Civil Engineering Decision Support Systems in Lithuania

E. K. Zavadskas, Vilnius Gediminas Technical University, 10223 Vilnius, Lithuania (edmundas.zavadskas@adm.vtu.lt)

A. Kaklauskas, Vilnius Gediminas Technical University, 10223 Vilnius, Lithuania (arturas.kaklauskas@st.vtu.lt)

Summary

Civil engineering decision support systems (construction, building life cycle, refurbishment, total quality management, innovation, etc.) created in Lithuania are described in this paper. The above decision support systems comprise of the following constituent parts: data (database and its management system), models (model base and its management system) and a user interface. Presentation of information in databases may be in conceptual (digital, textual, graphical, photographic, video) and quantitative forms. Quantitative information presented involves criteria systems and subsystems, units of measurement, values and initial weight fully defining the variants provided. The databases were developed providing a multiple criteria analysis of alternatives from economical, infrastructure, technical, technological, qualitative, legislative, social and other perspectives. This information is provided in a user-oriented way. Since the analysis of alternatives is usually performed by taking into account economical, infrastructure, technical, technological, qualitative and other factors, a model-base include models which enable a decision maker to carry out a comprehensive analysis of the variants available and make a proper choice. These systems, related questions and practical case study were analysed the paper.

1. Application of Information Systems, Neural Networks, Expert and Decision Support Systems, E-commerce at National, Organization and Project levels

Thousands of various purpose construction Web sites (Architecture and Design, Building Process, CADD Software, Codes and Permits, Contractors and Suppliers, Investment Services, Mortgages Services, Development, Marketing, Consulting, Insurance and Inspection Services, etc.) can be found on the Internet. Different types of Web-based information systems, neural networks, expert and decision support systems, e-commerce are possible to be found on the above types of construction Web sites.

Construction information technology (IT) can be used on the national, organization and project levels.

On the national level IT may be used to disseminate the information on laws, norms, standards, technical issues, the results of research and experiments, contract offers, foreign experience, etc. IT enables one to find and analize the required data quickly and from various perspectives, as well as allowing effective communication between interested parties (i.e. videoconferences, e-mail, etc.) for making important decisions at a distance.

IT at country or European levels have been analyzed and written about in a variety of research literature. For example, (Hassan and Mc Caffer 2002) report on findings from a project funded by the European Commission entitled European Large Scale Engineering Wide Integration Support Effort (eLSEwise) and present business and ICT trends in the European LSE construction industry. As an example, they performed investigation into clients' views and perceptions of the European Large Scale Engineering ICT environment and showed that the most important systems currently for client organizations are finance and accounting, project planning and human resources. Also, there is an anticipated increase in the importance of

project planning, QA systems and document control, e.g. material procurement, CAD systems and communications systems during the next 10 years (Hassan and McCaffer 2002).

(Liao et al. 2002) demonstrated how the electronic Taiwan government procurement system functions and reengineers its internal procurement processes, which in turn benefits both government bodies and venders. The system features explored herein include posting/receiving bids via the Internet, vender registration, certificate authorization, contract development tools, bid/Request For Proposal development, online bidding, and online payment, all of which can be integrated easily within most existing information infrastructures.

ProcureZone is (see 1) a "One-Stop Procurement Resource and Hub" that simplifies the purchasing process for buyers and suppliers throughout the construction industry. An average of about 40 percent of the dollars spent on construction and maintenance projects goes towards the purchase of goods and materials. A significant portion of these procurement dollars is spent on engineered equipment and materials. ProcureZone can reduce the cost of specified equipment and material by an average and up to 20 percent.

On the organizational level IT is used to get and process the data on financing and investment possibilities (videotext) as well as on real estate (GIS), government-provided services (expert systems), producers and their products (electronic catalogues), etc. For example, organizations using telecomunication networks and IT get the possibility to search for most suitable suppliers, contractors and use market offers for the best advantage. IT also provides the opportunities for learning and qualification improvement (by distance learning, the availability of electronic library). For example, a recent European survey (Mc Caffer and Hassan 2000) has highlighted the need for electronic sharing of information between Large Scale Engineering (LSE) clients' information systems and those of:

- Funding bodies in the areas of finance and accounting;
- Consultants in the areas of modeling and calculations;
- Project Managers in the areas of project planning and QA systems and document control;
- Contractors in areas of CAD drawings, materials procurement, project planning, QA systems and documents monitoring, and communication systems; and
- Suppliers in the area of material procurement.

On the project level the use of information and artificial intelligence systems (i.e. expert, decision-support systems, etc.) allows all the interested parties, (i.e. designers, economists, architects, builders, facilities management personel) to solve the problems concerning the life time of a building (including brief, design, construction, maintenance, facilities management and demolishing stages). For this purpose data bases are being created embracing the data and knowledge obtained from the previously made similar projects as well as the experience of experts and the data contained in various norms, standards and other sources of information.

(Cheung et al. 2004) describe the development of a Web-based Construction Project Performance Monitoring System (PPMS) that aims at assisting project managers in exercising construction project monitoring. With the aid of a panel of project management specialists, the following project's performance measure categories that are identified for inclusion in the PPMS: People, Cost, Time, Quality, Safety and Health, Environment, Client Satisfaction, and Communication.

(Alshawi and Ingirige 2003) briefly explain the main features of the currently available web-based software, which comes under the umbrella of web-enabled project management tools:

- Tender stage. The main functions of this type of software are to advertise and distribute tender documents, select successful tenders and award contracts. Software used at this stage

can: speed up the distribution of documentation and tenders' communications; register tenders online and download tenders/work packages electronically; provide a simple environment to evaluate the tenders' responses through standard templates; prevent unauthorized access through built-in security mechanisms; and communicate changes in tender documents, during the tender process, quickly and easily.

- Design and construction stage. Project manager's monitor and manage the exchange of documents between members of the project team so that the overall deadlines of the project are met. It is essential that each team member receive the right documents at the right time, such as the latest version of drawings, specifications and requirements.

- Trading (e-commerce). Purchasing of materials is a lengthy and complex process, which requires the identification of considerable resources and potential suppliers as well as the evaluation of quotes that are normally received in different formats. Web-enabled Software used at this stage can: save time in the procurement of materials by automating document distribution and communications (E-procurement); reduce the administrative costs of document handling and their distribution to multiple parties; reduce errors because of more effective communication; ensure ease of comparison and the evaluation of bids (Alshawi and Ingirige 2003).

(Mohamed and Stewart 2003) have performed an empirical investigation of users' perceptions of a web-based communication tool that has been adopted by large construction projects. According to this investigation, the IT can make a positive contribution to operational indicators such as document transfer and handling, enhanced coordination and communication between project participants, and reduced response time to answering queries, etc.

(Husin and Rafi 2003) review current available Internet-based computer-aided design tools and explore the possible utilization of these in architectural practices.

An experimental Internet-enabled system that integrates Building and Facilities Management Systems has been developed and tested (Wang and Junlong 2002).

Expert systems today generally serve to relieve a 'human' professional of some difficult but clearly formulated tasks. Expert systems are most frequently applied at project level. More seldom they are applied at organization level, and much more rarely at construction industry level.

According to (Mohan 1990), the next construction areas are covered by expert systems: project planning, scheduling, and control, project management, construction methods, equipment management, legal issues, human resource management, concrete mixing and placement and temporary-facilities layout. Further, particular fields are given in which expert systems help to solve different problems: e.g. automated schedule updating, layout of temporary construction facilities, safety analysis, predicting time and cost of construction during initial design, cost estimating from preliminary design, masonry construction, differing site conditions analysis, strategic planning of construction alternatives, construction risk identification, vertical construction schedules and failure diagnosis, etc. Web-based training tools on construction topics (see 2) are highly illustrated and utilize graphical menus as well as expert system modules. These modules (construction, evacuation plans and procedures, ergonomics, respiratory protection, safety and health management, scaffolding, steel erection, wood products, woodworking, etc.) enable the user to answer questions, and to receive reliable advice on how OSHA regulations apply to a work site. Expert Advisors (asbestos, confined space, fire safety, hazard awareness, lead in construction, etc.) are based solely on expert systems (see 2). As an example, two expert systems will be described further in brief.

(Rebolj 1998) developed a quality management expert system QM-XPS allowing the ensuring of alternative quality through all stages of its execution. This system also allows the comparison

of an alternative that is being designed or executed with earlier realized alternatives, as well as detecting its drawbacks and providing recommendations (using knowledge base) as how to ensure its quality.

A Knowledge-Based Instructional System for Claims Management evaluates the relative strength of the claim and reminds the user of the applicable claims' procedures, notice requirements, and time limitations. When the actual construction claims' cases were evaluated by the system, a high degree of reliability between the system's conclusions and the litigation results were observed (Cooper 1995).

Recently traditional decision support systems and their varieties such as hybrid and group decision support systems are getting more and more popular. These systems can use various latest technologies such as Multimedia, pattern recognition, image processing and other technologies. Decision support systems are rarely applied at organization level and are hardly applied in a construction branch. The most samples of application are traced at project level.

For example, the hybrid computerized decision support system for construction quality assessment (see 3) that automate the assessment process by acquiring digital images of the areas to be assessed and analyze the images to identify and measure defects. By means of using advanced technologies such as digital cameras, optical scanners, gyroscopic technology, machine learning, pattern recognition, and image processing, the hybrid computerized decision support system for construction quality assessment (see 3) can produce objective, quantitative, and reliable results of assessment, and can reduce the time needed to interpret the results.

(Shen et al. 2004) introduced the application of Group Support System (GSS) to support Value Management (VM) studies so as to improve the implementation of VM in the construction industry. This is followed by a description of a GSS framework for VM studies and a specific GSS prototype system to illustrate how this framework can provide support in discussion, information, and collaboration and decision analysis to overcome existing problems in VM studies.

(Kam and Fischer 2004) discuss the needs for research on a Decision Dashboard to formally represent, organize, and decouple various decision contents (i.e., options, alternatives, predictions, and criteria) to support a better evaluation and re-formulation of architecture, engineering, construction alternatives. The Decision Dashboard is not a tool for the automatic generation or coupling of project options, but a visual and interactive tool for the synthesis of ideas, predictions, and requirements among architecture, engineering, construction stakeholders (Kam and Fischer 2004).

(Chau et al. 2003) developed the Construction Management Decision Support System that is advanced in the following aspects: the System enables managers to make decisions and improve management performance; users can interact with the computer so that users can constantly refine and view data so as to pursue various ways of thinking; users can view figures from a multiple of perspectives and can also choose different viewing angles, etc.

(Cheng et al. 2002) focused on the development of a GIS-based decision support system to assist construction engineers in monitoring and controlling excavation conditions. The primary features of the system are as follows:

- Development of a knowledge base for planning the layout of instruments according to design requirements, site characteristics, or instrument capabilities;
- Provision of a quality control checking list for instrument installations;
- Collection and transmission of measured data to the job site's office by using automated transmission technology;

- Analysis of the collected data and diagnosis of the possible causes of adverse conditions.

(Cheng and Ko 2002) described the development of a decision support system for the safe monitoring of hillsides. When applying fuzzy set theory, the system analyzes the collected data and identifies slope stability, locating areas of adverse conditions requiring attention and lists their possible causes.

The research project "Life Cycle Cost Analysis and Decision Support System" (see 2) presents a framework for a Decision Support System (DSS) that articulates a specific approach for forecasting the maintenance and repair budget as well as providing a methodology for prioritizing maintenance activities. DSS considers the influence of the past maintenance history of building systems and components, as well factors that contribute to their deterioration, and will assist facility managers in making informed decisions on the repair and maintenance costs and the implication of deferring maintenance.

(Nobe et. al. 1999) summarize the findings of a previous research, which examined the area of decision support as it relates to the generation of real estate conceptual cost estimates. The purpose of this research was to evaluate a prototype development cost estimating decision support system for use in the pre-development planning stage of real estate development.

Neural network technology has been successfully applied to a wide range of real-world construction applications, such as (see 5): cost management, quality control, signal processing, credit rating, sales forecasting, modeling, quality control, portfolio management, targeted marketing and education, finance, etc.

Many e-commerce systems for construction material procurement have emerged in the past few years. These systems have become the e-trading marketplaces for manufacturers, suppliers, agents and purchasers for buying and selling construction materials. Owners of these E-commerce systems vary from manufacturers, suppliers, agent companies, or even application service providers (Kong et al. 2004).

According to (Kong et al. 2004), construction material information in current e-commerce systems is isolated without interaction with one other and purchasers usually cannot find all the required information (material information, supplier information, manufacturer information, buyer information, agent information, and market information such as the amount of sales of different materials, buying patterns, buyers' comments on materials and services, etc.) and material from one system or another. (Kong et al. 2004) expected that by enabling information sharing between different parties in the construction material procurement process one can facilitate improved information communication and coordination, have better strategic planning and decision making, and rapidly and flexibly supply chain management.

On analysing Web-based systems (information systems, neural networks, expert and decision support systems, e-commerce) applied world wide from decision support aspect, it is possible to notice in construction that they supply full-scale information needful for decision support.

However, most of all neural networks, decision support and expert systems are seeking to find how to make the most economic construction decisions, and most of all these decisions are intended only for economic objectives. Construction alternatives under evaluation have to be evaluated not only from the economic position, but take into consideration qualitative, technical, technological, comfort and other factors as well. Construction alternative solutions allow for a more rational and realistic assessment of economic, technical, technological conditions and traditions and for more satisfaction of different customer requirements. Therefore, application of multiple criteria analysis methods and multiple criteria decision support systems can increase the efficiency of construction process.

2. Web-based Decision Support Systems as Created by Vilnius Gediminas Technical University

Many internet based systems are processing and submitting only economic information for decisions. Alternatives under consideration have to be evaluated not only from the economic position, but take into consideration qualitative, technical and other characteristics. Therefore, the efficiency of e-business and Web-based systems may be increased by applying multiple criteria decision support systems.

Web-based decision support systems created by authors in cooperation with their associates are described in various publications:

- Multiple Criteria On-Line Export Decision Support System (Kaklauskas 2002a, 2002b).
- Multiple Criteria Decision Support Web-Based System for Facilities Management (Zavadskas 2002a, 2002b).
- Ethical Multiple Criteria Decision Support Web-Based System (Kaklauskas 2002c).
- Internet Based DSS for Real Estate (Kaklauskas 2002d, Zavadskas 2001).
- Multiple Criteria Decision Support On-Line System for Construction Products (Kaklauskas 2002e, Zavadskas 2002c), etc.

The above decision support systems comprise of the following constituent parts: a data (database and its management system), models (model base and its management system) and a user interface.

When creating the Web-based decision support systems the authors based their work on the following major principles and methods:

- Method of complex analysis. The use of a complex analysis makes it possible to carry out economic, technical, qualitative, technological, environmental, managerial and other kinds of optimisation throughout the life cycle of a project.
- Method of functional analysis. The expenditures associated with project functions are usually determined by taking into account the benefits of a function and the cost of its realization.
- Principle of cost-benefit ratio optimisation. Efforts are made to get maximum benefit (economic, qualitative, environmental and social, legal, etc.) at minimum project's life cycle expenses, i.e. to optimise the cost-benefit ratio.
- Principle of interrelation of various sciences. The problem of cost-benefit ratio may be successfully solved only when the achievements of various sciences, such as management. economics, law, engineering, technology, ethics, aesthetics and psychology, etc. are used.
- Methods of multi-variant design and multiple criteria analysis. These methods allow us to take into consideration the quantitative and qualitative factors, as well as cutting the price of the project and better satisfying the needs of all interested parties.
- Principle of close interrelation between project's efficiency and interested parties and their aims.

Presentation of information in databases may be in conceptual (digital, textual, graphical, photographic, video) and quantitative forms.

Conceptual information means a conceptual description of alternatives, the criteria and ways of determining their values and weight. Conceptual information is needed to make more complete and accurate analysis of the alternatives considered. In this way, the above DSS enable the

decision maker to receive conceptual and quantitative information on alternatives from a database and a model-base allowing him/her to analyze the above factors and form an efficient solution.

Quantitative information presented involves criteria systems and subsystems, units of measurement, values and initial weight fully defining the variants provided. Quantitative information of alternatives is submitted in the form of grouped decision-making matrix, where the columns mean n alternatives under analysis, and rows include quantitative information.

The databases were developed providing a multiple criteria analysis of alternatives from economical, legislative, infrastructure, social, qualitative, technical, technological and other perspectives. This information is provided in a user-oriented way. To design the structure of a database and perform its completion, storage, editing, navigation, searching, and browsing, a database management system was used in this research.

Then the brief study of authors above developed (construction and facilities management) Web-based DSS follows.

2.1 Multiple criteria decision support on-line system for construction products

Today there are a great number of directories and electronic commerce systems, in the world related to construction products. Some of the well known Web-sites are: www.needproducts.com, www.4specs.com, www.buildscape.com, www.commerce.net and www.sri.com.

This section deals with Multiple Criteria Decision Support On-Line System for Construction (OLSC) developed by authors with V.Trinkunas. At the present moment the developed OLSC allows the performance of the following functions:

1) Search of construction products. A consumer may perform a search of alternatives from catalogues of different suppliers and producers. This is possible since the forms of data submitted are standardized into specific levels. Such standardization creates conditions to use special intelligent agents who perform a search of the required construction products from various catalogues, and gather information about the products. One or several regions may limit such search.

2) Finding out alternatives and making comparative tables. Consumers specify requirements and constraints and the System queries the information of specific construction products from a number of online vendors and returns a price-list and other characteristics that best meets the consumer's desire. The System performs the tedious, time-consuming, and repetitive tasks of searching databases, retrieving and filtering information, and delivering the information back to the user. Results of a search of specific construction products are submitted in tables, which may include direct links to a Web page of a supplier or producer. By submission such a display, of the multiple criteria comparisons can become more effectively supported. The results of the search of a concrete construction product are often provided in one table where one can sometimes find direct links to the Web page of the supplier or manufacturer.

3) Evaluation stages of alternatives (i.e. multiple criteria analysis of alternatives and selection of most efficient ones). While going through the purchasing decision process a customer must examine a large number of alternatives, each of which is surrounded by a considerable amount of information (price, discounts given, thermal insulation, sound insulation, rate of harm to human health of the products, aesthetic, weight, technical specifications, physical and moral longevity). Following on from the gathered information the priority and utility degree of alternatives is then calculated. The utility degree is directly proportional to the relative effect of

the values and weights of the criteria considered on the efficiency of the alternative. It helps consumers to decide what product best fits their requirements.

4) Analysis of interested parties (competitors, suppliers, contractors, etc.).

5) The after-purchase evaluation stage. A consumer evaluates the usefulness of the product in the after-purchase evaluation stage, etc.

2.2 Multiple criteria decision support Web-based system for facilities management

An analysis of multiple criteria decision support systems (see first section) and facilities management Web-based automation applications {calculators (see 1-5), analyzers (see 6-8), information systems (see 9-13), expert (see 14) and decision support (see 15-17) systems, etc.} that were developed by researchers from various countries assisted the authors to create one of their own Multiple Criteria Decision Support Web-Based System for Facilities Management (DSS-FM). The DSS-FM developed by authors with M.Gikys and A.Gulbinas is presented in this section. The following tables form the DSS-FM's database:

- Initial data tables. These contain information about the facilities (i.e. building, complexes, alternative facilities management organisations).

- Tables assessing facilities management solutions. These contain quantitative and conceptual information about alternative facilities management solutions: space management, administrative management, technical management and management of other services, complex facilities management, market, competitors, suppliers, contractors, renovation of walls, windows, roof, etc.

The tables assessing facilities management solutions are used as a basis for working out the matrices of decision-making. These matrices, along with the use of a model-base and models, make it possible to perform a multiple criteria analysis of alternative facilities management projects, resulting in the selection of the most beneficial variants. The efficiency of a facilities management variant is often determined by taking into account many factors. These factors include an account of the economic, aesthetic, technical, technological, management, space, comfort, legal, social and other factors. The model-base of a decision support system includes models that enable a decision-maker to do a comprehensive analysis of the available variants and to make a proper choice.

Below is a list of typical facilities management problems that were solved by users: multiple criteria analysis of space management, administrative management, technical management and management of other services alternatives; analysis of complex facilities management alternatives; analysis of interested parties (competitors, suppliers, contractors, etc.); determination of efficient loans; analysis and selection of rational refurbishment versions (e.g. roof, walls, windows, etc.); multiple criteria analysis and determination of the market value of a real estate (e.g. residential houses, commercial, office, warehousing, manufacturing and agricultural buildings, etc.), analysis and selection of a rational market, determination of efficient investment versions, etc.

3. Conclusions

The analysis of Web-based information systems, neural networks, expert and decision support systems, e-commerce used in construction, real estate and facility management that were developed by researchers from various countries assisted the authors to create of their own Web-based decision support systems. These systems differ from others in the use of new multiple criteria analysis methods as were developed by the authors. The databases were

developed providing a comprehensive assessment of alternative versions from the economic, technical, technological, infrastructure, qualitative, technological, legislative and other perspectives. Based on the above complex databases, the developed systems enable the users to analyse alternatives quantitatively (i.e. a system and subsystems of criteria, units of measure, values and weights) and conceptually (i.e. the text, formula, schemes, graphs, diagrams and videotapes). The efficiency of Web-based information systems, neural networks, expert and decision support systems, e-commerce may be increased by applying multiple criteria Web-based decision support systems.

4. Endnotes

1) "My facilities.com-comfort calculator", Available: http://www.automationcollege.com/myfacilities/tools/comfortcalculator.asp (Accessed: 2002, January)

2) "My facilities.com–lighting calculator", Available: http://www.automationcollege.com/myfacilities/tools/lightingcalculator.asp (Accessed: 2002, January)

3) "My facilities.com–ventilation calculator", Available: http://www.automationcollege.com/myfacilities/tools/ventilationcal.asp (Accessed: 2002, January)

4) "Homestore.com–Moving calculator", Available: http://www.homefair.com/homefair/calc/movecalcin.html?type=to (Accessed: 2002, January)

5) "Realtor.com – home inprovement calculator", Available: http://www.homestore.com/home_improvement/planning/calculators/default.asp?gate=realtor&source=1xxxotzzz9 (Accessed: 2001, October)

6) "QPS, Inc – property analyzer", Available :http://www.qualityplans.com/propertyanalyser.htm (Accessed: 2002, January)

7) "Analyzer USA, Inc – Analyzer USA", Available: http://www.analyser-usa.com/services.htm (Accessed: 2002, January)

8) "Expedition analyzer", Available: http://www.mass-systems.co.uk/analyser.htm (Accessed: 2002, January)

9) "Archibus, Inc–ARCHIBUS/FM information systems", Available: http://www.archibus.com/ (Accessed: 2001,October)

10) "FM: Systems, Inc"–FM:Interact and FM:Space information systems, Available: http://www.fmsystems.com, (Accessed: 2002, January)

11) "Peregrine Systems"–SPAN. Facility and Real Estate Management information systems http://sdweb02.peregrine.com/prgn_corp_ap/pstHomePage.cfm?mylanguage=en (Accessed: 2002, January)

12) "Drawbase information systems–Facilities management", Available: http://www.drawbase.com/ (Accessed: 2001, September)

13) "Aperture technologies, Inc.–Facility and real estate management", Available: http://www.aperture.com (Accessed: 2001, November)

14) "NECA" –Safety Expert Information systems, Available: http://www.vulcanpub.com/ecen/article.asp?article_id=59995 (Accessed: 2002, January)

15) "PCSWMM 2000-decision support system", Available: http://www.chi.on.ca/pcswmmdetails.html (Accessed: 2002, February)

16) "Visual DSS", Available: http://www.trueblue.com.au/vdss/ (Accessed: 2002, January)

17) "TATA Infotech Services–DSS", Available: http://www.tatainfotech.co.in/html/frames/ServiceFrame.html (Accessed: 2001, September)

5. References

Alshawi, M. and Ingirige B. (July 2003); Web-enabled project management: an emerging paradigm in construction. Automation in construction, Volume 12, Issue 4, Pages 349-364.

Chau, K. W., Cao, Y., Anson, M. and Zhang, J. (March 2003); Application of data warehouse and Decision Support System in construction management. Automation in construction, Volume 12, Issue 2, Pages 213-224.

Cheng, M. and Ko, C. (June 2002); Computer-aided decision support system for hillside safety monitoring. Automation in construction, Volume 11, Issue 4, Pages 453-466.

Cheng, M., Ko, C. and Chang, C. (June 2002); Computer-aided DSS for safety monitoring of geotechnical construction. Automation in construction, Volume 11, Issue 4, Pages 375-390.

Cheung, S., Suen, H. C. H. and Cheung, K. K. W. (May 2004); PPMS: a Web-based construction Project Performance Monitoring System. Automation in construction, Volume 13, Issue 3, Pages 361-376.

Cooper, T. (1995); A Knowledge-Based Instructional System for Claims Management. ASC Proceedings of the 31st Annual Conference Arizona State University, Pages 1-8. Tempe, Arizona, USA. <http://asceditor.unl.edu/archives/1995/cooper95.htm>.

Garner, S. and Mann, P. (September 2003); Interdisciplinarity: perceptions of the value of computer-supported collaborative work in design for the built environment. Automation in construction, Volume 12, Issue 5, Pages 495-499.

Hassan, T. M. and Mc Caffer, R. (June 2002); Vision of the large scale engineering construction industry in Europe. Automation in construction, Volume 11, Issue 4, Pages 421-437.

Husin, R. and Rafi, A. (September 2003); The impact of Internet-enabled computer-aided design in the construction industry. Automation in construction, Volume 12, Issue 5, Pages 509-513.

Kaklauskas, A., Zavadskas, E. K., Kaminskas, Z., Trinkūnas, V. and Kaklauskienė, J. (2002a); Efficiency Increase of Export On-Line Systems by Applying Multiple Criteria Decision Support Systems. Global E-Business in Knowledge-Based Economy: Management, Practice, and Opportunities. ICEB 2002, Pages 45-47. Taipei.

Kaklauskas, A., Zavadskas, E. K., Banaitis, A. and Trinkūnas, V. (2002b); Efficiency Increase of Export E-Commerce Systems by Applying Multiple Criteria DSS. ACS'02-SCM conference, Pages 589-597. Poland.

Kaklauskas, A. and Zavadskas, E. (2002c); Web-Based Decision Support. Technika. Vilnius, Lithuania.

Kaklauskas, A., Zavadskas, E. K., Gikys, M., Gulbinas, A. and Malienė, V. (2002d); Multiple criteria property e-business system. Construction innovation and global competitiveness. 10th International Symposium. Cincinnati, USA.

Kaklauskas, A., Zavadskas, E. K., Vainiunas, P. and Trinkūnas, V. (2002e); Construction Calculators, Analysers, Information systems, Experts and Decision Support Systems, their Integration and Applications. Second International Conference on Information Systems and Engineering and Construction. Conference Proceedings. Cocoa Beach, Florida, USA.

Kam, C. and Fischer, M. (January 2004); Capitalizing on early project decision-making opportunities to improve facility design, construction, and life-cycle performance – POP, PM4D, and decision dashboard approaches. Automation in construction, Volume 13, Issue 1, Pages 53-65.

Kong, S. C. W., Li, H., Hung, T. P. L., Shi, J. W. Z., Castro-Lacouture D. and Skibniewski, M. (March 2004); Enabling information sharing between E-commerce systems for construction material procurement. Automation in construction, Volume 13, Issue 2, Pages 261-276.

Liao, T. S., Wang, M. T. and Tserng, H. P. (October 2002); A framework of electronic tendering for government procurement: a lesson learned in Taiwan. Automation in construction, Volume 11, Issue 6, Pages 731-742.

Mc Caffer, R. and Hassan, T.M. (October 2000); Changes in large scale construction arising from ICT developments. In: Proceedings of the Millennium Conference on Construction Project Management, Pages 8–15. Hong Kong Institution of Engineers. Hong Kong.

Mohamed, S. and Stewart, R. A. (January 2003); An empirical investigation of users' perceptions of web-based communication on a construction project. Automation in construction, Volume 12, Issue 1, Pages 43-53.

Mohan, S. (1990); Expert systems application in construction management and engineering. Journal of construction engineering and management, Vol. 116, No.1, Pages 87-99.

Nobe, M. D., Sharkawy, M. A. and Nobe, M.C. (1999); Decision Support System Impact on Conceptual Cost Estimating and Risk Analysis. ASC Proceedings of the 35th Annual Conference. California Polytechnic State University, Pages 335-348. San Luis Obispo, California, USA. <http://asceditor.unl.edu/archives/1999/nobe99.htm>.

Rebolj, D. and Psunder, I. (1998); Product Model Based Quality Management System. The Life-Cycle of Construction IT Innovations. Proceedings of the CIB Working Commission W78 Information Technology in Construction, Pages 367-372. Royal Institute of Technology.

Sauter V. (1997); Decision Support Systems. John Wiley & Sons, Inc. New York, USA.

Shen, Q., Chung, J. K. H., Li, H. and Shen, L. (March 2004). A Group Support System for improving value management studies in construction. Automation in construction, Volume 13, Issue 2, Pages 209-224.

Wang, S. and Xie, J. (October 2002); Integrating Building Management System and facilities management on the Internet. Automation in construction, Volume 11, Issue 6, Pages 707-715.

Zavadskas, E. K., Kaklauskas, A., Lepkova, N., Gikys, M. and Banaitis, A. (2002a); Web-Based Simulation System for Facilities Management. ACS'02-SCM conference, Pages 515-522 Poland.

Zavadskas, E. K., Kaklauskas, A., Lepkova, N. and Gikys, M. (2002b); Multiple Criteria Decision Support On-Line System for Facilities Management. Facilities Management and Asset Maintenance. Applying and Extending the Global Knowledge Base, Pages 242-256. Glasgow, Scotland.

Zavadskas, E. K., Kaklauskas, A. and Vainiunas, P. (2001); Efficiency Increase of Real Estate E-Business Systems by Applying Multiple Criteria Decision Support Systems. Proceedings. Eighth European Real Estate Society Conference. Alicante.

Zavadskas, E. K., Kaklauskas, A. and Trinkunas, V. (2002c); Increase of efficiency of construction materials e-commerce systems applying intelligent agents. Construction innovation and global competitiveness. 10th International Symposium. Cincinnati, USA.