning weight to a given feature, prioritization is established, and thus the level of significance of a given criterion is determined. The method used in the work reduces bias in making the right decision, and in its interpretation of the result AHP takes into account both subjective and objective assessments of experts. Thanks to

this, the obtained result is representative and consistent with the real state. In the considered problem of choosing the right GIS system, the AHP algorithm finds an ideal application. The idea of the algorithm ensures that a compromise is reached and a common consensus is reached thanks to the synthesis of all criteria and partial results. The AHP method seems to be the best method due to the possibility of obtaining a representative and factual result, taking into account both subjective and objective assessments of experts. In addition, this method detects inconsistencies in operational data and reduces bias in decision-making (Mu & Pereyra-Rojas, 2017; Saaty, 2012).

Review of the studied GIS systems

There are plenty of GIS systems on the market, designed for a wide range of applications. Many of the offered solutions come from various domestic and foreign companies. To illustrate the number of foreign players and market tycoons, a summary in the form of the Gartner magic quadrant was presented (Fig. 3).

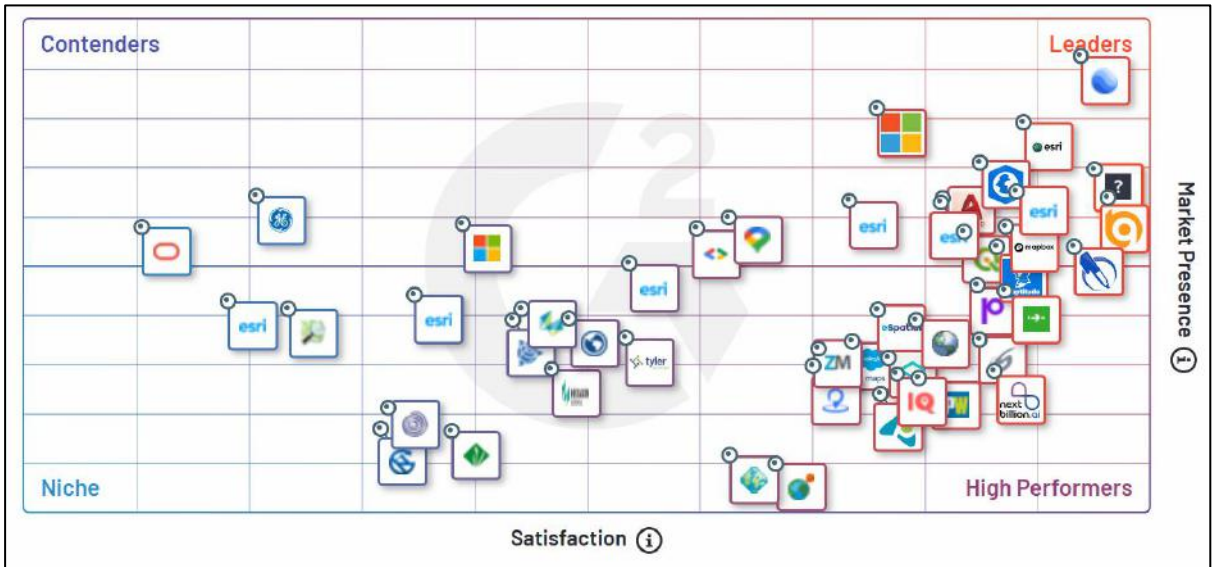
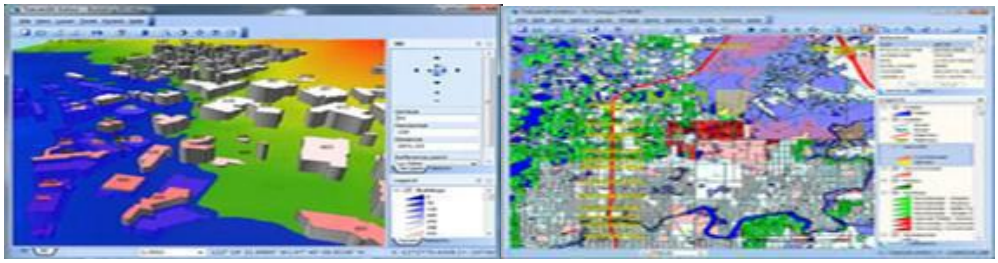


Fig. 3. GIS class solutions for enterprises
Source: own elaboration

Bearing in mind the limitations concerning the volume of the article, only six systems will be characterized in this subchapter: TatukGIS, Cadcorp, CARTO, Map Salesforce, GeoExpress, Geopointe. Other GIS can be found in studies (Miłek et al., 2023a; Miłek et al., 2023b).

TatukGIS is a professional all-in-one GIS mapping and data editing application with a built-in scripting environment for customization and feature extensions. TatukGIS is not just a simple tool to open and view GIS and CAD files. Its advanced feature set makes it a winner in its category, providing a comprehensive tool for rendering high-quality maps and working with GIS data. The program is equipped with typical GIS features and provides an extensive feature set, allowing you to include

multiple vector file formats in one project, organize, group and prioritize layers, customize layer properties, legend and map appearance by changing colors and styles, adding labels and adjusting transparency. Official screenshots:



Basic functions:

The program is equipped with typical GIS functions. Functional range incl. includes:

- Zoom in, zoom out, pan maps.
- Multiple vector file formats (layer types) in the same project.
- Extended legend for hierarchical layers, layer grouping, subprojects.
- MiniMap window with options for the World Map or Continent Map tabs.
- TatukGIS project files.

Advantages:

- The editor has a very high level of flexibility in handling data.
- Loading, editing, exporting, importing – all basic GIS functions available.
- A very long list of supported formats in raster and vector data.
- Supported różnedatabase formats and finally supported web services.
- TatukGIS DK API.
- The application speed is great and has left many GIS applications behind.
- The Script Editor can be used in conjunction with other GIS applications on the market.

Disadvantages:

- Some parts of the GUI should be updated to use other GIS solutions.
- You would need to write a number of import routines and a number of data enrichment tools using the built-in script editor.

Cadcorp – is an integrated family of geospatial products that includes desktop, web and software products. It has been designed with the needs of both end users and application developers in mind, to be used in all phases of spatial data management – from development, through application development, deployment and data distribution. Cadcorp offers an integrated family of geospatial software that includes desktops, servers, websites, and software products. Cadcorp provides a wide range of map and data services that feature content from a variety of providers, including Ordnance Survey. Official Screenshots:

Basic functions:
Cadcorp integrates both GIS and CAD into one application. It almost flawlessly adds rich functionality to mapping and styling. It adds several features, ribbon interface, interoperability and development tools. But when you combine it with server and cloud tools, the lesser-known Cadcorp shines on several levels. Range functional:

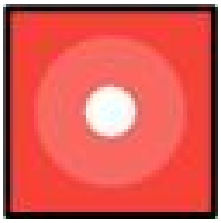
- Cropping, color balance, remapping and more.
- Combining multiple images into seamless mosaic datasets.
- Creation custom images.
- Create MrSID files using existing images and GIS data.
- Export only the selected fragments of photos, exactly in the required size and resolution.

Advantages:

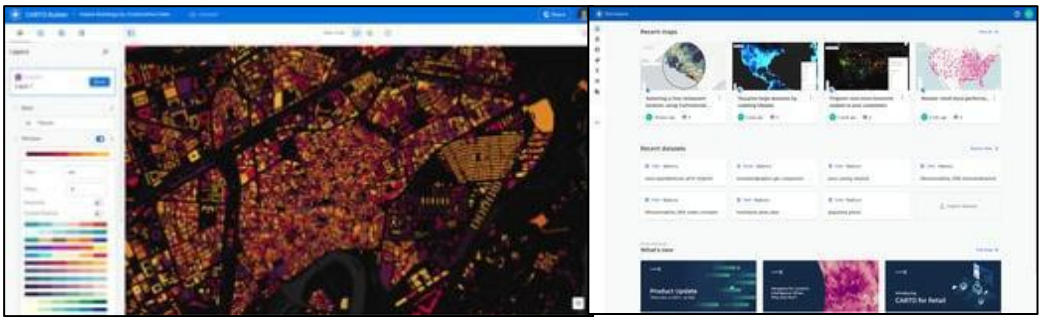
- Intuitive interface for Desktop GIS.
- Creating Cadcorp SIS web maps.
- Hosting and sharing data in the cloud.
- Deloy web applications via server.
- Development tools available for customization.

Disadvantages:

- Lack community forum support.
- A small collection of tools remote sensing.
- A new product without much background information.
- CAD/GIS specialist, but lacks other fields.



CARTO is the leading Location Intelligence platform. It enables organizations to use spatial data and analytics for more efficient delivery routes, better behavioral marketing, strategic store placement, and much more. Data Scientists, Developers and Analysts use CARTO to optimize business processes and predict future results with the power of Spatial Data Science. CARTO is the user interface for our next-generation cloud-native Location Intelligence platform. CARTO is available for both individuals and enterprises, both in cloud and self-hosted deployments. Depending on how you use the CARTO platform, whether for visualization, analysis, data access or application development, you will use different platform components. Official screenshots:



Basic functions:

It allows you to create stunning maps and perform large-scale spatial analysis, all running directly on cloud data warehouses. The platform helps you visualize, analyze and build apps using location data natively on cloud data warehouse platforms.

Cartography:

- Design.
- Mapping vector.
- Visualization data.
- Overlaying.

Analysis:

- Analysis predictive.
- Analysis distances.
- Analysis spatial.
- Stream data.

Reporting:

- Transformation data.
- WYSIWYG design.
- Integrations.

Advantages:

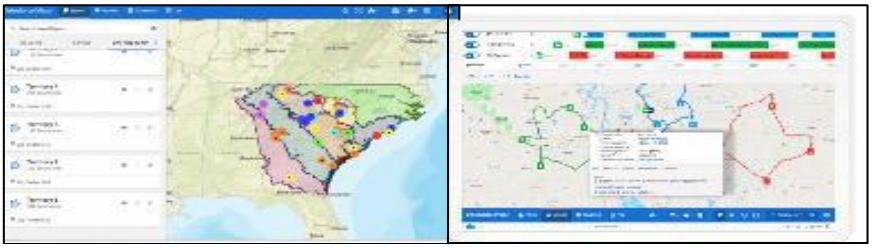
- Flexibility APIs.
- An easy-to-use way to manipulate geospatial data.
- A huge variety of tools, from a friendly user interface (builder), to a python library (cartoframes), as well as an SDK and API pool.
- Extensive documentation and fast response of the CARTO support team.

Disadvantages:

- There are discrepancies in how billing is done and a gap between billing and those who deal with marketing and negotiating.
- Guidelines for embedding, creating and modifying maps could be easier for users.
- Data integration and scheduled refresh need to be more user friendly.

The leading location analysis tool for Salesforce | Leverage mapping and optimization technologies to maximize the productivity of your sales and service assets. Salesforce is your customer success platform, designed to help you sell, service, market, analyze, and connect with your customers. Run your

business from anywhere with Salesforce. Use standard products and features to manage relationships with prospects and customers, collaborate and engage with employees and partners, and store your data securely in the cloud. But standard products and features are only the beginning. With our platform, you can customize and personalize the experience for your customers, partners, and employees and easily extend beyond out of the box functionality. Official screenshots:



Basic functions:
The program is equipped with typical GIS functions. Functional range incl. includes:

- Sales automation.
- Contact and account management.
- Task / activity management.
- Territory and quota management.
- Management of products and price lists.
- Management of offers and orders.
- Customer contract management.
- Marketing automation.
- Campaign management.
- Lead management.
- Customer service.
- Case management.
- Reporting and analytics.
- Reporting.
- Forecasting.

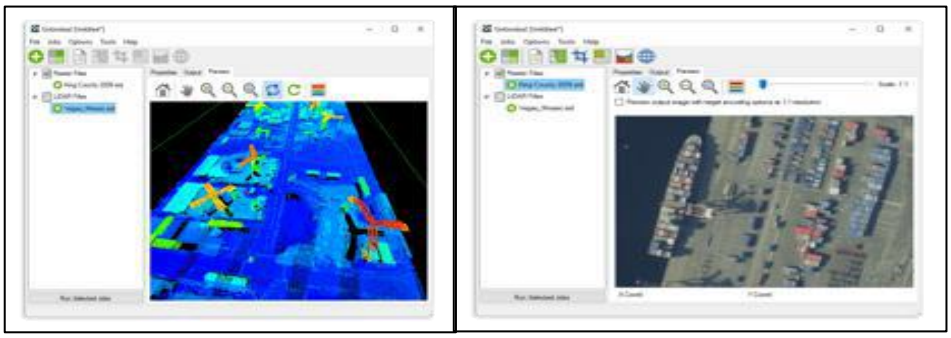
Advantages:

- Provides a clear line of communication between the parties and creates a solid reporting structure.
- Very satisfying and easily accessible.

Defects:

- Interfejs unfriendly to use.
- Flows and more complex business process workflows continue to be a technical challenge.
- Administrator management can be complicated, hard to find what you need when setting up an instance.

GeoExpress – A powerful tool for compressing and adjusting images and GIS data. GeoExpress provides a comprehensive set of editing tools to create the exact image you need GeoExpress enables geospatial specialists to compress images into our proprietary, industry standard MrSID format. This format supports lossless and visually lossless compression, allowing users to reduce file sizes without sacrificing image quality. Using GeoExpress and Express Server reduces our storage costs and allows us to manage images in a central location, which in turn reduces redundancy and increases our efficiency. Official screenshots:



Basic functions:

The program is equipped with typical GIS functions. GeoExpress also provides editing capabilities to compress geospatial photos so you can provide enhanced visual data for analysis. It includes standard photo editing features such as cropping and color balancing, as well as re-display, mosaic and more. Functional range incl. includes:

- Spatial analysis.
- Data acquisition.
- Data visualization.
- Data storage.
- Cropping, color balance, remapping and more.
- Combining multiple images into seamless mosaic datasets.

Advantages:

- COMPRESSION! No other software compresses and displays like this product.
- Images are easy to crop and reduce to a smaller target area.

Defects:

- You must purchase a container to convert to MrSID compression.
- Difficult to manage large aerial photos and image data.

Geopointe was launched in 2010 and is based in the city of Irvine, California with a presence in the United States. Geopointe is a Salesforce partner AppExchange and the leading geolocation application available on AppExchange. Geopointe is a great mapping tool that is constantly updated to meet customer needs. Geopointe provides end users, managers, administrators and developers with multiple

ways to leverage the geographic aspects of their data to improve efficiency and streamline processes. Official drops screen:

Basic functions:
At work:

- Location.
- Communication with employees.
- Behavior monitoring.
- Reports.
- CRM integrations.

Analysis:

- Distance Analysis.
- Spatial Analysis.

Cartography:

- Map design.
- Data visualization.
- Overlaying.

Reporting: Data transformation.
Advantages:

- A great mapping tool that is constantly updated to meet customer needs.
- Integrates well with Google Maps.
- Powerful mapping ability – visualize any geographic information in Salesforce.
- Seamless integration with Salesforce – ready functionality for geocoding addresses from Salesforce fields.
- Ease of use – very low to minimal learning curve. It is very user friendly and intuitive.
- Continuous implementation of new features and improvements.

Defects:

- Filtering and creating a dataset may seem too complicated at first.
- Sometimes the map doesn't like to load all amenities.
- no mechanisms to export the Geopointe list directly to reports or Salesloft.
- The scrolling feature on the map is a bit tricky to use.

Methodology

A methodology called AHP was used to prepare the proper ranking of the examined GIS class systems. This methodology allows for a hierarchical decomposition of the problem issue into individual, smaller units – actions to be considered. The AHP strategy allows for a convenient compilation of data, and thanks to the use of the mutual pairwise comparison mechanism, *pairwise comparison*) of individual criteria, through association - assigning a weight to a given feature, prioritization is established, and thus the level of significance of a given criterion is determined. The method used in the work reduces bias in making the right decision, and in its interpretation of the result AHP takes into account both subjective and objective assessments of experts. Thanks to this, the obtained result is representative and consistent with the real state. AHP consists of three main steps: constructing a hierarchy, creating a pair comparison matrix, and calculating the importance of individual criteria . The complex idea of the algorithm is presented in the following diagram (Fig. 4) in the three-step form (synergy of three components):

Fig. 4. A step-by-step approach to the AHP algorithm when evaluating GIS systems
Source: own elaboration

Step 1: Hierarchy construction. The first step in the AHP method is to build a decision hierarchy where all the factors that influence the decision are broken down into levels of the hierarchy, starting at the highest level and then going down in the hierarchy. The top level of the hierarchy usually represents the goal or main goal to be achieved, and the lower levels represent criteria or alternatives that are related to achieving the goal (Mu & Pereyra-Rojas, 2017). The general structure of the hierarchy is shown in the figure below (Fig. 5).

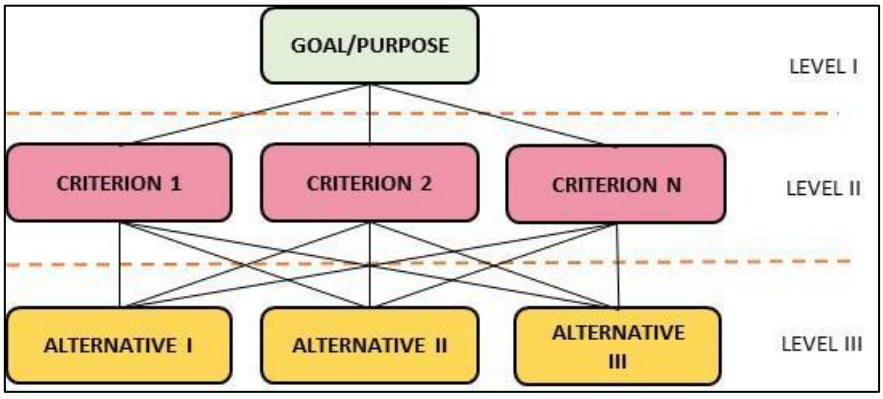


Fig. 5. Scheme of the structure of the hierarchical model
Source: own elaboration

The first level of the hierarchy is the goal, which is the general decision problem that needs to be solved. At this level, the goal and general category of the problem to be solved by the AHP method should be defined. The second level is the criteria, i.e. the factors that must be taken into account in the decision-making process. At this level, all criteria that are relevant to solving the problem should be specified. These criteria can be assessed on the basis of qualitative and quantitative information. The third level is alternatives, i.e. possible solutions to the problem. At this level, alternative solutions to the problem must be identified, which will be evaluated against criteria from the second level of the hierarchy. Then, at each level of the hierarchy, benchmarking should be done to determine the relative importance of each item to other items in the same category. Comparison of items can be done on a pair or group level. In this way, the construction of the hierarchy in the AHP method makes it possible to determine the hierarchical structure of the problem, which allows for a thorough and systematic comparison of different alternatives to solve the problem, as well as the evaluation of each of them on the basis of specific criteria.

Step 2: Create pair comparison matrix. A Pairwise Comparison Matrix (MPP) is then created where each criterion is compared to every other criterion in the hierarchy to determine their relative importance (Bielecka, 2006). The MPP ranges from 1 to 9, where 1 means that two criteria are equally important and 9 means that one criterion is more important than the other. Values between 1 and 9 represent the importance of one criterion relative to the other. The weighted average of the column in the MPP is then computed to give a vector of weights for each criterion. To create a comparison matrix, the Saaty scale is used, which is presented in the table 2 (Saaty, 2012).

Table 2. Scale of comparisons used in the AHP method

Importance scale	Definition	Explanation
1	Equal importance	Both elements have an equal impact on achieving the goal, or when it is difficult to determine which of them is more important for achieving the goal.
3	Weak or moderate advantage	Slight (moderate) distinction or slight preference for one element over another.
5	Strong advantage	A clear distinction or significant favoritism of one element over another.
7	A very strong advantage	Predominance or clear preference for one element over another.
9	Extreme or absolute advantage	Extremely clear advantage of one element over the other, which reaches the maximum level possible to estimate.
2, 4, 6, 8	Intermediate values are used only when necessary	In some cases, it is necessary to numerically interpolate compromise opinions because there are no adequate words to describe them (intermediate values from the above scale are used in such situations).

Source: own elaboration

Based on the above scale, the decision maker issues scores for individual criteria, which are then placed in a square matrix. When making pairwise comparisons, a rule should be followed that the rating value for the less important or less preferred item is the reciprocal of the rating value for the more important or more preferred item, as determined by the decision maker. If one element is more important than the other, it receives a higher score, e.g. 3, 5 or 9, depending on the degree of superiority over the other element. On the other hand, less important or less preferred elements in the compared pairs receive lower rating values, e.g. 1/3, 1/5 or 1/9. When the decision maker considers that two items are equivalent, they are given a score of 1. The table 3 shows an example pairwise comparison matrix.

Table 3. Matrix of comparisons

	Criterion A	**Criterion B**	**Criterion C**	**Criterion D**	**Criterion E**
Criterion A	1	5	1/2	1/2	3
Criterion B	1/5	1	1/3	1/5	1
Criterion C	2	3	1	2	2
Criterion D	2	5	1/2	1	3
Criterion E	1/3	1	1/2	1/3	1
Sum	5.53	15	2.83	4.03	10

Source: own elaboration

The next step in this step is to normalize the matrix shown above to the next matrix by dividing each element of a given column by its sum. The weights were calculated using the arithmetic mean of the row data. The result of this operation is presented in table 4.

Table 4. Normalized matrix of comparisons

	Criterion A	**Criterion B**	**Criterion C**	**Criterion D**	**Criterion E**	**Scales**
Criterion A	0.18	0.33	0.18	0.12	0.3	0.222
Criterion B	0.04	0.07	0.12	0.05	0.1	0.076
Criterion C	0.36	0.2	0.35	0.5	0.2	0.322
Criterion D	0.36	0.33	0.18	0.25	0.3	0.284
Criterion E	0.06	0.07	0.18	0.08	0.1	0.098

Source: own elaboration

Step 3: Calculate the importance of individual criteria. In this step, the preference matrix is built and its coherence index is calculated, which means that the global coherence of the matrix at each level of the hierarchy is examined (Mu & Pereyra-Rojas, 2017; Saaty, 2012). This is to check how consistent the information provided by the decision maker is when creating the comparison matrix. It is built on the principle that element A is equivalent to itself, while the value assigned to element *B* in relation to element *A* is the reciprocal of the value assigned to element A *in* relation to element *B.* Part of this step is also to examine the coefficients of coherence of the resulting matrix, determined by: Consistency Index (CI) and Consistency Ratio (CR). These coefficients are described by the formulas:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

where:
λ_{max} – the largest eigenvalue of the matrix
n – matrix size
RI – randomness index (constant value from the Random table Consistence Index, developed for this method)

The weights for table 5 are calculated on the basis of the arithmetic mean of the rows of the matrix.

Table 5. Matrix of preferences

	Criterion A	**Criterion B**	**Criterion C**	**Criterion D**	**Criterion E**	**The weights of the sum of the values**
Criterion A	1*0.222=0.222	1.11	0.111	0.111	0.666	0.444
Criterion B	1/5*0.076=0.0152	0.076	0.025	0.0152	0.076	0.041
Criterion C	2*0.322=0.644	1.61	0.161	0.322	0.966	0.745
Criterion D	2*0.284=0.568	1.42	0.142	0.284	1.42	0.767
Criterion E	1/3*0.098=0.0327	0.098	0.049	0.0327	0.098	0.062

Source: own elaboration

Then, the weights of the criteria (Weights of the sum of values) for table 5 are divided by the weights of the criteria (Weights) for table 4. The highest value of the own matrix is calculated on the basis of the arithmetic mean of the results obtained by dividing the weight of the sum of values (Table 6) by the weights of the criteria (Table 5) and amounts to:

$$\lambda_{max} = \frac{2 + 0{,}539 + 2{,}314 + 2{,}701 + 0{,}633}{5} = 1{,}6374$$

The index of the random discrepancy index is presented in (Table 6), which contains the average weights of the coherence indexes of random pairwise comparisons.

Table 6. Compliance index acc. Saaty

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: own elaboration

Results and discussion

In a series of studies, a comprehensive set of selected eighteen GIS class systems was subjected to a detailed analysis. Heuristic techniques were used, which allowed the estimation of individual parameters, determination of their significance function as well as the ranking and classification of the considered set of objects. It is also mentioned that the scope of the criteria has been limited by excluding the cost factor from such a large group of criteria. A full domain reconnaissance was made, covering both commercial systems and free, open source solutions. After proper data acquisition, it was decided to select objects from commercial GIS systems. The final set of systems intended for analysis included the following items: ArcGIS Pro, WebGIS, BatchGeo, Google Earth Pro, Maptitude, ArcGIS Desktop, Hexagon Geomedia, MapInfo Pro, Surfer, GIS Cloud Track, ArcGIS Enterprise, GE Smallworld, TatukGIS, Cadcorp, CARTO, Salesforce Maps, GeoExpress, GeoPointe.

Stage 1. Construction of the hierarchy. The general structure of the hierarchy is shown in the figure 6.

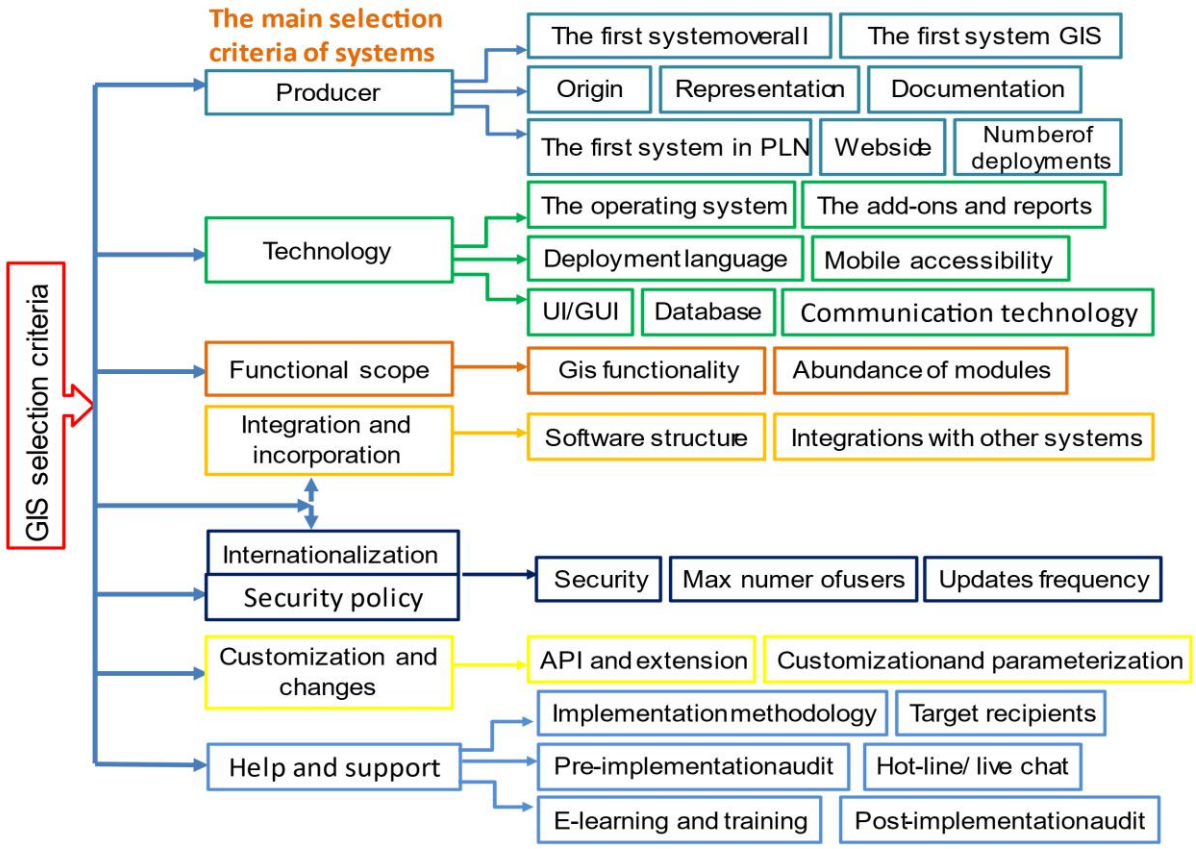


Fig. 6. Hierarchical tree structure of the GIS system selection problem
Source: own elaboration

The ordering of criteria is aimed at appropriate numbering (indexing) of feature functions and their arrangement – configuration in the appropriate order at specific levels of the hierarchy of significance. In order to achieve this goal, a nine-point adjective scale of the algorithm was used in the construction of the matrix for the assessments of

decision-makers and experts. Numerical values of consecutive comparisons (*pairwise comparise*) denote the significance function of a given assessment and, according to the idea of the algorithm, they should be included on a discrete scale, from 1 to 9. The translation of individual verbal assessments of criteria (provided by experts) into specific weight values is presented in table 7.

The weight criteria of the significance function defined in this way were used in the next step, where the decision maker (*decision maker*) or a domain expert determines the significance level of criterion A in relation to criterion B. Next, the next pairs of criteria taken from the feature matrix are scored. The study must be carried out very meticulously and precisely, due to the representativeness of the results obtained later. It is, among others, due to homogeneity – homogeneity (and thus convergence in relation to common features) in the acquisition of comparison values, the previously presented Delphi method was used. The basic matrix for the algorithm is presented in table 8.

Table 7. Translating the qualitative verbal assessments into the weights of the AHP algorithm criteria

Qualitative verbal assessment	**Translating into rank, numerical evaluation**
Equally recommended/preferred {equal importance}	1
From equally to slightly recommended/preferred	2
Slightly recommended/preferred {moderately preferred}	3
From slightly to strongly recommended/preferred	4
Strongly recommended/preferred {Strongly preferred}	5
From strongly to very strongly recommended/preferred	6
Very strongly recommended/preferred {Very strongly preferred}	7
From very strongly to extremely recommended/preferred	8

Source: own elaboration

Table 8. Matrix of comparisons of the level of significance of individual criteria in the AHP method

	Producer	Technology	functional range	Integration and incorporation	internationalization	Customization and expansion	security policy	Help and support
Producer		**2.0**	**7.0**	**4.0**	**2.0**	**6.0**	**5.0**	**4.0**
Technology			**8.0**	**5.0**	**1.0**	**5.0**	**6.0**	**6.0**
functional scope				**4.0**	**9.0**	**2.0**	**2.0**	**3.0**
Integration and incorporation					**3.0**	**5.0**	**3.0**	**5.0**
internationalization						**7.0**	**6.0**	**6.0**
Customization and expansion							**3.0**	**3.0**

Source: own elaboration

Based on the above scale, the decision maker issues scores for individual criteria, which are then placed in a square matrix (Table 9).

Table 9. The level of significance of individual criteria in the AHP method

	Producer	Technology	functional scope	Integration and incorporation	internationalization	Customization and expansion	System security policy	Help and support
Producer	1,000	2,000	0.143	0.250	2,000	0.167	0.200	0.250
Technology	0.500	1,000	0.125	0.200	1,000	0.200	0.167	0.167
functional scope	7,000	8,000	1,000	4,000	9,000	2,000	2,000	3,000
Integration and incorporation	4,000	5,000	0.250	1,000	3,000	0.200	0.333	0.200
internationalization	0.500	1,000	0.111	0.333	1,000	0.143	0.167	0.167
Customization and expansion	6,000	5,000	0.500	5,000	7,000	1,000	3,000	3,000
security policy	5,000	6,000	0.500	3,000	6,000	0.333	1,000	1,000
Help and support	4,000	6,000	0.333	5,000	6,000	0.333	1,000	1,000

Source: own elaboration

With the matrix created in this way, the ranking was started – the criteria groups were classified in accordance with the data contained therein. The further part of the article presents a step-by-step form of a network of actions that was undertaken to achieve the main objective of the study, i.e. to select the best GIS class system in terms of all criteria. In order to precisely classify the systems, four iterations of the algorithm must be carried out. Initially, in accordance with the assumptions of the AHP strategy, the expert evaluation matrix was multiplied by its second, mirror instance (i.e. by itself – it was raised to the second power), thanks to which the following result was obtained, also presented in the form of an 8x8 matrix:

$$\begin{bmatrix} 8 & 11.926 & 1.087 & 4.821 & 11.902 & 1.505 & 2.186 & 2.345 \\ 5.875 & 8 & 0.721 & 3.692 & 8.125 & 1.027 & 1.683 & 1.807 \\ 72.5 & 99 & 8 & 45.35 & 96 & 10.519 & 18.567 & 19.383 \\ 17.417 & 27.2 & 2.363 & 8 & 25.85 & 3.173 & 4.1 & 4.417 \\ 5.968 & 8.27 & 0.712 & 3.484 & 8 & 0.969 & 1.529 & 1.62 \\ 68.5 & 94 & 7.01 & 40.833 & 86.5 & 8 & 14.867 & 15 \\ 37.5 & 54.667 & 4.381 & 19.117 & 49.833 & 5.49 & 8 & 8.35 \\ 43.333 & 61.333 & 4.571 & 20.2 & 52.333 & 5.39 & 8.133 & 8 \end{bmatrix},$$

For the data set obtained in this way, the eigenvector was calculated. The calculation results are presented in table 10.

Table 10. Calculated eigenvector for the evaluation matrix

8	11,926	1.087	4.821	11.902	1.505	2.186	2.345	**8**	**0.021739**
5.875	8	0.721	3.692	8.125	1.027	1.683	1.807	**8**	**0.021739**
72.5	99	8	45.35	96	10.519	18,567	19,383	**203**	**0.55163**
17.417	27.2	2.363	8	25.85	3.173	4.1	4.417	**8**	**0.021739**
5.968	8.27	0.712	3,484	8	0.969	1.529	1.62	**8**	**0.021739**
68.5	94	7.01	40,833	86.5	8	14,867	15	**117**	**0.317935**
37.5	54,667	4.381	19.117	49,833	5.49	8	8.35	**8**	**0.021739**
43.333	61,333	4.571	20.2	52,333	5.39	8.133	8	**8**	**0.021739**

Source: own elaboration

The values in the first, highlighted column of data are mapped to the sums of subsequent rows of the matrix shown. On the other hand, the data placed in the right, bold column form the eigenvector of this matrix. Since for the penultimate column $\sum$ = 368, eigenvalues *were* obtained by dividing the value of the sum of each row by the mentioned quantity (here: 368). The estimation of the mentioned vector of eigenvalues completes the first iteration of the considered algorithm. In the next pass, the above matrix is multiplied (multiplied) by itself, which results in the following values:

$$\begin{bmatrix} 654.5546 & 932.7877 & 76.7028 & 362.5412 & 878.1439 & 99.2329 & 154.6408 & 161.5433 \\ 470.8308 & 672.4317 & 55.2636 & 259.011 & 631.8486 & 71.4253 & 110.6826 & 115.5921 \\ 5361.1515 & 7668.6807 & 633.3805 & 2951.0988 & 7225.0809 & 822.4163 & 1268.9209 & 1327.6839 \\ 1326.5647 & 1883.9362 & 155.1516 & 742.7794 & 1778.6798 & 201.1367 & 315.9461 & 330.1743 \\ 450.2885 & 642.7785 & 52.9708 & 248.8588 & 605.4309 & 68.6494 & 106.5141 & 111.3505 \\ 4591.4029 & 6573.6629 & 546.1672 & 2537.0964 & 6217.3923 & 713.2201 & 1097.6385 & 1150.9941 \\ 2607.0508 & 3715.9079 & 307.5807 & 1453.6298 & 3514.4384 & 400.4572 & 623.4263 & 652.7569 \\ 2723.4061 & 3884.147 & 322.8683 & 1523.7413 & 3683.9208 & 421.983 & 655.9174 & 687.8077 \end{bmatrix}$$

An 8x8 matrix was obtained with a large increment of individual values. Below (Table 11), the data is presented in tabular form, detailing the column of the sum of rows and the eigenvector values for the obtained matrix. This step is analogous to the one described previously. The value of the partial sums of the individual rows of the matrix (allocated in the penultimate column) is $\sum$ = 92593.4707. The last column is the vector of the newly created matrix. An 8x8 matrix was obtained with a large increment of individual values. Below, the data is presented in tabular form, detailing the column of the sum of rows and the eigenvector values for the obtained matrix. This step is analogous to the one described previously. The value of the partial sums of the individual rows of the matrix (allocated in the penultimate column) is $\sum$ = 92593.4707. The last column is the vector of the newly created matrix.

Table 11. Calculated eigenvector for the next evaluation matrix

654.5546	932.7877	76.7028	362.5412	878.1439	99.2329	154.6408	161.5433	3320.15	0.035857
470.8308	672.4317	55.2636	259.011	631.8486	71.4253	110.6826	115.5921	2387.09	0.02578
5361.1515	7668.681	633.3805	2951.099	7225.081	822.4163	1268.9209	1327.6839	27258.41	0.294388
1326.5647	1883,936	155.1516	742.7794	1778.68	201.1367	315.9461	330.1743	6734.37	0.07273
450.2885	642.7785	52.9708	248.8588	605.4309	68.6494	106.5141	111.3505	2286.84	0.024698
4591.4029	6573.663	546.1672	2537.096	6217.392	713.2201	1097.6385	1150.9941	23427.57	0.253015
2607.0508	3715.908	307.5807	1453.63	3514,438	400.4572	623.4263	652.7569	13275.25	0.143371
2723.4061	3884.147	322.8683	1523.741	3683.921	421,983	655.9174	687.8077	13903.79	0.15016

Source: own elaboration

The rightness of the next step of the algorithm that has just been implemented should be justified here. The idea of this methodology is to implement an iterative approach in eigenvector estimation. This vector determines the value of the significance function for each of the considered criteria. Hence, it was decided to perform the next (second and third step of the algorithm), thanks to which the trend of the calculated eigenvectors can be noticed. Thus, having a basic factual basis consisting of two eigenvectors, the difference that distinguishes subsequent values of vectors was calculated:

$$\begin{bmatrix} 0,02173913 \\ 0,02173913 \\ 0,55163043 \\ 0,02173913 \\ 0,02173913 \\ 0,31793478 \\ 0,02173913 \\ 0,02173913 \end{bmatrix} - \begin{bmatrix} 0,035857 \\ 0,02578 \\ 0,294388 \\ 0,07273 \\ 0,024698 \\ 0,253015 \\ 0,143371 \\ 0,15016 \end{bmatrix} = \begin{bmatrix} 0,014118119 \\ 0,004041151 \\ 0,257242361 \\ 0,050991363 \\ 0,002958524 \\ 0,064919379 \\ 0,121632188 \\ 0,128420395 \end{bmatrix}$$

Since there are slight differences between the corresponding relative elements of the computed vectors, the algorithm is terminated at this point, i.e. after the second iteration. This is consistent with the AHP idea, and the eigenvector values calculated in the last step have been rounded to the nearest thousandth and are approximated below:

$$\begin{bmatrix} 0,035857 \\ 0,02578 \\ 0,294388 \\ 0,07273 \\ 0,024698 \\ 0,253015 \\ 0,143371 \\ 0,15016 \end{bmatrix} \approx \begin{bmatrix} 0,036 \\ 0,026 \\ 0,294 \\ 0,073 \\ 0,025 \\ 0,253 \\ 0,143 \\ 0,151 \end{bmatrix}$$

Before the end of the algorithm, the third and fourth iterations were carried out. For illustrative purposes, the next matrices for the third and fourth AHP run are placed below (Table 12 and 13):

Table 12. The results of the third pass (iteration) of the AHP algorithm

3453917,347	4927875	407021,758	1915789	4650416	528734.5	821160.2409	859152.4784
2480473.282	3539036	292308.433	1375817	3339753	379716.4	589716.0504	616999.4448
28383668.86	40496882	3344910.54	15743257	38216792	4345187	6748158.603	7060403,847
7019765.302	10015353	827231,832	3893796	9451549	1074610	1668979.386	1746201.194
2380246.034	3396033	280499.593	1320242	3204826	364379.7	565898.6656	592082.0981
24464639.25	34905482	2883133.55	13569658	32940581	3745384	5816588,559	6085770.879
13857539.4	19771278	1633058.76	7686513	18658342	2121439	3294716,458	3447177.721
14543192.13	20749583	1713886.55	8066893	19581736	2226466	3457807.133	3617832.385

Source: own elaboration

Table 13. The results of the fourth pass (iteration) of the AHP algorithm

970326782 44969.484	138441952 366948.36	114348764 77680.184	538213425 10034.891	130648054 673509.3	148544572 95247.072	230696948 12326.031	2.41372E+13
696847461 59730.055	994231271 72264.031	821204236 6703.9424	386522010 71260.633	938258810 39311.188	106678399 95695.33	165676744 75570.758	173342886 04464,826
797403565 236610.5	1.13770029 24*10^15	939705204 26461.172	442297699 787854.69	1.07365092 34*10^15	122072248 482742.48	189584140 351511.84	198356517 004884.19
197212152 529143.03	281373614 729952.56	232405890 97879.938	109388125 771444.03	265533061 163132.5	301906486 69033.391	468875460 91592.359	490571116 15351.492
668697603 72711.852	954068294 12875.094	788030861 2021.7227	370908063 27178.469	900356897 03828.922	102369018 13694.16	158984065 14667.76	166340524 91351.289
687316986 714633.38	9.81E+14	809972989 47041.609	381235719 916627.69	9.25E+14	105219406 684545.64	163410857 171463.88	170972152 055241.97
389315946 242679.69	5.55E+14	458791804 75338.492	215942786 166716.84	524188056 628707.38	595992732 03762.016	925605706 31843.234	968435037 30640.844
408584423 331217.5	582950262 741160.13	481498861 82075.227	2.27E+14	550131780 947025.81	625490296 88251,484	971416859 40407.406	101636594 945140.48

Source: own elaboration

It was noted, however, that having both the input matrix and the eigenvector, there is no certainty that the results of the criteria ranking are in fact correct. This is due to the fact that the AHP algorithm is highly sensitive to input data. Although the data acquisition was carried out among a representative and independent group of experts using the Delphi method, the data may be inconsistent with the real ones. In order to eliminate any resulting errors, the algorithm is equipped with a very helpful mechanism validating both the input data set and the operational data set. Inconsistency Index and Consistency Index (because we are talking about them) allow you to determine the degree of data quality. The estimation of the mentioned ratios is presented below (Table 14):

Table 14. Vector table of the eigenvalues and partial sums of the AHP algorithm

[Verse 1]	0.0360	0.0260	0.2940	0.0730	0.0250	0.2530	0.1430	0.1510
[Verse 2]	28.00	34.00	2.96	18.78	35.00	4.38	7.87	8.78

Source: own elaboration

The first row is the vector of eigenvalues estimated in the second, final step of the algorithm for the input data matrix. It has been appropriately transposed to a horizontal

form. Directly below it is a second row, with subtotals. They were calculated on the basis of successive columns of data from the original – input matrix, for which criteria were compared in pairs.

Stage 2. Calculating the importance of individual criteria. The parameter value was calculated λ_{max}as follows:

$$\lambda_{max} = 0{,}036 * 28{,}0 + 0{,}026 * 34{,}0 + 0{,}294 * 2{,}96 + 0{,}073 * 18{,}78 + 0{,}025 * 35{,}0 + 0{,}253 * 4{,}38 + 0{,}143 * 7{,}87 + 0{,}151 * 8{,}78 = 8{,}56749$$

$\lambda_{max}$is the maximum eigenvalue (*eingenvalue*). Then, the *Consistency Index* (CI) was calculated. The following relationship was used here:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

where: n – the number of considered criteria and the size of the input data matrix.

The formula above uses the maximum eigenvalue *that* was calculated in the previous step. In the considered case λ_{max}= 8.56749, and the "n" parameter takes the value of 8 (eight criteria and an 8x8 matrix). After substituting these data into the above relationship, the following was obtained:

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{8{,}56749}{8 - 1} = 0{,}08107$$

In order to validate the obtained CI data consistency index, Saaty , as the creator of the algorithm, proposes detecting the value of the CR index, i.e. the degree of consistency (*Consistency Ratio*). In the problem under consideration and in the nomenclature, CR is defined as the ratio of the data cohesion index (consistency) and the random consistency index RI (*Random Consistency Index*). The RI value provided by the author of the algorithm is closely related to the size of the matrix and the number of considered criteria. In the case of a larger set of features, their discriminant analysis should be considered or, alternatively, this value can be extrapolated. The relation defining the appropriate values of the "RI" coefficient depending on the size of the "n" parameter is presented below (Table 15):

Table 15. Selection of the RI parameter when calculating the consistency ratio CR (*Consistency Ratio*) (Saaty, 2012)

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.9	1.12	1.24	1.32	**1.41**	1.45	1.49

Source: own elaboration

For the present case, the value of the RI coefficient is 1.41. This is shown in the table with the appropriate specified frame contour with an index of 8 for the parameter n. The sought CR (*Consistency Ratio*) value was calculated as follows:

$$CR = \frac{CI}{RI} = \frac{0{,}08107}{1{,}41} \approx 0{,}05$$

It follows that the value of the data consistency factor is 0.05, i.e. 5%. If this result is less than 10%, the inputs match. Saaty explicitly informs that obtaining larger values indicates inconsistency in the pairwise comparison of alternatives. Therefore, all presented results are considered correct. This implies the final step in which the ranking results are interpreted, which was carried out for the main criteria for the selection of the GIS system. They constitute the first level/layer in the hierarchical structure of the tree describing the problem of choosing a solution. The order of the ranking results is determined by the individual values of the eigenvector. They have been deliberately presented here in an unordered (unsorted) form, so that the eigenvalues of the vector can be related to the appropriate group of criteria. As a reminder, before the visual presentation of the research results, a list of the estimated eigenvalues of each criterion is included.

The results of the ranking of individual criteria in the AHP algorithm. Decisions program was used in the comparative analysis. Notable screenshots from the SuperDecisions app presented in the form of tables, diagrams and charts below (Fig. 7):

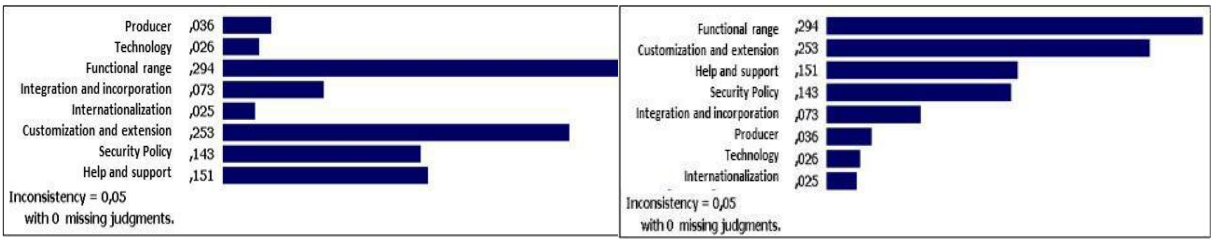


Fig. 7. Unsorted and ranked result data for the level of significance of each of the considered criteria
Source: own elaboration

As can be seen from the attached charts, the most important from the point of view of decision-makers (experts) is the functional scope of the system (i.e. the richness, abundance of the solution in modules), the possibility of its expansion, help and support provided, and the security policy that is increasingly considered. It is also mentioned that all the results obtained in the research were confirmed by carrying out all the calculations twice and obtaining certainty as to the correctness of the results obtained. All calculations were also checked using advanced mathematical environments such as Statistica and MathCAD version 14, and special, dedicated expert software SuperDecisions. In addition, it is worth emphasizing that the presented results are fully consistent with the latest surveys presented in previous chapters. These are the results of reports from, among others, the Aberdeen Group and a survey conducted in Poland for the Manufacturing Systems Information magazine "MSI Polska", Trademedia International Holding, June 2018, p. 5.

The components of the criterion taken into account in a given study for the group under consideration are presented below. In addition, subsequent matrix structures filled with appropriate values of the feature significance function, coming from experts (Delphi method), were presented. Estimated values of the IC inconsistency coefficient and obtained results of ranking (prioritization) of individual features were also given for each of the examined feature matrices. The first separated group was tagged as

"Producer" due to the common information and their superior, connecting noun, which de facto characterizes each of the individual sub-criteria. The group of criteria includes the following units (information subcriteria – Table 16; comparison matrix – Table 17):

Table 16. Information subcriteria

"First System Overall"	Information regarding the manufacturer's experience, which confirms the presence of the given vendor's product on the market;
"First Production System"	Data showing the historical period when the first system was released for the manufacturing sector;
"The first system in Poland"	Information on the introduction of the first product to the domestic market;
"Origin"	The country where the producer is registered or from;
"Representation"	data specifying a physical unit representing the manufacturer's instance in Poland;
"Documentation"	checks not only the mere physical presence of the user's manual, but also its completeness as well as the abundance and accuracy of information;
"Website"	determines the layout of the manufacturer's website and the wealth of information that may be important from the customer's point of view;
"Number of implementations"	an index showing the manufacturer's experience, thanks to the indicator, which is the so-called *track record*, i.e. the number of implemented implementations – system implementations.

Source: own elaboration

Table 17. Comparison matrix for the component features of the first package of core criteria "Manufacturer"

	Origin	representation	website	Documentation	First system overall	The first system in the country	the first production system	Number of implementations
Origin		3.0	3.0	5.0	3.0	3.0	2.0	5.0
representation			3.0	3.0	2.0	2.0	3.0	2.0
website				5.0	1.0	1.0	1.0	4.0
Documentation					7.0	7.0	9.0	3.0
First system overall						1.0	2.0	8.0
The first system in the country							2.0	4.0
the first production system								5.0
Number of implementations								

Source: own elaboration

For the matrix under consideration, the calculated IC index is 0.06, which translates into an acceptable (below the 10% limit) result of 6%. Of course, on the diagonal of the matrix, by default, there are indices equal to one, and below it – the inverse values to the estimates given by experts. On the basis of the calculated eigenvector, a priority-sorted graph of the significance level of each of the component criteria was created. Above each ranking, there is the main objective of the study, the considered components in the format Goal > current subcriteria (here: Goal: Selection of the GIS system > Manufacturer) and the value of the consistency coefficient of the decision maker's assessment IC, which, as mentioned, is 0.06 in this case (Fig. 8 and 9).

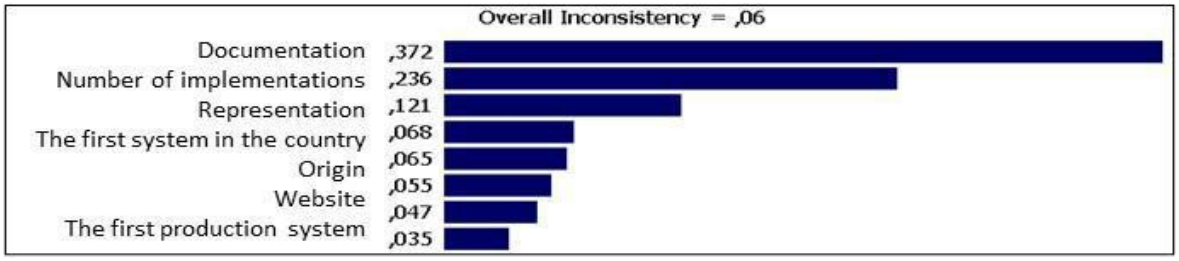


Fig. 8. Priorytetyfor the constituent characteristics
of the first main criterion – "Manufacturer"
Source: own elaboration

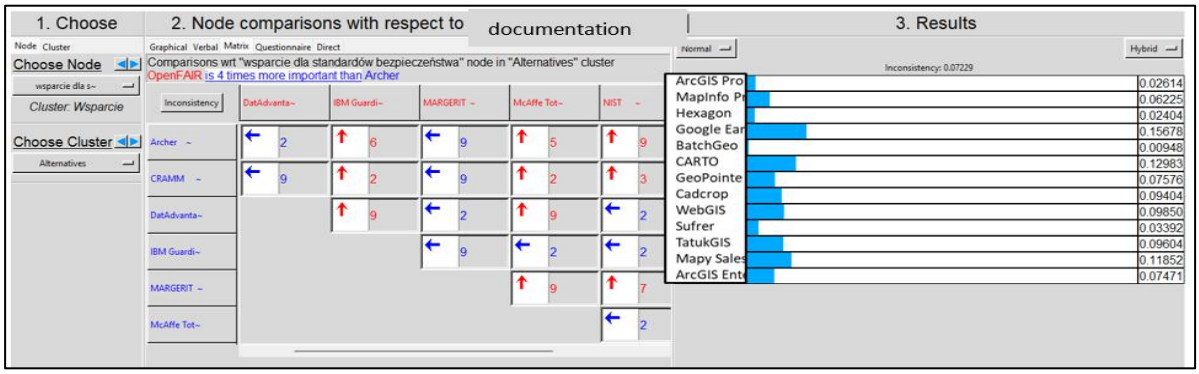


Fig. 9. Comparison of GIS in terms of the documentation subcategory
Source: own elaboration

For the remaining groups of the criterion, the results are as follows (Fig. 10):

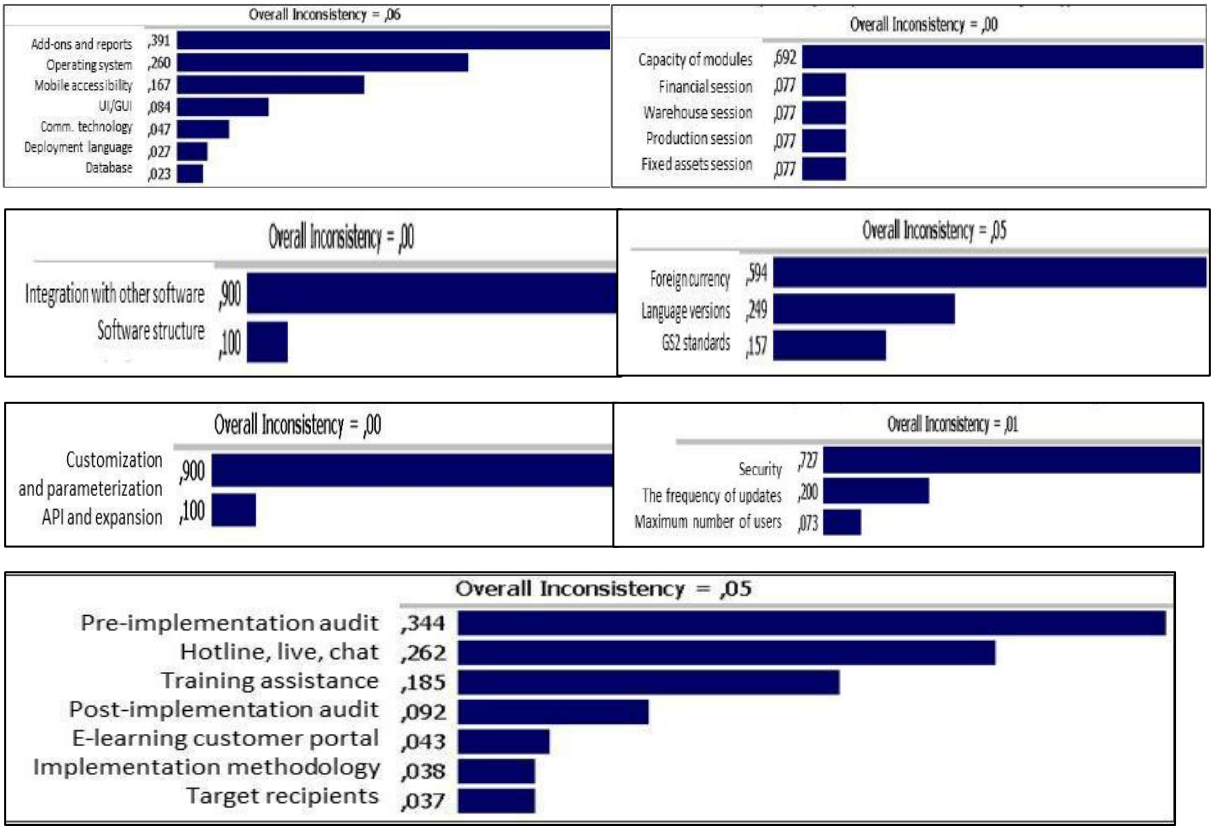


Fig. 10. Priorytetyfor the constituent features of the other seven main criteria
Source: own elaboration

The next step in the implementation of the algorithm is a mutual comparison of the considered systems in relation to each of the adopted criteria. Hence, for each of the eighteen features, tests were carried out to determine the value of the function of realization (or in other words, the degree of fulfillment) of a given criterion by the tested system. Since the actions taken so far were aimed at prioritizing the criteria and sub-criteria in relation to each other, in the next steps, all the examined systems were summarized in relation to each of the eight groups of criteria considered (Fig. 11–14). The obtained results are presented – eigenvalues *for* each of the performed numerical calculations. The results presented in tabular systems contain the gradation of results taken into account. The gradation emphasizes the fact that the results presented have been ranked in the correct order. The systems evaluated based on a given criterion were sorted according to the resulting eigenvector value. The order was made according to the decreasing degree of their intensification/intensity, i.e. from the strongest to the weakest from the point of view of the estimated eigenvalue of the system.

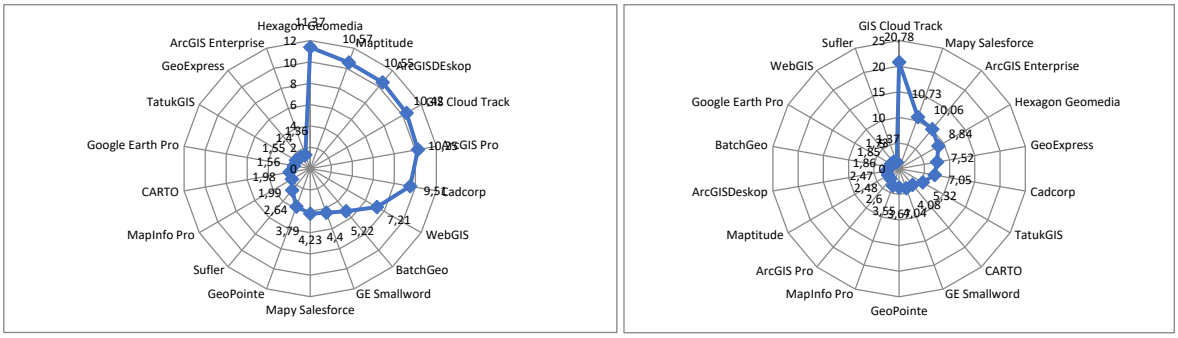


Fig. 11. Comparison of GIS systems against the first group of criteria, i.e. "Manufacturer" and "Functional scope"
Source: own elaboration

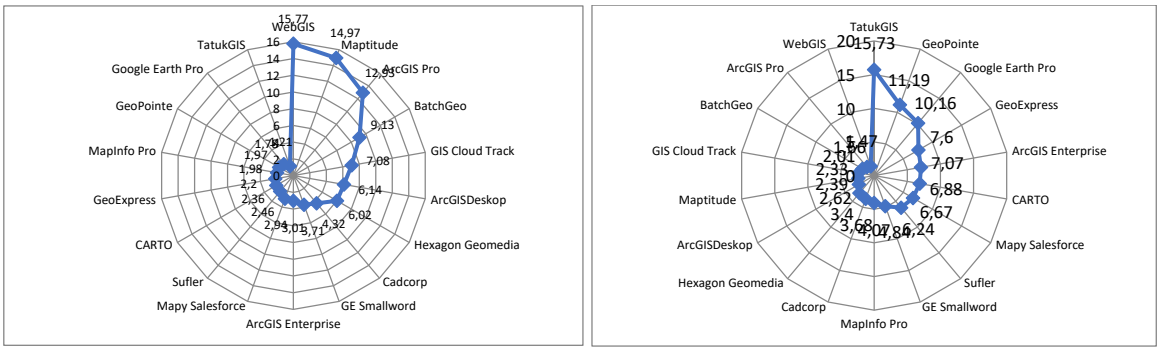


Fig. 12. Comparison of ERP systems against the third group of criteria, i.e. "Integration and incorporation " and "Help and support"
Source: own elaboration

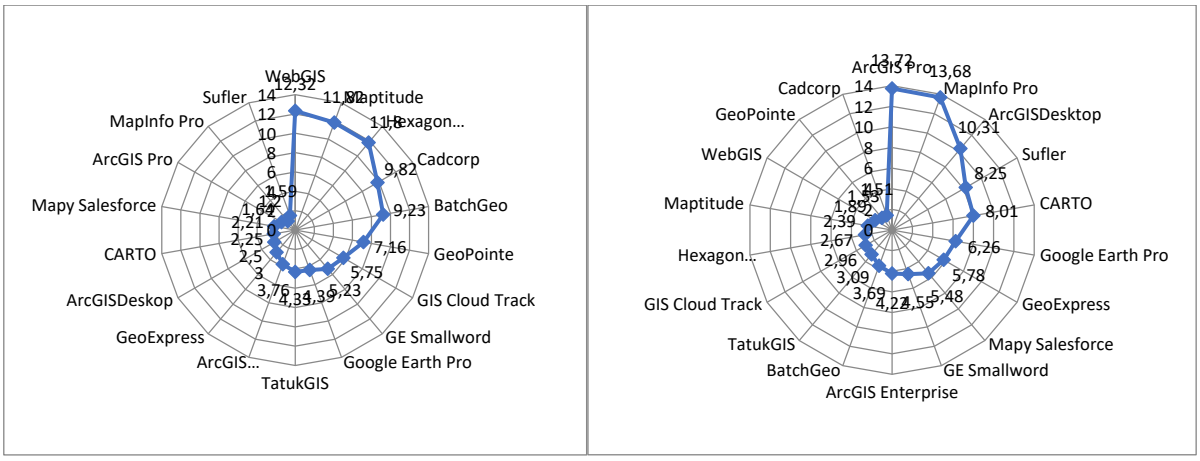


Fig. 13. Comparison of GIS systems against the fifth group of criteria, i.e. "Customization and expansion" and "Internationalization"
Source: own elaboration

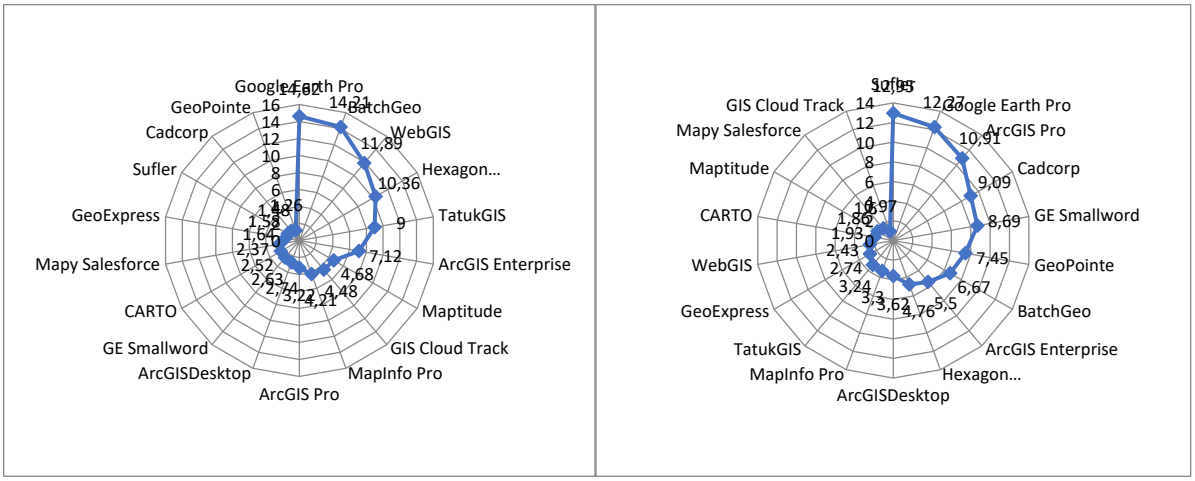


Fig. 14. Comparison of ERP systems against the seventh group of criteria, i.e. "Technology" and "Security policy"
Source: own elaboration

For each of the eigenvectors presented in this way, the checksum coefficient of the individual components of the vector and the estimated value of the IC coefficient (*Inconsistency Index*) are attached. As you can see, its value, depending on the set of expert data, fluctuates, taking the level from 4% to 8.4%, which is obviously within the AHP acceptance limits. Of course, these fluctuations are not a completely random stochastic process, as they are highly dependent on the input data that will be taken from domain experts. Therefore, it seems reasonable to use the Delphi method in the work, which guarantees the consistency and representativeness of data from independent groups of decision-makers. However, it is worth bearing in mind that these fluctuations are not random, and the value of the deviation is represented by the Inconsistency Index (IC). As a reminder, it is emphasized that when the IC exceeds the value of 10%, then the process of data acquisition from experts should be repeated. Then, due to the variance between the individual pieces of information, the data are inconsistent and cannot be a representative carrier of the resulting information in the

considered problem issue (according to the assumptions of the AHP strategy). Below (Table 18) is a summary of the obtained eigenvectors of each group of criteria in relation to the eighteen tested GIS class systems. For each system, the value of the own index was presented, which was calculated when comparing the product with competitive solutions for the subsequent groups of comparative criteria considered.

Table 18. Obtained eigenvectors for the eighteen tested systems

	Producer	functional scope	Integration and incorporation	Help and support	Customization and expansion	internationalization	Technology	security policy
Cadcorp	9.51	7.05	4.32	3.68	9.82	1.51	1.48	9.09
MapInfo Pro	1.99	3.55	1.98	4.07	1.2	13.68	4.21	3.3
GeoExpress	1.4	7.52	2.2	7.6	3	5.78	1.64	2.74
BatchGeo	5.22	1.86	9.13	2.01	9.23	3.69	14.21	6.67
GIS Cloud track	10.42	20.78	7.08	2.33	5.75	2.96	4.48	0.97
GeoPoint	3.79	3.67	1.97	11.19	7.16	1.53	1.26	7.45
TatukGIS	1.55	5.32	1.21	15.73	4.33	3.09	9	3.24
GE Smallword	4.4	4.04	3.71	4.84	5.23	4.55	2.63	8.69
ArcGIS Enterprise	1.36	10.06	3.01	7.07	3.76	4.22	7.12	5.5
Google Earth Pro	1.56	1.85	1.78	10.16	4.39	6.26	14.62	12.27
CARTO	1.98	4.08	2.36	6.88	2.25	8.01	2.52	1.93
Salesforce maps	4.23	10.73	2.94	6.67	2.21	5.48	2.37	1.6
WebGIS	7.21	1.73	15.77	1.47	12.32	1.89	11.89	2.43
hexagon Geomedia	11.37	8.84	6.02	3.4	11.8	2.67	10.36	4.76
Prompter	2.64	1.37	2.46	6.24	1.59	8.25	1.58	12.95
ArcGISDEscope	10.55	2.47	6.14	2.62	2.5	10.31	2.74	3.62
ArcGIS Pro	10.25	2.6	12.93	1.66	1.64	13.72	3.22	10.91
maps	10.57	2.48	14.97	2.39	11.82	2.39	4.68	1.86

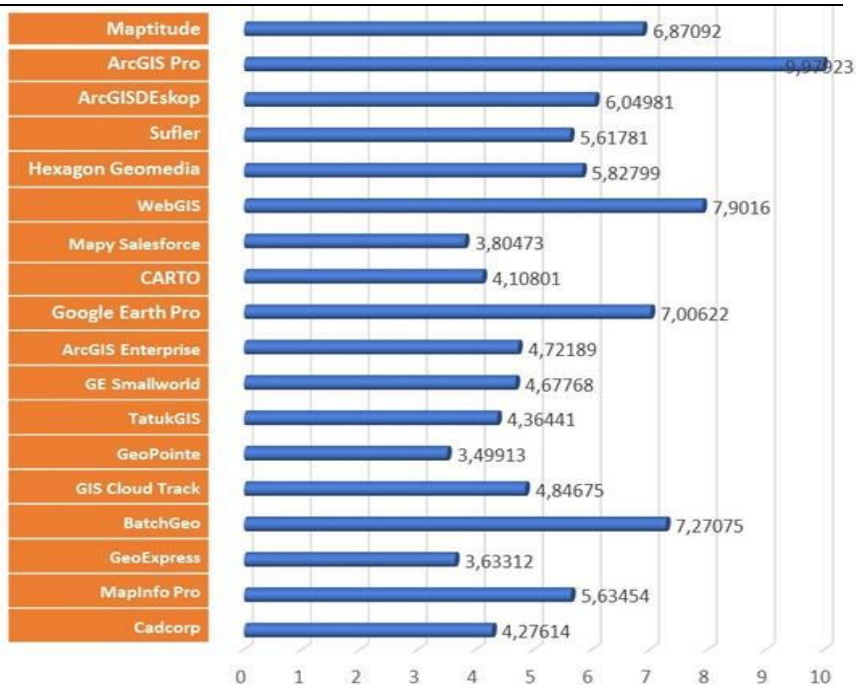
Source: own elaboration

The result vectors presented below are the searched solution that ranks the systems according to the assumed characteristics. The chart below (Table 19) presents the final results of the selection of the GIS class system based on the Analytic Hierarchy Process strategy and a wide, comprehensive set of comparative criteria.

According to calculations based on expert data, the best system in terms of the considered set of criteria is ArcGIS Pro (Table 20). It can be seen that it significantly differs from competing products, achieving an advantage over the second, WebGIS, equal to 2.07763 adopted function points. It is worth noting that the difference between the obtained results is not large, which indicates a very similar nature of the studied GIS systems. The final ranking of the tested systems after normalization of the results is as follows (Table 20).

Table 19. Validation and comparison of calculation results. Calculation results, obtained analytically and manually (which were then compared with those calculated in the Micfosoft Office Excel 2017 spreadsheet)

9.979	**ArcGIS Pro**
7.901	**WebGIS**
7,270	**BatchGeo**
7.006	**Google Earth Pro**
6,870	**maps**
6,049	**ArcGISDEscope**
5.827	**hexagon Geomedia**
5.634	**MapInfo Pro**
5.617	**Prompter**
4,846	**GIS Cloud track**
4,721	**ArcGIS Enterprise**
4.677	**GE Smallword**
4.364	**TatukGIS**
4.276	**Cadcorp**
4.108	**CARTO**
3.804	**Salesforce maps**
3.633	**GeoExpress**
3,499	**GeoPoint**



Source: own elaboration

Table 20. Ranking of the tested systems after normalization of the results

The name of the GIS system	Position	Estimated value after normalization
ArcGIS Pro	1	1
WebGIS	2	0.791804578
BatchGeo	3	0.728588278
Google Earth Pro	4	0.702080221
maps	5	0.68852206
ArcGIS Desktop	6	0.606240161
hexagon Geomedia	7	0.584011993
MapInfo Pro	8	0.56462673
surfer	9	0.562950248
GIS Cloud track	10	0.485683765
ArcGIS Enterprise	11	0.473171778
GE Smallworld	12	0.468741576
TatukGIS	13	0.437349375
Cadcorp	14	0.428504003
CARTO	15	0.41165601
Salesforce maps	16	0.381264887
GeoExpress	17	0.36406817
GeoPoint	18	0.350641282

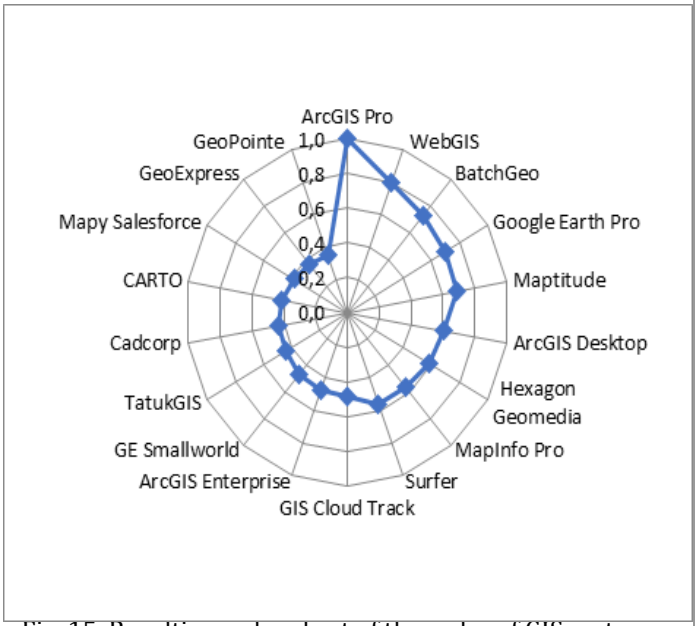


Fig. 15. Resulting radar chart of the order of GIS systems after being ranked against all comparison criteria
Source: own elaboration

Source: own elaboration

It is very important that the obtained results fully coincide with the initially assumed predictive results of the statement. The results obtained in the study are identical to those expected, which resulted directly from the acquisition procedure when familiarizing with the system. Already at the time of data acquisition, the advantage and dominance of certain solutions over competing products was noticed, while the study fully confirms the assumptions as to the order of GIS systems in the comparison. This is a key fact from the point of view of work. The AHP method, despite being sensitive to data and classified as a heuristic strategy, gives very good results that are fully representative. You can validate the results based on your knowledge of the domain of the study being dealt with. A full coverage of considerations is noticeable here, which were justified in an inductive way, proving numerically all conjectures.

Conclusion

The main purpose of this article was to analyze the GIS class systems available in the professional literature and the Internet and to perform a comparative analysis using the AHP method in order to select the best geoinformation solution in terms of selected criteria. It is also noted that out of the plethora of materials that have been known and ever encountered, the assessment method presented in this paper is rarely used. Few people evaluate the same set of objects (here: GIS systems) using several different, completely different approaches. Unfortunately, currently there is a noticeable trend in which methods dedicated to the adopted and defined assessment result are most often used, hence an innovative approach was used in the work, in which a set of eighteen systems was evaluated based on various strategies, the results of which were synthesized using the AHP method. In the comparison, the most important of the criteria were used, because the use of all of them (which were only a suggestion) did not have a major impact on the real comparison. It should be taken into account that the comparison of GIS with each other was based on the subjective assessment of the author. The results obtained in the work fully agree with the current state, which characterizes the considered set of GIS systems. At the same time, it is mentioned that the obtained results should be treated as advice and guidance in the decision-making process.

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COMPARATIVE GIS ANALYSIS USING TAXONOMY AND CLASSIFICATION TECHNIQUES

Abstract: The article discusses the methodology of comparative analysis of GIS class computer systems using the current elements of taxonomy and classification theory. Eighteen selected GIS class systems that meet the criterion of completeness of all data required in the conducted research were fully analyzed. The proper comparative characteristics were preceded by the recognition of the market situation in terms of the availability of GIS systems. Eight thematic groups of criteria were used in the research, based on which the selection of GIS solutions for comparison was carried out. The adopted system selection criteria carry out the selection of objects in a binary manner. The chosen rules of classifying the system into a set of objects for comparison covered the issue of the availability of the required information. Due to the characteristics carried out, this information was obligatory, because a full set of data is required, which will allow for a comprehensive and factual comparison, based on which a given product (GIS system) can be indicated to the consumer with full responsibility. The set of features and comparative criteria was created based on own experience and numerous consultations with specialists and field experts. The selected criteria are the most widely used and most accepted in the environments that systems of this class use daily. Both the functional scope (features, functions, properties, advantages and disadvantages) as well as the degree of fulfillment of subsequent criteria by the considered systems were determined and described.

Keywords: GIS, classification, estimators, hierarchical methods

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Introduction

The development of geoinformation technologies and methods of geodata analysis in the early dz2000s ąbrought classification and taxonomy to a qualitatively new level. Many sciences developed independently of each other. Therefore, in publications on classification issues, one can find special cases of methods that were already known and systematized in the statistics used at that time. The article discusses the current issues of the use of classification and taxonomy in relation to geoinformation systems in the field of comparative analyses. The problems of GIS classification for the purpose of conducting comparative characteristics have been studied in the works of many authors (Miłek et al., 2023a; Miłek et al., 2023b; Xuan, 2015). There are also materials on the subject on the Internet, as well as in foreign sources (Zhang et al., 2917; Lubis et al., 2017; Neema et al., 2020; Risky, 2018).

In this article, the overarching goal of GIS classification is to determine the similarity of individual instances and their clusters (i.e. classes). Generally, the classification can be defined as a division of the set of considered objects – here GIS systems into classes, containing such objects that will be similar in terms of the observed values of their features. It is very important here that the objects allocated in different classes have the greatest possible differences. They should show the greatest correlation within the cluster – class. Hence, a well-conducted classification guarantees the fulfillment of the two postulates: internal coherence and external isolation.

The purpose of this article is to present the methodology of selection, ranking and classification of GIS enabling the selection of a properly tailored and effective solution for a given enterprise. The problem is not trivial, but difficult. Therefore, this paper presents its own way of thinking and several techniques that can be used by a decision maker in making everyday decisions. It is important and repeatedly emphasized that all these techniques are universal and can be applied to almost any problem that can be encountered today.

The results obtained both by means of multi-criteria optimization in the sense of PARETO or classification can and very often constitute a kind of help, guidance and advice in decision-making, however, one should not base one's choice solely on them. As indicated at the research stage, these methods are characterized by high sensitivity (sensitivity) to data, and their proper implementation is associated with the meticulousness, knowledge and precision of the researcher.

Assumptions and literature review

The GIS software industry includes a wide range of commercial and open source products that provide some or all of these capabilities under various information technology architectures (Fu & Sun, 2010).

With the transition to networking and cloud computing, and integration with real-time information via the Internet of Things, GIS has become a vital platform for almost every human endeavor – enterprise GIS. Table 1 lists notable types – Enterprise GIS.

Table 1. Types of GIS – Enterprise GIS

GIS type	Characteristic (reference to literature)
Enterprise GIS	Enterprise GIS refers to a geographic information system that integrates geographic data across multiple departments and supports the entire organization (Chang & Kang-tsung, 2016). The basic idea of enterprise GIS is to deal with the needs of departments collectively, not individually. When organizations began using GIS in the 1960s and 1970s, the focus shifted to individual projects where individual users created and maintained datasets on their own desktop computers. Due to the extensive interaction and workflow between departments, many organizations in recent years have moved from independent, standalone GIS systems to more integrated approaches that share resources and applications (Goodchild, 2010).
Corporate GIS	A corporate geographic information system is similar to enterprise GIS and meets the needs of the organization as a whole in terms of spatial information in an integrated manner. Enterprise GIS consists of four technological components, which are data, standards, information technology, and expertise personnel. It is a coordinated approach that moves away from fragmented desktop GIS. The corporate GIS project involves the construction of a centralized corporate database, which is to be the main resource for the entire organization. The enterprise database is specifically designed to efficiently and effectively meet the requirements of the organization. Essential to enterprise GIS is the effective management of the enterprise database and the establishment of standards such as the OGC for mapping and database technologies. The benefits include that all users in the organization have access to shared, complete, accurate, high-quality, and up-to-date data. All users in the organization also have access to common technology and people with knowledge. This improves the efficiency and effectiveness of the organization as a whole. An effectively managed corporate database reduces unnecessary collection and storage of information throughout the organization. By centralizing resources and efforts, it reduces overall costs (Somers, 1996; Vastag et al., 1994; Weil & Broadbent, 1994).
Internet GIS	Internet GIS, or online geographic information systems, is a term that refers to a broad set of technologies and applications that use the Internet to access, analyse, visualize and distribute spatial data (Broome & Meixler, 1990; Fitzgerald, 2007; MacHarg, 1971; Tobler, 2009). Web GIS (also known as Web-Based GIS) or Web Geographic Information Systems is a GIS that uses the World Wide Web to facilitate the storage, visualization, analysis and distribution of spatial information on the Internet (www.esri.com; www.wiki.osgeo.org; Xuan, 2015).
Mobile GIS	With ~80% of all data considered to have a spatial component, modern Mobile GIS is a powerful geocentric business process integration platform enabling Spatial Enterprise (Fu & Sun, 2010). The number of mobile devices in circulation surpassed the world's population (2013) thanks to the rapid acceleration of the use of iOS, Android and Windows 8 tablets. Tablets are rapidly becoming popular in field applications. Affordable MIL-STD-810 certified cases transform consumer tablets into fully ruggedized yet lightweight devices for field use that cost 10% of older ruggedized laptops. While not all mobile GIS applications are device-limited, many are. These restrictions apply more to smaller devices such as mobile phones and PDAs. Such devices have: small screens with poor resolution, limited memory and computing power, weak (or no) keyboard and short battery life. Additional limitations can be found in web client-based tablet applications: poor graphical web interface and device integration, on-line reliance, and very limited off-line network client cache (www.wiki.osgeo.org; Weill & Broadbent, 1994).

Source: own study

Some of the potential benefits that an enterprise GIS can provide include greatly reduced system-wide data redundancy, greater accuracy and integrity of geographic information, and more efficient use and sharing of data (Maliene et al., 2011). Since data is one of the most important investments in any GIS program, any approach that reduces acquisition costs while maintaining data quality is important. Deploying enterprise GIS can also reduce overall GIS maintenance and support costs, ensuring more efficient use of departmental GIS resources. Data can be integrated and used in decision-making processes throughout the organization (Maliene et al., 2011).

GIS today gives people the ability to create their own digital map layers to help solve real-world problems. GIS has also evolved into a means of data exchange and collaboration, inspiring a vision that is now rapidly becoming a reality – a continuous, overlapping and interoperable GIS database around the world covering virtually all topics. Today, hundreds of thousands of organizations share their work and create billions of maps every day to tell stories and reveal patterns, trends, and relationships about everything. GIS is all about discovering meaning and insights from within data. It is rapidly evolving and provides a whole new framework and understanding process.

As our world faces issues of increasing population, loss of nature and pollution, GIS will play an increasingly important role in how we understand and solve these problems and provide the means to communicate solutions using a common mapping language.

Review of the studied GIS systems

There are plenty of GIS systems on the market, designed for a wide range of applications. Many of the offered solutions come from various domestic and foreign companies. To illustrate the number of foreign players and market tycoons, a summary in the form of the Gartner magic quadrant was presented (Fig. 1).

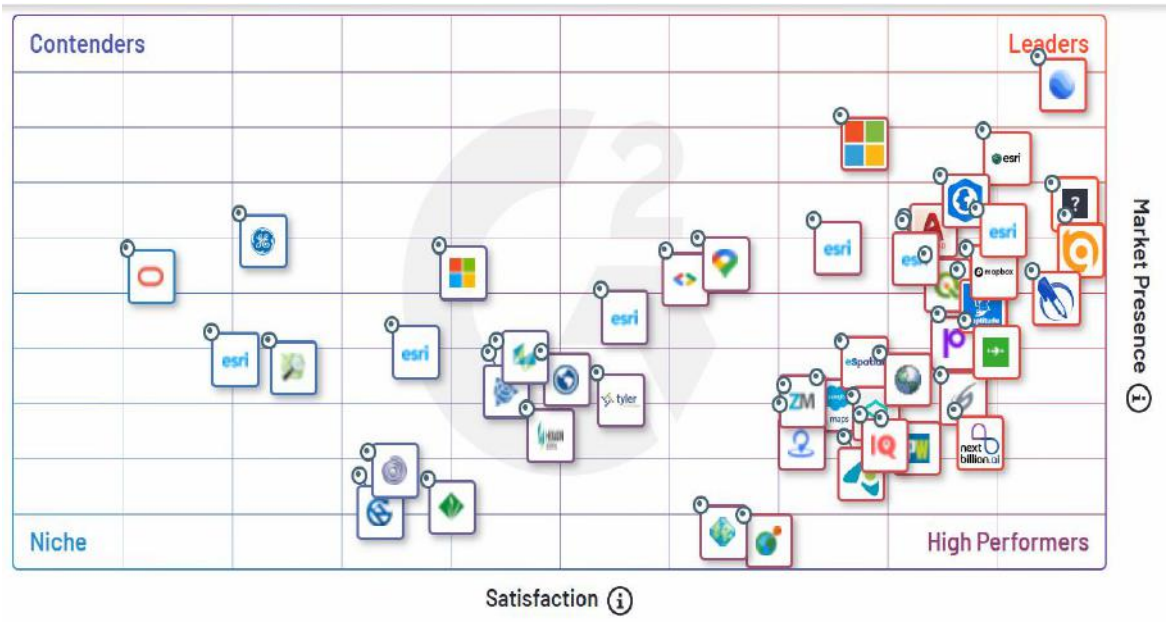
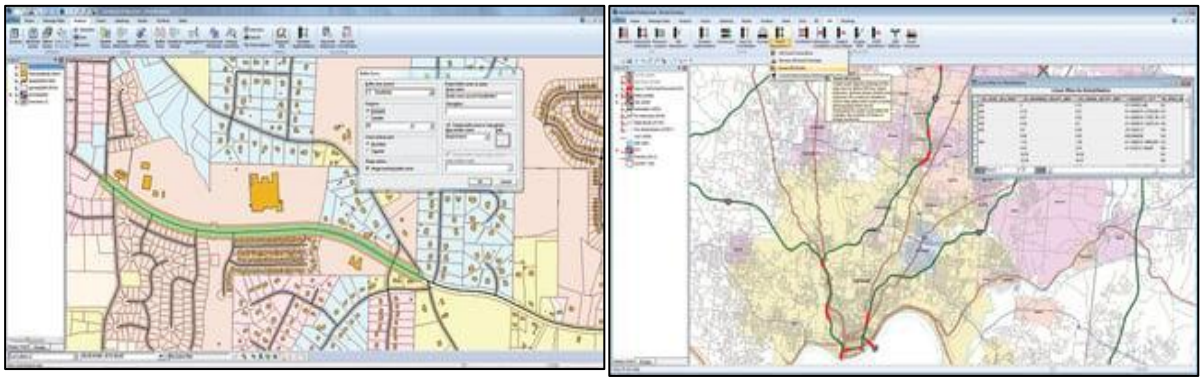


Fig. 1. G2 Grid® for GIS
Source: own study

Bearing in mind the limitations of the article, only six systems will be characterized in this subchapter: Hexagon GoeMedia, MapInfo Pro, Surfer, GIS Cloud Track, ArcGis Enterprise and GE Smallword. Other GIS can be found in studies (Miłek et al., 2023a; Miłek et al., 2023b; Mironova, 2018; Mironova, 2020).

Hexagon GeoMedia – GIS software with a powerful set of remote sensing tools. It is a powerful, flexible GIS management platform that allows you to aggregate data from various sources and analyze them in unison to extract clear, actionable information. It provides simultaneous access to geospatial data in almost any form and displays it in one unified map view for efficient processing, analysis, presentation and sharing. It is a comprehensive and dynamic GIS that extracts intelligence from geospatial data. This app can access geospatial data directly; There is no need to import, convert or use proprietary technologies to connect to spatial databases. The most popular versions of Hexagon GeoMedia are Desktop 16.0 and 15.0. The actual developer of the software is Hexagon Geospatial. Official screenshots:



Basic functions:
GeoMedia's functionality makes it ideal for extracting information from a range of dynamically changing data to support informed, smarter decision making. functional scope:
Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Creating a map:

- Buffer zone query.
- Overlaying.

Analysis:

- Spatial analysis.
- Reporting.

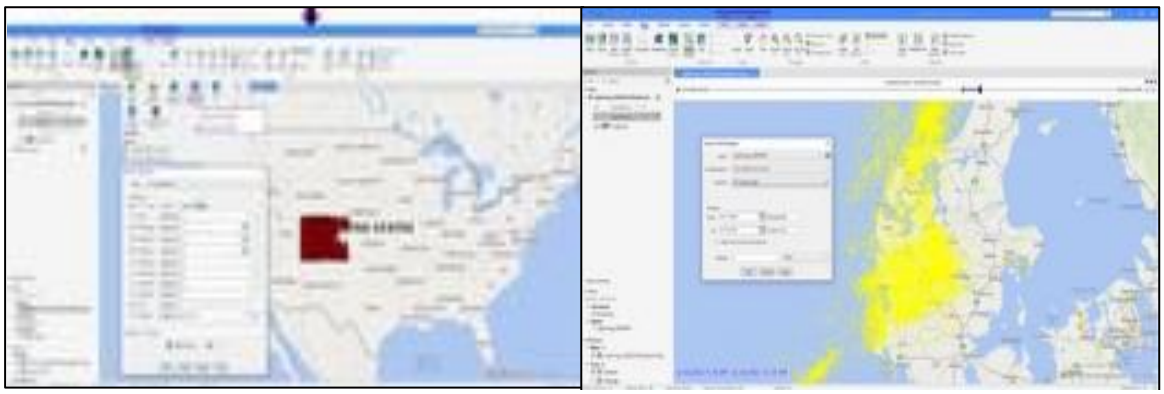
Pros:

- Fast query and analysis.
- Robust cartography with smart labelling.
- Remote sensing with ERDAS Imagine.
- Universal mapping with multiple layouts.
- Perfect editing with smart snapping.
- Mature software with 40+ years of history.

Minuses:

- Confusing license levels.
- A small community of users to troubleshoot.
- You cannot drag and drop files into GeoMedia.
- Poor interoperability with other GIS formats.
- Database connectivity can be slow.

MapInfo Professional. GIS software with a focus on business and location intelligence. MapInfo Professional is a well-rounded GIS software suite with a greater focus on business decision making. It is based on location intelligence like GeoMedia . MapInfo Pro works with a variety of spatial data formats and many types of databases. Data imported to the program are displayed in the form of layers consisting of a map and a table of attributes. This enables the integration of data from e.g. Microsoft Excel, Access or database servers (Oracle, PostgreSQL , etc.) with the map, and then their visualization. Official screenshots:



Basic functions:

MapInfo Pro is a GIS class program that allows you to create, manage and update spatial data. With its help, you can visualize and analyze data on maps, as well as successfully build advanced spatial information systems. functional scope:

Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Creating a map:

- Geocoding.
- Data vectorization.
- Generating spatial queries.
- Editing objects on the map and in tabular data.
- Visualization of data on a map from external data sets.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.
- Spatial analysis of customer locations.
- Analysis of the potential of the regional market.
- Analysis of the scope of competition.
- Distribution network analysis.

Cartography:

- Map design.
- Data visualization.
- Overlaying.

Pros:

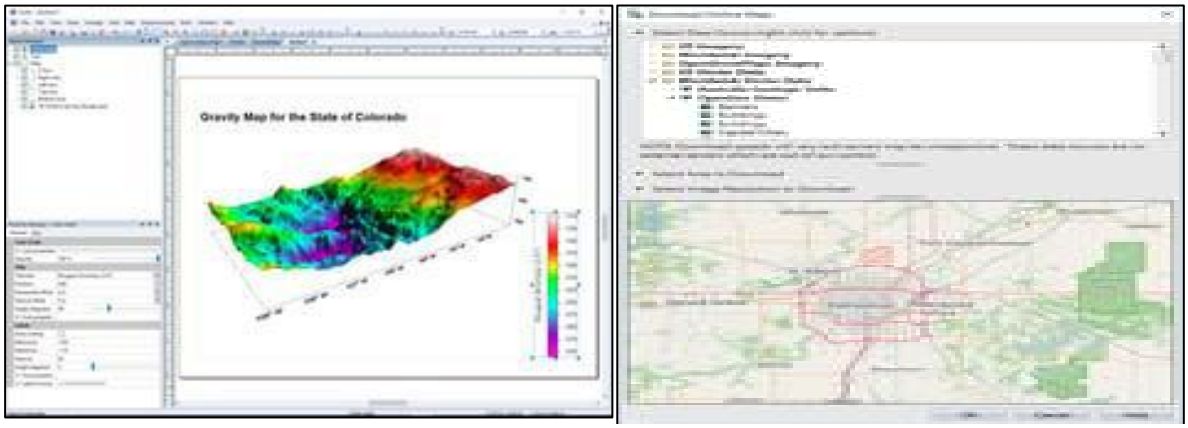
- Ease of use and 64-bit processing.
- Query execution and improved table management.
- Advanced addressing and geocoding.
- Side-by-side mapping.
- Improved visualization integration.
- Smart ribbon-based navigation.

Minuses:

- Data processing and analysis will take a long time.
- Interoperability and poor format support.
- High license cost.
- No cloud-based platform.
- Low functionality of online web maps.
- Weak support for remote sensing analysis.

SURF. Product by Golden Software, Inc. Surfer ® is a full-featured 2D and 3D mapping, modeling and analysis software package for scientists and engineers. Surfer's advanced interpolation engine quickly converts XYZ and XYZC data into publication-quality maps. Virtually every aspect of the map can be customized. Enhance your maps with profiles, legends, titles and labels, faults and breaklines, or external maps from any online map service. The Surfer is widely used by geologists, geophysicists, hydrologists, archaeologists, oceanographers, biologists, consultants, engineers and many others around the world. Thanks to its basic features, Surfer has

been used primarily for creating maps. It not only allows you to create contour maps and their spatial images, but also allows you to make calculations based on a regular grid of values. Specialized procedures allow you to generate map sections along any selected polyline. The program allows you to calculate the area of curvatures, the area of projections on the XY plane and volumes. Official screenshots:



Basic functions:

Surfer ® 25 is a program designed for comprehensive visualization of XYZ data, thanks to which it is most often used for mapping and modeling terrain surfaces, but this is not the only application of this program. The built-in wide set of interpolation methods for generating a regular grid of values allows you to choose the optimal algorithm for the nature of the input data.

Functional scope:

Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Create a map:

- Geocoding.
- Buffer zone query.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.

Advantages:

- Is the easiest to use contouring, meshing and surface mapping software.
- It is very accurate and helps you to design the best rough map with grids.
- Has a wide selection of mapping methods and tools, including all known and tested grid algorithms.

- It has more map types including vector, wireframe and base unlike other apps.
- Does not require high-capacity machines.

Defects:

- It is difficult to manage.
- No direct integration with ESRI.
- Map resolutions are not at the best level.
- Sometimes the interpolation was not very accurate.
- No in-depth analytics like other comparable platforms.

GIS Cloud Track – Track your fleet, people and assets. GIS Cloud Track – is a new generation platform for applications that manage location information. GIS Cloud Track allows you to dynamically visualize your assets in real time, track their location, and get detailed reports, charts, and historical data based on multiple parameters. Official screenshots:

Basic functions:

GIS Clouds Track supports multiple vector and raster formats, rich GIS symbology, and has built-in collaboration features for real-time editing and sharing. functional scope:

Data management"

- Data storage.
- Data manipulation.
- Data visualization.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.

Pros:

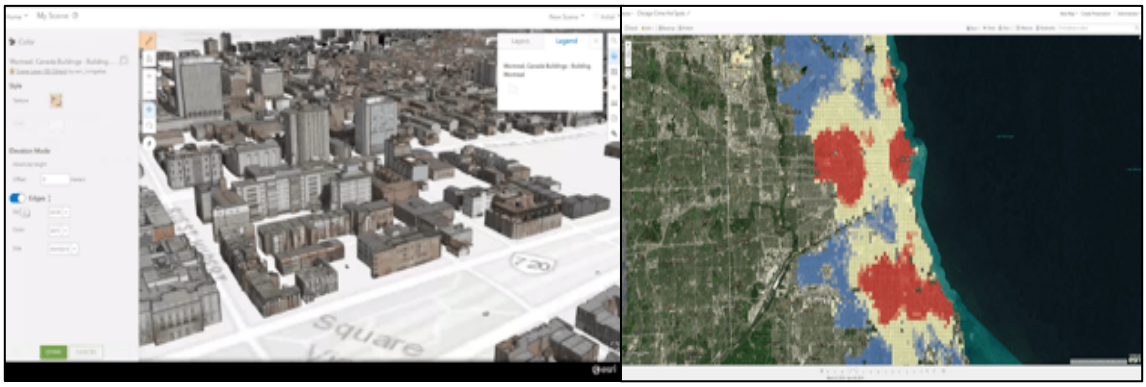
- Extensible with ArcGIS , QGIS and WhiteBox tools.
- Reads many formats.
- Publishing web maps via MangoMap.

Cons:

- Poor symbols and print layouts.
- Editing tools are not reliable.
- No new technologies.

- Limited cartography, labeling and symbolization.
- There is no data management directory.
- Metadata cannot be saved or edited.

ArcGIS Enterprise. ArcGIS Enterprise is a full-featured mapping and analysis platform that includes a powerful GIS server and a dedicated web-based GIS infrastructure to organize and share your work. ArcGIS Server Enterprise consists of four major software components, such as ArcGIS Server, Portal for ArcGIS , ArcGIS Data Store , and ArcGIS Web Adapter . These components facilitate the creation of web-based spatial data management and sharing systems that can be run on both local and cloud platforms. The online system consists of options for publishing, managing, organizing, customizing and downloading spatial data. This allows users to work in an integrated environment and helps create efficient geospatial workflows . In addition, it can support advanced image processing, real-time analytics, and big data integration with additional license purchases. Official screenshots:



Basic functions:
ArcGIS Enterprise provides a secure, browser-based mapping and analytics platform that leverages Esri 's advanced technology to extend big data, imagery, and more in real time. functional scope:
Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Create a map:

- Geocoding.
- Buffer zone query.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.

- Reporting.
- Streaming in time of things.

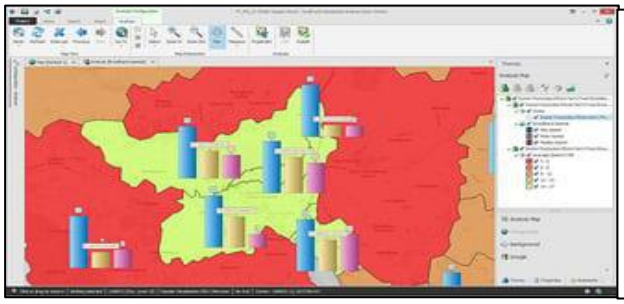
Advantages:

- Very easy to use and to create a quick web map.
- Best of all, geography and track logging.
- Can create apps without coding; easily share data within your organization and publicly.
- ArcGIS is very user – friendly; This mapping app allows for quick and organized data collection. You can run the program on a computer on a portable device such as an iPhone.
- The centrality of the tool is extremely helpful and allows you to collaborate and build solutions to all your geospatial problems as well as assist with hosting solutions.

Defects:

- You cannot migrate directly from bigdata or teradata.
- There are some bugs in the software that cause delays and problems randomly and there is no pattern to solve them, and they require extreme patience and can be annoying at times.
- Receiving data online is not good; data download is quite slow.

GE Smallworld. GE's market-proven comprehensive suite of integrated tools enables customers to reduce cost of ownership, simplify critical network infrastructure, and provide the flexibility required to meet dynamic network requirements. This revolutionary, object-oriented, database-driven product provides an efficient, consistent architecture at the heart of many applications, such as those used to plan electricity, gas and water distribution systems, design telecommunications networks and evaluate strategic market opportunities. The software integrates with other products that require spatial information, including systems for customer relationship management, market analysis, network and work management. The architecture is built on open technology standards and supports scaling to the largest customer needs. Deployment options using industry-leading technology platform solutions. Official screenshots:



Basic functions:
GE's innovative networking software is mainly based on Smallworld ™ Core technology Spatial Technology. Smallworld Core provides a comprehensive portfolio of solutions that support critical processes in planning, designing, building, operating and maintaining the lifecycle of network-intensive industries. functional scope:
Data management:

- Data storage.
- Data manipulation.
- Data visualization.

Creating a map:

- Geocoding.
- Overlaying.
- Spatial analysis – GIS.
- Reporting – GIS.
- Data visualization – GIS.

Advantages:

- The ability to capture detailed network inventory and connectivity between network elements.
- Stability and speed compared to other platforms.
- Smallworld was very detailed and allowed the company to tailor the product to what it felt was important.
- It has many positives for the GIS Utilities market.

Defects:

- The mapping capabilities and some spatial queries from a user perspective are quite limited.
- A bit more complex than other platforms; harder to learn.
- Bulk data loading is the biggest problem and makes it not very useful for the initial customer.

Methodology

The following concept of conduct was adopted in the study. Comparison criteria and rules for the selection of GIS systems for comparison were defined. Then, factors were specified, which, based on the research and experience, are considered critical in the process of selection and implementation of appropriate GIS class solutions. The most important selection criteria – selection of systems were indicated and on their basis a list was prepared and a comparative analysis of GIS systems was carried out. The comprehensive characterization was carried out based on a number of experiences, interviews and information obtained from many different sources, ranging from periodicals and industry literature with a high eigenfactor, to websites and consultations with system manufacturers. However, environmental conditions made companies reluctant to share any information about their products. Most of the data was very general.

Due to the large number of GIS systems on the market, it is impossible to obtain information about all products. The main difficulties were related to the acquisition of the necessary materials. Therefore, for the purpose of comparison, the following rules have been defined, according to which the solutions operating on the market will be classified into the set of compared systems:

- the system selection criteria were tailored to the needs of the small and medium-sized enterprise (SME) sector,
- the selection of systems for comparison was based on the binary technique, in which the presence of any information in the aspect of eight thematic groups of criteria was detected,
- the size of the considered set of studies consists of GIS systems selected from all available on the world market today, source " systems, but to be a true GIS, the system must contain a significant group of components (Fig. 2.)

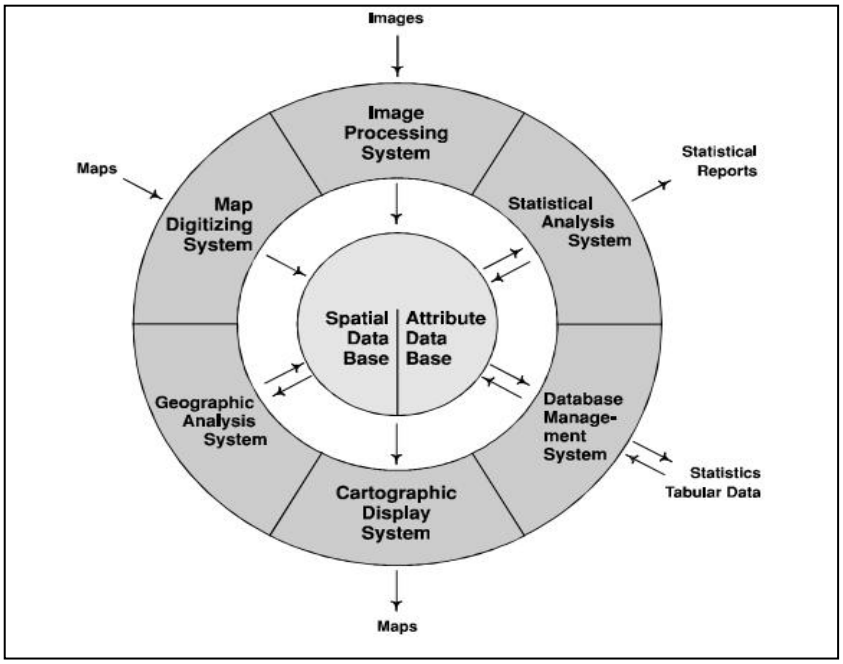


Fig. 2. Basic components of the GIS system
Source: own study

It is also mentioned that the list was based on a number of own experiences, as well as the experience of people who are closely related to the GIS class under consideration.

Since the implementation of the work objective requires a mutual comparison of the examined systems, in the second step, the criteria for comparing selected GIS solutions were selected. Previously, a selection of the market was carried out, during which a classification (depending on the adopted rules and selection criteria) of subsequent systems dedicated to small and medium-sized enterprises (SMEs) was carried out. When comparing the systems, decomposed component criteria (sub-criteria, sub-criteria) of eight, thematically aggregated groups of main features were used, on the basis of which

the systems for the study were classified. Hence, the current criteria are a subset of the features that were used to select GIS systems for comparison.

The adopted comparative criteria have been presented in a hierarchical form, grouped into appropriate thematic classes using a mindmap scheme (Fig. 3):

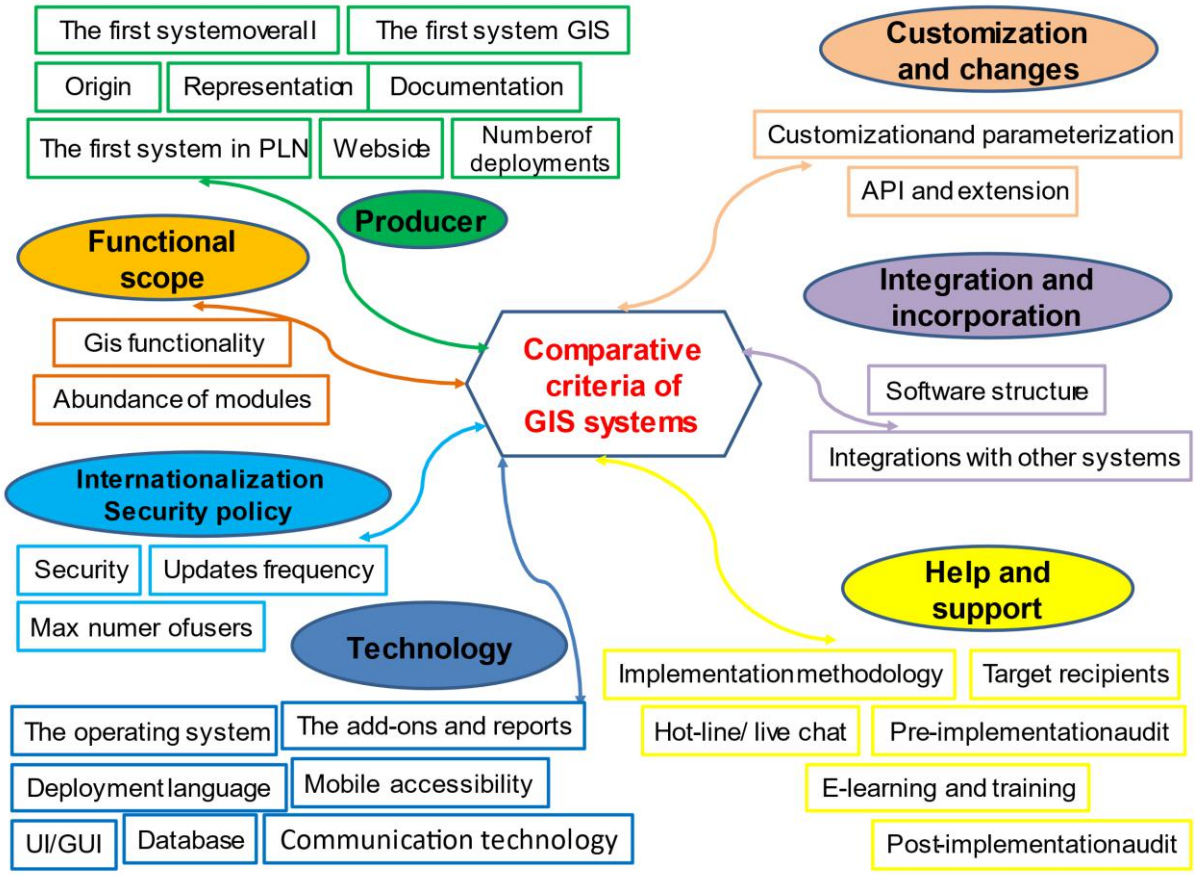


Fig. 3. Groups of comparative criteria of the considered GIS class systems
Source: own study

Eight thematic groups of criteria were used in the research, based on which the selection of GIS solutions for comparison was carried out. The adopted criteria for the selection of systems carry out the selection of GIS in binary way . If a given criterion is not met (required information not obtained), then the GIS is excluded from further consideration and analysis . The chosen rules for the classification of the GIS system for the set of objects to be compared covered the issue of the availability of the required information. Due to the characteristics carried out, this information was obligatory, because a full set of data is required, which will allow for a comprehensive and factual comparison, on the basis of which z a given product (GIS system) can be indicated to the consumer with full responsibility. In further research, thematic groups of features were decomposed into sub-criteria (component sub-criteria), incl based on which a proper comparison of the systems under consideration was carried out .

When considering the problem of selecting the appropriate GIS class system, classification methods were used. For the normalized form of data, classification was carried out using agglomeration combinatorial methods, for which distances were

estimated using the Euclidean metric (i.e. for p=2). The performed classification grouped and allocated the considered objects to particular classes. The direct result of the classification of objects is the resulting matrix, while its visual representation is presented later, using the created dendrogram of objects. It presents (dendrogram) in a very legible way individual categories to which each of the eighteen considered systems was allocated.

The presented dendrogram is a graphical result of the classification of the eighteen considered systems. In order to be able to more accurately interpret its structure, the idea of classifying using hierarchical and non-hierarchical methods was outlined.

When making a proper analysis of the obtained results, the presented dendrogram should be carefully analyzed. It presents in a graphic way the division of the set of examined GIS systems, obtained in the process of its classification. When grouping objects, the mathematical apparatus turned out to be very helpful, which showed the degree of correctness and quality of the model through a set of appropriate indicators (indicators).

Result and discussion

In relation to GIS-class systems, classification and taxonomy are methods of organizing and categorizing geoinformation solutions in a form that people are able to understand. These are tools that allow us to maintain GIS computer systems so that they can be easily compared and contrasted. For the purposes of this article, the classification is defined as a set of clusters (in other words, clusters or classes) of the form:

$$K = \{K_1, K_2, \dots, K_n\},$$

which are appropriately highlighted in the set O defined as the following set O of objects:

$$O = \{O_1, O_2, \dots, O_n\}.$$

Additionally, objects included in the O set must have the following triduum of features:

$$\bigvee_{t=1,2,\dots u}[(K_t \in O) \wedge (K_t \notin \emptyset)] \bigvee_{t\neq v;t,v=1,2,\dots,u}(K_t \cap K_v = \emptyset\,);\ \bigcup_{t=1}^{u} K_t = O.$$

The primary purpose of classification is to determine the similarity of individual instances and their clusters (i.e. classes). Generally, the classification can be defined as a division of the set of considered objects - here GIS systems into classes, containing such objects that will be similar in terms of the observed values of their features. It is very important here that the objects allocated in different classes have the greatest possible differences. They should show the greatest correlation within the cluster - class. Hence, a well-conducted classification guarantees the fulfillment of the two postulates: internal coherence and external isolation.

The most important stages of classification and typical actions taken in this type of research are listed below:

1. selection of objects to be classified and classification features:
   a) all objects of the population or its selected samples may be qualified. Very often, the appropriate sample size of the entire population is determined mathematically;

   b) the choice of object features is very important – the quality of classification and the accuracy of the decisions made depend mainly on them;
   c) it is extremely important to include in the set only those objects and features that bring the greatest added value to the purpose of classification;
   d) discriminant assessment of features is made possible by, among others, asymmetry (skewness) and kurtosis (flattening, Donoghue's measure) metrics;
   e) aggregates, i.e. artificial features that are substitutes for subsets of the original features, are often introduced; these are usually linear combinations of the original features;
2. selection of the formula for normalizing the values of object features;
3. choice of distance measure between objects:
   a) the classification is based on the distance matrix;
   b) the distance matrix is always created on a standardized, i.e. normalized, data matrix;
   c) most often, the distances separating individual objects are determined by Euclidean and Mahalanobis metrics;
4. choice of classification method:
   a) single-linkage, as the distance of the nearest neighbor in terms of a single link. The distance between two classes is the shortest distance among all distances between objects belonging to the considered classes;
   b) complete linkage, as the furthest neighbor metric in terms of complete linkage. It represents the distance between two classes, which is the greatest distance among all distances between objects belonging to the considered classes;
   c) median as the distance between two classes, which is the median of all distances between objects belonging to the studied classes;
   d) group average-link, as a group average, in which the distance between two classes is the arithmetic average of all distances between objects belonging to the considered classes;
   e) centroid, i.e. the center of gravity – the distance between the two classes, which is estimated as the distance between the centers (centers) of the considered classes;
   f) ward – the grouping criterion is based on minimizing the variance (square of the difference) of the distance between objects belonging to the considered classes;
5. determination of the number of classes;
6. classification evaluation.

It is also worth emphasizing that the classification of the same set of objects in the same feature space, which (classification) will be carried out using different methods, very often can lead to different results. Hence, there is a need to assess the quality of the classification carried out in this way. The available metrics allow for an unambiguous assessment of the relationship that characterizes two objects classified into different

classes. Therefore, their heterogeneity is investigated. Among many measures, the following estimators are widely used:

- individual – they are used to assess individual classes from the point of view of their homogeneity and heterogeneity;
- homogeneity – they examine the compactness of all created classes; lower values of these measures indicate a better classification, which means that the created classes are more compact;
- heterogeneity – they examine the distinctiveness of all created classes; higher values of these measures indicate a better classification, i.e. greater differentiation of the created classes (then they differ more from each other);
- correctness of clusters – they are used to assess the quality of the entire classification and are usually constructed as quotients of homogeneity and heterogeneity measures; they are based on the maximum and average distance between the objects of the classified community, while their lower values mean a more correct classification;

It should be noted that each of the above-mentioned metrics uses the estimated distance matrix of the examined objects as input data. As you can see, classification methods are very widely supported by the statistical and mathematical apparatus. Currently, there are many methods of classifying a set of objects, among which the following can be mentioned:

- agglomeration combinatorial methods (eleven methods);
- agglomeration non-combinatorial methods (two strategies);
- method – FANNY algorithm (Fuzzy Analysis);

Considering the problem of choosing the appropriate GIS class system in the current aspect, in addition to the previously presented ranking strategies, classification methods were used. For the normalized form of data, classification was carried out using agglomeration combinatorial methods, for which distances were estimated using the Euclidean metric (i.e. for p=2). The performed classification grouped and allocated the considered objects to particular classes. The direct result of the classification of objects is the resulting matrix, while its visual representation is presented later, using the created dendrogram of objects. It presents (dendrogram) in a very legible way individual categories to which each of the eighteen considered systems was allocated.

The dendrogram presented on Fig. 4 is a graphical result of the classification of the eighteen considered GIS systems. In order to be able to interpret its structure more precisely, the idea of classifying using hierarchical and non-hierarchical methods will be outlined. The second of the mentioned types is based on the arbitrary determination of a certain size of the similarity measure of objects, which is a threshold value for their division. Area methods are mainly used here, in which the fragmentation of a set of systems (elements) into appropriate classes is carried out by assigning (classifying) them to previously distinguished areas in the feature space of objects. As part of non-hierarchical methods, e.g. the hyperlink technique is very often used. Hierarchical methods constitute a contrasting group, which, from the point of view of the study, are very important. Hierarchical methods lead to the extraction of a complete hierarchy.

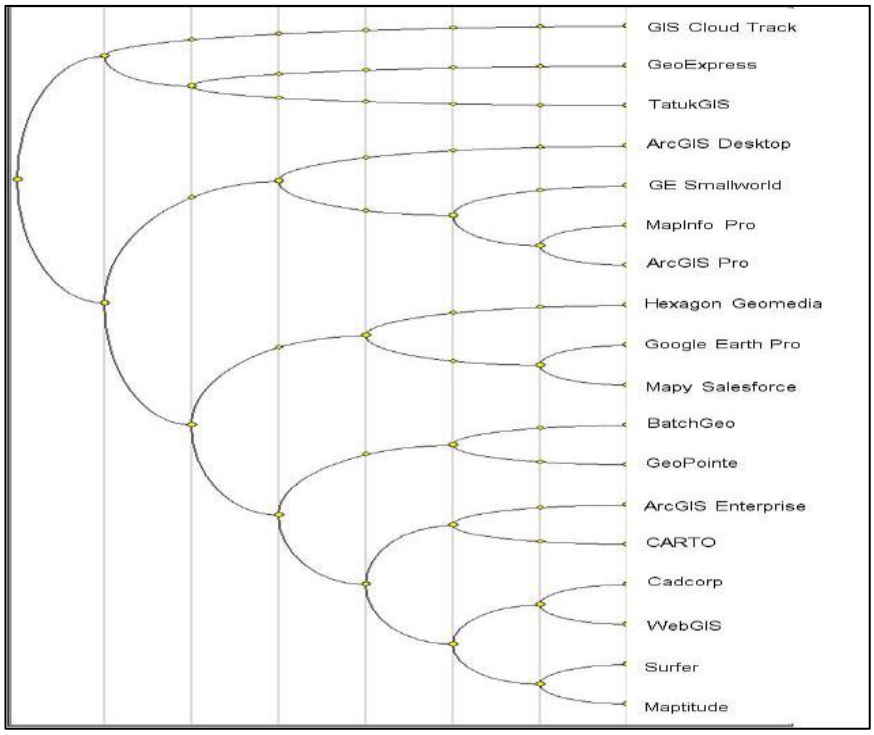


Fig. 4. Dendrogram as a graphical representation of the classification results of the tested systems
Source: own study

These methods create cluster structures that can be represented by a dendrogram. Dendritic techniques (another name for hierarchical methods) allow to obtain such a hierarchy of classes, in which a class belonging to a higher hierarchical level (level) is a multiplicity sum of disjoint classes belonging to the immediately lower level. The considered non-hierarchical methods in a direct way, omitting all intermediate sets, allow to obtain classes at the lowest level of the hierarchical structure.

These hierarchical structures are subject to further decomposition into agglomeration and division methods, deglomeration. In the first of them, each object is considered as an autonomous class, containing a single instance – one element, object (similar to the Singleton pattern). Then the classification process is based on combining these classes until an interesting – desired division is obtained. In the opposite, deglomeration approach, a complex set of objects is treated as a single class, which is then subject to gradual decomposition (division).

When making a proper analysis of the obtained results, the presented dendrogram should be carefully analyzed. It presents in a graphic way the division of the set of examined GIS systems, obtained in the process of its classification. When grouping objects, the mathematical apparatus turned out to be very helpful, which showed the degree of correctness and quality of the model through a set of appropriate indicators (indicators). The discussed group of measures that were used to validate the model structure included:

1. an h-type meter that tests the heterogeneity of the indicated class; it has the following three degrees showing heterogeneity:
   a) h** – very good heterogeneity;
   b) h* – good heterogeneity;
   c) h – weak but acceptable heterogeneity;
   d) h'– the weakest degree of isolated point heterogeneity; occurs when a class containing only one object;
2. type H meter, which tests the quality of the entire classification carried out; it also has three indicators that show differentiation:
   a) H** – very good classification quality; shows that all classes have degree h** heterogeneity;
   b) H* – good classification, in which all classes have heterogeneity to a minimum degree of h;
   c) H – weak but acceptable classification; for this indicator to take the value of H, all classes must have a differentiation of at least degree h;
3. estimator – SC (Silhoute Coefficient) algorithm shaping its value in the range closed on both sides (sharp) from zero to one. This coefficient is used when the evaluation has to be done with the model itself. When the Silhouette Coefficient takes a higher value, it reflects a model with better quality and number of clusters. The SC metric is determined for each sample and is expressed by the following relationship:

$$s = \frac{b - a}{\max(a, b)}$$

where:
a – average distance between the sample and the remaining points within the class;
b – average distance between the sample and all others points in the next closest cluster.

From the presented group of measures, it can be deduced how much value added is brought by the mathematical apparatus, which is fully and 100% applicable in the problem under consideration.

Returning to the resulting dendrite and its final analysis, it is worth mentioning that through a series of studies it was noticed that this method is characterized by high sensitivity to the data. After a slight change in the configuration of the values of selected attributes of the input matrix, both the construction of the dendrogram itself and its individual measures h, H, SC change. It was also noticed that for certain values the main cut (constituting the classification of nodes in the first order counting from the root - the root of the dendrogram) contains an error which is not propagated in the subsequent classifications. Examining the successive values of the coefficients for each row and object of the dendrogram in more detail, it can be seen that the quality of grouping is significantly improving, reaching a very good level of both the degree of differentiation (heterogeneity) and the classification itself. The obtained dendrogram was tagged with

appropriate indexes for subsequent cuts of the set of examined objects – GIS systems (Fig. 5):

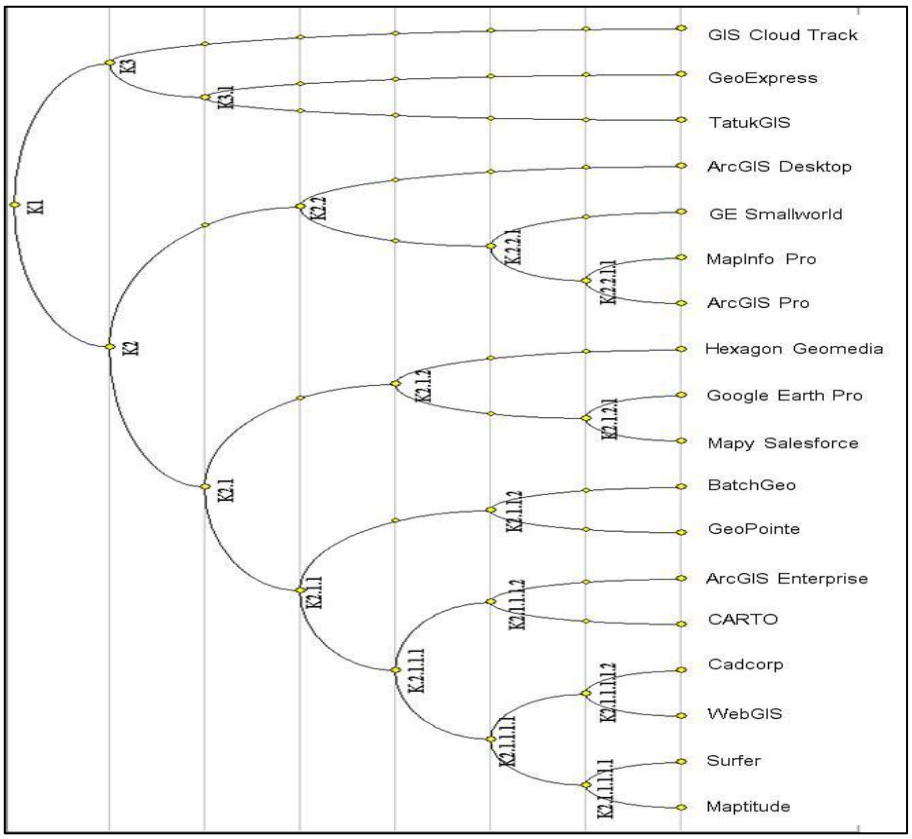


Fig. 5. The resulting dendrogram with appropriately tagged cuts of individual sets
Source: own study

The dendrogram shows the obtained distribution of classes and the association of individual systems to the appropriate sets. The operation of grouping objects consists in dividing the dendrite into appropriate units (parts) that contain homogeneous sets of objects. The first main, abstract class is superior, while the next ones are further decomposed. The final division of classes is presented in the table 2.

For the division into subsequent classes, each cut was assigned an appropriate value, indicating the quality of the heterogeneity of the resulting sets. Subsequent numerical ratings reflect the degree of class differentiation. The value of one means the basic, sufficient and poor quality of the division, while the score of "five" identifies the desired result, i.e. very good, which proves the greatest dissimilarity of the newly created sets. It is obvious here that the best division is the one that guarantees obtaining two most different subsets, where the objects in each of them are as homogeneous as possible in relation to each other. In the initial phases (stages) of creating a tree, this quality is improved, which in turn allows to obtain the most heterogeneous classes in relation to each other. This dependence has been shown in the form of the Pareto diagram presented below (Fig. 6).

Table 2. Sets of objects and their features created as a result of classification

Class/category	The number of instances – objects contained in the class	Variation index – heterogeneity of sets
K1	18	1
K2	15	2
K2.1	11	2.5
K2.2	4	2.5
K2.1.1	8	3
K2.1.1.1	6	3.5
K2.1.1.2	2	3.5
K3	3	4
K2.1.2	3	4
K2.1.1.1.1	4	4.5
K2.2.1	3	4.5
K3.1	2	5
K2.1.1.1.2	2	5
K2.1.1.1.1.1	2	5
K2.1.1.1.1.2	2	5
K.2.1.2.1	2	5
K2.2.1.1	2	5

Source: own study

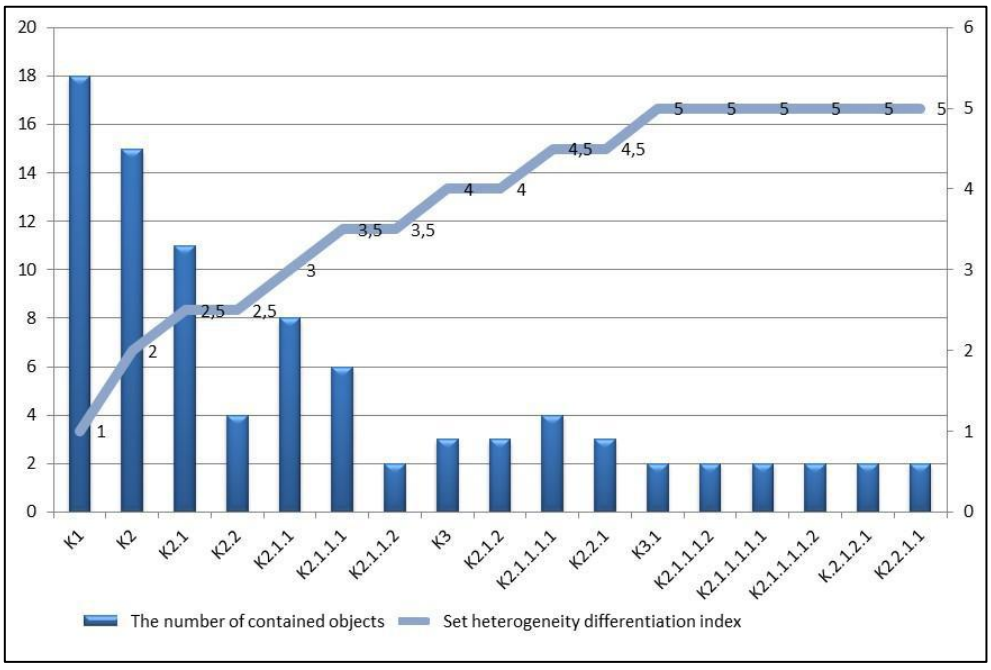


Fig. 6. Pareto diagram showing the diversity of heterogeneity of sets
Source: own study

The above considerations directly lead to the conclusion that the greatest separation of objects was noticed at the lowest level of the tree structure, which indicates the

correct construction of the dendrogram and the appropriately high quality of the classification, which is confirmed by the SC, h, H indicators. An effort was made to present the qualitative distribution of the standard of individual classification cuts, carried out on a set of tested systems, using the author's magic quadran'ut form (Fig. 7):

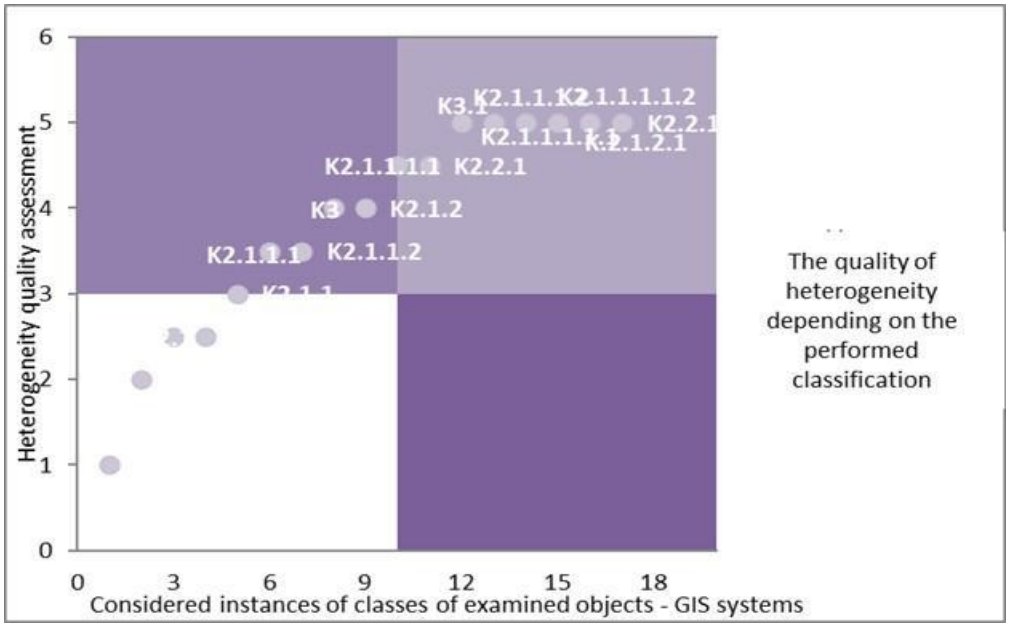


Fig. 7. Quality of collection heterogeneity depending on classification
Source: own study

Conclusion

Through the use of a developed mathematical and statistical apparatus, it was shown how the applied techniques support decision-makers, providing them with credible and reliable support. The results obtained in the work fully agree with the current state, which characterizes the considered set of GIS systems. At the same time, it is mentioned that the obtained results should be treated as advice and guidance in the decision-making process. Elements of taxonomy and classification, which determine the set of compared systems, were integrated into the analysis. Objects characterized by appropriate values of selected coefficients (e.g. heterogeneity and homogeneity) are allocated in appropriate collections (classes, containers), grouping units with similar properties. It was also noted that the differences in the obtained results are very often implied by the specificity of the methodology used - the algorithm. Therefore, it was decided to use a taxonomic approach, evaluating the studied GIS systems not in terms of best-worst, but in the context of classification, allocating them to appropriate systems comparison sets. The applied approach brings an advantage to the analysis of systems and leaves the user the opportunity to make the final choice between the set of objects that he is interested in. Advantage is in other words profit, benefit. It is about the intangible advantage that distinguishes this work, among others, by evaluating the considered set of objects through many different techniques, strategies and methods, which makes the obtained results credible and representative. This aspect is particularly

important due to the fact that the adopted criteria do not take into account all the outlines in which a given GIS will be installed, embedded and used. Therefore, due to the knowledge of the specifics of the target GIS workplace, the final decision is left to the user. The taxonomy used complements and confirms all dependencies that have been detected during the evaluation and comparison of systems. Another element of innovation is the visualization of all obtained results by using the structures of the Voronoi diagram and dendrogram, which are a clear and accessible form of presentation and inference of all existing dependencies.

Acknowledgments

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MULTI-CRITERIA COMPARATIVE ANALYSIS OF GIS CLASS SYSTEMS

Abstract: The article discusses a multi-criteria comparative analysis of GIS class computer systems using the Pareto method . Referring to this problem, to find a GIS system (a compromise solution) that would be acceptable for each decision criterion, to make a Pareto optimal decision, multi-criteria optimization was obligatory. To find the mentioned optimum (the Pareto optimum), it is necessary for the decision maker to make a choice concerning the set of admissible decision solutions. Here, a matrix of criteria constructed by the authors is available, filled in with appropriate weights by field experts. This structure is very useful when evaluating the admissible solutions of the resulting algorithm. The space of acceptable solutions in the considered problem task is a set of systems, limited to their eighteen instances, which meet the criterion of completeness of all data required in the conducted research. The selected criteria are the most widely used and most accepted in the environments that systems of this class use daily.

Keywords: GIS, multi-criteria optimization, ideal point, space of admissible solutions

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Introduction

We are witnessing technological progress and the development of individual fields of knowledge, which imply a huge technological leap in the constant road to perfection. Both information technologies and all emerging innovations are ultimately intended to serve man in the implementation of his daily tasks and duties, making his work easier and more efficient in implementation geoinformation technology patterns and shows how GIS technology can best meet business needs (Fig. 1).

Fig. 1. GIS technology has evolved to support a wide integrated range of business needs across the organization
Source: http://wiki.gis.com/wiki/index.php/System_Implementation

GIS systems have already perfectly integrated into today's reality and the concept of enterprise 2.0 (e.g. *high technology, knowledge management*), and the degree of their integration with organizations in the current economic reality makes them not only an indicator of success on the market, but eo ipso (*eo ipso* in translation from Latin means: *the same, as a result, as a result)* also an inseparable element of any modern business organization.

The purpose of this article is to present a multi-criteria comparative GIS analysis that enables the selection of a properly tailored and effective GIS solution for a given enterprise. The problem is not trivial; hence this work presents its own way of thinking and several techniques that can help the decision maker in making effective decisions. It is important and repeatedly emphasized that all the techniques described in this article are universal and can be applied to almost any problem that you can currently encounter.

The results obtained by means of multi-criteria optimization in the PARETO sense can and very often constitute a kind of help, guidance and advice in decision-making, however, one should not base one's choice solely on them. As indicated at the research stage, these methods are characterized by high sensitivity (sensitivity) to data, and their proper implementation is associated with the meticulousness, knowledge and precision of the researcher.

This article consists of six sections. The first section covers assumptions and key concepts. The second section contains the results of the literature review, based on which the types and categories of GIS were specified and then characterized for the purposes of comparative analysis. The third section presents the research methodology. The fourth section contains information on the problem analysis and research results. Finally, section five describes the conclusions and recommendations.

Assumptions and key concepts

GIS is a technology rooted in geographic informatics that allows users to delve into geospatial data . GIS programs require both hardware and software, such as the desktop needed to display information.

GIS helps users make more informed decisions. When working with a physical location, you need to understand every aspect of it – air, land, water, surroundings, and more. The GIS captures this array of data, detailing various aspects of the landscape, and stores them all in one platform.

GIS software is used to deploy GIS functionality and business logic where it is needed – on desktops, servers, custom applications, web services and mobile devices. GIS applications are supported by a common set of software components. Figure 2 shows the ArcGIS cloud-based architecture. Figure 2 shows how GIS architecture is evolving to enable more adaptive and functional exchange of geographic information.

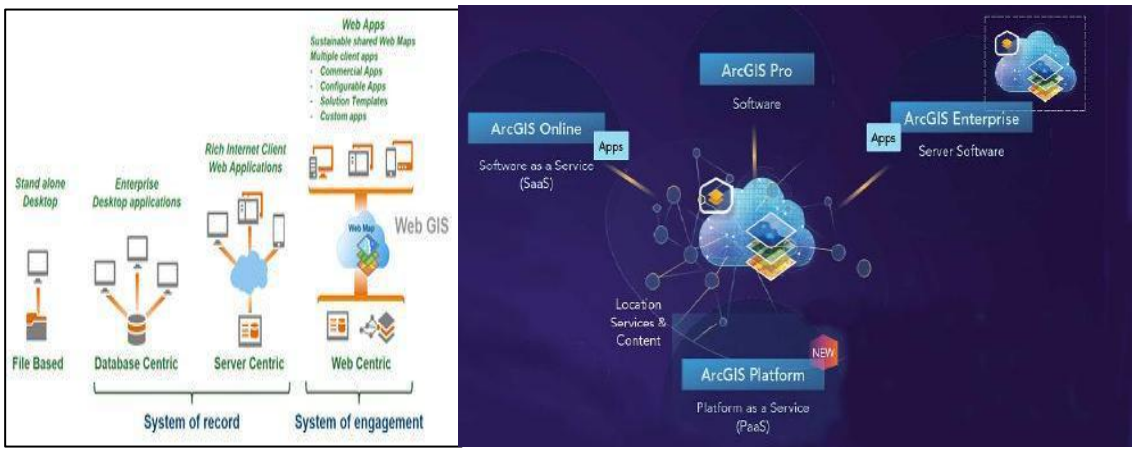


Fig. 2. GIS architectural patterns have evolved from standalone single-user desktop file-based systems to more collaborative Web GIS systems
Source: own study

Table 1 presents a brief description of selected GIS architecture patterns available in the professional literature.

Table 1. Notable Patterns of GIS Architecture

Template	**Description** [literature]
File based systems:	Desktop apps that created file-based datasets that were unique to a given user. Building and sharing information was limited to individual relationships, and data integration was limited. (Chang & Kang-tsung, 2016; Fu & Sun, 2010; Marler & Arora, 2004)
Database orientation:	Enterprise Desktop customers would access a centrally shared geodatabase data source . The data was maintained and made available in an integrated database environment, improving the continuity of information and the quality of available data resources. Published data can be managed and controlled to promote a common view of available verified data resources. Access to data resources was limited to desktop users in the local network. (Goodchild, 2010; Marler & Arora, 2004; Xuan & Zhu, 2016)
Server orientation :	Database resources were published as Web services, making information products available to a wide Internet community of Web clients. Rich Internet clients can access services from multiple server locations, extending access and integration of information resources to a much wider community of users. Applications have been developed and deployed to take advantage of available Internet services. *Best practice: Database and server-oriented architecture patterns provide optimal record content system management.* (DeMers, 2009; Miłek et al., 2023a; Saaty, 2012)
Network Oriented:	The introduction of the portal architecture has expanded web content development for the business community, no longer requiring the design effort of developers to implement new web information products. General commercial applications with the ability to leverage web maps created and shared by business users provide quick access to information products anywhere and on any supported device. Users can create and administer their own groups to share content, use customizable apps to build new web apps, and use solution templates to quickly create and deploy content to a wide user community. *Best practice: The web portal architecture provides the optimal solution for the engagement system.* (Bolstad, 2019; Maliene et al., 2011; Mironova, 2020)
Focus on cloud solutions:	With the shift to networking and cloud computing, and integration with real-time information via the Internet of Things, GIS has become a vital platform for almost every human endeavor – the nervous system of the planet. As our world faces issues of increasing population, loss of nature and pollution, GIS will play an increasingly important role in how we understand and solve these problems and provide the means to communicate solutions using a common mapping language. (Miłek et al., 2023b; Peuquet & Marble, 1990; Somers, 1996)

Source: own study

Optimization is an engineering discipline that seeks extreme values of design criteria. However, quite often there are many conflicting criteria that need to be resolved. One of these criteria is met at the expense of another. In the literature, multi-

criteria decision making (MCDM) and optimization approaches have been used in various ways. The problem with MCDM methods is generally a selection problem where one tries to select the best or optimal alternative from a predetermined but finite set of alternatives. The choice of a particular MADM method depends on the characteristics of the problem and is also partly based on the preferences of the decision maker. Two approaches can be used to solve MADM problems with a homogeneous data type. First, the data can only be treated to form a set of uniform input parameters, and classical MADM methods can be used to solve the problem. Second, the MADM methods should be modified to accept mixed input parameters. Both approaches should lead to the same result, but the first seems to be simpler and more effective (Chen & Hwang, 1992). In recent literature, common MADM methods include the simple weighted addition (SWA) method, the analytic hierarchical process (AHP) and various lookahead methods such as reality translating elimination and selection (ELECTRE). AHP was developed by Saaty (Saaty, 1980). A multi-criteria problem begins when a decision maker has a situation that requires a decision (Ameljańczyk, 1984). There are a number of criteria that should be addressed by the decision maker, and several different courses of action may be available to address most or all of the criteria in some way. The problem faced by the decision-maker is to determine which course of action or alternative would best meet the criteria and fully meet the constraints (Rao & Davin, 2008; Zimmermann, 1991).

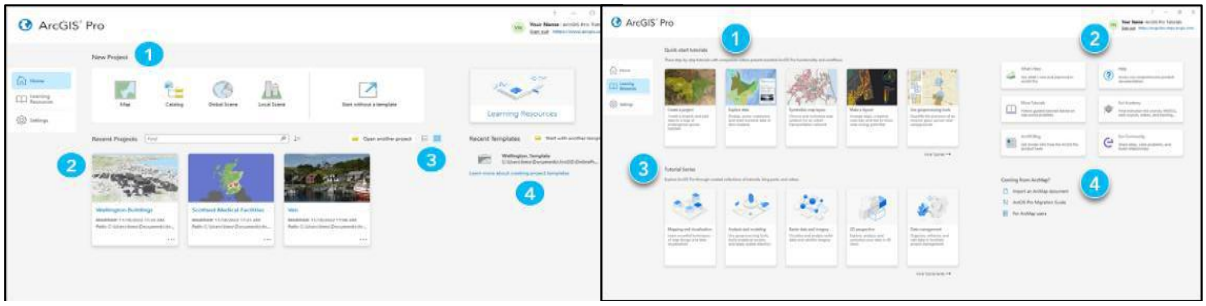
Review of the studied GIS systems

There are plenty of GIS systems on the market, designed for a wide range of applications. Many of the offered solutions come from various domestic and foreign companies. To illustrate the number of foreign players and market tycoons, a summary in the form of the Gartner magic quadrant was presented (Fig. 3).

Fig. 3. GIS class solutions for small and medium enterprises
Source: own study

Bearing in mind the limitations regarding the volume of the article, only six systems will be characterized in this subchapter: ArcGIS Pro, WebGIS, BatchGeo, Google Earth Pro, MAPTITUDE, ArcGIS Desktop application. Other GIS can be found in studies (Miłek et al., 2023a & 2023b; Peuquet & Marble, 1990; Somer, 1996).

ArcGIS Pro is a full-featured professional desktop GIS application from Esri . With ArcGIS Pro, you can explore, visualize, and analyze data; create 2D maps and 3D scenes; and share your work to ArcGIS Online or your ArcGIS Enterprise portal. The sections below introduce the sign-in process, the start page, ArcGIS Pro projects, and the user interface. ArcGIS Pro is tightly coupled with the ArcGIS platform for sharing data with ArcGIS Online and ArcGIS Enterprise through Web GIS. ArcGIS Pro is a next-generation 64-bit GIS application that offers professional 2D and 3D mapping tools in an intuitive user interface. ArcGIS Pro accelerates data visualization, analysis, image processing, management, and integration. ArcGIS is a GIS mapping software that provides a platform for map creation and analysis of captured geographic data. ArcGIS can be used as a standalone application and combined with others to support location mapping. It is helpful in working with a set of analytical data and spatial algorithms. ArcGIS programming is useful in monitoring the location of any type of sensor or device. Official screenshots:



Basic functions:
ArcGIS extends some of its unique potential with flexible licenses to apply location-based analytics to any business practice. Provides insights for data visualization and analysis, and data sharing in the form of maps, dashboards, reports, and more. ArcGIS Pro supports data visualization, advanced analytics, and reliable data handling in both 2D and 3D. functional scope:
Data management:

- Data capture.
- Data storage.
- Data manipulation, data visualization.

Map creation:

- Geocoding.
- Buffer zone query.
- Overlay.

- Publishing.

Analysis:

- Spatial analysis.
- Reporting,.
- Real-time streaming.
- Distance analysis.
- Spatial analysis.

Cartography:

- Map design.
- Data visualization.

Pros:

- Can be easily used for a variety of jobs such as changing slope, aspect, etc.
- It is very user friendly.
- Unified 3D Integration.
- Clear cartography and labeling.
- True integration with ArcGIS Online.
- Contextual smart ribbon interface.
- 64-bit processing.
- Improved and intuitive editing.
- Geospatial analysis.

Minuses:

- High license cost.
- Project files are bulky.
- The MXD conversion skips all objects.
- Assign licenses through ArcGIS Pro.
- High learning curve.

WebGIS. The web app includes built-in tools to create 2D and 3D web apps for job and branding tasks. It is user-friendly, flexible and full of GIS features. The WebGIS application can be used by any user, at any time and on any device. Maps, apps, analytics, data management, collaboration - you can do it all with ArcGIS Online. You can use ArcGIS Online as an integral part of ArcGIS to extend the capabilities of ArcGIS Desktop, ArcGIS Enterprise, ArcGIS Web APIs, and ArcGIS Runtime SDKs. It can also be used as a standalone Web GIS.

WebGIS is quite fast and efficient for setting up web applications that are visually appealing and useful to non-GIS users. Once they're set up, they should be able to run with relatively little effort on my part and save me time to focus on other priority projects. Official screenshots:

Basic functions:

The program is equipped with typical GIS functions. Its features are incomparable to simple mapping solutions, yet very intuitive for everyone throughout the organization and beyond. Developers can create custom widgets and themes to extend ArcGIS Web AppBuilder. Functional range incl. includes:

Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Create a map:

- Geocoding.
- Buffer zone query.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.

Cartography:

- Map design.
- Vector mapping.
- Data visualization.
- Overlaying.

Advantages:

- Web AppBuilder is a great tool for building custom and customizable apps.
- You can get a relatively easy application in a few minutes.
- It is easy to import data into it and create a completely new application.
- The adaptability between different layers and designs makes it even more promising.

Defects:

- The UI is not very user friendly and the documentation is poor in some parts.
- ESRI Living Atlas data in the Add Data panel, making it difficult to focus and view only internally created data instead of searching with keywords.
- No custom widgets.

BatchGeo. BatchGeo is software that allows you to paste location data to map them. This is one way to create Google Maps with your data. Just copy the data, validate and set options, then map the locations. The result is a colorful, information-rich map where you can easily visualize spreadsheet information. BatchGeo is also the easiest way to get a list of addresses on a map.

BatchGeo since 2006 hosts millions of maps for Fortune 50 companies , nonprofits, and individuals. The idea behind BatchGeo is that most geographic data is stored in a spreadsheet, list, or simple table (e.g. Excel, CSV, Google Spreadsheets, etc.) It is optimized for these formats, making it very easy to drag or copy/paste data tabular on the map. Official screenshots:

Basic functions:

The program is equipped with typical GIS functions.

Functional range incl. includes:

Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Create a map:

- Geocoding.
- Buffer zone query.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.

Advantages:

- BatchGeo is a leader in the mapping category.
- BatchGeo is extremely easy to use - the user interface is very intuitive.
- You can easily create regional maps or projects in a few simple steps.
- You can easily and quickly create a map using the data in an Excel file.

Defects:

- Some reporting features are missing for further analysis of geocoded batch addresses.
- If you make a mistake, it's hard to go back and make changes.

Google Earth Pro. Google Earth Pro is a powerful and feature-rich tool for exploring the world and visualizing geographic data. It can import and analyze large amounts of data, including vector and raster images, 3D models and GIS data. The software also allows me to measure distances, create custom maps and visualizations, and export high-quality photos and videos. Overall, Google Earth Pro is an extremely versatile and user-friendly application that offers a wealth of tools for anyone interested in exploring and understanding our planet.
Official screenshots:

Basic functions:
Overall, Google Earth Pro is an extremely versatile and user-friendly application with the following functional scope:
Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Creating a map:

- Geocoding.
- Buffer zone query.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.

Advantages:

- Google Earth pro is the best service to explore different regions of the whole earth.
- Easy, convenient and simple to use mapping tool.
- The best tool for accessing geolocation and maps.
- The best virtual roaming tool around the world.

Defects:

- Quite demanding in terms of required computing power.
- Some remote areas are off-limits to high-resolution photos.
- There is no easy way to store your personal pins , placemarks, starting points, etc. in the cloud – you must go through the entire registry to make these changes.

Maptitude. Maptitude is one of the best mapping software on the market with the richest set of features and the highest performance. Full-featured mapping software. It is one of the GIS mapping programs that provides tools, maps and demographics that are useful for visualizing data by discovering geographical patterns from the available data and presenting the data in a more elementary way. Maptitude offers the benefits of desktop mapping and spatial analysis in one easy-to-use package. With Maptitude, you can easily and efficiently create maps and map images from spreadsheets. You can import external data into your map from various sources, including Google Maps KML/KMZ files . Official screenshots:

Basic functions:

Maptitude is designed for data visualization and geographic analysis. Some of its best and enhanced features include creating and editing maps, adding data to maps, analyzing data. functional scope:

Data management:

- Data capture.
- Data storage.

- Data manipulation.
- Data visualization.

Create a map:

- Geocoding.
- Overlaying.

Spatial analysis:

- Reporting.
- Data visualization.

Advantages:

- The most efficient and cheapest.
- Ease of use.
- High quality support.
- Ease of setup.

Defects:

- Less community supports.
- Archaic cartography and symbolism.
- Dated 3D rendering with NASA World Wind.
- Little about metadata standards.
- Little support for LiDAR data.
- No cross-platform mobile data collection.
- Adding data without geometry icons.

ArcGIS Desktop app. An integrated collection of GIS software. It provides a standards-based platform for spatial analysis, data management and mapping. ArcGIS Desktop is the latest in GIS. It raises the bar to the next level by doing what other GIS software can't. Its success lies in the fact that it can be expanded. From field applications to modeling and scripting, ArcGIS Desktop is a powerhouse for all GIS systems. ArcGIS Desktop is a tool that allows you to create, analyze, share and manage geographic information in such a way as to support decision makers in making optimal business decisions based on collected and developed data. Using data from multiple sources, ArcGIS Desktop allows you to create intelligent and visually attractive maps, identify spatial patterns, and share information depending on the purpose, in the organization, on the Internet or in mobile applications. Official screenshots:

Basic functions:
ArcGIS Desktop is a tool that allows you to create, analyze, share and manage geographic information. functional scope:

- Advanced analytics – has analytical tools to identify relationships and patterns, their changes over time, as well as forecasting and answering key business questions.
- Image processing – provides advanced tools for managing and analyzing images from drones, satellites, lidar data and more.
- Advanced visualization – it is possible to use advanced cartographic tools to visualize data on interactive maps.
- Sharing – share maps on the Internet and integrate them with other systems.
- Data Management – Ensures data integrity and accuracy with a complete set of tools for storing, editing, evaluating and managing all types of spatial information.

Advantages:

- ArcGIS Desktop is an easy-to-use and user-friendly GIS tool.
- Scalability for additional capabilities.
- Robust geoprocessing framework.
- Beautiful options for cartography symbolism.
- Full set of editing and topology tools.
- ArcGIS Online for web and app maps.

Defects:

- High use and maintenance costs.
- License levels provide limited tools to the basics.
- Poor performance on interoperability.
- Retiring ArcGIS Pro.
- 32-bit application from ArcCatalog.

Methodology

As already mentioned, the purpose of this article is to conduct, using the formal method, which is multi-criteria Pareto optimization, a comparative characteristic of GIS class information systems, intended for various entities of operation. Due to the large number of GIS systems on the market, it is impossible to obtain information about all products. Therefore, for the purpose of comparison, the following rules have been defined, according to which the solutions operating on the market will be classified into the set of compared systems:

- the system selection criteria were tailored to the needs of the small and medium-sized enterprise (SME) sector,
- source systems, but to be a true GIS, the system must contain a significant group of components (Table 2).

Table 2. Basic GIS components

Name	**A brief description of the component**
Spatial databases and attribute databases	The central element of the system is the database - a collection of maps and related information in digital form. Since the database deals with the features of the earth's surface, it consists of two elements – a spatial database describing the geography (shape and location) of the earth's surface features, and an attribute database describing the features or characteristics of these features.
Cartographic display system	We have several software components around the central database. The most basic of these is the cartographic display system, which allows you to download selected database items and generate output maps on a screen or paper device such as a printer or plotter.
Map digitization system	After the cartographic display, the next most important element is the map digitization system, which is used to convert existing paper maps into digital form. Map digitization can be done using scanning devices.
Database management system	Another logical component in GIS is a database management system (DBMS). GIS typically includes not only a traditional DBMS, but also a variety of tools to manage the spatial and attribute components of stored geographic data. With a DBMS, it is possible to enter attribute data such as tabular information and statistics, then extract specialized tables and statistical summaries to provide new tabular reports.
Image processing system	In addition to the essential elements of the GIS described above, some software systems also include the ability to analyze remotely sensed images and provide specialized statistical analysis. This is a significant component of the system as computer-aided interpretation of remote sensing data can be an important data acquisition technique, particularly in developing countries where current maps of many features are not available.
Statistical Analysis System	For statistical analysis, GIS must offer both traditional statistical procedures and some specialized spatial data analysis procedures.

Source: own study

In a series of studies, a comprehensive set of selected eighteen GIS class systems was subjected to a detailed analysis. Heuristic techniques were used, which allowed the estimation of individual parameters, determination of their significance function as well as the ranking and classification of the considered set of objects. The following concept of conduct was adopted in the study. Comparison criteria and rules for the selection of GIS systems for comparison were defined. Then, factors were specified, which, based on the research and experience, are considered critical in the process of selection and implementation of appropriate GIS class solutions. In the next step, the most important selection criteria were defined – the selection of systems, and on their basis a summary and comparative analysis of GIS systems will be carried out. Eight thematic groups of criteria were used in the research, based on which the selection of GIS solutions for comparison was carried out. The adopted comparative criteria have been presented in a hierarchical form, grouped into appropriate thematic classes using a mind map scheme (Fig. 4):

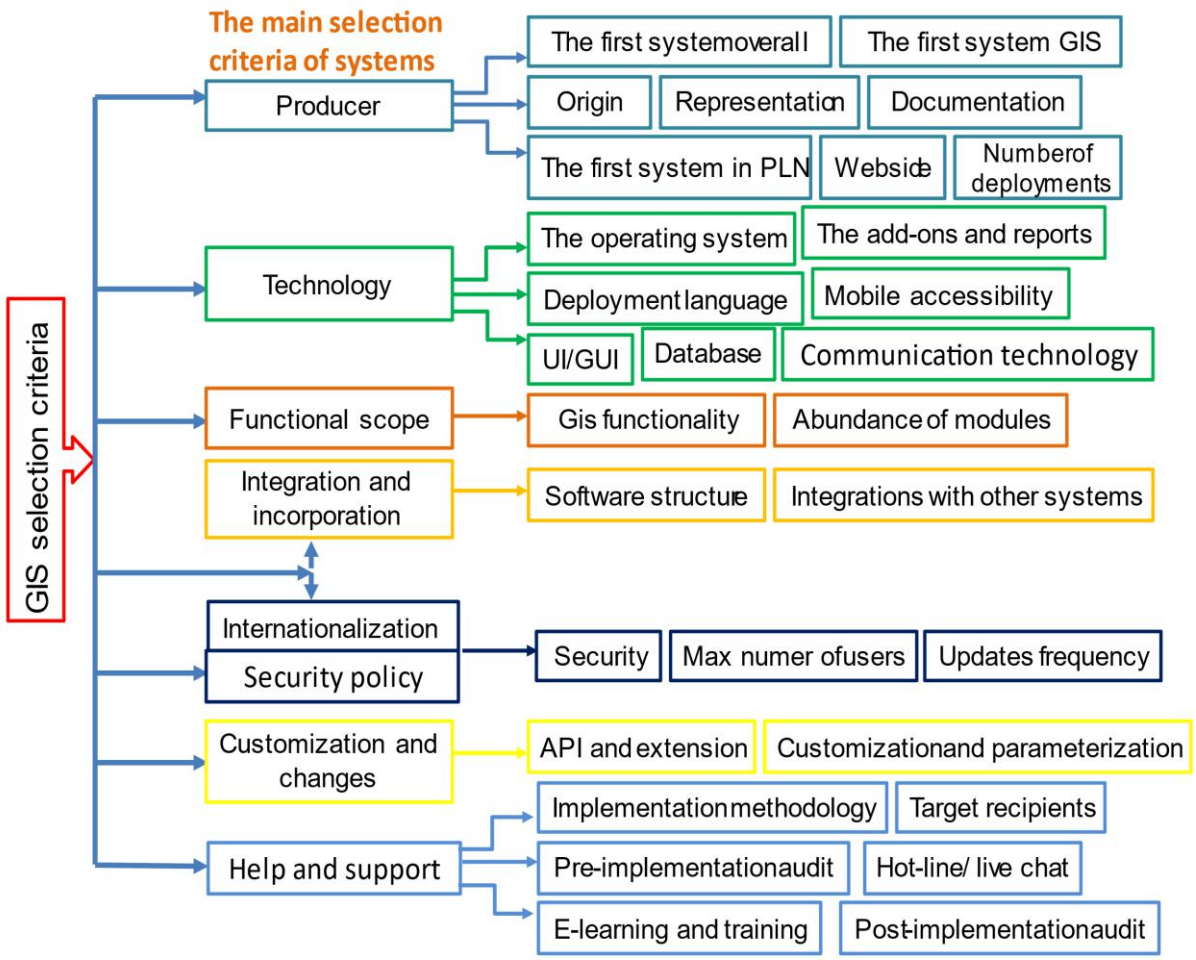


Fig. 4. Hierarchical structure of the ERP system selection problem tree
Source: own study

The comprehensive characterization was carried out based on a number of experiences, interviews and information obtained from many different sources, ranging from periodicals and industry literature with a high eigenfactor, to websites and consultations with system manufacturers. However, environmental conditions made companies reluctant to share any information about their products. Most of the data was very general.

The final step of the undertaken network of actions is to determine the exact distance that separates each of the tested GIS class systems from the set ideal point.

Results and discussion

In order to find the optimum (Pareto optimum), it is necessary for the decision maker to make a choice concerning the set of admissible decision solutions. Here you have a self-constructed matrix of criteria, filled with appropriate weight values by domain experts. This structure will be very useful when evaluating admissible solutions of the resulting algorithm. The space of acceptable solutions in the considered problem is a set of GIS systems, limited to their eighteen instances.

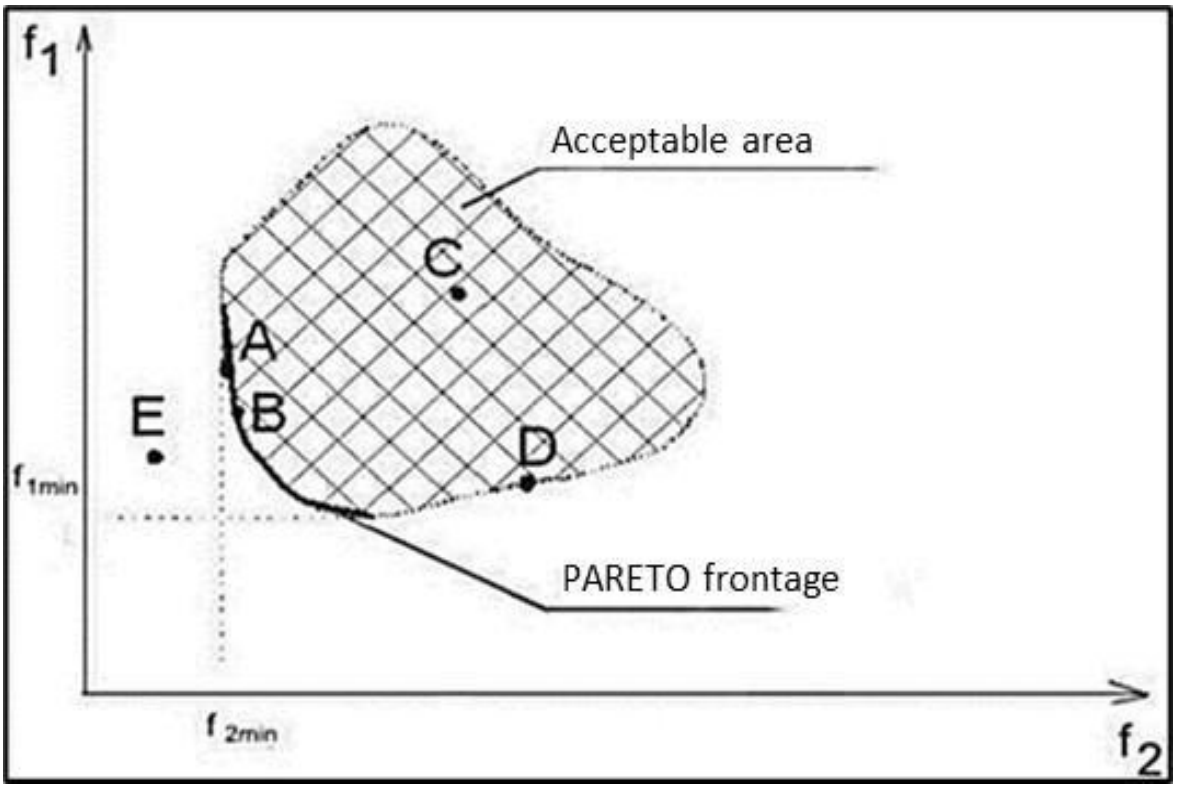


Fig. 5. A visual, graphical representation of Pareto- optimal decision solutions
Source: own study

On the axes of the coordinate system there are selected quality indicators, while the filled space is mapped to the decision space. The indexes A, B, C, D have marked the individual elements constituting the solution. The point located in the closest distance to the optimum, lying on the Pareto front, is optimal. The area of the Pareto front is a space of non-dominated solutions and at the same time it creates a set of solutions that are optimal from Pareto's point of view (Fig. 5).

Starting to determine the set of acceptable solutions, we decided to evaluate the considered GIS systems using the Delphi method in accordance with the algorithm presented in Fig. 6. Collecting the individual assessments of decision-makers and field experts, the range of assessment functions from one to nine was adopted (analogous to the AHP method, which is presented in (Saaty, 2012). An increase in weight means a greater importance of the considered feature. The final matrix showing the comparison of solutions from the considered set of GIS systems and their degree of fulfillment of a given feature (criterion) is presented in table 3.

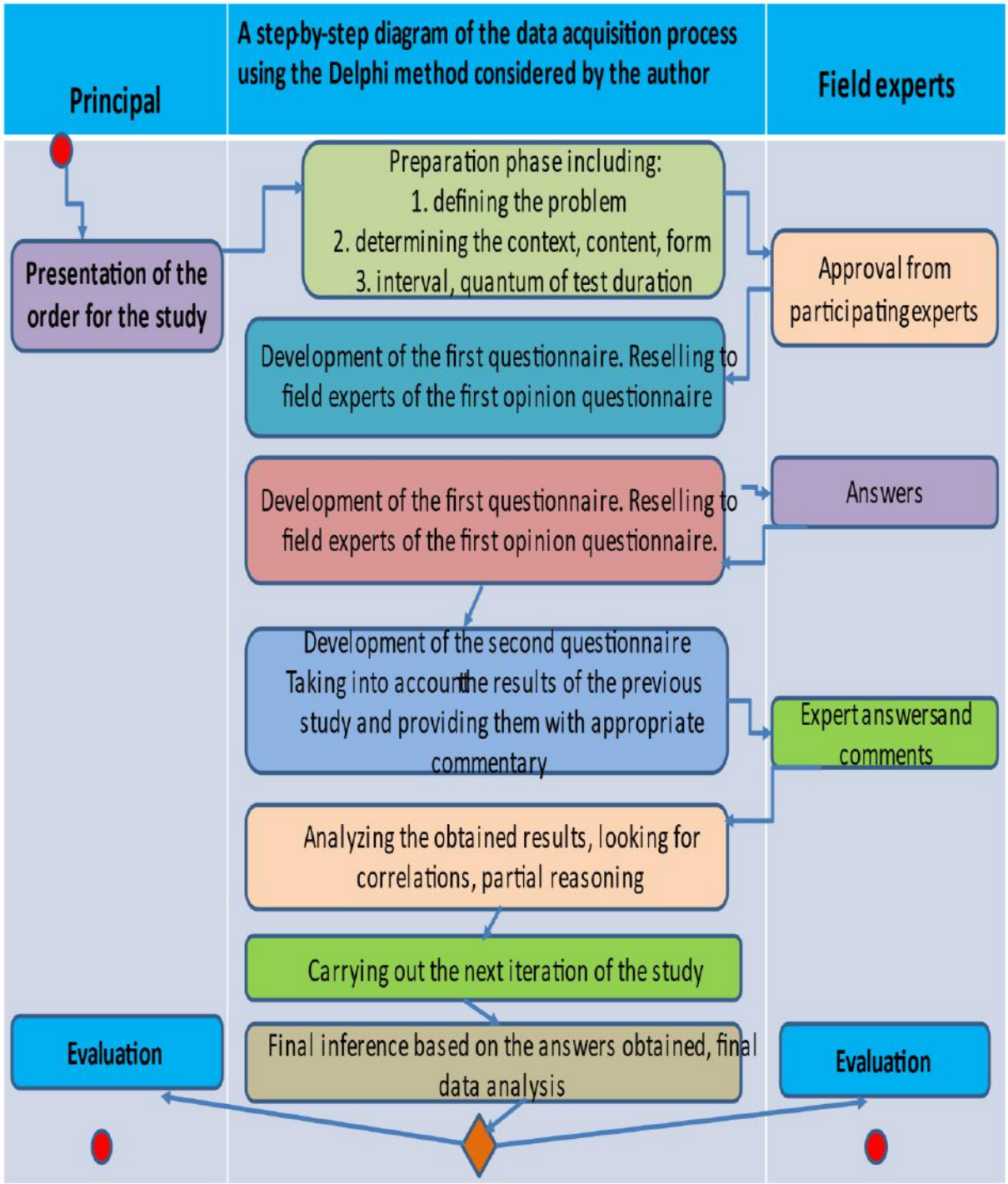


Fig. 6. The Delphy method in UML notation: *swimming lanes* and *activity diagram*
Source: own study

Table 3. Comparative matrix of systems and the degree of fulfillment of the criteria

	Cadcorp	MapInfo Pro	GeoExpress	BatchGeo	GIS Cloud track	GeoPoint	TatukGIS	GE Smallworld	ArcGIS Enterprise	Google Earth Pro	CARTO	Salesforce maps	WebGIS	hexagon Geomedia	surfer	ArcGIS Desktop	Insert GT	maps
Producer	8	7	6	8	8	9	7	8	7	7	8	6	8	8	8	6	4	8
Technology	9	7	4	9	5	9	6	9	8	9	7	8	9	8	9	7	9	7
Range of Functions	6	6	6	6	6	6	6	6	6	3	5	5	6	6	5	6	7	6
Integration and incorporation	4	3	5	7	3	4	8	1	5	7	4	6	5	9	4	3	4	3
Cryptography	6	3	6	9	6	8	4	2	6	2	6	3	4	6	3	6	5	6
Innovation	7	8	8	7	6	6	7	8	7	5	6	2	7	8	8	6	7	7
Security policy	5	5	7	8	6	6	6	6	9	7	5	6	6	6	9	5	6	9
Help and support	8	2	7	6	7	5	8	8	9	9	6	4	5	8	4	8	9	8

Source: own study

The data collected in this way from an independent opinion-giving group allows us to assume and assume the representativeness of both the information itself and the results of the study. However, the study does not have any tool that could validate this data. Spearman's correlation coefficient was used to determine the correctness of the assessments obtained. It is also mentioned that other metrics can be successfully used for this purpose, such as the coefficient of the level of linear dependence by Karl Pearson or the Cronbach reliability index Alpha. The Cronbach Reality Index Alpha is a statistical measure used to assess the reliability of a measurement scale. Using Cronbach's alpha, the correlation between the answers to individual questions from the interview questionnaire and the total result of the measurement is checked. The stronger the correlation, the greater the likelihood that the scale is reliable and measures the specific construct, dimension, property that is being measured. Cronbach's alpha can take a value from 0 to 1, where 0 means no correlation at all (the scale is not reliable) and 1 means "perfect" correlation (the scale is fully reliable). The correlation coefficient r, also known as the Pearson correlation *coefficient Pearson Product Moment Correlation Coefficient*) is a measure of the strength of the linear relationship between two quantitative variables and is defined as follows:

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{(n-1)S_x S_y}$$

where:

S_x – sample standard deviation for variable x

S_y – sample standard deviation for variable y

The correlation coefficient is always between –1 and 1, including –1 and 1. In further considerations, Spearman's measures were used because they are characterized by low

sensitivity to input data, which is a key issue from the point of view of this work. Spearman's rank correlation coefficient was chosen because it is an excellent estimator of the value of individual ranks for the information obtained (included in the table above). Knowing the value of the rank calculated in this way, we can determine the mutual relationship between the two values. The overriding motive for using the described mechanism is the ability to ensure that the consistency and consistency of data has been ensured and maintained. Hence, the Spearman index was used . It is also worth mentioning that the obtained Spearman values are not as sensitive as, for example, those presented in the AHP strategy. The successive values of the coefficient was calculated as follows:

$$Q = 1 - \frac{6\sum d_i^2}{n^3 - n}$$

where:

d_i – difference of successive ranks in values compared in pairs;

n – number of tested features (criteria).

To estimate successive values of the correlation coefficient, the data was normalized as follows, assuming the value of parameter P equal to unity:

$$x_i = \left(\frac{x_i - \min}{\max - \min} \right)^P$$

The introduced normalization was adopted to facilitate the calculations. It is emphasized that all proportions have been preserved, because the chosen method of normalization does not change the level of system differentiation. The table 4 shows the data after normalization.

Table 4. A normalized matrix of values for the degree to which the criteria for comparing systems are met

	Cadcorp	MapInfo Pro	GeoExpress	BatchGeo	GIS Cloud track	GeoPoint	TatukGIS	GE Smallworld	ArcGIS Enterprise	Google Earth Pro	CARTO	Salesforce maps	WebGIS	hexagon Geomedia	surfer	ArcGIS Desktop	Insert GT	maps
Producer	0.8	0.8	0.5	0.6	1	1	0.7	0.8	0.5	0.7	1	0.6	0.8	0.67	0.8	0.6	0	0.8
Technology	1	0.8	0	1	0.4	1	0.5	1	0.7	1	0.7	1	1	0.66	1	0.8	1	0.6
Range of Functions	0.4	0.6	0.5	0	0.6	0.4	0.5	0.6	0.2	0.1	0.5	0.5	0.4	0	0.3	0.6	0.6	0.5
Integration and incorporation	0	0.1	0.2	0.3	0	0	1	0	0	0.7	0	0.6	0.2	1	0.2	0	0	0
Cryptography	0.4	0.2	0.5	1	0.6	0.8	0	0.1	0.3	0	0.5	0.2	0	0	0	0.6	0.2	0.5
Innovation	0.6	1	1	0.3	0.6	0.4	0.8	0.9	0.5	0.4	0.5	0	0.6	0.67	0.8	0.6	0.6	0.7
security policy	0.2	0.5	0.8	0.7	0.6	0.4	0.5	0.6	1	0.7	0.3	0.7	0.4	0	1	0.4	0.4	1
Help and support	0.8	0	0.8	0	0.8	0.2	1	0.9	1	1	0.5	0.3	0.2	0.67	0.2	1	1	0.8

Source: own study

With the normalized evaluation values of individual GIS systems, certain conclusions can be drawn. To illustrate them, a special type of chart was used, in which all considered features – criteria were grouped and the degree of fulfillment of a given criterion by the considered system was visually shown (Fig. 7). Further indicators (weights) have not been included in the chart due to its legibility.

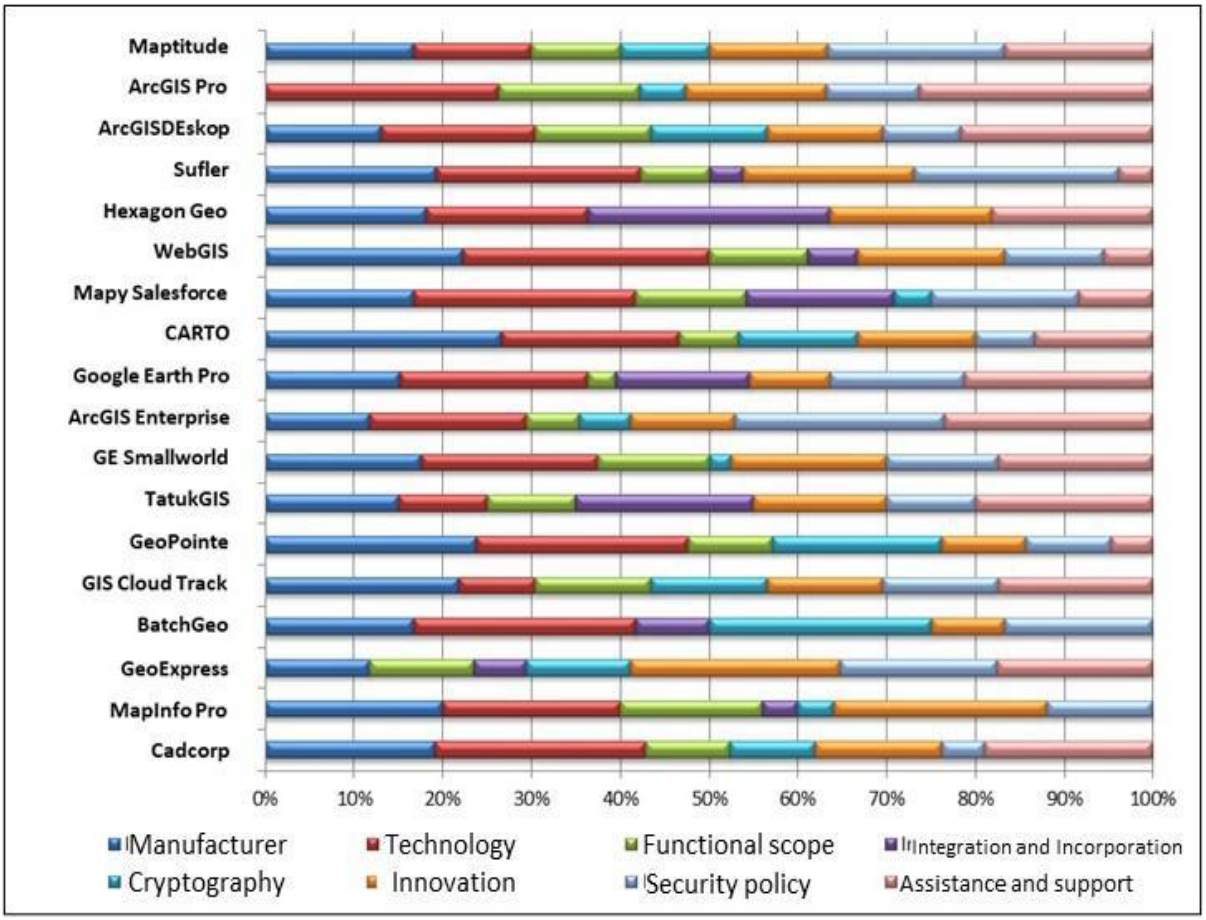


Fig. 7. The degree of fulfillment of the criteria
Source: own study

With normalized input data for the algorithm, the significance function was examined – the assessment of the implementation (fulfilment) of a given criterion by the considered business system. After creating the interval ranges for the evaluation function, they were assigned an appropriate numerical value, which was mapped to the saturation intensity of a particular cell color. When determining subsequent classes, the following classification criteria were created:

- ★ class I – min+a *0;
- ★ class II – min+a *0.52;
- ★ class III – min+a *0.69;
- ★ class IV – min+a *0.81;
- ★ class V – min+a *0.91;
- ★ class VI – min+a *1;

where:

min – the minimum known value from the input matrix that groups the expert evaluations

a – specific value (feature weight) of a given cell

In this way, a map was created showing the degree of fulfillment of individual criteria for each of the tested systems, which is presented in table 5.

Table 5. Individual assessments and significance classes presented in the form of an assessment map

	Cadcorp	MapInfo Pro	GeoExpress	BatchGeo	GIS Cloud track	GeoPoint	TatukGIS	GE Smallworld	ArcGIS Enterprise	Google Earth Pro	CARTO	Salesforce maps	WebGIS	hexagon Geomedia	surfer	ArcGIS Desktop	Insert GT	maps
Producer	0.8	0.83	0.5	0.67	1	1	0.75	0.87	0.5	0.71	1	0.67	0.8	0.67	0.83	0.6	0	0.83
Technology	1	0.83	0	1	0.4	1	0.5	1	0.7	1	0.75	1	1	1	1	0.8	1	0.67
Range of Functions	0.4	0.67	0.5	0	0.6	0.4	0.5	0.63	0.3	0.14	0.25	0.5	0.4	0.5	0.33	0.6	0.6	0.5
Integration and incorporation	0	0.17	0.25	0.33	0	0	1	0	0	0.71	0	0.67	0.2	0.67	0.17	0	0	0
Cryptography	0.4	0.17	0.5	1	0.6	0.8	0	0.13	0.3	0	0.5	0.17	0	0.17	0	0.6	0.2	0.5
Innovation	0.6	1	1	0.33	0.6	0.4	0.75	0.88	0.5	0.43	0.5	0	0.6	0	8.83	0.6	0.6	0.67
Security policy	0.2	0.5	0.75	0.67	0.6	0.4	0.5	0.63	1	0.71	0.25	0.67	0.4	0.67	1	0.4	0.4	1
Help and support	0.8	0	0.75	0	0.8	0.2	1	0.87	1	1	0.5	0.33	0.2	0.33	0.17	1	1	0.83

Source: own study

In the conducted study, the aim is to obtain an occurrence – an instance of the system, which is the best in terms of all considered criteria, an approximation to the so-called model of an ideal system that meets all the criteria to the greatest extent possible. Therefore, the coordinates of the standard were determined based on table 4 as the maximum (best) values of the degree of fulfillment of the criteria by the tested systems. The coordinates of the pattern are presented in table 6.

Table 6. Pattern coordinates

	Producer	Technology	Range of functions	Integration and incorporation	internationalization	Customization and expansion	Policy safety	support
Template	1	1	0.667	1	1	1	1	1

Source: own study

Determining the best GIS system, i.e. the system closest to the pattern, requires defining the concept of the distance of the system from the pattern. In taxonomy, there are many measures of distance between multi-feature objects that can be used in this work. Due to the nature of the values adopted to assess the degree of fulfillment of the criteria (continuous), the Mińkowski metric with the parameter p = 2 (Euclidean distance) was used in the work to determine the distance between the tested systems and between them and the adopted model:

$$d(x_i, x_k) = d_{ik} = \sqrt{\sum_{j=1}^{m} (x_{ij} - x_{kj})^2}$$

where:

x_{ij} – the value of the object x_i in terms of the examined feature j

m – number of features.

The system (compromise solution) with the smallest Euclidean distance from the pattern will be considered the best. Table 7 gives the Euclidean distances between the tested systems and between the systems and the reference.

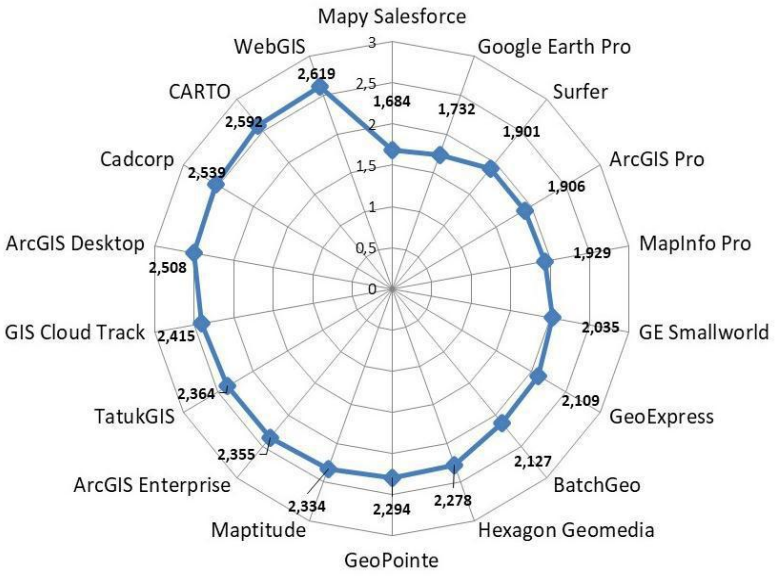
Table 7. Matrix of Euclidean distances between the tested systems and the standard

	Cadcorp	MapInfo Pro	GeoExpress	BatchGeo	GIS Cloud track	GeoPoint	TatukGIS	GE Smallworld	ArcGIS Enterprise	Google Earth Pro	CARTO	Salesforce maps	WebGIS	hexagon Geomedia	surfer	ArcGIS Desktop	Insert GT	maps
Cadcorp	0.0	1.1	1.2	1.0	0.9	0.6	0.9	0.7	1.1	1.2	0.6	1.3	0.6	0.7	1.3	0.6	0.9	1.1
MapInfo Pro	1.1	0.0	1.2	1.4	1.0	1.1	1.1	1.0	1.5	1.6	0.9	1.2	0.7	1.3	1.2	1.0	1.3	1.4
GeoExpress	1.2	1.2	0.0	1.2	0.7	1.3	0.7	1.3	1.0	1.5	1.0	1.5	1.2	1.1	1.4	0.9	1.2	0.9
BatchGeo	1.0	1.4	1.2	0.0	1.2	0.7	1.1	1.4	0.8	1.4	1.1	1.4	0.9	0.8	1.1	1.2	1.3	0.9
GIS Cloud track	0.9	1.0	0.7	1.2	0.0	0.9	0.8	1.1	1.1	1.4	0.6	1.2	0.9	1.0	1.3	0.6	1.2	0.9
GeoPoint	0.6	1.1	1.3	0.7	0.9	0.0	1.1	1.1	1.1	1.4	0.7	1.2	0.6	0.9	1.1	0.9	1.3	1.0
TatukGIS	0.9	1.1	0.7	1.1	0.8	1.1	0.0	1.1	1.0	1.1	0.8	1.2	0.9	0.6	1.3	0.8	1.0	1.1
GE Smallworld	0.7	1.0	1.3	1.4	1.1	1.1	1.1	0.0	1.1	1.2	1.0	1.4	0.7	1.2	1.1	0.9	1.0	1.1
ArcGIS Enterprise	1.1	1.5	1.0	0.8	1.1	1.1	1.0	1.1	0.0	1.2	1.2	1.4	1.0	0.9	0.9	1.1	1.0	0.4
Google Earth Pro	1.2	1.6	1.5	1.4	1.4	1.4	1.1	1.2	1.2	0.0	1.2	1.1	1.1	1.2	1.2	1.3	1.4	1.3
CARTO	0.6	0.9	1.0	1.1	0.6	0.7	0.8	1.0	1.2	1.2	0.0	1.0	0.7	0.9	1.2	0.6	1.2	1.1
Salesforce maps	1.3	1.2	1.5	1.4	1.2	1.2	1.2	1.4	1.4	1.1	1.0	0.0	1.0	1.4	1.4	1.1	1.3	1.5
WebGIS	0.6	0.7	1.2	0.9	0.9	0.6	0.9	0.7	1.0	1.1	0.7	1.0	0.0	0.8	0.8	0.9	1.0	1.0
hexagon Geomedia	0.7	1.3	1.1	0.8	1.0	0.9	0.6	1.2	0.9	1.2	0.9	1.4	0.8	0.0	1.3	1.0	1.1	1.1
surfer	1.3	1.2	1.4	1.1	1.3	1.1	1.3	1.1	0.9	1.2	1.2	1.4	0.8	1.3	0.0	1.4	1.4	0.9
ArcGIS Desktop	0.6	1.0	0.9	1.2	0.6	0.9	0.8	0.9	1.1	1.3	0.6	1.1	0.9	1.0	1.4	0.0	0.7	1.1
Insert GT	0.9	1.3	1.2	1.3	1.2	1.3	1.0	1.0	1.0	1.4	1.2	1.3	1.0	1.1	1.4	0.7	0.0	1.2
maps	1.1	1.4	0.9	0.9	0.9	1.0	1.1	1.1	0.4	1.3	1.1	1.5	1.0	1.1	0.9	1.1	1.2	0.0
Distance from the pattern	2.5	1.9	2.1	2.1	2.4	2.3	2.4	2.0	2.4	1.7	2.6	1.7	2.6	2.3	1.9	2.5	1.9	2.3

Source: own study

Based on the above relationships, a pattern was established, which is a reference point for each system under consideration for each system under examination. This pattern is equivalent to an ideal system. Below, in the tabular layout, in the last line, the model value of the significance function is presented, which is performed by each of the examined systems. Of course, the model value depends on the experts' assessments, and in this case its components are created by the maximum number (the highest rating) of features among the subsequent considered GIS systems. The final step of the undertaken network of actions is to determine the exact distance that separates each of the tested GIS class systems from the established ideal point. Referring to the pattern coordinates shown above (table 8), the following results were obtained (sorted in ascending order from the ideal point).

Table 8. Distance of individual systems from the pattern

Salesforce maps	**1.684**	
Google Earth Pro	1.732	
surfer	1.901	
ArcGIS Pro	1.906	
MapInfo Pro	1.929	
GE Smallworld	2.035	
GeoExpress	2.109	
BatchGeo	2.127	
hexagon Geomedia	2.278	
GeoPoint	2.294	
maps	2.334	
ArcGIS Enterprise	2.355	
TatukGIS	2.364	
GIS Cloud track	2.415	
ArcGIS Desktop	2,508	
Cadcorp	2,539	
CARTO	2,592	Dirichlet tessellation of the results of ranking a set of GIS systems according to multi-criteria Pareto optimization
WebGIS	2.619	

Source: own study

As mentioned, the table 8 presents the distance of the tested systems from the reference solution. *Rank In Cathegory* (RIC) values are presented in the form of Dirichlet tessellation, which represent the distances of the systems from the pattern. The attached Voronoi diagram shows directly that all considered systems are within (orbit) the ideal point due to slight differences in distances. However, only some of them can be regarded as Pareto optimal choices. Analyzing the obtained results, the Pareto optimal system in relation to the considered set of criteria is the QuickStep product. It is repeatedly emphasized that the considerations conducted here include a comprehensive set of criteria, so the selected GIS system is the best in terms of all considered features. This is a very important property of multi-criteria optimization. The obtained ranking results also highlight another fact, which shows to what extent the considered systems are like each other. The difference between the first two features (the winning Salesforce Maps

and second in the Google Earth Pro ranking) is only 0.047127121. Similarly, there are slight deviations from the next values obtained in the ranking, between successive pairs of the tested systems.

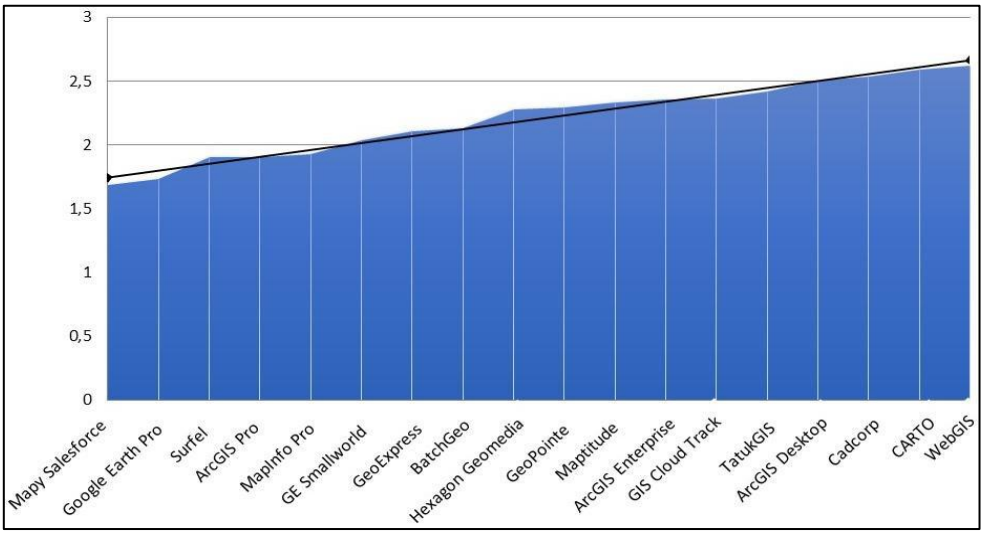


Fig. 8. An area chart with a trend obtained in a multi-criteria analysis of Pareto optimization
Source: own study

The above-mentioned dependence was illustrated by means of a layer diagram, showing the value of the function of the distance of a specific object (system) from the pattern (Fig. 8). There is an almost linear upward trend (placed on the chart), but it is not rapid. The distance closest to the pattern (in relation to the currently used multi-criteria optimization method) is represented by Salesforce Maps and Google Earth Pro, while the farthest are WebGIS and CARTO. Concluding the conducted research, it was found that the applied multi-criteria optimization method is perfectly applicable in the considered problem of selecting the best solution. It implies the creation of a ranking of objects and their alternatives in a properly established order.

Conclusion

The aim of the research was to conduct a multi-criteria comparative analysis of integrated GIS-class IT systems for small and medium-sized enterprises (SME). The main reason for using Pareto multi-criteria optimization (also in this work) is to model the collective (group) preferences studied in the work and to support the decision maker in making strategic decisions for the company. Of course, it should be borne in mind that a single solution (solution) will never be optimal for all considered criteria, which are quality indicators. Hence, the algorithms of this class make it possible to choose from among all features or criteria, the solution allocated closest (or located – in the immediate vicinity) to the Pareto optimal point (also called the ideal point). Since a large group of criteria was used in the work, deciding with so many factors often boil down to searching for a compromise solution against the background of contrasting, colliding criteria. Referring to the problem under consideration, to find such an ERP

system (a compromise solution) that would be acceptable for each decision criterion, to make a Pareto optimal decision, multi-criteria optimization should be obligatory.

Eighteen selected GIS class systems that meet the criterion of completeness of all data required in the conducted research were fully analyzed. The proper comparative characteristics were preceded by the recognition of the market situation in terms of the availability of GIS class systems in global realities. At the data acquisition stage, extensive research was carried out on commercial and free GIS solutions designed for the small and medium-sized enterprise sector.

During the implementation of the research, many difficulties were encountered that directly result from the encapsulation of companies. Currently, most organizations provide only cursory, cursory data, which they publish in the form of advertising materials and folders. In most attempts, obtaining any materials describing even basic functionalities turned out to be a very difficult task and bordered on a miracle. Certainly, this is partly due to the current shape of the law, which makes it difficult to provide and disclose information on given products, both to producers, distributors and implementers. The aspect of competition and rivalry on the market, between competing manufacturers, is also significant.

When assessing individual GIS class systems, an innovative approach was used, in which the price criterion was excluded from the analysis. The previously conducted diagnosis shows that in the vast majority it is one of the most important determinants of the evaluation of a given object, while as a reminiscence, it is worth bearing in mind that this factor is very often given by manufacturers in an imprecise way. Often, the price being a dumping or temporary – promotional price is not disclosed as the final value. In addition, it is strictly dependent on fluctuations, market moves, the frequency of introducing new versions of the system or other factors that are de facto independent of the level of advancement of the product itself.

Since the cost factor is strongly correlated with other features and criteria included in the work, the other criteria included successfully cover the cost factor. On the other hand, the contributions, functionalities and properties of the systems presented in the work, in terms of other features, are objectively measurable, constant and unchanging.

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Artur Kotowski[1]

IUS OR LEX ? THE EVOLUTION OF THE CONCEPT OF LAW IN CONTINENTAL EUROPE

Abstract: The paper analyses the evolution of the concept of law in continental Europe in order to answer the research question – to what extent European law and the direction of its development is closer to the idea of ius or lex. The former obviously implies treating law in a stratified manner. Positive law is limited by an unchanging and not fully human-dependent order of values. The idea of lex, on the other hand, is embedded in the positivist primacy of statute law. The history of European culture has been associated with the mutual inhibition of these two macro-conceptions of law. Meanwhile, the federative legal order of the Union, which is emerging before our eyes, seems to refer exclusively to the idea of lex.

Keywords: theory of law, statutory law, philosophy of law, European Union

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Introduction

Ius or lex – this division is as old as any reflection on law. At the same time, contrary to the convention, which is sometimes adopted, it has not always consisted (and this is still the case today) of a dispute over what is <real> law, i.e. that one formula excludes the other. Often, it was simply a matter of determining the reciprocal relationship between ius and lex and, in particular, of demonstrating the superior position of the content signified by these terms. In fact, a century-old episode of original legal positivism can be consigned to the past, according to which only the lex is the law and the ius is not and cannot be, because it does not meet the test of the origin and social efficacy of the law.

Nowadays, in the lex – which may be lex scripta as well as lex iudicialis – we find references to ius in various formulations and both in the preambles and in the articulated part of the normative act. Indeed, the modern understanding of human rights is founded on the inalienable human dignity that exists independently of political power. Even when arguing about the extent of this freedom or specific rights, lex is an affirmation of ius. It does not, therefore, function based on recognition of what is and what is not a right. It is the element of binding the being of law to the will of the political sovereign that is the fundamental determinant differentiating lex – symbolised by the conception of positive law (while not specifically referring to legal positivism) and ius – i.e. the non-positivist conception of law.

The history of law in Euro-Atlantic legal cultures is a path of mutual coexistence, dispute and inhibition of these two, great concepts of law, which move the level of consideration of the essence (ontology), cognition (epistemology) and valuing of law (axiology) to the metaphilosophical level. In this paper, we will trace how the approach to law evolved in selected events, although considered groundbreaking in general history. First and foremost, we will consider what civilisational repercussions are brought about by the tilting of the dominance of the philosophy of law in certain epochs towards, respectively, lex or ius. After all, is a balance between the two and a neutral attitude possible? It would appear not, and the more than 2,500-year history of the culture of established law proves that there is always a supremacy of one of the concepts mentioned. This analysis cannot, of course, be carried out completely neutrally and presupposes an axiological commitment on the part of the author. However, the assertions and evaluations presented in this study – by design – are intended to correspond to the dominant, or at least recognised as functioning, positions in the scholarly discourse. This review is carried out not only to describe the evolution of the concept of law, but to answer the question whether the European legal order that is being created before our eyes (we probably cannot speak of a system for the time being) is based more on ius or lex?

The article was prepared in the current of so-called analytical jurisprudence, using the method of conceptual analysis of historical and doctrinal literature.

Discussion

Antiquity – the origin of the dichotomy. Historically, the first was ius. The reason was obvious. The first settlements, therefore the first more or less elaborate political associations, did not know writing. Compact settlements arose with the invention of agriculture, which ended the nomadic stage around 7,000 BC. (Wolski, 2000, p. 9). The lex does not always take the form of a scripta, but for the certainty of the law and the ease of knowing it, writing it down is most desirable and effective. This, in turn, only became possible with the invention of writing, which occurred around the 3rd thousand BC. (Wolski, 2000, p. 9). This did not mean that human law was then automatically given precedence. The recognition of ius as the most important in the hierarchy of sources of law was fostered by the acceptance of the divine origin of the ruler and the ancient concept of despotic power. The ruler thus conferred divine law, and this fact further legitimised it. The lex was thus subordinate to the ius, but the ius constituted the non-subordinate sovereign. Reference to the divine origin of the ruler is found in the oldest sources of the lex scripta. Such a procedure was performed, for example, by Hammurabi in his Code (c. 1780 BC):

When the lofty Anu, king of the Anunnaki, and Enlil, lord of heaven and earth, determining the destinies of the country, to Marduk, the first-born son of the god Ea, they conferred supreme power over all men, and among the Igigi deities they made him the greatest, when they named Babylon after him loftily, and in the four corners of the world they made him reign, and in the interior of it an everlasting kingdom, the foundations of which, like heaven and earth, are firmly established.

Then they called me, Hammurabi, a pious prince, worshipping the gods, in order to bring justice to the country, to exterminate the wicked and the wicked, so that the strong would not harm the weak, so that, like the sun for the black-headed, he would rise and radiate the country, Anu and Enlil, in order to care for the well-being of the people, by my name (Stępień, 2000, p. 9–10).

It is not without reason that the first reflection on the juxtaposition of lex and ius occurred in political organisms with a non-despotic form of government. We are, of course, talking about ancient Greece. A monument to this dispute is Sophocles' Antigone, a power drama from 442 BC and a philosophical treatise whose central theme is the attempt to construct a justification for taming the unfettered lex. Here, ius symbolises not the despotic will of the ruler, but "the holy laws of God, which are eternal and have lasted from age to age, that their beginning no one can examine" (Sofokles, 1939, p. 14). With the process of the positivisation of law, its separation from ius is perceived, a hypothetical contradiction between these normative orders was born. Because everything depends on who creates lex and on what principles. However, both ius and lex require interpretation – giving shape to a general rule. In ancient Greece, ius had a specifically divine legitimation. The ius was personified as Dike – justice eternal and immutable, daughter of Themis and of Zeus himself (Maureira 2015, p. 299). Here we find the first stratification of natural law (developed centuries later in the concept of St Thomas - with the division into lex aeterna and lex naturalis). The Greeks are thus the

first to attempt to contrast and define the relationship between ius and lex. These considerations – undertaken, of course, with varying intensity – can be found in the works of Homer (8th century BC), Plato, Aristotle (for example, in the Nicomataean Ethics) and even the Pythagoreans, for whom mathematical order and order was also an element of the natural order of things (Domingo, 2010, p. 5).

A fuller characterisation of ius a lex is of course found in ancient Roman law. Generalizing, ius is a right to something, derived from the natural order of things, in principle unchangeable by political authority. Lex is man-made law, whereby it can also constitute written ius. Lex was divided into statute law, magisterial (praetorian) law and doctrine, which sometimes had the value of a source of law. It is worth noting that the whole Roman conception of law is based on ius, not lex (ius es ast boni et aequi, ius gentium, etc.). Law becomes a cultural archetype, for it binds society and the state together; "The Republic, says Scipio Africanus, is the thing of the people, and a nation is not every association of people assembled in any way, but an association of the whole united by the consent of the law and the commonality of usefulness" (Cicero, De re publica, 1948, p. 6). Cicero, however, elaborates on this division. For him, all law consists of the law of nations – ius gentium – and the law of the state – civil law (Domingo, 2010, p. 7). For the Romans, law was a confirmation of virtue, morality, and universal values – it was therefore created in a significantly different way from the contemporary process of its creation.

In conclusion, one may risk a claim that, on the example of the evolution of the discussed concepts in the ancient period, the relationship between the role played – respectively – by ius and lex and the form of political system is outlined. Ius, by the fact of not being written down, is more susceptible to instrumentalization. The lex, on the other hand, without a foundation in ius, easily becomes an instrument of tyranny and arbitrary political power.

The Christian community – ius comune. The concept of universal (common) law found widespread acceptance during the medieval period. The starting point was, of course, Roman law, which, thanks to the Justinian Code, survived and became the universal body of law of early medieval Europe. In the light of the division that interests us, between ius and lex, the status of the Justinian codification is not that clear, even though the emperor's intention was obviously to made Roman law positivistic one (although no one used that name at the time). Like any 'codification', therefore, it was classical statutory law, therefore lex. On the other hand, codification quickly acquired the status of ius, for it became the basis for the reception of Roman law as universal law in Europe, in the sense that it ceased to be the law of a particular state and acquired the status of universal law. It was thus the point of reference of any 'newly' created statute law – as Corpus Iuris Civilis. For the secondary 'lex' thus became a kind of ius.

This process coexisted with the formula of the Christian world created from the beginning of the era, and just as the process of the transition from antiquity to the "Middle Ages" is not easy to carry out in a periodisation of history. Historians also have difficulty in defining the end of this time. The most accepted date known as the

beginning of the era is the fall of the Western Roman Empire is conventional (fall of Rome in 476). So is the end of the Middle Ages – the fall of Constantinople (1453). Both dates are mere symbols. It is better to refer to historical processes. Thus, the beginning of the Middle Ages is the emergence of a feudal socio-economic structure, the origin of which was the Roman legal institution of colony. Divided property, so characteristic of the Middle Ages, resulted in the formation of a network of political dependencies that entwined Europe for more than 1000 years. This phenomenon, referred to in the literature as the triumph of particularism, consisted in the transformation of the city-state system, developed thanks to the Roman Empire and linked by a central authority, into a system of feudal fragmentation, where the feudal lord, reigning "by the grace of God", with a dispersed and weak (or if strong, as in the Frankish state, it was not sustainable) royal power at the beginning of the Middle Ages, strove for self-sufficiency in the domains he ruled. Hence, the cognitive horizon of the people of the time tightened, Roman common schooling declined and Justinian lex was transformed into ius, in places weakened by particularism based on common law. At the same time, under such conditions "private war became endemic" and in the early Middle Ages "someone was constantly defending or attacking someone" (Manteuffel, 1996, p. 106).

The above formula was exhausted with the flourishing of the Middle Ages (conventionally the 11th-12th centuries). At that time, several processes take place that contradict feudal particularism. In this context one points to economic development (more advanced agriculture, the growth of trade, the development of agglomerations), the rise of the bourgeoisie and, above all, the development of centralism – both on the side of the secular power and the Pope. The heyday of the Middle Ages is linked to the emergence and development of strong royal power, which is gradually taking place in France, England, Spain. Those regions that remain in the fetters of particularism will be subject to the expansion of the distributing powers of absolute monarchies (ex. Italy, German Reich).

In the Middle Ages, the conflict between ius and lex came to a head as part of the rivalry between the empire and the papacy, which lasted for several centuries – the so-called investiture dispute. The origins of this event can be traced as far back as Christmas Eve 800, when Charlemagne was 'unexpectedly' crowned Emperor by Pope Leo III. This was a skilful move by the latter, as he was becoming, in the opinion of the Christian world, the dispenser of the imperial crown (Charlemagne left Rome furious, perfectly aware of the danger). In this conflict, which lasted almost three centuries (ending with the Concordat of Worms in 1122), the roles were clearly divided. The papacy represented ius, referring to divine law and the role of the pope as God's sole representative on earth. Gregory VII in 1075 escalated the dispute by producing the document Dictatus papae with bold theses: the pope could dethrone emperors, secular rulers should “kiss his feet”, supreme authority in the Christian world belonged to the pope. The empire, of course, symbolised lex and the emerging tendencies in Europe towards strong, central political power. The dispute over investiture, as a historical event, determined the cultural identity of Europe and, above all, the developed legal and political system. It was the only moment when the Christian world could, like the Arab

world, choose the path of theocratism. However, this was not the case, and the political victory of the empire paved the way for the gradual domination of state law (lex), treated as a separate normative order from religion and morality.

To conclude this section, it is appropriate to mention what happened across the Channel. I refer, of course, to the rise of England because of the invasion of William the Conqueror (and his great victory in Battle of Hastings – 1066) and the subsequent three centuries of the development of a new legal culture. From the outset, a feature of English law was the lack of reception of Roman law (Corpus iuris ...) due to the separation of Britain from mainland Europe and the many migrations of people in the first centuries of the Middle Ages. The unification of the law of the English tribes also took on a different character. Common law emerged as an inventory (records then reports) of judicial decisions, based on the principle of stare decisis. Continental ius and lex replaced the English 'right' and 'law', where 'right' still takes precedence today, in the sense that it underlies the judge's autonomous decision on matters that are generically similar, which is the essence of precedent.

The era of centralisation and codification. Although the conquest of Constantinople by the Turks in 1451 is symbolically considered to mark the end of the Middle Ages, a new era occurred with the discovery of America (1492) and the speech of Martin Luther (1517). This led to a rearrangement of the perception of the world by the people of the time (Domingo, 2010, p. 22). Europe, possibly the Mediterranean basin (the Holy Land), ceased to be the whole world that had filled the entire cognitive horizon of man almost since antiquity. It turned out to be larger, to contain other peoples and riches. Apart from the attack on the very institution of the Catholic Church, the Reformation was also associated with a paradigm shift in the practice of philosophy – as Umberto Eco metaphorically put it – it was no longer enough just to 'store up knowledge', Renaissance man wanted to know the world around him. Perhaps not yet to understand it (as in the Enlightenment), but for profit, but he certainly broadened the horizon of his own mind.

This period sees a rapid transformation of the perception of law in continental Europe. This is due to the new legal and constitutional doctrine of absolutism. Although the consideration of legislative sovereignty as an immanent feature of the secular ruler had already been undertaken by imperial theologians, above all by Marsilius of Padua, it took the French and Italian theorists of absolute monarchy in the 16th and 17th centuries to shift the emphasis even more strongly from ius to lex. The former is only a guideline for the ruler and binds him only in so-called cardinal laws. These do not actually constrain royal power but extend its continuity and reproduce it (in absolute France: prohibition of disposal of the royal domain, male promignty, catholicity of the king). In the modern era, justifications for non-religious justification of the law are increasingly bold, despite the possibility of being accused of heresy. The lex positiva ceases to be a reflection of the lex naturalis (therefore ius), but is a fully autonomous normative order. With absolutism, political power becomes highly bureaucratic and centralised. As such, it seizes all lawmaking powers and displaces local law, including

customary law. The absolute monarch could not tolerate other subjects having the right to legislate, thus local communities, custom and so on. He therefore comes into conflict with parliament. Its front is suppressed (as in France) and if it loses (as in England) absolutism collapses. Ultimately, it is parliament that will end the era of absolutism in Europe – as we know from the example of the French Revolution.

As already mentioned, the justification for the existence of law begins to be sought in cognition by means of reason. Its source is found in the social contract (Hobbes), state power personified by the king (Jean Bodin, Machiavelli) or the imperative of reason to require of everyone what is required of oneself (Grotius, Kant). Natural law ceases to have a metaphysical foundation. Famous in this respect is the claim of Grotius, who reasoned that his rules bind us because divine intervention in the temporal world cannot be justified (God is therefore law-neutral).

The culmination of the above positions was thus the increased use of statute law, in addition centrally created in continental Europe, loosely based on axiological demands. Ius can only be subject to interpretation by the absolute monarch, whose will determine whether lex is consistent with it. If the lex is established, it enjoys a presumption of conformity with the ius. From the point of view of the peculiarities of the culture of statute law, the beginning, and the subsequent process of the codification movement, which lasted several centuries, would lead to the supremacy of lex in European thinking about the essence and cognition of law and bind it to the law-making activity of central, bureaucratic state bodies.

Transformations in the Age of Enlightenment, the historical school, the school of exegesis, legal positivism. The Enlightenment in the 18th century was the genesis of philosophical concepts that deepened the rift between ius and lex on the European continent. Central to this seems to be the consolidation of the theory of the social contract, the emergence of the concept of political utopias, which represented the opposition of the time to feudalism and absolutism. The former as a socio-economic system and the latter as a legal-political system were increasingly regarded by Europe's elites as outmoded and leading to wars, tensions, and misery. It is worth pointing out, however, that in Anglo-Saxon culture, proponents of the social contract, such as the mentioned T. Hobbes or J. Locke, sought to find the support of lex in the nature of society, immutable from political will or subjective human judgements changing over time. This was due, among other things, to the peculiarities of the already developed precedent and the dualistic structure of the sources of law, which was still dominated by judicial case law at that time. Private law, including the right to property, had since the dawn of common law culture been seen as an element of ius, not lex, and therefore an inalienable human right, the scope of which could not be freely shaped by political power. In continental Europe, because of a tradition of absolutism spanning several centuries, the concept of law was increasingly linked to the exclusive prerogative of the monarch, thus the central authority. As we have already shown, this had its genesis as far back as the beginning of the Middle Ages, thus nearly fifteen centuries earlier, when

Justinian the Great promulgated his codification, which acted as the main source of law in many parts of Europe even in 'recent times' (Palmirski, 2022, p. 11).

It is possible to formulate the thesis that Continental Enlightenment thinkers were less interested in extending the autonomy of ius in favour of lex, but rather in changing the centre constituting the latter according to their vision of the world as an opposition to absolutism and feudalism. This line of thought is found particularly strongly among French philosophers. Opposition to private property and progress and the aspiration to create an equal society governed by political power is the credo of the concept of the main representative of the continental theory of the social contract, Jean-Jacques Rousseau. The utopianism of the views he presented is sometimes the basis for the harsh assessment that he was 'the first of the wise men to love humankind and hate humans' (Cisek, 2023, p. 41). An outlet for opposition to social inequalities that could not be overcome in any way, but also to the increasingly perceived ineptitude of absolute monarchy, which was increasingly regarded as a system that did not fit with social realities, was of course the French Revolution (suffice it to recall the case of the so-called Marie Antoinette necklace, in which 'Mirabeu saw the prelude to the revolution and Napoleon I one of its three causes (Żywczyński, 2001, p. 23).

The awakening of the peoples in the two, great revolutions of the time – the American and the French – is widely regarded as the beginning of modern republican forms of government. The proclamation of human and civil rights, the recognition of so-called inherent rights, the introduction of equality before the law or the inviolability of property (the allodial conception of it later adopted in the Napoleonic Code) can lead to the belief that we are dealing only with a transformation of the conception of ius naturale into its so-called variable law variety. For the political sovereign ceases to be the full disposer of law. A specific area of it is deemed to be separated from the free shaping of the scope of individual freedom by political power. In fact, the French Revolution led to the further supremacy of statute law and is regarded as the end of the multicentric conception of the sources of law in continental Europe inherent in previous eras. This was particularly evident within the framework of the French school of exegesis, developed in the first half of the nineteenth century, whose chief demand was the 'prohibition of the interpretation of law' by judges. This was dictated by the fear that the legal establishment, including judges and clerks still remembering the times of the ancient regime, would not try to reactivate the axiology and selected solutions of the previous regime by interpreting the new in content law.

While the French school of exegesis developed gradually, the situation in German jurisprudence was more polarised in the 19th century. The first half of the century was dominated by an anti-naturalist philosophy of law referred to as the historical school of law. Its qualification is most often to be associated with the positivist current, although in its assumptions it was the radical opposite of legal positivism itself; in turn, positivists also fiercely opposed its assumptions – 05.07. 1847, in Berlin, Julius Herman von Kirchman, then a prosecutor in Berlin, in a lecture entitled "On the lack of value of jurisprudence as a science" criticised that "jurists have become worms that live in the rotten tree, turning away from what is healthy, nestling and spinning their filaments in

what is diseased [...] the science of law becomes the handmaiden of chance, error, passion, and misunderstanding, looking only to the past. [...] Where positive law is unambiguous, the science of law should remain silent, for it has nothing to say' (Stelmach, 2012, p. 7). Representatives of the natural law school (above all its most prominent protagonist, Friedrich Carl von Savigny) opposed the idea of statute law, proclaiming a commitment to legal custom, customary law, something along the lines of Anglo-Saxon case law. This current deepened the further separation of lex from the idea of ius.

This culminated, of course, in the rise of the philosophy of legal positivism in the mid-nineteenth century, and analytical jurisprudence in England a little earlier. There is no consensus in legal theory as to whether these orientations coincide with each other or whether they should be treated as independent philosophies of positive law. We do not need to explore this dispute in this paper. We are only interested in continental legal positivism, which for nearly 100 years became the dominant and highly influential philosophy of law in state law culture, whose tenets are still alive today. Bearing in mind, of course, the basic division of the philosophy of law in question, into positivism of the hard (original) variety and soft (refined) variety after the Second World War. The former is nowadays commonly treated as an anachronistic, extinct and theoretically erroneous concept (its most complete methodological critique was carried out by H. Hart).

It can be pointed out very generally that the positivists rejected ius, completely linking law to lex. At the same time, this is not a textual conception of law, although it is very often – albeit erroneously – regarded as such. For the positivists, law was a relation of social subordination of the addressee to political power. The science of law was to be based on a methodology derived from the applied sciences, for the positivists saw the correctness of the science of law in methodological naturalism. The philosophy was steeped in scientism (Zirk-Sadowski, 2020, p. 44). Positivists identified law through the test of origin and its social efficacy. In such a paradigm, only that which came from a political sovereign could be regarded as law, in a monocentric catalogue of sources of lex juris. This was emphatically emphasised (critically, after all) by Radbruch (1990, p. 159), who wrote that 'to us every law was a law and every law a law; the science of law meant only the interpretation of a law, and jurisprudence meant only the application of a law. We called ourselves positivists ...". At the same time, the conviction of the necessity of empirical identification of the law did not cease even after the tragedy of the Second World War. A hallmark of legal-positivist thinking is the search for an empirically verifiable source of law that provides a specific legal relationship – thus is normatively binding and allows for the enforcement of law by public authority (Dworkin, 1998, pp. 47–48). Among others, in 'Five Minutes in the Philosophy of Law', Radbruch still tried to identify 'the principles of law that surpass all statutes in validity', despite the 'interpretative doubts' that 'the efforts of centuries have created [...] in the Declaration of the Rights of Man and of the Citizen' (Radbruch, 1988, p.65).

The fundamental problem of the non-positivist conception of law combined with the idea of ius is always related to the fulfilment of the requirement of legal certainty and,

regarding law imposing particularly onerous sanctions (such as criminal or financial sanctions), of fairness, understood as the prohibition of circumventing the principle of nullum crimen sine lege et al. (Alexy, 1993, p. 44 and 48). This is why, immediately after the Second World War, a process called the positivisation of natural law, rather than the naturalisation of positive law, came into existence. This is not just an apparent play on words. The name conveys the true direction of change and the location of the centre of gravity on – respectively – ius or lex.

Conclusions: Ius or lex – the contemporary picture of European law and possible directions for its further development

Having so far established the concepts and recalled the most important stages in the development of the mutual inhibition of ius and lex in Europe – with a gradual assumption of the leading role by statute law – we will now consider whether the system of European law – understood as the law of the European Union together with the conflict-of-law rules, which are intended to resolve possible conflicts with the national law of the Member States – is closer to the idea of ius or whether it is in fact the primacy of lex and a positivist conception of law? This question is important, as in the doctrine the assessments in this regard are strongly divided. Some point out that 'we Europeans have created a fiction in which instead of natural law and instead of ius there is only international law and lex' (Czarnek, 2018, p. 28). Others present a more cautious position that points to the role of Article 2 of the Treaty on European Union (TEU), which, among the ethical concepts of principlism, relativism, situationism and anti-moralism, refers to Europe's liberal democratic legacy (Armin, 2020, p. 705). Such a position, however, is extremely positivist, for it rejects the ius entity, immutable from human will, replacing it with a relative perception of values, which can (and should) be defined according to the current standard of their understanding. Thus, morality ceases to be a set of permanent and unchanging values but is transformed with the transformation of matter and man's perception of it. This position therefore coincides with the extreme empiricism inherent in historical materialism (Lenin, 1949, p. 63).

Obviously, references to extreme communist ideology are not found in the main normative acts establishing the European Union (we are talking about the TEU, and the Treaty on the Functioning of the EU, TFEU) – above all in the preamble of the TEU. There are only symbols whose significance can be exaggerated or taken as dangerously glorifying representatives of the totalitarian ideology of Marxism – we are talking, for example, about Altiero Spinelli, who in the famous Ventotene Manifesto proposed a social reform of the EU states preceded by a strong criticism of the idea of the nation-state. The fact is that this very document "in the White Paper on the Future of the European Union" published by the European Commission in 2017. [...] was mentioned as the sole ideological foundation of the organisation" (Zych, 2019, p. 7). Another important element of this EU programmatic document (and this is how it is referred to on the websites of the Parliament and the European Commission) is the programmatic deficit of classically understood democracy – as the will of the majority, the voice of the

people, the dependence of policy directions on the opinion of the demos or, most importantly, the possible redefinition of concepts as a result of changes in people's views. On the other hand, the concept of democracy itself is extremely susceptible to values and worldviews as well as legal and political views (Heywood, 2009, p. 3).

It should be noted that this paper is not concerned with assessing the status quo. We are only interested in answering the question to what extent (and whether at all) law in the European community refers to the idea of ius, or whether it is in fact a completely relativised lex.

Of course, references to the values and origins of legislation can be found both in the TEU argot (the TFEU is devoid of it) and in several provisions of the Treaties, the most relevant of which is the already mentioned Article 2 TEU. To put it succinctly, 'on paper' everything looks pretty good. The first source of inspiration for European integration is indicated in the preamble as 'the cultural, religious and humanist heritage of Europe'. Of course, for conservative circles, this is sometimes not enough and points to the lack of reference specifically to Europe's Christian heritage or precisely to the concept of natural law. On the other hand, it can also be judged a good thing that such an admonition has a place in the preamble at all, and in view of the already summarised evolution of Europe's juridical and constitutional heritage, we have never really had to deal with theocratism on the continent. The treaties emphasise two elements very strongly: human rights and the rule of law. This conclusion is also reinforced by an analysis of the order of the values mentioned in Article 2 TEU. This provision states that 'the Union is founded on the values of respect for human dignity, freedom, democracy, equality, the rule of law and respect for human rights, including the rights of persons belonging to minorities. These values are common to the Member States in a society based on pluralism, non-discrimination, tolerance, justice, solidarity and equality between women and men". Indeed, on the other hand, 'the Treaty clearly takes the position of conferring competence, subsidiarity, and proportionality – as it is evident, for example, from the wording of Article 5(1) and is supported by the wording of Article 4(1) TEU. It would seem that the willingness to adopt a different policy – based on perhaps legitimate and necessary objectives arising from contemporary challenges – would require a redefinition of the Treaty, precisely because of the need to respect, inter alia, the principle of the rule of law, i.e. the action of public institutions on the basis and within the limits of the competences conferred" (Kotowski & Syryt, 2023, p. 11–12).

However, the literature signals the absence of any limitation of the political sovereign in both the EU CAT and its policy documents, which is only required to be democratically established and to act on the basis and within the limits of the law. Freedom is thus limited by the 'civic collective', whose omnipotence is sometimes criticised by, among others, proponents of natural law, that 'the omnipotence of the sovereign collective led to the Jacobin terror' (Wielomski, 2023, pp. 85–86).

Another problem of the very dynamically emerging EU legal system is the phenomenon described as the democratic deficit in its systemic aspect (Muntean, 2000). This issue is more of a political question than a legal one, but it cannot be ignored in the analysis between ius and lex. The non-transparency of certain decision-making

processes or the very structure of the supreme institutions of the Union are very often cited as examples of the phenomenon in question. However, not all these arguments seem to be correct. After all, the European Parliament is elected by universal suffrage. It therefore has a democratic mandate. The European Commission is represented by representatives-designate of all states. These designating authorities, in turn, have a democratic mandate. Simply put, the democratic legitimacy deficit is due to the distance of the decisions to be taken from the individual societies and is the result of the double-stage nature of the appointment of a person to a particular function. By being multi-member bodies, EU bodies do not have the same strong democratic legitimacy as personalised single-member bodies. It is like making accusations against the cabinet system by comparing it with the presidential system. In a national government, citizens are also not sure who the leader of the winning party designates as individual ministers or with whom he or she enters into a coalition. Much of the problem with the legitimacy of EU power, on the other hand, stems not from normative solutions, but from the political culture that has developed. It is often pointed out that deserving politicians of the Member States who, for various reasons, would find it difficult to gain support at home (e.g. as a result of making difficult decisions) are appointed to EU organisations. The crux of the problem of the democratic deficit is seen by more insightful authors as being in the genesis of European integration and the axiological concept adopted (Haller, 2008, p. 313). The problem is that the fragmentation of Europe into nation states prevents the creation of a common European demos. The values on which the Union is based are also understood differently in various parts of the continent. Perhaps the most serious problem is related to the contradiction of political interests between, for example, the core states of the Union (Germany, France) and the others, either west and east or north and south. The best example of this is the Union's energy policy, which for years has been based on Russian gas imports, putting the countries of central and eastern Europe at risk. Drastic differences in foreign policy were revealed by the Russian aggression against Ukraine. In Western Europe, this conflict is sometimes treated as distant or even as one that poses a problem for the hitherto established economic line based on cooperation with Russia. In contrast, for the countries of Central and Eastern Europe – including, of course, Poland – it directly threatens sovereignty and security. The attitude of Germany and France at the outset of the conflict makes one wonder whether, in the event of an aggression against Poland, the western states of the Union would not decide to help, but only up to the Vistula line, according to an illusory security treaty or a new division of influence. At one time these considerations may have seemed preposterous, but reality evolves very quickly.

History teaches that federated; multi-ethnic states were created based on the shared, positive values of the people who came to build them. Thus, they were created from below and not from above – as creations of elites. On the contrary, the latter option always ended in failure. This one was merely postponed. The USA – the best example of a multi-ethnic state – was built by emigrants seeking, however, a common frame of reference: broad economic freedom, opposition to feudal social relations, subjectivity, and individual autonomy (in the sphere of customs, religion and even self-identification,

with which the right to bear arms is linked). States created by elites, by force as it were, to unite the conflicting interests and axiologies of nations, collapsed more or less violently. We can mention here: Austria-Hungary, Yugoslavia, the German Reich (after all, forcibly united by Prussia), and centuries earlier the Roman Empire, whose decay accelerated with the introduction of the Dominion. Meanwhile, European integration involves the imposition of an axiology chosen from among its various models and social transformation through more or less overt processes of social engineering. These, in turn, are implemented with little acceptance by European elites of traditional democratic institutions (Haller, 2008, p. 336–337). The institution of the European referendum was almost compromised by the double votes on the Constitution for Europe in France and the Netherlands, which 'came as a shock to the political establishment' (Haller, 2008, p. 1-2). The most important decisions affecting the future of European societies were taken with little, no, or illusory consultation with citizens. We are talking about climate, immigration, or economic policy. Basically, all these decisions are taken from the top down, in fear of confronting the people.

If we consider the basic requirements of the concept of ius, the absence of this idea in European legal thought becomes readily apparent. Man is the exclusive creator and disposer of law, the system of sources of law is based on a monocentric, highly detailed set of normative acts, the necessity of their implementation into national systems and the verification of this process as well as application. Decision-making discretion, including judicial discretion, is only desirable when operating within the paradigm of unilaterally conceived European integration. It is, after all, contrary to the requirements of the rule of law for elected European Commissioners to criticise rulings by national (constitutional or supreme) courts, which introduce a certain limitation of the powers of the EU institutions or explicitly point to limitations on their competences arising from the principle of conferral of powers and such an understanding of the primacy of EU law that cannot extend to competences not conferred by the Treaties or exercised jointly within the framework of subsidiarity and proportionality (Article 5(2) and (3) TEU).

In conclusion, if we analyse the evolution of the macro-concept of law in continental Europe, the direction of the development of Union law appears to be extremely positivist (while not to be judged in terms of: good or bad, etc.). This obviously entails certain repercussions for the integration process and a repository of future possible tensions in the absence of a common European axiology that respects the autonomy of the societies of individual Member States (Bunikowski, 2013, p. 18). Without positive law being based on absolute values, its enforcement and justification becomes merely physical coercion (Szyszkowska, 1995, p. 142). EU lex is a highly formalised lex scripta, based on a top-down created axiology with little grounding in ius.

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Nadir & Oblique Aerial Imagery – new possibilities in 3D mapping

Abstract: The new generation of aerial photogrammetric cameras brings camera constructions with several fields of view, instead of a traditional vertical one, which, in addition to vertical images, also enable oblique images. Although this imaging method allows higher quality when making a 3D model of the imaged area, it is still not used in Croatia. This paper describes the technology of aerial photogrammetric cameras with multiple fields of view and the advantages of using nadir & oblique aerial imagery, especially in photogrammetric algorithms that allow automated orientation and measurement of images. The tests were performed on nadir and oblique images taken by Vexcel Osprey nadir & oblique camera. Finally, the result obtained only with vertical images was compared with the result with oblique images when making a 3D model of the urban area. Special attention to the quality of modeling of buildings and urban vegetation is drawn and discussed.

Keywords: Photogrammetry, 3D city model, Nadir & oblique imaging, Multiple view camera

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Introduction

There is a high demand for current photogrammetric airborne and high-resolution satellite data due to the widespread use of standard vertical images as a topographic background in GISs today. Most of the National Mapping Agencies (NMAs) still rely on the traditional workflow based on vertical photography but changes are slowly taking place also at production level. The available orthophoto Internet services, for instance in Google Earth and other similar services, are primarily used for orientation and visual inspection of chosen features by planners, administrative users, and the general public. However, not everyone will be able to understand orthophotos. Oblique photography's undeniable benefits include the ability to show building facades and footprints. As a result, the data is easier for non-expert users to understand because it more closely resembles what is observed on the ground. (Fig. 1)

Fig. 1. View of the urban part in the central part of the vertical aerial photograph (left) and on the oblique photograph (right)
Source: Bakici et al., 2017

That is why in the past, oblique images have been used more for visualization and interpretation than for metric applications. The military and archaeology are applications, where oblique images have long been the norm for reconnaissance purposes (Welzer, 1985). But up until recently, photogrammetrists rarely paid attention to oblique images. They can therefore be considered to be a new source of data for photogrammetry and GIS. Oblique photogrammetry is a technique for creating 3D city models using texture information obtained from oblique images. It combines traditional nadir images with oblique images acquired at high angles (Petrie, 2008). This method can be applied to single or multiple camera systems mounted on an unmanned aerial vehicle, helicopter, or aircraft. It also uses the integration of GPS and IMU, just like traditional aerial photogrammetry. Oblique photogrammetry has the following advantages, which can be categorized as follows (Karbø & Schroth, 2009):

- Imaging of the entire structure and precise measurements on all sides;

- Measurement of distance, elevation, and slope in the terrain;
- Detection of blind spots;
- Identification of hard-to-see objects in orthophotos, e.g., lampposts, telephone poles, etc.;
- Use of a GIS database integration and 3D visualization of GIS data.

Numerous camera systems are used in oblique photogrammetry. Approaches vary depending on whether a system uses a single camera or multiple. The system where vertical and oblique cameras work together is considered the most popular and effective. Examples include Vexcel UltraCam Osprey, Pictometry's PENTA DigiCam, Hexagon Geosystems' Leica RCD30 (Fig. 2.), and Track'Air Aerial Survey Systems' MIDAS (Petrie, 2008). In such a system, oblique cameras are mounted at an angle of approximately 40°-45° looking forward/backward and left/right, comparing to nadir camera, which is placed in the center. The resolution is about 15 cm for nadir images and 12-18 cm for oblique images, when an average flight altitude is of 1000 m. (Nelson, 2013).

Fig. 2. Leica RCD30 Oblique Penta footprint with RCD30 cameras
Source: Pepe & Prezioso, 2016

A point can typically be represented by 12 to 24 images in this configuration. This allows for the creation of image libraries by compiling images that meet the required quality standards once the photogrammetric processes are complete. These image libraries can then be used for a variety of purposes, including mapping, land use change tracking, and disaster management. Unmanned aerial vehicles (UAVs) are also becoming increasingly popular as a means of aerial photography, as they can capture high-quality images for less money than traditional manned aircraft. In this article, the Vexcel Ultracam Osprey images and products are analised, that's why the imaging geometry of this camera is discussed.

Geometry of oblique images

The efficiency of an oblique camera system is built on the camera geometry. To design a highly effective camera system, key parameters including pixel size, length-to-width ratio of the imagery, focal length of the nadir and oblique cones, installation angle of the oblique cones, frame rate, flight speeds, and motion compensation must all be

optimized against one another. To guarantee a similar ground sampling distance (GSD) in both nadir and oblique imagery, the focal length ratio between the nadir and oblique cones must be clearly defined. Unlike vertical aerial images, oblique aerial images have some properties that need to be taken into account when considering the mapping geometry. The imaging scale is not nearly constant across the entire recording format. Therefore, the size of the pixel imaged on the ground (Ground Sampling Distance – GSD) changes significantly along the image. And that, in the foreground of the image, the image scale is larger and the GSD is smaller, while in the background of the image, the image scale is smaller and the GSD is also larger (formula no. 2). When planning to take oblique images, you should take into account not only the field of view of the individual camera βy, but also the flight height hg and the deflection angle of the shooting axis αy (Fig. 3).

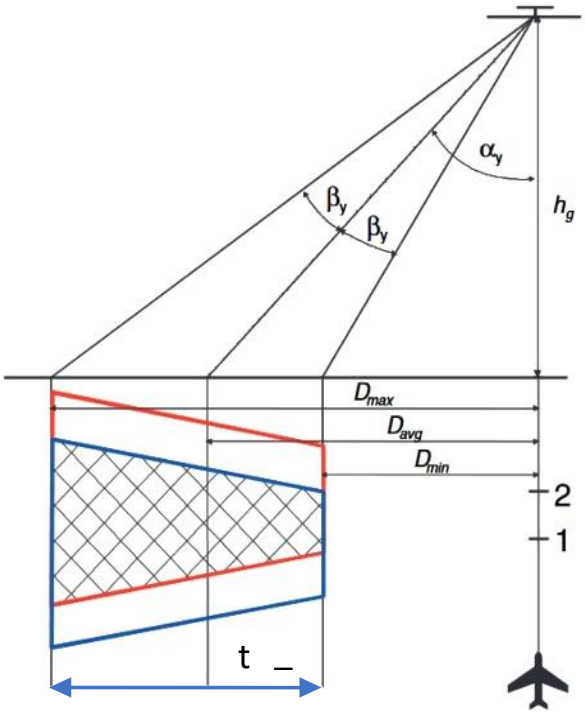

Fig. 3.Oblique imaging geometry
Source: Grenzdörffer et al., 2008

Acording figure 3 following relations can be derived (Grenzdörffe et al., 2008):

$$D_{min} = h_g \tan\left(\alpha_y - \beta_y\right),\ D_{max} = h_g \tan\left(\alpha_y + \beta_y\right),\ \mathrm{W} = D_{max} - D_{min} \qquad (1)$$

Where are:
D_{min} – distance to image foreground, measured from projected trajectory of flight
D_{max} – distance to image backgroud, measured from projected trajectory of flight
D_{avg} – distance from the centre of image to the projected trajectory of flight
W – image width, that corespond to strip width in photogrammetric flight

And the denominator of imaging scale is calculated as follows:

$$m_{min} = \frac{h_g \cos(\beta_y)}{f\cos(\alpha_y - \beta_y)}, \quad m_{max} = \frac{h_g \cos(\beta_y)}{f\cos(\alpha_y + \beta_y)}, \quad m_{avg} = \frac{h_g}{f\cos(\alpha_y)} \tag{2}$$

Where are:
m_{min} – image scale denominator in the image foreground
m_{max} – image scale denominator in the image background
m_{avg} – average image scale denominator

In conclusion, having a very large nadir footprint does not increase the effectiveness of an oblique camera system. With a 60 percent side overlap configuration, the UltraCam Osprey 4.1 creates a 25 percent forward and backward oblique footprint overlap, as marked with blue rectangles on figure 4. The flightlines must be extended for the left and right, as well as the forward and backward, oblique cones in order to ensure complete coverage of the area of interest. Extending the flightlines will not only ensure that the entire area is covered, but it will also enable the capture of more accurate and detailed imagery.

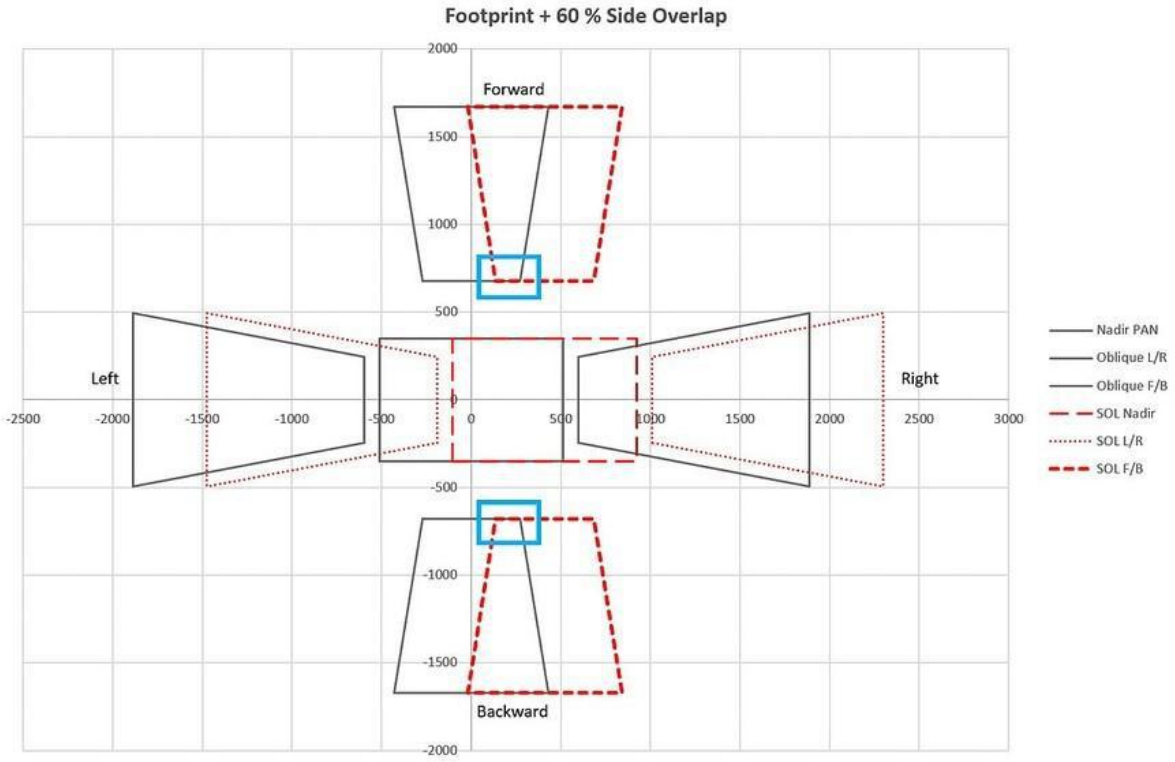

Fig. 4. Overlap geometry of Vexcel Ultracam Osprey camera with 5cm GSD and 60% side overlap
Source: Reinisch, 2022

Additionally, extending the flightlines enhances triangulation and the final product's overall quality. Therefore, to maximize the effectiveness and efficiency of the oblique

camera system, careful planning and consideration must be made when deciding the length and placement of flightlines. The local topography and terrain should be taken into account when extending flightlines. In order to ensure the best image capture, the flight path may need to be adjusted for steep slopes or uneven terrain. To further ensure a smooth and thorough data collection process, coordination with other aerial survey operations in the area is essential to prevent any potential conflicts or overlaps.

Point matching

To get the dense point cloud from imagery, which is the base for 3D modeling of the earth's surface and objects on it, the matching algorithm is used. It heavily relies on the Structure from Motion (SfM) algorithm and Multiview Stereo (MVS) algorithm. Both of them help to reconstruct the 3D structure of a scene from a sequence of 2D images, as is shown on figure 5.

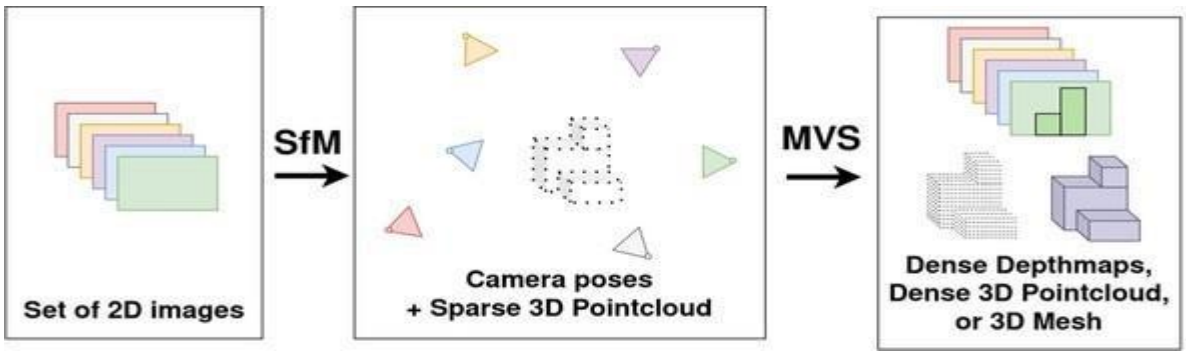

Fig. 5. SfM and MVS principles
Source: Reinisch, 2022

The key steps of the SfM followed by MVS algorithm are (Metashape Professional, 2023):

- Feature Extraction: The first step is to extract distinctive features from the input images. These features can be corners, edges, or other distinctive points that can be easily detected in multiple images.
- Feature Matching: The extracted features are then matched across different images to establish correspondence between the feature points. The matching process involves searching for similar feature descriptors or using geometric constraints to determine the correct matches.
- Camera Pose Estimation: Based on the matched feature points, the camera poses for each image are estimated. This involves determining the position and orientation of each camera relative to a common coordinate system.
- Triangulation and bundle adjustment: Once the camera poses are estimated, the 3D positions of the matched feature points are reconstructed through triangulation. This process involves intersecting the rays from multiple camera viewpoints to find the 3D coordinates of the corresponding points. Bundle adjustment is performed to refine the estimated camera poses and 3D point positions.

- Depth or disparity Estimation: Each pixel in the images is assigned a depth value or disparity map. This can be achieved by triangulating the matched features and estimating the depth based on parallax or using techniques like block matching.
- Depth refinement: The initial depth estimates are refined using optimization techniques. This could involve minimizing energy functions that enforce smoothness, consistency, or uniqueness of the depth map.
- Surface reconstruction: Finally, a 3D point cloud is generated by projecting the refined depth maps back into 3D space. This point cloud can be further processed to create a more detailed surface mesh representation of the object or scene.

In the last decade, matching algorithms have been improved and several of them even newly developed (Haala & Rothermel, 2012). These algorithms make it possible to create point clouds with 100 points/m2 from images with a GSD of 10 cm. However, these point clouds are usually noisier than those recorded by LIDAR. To achieve better results in point cloud reconstruction, increasing the number of overlapping images and better filtering are essential (Rupnik et al., 2014). Thus, there is a possibility of using oblique images, in order to achieve better reconstruction results and more extracted points compared to using only nadir images.

Study area

The part of Graz chosen for this study is highly urbanized and has a variety of topographic features, including wide and narrow streets, buildings, squares (Südtiroler Platz), modern buildings (Graz Museum of Contemporary Art), vegetation (Castle Hill), and water (river Mur). Graz is located in southeast Austria on both sides of the Mur River (Figure 6 A). The study area (Figure 6C) is about 15 hectares in size and is located primarily in the I. district, in the city center (Figure 6 B).

Fig. 6. Location of the study area (C) on Austria map (A) and on the map of Graz (B)
Source: Austria Base Map, 2023

Data source

This study made use of images captured by the photogrammetric Vexcel Ultracam Osprey M3p camera made by Vexcel Inc. and made accessible for research on the following URL: ftp.vexcel-imaging.com. A whole set has 60 pictures from 12 different places. Three parallel strips, each with 4 imaging locations, were used to image the entire study area. There were 5 images captured simultaneously at each imaging point. According to Figure 4, the central (nadir) image is captured using a vertical optical axis,

and four oblique images were captured using an oblique optical axis in the four cardinal directions of the flight line (ahead, backward, left, and right).

Results and discussion

In this study, we analyze two datasets that were both created using photogrammetric data from an aerial camera, the Vexcel Ultracam Osprey M3p. To create the 3D model for the first dataset, we simply used the nadir photos. For the same purpose in the second, we combined nadir and oblique photos. Basic mesh statistics already reveal significant differences between these 3D models in terms of the total number of points and faces gathered across the same area (Table 1).

Table 1. Mesh statistics of 3D models

	3D model from nadir images	3D model from nadir & oblique images
Total faces	305102	2890461
Total vertices	280692	1450082
Similar vertices	3557	0
Open edges	251030	8501

Source: own elaboration

Similar vertices are vertices in the mesh model that are spatially close to each other, potentially indicating redundant or overlapping geometric information. Open edges refers to edges in the generated mesh model that do not form a complete loop or are not connected to other edges. These open edges can indicate potential issues in the mesh, such as missing or incomplete geometry, and may affect the overall quality and integrity of the model. When a mesh has open edges, it means that some parts of it are not properly connected or closed, resulting in gaps or holes in the geometry. These gaps can lead to inaccuracies in the reconstructed surface or affect the visual appearance of the final 3D model. Visually comparing the two models in an orthogonal projection from the top reveals that, even in that projection, the nadir & oblique images based photogrammetric reconstruction (Figure 8) has a substantially higher quality than the model that relies only on nadir photos (Figure 7).

Fig. 7. 3D model from nadir images in orthogonal projection
Source: own elaboration

Fig. 8. 3D model from nadir&oblique images in orthogonal projection
Source: own elaboration

As compared to reconstruction using only nadir images (Fig. 10), the quality of photogrammetric reconstruction using nadir and oblique images is significantly better due to better spatial resection of photogrammetric rays and the use of more images to measure individual points in the 3D model (Fig. 9).

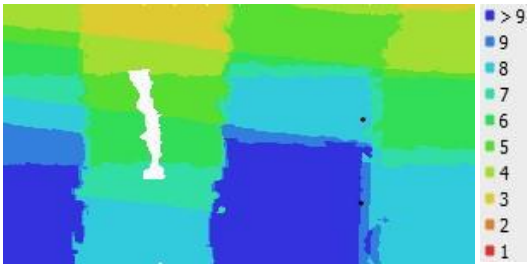

Fig. 9. Number of images in overlap nadir & oblique images
Source: own elaboration

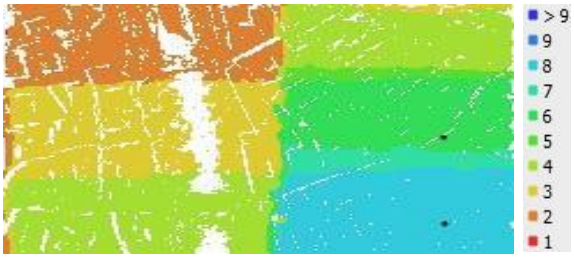

Fig. 10. Number of images in overlap by by nadir images
Source: own elaboration

The difference between reconstruction by nadir & oblique photos in comparison to results of reconstruction by nadir images is much more significant when looking at the quality of reconstruction of vertical sides of buildings (walls) and the vertical structure of greenery (particularly trees). In locations where the entire wall is photographed on numerous nadir photos (such as city squares, Figure 11A), nadir images may be sufficient for reconstructing details on vertical walls. The comprehensive reconstruction of vertical walls and urban vegetation using only nadir photos, however, is almost hardly practicable (particularly in narrow streets) (Figure 11B and 11C).

Fig. 11. Izometric view of 3D model from nadir images, (A – whole area, B – detail of building area, C – detail of urban vegatation)
Source: own elaboration

The reconstruction by nadir and oblique images is much more detailed and makes possible proper 3D modelling of urban areas with all objects within it (Figure 12A). Buildings are almost completely modeled correctly and detailed textures are projected onto the model with no visible deformations (Figure 12B). The trees are correctly modeled and photo-textured not only from above but also from the vertical sides (Figure 12C).

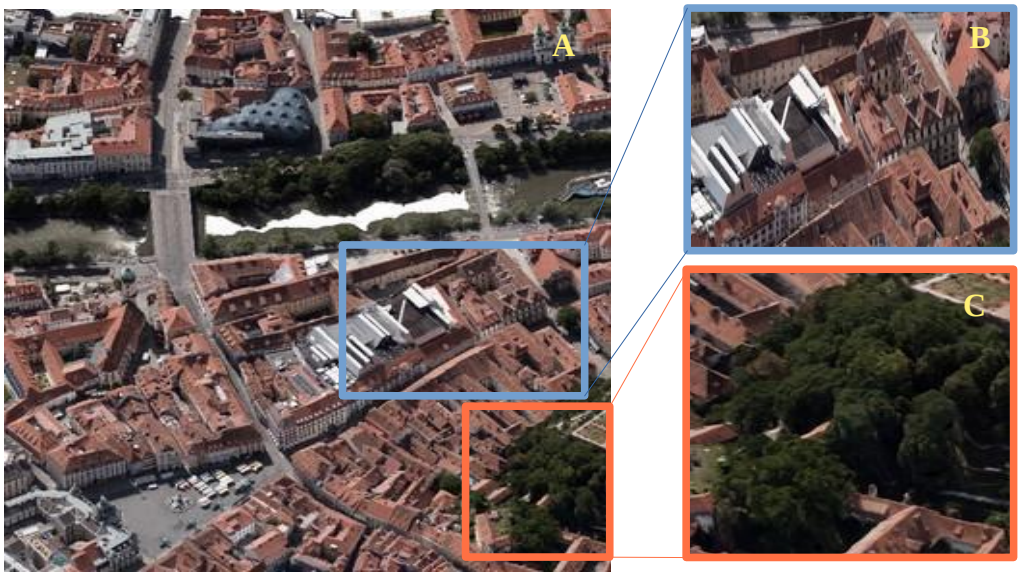

Fig. 12. Izometric view of 3D model from nadir & oblique images, (A – whole area, B – detail of building area, C – detail of urban vegatation)
Source: own elaboration

Conclusion

Although cameras with multiple fields of view and oblique images are not yet recognized as suitable imagery for photogrammetric survey in Croatia, this research shows that this method of recording with nadir and oblique images provides much more detailed and reliable photogrammetric measurement, especially in photogrammetric survey and the creation of complete 3D models of urban areas. The resistance to a wider application of the combination of nadir and oblique imagery is certainly due to the fact that the mapping geometry is much more complex in the case of nadir and oblique imagery compared to pure nadir imagery. Therefore, it is necessary to apply a more complex mathematical model of mapping and to use software and methods that make this possible. Today's modern photogrammetric technologies, based on fully automated photogrammetric measurement techniques and computers with processing power that allows large amounts of data to be processed in a timely manner, achieve better results in spatial reconstruction and the creation of 3D models when they have a larger number of images taken from different shooting positions and from different viewing angles. This means that cameras with multiple fields of view and the images obtained from them are becoming increasingly important.

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NEW TECHNOLOGIES IN REAL ESTATE MANAGEMENT AND PROTECTION OF PRIVACY

Abstract: The article examines the impact of new technologies on the property market, focusing on the integration of geospatial analytics with artificial intelligence (AI) to improve property management and gain competitive advantage. The analysis considers how AI tools, tailored to individual preferences, can assist in the management of large datasets that are critical to various sectors, including residential, commercial, office and hospitality. The primary research question addresses the extent to which the application of these innovative technological solutions affects privacy. The study identifies both challenges and potential risks, particularly in relation to privacy. It analyses the legal frameworks at national and European level, highlighting important similarities and differences. It concludes that current legal systems may struggle to adapt to the technological boom and the complexity of emerging technologies, in particular AI. The research highlights a gap in understanding the impact of advanced technologies on individual privacy and underlines the importance of responsible and ethical use of technology.

Keywords: Proptech, geo-spatial analysis, new technologies law, right to privacy, real estate

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Introduction

With the rapid advancement of technology, the property market has undergone a revolutionary change. Traditionally conservative and based on established management models, the market is now evolving under the influence of proptech - the innovative fusion of 'property' and 'technology'. Tools such as Artificial Intelligence (AI), the Internet of Things (IoT) and GIS systems with machine learning algorithms have fundamentally changed the way property is managed (Trincado-Munoz et al., 2023).

The use of geospatial data is central to proptech. Thanks to AI-based geospatial analysis, it is possible to accurately assess the location and potential of properties, which in turn makes it possible to predict market trends or identify building problems. Proptech also introduces the concept of smart buildings, which use the Internet of Things (IoT) to improve occupant comfort and energy efficiency. This contributes to sustainable development goals. Such innovations also support the idea of smart cities by changing the way people interact with their environment.

However, technological advances also bring challenges. While tools such as AI and IoT offer myriad benefits, their use also leads to the collection of vast amounts of data, which may violate users' privacy. This begs the question: to what extent does the use of new technologies in property management affect privacy?

To answer this question, it is essential to understand the complex relationship between technological benefits and privacy responsibilities. Key players in the property market, from managers to lawyers and regulators, need to be prepared for the challenges of modern technology.

This paper aims to analyse the impact of digital innovation and technology on the property market and assess the implications for privacy. With the increasing use of technology in property management, both lawyers and regulators need to be aware of the potential implications. As these tools become more prevalent in society, it is important to understand their ethical and legal implications.

Materials and methods

The study focuses on the legal aspects of the use of innovative technologies in property management. Special attention is paid to the issue of protecting the privacy of its users. The article was prepared using the legal-dogmatic method, including an analysis of legal regulations, including the Constitution of the Republic of Poland (Constitution, 1997), and a literature review. A comparative method was also used, contrasting national legislation with European regulations on the right to privacy.

Considering the new legal context of technologies in property management, the research was based on contemporary national and European legislation. The focus was on constitutional provisions, private law provisions and standards under the ECHR (European Court of Human Rights, n.d.) and the GDPR (Regulation (EU) 2016/679). In addition, the Council of Europe's position on artificial intelligence (AI) was assessed, in particular with regard to the work of the Committee on Artificial Intelligence (CAI, 2023).

The aim of this study is to identify potential normative areas that could affect the rights of property users and influence subsequent decisions related to the integration of new technologies in property management. While the study is grounded in the context of Polish law, its findings may be valuable for other jurisdictions facing similar regulatory challenges.

Results and discussion

The property market is undergoing a period of intense digital transformation, disrupting traditional business models and increasing transparency, efficiency and competition. At the heart of these changes is PropTech, a response to the demand for smart, sustainable development and economic growth. Defined as the broad application of innovative technologies in the real estate sector, PropTech offers benefits to users, property managers and land managers. It includes property selection tools, drones, virtual reality, building information modelling (BIM), data analytics, AI, IoT, blockchain, smart contracts and technologies related to real estate crowdfunding and fintech (Siniak et al., 2019). These innovations can increase productivity, improve energy efficiency and promote environmental conservation, enabling countries to make progress in line with the 2030 Agenda for Sustainable Development (UNIDO, 2016).

Technological advances have transformed real estate management over the past decade. Such tools have become indispensable and have introduced new methods of management and communication. Oxford University's concept of 'PropTech 3.0: the real estate of the future' (Baum, 2017) posits that PropTech is central to the future of property management. This now encompasses not only the property sector, but also related areas such as smart cities, the sharing economy, ConTech and FinTech. The World Economic Forum classifies the development of PropTech into three main phases: the initial development of online listing sites (PropTech 1.0), the incorporation of data analytics and virtual reality to enhance the customer experience (PropTech 2.0), and the exploration of emerging technologies such as drones, virtual reality tools, IoT and blockchain (PropTech 3.0) (Couse, 2018).

Modern property management is increasingly using tools such as geographic information systems (GIS). As a tool for collecting, storing and analysing geographic data, GIS has a core spatial analysis capability that facilitates the study of spatial patterns, affiliations and dependencies (Clapp et al., 1997). This capability, coupled with geocoding, provides property professionals with a deeper understanding of spatial relationships and paves the way for more accurate property valuations.

Geospatial analytics, especially when supported by artificial intelligence (AI)-based tools, play a central role in the transformation of the property sector. This technological amalgamation enhances the study of urban development trends and facilitates the identification of rising demand for different property genres in different locations. At the heart of this is the ability of AI-driven models to decipher a wide range of geospatial data, including aspects such as location, neighbouring infrastructure characteristics and public transport availability. Using historical price records, these models can predict future property values in different areas. One manifestation of this methodology is

Zillow's 'Zestimate' tool, which cleverly combines geospatial verification with AI to provide accurate property value estimates using a comprehensive dataset of geolocation details (Zillow, 2023). Assessing the value of a property, particularly in locations that are undergoing rapid change, requires the evaluation of numerous variables. The 'Zestimate' algorithm, which integrates deep learning methods and geospatial analytics, can take into account complicated factors such as a property's proximity to educational institutions, parks or shopping centres, in addition to a region's price history. As a result, a property's value can be meticulously assessed, taking into account not only its intrinsic attributes but also its external context.

A key area of technological intervention is the assessment of investment risk. Sophisticated AI blueprints allow property investors to meticulously assess the latent risks associated with investing in specific locations. These analyses incorporate data sets such as criminal activity, predicted climate change, natural disaster threats and expected demographic escalation. Cutting-edge AI-driven tools from leading technology companies are fusing this geospatial information from multiple sources to provide a comprehensive analysis (WeWork, 2023). In addition, AI is having a significant impact on space optimisation, as evidenced by WeWork's use of advanced sensors coupled with AI to study office space usage patterns. By monitoring employee movements on a daily basis, these systems can modify and optimise space usage, resulting in increased efficiency and comfort.

In the real estate panorama, image recognition technologies cannot be overlooked. Tools such as those presented by Orbital Insight autonomously identify property features in aerial photographs (Orbital Insight, 2023). Combined with AI-driven environmental and climate risk analysis, investors can gain a more holistic view of the potential hazards associated with specific properties, such as the risk of flooding or fire. HazardHub is an example of a platform that fuses geospatial intelligence with advanced AI paradigms to provide complex risk analysis (HazardHub, 2023).

The digital transformation of the property industry is evident in the rapid evolution of technologies such as the Internet of Things (IoT) and blockchain technology. The infusion of IoT into smart buildings fosters an interconnected web of devices and sensors, laying the foundation for smart homes. In such environments, systems facilitate the remote manipulation of functions such as heating or lighting via mobile devices (Sarah Shaharuddin et al., 2023). For property managers, IoT is emerging as an important tool, allowing them to collect and analyse data from a myriad of devices to optimise resource management and identify user preferences (Daissaouia et al., 2020). At the same time, blockchain technology is burgeoning, ensuring transparency and security of transactions, while cloud innovations enable global access to remote data.

A key tool in the property sector is BIM (Building Information Modelling). Its evolution introduces the concept of the digital twin – a virtual mirror that reflects tangible structures and processes (Sasikumar et al., 2023). This digital surrogate helps to monitor, evaluate and predict the behaviour of real-world objects, streamlining accurate management. Augmented by data analytics, cloud resources or artificial

intelligence, the digital twin enables risk prediction and optimisation, which is critical for the real estate sector (Afanasjew, 2021).

In addition, these technological advances have implications for property security and preservation. Drones, also known as unmanned aerial vehicles (UAVs), are revolutionising property surveillance. They enable meticulous property assessment, area analysis and property marketing with stunning visuals (Stępień-Załucka, 2022). As well as providing accurate property valuations, drones make it easier to inspect sites for potential investments. Equipped with imaging devices, they also improve the security of properties. However, the use of drones could breach the boundaries of privacy. Similarly, surveillance mechanisms such as CCTV cameras could invade the privacy of individuals (Badowska & Badowski, 2019). With these advances comes the risk of cyber-attacks on sophisticated building management systems. Technology providers therefore have a responsibility to ensure privacy, which requires the implementation of robust safeguards (Finn & Wright, 2016).

Right to privacy for immovable property users. A comparative analysis of national and European regulations

Modern information and communication technologies (ICT), including the Internet, are an integral part of people's daily lives. These technologies serve as central communication channels, offering convenience, speed and access to a vast reservoir of information. As a primary means of communication, the Internet is both a source of information and a threat to privacy. Inappropriate use of technology poses serious challenges. With the rapid evolution of technology, age-old privacy protection tactics are becoming obsolete. Privacy incidents are escalating, increasing the threat to the right to privacy. There are many instances where our data is collected and processed without our knowledge, leading to privacy violations.

This makes it all the more urgent to develop rules that can cope with today's technological challenges. Such rules need to be adaptable to ever-changing technologies, while ensuring robust privacy safeguards. The modern paradigm of data protection requires a fusion of reactive legal intervention and foresight in order to identify and address future dangers in advance (Petrović, 2022).

In Poland, the right to privacy occupies a fundamental position among civil rights, which is strongly supported by the Constitution of the Republic of Poland (Journal of Laws, 1997). In particular, Article 47 of the Constitution reinforces the right to privacy by stating that everyone has the right to the protection of his or her private and family life, dignity and reputation, as well as to the management of his or her personal life. This protective umbrella is further strengthened by Article 51 of the Constitution, which emphasises informational autonomy (Karpiuk, 2017).

The cited provision bifurcates and addresses two scenarios. The first concerns the individual's right to legal protection, while the second emphasises autonomy in decision-making. The first scenario emphasises the state's duty to enact formidable legal constructs that protect 'private life, family life, dignity and reputation'. The latter

emphasises individual freedom, especially in the area of decision-making (Sarnecki, 2016).

In Poland, constitutional regulation has not led to a consistent definition of the right to privacy. It's synonymous with the guarantee of freedom and equality, but it's also seen as a tool to protect identity and dignity from discrimination or unjustified intrusion into the private sphere (Karpiuk, 2017; Constitutional Tribunal, 2014).

The arguments presented so far help to delineate the scope of the protection of privacy in different facets of human life. It encompasses the protection of the integrity and sanctity of this asset, as well as an individual's expectation that others won't access their private information without consent.

It follows that privacy is a staunchly defended constitutional value, and the right to privacy can be seen as a broad clause under which individuals find protection in their relations with both other individuals and the state (Uliasz, 2018). Privacy is an area that should be immune from intrusion, with individuals having the prerogative to set limits on the exposure of their personal lives. The subjective scope of the right to privacy encompasses everyone, which means that it includes both natural persons, such as Polish citizens and foreigners, and, according to the Supreme Court's rulings, legal persons in terms of honour and reputation (Supreme Court, 2008).

It's important to note that the right to privacy does not enjoy unlimited constitutional protection. Article 31(3) of the Constitution of the Republic of Poland sets out the conditions under which it may be restricted (Florczak-Wątor, 2019). However, such restrictions can only be introduced by law and are only allowed if they meet certain strict criteria, which ensure that they don't trample on the core of rights and freedoms (Karpiuk, 2015).

According to the Polish Constitution, every individual has the right to privacy and the right to defend it. As a result, privacy violations can occur in scenarios where, for example, surveillance drones interfere with the autonomy of private and family life or damage the reputation of neighbours. Importantly, it is up to the individual to determine the extent to which private family data is shared with others. In the context of drone surveillance, potential civil liability must be considered, primarily in relation to possible violations of personal property protected by the Civil Code (Civil Code, 1964). The aforementioned reference to personal property requires an explanation of this concept. In legal discourse, personal property is understood as intangible values that are relevant to the social functioning and mental state of an individual. The list in Article 23 CC isn't exhaustive, as the inclusion of a particular asset is determined by specific criteria (Olejniczak & Radwański, 2021).

At the international level, the importance of protecting privacy is underlined by instruments such as the 1948 Universal Declaration of Human Rights, the 1950 European Convention on Human Rights and the 1966 International Covenant on Civil and Political Rights. The European Court of Human Rights in Strasbourg emphasises the need to protect personal data in the age of digitalisation, taking into account communication methods such as the internet and email (Popović & Jovanović, 2017).

The right to privacy is protected internationally, particularly in the context of human rights. The European Convention on Human Rights, to which Poland is a signatory, is the central document guaranteeing this right in Europe. Article 8 of the Convention regulates this right, paragraph 1 of which states that "everyone has the right to respect for his private and family life, his home and his correspondence". This clause aims to protect the individual from arbitrary action by public officials and is largely individualistic (Kroon and Others v. the Netherlands, 1994).

The personal scope of this right extends to 'everyone', as made clear in Article 1 of the Convention, which states that 'the High Contracting Parties shall secure to every person within their jurisdiction the rights and freedoms set forth in Chapter I of the present Convention'. Legal literature points to an inaccuracy in the translation of this article. The inaccuracy is in the phrase where the High Contracting Parties guarantee rights and freedoms to 'every person'. However, legal scholars argue that the emphasis should be on "every person" and not just "the person". As a result, the right to privacy is not limited to natural persons alone, making its personal scope broader than the official translation suggests (Garlicki, 2010).

The Convention's rights and freedoms are primarily directed at natural persons, including those under the jurisdiction of the state and foreigners. It's important to understand that jurisdiction is not limited to the borders of a state, but can include acts that have effects outside its territory. Thus, the scope of jurisdiction is not limited to the geographical borders of a particular state, but can include acts that have effects outside its borders (Uliasz, 2018).

The material scope of Article 8 of the Convention includes the terms 'private life', 'family life', 'home' and 'correspondence'. These terms are inextricably linked to the issues discussed above. Although the definitions may seem clear, the case law of the ECHR reveals the complexity of their interpretation. For example, the ECHR has articulated that the scope of 'private life' is so broad that it defies exhaustive definition (Costello-Roberts v. the United Kingdom, 1993). It also encompasses facets of one's existence such as identity, both in mental and physical integrity, and includes elements such as reputation, honour and the collection and disclosure of personal data (Garlicki, 2020). At the same time, this autonomy empowers individuals to make personal choices. This autonomy extends not only to trivial choices, but to all matters of concern to the individual, including the prerogative to determine the end of one's life. The ECHR has emphasised in its judgments that this ability to decide embodies the power to direct one's life, even if it leads to decisions that may be morally or physically dangerous (Pretty v. the United Kingdom, 2002).

It follows that the right to privacy, as recognised by both the Polish Constitution and the European Convention, becomes crucial when assessing the legal implications of the use of novel technological interventions in the management of property. If such technologies interfere with an individual's daily life, they may violate Article 8 of the Convention. Thus, measures such as drone surveillance of property could fall under the protection of the ECHR.

Within the European Union, the Charter of Fundamental Rights clarifies the right to privacy, emphasising the protection of personal data (Article 8) and the preservation of private and family life (Article 7). Contemporary legislation, such as the General Data Protection Regulation (GDPR) of 2016, responds to current technological advances and emphasises the primacy of ensuring the confidentiality of personal data in an increasingly digital age (Tomić & Petrović, 2009).

A key issue concerns the use of surveillance in the context of data protection. A close analysis of RODO shows that several of its provisions directly address this concern. According to Article 2(2)(c) of RODO, its provisions do not apply when data are processed by individuals in the course of activities that are exclusively personal or domestic in nature. This means that the GDPR may not apply to property surveillance carried out for security reasons. In addition, Article 6 of the GDPR clarifies the circumstances in which data processing is considered legitimate. In this regard, the case law of the Court of Justice of the EU of 11 December 2014 emphasised that surveillance is excluded from the scope of the GDPR if it is aimed at protecting the genuine interests of the data controller (František Ryneš / Úřad, 2014).

Given these regulations and case law, the use of visual surveillance by a landowner against a neighbouring landowner will most likely fall outside the GDPR obligations. This applies in particular to monitoring aimed at safeguarding those 'legitimate interests' mentioned above. These interests include, in particular, the "protection of the property, health and life of the controller and his dependants". However, the application of such surveillance requires caution and adherence to the principles of the GDPR, with each case warranting individual consideration, taking into account both the rules governing the protection of personal data and the potential for civil claims arising from breaches of the right to privacy. This issue was discussed in the decision of the Polish Data Protection Authority of 17 July 2023, reference ZKE.440.81.2019. Consequently, it can be argued that surveillance aimed at the protection of property is consistent with the rights defined in the GDPR.

Contemporary legislation, which spans both international and national landscapes, attempts to navigate the intricacies of technological advances while upholding the rights and protections of individuals in an era overwhelmingly influenced by technology (Petrović, 2022). Privacy, a cornerstone of individual autonomy and well-being, is defended as an essential principle in contemporary societies. Such privacy enables individuals to defend themselves against unwanted intrusions into their personal sphere. Ensuring this privacy through transparent and lawful means is imperative.

Artificial intelligence and smart homes: new challenges for privacy

Artificial Intelligence (AI) is driving transformative changes in various facets of our existence, and its impact on privacy and data management is becoming increasingly important. Many AI-based applications use data sets, a significant proportion of which process personal data, raising privacy concerns. The integration of AI into property management frameworks, such as smart home systems, offers users the luxury of remote device control. However, this also increases the risk of privacy breaches. Such

systems facilitate remote monitoring of myriad household functions, creating new privacy and security dilemmas. AI innovations exacerbate existing vulnerabilities by facilitating extensive surveillance based on biometric or genetic data. A study by Fránik & Čermák (2020) identified critical security vulnerabilities in smart home hubs marketed by three major European companies. These vulnerabilities threaten fundamental human rights, including the right to life, liberty and security (Fránik & Čermák, 2020).

Modern technologies, especially those related to smart homes, offer countless benefits. However, they also pose risks to people's privacy and security. Security vulnerabilities in smart home devices can affect fundamental human rights such as life and liberty. Threats such as man-in-the-middle attacks, which disrupt device communication, and denial-of-service attacks can disable devices, putting users' health and livelihoods at risk.

A publication by the European Union Cyber Security Agency (ENISA) highlights the dangers of relinquishing control over devices such as thermostats or smart locks, and stresses that such vulnerabilities can directly endanger human lives. Attacks on smart homes can take many forms, from malfunctioning devices and data theft to burglary and property theft. Given the paramount importance of human safety, it is imperative to mitigate these potential threats (ENISA, 2023).

Beyond the realm of tangible security, the gravity of privacy concerns escalates, especially when considering smart homes. Cyber adversaries have the ability to monitor users and potentially access confidential information, culminating in identity theft or unwarranted location monitoring. These looming threats are multifaceted, encompassing both privacy and security breaches.

The responsibility for ensuring security lies with both manufacturers and users. Manufacturers should prioritise high security standards in their products, while users need to be aware of potential risks and exercise caution in their purchasing decisions. UNESCO emphasises the primacy of human safety when it comes to products or services that use artificial intelligence (UNESCO, 2023). The safety integrity of AI-based systems depends on their accuracy, reliability and resilience to vulnerabilities.

To address these challenges, the effective application of privacy principles in AI remains essential. The European Commission's High-Level Expert Group on Artificial Intelligence (AI HLEG) has developed ethical guidelines that highlight the importance of respecting privacy, maintaining data quality and integrity, and ensuring controlled access (AI HLEG, 2019). However, some research suggests that not all systems are impeccably secure. A study by Denko highlighted privacy vulnerabilities in certain smart home IoT devices (Denko, 2017), while another study by Apthorpe et al. highlighted the potential threat of data breaches (Apthorpe et al., 2017).

The Information Commissioner's Office (ICO) has highlighted the need to implement optimal levels of security in AI systems to prevent unauthorised or unlawful processing and to mitigate the risk of data loss, erasure or damage (ICO, 2020). In the field of AI, where myriad entities contribute to the development and operation of systems, the delineation of responsibilities becomes complicated (AI HLEG, 2019). The 2018

Montreal Declaration makes clear that humans cannot escape responsibility for decisions made by AI systems. However, it notes that holding individuals accountable for a properly functioning AI system is not justified. The OECD's definition of accountability emphasises the commitment of organisations and individuals to ensure the consistent performance of AI systems, taking into account their respective roles and the relevant legal context (AI HLEG, 2019).

Existing regulatory tools are critical to ensuring accountability for actions dictated by AI. The complexity of unravelling how algorithms work, and the apparent gaps in accountability, are becoming increasingly prominent issues. The European Parliament highlighted in its 2020 resolution that while adapting to new technologies is paramount, it doesn't require a complete overhaul of existing accountability structures (Montreal Declaration for Responsible Development, 2018). A key aspect is the recognition of humans as the primary architects and overseers of AI systems. The Parliament also advocated for changes to the Product Liability Directive to adapt it to the dynamics of modern digital technologies (Buitena et al, 2023).

In order to skilfully mitigate the adversities and repercussions of artificial intelligence, a fusion of different regulatory positions is essential. Liability paradigms can be divided into different taxonomies, including fault-based liability, strict liability and contractual liability. These categories address different objectives, particularly in terms of protecting the rights of consumers and individuals affected by AI-driven actions.

However, grappling with the nuances of liability isn't the only conundrum arising from the technological advancement of AI. A prominent feature of current AI systems is their reliance on massive datasets, which are central to the competent training and validation of AI designs. This reliance triggers profound considerations about data ownership and accessibility, which are intimately linked to the prevailing distribution scheme of economic goods. As a significant proportion of these datasets contain personal data, any misuse can potentially violate privacy.

Conclusions

Technological advances in property management, particularly through geospatial analytics and artificial intelligence, are creating new opportunities for the property sector. This digital shift facilitates the effective processing of large amounts of data, which is becoming increasingly important in various market sectors, from residential to hospitality. Accurate analysis of this data can greatly accelerate the identification of trends and the forecasting of market shifts.

The analyses carried out highlight the potential for AI to be tailored to individual user preferences in the property sector. The use of such tools is revolutionising traditional ways of working, while paving the way for new avenues of growth. The privacy implications of AI are particularly important in the property management sector. Potential privacy concerns associated with the implementation of AI in smart homes and similar technologies have been addressed in previous sections.

A predominant challenge posed by contemporary technologies revolves around the protection of privacy. The legal aspects of this concern have been addressed in the light of different regulatory frameworks at national, EU and international levels. The juxtaposition of these different privacy policies reveals both marked differences and parallels. Despite these differences, it's clear that the existing legal architecture may be ill-equipped to deal with the complexities introduced by modern technology, particularly AI.

It's clear that, despite the myriad benefits of the digital metamorphosis, there is an imperative to deeply understand the implications of such changes for individual privacy. This places a responsibility on technologists, professionals and policymakers to use technology wisely and ethically, and underlines the need for a more appropriate legal framework.

Ongoing studies exploring the impact of AI technologies on property management are recommended. The findings from the primary research question point to the urgency of continued observation and scrutiny of this rapidly evolving field. Such academic endeavours can provide invaluable perspectives that will enable the sector to skilfully navigate the evolving technological terrain while maintaining strict privacy standards.

In essence, the digital evolution of real estate is both a treasure trove of opportunities and a cauldron of challenges. The sector must be prepared to be nimble and ensure that technology is used to enhance, rather than hinder, human endeavour.

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TLS AND LOW-COST UAV PHOTOGRAMMETRY AS AN EFFECTIVE COMBINATION OF SPATIAL DATA COLLECTION METHODS FOR CREATING DETAILED 3D SURFACE MODELS (DEM)

Abstract: The development of surveying methods and equipment has moved from conventional surveying methods to modern technologies such as Unmanned Aerial Vehicle (UAV) aerial photogrammetry or Terrestrial Laser Scanning (TLS). Our research deals with the comparison of spatial data obtained by these methods in the surface quarry Dreveník, Slovakia. Point clouds obtained by both methods were compared using CloudCompare and Leica Cyclone 3DR software. The mean absolute distance of the point clouds was 2.02 cm and the standard deviation between point clouds was 2.48 cm. Our results confirmed the compatibility and the possibility of combining point clouds.

Keywords: TLS, UAV, SfM photogrammetry, geohazard, point cloud, open-pit quarry

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Introduction

The development and application of modern surveying techniques can speed up, refine and simplify the process of obtaining spatial data about objects. One of the most advanced methods is photogrammetry using the Structure-from-Motion processing approach, which produces 3D models and orthophotos with high accuracy and detail. A current trend is the use of aerial photogrammetry, where a camera is mounted on an unmanned UAV. This approach is particularly suitable for smaller areas due to its ease of use, low acquisition costs, speed of data collection and high accuracy of terrain models, and it has become a suitable alternative in terms of quality and efficiency compared to conventional surveying methods. Surveying using UAV technology has been applied in various fields and disciplines such as mining (Park & Choi, 2020; Ćwiąkała et al., 2020), cadastre (Šafář et al., 2021; Fetai et al., 2019), industry (Ajayi et al., 2021; Kovanič et al., 2021), geology (Blišťan et al., 2016; Jacko et al., 2021), archaeology (Fiz et al., 2022; Schroder et al., 2021; Marčiš et al., 2023), architecture (Lin & Sang, 2022; Germanese et al., 2019), agriculture (Lambertini et al., 2022; Marín-Buzón et al., 2020) or for monitoring natural processes in the landscape such as slope stability (Migliazza et al., 2021; Junaid et al., 2022), geohazards (Kovanič et al., 2020; Urban et al., 2019) or landslides (Kyriou et al., 2021; Gantimurova et al., 2021).

Terrestrial laser scanning (TLS) is used to survey objects and small landscape areas. TLS is characterized by high speed of measurement and high point density. It is used to measure the positions and shapes of various asymmetric and irregular objects and features. With sufficient detail, speed and number of points, creating an accurate 3D digital model of a non-uniform object of varying size and shape is possible. TLS uses the spatial polar method principle to determine the points' spatial coordinates. The application of TLS is in the fields of structural design (Bariczová et al., 2021; Erdélyi et al., 2020), engineering and industry (Sofranko & Zemen, 2014; Wittenberger & Sofranko, 2015; Kovanič et al., 2020; Kovanič et al., 2023) or mapping (Pukanská et al., 2020).

Ground control points are commonly used to georeference TLS and photogrammetric models (Ren et al., 2020). In photogrammetry, GCPs are also used to correctly determine the elements of the internal and external orientation of the camera. GCP coordinates are determined in the field by direct measurement, e.g. using total stations or GNSS receivers. GCPs for georeferencing photogrammetric data have been used by (Vanneschi et al., 2019; Cao et al., 2019; Wallace et al., 2016; Štroner et al., 2021; Tomaštík et al., 2019). Acquiring photogrammetric data without GCPs is possible if a UAV with RTK/PPK is used. In this case, the use of checkpoints is recommended. The authors have addressed measurements without using GCPs (Štroner et al., 2020; Zeybek, 2021; Salach et al., 2018; Forlani et al., 2018).

The most common outputs from non-contact data collection are aerial photographs, digital models (Kovanič et al., 2021; Kovanič, 2013), digital surface models, digital elevation models, point clouds, vector maps or orthophoto maps (Santagara, 2017; Kunina et al., 2018; Puniach et al., 2018) representing real-world objects.

Material and methods

The site chosen for this work was the Dreveník quarry, located in the cadastral area of Spišské Podhradie near the village of Spišské Podhradie (Fig. 1) in the eastern part of the Slovak Republic. The town is located in the Hornád basin in the valley of the Margecianka river, about 12 km east of Levoča (Spišské Podhradie, 2023; Úrad geodézie, kartografie a katastra SR, 2023; Univerzita Komenského v Bratislave, 2023).

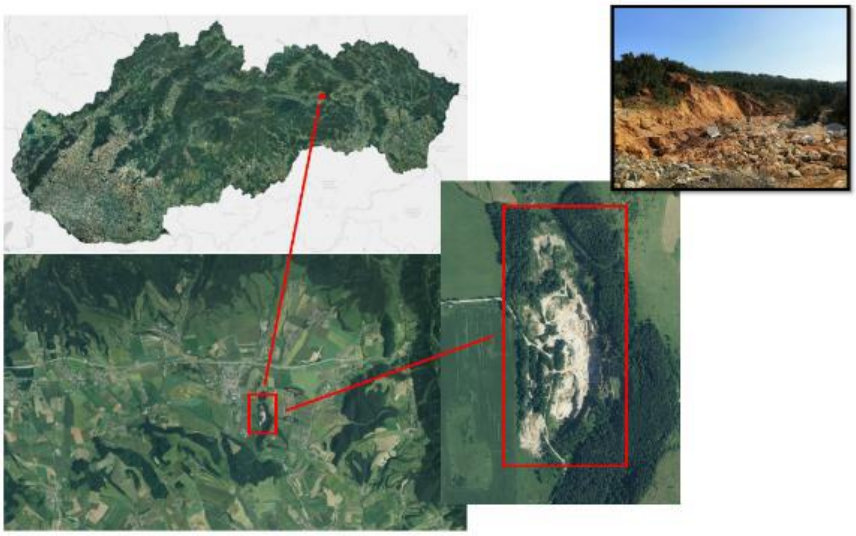

Fig. 1. Location of the Dreveník quarry
Source: Own elaboration

Entire quarry and its surroundings have been on the state list of specially protected natural sites in the Slovak Republic since 1925. The quarry was formed by joining several travertine piles deposited here from mineral springs and is part of the National Nature Reserve. It is located in the Hornádská Basin on the border of the districts of Spišská Nová Ves and Levoča. It has been on the World Heritage List of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) since 1993. The Slovak Paradise National Park administers the national nature reserve and is in the highest fifth level of protection. Dreveník is one of the largest and oldest protected areas of karst morphology in Slovakia. It is essential as a cultural and natural monument and for its travertine quarries.

Surveying equipment. GNSS rover Leica GS07. Nowadays, thanks to GNSS technology, high-precision positioning anywhere on Earth is already available. It's simple real-time operation is widely used in surveying, mapping and other applications. The Leica GS07 (Fig. 2) is a lightweight and compact Leica Geosystems instrument consisting of a Smart Antenna, a Leica CS20 controller and a telescopic boom. Thanks to the adaptive satellite selection. All other specifications related to the instrument are listed in a clear table (Table 1) (Geotech s.r.o., 2023).

Fig. 2. GNSS rover Leica GS07
Source: Geotech s.r.o., 2023

Table 1. Specification of GNSS rover Leica GS07

Technology	Leica RTKplus	
Weight	2,85 kg	
Channels	320	
SmartCheck	Continuous monitoring of the RTK solution	
Initialization	6 sec	
RTK accuracy	Single base	Horizontal: 10 mm + 1 ppm
		Vertical: 20 mm + 1 ppm
	Network RTK	Horizontal: 10 mm + 0,5 ppm
		Vertical: 20 mm + 0,5 ppm
Post-processing	Static long observation	Horizontal: 3 mm + 0,5 ppm
		Vertical: 6 mm + 0,5 ppm
	Static and fast static	Horizontal: 5 mm + 0,5 ppm
		Vertical: 10 mm + 0,5 ppm

Source: Own elaboration based on: Geotech s.r.o., 2023

Surveying equipment. Terrestrial laser scanner Leica RTC 360. The Leica RTC360 laser scanner (Fig. 3) from Leica Geosystems is a mobile, automated and efficient 3D laser scanner with a range of up to 130 m. It can reliably and accurately scan everything around the instrument in a short time interval. As a result, a colored point cloud of millions of points is obtained. Automatic registration in the field using VIS technology is also a significant advance, reducing processing time. Specifications and technical parameters are shown in Table 2. During the measurement, the laser scanner is placed on a fixed-head carbon tripod consisting of three telescopic legs (Geotech s.r.o., 2023).

Fig. 3. Terrestrial laser scanner Leica RTC 360
Source: Geotech s.r.o., 2023

A new feature is double scanning, which automatically removes moving objects, whether indoors or outdoors. An integrated large colour touchscreen or a mobile phone or tablet can control the device. The Leica Cyclone FIELD 360 app, designed to view and control the data acquired by the laser scanner, works quickly and easily. The practical application of the device is versatile, whether in industry, surveying or the civil sector (Geotech s.r.o., 2023).

Table 2. Specifications and technical parameters of Terrestrial laser scanner Leica RTC360

Technology	3D laser scanner with integrated system for capturing HDR panoramic images and VIS (Visual Inertial System) for real-time cloud data registration		
Data acquisition	< 2 minutes for full scan and HDR panoramic image at 6mm @ 10m scan resolution		
Weight	5,35 kg (without batteries)		
Scanning	Double scanning	Automatic removal of moving objects	
	Scanning speed	2 000 000 points/sec	
Accuracy	Angle	18"	
	Distance	1,0 mm + 10 ppm	
	3D point	1,9 mm @ 10 m	
		2,9 mm @ 20 m	
		5,3 mm @ 40 m	
Camera	Quality	36 MPx	3-camera systém
		432 MPx	Raw data for calibrated 360° x 300° panoramic image
	Capturing speed	1 minute for 360° HDR panoramic image in any lighting conditions	
Range	0,5 m – 130 m		
Resilience	IP54		
Working temperature	- 5°C až + 40°C		
Storage temperature	- 40°C až + 70°C		

Source: Geotech s.r.o., 2023

Surveying equipment. UAV DJI Phantom 4 RTK. Thanks to modern and constantly evolving times, it is possible to collect large amounts of data even from the air in the required quality and in a short time interval. The DJI Phantom 4 RTK UAV (Fig. 4) is a compact, precise, fast UAV operating at low altitudes. The DJI Phantom 4 RTK is controlled using a controller with an integrated display by the DJI GS RTK app. The device is controlled by a trained pilot safely on the ground. Using an integrated RTK module, this UAV provides centimetre accuracy in the flight. Precise coordinates are used in post-processing. At the bottom, a 20 MPx camera mounted on a gimbal captures images or video.

Further specifications of the device can be seen in Table 3. With these features, the manufacturer provides a spatial resolution (GSD) of only 2.74 cm at a flight height of 100 m at high-resolution imaging. Combining RTK image files and proper georeferencing using the SfM processing method allows detailed three-dimensional (3D) models and point clouds to be reconstructed with centimetre-level accuracy (DJI, 2023).

Fig. 4. UAV DJI Phantom 4 RTK
Source: DJI, 2023

Table 3. Technical parameters of UAV DJI Phantom 4 RTK

Aircraft	Weight	1391 g	
	Max. speed	Ascending	6 m/s
		Descending	3 m/s
		Flight	50 km/h (mode P) 58 km/h (mode A)
	Max. time of flight	cca 30 min	
Accuracy	active RTK	Horizontal	± 0,1 m
		Vertical	± 0,1 m
	Non-active RTK	Horizontal	± 0,3 m
		Vertical	± 0,1 m
Camera	Senzor	1" CMOS	
	Quality	20 MPx	
	Size of image	4864 × 3648 (4:3)	
	Angle	- 90° to + 30°	
GNSS	GPS, BeiDou, Galileo, GLONASS		
Batteries	Type	LiPo 2S	
	Kapacity	4920 mAh	
	Voltage	17,5 V	

Source: Own elaboration based on: DJI, 2023

Fieldwork. GCP for UAV photogrammetry. During the on-site reconnaissance, 23 temporarily stabilized GCPs were placed directly in the field. Their types and location can be seen in Figure 5. Thus, the GCPs uniformly placed throughout the area play an essential role in the survey, as they are used to georeference the point clouds to a reference coordinate system or check of RTK/PPK georeferencing. For expediency, two types of targets were used, one represented by a black and white circular target and the other circular designed by the authors.

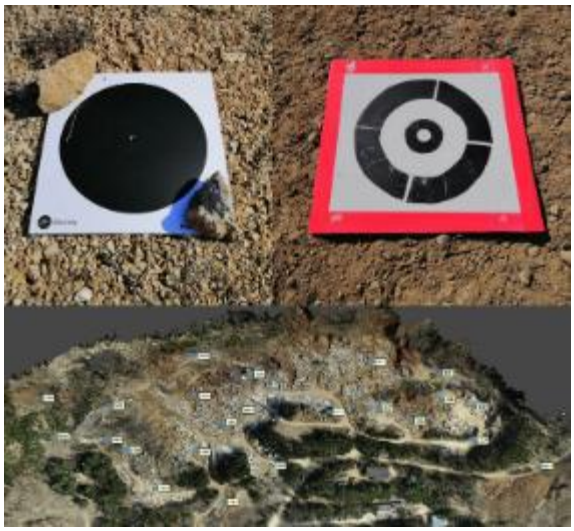

Fig. 5. GCP for UAV photogrammetry
Source: Own elaboration

Fieldwork. GCP for TLS surveying. For the TLS surveying, 11 temporarily stabilized GCPs were evenly distributed on the site. Their location can be seen in Fig. 6. For this measurement, Leica GZT21 HDS 4.5″ black and white circular scanning targets (Fig. 6) placed on pillar pads were used. The position of these targets was also surveyed by GNSS Leica GS07.

Fig. 1. GCP for TLS surveying
Source: Own elaboration

Fieldwork. UAV photogrammetric surveying. UAV DJI Phantom 4 RTK was used to capture the terrain from a height. Surveying over the 60,000 m^2 site was carried out in four separate flights. All flights were conducted using flight plans created in the Pix4D app from an average flight altitude of 70 m AGL. The camera positions during the acquisition of photogrammetric data are shown in Fig. 5. During the first flight, 430 images were captured, the second flight captured 285 images, the third captured 356 images, and the fourth captured 175 images. A total of 1246 images were captured. The image overlap was set to 70%, camera tilt was set to 80°. The total flight time was approximately 2.5 hours. Image processing was performed in the Agisoft Metashape Professional software. The acquired point cloud was georeferenced to the coordinate system using GCPs.

Fig. 7. UAV mission plan
Source: Own elaboration

Fieldwork. TLS surveying. TLS surveying was performed using a Leica RTC360 laser scanner mounted on a tripod made of carbon fibre. The measurements were performed at 19 positions (Fig. 8) with a total measurement time of about 1 h. The area of the scanned site was 14,000 m^2. For each site, 3 temporary GCPs were assigned. The scanner resolution was set to medium density at all sites with a point density of 2.9 mm at 20 m. The function for automatic removal of moving objects offered by the scanner was switched off to reduce the time. Processing with automatic GCP detection and registration was performed in the Leica Cyclone REGISTER 360+ software environment. The data processing time in the software took 2 hours.

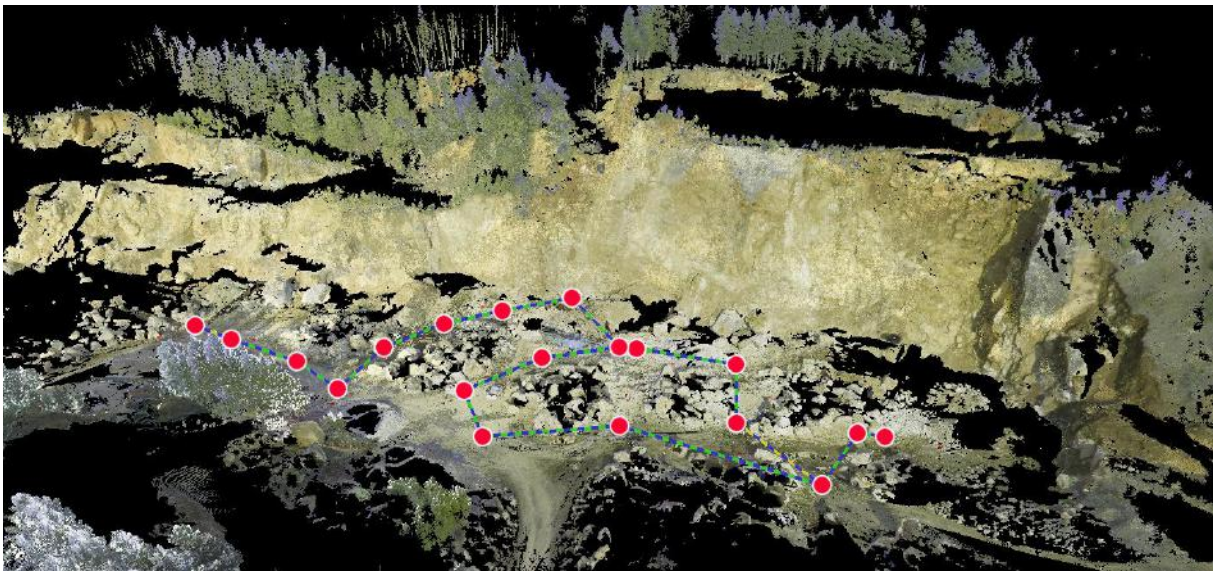

Fig. 8. Positions of the laser scanner in the TLS method
Source: Own elaboration

Data processing. SfM Processing of UAV Photogrammetry. The UAV photogrammetry produced a point cloud with a density of 85,416,175 points for the entire site. The medium quality of dense point cloud generation was chosen from 1246 images using the SfM method in Agisoft Metashape Professional software. The spatial resolution (GSD) on the processed model was 0.018 m/pix. The average point density at this location was 200 points/m^2. The root mean square positional error (RMSE) was determined with a value of 0.027 m. After filtering unwanted points, the point cloud comprised 178,805 points. Only a part of the quarry wall, with its rugged terrain, was selected from the entire site. From the processed point cloud, a digital terrain model (DTM) was created and displayed in a Smooth visualization style using CloudCompare and Leica Cyclone 3DR software, where an extraction grid size of 0.05 m was specified for GRID. CloudCompare software processing resulting in the Hillshade visualization style DTM. Another approach to data processing using Leica Cyclone 3DR software resulted in the Grey visualization style of DTM. Created Digital Elevation Model (DEM) has a resolution of 0.071 m/pix resolution DEM.

Data processing. TLS data processing. The TLS method produced a point cloud of 409,735,649 points for the entire scanned area, with a total cloud overlap of 74% and a strength of 78%. The bundle error was 0.007 m, and the cloud-to-cloud error was also 0.007 m. The root mean square position error value (RMSE) was determined with a value of 0.018 m. The average point density at this location was 8,546 b/m^2. After filtering unwanted points, the point cloud consisted of 5,636,499 points. As with the UAV, only a part of the quarry wall with its rugged terrain was selected from the entire area. The resulting DTMs were created in the same way as from the UAV photogrammetry.

Results and discussion

In this area, vegetation removal was necessary before data processing, as its presence biases the results. The Trimble Realworks 10.0.4 software was used to classify the point clouds from the UAV photogrammetry and TLS methods. Each method's shortcomings become apparent when the resulting model is inspected in more detail. For this site, the deficiencies (Fig. 9) were due to insufficient visibility, point density and dark spots. The first such example is a sample (a), where the points were not generated due to the obscuring of this location when captured from a height of 70 m AGL.

Consequently, the SfM method failed to produce a point cloud at these locations, and there are holes in the overall point cloud. The SfM method did not have sufficient visibility, and on account of this, the points formed very sparsely in places, almost not at all. In demonstration (b), the laser scanner did not sufficiently reach spots in the ground laser scanning. The locations were hidden – out of sight of the scanner, resulting in a sparse point cloud formation.

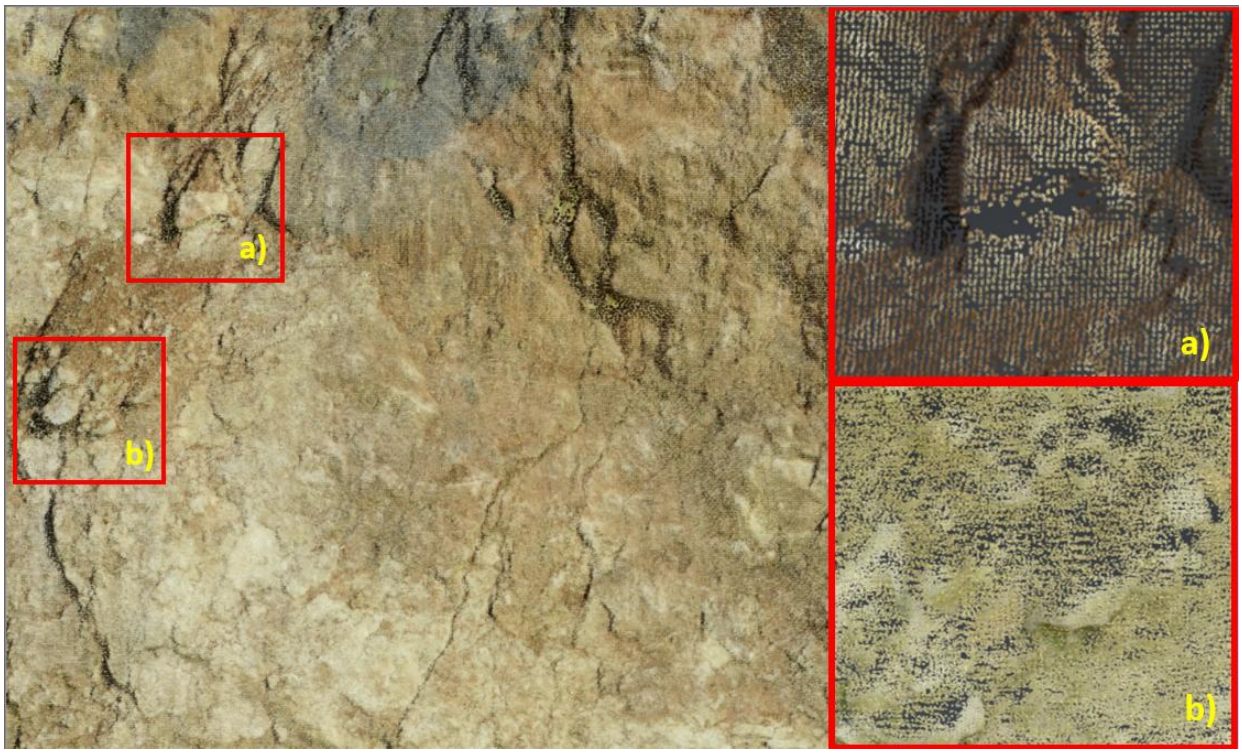

Fig. 9. Point cloud with specific comments on the completeness
Source: Own elaboration

For comparison and evaluation, DTMs (Fig. 10) of the selected section were created and processed using CloudCompare and Leica Cyclone 3DR software. The same parameter was specified for each model for an extraction grid size of 0.05 m. The detail of the models is dependent on the density of points. Their compatibility can be assumed by visually comparing the TLS and UAV data.

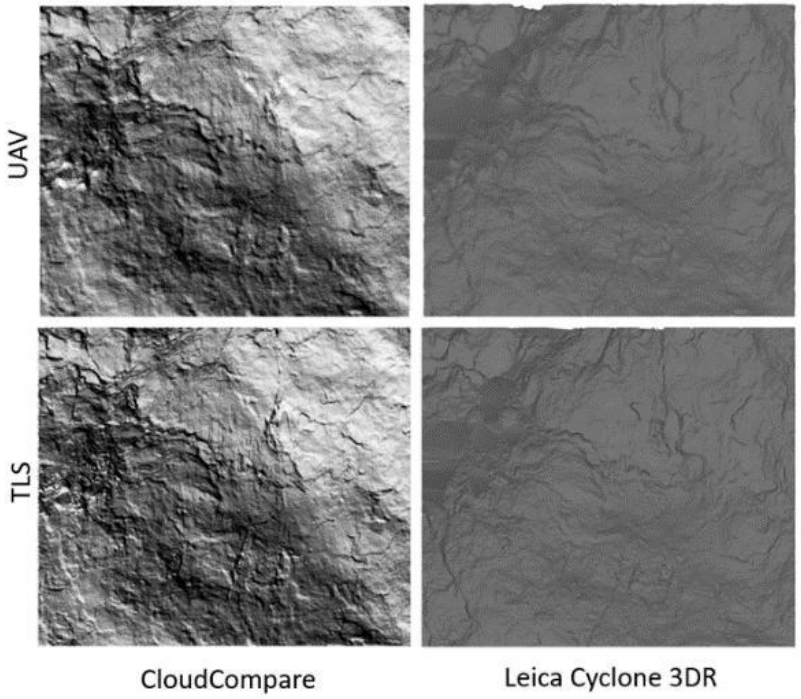

Fig. 10. DTM – TLS a UAV photogrammetry
Source: Own elaboration

The UAV and TLS point clouds were compared based on distance (Fig. 11) using the Leica Cyclone 3DR software using the Inspect Cloud vs. Cloud tool. A part of the quarry wall was selected. The maximum distance was set to 0.05 m for all comparisons. The plot shows that most points (22.7%) were located at a distance of 0.019 – 0.025 m. Overall, the most significant errors came out at locations with insufficient overlap between the two clouds due to low point cloud density or incomplete vegetation removal.

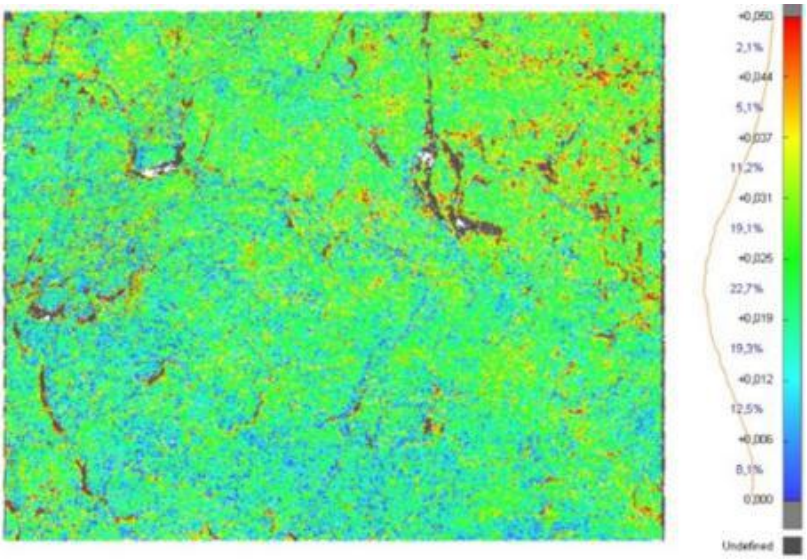

Fig. 11 Differential model – TLS and UAV photogrammetry point clouds
Source: Own elaboration

Compared were point clouds obtained by the photogrammetric method against the point cloud produced by the TLS method. This comparison was performed in CloudCompare and Leica Cyclone 3DR software. In Leica Cyclone 3DR, it can be observed that the most significant representation of points is between 0 and 3 cm and the percentage of points at error values. The CloudCompare program calculated the mean absolute distance, which gives the systematic displacement of each cloud and the standard deviation of the differences. The mean absolute distance of the point clouds is 0.0202 m, and the standard deviation is 0.0248 m. The standard deviation value was affected by incomplete vegetation removal, incomplete point cloud TLS, flight height and geometry in UAV photogrammetry, point cloud generation, etc.

Conclusions

Based on our results, it is appropriate to state that the point cloud parameters obtained by photogrammetric methods are qualitatively, accurately and comparable to the point cloud parameters obtained by terrestrial laser scanning, and both methods are thus suitable as a basis for systematic monitoring of natural or artificial objects. The advantage of the TLS method is a significantly higher point density and a better representation of the terrain in creating the DTM. However, using photogrammetric methods is preferable to using TLS due to the ease of data acquisition, flexible and quick use, cheap acquisition and equipment cost and high point cloud density. In contrast, for TLS, the equipment costs and risk of damage to expensive instruments are higher. Combining TLS and photogrammetric measurements can be considered mutually compatible and recommended as a suitable solution for documenting spatial objects.

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