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Application of GIS in the design of process facilities and environmental impact analysis

Geographic Information System (GIS) is widely used in the design process, particularly as a support for civil engineers and construction. However, in combination with AutoCAD and MEP (mechanical, electrical, and plumbing) software GIS can be a powerful complementary tool for the design of process facilities. Presented characteristic examples include pipelines for district heating; oil & gas pipelines with interconnected complex gas transmission facilities; distributed systems in large power plants, refineries, and wastewater treatment plants; transport, distribution, and storage of treated potable water; determination of basic sizes of landfill and basis for calculation of landfill gas generation. Another useful application of GIS is related to Environmental Impact Analysis due to its capability for custom application development for modeling using maps, spatial, and other available information. Some examples are: the calculation of the release and distribution of polluting components in the environment, in particular regarding the emission in the atmosphere; basic concepts and models related to airflow, atmospheric stability, turbulence, atmospheric water circulation, meteorology, and dispersion models. Finally, emphasis is given to the possibility for constant update of data in GIS, utilizing of feedback, rerunning of models, and spatial and temporal comparison of results.

1 Introduction and objectives

1.1 Aspects of design in process engineering relevant for the use of GIS

Process facilities and industries are in many cases complex systems whose creation require multi-disciplinary approach and close cooperation between different professions. Examples of such facilities include chemical plants, power generation and the food and pharmaceutical industry. Contemporary approach to development of such facilities relies heavily on IT systems and the use of various software. In relation to general engineering, the integration of geographic information systems (GIS) to a certain extent with architecture, engineering, and construction (AEC) world and building information modelling (BIM) took place some time ago and has widespread application. For example, GIS might support operations and analysis while BIM provides design that includes bill of materials. Positioning of future facility at the actual location with current topography and other corresponding information improves decision making, planning, and permitting phases and in the same time paves ground for environmental and social studies. For the time being those benefits are mainly used by civil engineers, architects and other professionals involved in infrastructure. Such solutions can be efficiently used in similar manner as a part of a design of process facilities.

However, when one discusses the work of a process engineer it involves the use of software more adjusted to mechanical engineering needs. Assistance in detailing designs starts from general computer-aided design (CAD), both in 2D and 3D, and goes up to specialized software like SolidWorks from Dassault Systems or AutoCAD PLANT 3D or Revit for Mechanical Design from Autodesk (to mention just a few examples). Though less common in practice, the synergy between GIS and mechanical engineering software is a reality and should be utilised wherever and whenever possible.

1.2 Overview of GIS advantages

In comparison to other software, GIS is a powerful tool for placing elements in the environment, simultaneously keep track of various related spatial information, handle both vector and raster data formats, support the utilisation of data bases of different types and perform spatial analysis. Furthermore, GIS can operate with real-time interactive information (not static) and allow the access to data from any location in the world, either from PC in the office or in the field with mobile applications. It can include applications of remote sensing in environmental monitoring and assessment, disaster management (e.g. for transmission gas pipeline), etc. GIS supports more flexible field data collection and processing, as well as handy project status tracking both for a design and for construction (e.g. for supervision). Besides simplification of production process and better strategic planning, GIS can be used for visualization and presentation to investors and decision makers. Finally, stored data can also have a temporal component which gives the capability to analyse changes during a period of time or adjust project parameters to specific conditions. A good example might be to run a set of simulations of emission from specific source during different periods over a year with corresponding local climate conditions based on valid meteorological data. In such case the same model can combine spatial and temporal elements of environmental impact analysis or other type of simulation. Once a process engineer is aware of GIS capabilities and possibilities for interconnection with more commonly used software, GIS can become a powerful auxiliary tool.

2 Methods

Selection of the appropriate approach and method for the design of process facilities can be a difficult task in cases of complex technology involved, spatially distributed units, specific environmental or other requirements, etc. Following are two common engineering issues whose solution would benefit from the use of GIS. In the same time they illustrate several options that could assist a process engineer in his work.

2.1 Design and Tender Documents

Similar to other areas, the design of process facilities can benefit notably from using GIS, in particular in early stages (e.g. solution or preliminary design phases). Placing of design elements, even just the main ones, on the map with different ways of data interpretation and presentation by GIS can reveal facts about the concept quality, possible shortcomings and overall indicative workflow. It can assist in discussing details with other members of the team from different professions, assist estimates and provide elements for graphical documentation if needed for tender documentation or discussions with investors. In cases of distributed facilities like pipelines, already available utility mapping and modeling routines can utilize existing data, overlay the measurements of surveyors and other field info and derive parameters for further work. On the segment of feasibility analysis, GIS can estimate transportation costs in combination with potential supply chain performance and timetable for construction.

As an example from practice was selected a project containing waste water treatment plant (WWTP) with the overall title: Masterplan, Feasibility Study, Detailed Design and Tender Documents for the stormwater drainage, sewerage and wastewater treatment works for the western suburbs of Greater Athens in Thriassio (Greece). [1] The project was targeting app. 200,000 PE, it has been performed in the period 1993-2007 and contained:

- Masterplan and feasibility study for the wastewater and stormwater management of the region. This included a complete inventory of contributing industrial units and assessment of future population per subarea to estimate load scenarios, as well as a disposal study for the Elefsis Bay.
- Detailed design and tender documents for the wastewater and stormwater collection systems.
- Tender design and tender documents for the sewage treatment works.

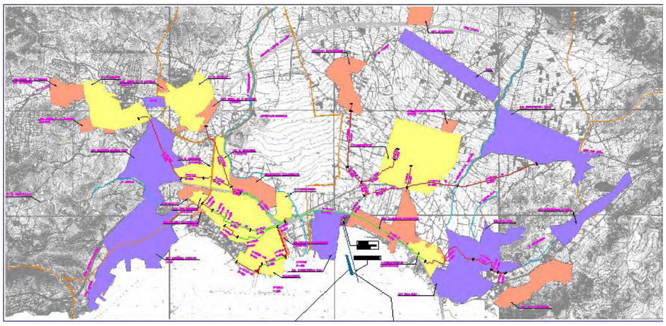


Figure 2.1a: Thriassio project location and main elements [1]

The WWTP includes the following units: pre-treatment (screening, sand removal), primary sedimentation, activated sludge treatment, including nitrification – denitrification, phosphorus removal, secondary sedimentation, polishing and UV disinfection as well as mechanical thickening, anaerobic digestion and dewatering of produced sewage sludge. [1]

Main application used for network distribution, spatial analysis of loads and other preparatory tasks, including evaluation of scenarios, was ArcGIS. Obtained information was utilized by both civil and mechanical engineers, e.g. some processed information was exported to Excel for sorting and use in calculations. GIS also provided locations and profiles for detailed design that was drafted in AutoCAD using exported DWG files, as well as maps both for design and tendering purposes.

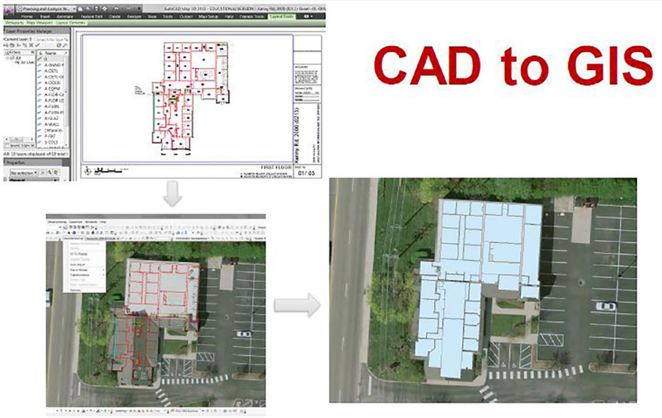
Most engineering software today have some form of data import and export, including modules for conversion. In one article the authors describe main design steps of a remote access information system for analysis of chemical engineering objects using various technologies: simulation modeling, geographic information systems (GIS), Internet technologies, etc. The core system used for design of a virtual model is GIS which allows creating spatial models of enterprises including all major production facilities. There are three information fields, each of which displays its own information type: a two-dimensional (three-dimensional) model of an enterprise; a simulation model of technological processes of an enterprise, a textual reference with production procedures. [2]

Figure 2.1b: 3D-view of a spatial model of the enterprise's territory [2]

2.2 Application of GIS in selection of location for design and construction of facilities

Some facilities don't need to be significantly spatially distributed in order to be very demanding for design. Power plants are one of such types. Decision upon the location of the future power plant is a complex question which requires a multi-criteria analysis. Even if one knows the type of the power plant, various technical, economic, environmental, social, political and other aspects of a potential location have to be considered related to design and, on the later stage, construction. In that case GIS as a tool can transform various georeferenced data related to aforementioned location selection aspects and perform multi-criteria analysis that would provide meaningful result for decision making. The system can be applied to all types and sizes of plants, even nuclear ones. For example, an analysis of natural (seismicity, geological background, hypsometry, slope of the terrain, distance from faults, ground cover, land use method) and anthropogenic conditions (distance from the state and other borders, settlements, industrial facilities, roads and railways) can be performed, taking into consideration protected areas due to its ecological significance. With multi-criteria analysis, weighting coefficients can be assigned for each criterion using appropriate method. [3] Similar procedures can be applied in cases like determination of basic sizes of landfill and evaluation of spatial related volumes as basis for calculation of landfill gas generation.

The location check with positioning of plants and other industrial objects can also be performed by bringing segments of the design from other software into GIS, as presented in the Figure 2.2 in case of transferring CAD drawing to GIS.



Slika 2.2: CAD2GIS [4]

3 Results and examples

3.1 Complex facilities - Psyttalia Wastewater Treatment Plant

In short, the Psyttalia WWTP is the main wastewater treatment plant in the greater Athens area, receiving an average wastewater flow of approximately 730,000 m3/day. The Psyttalia WWTP capacity is 5,600,000 PE, being one of the biggest WWTPs in Europe and worldwide. Primarily treated wastewater further undergoes advanced secondary biological treatment, using activated sludge processes, achieving both organic load removal and a considerable reduction of nitrogen load in the biological stage, which comprises bioreactors and final settling tanks, where biological sludge sedimentation clarifies the treated wastewater. The sludge drying unit final product (120 – 150 t/day with approximately 92% dry matter) is a renewable source of energy and it is being utilized as secondary fuel in cement factories and power stations. Biogas produced at Psyttalia WWTP is a renewable source of energy and it is being utilized as the fuel in two CHP plants, with 11.4 MWe in total. Additionally a 12.9 MWe CHP plant using natural gas operates at Psyttalia, supporting the operation of the sludge thermal drying unit. [5]

Slika 3.1: Areal view of the Psyttalia WWTP [5]

Company GK Consultants were awarded as a member of a consortium the long-term contract to provide technical consultancy of services for the Construction of Phase B Biological Treatment Works in Psyttalia, which ended in 2006. Types of services provided include [1]:

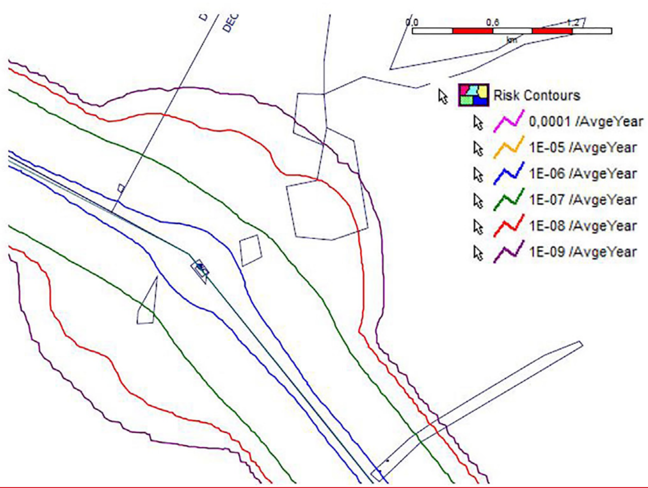
- Owner's Engineer
- Reporting to EU Cohesion Fund
- Technical assistance for operation of primary treatment plant
- Preparation of Basic Engineering Design and Tender Documents, Bid Evaluation, Contractor's design checks
- Sludge management study
- Construction and Commissioning Supervision,
- Checking of Contractor's detailed design and Project Management
- Design of sludge thermal drying unit

Perhaps one of the most important facts is that the location is actually a Psyttalia island. First phase was not so critical regarding sizing and distribution of the equipment and units. However, the Phase B required far more careful planning. That part of the work was performed mainly by combining ArcGIS and Autodesk Land Desktop. Some elements of the output were also used for tender documentation, evaluations and during construction, further involving specialized software for calculations, Excel and AutoCAD. It is worth noting that Autodesk Land Desktop has evolved to Civil 3D from 2006, providing even more capabilities for interconnections and collaboration between mechanical and civil engineers.

3.2 Pipelines

Companies that transport oil and gas may have thousands kilometers of pipeline length in the field with numerous segments and attached equipment. Most mechanical engineers are capable of using AutoCAD or similar software to create pipeline layout and isometric drawing. Such drawings contain pipeline length, material, wall thickness, etc. Introduction of GIS can provide a simpler and less prone to errors solution to pipeline layout drawings as already elaborated, as well as the handling of pipe data base. Furthermore, it is possible to perform an oil spill simulation by using an application that runs on GIS. The simulation can predict the spread and impact of pipeline accident and the extent of water contamination by such spill.

In case of a gas pipeline, the population density in the territory through which the pipeline passes has to be considered. Risk levels are defined in relation to the population density and the gas pipeline corridor is classified in accordance with the relevant regulations, which in turn define the minimum wall thickness. GIS is a very suitable tool for such tasks. The example of relevant regulations in Serbia would be SRPS EN 1594:2015 (Gas infrastructure - Pipelines for maximum operating pressure over 16 bar – Functional requirements). Figure 3.2 gives the example of four classes of risks and their spatial distribution as contours in relation to a location of a pipeline segment with one unit (e.g. block valve station).



Slika 3.2: Risk contours around the gas pipeline segment

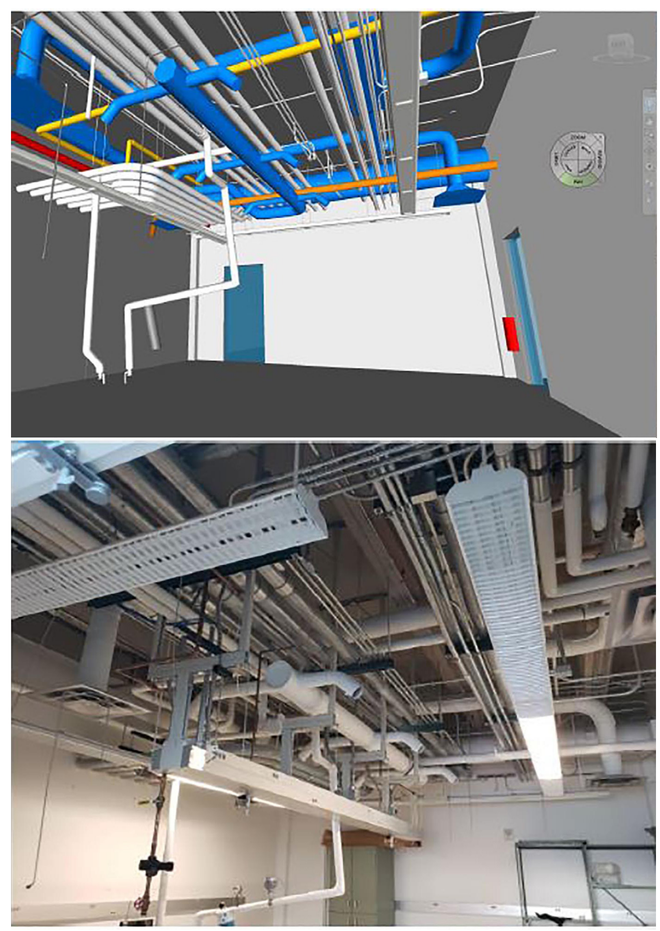
3.3 District heating

The design, dimensioning and cost estimation of a district heating network has many challenges. That is especially true for large networks where a manual production of a layout is complex and time-consuming task. On the other hand, specialized software and custom-made spreadsheets allow automated hydraulic calculations and pipe selection, but can be error-prone if not properly used and are might not be suitable for large networks. In short, the different design aspects typically require different software tools and the process is usually not well-integrated. E.g. a methodology for assessing the energy and economic feasibility of new district-heating networks in urban areas for the integration of industrial waste heat sources could use GIS with build-in data analysis tools, combining various georeferenced data. [6]

3.4 Maintenance and inspection data

In GIS we can see pipeline attribute, find the location, visualize it and query the associated database. Pipeline location is associated with GIS database, allowing the control center and maintenance crews to find the pipeline location at field and derive scheduled tasks or issues that have to be handled. This illustrates the idea of using GIS software to visualize a facility segment and its condition related to the specific location, enabling maintenance and inspection data to be tied to the industrial object. With the GIS temporal component one could also perform analysis on several years of historical inspection and service information, or plan ahead.

GIS can be used to model anything that has both a physical or spatial component and associated attribute data. But besides large segments and units, smaller-scale detailed models can also be created for facilities like combustion turbines or power plant boilers. These models can be 2D or 3D ones depending on users needs for detailed visual information.



Slika 3.4: Example of 3D model for facility management [4]

3.5 Air quality monitoring - a GIS-based atmospheric dispersion model for emitted pollutants

Besides integrating spatial and temporal components with georeferenced databases, GIS is also capable to support programing and development of custom applications. Such applications can utilize all associated structure and combine the use of existing tools with new routines for calculations. The input/output and simulations can be completely managed in GIS environment. Possible use in process engineering domain might include a distribution simulation and calculation of the spread of polluting components into the environment. For such work GIS would integrate mapping with historic or current meteorological and corresponding data, including remote sensing. Simulations and calculations could be related to air flow, atmospheric stability, turbulence, water circulation in the atmosphere, dispersion models, etc. GIS software can handle thousands of gridded or scattered receptors and thousands of complex sources with hundreds of vertices and holes. Besides engineering tasks, such approach might also be useful for public services, e.g. environmental protection authorities.

One example is a development and performance evaluation of a GIS-based metric to assess exposure to airborne pollutant emissions from industrial sources using historical data. The evaluation used a set of relevant parameters like local meteorological data and characteristics of industrial sources, (e.g. emission intensity and stack height). To integrate wind directions into the GIS, a GIS data layer named contributing area for dioxin dispersion (CADD), was created for each dioxin source, based on equal segments of the wind rose and proportion of annual wind blow and speed at each segment (Figure 3.5). [7]

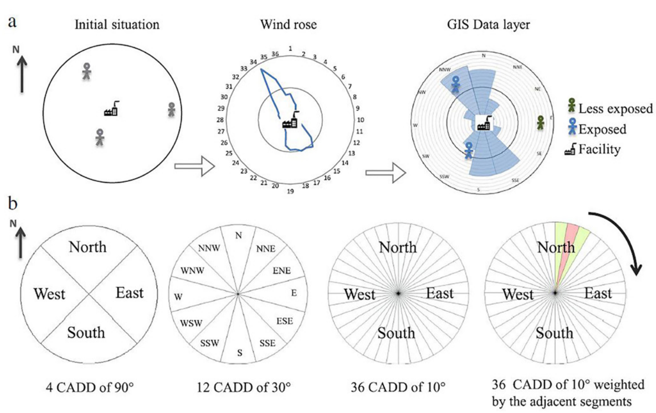


Figure 3.5: From a wind rose to the creation of contributed area for dispersion, with tested degrees of CADD for wind directions [7]

4 Conclusions

The introduction of GIS as a complementary tool for the design of process facilities can be very beneficial. The capabilities of data exchange and/or concurrent use of GIS, CAD, Excel and various specialised mechanical engineering software allow for more efficient performing of engineering tasks. GIS has a strong support of database handling and queries, assigning of attributes to entities and combined spatial and temporal analysis. Such options make GIS also an excellent choice for maintenance tasks, inspection, supervision or control use, with the possibilities for online operation, risk analysis, simulations and evaluation of scenarios. GIS can handle real-time interactive information for monitoring purposes, or perform constant updates of data providing feedback and supporting decision makers. Though not designed for process engineering, GIS has evolved and currently provides intelligent geospatial solutions for every type of industry, with emphasize on energy and environmental applications.

References

[1] GKC, Selection of projects, G. Karavokyris & Partners Consulting Engineers S. A., Athens, Greece, 2021. http://www.gk-consultants.gr/files/Selection_of_Projects.pdf

[2] **Nemtinov, V., Nemtinova, Yu.V., Borisenko, A., Manaenkov, A.**, *Analysis of chemical engineering objects with remote access geographical information system*, 15th International SGEM GeoConference, 2015, pp. 463-470

[3] **Ćorović, N., Durlević, U.**, *Application of GIS in selection of location for construction of nuclear power plants in Serbia*, Collection of Papers - Faculty of Geography at the University of Belgrade, Serbia, 2020, pp. 63-78. doi:10.d5937/zrgfub2169063C

[4] **Renteria, A., Kruger, L.**, *CAD, BIM & GIS Integration: Linking Design with Context to Drive Life Cycle Value*, ESRI Federal GIS Conference, Washington D.C., 2020

[5] EYDAP, *Psyttalia Wastewater Treatment Plant*, Athens Water Supply and Sewerage Company (EYDAP S.A.), 2021. https://www.eydap.gr/userfiles/c3c4382d-a658-4d79-b9e2-ecff7ddd9b76/Factsheet-PW

[6] **Jebamalai, J. M., Marlein, K., Laverge, J., Vandevelde, L., Van den Broek, M.**, *An automated GIS-based planning and design tool for district heating: Scenarios for a Dutch city*, Elsevier, Energy 183, 2019, pp. 487-496

[7] **Coudon, T., Danjou, A. M. N., Faure, E., Praud, D., Severi, G., Mancini, F. R., Salizzoni, P., Fervers, B.**, *Development and performance evaluation of a GIS-based metric to assess exposure to airborne pollutant emissions from industrial sources*, Environmental Health 18, 2019 https://doi.org/10.1186/s12940-019-0446-x

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