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EDUCATIONAL TRAINING SYSTEM FOR DESIGN OF EFFICIENT WATER TREATMENT

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The actual trend in design of water treatment is to focus on equipment ignoring such essential factors as skills and training. The work presents training and reference computer system on wastewater treatment and efficient water reuse. The information system is a package of computer applications supplemented by data files, text notes and animations. It is composed of four parts: reference library, case base manager, treatment adviser, and process builder. The system contains the cases of industrial and municipal real-life applications. It involves also several methods for automated construction of the treatment sequence for a given wastewater. The dataset includes schematic pictures, photographs, 3D images and virtual tours to working process of a number of wastewater treatment technologies. The general description of the water treatment technology is supplemented by the theoretical background with examples and a model. It is possible to construct a simple treatment scheme from the blocks, represented treatment methods, using the component of the system. The educational training system is capable to satisfy the needs of many users: teachers of environmental engineering, the consultants who are seeking a solution to client's problem, the engineers who would like to have an easy access to background knowledge, the students looking for the support to understand the wastewater problems.

1. INTRODUCTION

The design of efficient water treatment systems is a complicated task which requires significant engineering experience as well as deep theoretical knowledge of the designers. Usually the task facing an engineer is to determine the levels of treatment that must be achieved and a sequence of methods that can be used to remove or to modify the components found in wastewater in order to reduce the environmental impact and to meet ecological requirements. The solution of the this task requires the detailed analyses of local conditions and needs, application of scientific knowledge and engineering judgment based on past experience. Therefore, an information reference system accumulating knowledge in the field of the wastewater treatment and water reuse in an easily accessible way would be of great interest to the engineers.

While approaches towards effective waste management, such as waste elimination at source, renewable energy, life cycle assessment and cleaner production technology have altered radically university curricula, traditional pollution control and technologies for clean-up processes remain an integral part of engineering education and have a lot to offer in environmental preservation and economic development (Brennecke & Stadtherr, 2002; Gutierrez-Martin & Huttenhain, 2003).

Very often there is an astonishing lack of awareness among many technical service providers and environment practitioners with regard to the range of wastewater treatment methods and equipment available. Moreover, the actual trend is to focus on equipment, ignoring such essential factors as skills and training. Computer science has created new tools for education, visualization and practical experience, in a rapid and cost-effective way, where the learners have fast and easy access to information and is allowed to experiment in design by testing several engineering scenarios (Paraskeva et al., 2007).

In environmental engineering, laboratory simulations offer interactive teaching and learning through the web with virtual instrumentation and simulations of pollutant transfer and transformation pathways in air, water or soil (Zhou, Jiang, Fan, 2005; Brenner, Schacham, Cutlip, 2005). There are also applications of expert system for

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wastewater treatment sequencing (e.g. Yang, Kao, 1996), however such part of design support activity has not been included into training system.
The focus of the presented work is to improve training aspects of water use by developing an education training system. The system contains the cases of industrial and municipal real-life applications. It also includes decision supporting system for selection of wastewater treatment. The system can be used for training in selection of technologies for wastewater treatment including reclamation & reuse, without investment in expensive pilot plant infrastructure.

2. FEATURES AND FUNCTIONS OF THE TRAINING SYSTEM

The main function of educational training system is to provide knowledge on wastewater unit operations, fundamental understanding of the mechanism of wastewater treatment, and analysis of past design cases. The training system dealing with wastewater treatment should be able to offer to the learners the following:

- Theoretical knowledge of available technologies for wastewater treatment and reclamation.
- Practical understanding of the mechanisms involved in unit processes.
- The ability of designing a simple unit operation based on practical information.
- The possibility of accessing real industrial data on current practices and results.
- The ability to check simple problem-solving scenarios.
- The information to problem-solution practices.
- Applied techniques in wastewater minimization in regional industries.

This educational system combines the elements of traditional engineering education and modern computer-based virtual tools including theoretical information, virtual demonstration of technologies, spreadsheet models, a small database of case studies in select municipal and industrial sector and a basic case base reasoning system allowing the user to access the most suitable treatment sequence or create own one.
The primary target group for the training is students and academics. The system is by no means a substitute for a proper textbook and, in any case, despite containing a lot of theoretical material, must be supplemented by appropriate reading material and coursework.

3. STRUCTURE AND COMPONENTS OF THE SYSTEMS

The educational training system is a set of computer software tools supplemented by data files, text notes and animations, implemented on platform Microsoft ® Windows ®, for imparting training on wastewater treatment technologies. The main function of educational system is to provide knowledge on wastewater unit operations, fundamental understanding of the mechanism of wastewater treatment, and analysis of past design cases.
The system has two variants of package: training set and administrative set. As it can be noticed from the caption the administrative set is used to edit data in the system bases and to add new information related to wastewater treatment design, while the training set is supposed to use in the classrooms.
The system structure contains four main modules:

1. Reference Library (RL) a structured e-book with theoretical knowledge on wastewater unit operation as well as training examples;
2. Case study Manager (CM), with case studies from real life applications;
3. Process Builder (PB) serves to construct a treatment sequence from unit operations presented as blocks;
4. Treatment Adviser (TA) assists in problem-solving exercises;

Each module, except Process Builder, is linked to the corresponding storage of resources: library of technologies, case base and treatment base. The components support the complete training activity from presentation to problem solving and design. Reference Library contains all background knowledge presented in the system. The user can use the case study manager to learn the past situations of wastewater treatment and even search for the solution of the current situation. If acceptable solution cannot be found, the treatment adviser tries to generate a sequence of operations for removal of the compounds found in the given wastewater treatment problem. Generated sequences can be visualized in the process builder. The user can also build the treatment sequences from blocks, utilizing the special drag and drop builder where a block corresponds to an operation of treatment. The schema of the use of the system as the educational tool (student set) is presented in Fig. 1.

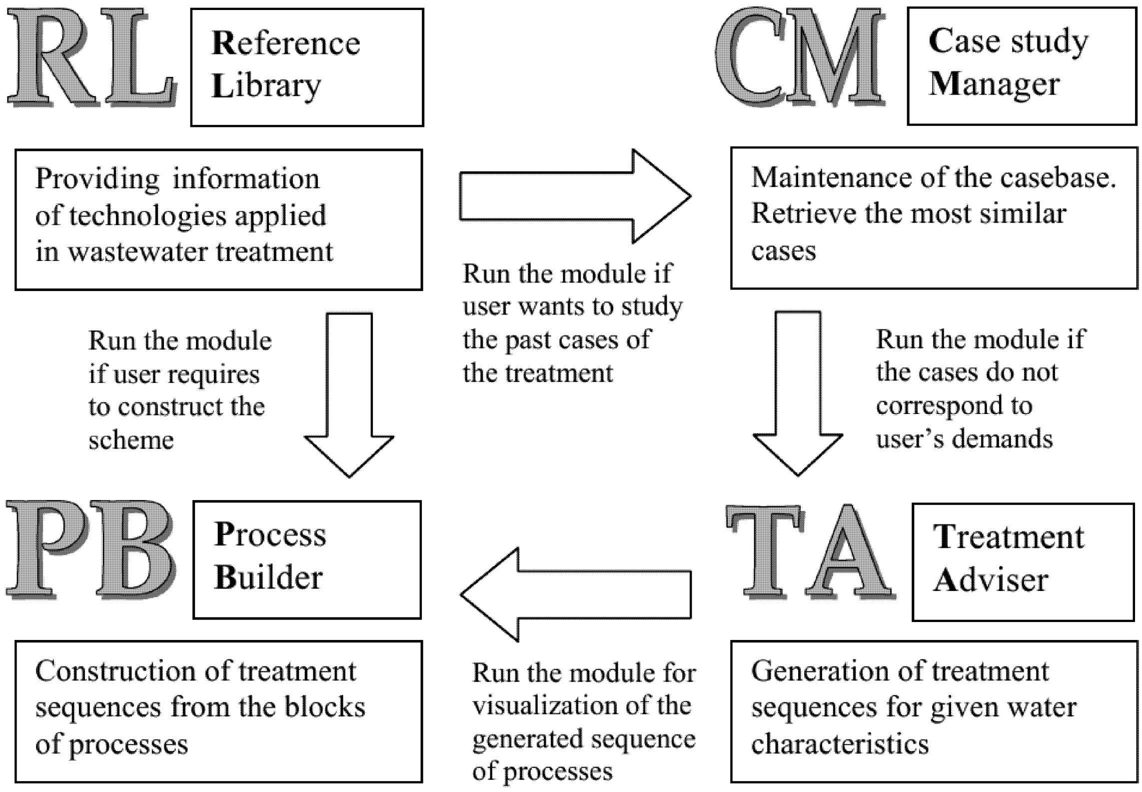

Figure 1. The use of the training system

Administrative set includes, in addition to listed components, the tools for data management of the storage of resources: Registrar of New Technology (RNT), Case Submission Director (CSD) and Treatment Base Editor (TBE).
The system is updateable, and new technology with all supplemented data can be added using RNT tool. In order to add new case CSD tool can be used. The tool also allows the administrator to edit the case data or add additional information to the case. The treatment base is also editable, and the corresponding tool, TBE, is served to modify the knowledge set for the generator of the wastewater treatment sequences.

3.1 Reference Library

The purpose of the reference library is to provide the user with comprehensive overview of processes and
The purpose of the reference library (RL) is to provide the user with the comprehensive overview of 21 processes and operations used for wastewater treatment. The complete list of technologies presented in the Library, grouped into the levels on treatment they provide, is given in Fig. 2.
The particular treatment processes are usually classified as physical operations, chemical and biological processes. Reference library supports several classifications of the unit operations and processes. They are grouped according to the level of the provided treatment (preliminary, primary, secondary, and advanced treatment), type of unit operations (physical, chemical, biological) and in the alphabetic order.
All materials are presented with thematic ways. The general description of the wastewater treatment technology is supplemented by the theoretical part as well as practical knowledge with a worked out example. The sections of the description of the technology are as follows, the:

- Summary, where an overview of a treatment technology and its purpose is presented.

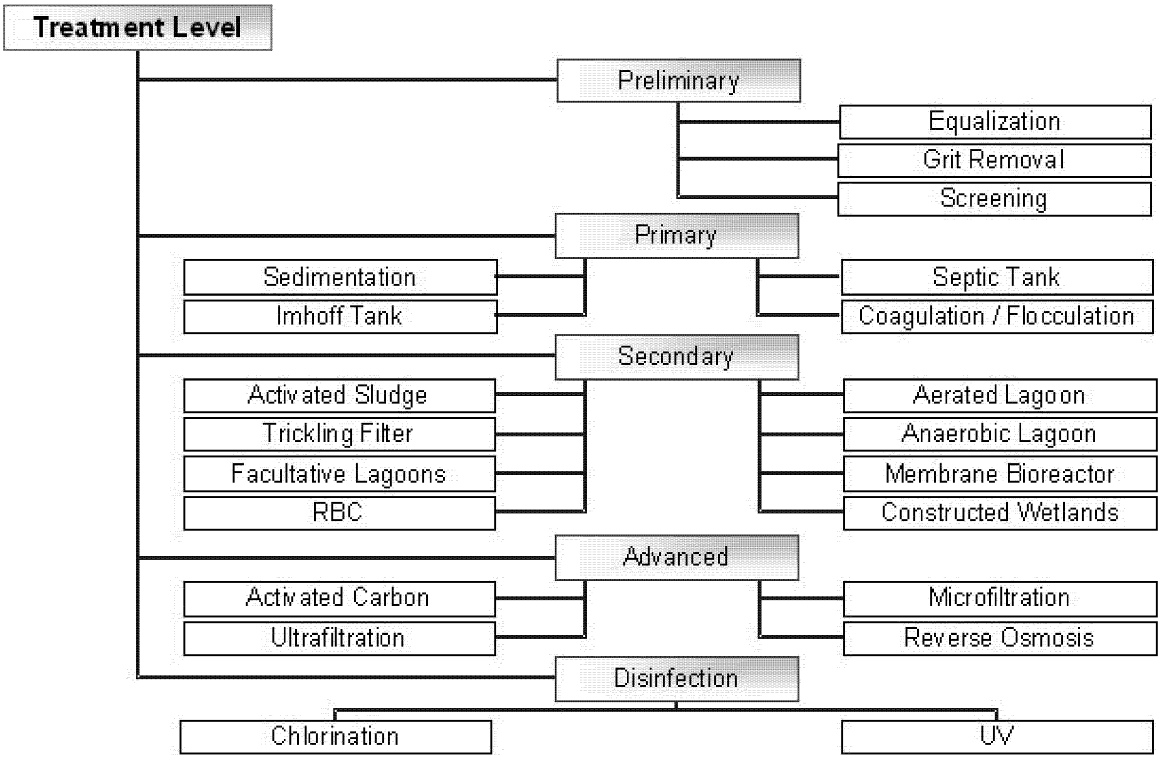

Figure 2. The list of wastewater treatment technologies included in the Reference Library

- Theory, which is the theoretical background for the processes of the described technology; this section is based on textbooks and published papers and provides theoretical information about the principle of each technology as well as an analysis of the elements of each unit operation.
- View, where a schematic representation of the technology as well as 3D image(s) of typical equipment used in the technology is located; in most cases 3D images were rendered from digital pictures and engineering drawings, from operating wastewater treatment plants.
- Animation, which contains an animated picture with explanatory text showing and describing each step of process.
- Design parameters, which provides practical information about the range of parameters used in the design of the technologies and in sizing the various tanks/reactors.
- Example, which is a worked out example in basic design and sizing of described wastewater treatment unit operation; examples were taken from real wastewater treatment plants, textbooks and classroom coursework.
- Model, which is a spreadsheet calculation implemented using Microsoft Excel ® and contains the solution of the example of the previous section.
- References, where the titles of textbooks and material used can be found for further reading.

In animations, cross section view of unit operations allows the user to have an inside view, not visible in a real wastewater treatment plant visit. An animation usually includes several cross-sections represented various parts of the equipment. The user is taken in a virtual step-by-step walk through each process. Pointers, labels and accompanying text explain the main features of each technology during the show.

The Reference Library is supplemented with a glossary section, where the user can find definitions of terms used in the text of the RL concerning water and wastewater parameters and treatment processes. The terms are indexed by alphabetic order.

The model allows the student to modify the selected parameters (data) in the spreadsheet and observe the effect on the units (size, outcome) in order to understand better the operation and the limitations of each process. The

data used are taken from real design applications or from textbooks and all parameters and formulas can be found in the theoretical background and in the design parameters section. The user can modify the selected parameters in the spreadsheet to understand their effect on the unit performance.
The administrative set contains the facility to add new technology into the library of technologies. The tool can also be used when it is necessary to recompose existing data files of the registered technologies.

3.2 Case study Manager

The case study manager (CM) accumulates the specific design experience contained in real life situations, and tries to reuse it when solving new user's problems. The component serves the dual aim of first acquainting the user with real wastewater treatment practices in the selected sectors, and then familiarizing oneself with parameters of concern and their range in the relevant industry and with the degree of achievement of treatment. The module can also be used to help in solving user problems, either by the user composing a new case study or a problem or by entering influent wastewater characteristics, demanded flow and sector of industry.
The case base of the CM includes more than 110 case studies obtained from municipal and industrial wastewater treatment plants from Asia and Europe. The industrial sectors include pulp and paper mills, alcohol distilleries, tanneries, rubber and latex processing, textile and garment manufacturing and metal-finishing units. The scope of the case base is presented in Figure 3.

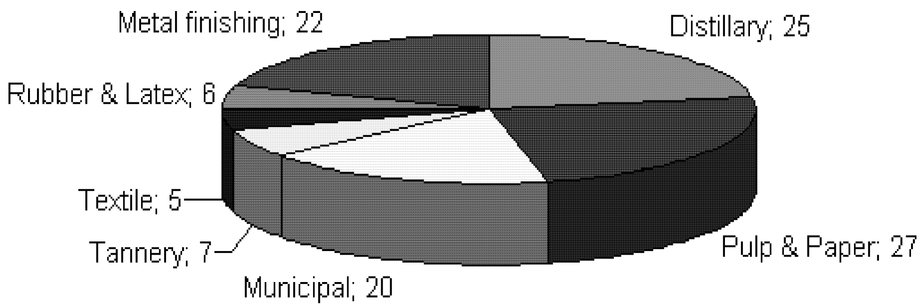

Figure 3. The scope of the case base

The representation of the case includes:

- Type of industry, (pulp & paper, distilleries, tanneries, rubber & latex, textile, metal-finishing, or municipal);
- Overview of the industrial plant produced the wastewater;
- General technical parameters of treatment, such as flow rate, cost of treatment, water supply etc;
- Influent wastewater characteristics, divided into four groups – physical parameters, organic and inorganic matters and microbiological data;
- Effluent water characteristics, presented by the same groups as influent characteristics;
- Treatment sequence, presented both as list of used technologies and as schematic representation;
- Remarks.

The manager performs the retrieval of the most similar cases to the new problem from the case base containing the past situations of wastewater treatment. The treatment sequences of similar cases are provided as promising solutions.
The CM utilizes the case-based reasoning (CBR) approach in solving new design problem. The technique is based on the assumption that the similar problems have the similar solutions. A single case is composed of two parts: a problem and its solution. In solving a current problem, there are retrieved a similar, past problem and its solution using a set of formulas for measuring similarity between actual problem and those stored in case base.

In order to define a similarity between cases containing both numeric and textual-symbolic information the general similarity concept is used (Avramenko & Kraslawski, 2006). The descriptions of new wastewater treatment problems are often incomplete and uncertain. The general similarity concept is able to cope with uncertainty and with the data represented in the different types (numeric, symbolic and hierarchical). The overall similarity between cases *A* and *B* is calculated as follows:

$$SIM(A,B)=\sum_{i=1}^{k}w_i\cdot sim(a_i,b_i)/\sum_{i=1}^{k}w_i \quad \textbf{(1)}$$

where sim_i is the local similarity; w_i – weight of importance of i-feature.
The importance of the features for each sector of industry has been weighted. The determination of local similarity of features of the problems is deepened on type of feature's data. For example, the local similarity for the symbolic sets is determined as follows:

$$sim(a,b)=\frac{|S_a\cap S_b|}{\max(|S_a|,|S_b|)} \quad \textbf{(2)}$$

where S_a and S_b – sets of symbolic features for *a* and *b* features correspondingly.
The CM can take a role of the case base browser, where it gives a user the ability to navigate on cases where professional experience of wastewater treatment is required, and to learn which treatment technologies are usually applied in the selected sectors.
The extra tool is involved in the administrative set for maintenance of the case base. The component provides the ability to add, edit and delete a case of case base. It is also able to download updates of cases from specific common server where all updates are collected. All changes can be submitted to common server for public access of other instances of the system.

3.3 Treatment Adviser

Treatment adviser generates a simple sequence of treatment technologies for a given water characteristics. It analyses the influent water characteristics and supplemented information of other factors (economical, technical or ecological) to select suitable technology of treatment.
There are two techniques to construct a sequence of treatment: based on set theory, analyzing the classes of contaminants in the wastewater, and based on decision trees, where the suitable technology selected according to logic gained from experts.
The first algorithm of selection is based on the search for deviations in wastewater parameters from those of clean environment (Avramenko, 2003). The goal is to eliminate the deviation, simply, to clean the wastewater. A deviation can be determined by a single or a number of wastewater characteristics. For example, the phenol concentration in water above 50 mg/l and up to 500 mg/l defines the 'medium' deviation of this contaminant. Each deviation can be treated by a number of wastewater treatment technologies that are capable to eliminate the deviation in wastewater. The treatment tree can be constructed to represent treatment options for each deviation. A fragment of such tree, which is stored in the treatment base of the TA, for the phenol class of contaminants is represented in Figure 4. The stream may contain a number of such deviations that can be processed by many sets of treatment methods. As a result of analysis, one or several treatment sequences are generated and then evaluated by economical and treatment efficiency criteria. The applicability of the set of technologies is evaluated based on data from the past applications of these technologies.
Another algorithm is the selection of the proper wastewater treatment method based on previously constructed rules represented as decision tree. A decision tree can be defined as a map of the reasoning process (Negnevitsky, 2002). The tree is a graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. The results of outcomes are retrieved from expert opinion and experience. By answering the question in the nodes of the tree the space of possible outcome reduces and finally a realization of treatment method is found in the end of the branch of the tree.

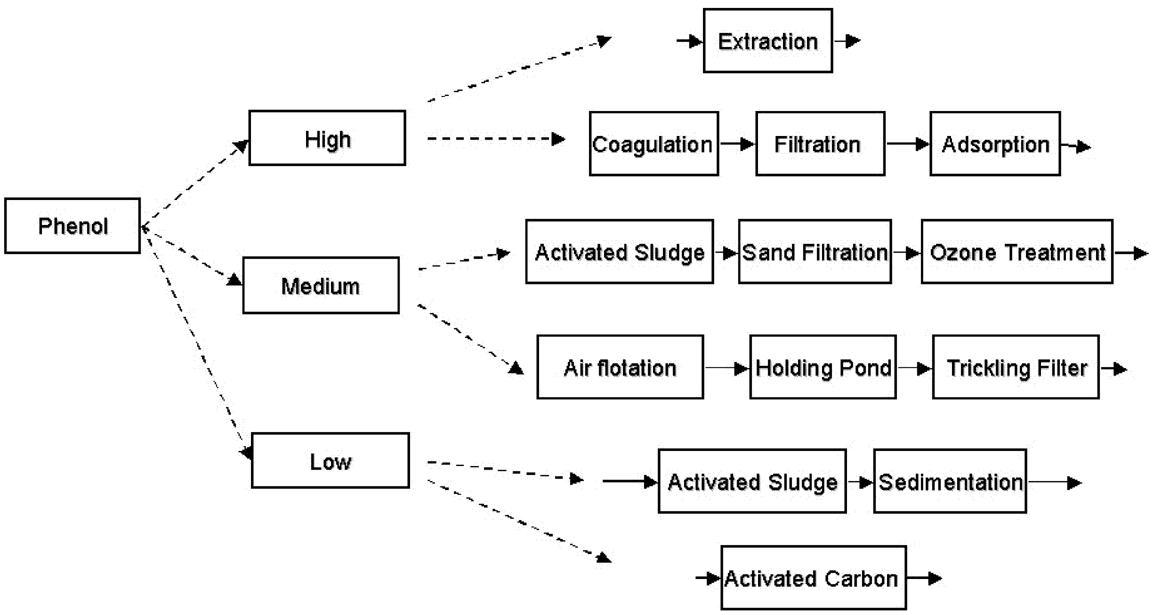

Figure 4. A part of treatment tree with phenol classes

The process of selection of treatment method from decision tree can be understand from the fig.2, where part of decision tree for selection of aerobic treatment type is presented. Each treatment level is considered consequently, and after successful passing all decision trees the final treatment sequence is constructed.
The modification of treatment base (ways of treatment for certain class of contaminants of wastewater) can be performed with additional tool of administrative set. It is possible to create several versions of treatment base with different division on classes of contaminants as well as different options for treatment.

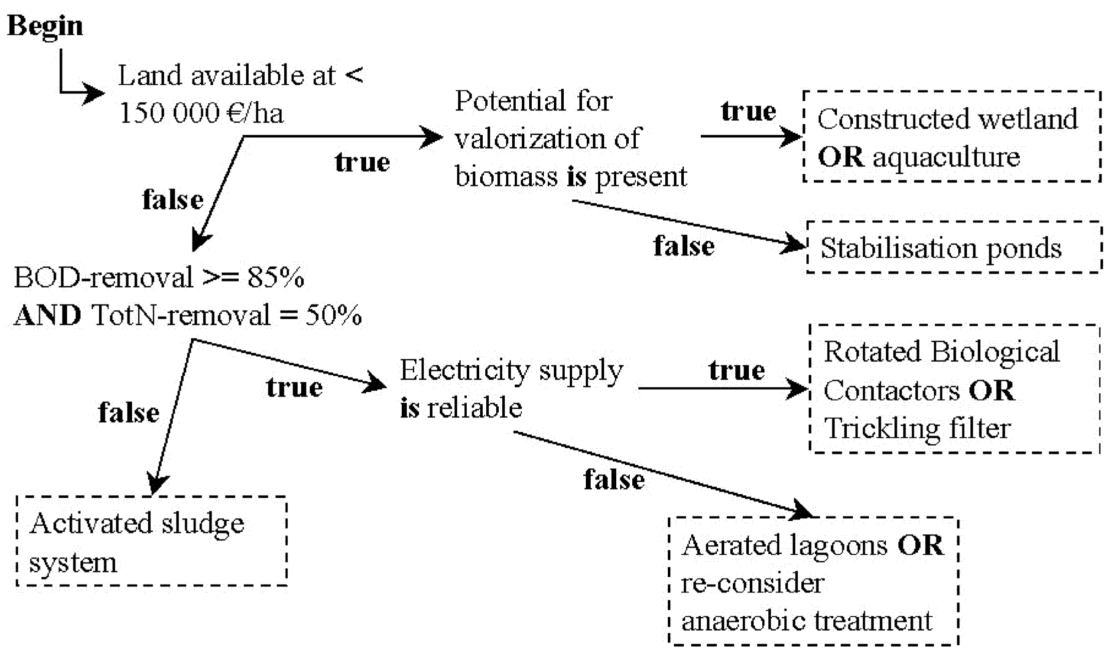

Figure 5. Decision tree for selection of type of aerobic treatment

3.4 Process Builder

Process builder serves to create a treatment system flow diagram from the unified blocks. Each of the blocks represents a type of the treatment processes or specific part of the process. Blocks can be linked according to internal restrictions, rules and locations of connection points. The module is based on a valid sequence matrix represents permission or the refusal of the sequence which is based on technical feasibility only and not on other parameters such as land availability, cost, energy consumption.
The aim of the module is that the user, after becoming familiar with the concept of the methods and with the practices used in the industry, creates one's own wastewater treatment sequence. The module is also used to visualize the result proposed by Treatment adviser.

4. CONCLUSIONS

The presented educational system is capable to satisfy the needs of many users: teachers of environmental engineering, the consultants who are seeking a solution to client's problem, the engineers who would like to have an easy access to background knowledge and students looking for the support to understand the wastewater treatment problems. One of the main functions of the educational system is to narrow the gap between the classroom teaching and real-life applications of wastewater treatment technologies. The summary of various options of the use of the system is depicted in Fig. 6.
The system provides an opportunity for the users to learn basing on the experience in wastewater treatment and approaches to water conservation in several countries in Asia and Europe. They also can have an overview of the theory & practice of wastewater treatment technologies applicable to municipal and various industrial sectors in Asia & Europe. One of the main advantages of the educational system is the visualization of operations involved in the wastewater treatment.

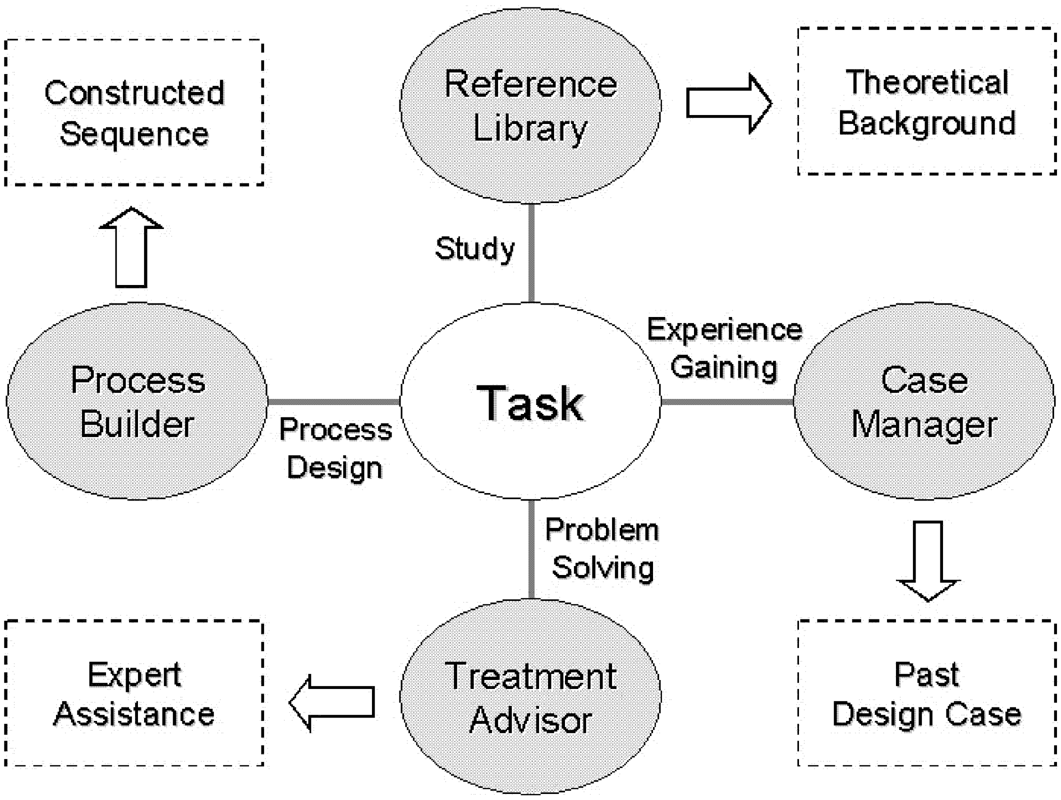

Figure 6. The tasks solved with the educational training system for design of water treatment

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