doi: 10.21307/ACEE-2018-061

A GIS BASED GRAPH ORIENTED ALGORITHMIC MODEL FOR POLY-OPTIMIZATION OF WASTE MANAGEMENT SYSTEM

Krzysztof GASKA [a], Agnieszka GENEROWICZ [b], Izabela ZIMOCH [c], Józef CIUŁA [d], Dariusz SIEDLARZ [e]

[a] PhD DSc Eng.; Institute of Water and Wastewater Engineering, Silesian University of Technology, Konarskiego 18, 44-100 Gliwice, Poland
E-mail address: *krzysztof.gaska@polsl.pl*

[b] PhD DSc Eng.; Institute of Water Supply and Environmental Protection, Cracow University of Technology, Warszawska 24, 31-155 Cracow, Poland
E-mail address: *agenerowicz@pk.edu.pl*

[c] Prof.; Institute of Water and Wastewater Engineering, Silesian University of Technology, Konarskiego 18, 44-100 Gliwice, Poland
E-mail address: *izabela.zimoch@polsl.pl*

[d] PhD Eng.; Nowy Sącz Water Networks Company,22 WincentegoPola Street, 33-300 Nowy Sącz, Poland
E-mail address: *jozef.ciula@swns.pl*

[e] MSc Eng.; Nowy Sącz Water Networks Company,22 WincentegoPola Street, 33-300 Nowy Sącz, Poland
E-mail address: *dariusz.siedlarz@swns.pl*

Received: 18.06.2018; Revised: 24.08.2018; Accepted: 2.10.2018

Abstract
The article presents an integrated (inferential) system of computer assistance in waste management designed in component-based technology. The system allows for the implementation of individual elements (system components) with native and managed programming languages and performance technologies, ensuring easy integration of those components into one coherent, cooperating whole. One of the key issues involves the placement of the objects, events and conducted spatial (geographical) analyses in the system through the application of GIS technology (ability to use digital (vector or halftone-based) terrain maps), execution of spatial analyses, data visualization on maps, etc., using also commonly available spatial data available as part of the Infrastructure for Spatial Information (established under the Act on Infrastructure for Spatial Information).

Keywords: **Graph oriented models; Waste management; poly-optimization; Model-oriented programming technology; High Performance Computing.**

1. OVERVIEW OF THE PROBLEM

The methodology of modelling and object analysis of management systems includes, inter alia, operations connected with the definition of special object types being an imitation of components (objects – sources of waste generation, objects for waste neutralisation, networks of roads, natural environment components, waste substances, etc.) [4, 6–7]. Since the systems are investigated in the GIS technology, some objects are assigned attributes of spatial representation (location coordinates, geometric and graphic attributes used for their recording on a map). Operations performed on the models of individual-class objects (e.g. topological operations) are interpreted (using object-related terminology) as the so-called methods (functions and procedures) which are in fact computer implementations of a range of algorithms used in system analyses

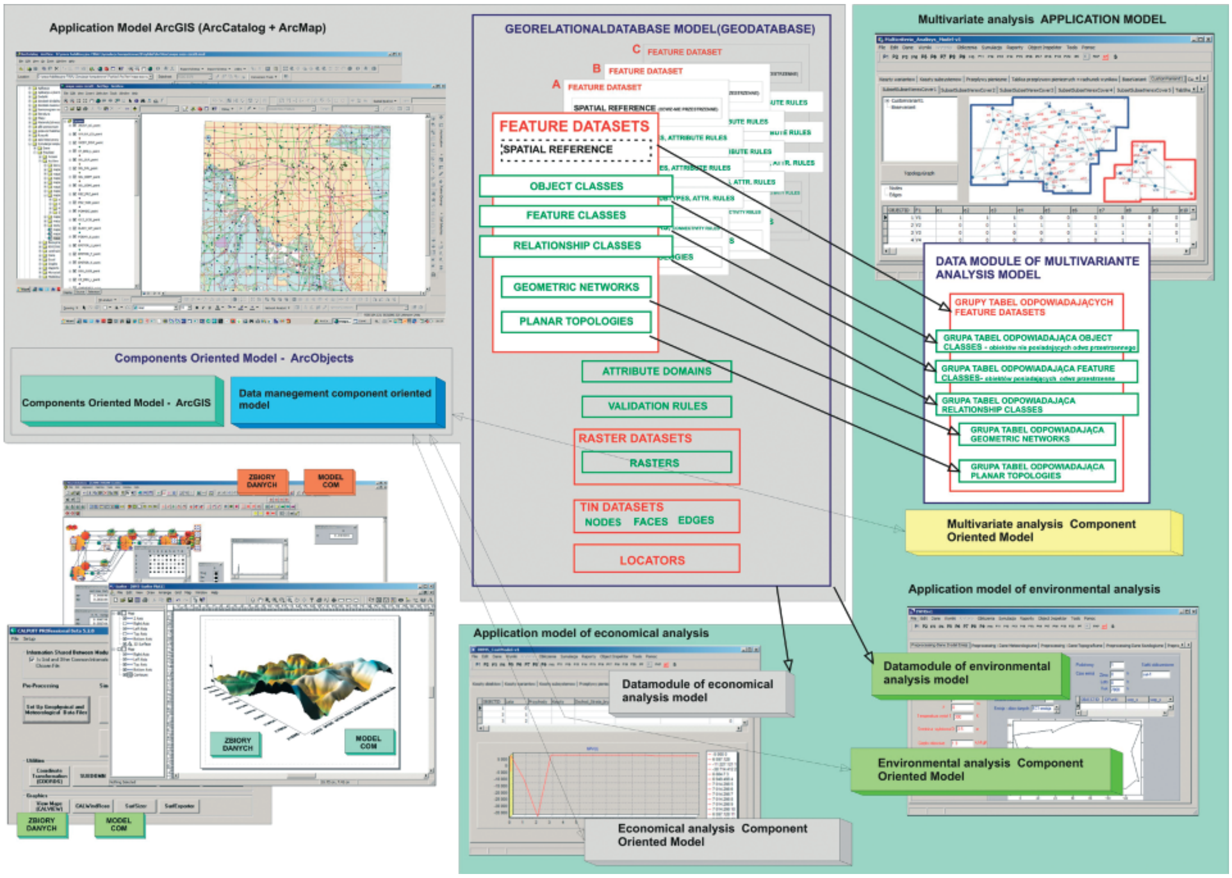

Figure 2.1.
A schematic model of the integration of IT systems [own elaboration]

(e.g. optimisation analyses). The definition of the object-related model is preceded by a range of operations applied to determine general assumptions (conceptual model) and to formulate the topology of the model, interaction method with the environment, dynamics of the system, variables of the state, etc. [1–3, 10–14, 19].

The most significant factor in the definition of the component model is the use of connection elements with physical databases (definition of database aliases in the ODBC standard) and with external applications (the concept of IT environment integration) by way of using elements of COM technology (Microsoft Component Object Model), which introduces a standard for the definition of component models whereof structure allows for the communication between objects created in different programmes (launched in different area spaces). As an example we can name most GIS environments (MapInfo, ArcGIS), sharing a range of object component categories recorded in runtime libraries (DLL or EXE) which can serve to develop own programmes through the direct application of predefined interfaces or by defining derived objects. The management of extensive data sets is provided by a geo-relational database comprising a range of visual (corresponding to the content of thematic numerical map layers) and non-visual component categories recorded in correlated tables, where spatial elements are assigned a special data format with the description of geometric properties and with spatial representation parameters [8, 17, 22].

2. DESCRIPTION OF THE WASTE MANAGEMENT MODEL

2.1. Conceptual model

The conceptual model of waste management system comprises the definition of assumptions determining the representation method of real components (objects and processes) in the form of simplified computational models implemented numerically with competent-oriented methodology. The topology of the model comprises a logical space of the models of classes of individual elements and processes in the waste management system, including also the processes of contamination propagation in the natural environment taking place during particular technological operations of waste processing [5, 9, 11].

A key element is the application of the geo-relational data model (geo-relational database) to store the attributes of individual system components. The use of an open connection in the ODBC standard (database alias) allows us to share database resources through various IT environments and to represent them in the form of data modules providing access to the data from the programme code of the developed application (Fig. 2.1 and Fig. 2.2). The definition of geo-relational database in the ArcGIS standard covers a range of visual (corresponding to the content of thematic map layers) and non-visual component categories recorded in correlated tables, where spatial elements are assigned a special data format with the description of geometric properties and spatial representation parameters. The logical structure of the geo-relational database contains basic tables with the attributes of graphic spatial elements (Feature class) ordered and arranged into datasets (Feature Dataset), tables with the attributes of relations occurring between objects of different classes (Relationship class) and tables with the attributes of elements without spatial representation (Object class) [18, 20, 21].

The numerical model of the waste management system was developed with component-oriented methods which implement most object paradigms whereof core is made up by a system of events and emergencies characterising the dynamics of individual processes and COM technology (Component Object Model) employed to provide communication between various IT environments. Open topology of the system allows for the modification of the programme code within individual classes defined within the system, implementing the specialisation process of model modules. It is a model of adaptation nature (the system modifies its data structures on its own so as to adapt to the actual process most efficiently, i.e. to minimise the mean squared error (MSE)) and of reactive nature, i.e. it is controlled with events (assigned to given elementary processes and objects) of modular structure, based on grouping the definitions of classes of individual submodule objects into separate modules. The topology of the global model is characterised by a modular structure which integrates the set of component models of objects and processes that can be used as independent, autonomous runtime models, or as elements of global structure of the application model.

The system is based on a predefined component environment – ProWasteObjects. NET, which is one of the ProWasteEnterpriseSolutionFramework. NET environment (author's solution). The real-time HPC (nVidia CUDA) system is a component-oriented environment with a specialized datebase of knowledge representing the elements of technological processes in the area of waste management system, considered as control objects. All variables related to the supported devices are updated on-line through the OPC UA servers of the monitoring and control system [10, 12].

2.2. Mathematical model

The definition of the mathematical model of the waste management system results from the logical decomposition into components (subsystems, variants in systems/subsystems, processes and objects of various classes) and covers a set of parameters unambiguously identifying a given element and a set of algebraic expressions for data processing. They constitute a basis for the construction of algorithmic models in a series of system analyses.

In the descriptions of mathematical system components, a discreet, deterministic system was adopted. The definition of the data set corresponds to the adopted logical model of waste management system, and its structure comprises the following [16]:

A) definition of objects of individual classes (objects – waste sources, objects of waste treatment, objects of logistic processes and other),

B) definition of global elements, i.e. system variants (K),

C) definition of waste management subsystems (subsystems K-A(B, C,D,..)-S) (acc. to a waste group) in different variants,

D) definition of component processes (K-S-L) in variant subsystems,

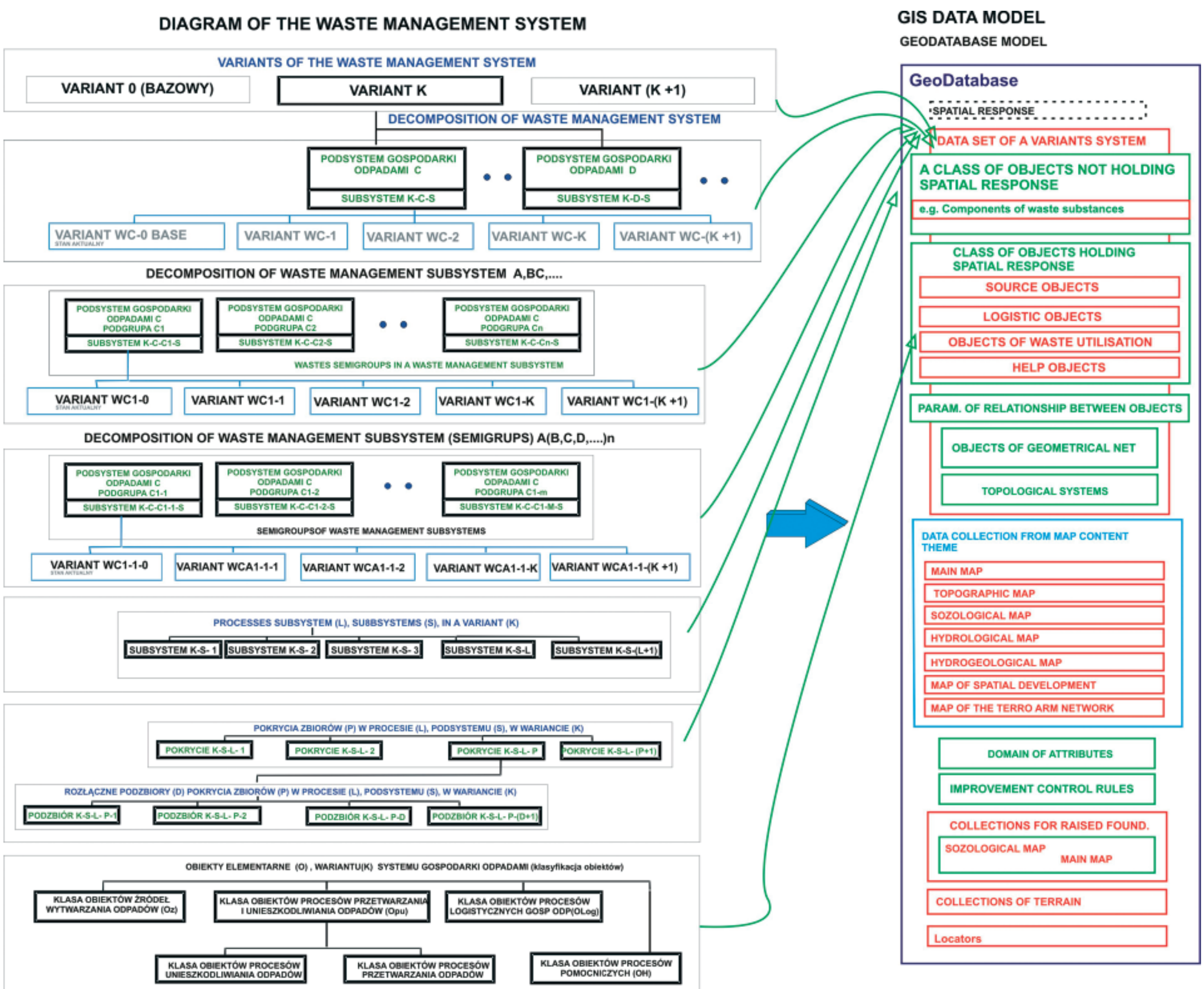

Figure 2.2.
The scheme of decomposition of the waste management system with mapping elements to the geo-relational data model [own elaboration]

E) definition of set covers in processes (K-S-L-P) of variant subsystems,

F) definition of separable subsets (K-S-L-P-D) of a given cover in processes of variant subsystems,

G) definition of topology (on the basis of parametrised planar graphs), topological relations,

H) definitions of parameters of cost components of individual variants, subsystems, processes and objects (model of costs and analyses of economic effectiveness),

I) definition of ecological parameters – environment quality indicator for variants (environment analysis model),

J) definition of quantitative and qualitative parameters of streams of waste in individual groups.

The concept of the mathematical model assumes the definition of categories of models (sub-models) dedicated to individual system components and issues under analysis.

The general classification of mathematical models includes:

- Models of objects.
- Models of system variants.
- Models of waste management processes.
- Models of environment processes.
- Topological models.
- Geometric models.
- Optimisation models.
- Models of environment analyses.
- Models of economic analyses and economic effectiveness.
- Models of multi-variant analyses.

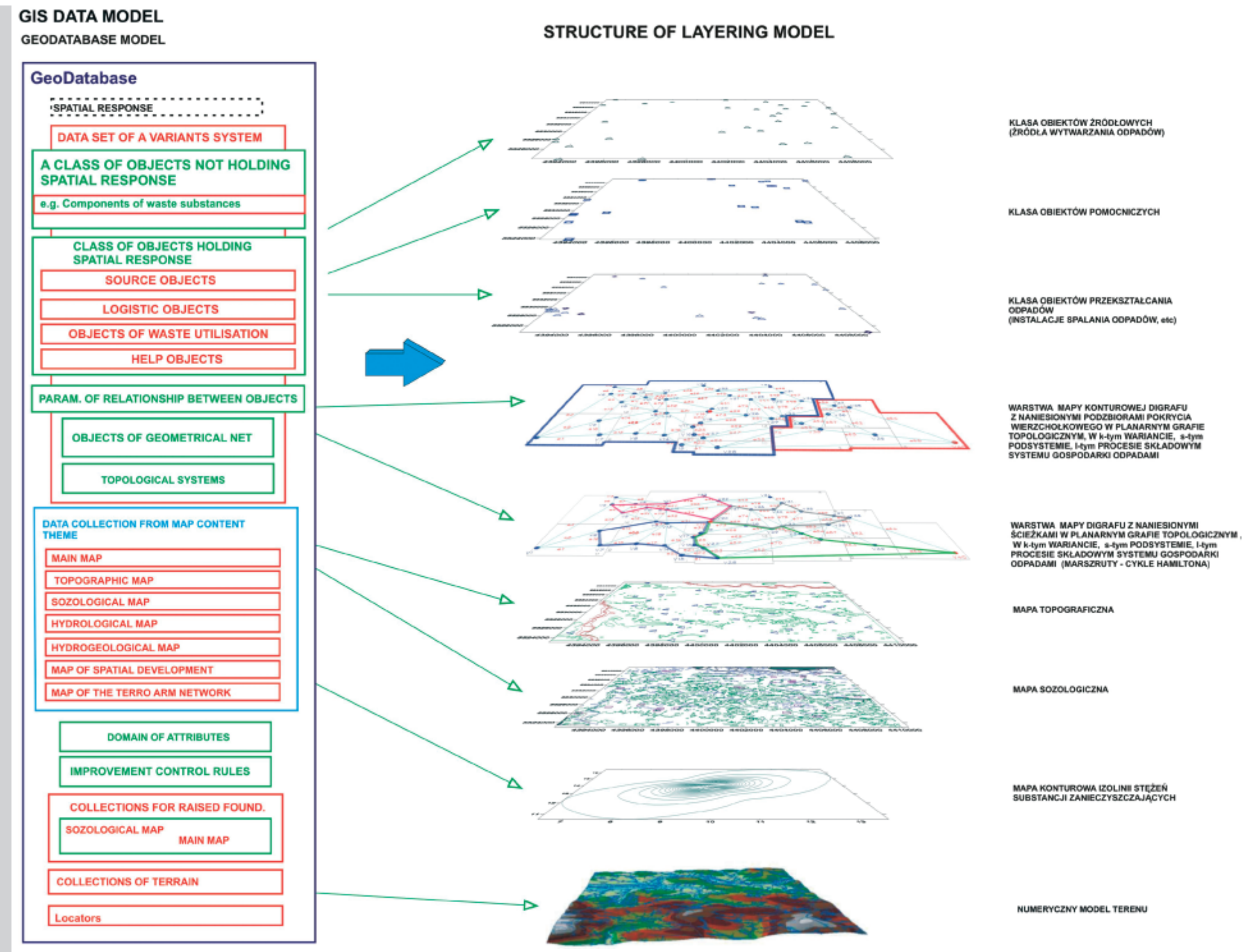

Figure 2.3.
Schematic representation of the georelational database model in the form of thematic layers [own elaboration]

2.3. Component-oriented model

The basis for the development of the component model is made up by the discreet deterministic mathematical model expressed with known functional relations obtained through the discretisation of ordinary and partial differential equations of the continuous model.

The component model is a result of the following sequence of transformations:

CONTINUOUS MATHEMATICAL MODEL (REPRESENTED BY A SET OF ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS) → (DISCRETISATION OPERATIONS) **DISCRETE MATHEMATICAL MODEL → DETERMINISTIC MATHEMATICAL MODEL** → (IMPLEMENTATION OPERATIONS) **COMPONENT-ORIENTED MODEL**

The global (component) model of the system contains general definitions of classes and basic methods being design templates for defining derived classes. The topology of the system model is composed of three logically linked parts imitating computational methods (the abstract part of the model) of the graphic user interface and relational database.

2.3.1. Model structure

The component-oriented model of the waste management system is a computer implementation of mathematical models (data sets and algebraic expressions) describing individual components (objects, processes and relations). The key point of the object definition is the use of special class types whereof structure allows for the imitation of specific properties of object components and performed operations on data structures in the form of so-called fields and methods. The fields of an object have another important advantage allowing (through correct assignments) to refer to object components (COM: Component Object Model) created in other programmes, e.g. Surfer Application, ArcGIS, which are launched in different address spaces. The purpose of those referrals is to use the properties and methods (of object components of the Arc Objects library) in (topological, geostatistical, etc.) operations performed on objects of the waste management system model, stored in the geo-relational data model (geo-relational database) and represented (visualised) in the content of layers of thematic maps in the ArcGIS application.

The fundamental element of GIS systems is the object-relational model of data developed with the use of the library of object components in the COM technology. It introduces a definition of visual (corresponding to the content of thematic map layers) and non-visual component categories recorded in correlated tables, where spatial elements are assigned a data format with the description of geometric properties and spatial representation parameters. Figure 2.3 illustrates a logical structure of geo-relational database, which distinguishes basic tables with attributes of graphic spatial elements (Feature class), ordered and arranged into datasets (Feature Dataset), tables with the attributes of relations occurring between the objects of different classes (Relationship class) and tables with the attributes of elements without spatial representation (Object class).

2.3.2. Data structures

The data structure of the component model of the waste management system is represented by the so-called data modules, which are a set of components of access to the resources of geo-relational database created in the ArcGIS system. Therefore, it is an element of representation of the GIS system model in the form of correlated tables containing attributes of objects which have and do not have their spatial representation (Fig. 2.3.). All database components are interlinked and form a structure within which they communicate with a system of events and methods. Communication is most frequently carried out between control objects of data edition and a physical data set [15].

Geo-relational database resources are managed by way of using standard methods, predefined in the object library of the BDS2006 environment and methods of the ArcObjects library interfaces, grouped in the category of Geodatabase Component Object Model, of the ArcGIS environment.

The structure of the geo-relational database model, consisting in recording the attributes of individual system elements in entries of correlated tables by way of defining the so-called aliases, allows obtaining access to data resources from the programme code of the application developed in the Microsoft Visual Studio environment for the component model of the waste management system.

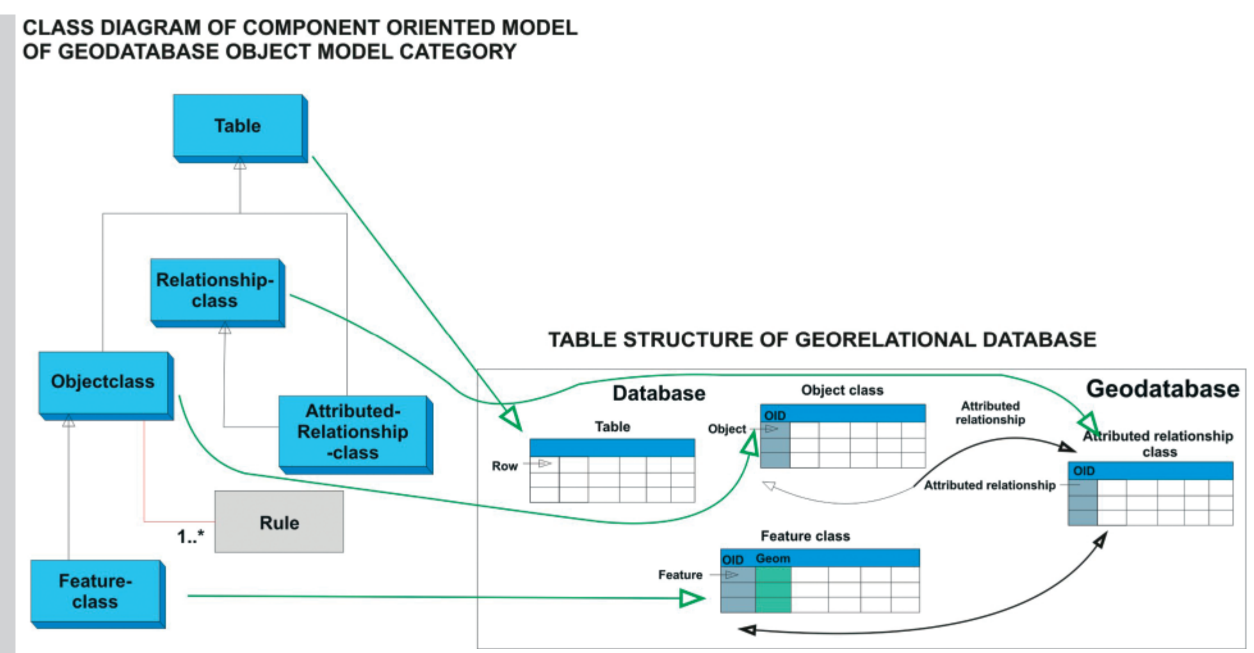

Figure 2.4.
Schematic structure of a model of the object – relational ArcGIS system [own elaboration]

The geo-relational database (Fig. 2.4) can store datasets recorded in various formats, and individual datasets are grouped in proper categories, as follows:

- Feature class – spatial objects (having parameters of spatial representation and geometric attributes symbolising classes of objects in numerical thematic maps).
- Feature dataset – a dataset containing classes of spatial objects,
- Object class – a class of objects without spatial representation (e.g. models of components of waste substances).
- Raster Datasets – sets of halftone primes for thematic maps.
- TIN Datasets – sets of numerical land models based on an irregular network of triangles.

What corresponds to the basic model of object component table (in the hierarchical tree) in the relational record is a table in the geo-relational database structure. Derived classes in relation to the Table object, i.e. classes of Objectclass, Featureclass, Relationshipclass, are also represented by tables containing the attributes of object components in records (lines), where each component is linked with a proper column in the table. In such defined tables, other lines represent the attributes of other objects identified by the proper field (attribute), OID in this case. As opposed to tables representing specific objects of the waste management system, the Attributed relationshipclass tables store parameters of inter-object relations in successive records.

2.3.3. Object component modelling

The library of object components of the waste management system model has been logically divided into two main categories (Fig. 2.5):

- Category of data management component.
- Category of models of application components of the waste management system.

System component modelling is performed by using a predefined Visual Component Library (VCL) in the environment of Borland Development Studio 2006 (BDS2006) for the models of application forms, a library of classes of objects of the described categories, with the use of component object models (COM) of the environments of ArcGIS (the ArcObjects library) and Surfer Application Object Model. The starting point for the modelling of all components is to develop diagrams of classes with the UML notation in the programmes Microsoft VISIO or BDS2006 and the Borland Together Control tool as a module supporting the creation of object application based on structural records. The use of COM technology, or object components developed in that technology to be exact, boils down to creating special links by defining proper references to specific interfaces, being instances of classes implementing them (the ArcObjects environment), of objects in the fields of class types of the environment of the SGO model. The references pertain to the access to properties and methods performing a series of operations on objects of components in the environment of the ArcGIS programme and the ArcCatalog programme. Each and every operation of reference to individual interface elements requires access to MxDocument in the ArcMap application, which manages data representation. The ArcMap application automatically creates that object after it is launched. In the object model of the ArcMap application, the component of MxDocument creates a new instance of the object of the Application, which in turn creates MxDocument of the object. In each session of the ArcMap application, one object of MxDocument is initiated. The object component of MxDocument manages the following objects: PageLayout, TOCCatalogView, TOCDisplayView, StyleGallery and TableProperties (details are included in the documentation of ArcGIS). The access to the MxDocument component is allowed by a reference, e.g. in C++: **IApplication: Document.**

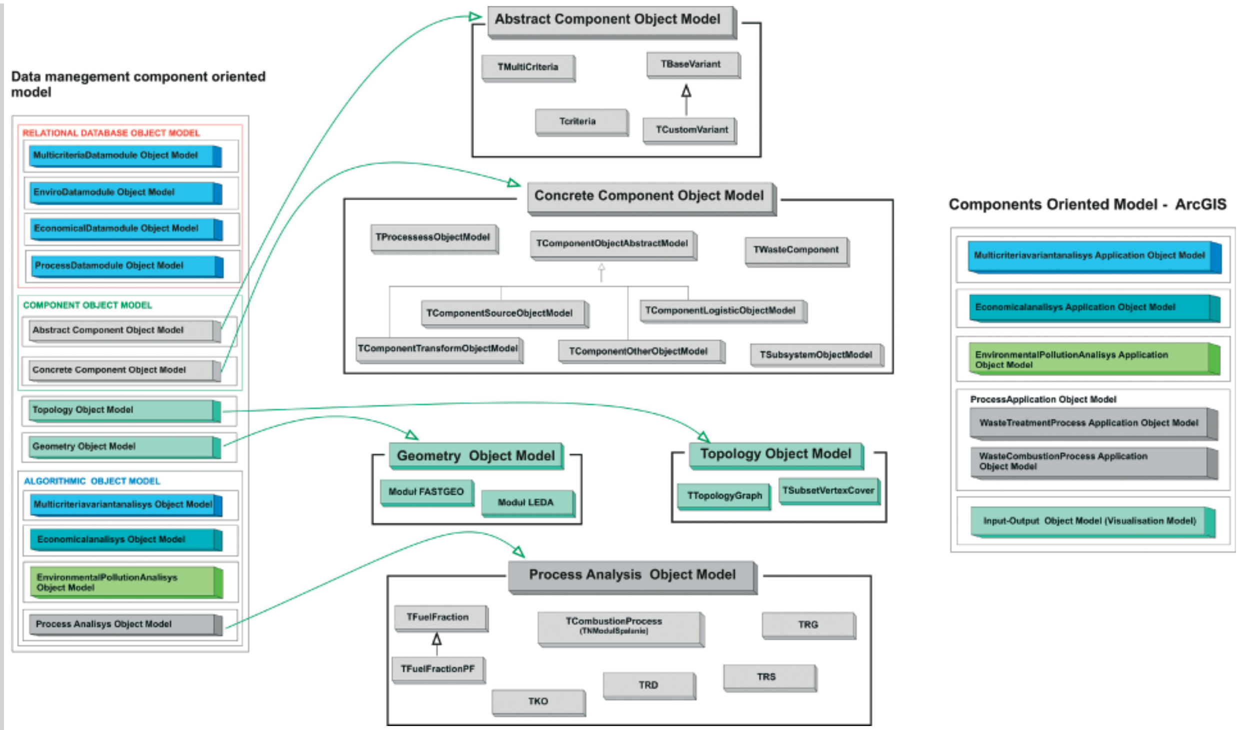

Figure 2.5.
Categories of the models of object components of a waste management system [own elaboration]

3. CONCLUSIONS

The paper presents the modelling methods of adapting, reactive computer assistance systems for issues involving modelling variants of waste management systems, taking into consideration contamination propagation (in terms of environment contamination analysis) generated in effect of technological processes of integrated waste management systems with the use of object-oriented methods (Object Oriented Analyses & Design). It presents also the development of design templates for the class library defined in high-level programming languages (Object Pascal, C++) which represents the actual systems, objects and processes in the form of numerical computational models.

The solution presented in the paper consists in the integration of programmers' environments, using the Microsoft Component Object Model technology (COM). The structure of the global model is characterised by modular structure, which integrates the set of component models of objects and processes which can be used as independent, autonomous runtime models or as elements of global structure of the application model. The definition of the model contains the elements of connection (through a database alias) with the geo-relational database (Geodatabase) developed in the ArcGIS environment (by ESRI). The definition of class type of component models (model of economic and optimisation analyses, model of environment analyses, model of multi-variant analyses) comprises fields and methods referring to the methods of interfaces of the Arc Objects environment (ESRI) and the Surfer Application Object Model, developed in the COM technology. This solution, consisting in the integration of several programming environments, allows using advanced tools defined in individual programmes along with the possibility to expand them, through the definition of polymorphic derived types or the definition of own component object models (the COM technology), compiled into runtime libraries DLL and added to the existing tools.

Certainly, the proposed model is a valuable contribution to the development of advanced ICT methods in managing municipal waste management. Systems based on graph algorithms will allow you to pass from your current passive waste management position to a more active one. This will facilitate decision-making when solving planning problems related to accurate recognition of the quantity and quality of waste generated in dispersed sources, the organization of a logistics system, distribution and solving problems related to the location of new facilities for transforming this waste group.

The research topic presented in the paper is one of the elements stimulating the development of the so-called smart cities (SMART Cities) in the scope of ensuring the safety of health and life of residents and reducing negative changes in all components of the environment.

REFERENCES

[1] Assad Arjang A., Golden Bruce L. (1995). Arc routing methods and applications, *Handbooks in Operations Research and Management Science*, 8, 375–483.

[2] Akouz, K., Benhammou, A., Malaterre, P. O., Dahbou, B., Roux, G. (1998). Predictive control applied to ASCE canal 2. in Proceedings of the 1998 IEEE International Conference on Systems, Man, and Cybernetics, San Diego, California, 3920–3924.

[3] Babalola A., Busu I. (2011). Selection of landfill sites for solid waste treatment in Damaturu Town – using GIS Techniques, *Journal of Environmental Protection*, *2*, 1–10, doi:10.4236/jep.2011.21001.

[4] Balcerzak W., Generowicz A., Mucha Z. (2014). Application of Multi-Criteria Analysis for Selection of a Reclamation Method for a Hazardous Waste Landfill, *Polish Journal of Environmental Studies, 23*(3), 983–987.

[5] Begovich, O., Ruiz, V. M., Besançon, G., Aldana, C. I. (2007). Georges D. Predictive control with constraints of a multi-pool irrigation canal prototype. *Latin American Applied Research, 37*(3), 177–185.

[6] Binder C. R., Quirici R., Domnitcheva S., Stäubli B. (2008). Smart Labels for Waste and Resource Management, *Journal of Industrial Ecology, 12*, 2, 207–228.

[7] Chang Ni-Bin, Pires A., Martinho Graça. (2011). Empowering Systems Analysis for Solid Waste Management: Challenges, Trends, and Perspectives, *Critical Reviews in Environmental Science and Technology,* 41, 16 (1449).

[8] Chang Ni-Bin, Wang S.F. (1996). The development of an environmental Decision Support System for municipal solid waste management, *Computers, Environment and Urban Systems, 20*, 3, 201–212.

[9] Dyson B., Chang N. B. (2005). Forecasting municipal solid waste generation in a fast-growing urban region with system dynamics modelling, *Waste Management 25*(7), 669–679.

[10] Gaska, K; Generowicz, A; Zimoch, I; Ciula, J; Iwanicka, Z. (2017). A high-performance computing (HPC) based integrated multithreaded model predictive control (MPC) for water supply networks, *Architecture Civil Engineering Environment, 10*(4), 141–151.

[11] Gaska, K; Generowicz, A. (2017). Advanced computational methods in component-oriented modelling of municipal solid waste incineration processes, *Architecture Civil Engineering Environment, 10*(1) 117–130.

[12] Gaska, K; Pikoń, K. (2012). Modelling of the integrated waste management systems using object-oriented methodology, Conference: WSEAS International Conference on Renewable Energy Sources/Energy Planning, Energy Saving, Environmental Education/Waste Management, Water Pollution, Air Pollution, Indoor Climate Location: Arcachon, FRANCE, 2007, LECTURE NOTES ON ENERGY AND ENVIRONMENT Book Series: Energy and Environmental Engineering Series: 2007.

[13] Generowicz A., Kowalski Z., Banach M., Makara A., A glance at the world, *Waste Management, 32*(2), 349–350.

[14] Ghiani G., Laganà D., Manni E., Musmanno R., Vigo D. (2014). Operations research in solid waste management: A survey of strategic and tactical issues, *Computers & Operations Research, 44*, 22–32.

[15] Goedkoop M., Spriensma R.(2001). The Eco-indicator 99: A damage oriented method for Life Cycle Impact Assessment.Methodology Report, Amersfoort.

[16] Lam H.L., Varbanov P.S., Klemeš J. (2010). Optimisation of regional energy supply chains utilizing, Computers & Chemical Engineering, 34, 5, 782–792.

[17] Kowalski Z., Generowicz A., Makara A. (2012). Evaluation of municipal waste disposal technologies by BATNEEC, *Przemysł Chemiczny, 91*(5), 811–815.

[18] Malczewski J. (1999). GIS and multricriteria decision analysis, JOHN WILEY & SONS INC. ISBN 0-471-32944-4, USA.

[19] Negenborn, R. R., De Schutter, B., Hellendoorn, J. (2008). Multi-agent model predictive control for transportation networks: Serial versus parallel schemes. *Engineering Applications of Artificial Intelligence, 21*(3), 353–366.

[20] Rada E. C., Ragazzi M., Fedrizzi P. (2013). Web-GIS oriented systems viability for municipal solid waste selective collection optimization in developed and transient economies, Waste Management 33, 4, 785–792.

[21] Szymura, Zimoch I. (2014). Operator reliability in risk assessment of industrial systems function. *Przemysł Chemiczny*. 93, 1, 111–116.

[22] Wang Q., Poh K.L. (2014). A survey of integrated decision analysis in energy and environmental modeling, *Energy*, 77, (691).