ANALYSIS OF THE LIFE CYCLE OF THE BUILT ENVIRONMENT

Monograph

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NOVA

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Research, theoretical and practical tasks of analysis of the life cycle of the built environment are revised in detail in this monograph; particular examples are presented as well. The concept of modern the life cycle of the built environment model is discussed. Theoretical and practical analyses, presented in the monograph, prove that intelligent decision support systems allow different stakeholders to reach higher results in work quality and productivity, organize a creative team of interested groups, which shall present more qualitative the life cycle of the built environment for the society. The reality is that most the life cycle of the built environment have both positive and negative features. The mission is to equilibrium the pros and cons, in order to optimize the life cycle of the built environment according to system of qualitative and quantitative criteria. The integration of intelligent decision support systems in the life cycle of the built environment is one of the most undoubtedly a step in the right direction. The edition presents knowledge on economic, legal, techno¬lo¬gi¬cal, technical, organizational, social, cultural, ethical, psychological, emotional, religious and environmental, as well as its management aspects, which are important for the development of the life cycle of the built environment. References to the most modern world scientific literature sources are presented in the monograph.
The monograph is prepared for the researchers, MSc and PhD students of civil engineering, construction management and real estate development. The book may be useful for other researchers, MSc and PhD students of economics, management and other specialities.

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INTRODUCTION

This monograph for multiple criteria analysis of the life cycle of the built environment reflects the author's experience since 1992 (Zavadskas, Kaklauskas, Bejder 1992[1], Zavadskas, Peldschus, Kaklauskas 1994[2]). It delivers us with exhaustive know-hows of authors and the up-to-date results of scholars about analysis of the life cycle of the built environment, targeting to inspire scientists to describe the forthcoming research directions.

Many authors analyzing only quantitative (energetic, technical, technological, economic, legal/regulatory, infrastructure, microclimatic, etc.) information of the life cycle process of the built environment. Options under consideration have to be evaluated not only from the quantitative position, but take into consideration qualitative (social, cultural, ethical, psychological, emotional, religious, ethnic and other) characteristics. Therefore, the efficiency of the life cycle process of the built environment may be increased by applying intelligent decision support systems. Numerous results of scientific investigations for the development of decision support systems developed by the monograph's author in conjunction with colleagues were announced in reviewed publications containing a citation index, the Web of Science Core Collection.

The research object of the monograph is the built environment life cycle, interested parties striving to attain their goals and micro, meso and macro environment making an integral whole. A comprehensive research into the above object required the development of new methods of project multiple criteria analysis enabling the user thoroughly assess its quantitative and qualitative (social, cultural, ethical, psychological, emotional, religious, ethnic and other) aspects. The diversity of the factors being assessed correspond to the various ways of presenting the data needed for decision making.

Various research of the life cycle of the built environment or its composite parts are being developed globally at the micro, meso and macro levels. The aforementioned research analyze their energetic, technical, technological, economic, legal/regulatory, innovative and microclimatic aspects. However, the social, cultural, ethical, psychological, emotional, religious and ethnic aspects of the life cycle of the built environment are generally paid no attention at all. It can be noticed that researchers from various countries engaged in the analysis of the life cycle of the built environment and its stages did not consider the research's object as was analyzed by the authors of the present investigation: the stakeholders involved in its life cycle as well as the micro, meso and macro environments, having a particular impact on it and making an integral whole.

Many decision support systems are processing and submitting only quantitative (energetic, technical, technological, economic, legal/regulatory, infrastructure, microclimatic, etc.) information for decisions. Options under consideration have to be evaluated not only from the quantitative position, but take into consideration qualitative (social, cultural, ethical, psychological, emotional, religious, ethnic and other) characteristics. Therefore, the efficiency

[1] Zavadskas, E. K., Kaklauskas, A., Bejder, E., (1991). *Multiple criteria analysis of projects*. Aalborg University. Aalborg: Aalborg Universitetscenter, p. 93.

[2] Zavadskas, E. K., Peldschus, F., Kaklauskas, A., (1994). Multiple criteria evaluation of projects in construction. Vilnius: Technika, p. 226.

of decision support systems may be increased by applying intelligent decision support systems.

The monograph will be of significant interest to academics, students and practitioners in the area of built environment, artificial intelligence and decision support systems. The book may be useful for other researchers, practicing engineers and managers, MSc and PhD students of economics, management and other specialities. Various stakeholders (clients, users, facilities and property managers, architects, designers, utilities engineers, economists, contractors, maintenance engineers, built environment material manufacturers, suppliers, contractors, finansing institutions, local government, state and state institutions) are involved in the life cycle of the built environment, trying to satisfy their needs and affecting its efficiency.

CONTENT

Chapter 1

1. THE LIFE CYCLE OF THE BUILT ENVIRONMENT AND ITS ANALYSIS

1.1. THE LIFE CYCLE OF A BUILDING

Every product or process goes through various phases or stages in its life. Each stage is composed of a number of activities. For industrial products, these stages can be broadly defined as material acquisition, manufacturing, use and maintenance, and end-of-life. In case of buildings, these stages are more fully delineated as (Bayer 2010):

- Material Manufacturing. This stage includes removal of raw material from the earth, transportation of these materials to the manufacturing location, manufacture of finished or intermediate materials, building product fabrication, and packaging and distribution of building products.
- Construction. This phase accounts for activities relating to actual construction of a building project. Typically, the following activities are included in this stage: transportation of materials and products to the project site, use of power tools and equipment during construction of the building, on-site fabrication, and energy used for site work. Permanent impacts to the building site also fall into this stage, though these impacts are fully considered in current LCA methods.
- Use and Maintenance. This stage refers to building operation, which includes energy consumption, water use, and environmental waste generation. It also takes into account the repair and replacement of building assemblies and systems. The transport and equipment use for repair and replacement is also considered in this stage.
- End of Life. This includes energy consumed and environmental waste produced due to building demolition and disposal of materials to landfills. The transport of waste building material is also included in this stage. Recycling and reuse activities related to demolition waste can also be included in this stage, depending on the availability of data (The return of significant high-value materials to the inventory through recycling can even be considered as a "negative impact").

Life cycle analysis examines the environmental impacts of a product by considering the major stages of a product's life, which are (Williams 2009):

- Raw material acquisition, which includes material harvesting and transportation to manufacturing sites;
- Processing, which involves materials processing and transportation to production sites;
- Manufacturing, which includes product manufacture and assembly, packaging, and transportation to final distribution;
- Product life, which includes energy and emissions during normal product life, required maintenance, and product reuse (refurbishing, material reuse); and

- Waste management/end of life, which includes recycling, landfills, liquid waste, gas emissions, etc.

Many studies on the building life cycle and its constituent parts have been performed worldwide. Some of them are briefly overviewed below.

Islam et al. (2015) describe life cycle assessment (LCA) and life cycle cost (LCC) analysis for typical Australian houses. It reports how different roofing (i.e. roof and ceiling) and floor designs affect the life cycle environmental impacts and cost (LCEI & LCC) over the various life stages of buildings (i.e. construction, operation, maintenance and final disposal). A case study house, called Base House, was modified with 8 alternative roofing and 4 floor designs to generate 12 variant houses. Specifically, one variable either from roofing or from floor was varied at a time while keeping wall and other components as in the Base House. The four life cycle environmental impacts were greenhouse gas (GHG) emission, cumulative energy demand (CED), water use, and solid waste generation, evaluated by LCA approach. The LCC was estimated based on life cycle costing approach. The results of LCEI & LCC of each house were evaluated on a whole of life cycle basis. A number of trades-off on the houses modified with roofing and floor designs were identified based on LCEI & LCC results. For the houses modified with roofing and floor designs, the high star skillion flat roofing and mixed floor houses were the attractive trades-off (Islam et al. 2015)).

Traditionally, building rating systems focused on, among others, energy used during operational stage. Recently, there is a strong push by these rating systems to include the life cycle energy use of buildings, particularly using Life Cycle Assessment (LCA), by offering credits that can be used to achieve higher certification levels. As LCA-based tools are evolving to meet this growing demand, it is important to include methods that also quantify the impact of energy being used by ecosystems that indirectly contribute to building life cycle energy use. Using a case-study building, this research provides an up-to-date comparison of energy-based indicators in tools for building assessment, including those that report both conventional life cycle energy and those that also include a wider systems boundary that captures energy use even further upstream. This research applies two existing LCA tools, namely, an economic input–output based model, Economic Input–Output LCA, and a process-based model, ATHENA® Impact Estimator, to estimate life cycle energy use in an example building. In order to extend the assessment to address energy use further upstream, this research also tests the Ecologically based LCA tool and an application of the emergy methodology. All of these tools are applied to the full service life of the building, i.e., all stages, namely, raw material formation, product, construction, use, and end-of-life; and their results are compared. Besides contrasting the use of energy-based indicators in building life cycle tools, this research uncovered major challenges that confront stakeholders in evaluating the built environments using LCA and similar approaches (Srinivasan et al. 2014).

Building construction consumes large amount of energy and material. Despite that, not much effort has been directed to examine the environmental impact of the construction phase, and this is particularly relevant to Hong Kong where the demand for building construction is ever increasing. In this study, a life cycle assessment (LCA) model namely the Environmental Model of Construction (EMoC) is developed to help decision-makers assess the environmental performance of building construction projects in Hong Kong from cradle to end of construction. The model provides comprehensive analyses of 18 environmental impact categories at the midpoint and endpoint levels. By inputting project specific data to EMoC, it can generate results of over two-hundred detailed processes. A public rental housing (PRH) project is fed into EMoC to examine the environmental performance of this type of projects. The results indicate that material is the major contributor to environmental impacts of the upstream stages of public housing construction. The carbon emissions of the studied project amount to 637 kg carbon dioxide equivalent per square meter of the gross floor area. Sensitivity analysis reveals that the environmental pollution can be significantly reduced by adopting a higher proportion of precast concrete components. The model should help support decision-makers identifying pragmatic solutions to reduce the environmental burden of a building project at the design, procurement and construction stages (Dong and Ng 2015).

The existing assessment tools for the life cycle carbon dioxide (LCCO2) have certain limitations in that users have to directly enter quantities of materials after the construction document phase and they are likely to find it difficult to formulate an optimal strategy to reduce CO2 emissions. Therefore, Global Environmental Model/Management-21P (GEM-21P) was developed for establishing a responsive and accurate system for suggesting methods for high energy efficiency in the planning phase. The objective of this study is to identify the requisites for an LCCO2 assessment program that is based on the technical elements of GEM-21P and that can be used in the schematic design phase. The life cycle of a building is divided into four stages: material production, construction, operation, and dismantlement/disposal. Further, the technical elements of GEM-21P are examined for assessing CO2 emissions in each of the stages (Baek et al. 2013). On the basis of the examination results, Baek et al. (2013) specify the requisites for a system that can assess, in the planning phase, the CO2 emitted from a building during its entire life.

The construction industry plays an important role in economic and social development, yet it is also a primary source of carbon emissions. Accordingly, owing to global climate change, energy conservation and carbon reduction have become critical issues in the construction industry. However, to date, no established theory has been proposed for the life-cycle carbon assessment of typical buildings in China. To address this, the present study proposes a detailed carbon emission inventory for buildings and divides the life-cycle of a typical building into three stages based on material and energy flow: the materialization stage, the operation stage, and the disposal stage. Additionally, an analytical framework and evaluation indices are established and the proposed methodology is applied to three case studies. The results demonstrate that residential and office buildings with a reinforced concrete block masonry structure could reduce carbon emissions by 38–112 kgCO2/m2 compared with either a reinforced concrete structure or a brick–concrete structure. Although the operation stage appears to contribute approximately 82–86% of the total emissions, the materialization stage is also of considerable importance in alleviating the present environmental pressure. Furthermore, possible measures to control carbon during the materialization stage are proposed and evaluated, including optimization design of building structures based on carbon emissions and the selection of insulation materials. Accordingly, this study provides a standard method for life-cycle carbon assessment of buildings, which will be critical for future low-carbon development (Zhang and Wang 2015).

In the framework of the European research project SB_Steel, a new life cycle methodology was developed aiming at the evaluation of life cycle impacts of buildings in the early stages of design. The proposed approach includes the estimation of the energy needs of the building during the operation stage. The early stages of design have the higher influence on the life cycle performance of the building; however, in these stages the availability of design data is often limited. Moreover, the estimation of energy needs is usually based on a performed-based approach, requiring a full definition of the building design. In the proposed methodology both problems are addressed by the macro-component approach, which provides a range of pre-defined construction solutions for the main components of a building, integrating life cycle embodied data. The approach enables a simplified estimation of the life cycle environmental performance of a building based on limited design data and provides aid for decision making in relation to the use of different materials and construction solutions aiming to lower life cycle impacts and lower energy consumption. The proposed approach is illustrated by a case-study, in which a residential building is assessed in the early stages. Finally, based in complete data, an advanced analysis of the building is performed in order to discuss the limitations of the developed approach (Gervásio et al. 2014).

The generation of significant amount of emissions from building construction process has led the promotion of controlling emissions as an important strategy for implementing sustainable development principles in the built environment. The emissions incurred during various stages include carbon dioxide, methane, nitrous oxide, sulphur dioxide, carbon monoxide, nitrogen oxide, non methane volatile organic compounds and particulate matter. This research conducts the life cycle assessment of the air emissions by using a particular case to examine emissions during construction stage. This study examines the emissions sources in each of the six stages and presents an inventory analysis method to measure air emissions to quantify the air emissions during the six life cycle stages for buildings. This method can help evaluating the impacts of implementing a building on the air quality, thus actions can be taken in early stages to reduce the environmental impacts during building life cycle. A case study is presented to demonstrate the practical application of the method with reference to the building practices for all life cycle stages in Hong Kong (Zhang et al. 2013).

Life Cycle Assessment (LCA) is a widely known methodology for “cradle to grave” investigation of the environmental impacts of products and technological lifecycles; however, this methodology has not been yet broadly used as an eco-design tool among the practitioners of the building sector (Asdrubali et al. 2013). Asdrubali et al. (2013) applied LCA on three conventional Italian buildings – a detached residential house, a multi-family and a multi-story office building. Our analysis includes all the life stages, from the production of the construction materials, to their transportation, assembling, lighting, appliances, cooling- and heating-usages during the operating phase, to the end of life of all the materials and components. Asdrubali et al. (2013) found that the operation phase has the greatest contribution to the total impact (from 77% of that of the detached house, up to 85% of the office building), whereas the impact of the construction phase ranges from about 14% (office building) to 21% (detached house). Asdrubali et al. (2013) carried further analyses to evaluate the influence of various optimizations of the buildings, e.g., more efficient envelopes and facilities, on the entire life cycle of the three buildings. In addition, Asdrubali et al. (2013) propose a methodological approach, which can contribute to the acceptance of LCA as a tool in the eco-friendly design of buildings, especially those buildings whose impact during the construction phase needs to be carefully checked, such as Nearly Zero Energy Buildings.

Domestic solar hot water systems (SHWS), which are used to reduce domestic energy use, represent one of the most widely known technologies of solar thermal applications. Taking into account the sizing of these systems during its design phase, it is also important to consider the effects on the environment of their use from a life cycle perspective. An evaluation method based on the Life Cycle Assessment (LCA) methodology is used in this paper to analyse the environmental implications of SHWS considering the production, use, maintenance and end-of-life stages. As a case study, 32 different types of SWHS to meet the hot water demand (HWD) of 2 dwellings and 2 hotels, located in the region of Aragón in Spain, are studied. The aim of the case study is to compare the environmental performance of SHWS and to select the best environmentally friendly solution while considering their energy pay-back time (Zambrana-Vasquez et al. 2015).

Residential buildings account for a large share of global carbon emission, while they play important roles in economic growth and social development at the same time. Therefore, the appropriate evolution routes of residential buildings need balancing their carbon emission and value creation, which is realized in this research by creating a new concept of life-cycle carbon efficiency and its relative methodology. First, the life-cycle carbon efficiency of a residential building is defined as the ratio of its life-cycle value to carbon emission, and the life-cycle of a residential building is divided into five stages, including construction materials preparation, building construction, building operation, building demolition, and construction & demolition wastes disposal. Second, the life-cycle carbon emission of a residential building is estimated through calculating the carbon emission at each stage based on its consumed energy and resources. Third, the product of the service life span of a residential building (in year), its building area (m2) and its storey height (m) is recommended to represent its life-cycle value, since this product is a physical measure and more useful to develop action plans to improve its performance. In the end, the proposed methodology is exemplified in estimating the life-cycle carbon efficiency of a five-storey brick-concrete residential building in Nanjing city (China) at its design phase. Possible measures to enhance the estimated carbon efficiency are further put forward, such as prolonging the service life span, enhancing 3R (reduce, reuse and recycle) principles of cement and rolled steel, saving electricity and natural gas at the stage of building operation (Li et al. 2013).

1.2. THE PHASES OF LIFE CYCLE ASSESSMENT

Two international standards, ISO 14040 and ISO 14044, describe an iterative four-stage or phased methodology framework for completing an LCA (Trusty 2009):

- Goal and Scope definition. An LCA starts with an explicit statement of the goal and scope of the study, which sets out the context of the study and explains how and to whom the results are to be communicated. This is a key step, and the ISO standards require that the goal and scope of an LCA be clearly defined and consistent with the intended application. The goal and scope document therefore includes technical details that guide subsequent work: the functional unit, which defines what precisely is being studied and quantifies the service delivered by the product system, providing a reference to which the inputs and outputs can be related; the system boundaries; any assumptions and limitations; the allocation methods used to partition the environmental load of a process when several products or functions share the same process; and the impact categories chosen.
- Life Cycle Inventory. Life Cycle Inventory (LCI) analysis involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land and water. To develop the inventory, a flow model of the technical system is constructed using data on inputs and outputs. The flow model is typically illustrated with a flow chart that

includes the activities that are going to be assessed in the relevant supply chain and gives a clear picture of the technical system boundaries. The input and output data needed for the construction of the model are collected for all activities within the system boundary, including from the supply chain (referred to as inputs from the techno-sphere). Inventory flows can number in the hundreds depending on the system boundary. For product LCAs at either the generic (i.e., representative industry averages) or brand-specific level, that data is typically collected through survey questionnaires. At an industry level, care has to be taken to ensure that questionnaires are completed by a representative sample of producers, leaning toward neither the best nor the worst, and fully representing any regional differences due to energy use, material sourcing or other factors. The questionnaires cover the full range of inputs and outputs, typically aiming to account for 99 percent of the mass of a product, 99 percent of the energy used in its production and any environmentally sensitive flows, even if they fall within the 1 percent level of inputs. However, industry people completing a questionnaire may have easier access to some types of data compared to others, depending on their situation. One area where data access is likely to be difficult is from the technosphere. National databases or data sets that come with LCA-practitioner tools, or that can be readily accessed, are the usual sources for that information. Care must then be taken to ensure that the secondary data source properly reflects regional or national conditions. Data from a European source, for example, may reflect quite different raw material sources, transportation modes and distances, energy forms used, and so on. Even within North America, or the United States for that matter, there can be significant regional differences and those should be properly reflected in the data.

- Life Cycle Impact assessment. Inventory analysis is followed by impact assessment. This phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results. Classical Life Cycle Impact assessment (LCIA) consists of the following mandatory elements: selection of impact categories, category indicators, and characterization models; the classification stage, where the inventory parameters are sorted and assigned to specific impact categories; and impact measurement, where the categorized LCI flows are characterized, using one of many possible LCIA methodologies, into common equivalence units that are then summed to provide an overall impact category total. In many LCAs, characterization concludes the LCIA analysis; this is also the last compulsory stage according to ISO 14044:2006. However, in addition to the above mandatory LCIA steps, other optional LCIA elements – normalization, grouping, and weighting – may be conducted depending on the goal and scope of the LCA study. In normalization, the results of the impact categories from the study are usually compared with the total impacts in the region of interest, the United States, for example. Grouping consists of sorting and possibly ranking the impact categories. During weighting, the different environmental impacts are weighted relative to each other so that they can then be summed to get a single number for the total environmental impact. ISO 14044:2006 generally advises against weighting, stating that “weighting, shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public.” This advice is often ignored, resulting in comparisons that can reflect a high degree of subjectivity due to weighting.

- Interpretation. The results from the inventory analysis and impact assessment are summarized during the interpretation phase. The outcome of the interpretation phase is a set of conclusions and recommendations for the study. According to ISO 14040:2006, the interpretation should include: identification of significant issues based on the results of the LCI and LCIA phases of an LCA; evaluation of the study considering completeness, sensitivity and consistency checks; and conclusions, limitations and recommendations. The working procedure of LCA is iterative. The iteration means that information gathered in a later stage can highlight effects in a former stage that may require further analysis. When this occurs, the former stage and the following stages have to be reworked taking into account the new information. At the end, the results and conclusions of the LCA must be completely and accurately reported to the intended audience. The data, methods, assumptions, limitations, and results must be transparent and presented in sufficient detail to allow interested parties to comprehend the complexities and trade-offs inherent in the LCA. The report must also allow the results and interpretation to be used in a manner consistent with the goals of the study. One continuing problem for LCA practitioners and entities promoting LCA is the limited understanding of the method by non-practitioners, and the corresponding problem of interpretation or, indeed, misinterpretation of results. Users of the results of studies are too frequently uninformed with regard to the appropriate and acceptable environmental impact measures, the sources of data, or even the relationship of data and tools to the ISO standards.

The LCA technique can be narrowed down to four main steps which address one or more of the product's life stages at a time (Williams 2009):

1. The definition and scope is determined along with information needs, data specificity, collection methods and data presentation.
2. The life cycle inventory (LCI) is completed through process diagrams, data collection, and evaluation of the data.
3. The life cycle impact assessment (LCIA) is determined with impact categories and their weights, as well as any subsequent results.
4. The final report should include significant data, data evaluation and interpretation, final conclusions, and recommendations.

European Commission (2010) offers a framework for life cycle assessment:

- The goal definition is decisive for all the other phases of the LCA (European Commission 2010):
    - The goal definition guides all the detailed aspects of the scope definition, which in turn sets the frame for the LCI work and LCIA work.
    - The quality control of the work is performed in view of the requirements that were derived from the goal of the work.
    - If the work goes beyond an LCI study, the final results of the LCA are evaluated and interpreted. Also this is to be done in close relation to the goal of the work.
- During the scope definition phase the object of the life cycle impact (LCI) and life cycle assessment (LCA) study (i.e. the exact product or other system(s) to be analysed) is identified and defined in detail. This shall be done in line with the goal

definition. Next and main part of the scope definition is to derive the requirements on methodology, quality, reporting, and review in accordance with the goal of the study, i.e. based on the reasons for the study, the decision-context, the intended applications, and the addressees of the results. When deriving the scope of an LCI/LCA study from the goal, the following scope items shall be clearly described and/or defined:

- The type(s) of the deliverable(s) of the life cycle impact LCI/LCA study, in line with the intend application(s).
- The system or process that is studied and its function(s), functional unit, and reference flow(s).
- LCI modelling framework and handling of multifunctional processes and products.
- System boundaries, completeness requirements, and related cut-off rules.
- Life cycle impact assessment (LCIA) impact categories to be covered and selection of specific LCIA methods to be applied as well as - if included - normalisation data and weighting set.
- Other LCI data quality requirements regarding technological, geographical and time-related representativeness and appropriateness.
- Types, quality and sources of required data and information.
- Special requirements for comparisons between systems.
- Identifying critical review needs.
- Planning reporting of the results.

- During the life cycle inventory phase the actual data collection and modelling of the system (e.g. product) is to be done. This is to be done in line with the goal definition and meeting the requirements derived in the scope phase. The LCI results are the input to the subsequent LCIA phase. The results of the LCI work also provide feedback to the scope phase as initial scope settings often needs adjustments. Typically, the LCI phase requires the highest efforts and resources of an LCA: for data collection, acquisition, and modelling. The inventory phase involves the collection of the required data for:
    - Flows to and from processes:
        - Elementary flows (such as resources and emissions but also other interventions with the ecosphere such as land use),
        - Product flows (i.e. goods and services both as "product" of a process and as input/consumables) that link the analysed process with other processes, and
        - Waste flows (both wastewater and solid/liquid wastes) that need to be linked with waste management processes to ensure a complete modelling of the related efforts and environmental impacts.
    - Other information identified in the scope definition as relevant for the analysed system. This includes statistical data (e.g. market mix data), process and product characteristics (e.g. functions and functional units), and all other data and information, except for those directly related to impact assessment.
- Life Cycle Impact assessment (LCIA) is the phase in an LCA where the inputs and outputs of elementary flows that have been collected and reported in the inventory

are translated into impact indicator results related to human health, natural environment, and resource depletion. It is important to note that LCA and the impact assessment is analysing the potential environmental impacts that are caused by interventions that cross the border between technosphere and ecosphere and act on the natural environment and humans, often only after fate and exposure steps. The results of LCIA should be seen as environmentally relevant impact potential indicators, rather than predictions of actual environmental effects. LCA and LCIA are equally distinct from risk based, substance specific instruments. LCIA is composed of mandatory and optional steps:

  - Based on classification and characterisation of the individual elementary flows, which is usually done by LCIA experts that provide complete sets of LCIA methods for use by LCA practitioners, the LCIA results are calculated by multiplying the individual inventory data of the LCI results with the characterisation factors.
  - In a subsequent, optional step, the LCIA results can be multiplied with normalisation factors that represent the overall inventory of a reference (e.g. a whole country or an average citizen), obtaining dimensionless, normalised LCIA results.
  - In a second optional step these normalised LCIA results can be multiplied by a set of weighting factors, that indicate the different relevance that the different impact categories (midpoint level related weighting) or areas-of-protection (endpoint level related weighting) may have, obtaining normalised and weighted LCIA results that can be summed up to a single-value overall impact indicator.

- The Interpretation phase of an LCA has two main purposes that fundamentally differ: during the iterative steps of the LCA and for all kinds of deliverables, the interpretation phase serves to steer the work towards improving the Life Cycle Inventory model to meet the needs derived from the study goal; if the iterative steps of the LCA have resulted in the final LCI model and results, and especially for comparative LCA studies (while partly also applicable to other types of studies), the interpretation phase serves to derive robust conclusions and - often - recommendations. In life cycle interpretation, the results of the life cycle assessment are appraised in order to answer questions posed in the goal definition. The interpretation relates to the intended applications of the LCI/LCA study and is used to develop recommendations. The life cycle interpretation is the phase of the LCA where the results of the other phases are hence considered collectively and analysed in the light of the achieved accuracy, completeness and precision of the applied data, and the assumptions, which have been made throughout the LCI/LCA study. If aimed at (e.g. in case of a comparative study or a weak-point analysis), the final outcome of the interpretation should be conclusions or recommendations, which are to respect the intentions and restrictions of the goal and scope definition of the LCI/LCA study. This especially relates to the appropriateness of the functional unit and the system boundaries, as well as the achieved overall data quality, in relation to the goal. The interpretation should present the results of the LCA in an understandable way and help the user of the LCI/LCA study appraise the robustness of the conclusions and understand any potential limitations of the LCI/LCA study (European Commission 2010).

- Reporting. The results and conclusions of the LCI/LCA study shall be completely and accurately reported without bias to the intended audience. The results, data, methods, assumptions and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA. The report shall also allow the results and interpretation to be used in a manner consistent with the goals of the study. The needs of different audiences should be recognized and addressed when presenting or disseminating the study. Target audiences can be internal, (defined) external, or public, and technical or non-technical. These audiences can include companies, trade associations, government agencies, environmental groups, scientific/technical communities, and other non-government organizations, as well as the general public / consumers. Communication in the public domain is especially critical because the risks of misinterpretation are heightened when LCA-derived information is provided to audiences not familiar with the complexity of the methodology and related limitations that may apply. Good reporting of LCI and LCA studies provides the relevant project details, the process followed, approaches and methods applied, and results produced. This is essential to ensure reproducibility of the results and to provide the required information to reviewers to judge the quality of the results and appropriateness of conclusions and recommendations (if included).

In order to complete a successful LCA, detailed steps should be followed. The following checklist of information needs is useful when completing a LCA, since it helps an analyst know what type of information to look for and include. The list is not all-inclusive, but it does offer a starting point and is meant to inspire more detailed questions in order to complete a successful and thorough LCA (Williams 2009):

- Step 1: Create a definition and scope. When developing the scope and definition, consider the following topics:
    - Goal of this life cycle analysis (aailable data and possible data gaps, current legislation, currently available designs of the product/process, environmental impacts of current processes and products, product or process comparison options)
    - Audience (end consumer, stakeholders, policy makers, manufacturers, processors, recyclers, refurbishers)
    - Production and process information (product usage, product or process materials, identifying the least environmentally damaging product/process, inclusion of all necessary data, possible result impacts (uncertainties, assumptions), possible process or product changes)
    - Data accuracy (type of data, specificity and required amount of data, system boundaries (regional, national, or global), availability of current data, need for additional data collection, data discrepancies, data equivalency for comparisons)
    - Result interpretation and display (data comparison of products and process steps, units for comparison, required data for accurate results, data clarity, amount of data to display, data gaps)

  - Ground rules (assumptions, quality assurance, in line with goal and scope, ground rule implementation during data collection).
- Step 2: Complete a life cycle inventory (LCI). LCI is a process which quantifies all inputs and outputs of a process or product. Consider inputs like energy and raw materials. The process outputs include any material emissions to the environment, such as water, air, and solid waste. An LCI is also a way to develop a comparison of the environmental impacts and potential improvements of the process or product. LCIs can be useful for finding improvement opportunities, supporting design changes, and developing new regulations.
- Step 3: Complete the life cycle impact assessment (LCIA). The LCIA is a way to interpret how the processes and products in the LCA impact human health and the environment. The LCIA addresses concepts like the depletion of resources and possible health effects by analyzing the stressors found within the manufacturing process or product. Therefore, the LCIA considers the LCI data but gives it a more meaningful basis for comparison. In order to calculate the environmental and health impacts of a product or process, science-based characterization factors are utilized.
- Step 4: Interpret the results and make recommendations. Life cycle assessments are performed in order to systematically examine a product's life cycle, from raw materials to the final disposal of products. LCAs utilize information from LCI and LCIA to draw conclusions on processes and make appropriate recommendations from their results.

1.3. INTEGRATION OF LCA IN GREEN BUILDING RATING SYSTEMS

Whole building assessment systems like BRE Environmental Assessment Method (BREEAM; used in the UK), Green Globes (Canada and USA), and Leadership in Energy and Environmental Design (LEED; USA) rightly place considerable emphasis on the selection of green materials or products as an important aspect of sustainability. Building design teams are clearly concerned about this topic, but are increasingly aware of the time and resources needed for, and the uncertainties associated with, the search for reliable information (Trusty 2010a).

There are several ways that LCA could be introduced in rating systems, ranging in level of effort from fairly easy to relatively onerous (Trusty 2009):

1. Educational credits — if you use LCA, you get points irrespective of the results or use of the results in the design process;
2. Credits that encourage manufacturers to implement LCA by giving points for the use of products that are accompanied by proof of an LCA or that have an LCA-based ISO Type III label (an Environmental Product Declaration);
3. Credits for selecting pre-studied building assemblies that are highly ranked in terms of LCA results; and
4. Credits for exceeding LCA benchmark levels at the whole building level.

The first two methods have appeal for obvious reasons, but they are not likely to advance the cause of environmental performance to a very great extent. One problem is that LCAs can vary in quality for a variety of reasons, and simply completing even a high-quality LCA has little value if the results are not brought to bear on decisions. The third method has the merit that the LCA work can be done in the background, without requiring the use of specialized tools by design teams, but there is the problem of maintaining a sufficiently rich menu of design options from which teams can choose. The fourth method puts the focus strictly on environmental performance measures, leaving it entirely up to the design team to decide how to achieve the required results. Moreover, this approach would allow embodied effects to be combined with operational effects so that realistic trade-offs between material use and operating performance would be handled automatically. Indeed, LCA performance criteria could entirely replace many of the credits in the operating energy section of a rating system. However, this method also puts an onus on rating system developers to study enough buildings to establish performance benchmarks at the whole building level (Trusty 2009).

Many studies on the integration of LCA in green building rating systems have been performed worldwide. Some of them are briefly overviewed below.

Life cycle assessment (LCA) is a powerful tool to help sustainable design move towards a performance basis. An analytical method for estimating lifetime environmental impacts due to a product or process, LCA can help building designers quantify and validate their sustainability decisions. LCA quantifies the resource consumption and emissions due to constructing, using and disposing of a building, and then estimates the resulting impacts to the environment. LCA can be a useful new skill set and a good match for existing skills in design offices or sustainability consultancies. Plus, the recent release of LEED v4 with a new three-point credit for LCA and a new 33-point LCA credit in Green Globes are creating an incentive to learn LCA. And it's easier than it sounds (O'Connor and Bowick 2014).

Four green building programs in North America now have incentives for designers to use LCA to minimize the environmental footprint of new construction. The whole-building LCA provisions in LEED®, Green Globes®, the International Green Construction Code and the California green code ask designers to show that the final design has lower LCA impacts than a "reference" building. The intention here is that the reference building is an early iteration of the building design; performing LCA during early design creates a performance benchmark to beat, helping inform decisions as they evolve from conceptual design through design development. The green building programs want to reward design decisions that ultimately lead to lower LCA impacts (O'Connor and Bowick 2014).

Common practice building regulations are not that far reaching as are required by sustainable building assessment schemes. At the same time, regulations over a number of indicators can be onerous even without sustainable considerations (Seinre et al. 2014). Seinre et al. (2014) compared indicators and their levels from Estonian regulations against LEED and BREEAM requirements. The differences and gaps between the best practice requirements were shown with the focus on the indoor climate, energy and transport categories of the sustainability assessment schemes. Five best practice buildings were positioned in LEED and BREEAM certification levels. The results show that the current regulations of indoor climate and energy indicators in Estonia form a solid base for high scores in these schemes. Indoor climate class I and class A energy performance achieved at least the second highest certification level in LEED and BREEAM. Thus, the gap between the current best practice and the highest score of a sustainable building scheme was not large. To make the comparison possible in a systematic way the Estonian building sustainability assessment scheme indicators were proposed and their compliance with LEED and BREEAM was quantified (Seinre et al. 2014).

The purpose of this study is to apply life cycle assessment (LCA) methodology for green building certification in South Korea. The method of environmental assessment in the field of building materials was examined using United States' LEED, and the United Kingdom's BREEAM building certification systems. Life cycle data and assessment methods were established on major categories of materials thorough theoretical consideration on life cycle assessment. Building materials, assembly methods, and building use considerations were used to develop an assessment model to evaluate the environmental performance of a building. Numeric values for use in the developed model were established for concrete, rebar, gypsum board, steel, cement brick, glass, and insulation materials to potentially reduce greenhouse gas (GHG) emissions by 95% or more. An assessment method and LCA database were established. The model will be used to show that the choice of building materials can affect the GHG emissions during the construction phase of a building (Gong et al. 2015).

Ferreira et al. (2014) compare the criteria weighting process of four sustainable construction assessment tools: LiderA, SB ToolPT, Code for Sustainable Homes, and LEED for Homes 2012. The actual weights are first discussed in conceptual and numerical terms by benchmarking those in the four tools that have similar criteria. These four tools are then used to assess the sustainability level of a Portuguese residential project, the Palácio dos Condes de Murça (Counts of Murça Palace), to discuss the real influence of the weighting process on the final classification, in a real situation. Based on these two approaches, the work debates how the weighting process can contribute to the quest for passive net zero-energy buildings (NZEBs) (Ferreira et al. 2014). Ferreira et al. (2014) intend to ascertain whether the energy criteria's weighting is singling out bioclimatic principles as a priority for NZEBs. In conclusion, this work showed that the four different weighting sets are robust and generally similar. In fact, the case study analysis demonstrated that the final class is equivalent in the various tools. However, as far as energy is concerned, it is not clear whether the tools are pointing to passive design as the primary answer to achieve efficient NZEBs (Ferreira et al. 2014).

There is now a substantial body of evidence suggesting that climate change is occurring as a result of human activities. Bottom-up approaches have been encouraged to enhance sustainability agenda. Assessment methods have been developed to ensure an incessant decrease in carbon footprint of buildings. It has long been discussed that many of such assessment methods systematically lack dedicated criteria to assess building beyond its physical boundaries (O'Malley et al. 2014). O'Malley et al. (2014) focuses on Code for Sustainable Homes (CSH) and attempts to map it against LEED and CASBEE with an aim to encourage assessment beyond physical boundaries of a building and into its immediate context and surrounding environment. A critical review of the latest literature was conducted to establish the general concepts and principles behind the CSH's method of assessment in comparison with CASBEE and LEED. Following this, differences, positive and negative aspects of the three assessment method were established through in-depth review of their official documents and by cross-referencing the different components, methodologies and assessment criteria of each. This led to a comparative analysis using a critical evaluation of findings of The Building Environmental Quality Evaluation for Sustainability through Time (BEQUEST), The European Sustainable Development Strategy (ESDS) and The Freiburg Charter (FC). Expert interviews were conducted to consolidate the findings of this study (O'Malley et al. 2014). This added technical in-depth expert opinions to the preliminary findings of O’Malley et al. (2014) research and helped pave the way for providing practical suggestions for possible areas of improvement for the CSH.

Sustainability Assessment Systems (SAS) quantify the value of sustainability the buildings have become popular not only in planning a sustainable real estate development, but also in scientific research. The main weakness of these tools is a lack of financial aspects, such as Building life-cycle cost analysis (LCC); inflexibility, complexity, unsound weights of the system and natural resources and environmental evaluation criteria dominance over the social and economic problems. Given this background, recommended Lithuania's recreational building sustainability assessment system is a modified BREEAM system which is complemented with social and economic criteria. Their importance is determined using analytic hierarchy process (AHP) method. Estimated Druskininkai “Snow Arena” sustainability's value according to the modified system is 66.54%, which equals “very good” result. According to BREEAM New Construction 2011 scheme 57.80% score was reached, which also corresponded to “very good” rating. The higher rating in the modified system was due to increased social and economic criteria weights, as well as the fact that the arena well satisfied these criteria (Raslanas et al. 2013).

Buildings are key target of policies that aim at promoting environmentally sustainable development. Amongst policy instruments that address environmental burdens incurred by buildings, labelling and certification schemes are arguably the most cost-effective. Since the first building environmental assessment scheme was launched in the 1990's, similar schemes have emerged in about 30 countries. These are mainly domestic schemes tailored to suit local contexts. Whilst most of these schemes take a voluntary, market driven approach, some have become a part of mandatory building approval requirements, though different certification schemes may co-exist in some regimes (Lee 2013). Benchmarking the strengths and characteristics of different schemes has been advocated. In this connection, Lee (2013) provides a comprehensive review and comparison of the issues and metrics of five representative assessment schemes, namely, BREEAM, LEED, CASBEE, BEAM Plus and the Chinese scheme ESGB. Comparison of these five schemes shows that BREEAM and LEED are the most comprehensive. A two-phase certification method is adopted in LEED, CASBEE and BEAM Plus, which is considered preferable. Statistical analysis also reveals that there is a moderate degree of agreement amongst the five schemes on weights and ranks of weights allocated to five key assessment aspects. Through comparison, the weighting coefficients adopted by ESGB were found the most representative. Strengths and characteristics of the five schemes have been identified for reference of policy makers in developing their domestic schemes (Lee 2013).

Berardi (2015) focuses on sustainability assessments in the built environment through multicriterion rating systems. Recent interpretations of the concepts of sustainability, assessment, and sustainability assessment in the built environment are discussed before reviewing existing assessment systems. In particular, Berardi (2015) focuses on sustainability assessments of buildings, communities, and cities. A comparison between assessment systems at these different scales of the built environment is performed before focusing on the need of cross-scale evaluations. In particular, rating systems that have tools for the different scales such as BREEAM, LEED, and CASBEE are presented and compared. Each one of these systems bases the assessment on the summation of rates for different criteria, often selected in a no transparent way. The comparison shows that previous systems often accept weak sustainability when natural resources may be substituted by other priorities. Moreover, missing assessment criteria are indicated mainly within the social and economic dimensions of sustainability. Berardi (2015) also shows that the dynamicity of the built environment suggests considering the sustainability assessment systems as tools to monitor the evolution of the built environment as well as citizens' lives. Finally, Berardi (2015) shows the importance of adapting sustainability goals and indicators of each specific situation (Berardi 2015).

BREEAM, LEED, CASBEE, BEAM Plus and Chinese ESGB have been formally launched at different stages in the last twenty years. How well the certified and rated buildings compare with each other is always an interest of building designers and policy-makers (Lee 2012). Lee (2012) presents a side-by-side comparison of energy use assessments of the five schemes. The comparisons are on the assessment method and criteria, default parameters, trade-offs allowed, performance scales, approved simulation tools, performance indicators and assessment results. Comparison results showed that all the five schemes are based on relative performance. It was also found that despite the variations in default parameters among the five schemes, market positions of certified buildings are comparable. LEED was found to be the most stringent and relatively less flexible in its assessment criteria. Nonetheless, the energy cost budget approach, adopted only by LEED, is able to fulfil emission reduction and cost saving objectives on the condition that a "fuel neutral" approach should be adopted (Lee 2012).

Following expansion in the field of environmental assessment methods, existing methods cannot be applied to all regions for a number of reasons, one of which is regional variation (Alyami and Rezgui 2012). Alyami and Rezgui (2012) investigate the most important and globally widespread environmental assessment methods: BREEAM, LEED, SBTool, and CASBEE. It identifies areas of convergence and distinction in order to enable the consolidation of environmental criteria into new potential schemes. As well as considered a starting point for the procedure of consensus-based process, it also provides a generic model for the development of an effective environmental assessment method intended for the establishment of environmental assessment method suited to Saudi Arabia (Alyami and Rezgui 2012).

Scientific evidence suggests important discrepancies between simulated and real energy performance of buildings. This is exacerbated in developing countries, such as Saudi Arabia, by the reliance on leading international building environmental and sustainability assessment schemes (e.g. BREEAM and LEED) (Alyami et al. 2013). Alyami et al. (2013) propose to test the overarching hypothesis that the leading international environmental and sustainability assessment schemes are not adapted to the Saudi built environment, with a focus on the residential sector. The research aims to (a) test the applicability of international leading schemes such as BREEAM and LEED for the assessment of Saudi's built environment, and (b) identify applicable building assessment categories and criteria for Saudi's built environment. As building assessment methods involve multi-dimensional criteria, a consensus based approach is used to conduct the research. Hence, the Delphi technique is selected and conducted in three successive consultation rounds involving world leading experts in the domain of environmental and sustainable assessment schemes, as well as professionals and highly-informed local experts from academia, government and industry. The results reveal that international assessment schemes are not fully applicable to the Saudi built environment, as reflected in the development of a new building environmental and sustainability assessment scheme (Alyami et al. 2013).

The purpose of this study is to construct a database of sustainable building technologies considering the performance of greenhouse gas (GHG) emissions reductions. Through analysis of various sustainable green building certifications such as G-SEED, LEED, BREEAM, and CASBEE, sustainable technology factor categories associated with GHG reduction technologies were derived. Environmental performance and economic characteristics according to the considered sustainable building technology was examined and a model was generated. This model will be used to determine the best sustainable technologies which will support optimum building design to reduce national GHG emissions in Korea, enhance energy efficiency and preserve natural resources (Park et al. 2015).

Green building assessment is currently being introduced into Serbian building practice. Since there is no Serbian certification system which could support building assessment, and especially lighting design evaluation, this research analyzes and compares the lighting design criteria of three international certification systems, LEED, BREEAM and CASBEE. Specific requirements for each considered criterion, as well as the grading structure and stringency of these systems, are also analyzed. Based on the conclusions of these analyses, a new set of criteria, some of which are original, are offered in order to be incorporated into the future Serbian certification system. Taking into account that the structure of the future system is unknown, the basic applied principle was simplicity for application and, therefore, a single requirement is defined for each criterion. Finally, a hierarchy within the new set of criteria is established for both indoor and outdoor lighting. Mandatory criteria are selected first, while the remaining criteria are divided into two groups based on their relevance. Although predominantly intended for the improvement of Serbian building practice, the proposed set of assessment criteria is general and can be used throughout the world (Stankovic et al. 2014).

Seinre et al. (2014) evaluated the weighting factors of five building sustainability assessment scheme categories – productivity, energy, water, materials and transport – to be used in Estonia. The method was based on environmental and economic assessment of available design options relevant for each category and transferring all impacts to euros through energy and carbon prices and productivity costs. The productivity category received the highest weighting, 89 or 70% share of the total impact with indoor climate reference class III and class II, respectively. This shows that the productivity effects are not enough recognized in current codes. To assign meaningful weightings for other categories the share of productivity was limited to 50%. The final weightings obtained with Estonian input data were 50% for productivity, 26% for energy, 21% for location, 2% for building materials and 1% for water efficiency. Obtained weighting factors for Estonia conflict quite remarkably with the weights of most well-known building sustainability assessment schemes, BREEAM and LEED, showing the importance of local conditions. Results denote that specific CO2 emissions of energy sources change the importance of categories in a considerable manner. All findings in this study show that local context should be considered when designing a building sustainability assessment scheme (Seinre et al. 2014).

The purpose of this research is to contribute to a better understanding of the concept of green building assessment tool and its role for achieving sustainable development through developing an effective green building rating system for residential units in Jordan in terms of the dimensions through which sustainable development tools are being produced and according to the local context. Developing such system is becoming necessary in the Developing World because of the considerable environmental, social and economical problems. Jordan as one of these countries is in need for this system, especially with poor resources and inefficient use. Therefore, this research studied international green building assessment tools such as such as LEED, CASBEE, BREEAM, GBTool, and others. Then defined new assessment items respecting the local conditions of Jordan and discussed them with (60) various stakeholders; 50% of them were experts of sustainable development. After selecting the assessment items they were weighted using the AHP method. The outcome of the research was a suggested green building assessment tool (SABA Green Building Rating System) – computer based program – that suits the Jordanian context in terms of environmental, social and economical perspectives (Ali and Al Nsairat 2009).

For a sustainable building, the use of energy always concerns clients and designers. In this respect, the UK national regulation on energy performance and 'carbon' accounting has asked for a greater consistency of construction information to achieve the CO2 emission target. Therefore, Clients and Industry should work closely together in developing plans to make the transition to low carbon buildings feasible in order to meet the CO2 emission target. In this context, Building Information Modelling (BIM) can play a key role in addition to its capability to create more homogenisation of the construction supply-chain. For the energy analysis packages, the designers usually receive feedback on their design; such as how much energy the building will use, what are the anticipated CO2 emissions and if the building will pass performance criteria (such as: LEED or BREEAM). BIM applications for energy analysis have been introduced to improve this process but mostly at the design stage. However, for the post-occupancy stage, there is a need for a proper and systematic methodology to monitor the behaviour of buildings and to make critical decisions to ensure that the energy criteria of the design are really met in practice (Motawa and Carter 2013). Motawa and Carter (2013) introduce a conceptual BIM-based model that can improve the post-occupancy evaluation process and meet the industry requirements for sustainable buildings.

Requirements of energy capacity, human occupancy and specialist conditions required are now far more demanding than in the past and, with it, the challenges and opportunities to control the amounts of energy and materials required – this is not the end of the line on the debate for energy, efficiency and selective use of the earth's resources, but just the beginning (Davda et al. 2010)! Davda et al. (2010) review facilities that require close control of temperature, relative humidity, air cleanliness and room pressure regimes to control the environment where manufacturing, research and quality control activities can be undertaken on a repeatable basis. Generally these facilities are required to comply with good manufacturing practice (GMP) and good laboratory practice (GLP). It discusses facilities generally found in pharmaceutical, life sciences, biotechnical, electronics technology, food, aerospace, universities and institutional or government departments. Subsequent discussions lead to choices of components and materials for energy efficiency and strategies for assessing the benefits or not of incorporating environmentally aware and/or energy reducing opportunities into such buildings, whilst taking into account the specialist nature of the facility and the specific energy requirements. This leads to categorising the selection of materials relating to payback periods, a review on BREEAM and future trends (Davda et al. 2010).

1.4. A MODEL FOR COMPLEX ANALYSIS OF THE LIFE CYCLE OF THE BUILT ENVIRONMENT WITH AN EMPHASIS ON BUILDING LIFE CYCLE ASSESSMENT

1.4.1. Life cycle of the built environment quantitative and qualitative analyses aspects

The Model for a complex analysis of the life cycle of the built environment was developed with the goal of integrating the energetic, environmental, health, technical, technological, economic, legal/regulatory, innovative, microclimatic, social, cultural, ethical, psychological, religious, ethnic and other aspects of the process over the life of the built environment (see Fig. 1.1).

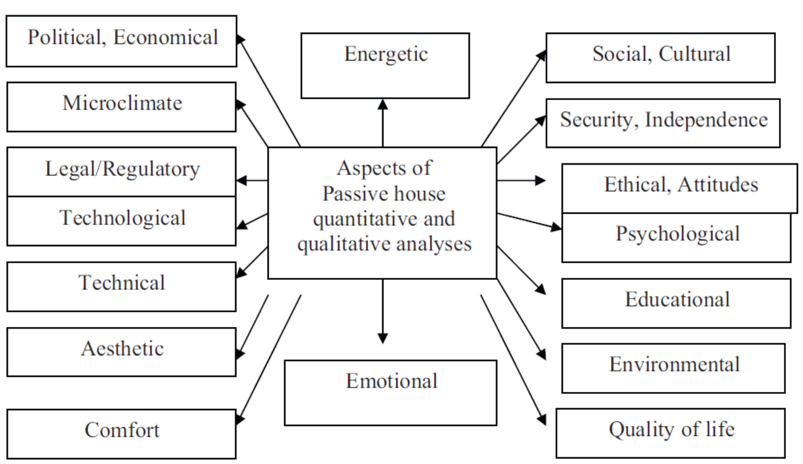

Figure 1.1. Life cycle of the built environment quantitative and qualitative analyses aspects

Some aspects of the above qualitative analyses are described below.

Todorović (2012) reviews crucial role of building performance simulation (BPS) – dynamic analysis of the inextricable linkage of building's energy demand for HVAC and other building's technical systems sustainable energy supply and renewable energy sources (RES) availability to reach building's zero energy status. Reviewed are BPS advances in buildings energy efficiency optimization, solar, geothermal and other renewable energy sources integrated implementation, as well as hybridization and mixed distributed energy generation, co- and tri-generation for building's greening and sustainable neighborhoods, settlements, as well as "high performance" Zero Energy Cities Planning. Stressed has been that it is impossible to reach sustainability without harmonious interdisciplinary interacting, without balance between materiality and spirituality, science and art, technology development and cultural and other human values improvement, without ethics of sustainability (Todorović 2012).

Norman (1998) suggests that information from a retrospective LCA is useful for making decisions that aim at avoiding life cycles and subsystems that have an undesirable environmental impact. In other words, the retrospective LCA is valid to an (hypothetical) audience that wants to avoid such product systems and subsystems. Likewise, the prospective LCA is valid if the audience considers changes of a product system ‘‘good’’ if consequences for the total environment are good. Apparently, one reason why different people do not agree on what type of LCA is the most relevant can be differences in the view on what constitutes an environmentally good action. To illuminate these differences and investigate whether a correct view in this matter can be identified, Norman (1998) turns to normative moral philosophy, or normative ethics. This is the area within moral philosophy that deals with the question of what kinds of actions are good or right in general (Norman 1998).

It is relevant to base this decision on information from a retrospective LCA if the ethical rule is to avoid being associated with systems that have undesirable environmental impacts. When such a rule is adopted without reference to its consequences, this is a special case of deontological rule ethics. However, the rule can be expected to have good consequences, since it is reasonable to assume that it will give rise to systems with preferable environmental impacts. In other words, the rule can also be a special case of teleological rule ethics. If an individual action should be assessed according to its particular consequences, it is appropriate to base decisions on information from a prospective LCA, since such a study is designed to describe the environmental consequences of a change. In other words, the choice of a prospective LCA methodology is valid from the perspective of teleological situation ethics. There is no doubt that retrospective and prospective LCAs result in different type of information (Ekvall et al. 2005). Ekvall et al. (2005) illustrates that these two types of information are related to different views – connected to different theories of normative moral philosophy - on the characteristics of a good action. A prospective LCA methodology is valid from the perspective of teleological situation ethics. It is also effective for assessing or generating rules in teleological rule ethics. On the other hand, retrospective LCA methodology is valid for special cases of teleological and deontological rule ethics, where the rule is to avoid being associated with systems with an undesirable environmental impact (Ekvall et al. 2005).

Environmental performance is measured in terms of a wide range of potential effects, such as fossil fuel depletion, global warming potential, stratospheric ozone depletion, and acidification. All of these measures are indicators of the environmental loadings that can result from the manufacture, use, and disposal of a product. These “mid-point” indicators are linked to, but do not directly address, the ultimate human or ecosystem health effects, a much more difficult and uncertain task. However, they do provide good measures of environmental performance, since reducing any of these effects benefits the environment. In LCA, the effects associated with making, transporting, using, and disposing of products are referred to as “embodied effects,” where the word embodied is not meant to imply true physical embodiment, but rather attribution or allocation in an accounting sense. In the building community, the tendency is to refer primarily to “embodied energy,” but there is a wide range of embodied effects, as noted above. The energy required to operate a building over its life overshadows the energy attributed to the materials used in its construction and maintenance. However, other embodied effects generated during the resource extraction and manufacturing stages greatly outweigh any such releases associated with building operations (Trusty 2009).

The LCA allows analysts to determine and analyze the technological, economical, environmental, and social aspects of a product or process necessary to manage the complete life cycle. With this quantitative data, desired changes can be justified with respect to the cost and environmental impacts of a product or process (Williams 2009).

A building project can be regarded as sustainable only when all the various dimensions of sustainability (environmental, economic, social, and cultural) are dealt with. Nearly all building sustainability rating and certification methods are based in local regulations or standards, and in local conventional building solutions. The weight of each parameter and indicator in the evaluation is predefined according to local socio-cultural, environmental, and economic contexts, and therefore most of the approaches developed so far can only have reflexes at local or regional scales. Despite the fact that it is easy to quantify functional parameters, the manner in which each parameter influences the functional performance, and therefore the sustainability, is not consensual. This assessment involves subjective ratings and depends, above all, on the type of solution and on the evaluator's social-cultural and economic status. The Portuguese building technologies and the indoor environmental quality standards are quite different from most European countries. The first situation is mainly related to economic and socio-cultural constraints, while the second is related to the mild climate (Bragança et al. 2010).

Although social, economic, and cultural indicators are of substantial importance to the concept of sustainable building, this concept is usually related to environmental characteristics. Any building level assessment method is complex and involves contradictory aspects. Moreover, emphasizing qualitative criteria only increases confusion. R&D and standardization are thus concentrated to transparency and usability of the environmental methods. Other directions of research aim at performance-based design and methods to take regional and cultural aspects into account. In this research, the perspectives of the sustainability assessment of a whole building are presented, based on a state of the art, feasibility study on performance analysis and the development of an extended life-cycle assessment for buildings. Using various tools, and based on the case studies of building sustainability assessment, environmental indicators were often shown to be of lesser importance than the other, soft ones (Bragança et al. 2010).

Hauschild et al. (2005) review the current state of Life Cycle Assessment (LCA) introducing the central elements of the methodology and the latest developments in assessment of the environmental, economic and social impacts along the product chain. The central role of LCA in Integrated Product Policy (IPP) is substantiated describing the different tools of the IPP. The role of industry in meeting the sustainability challenge to our societies is discussed, and it is concluded that industry must include not only the eco-efficiency but also the product's environmental justification and the company ethics in a life cycle perspective in order to become sustainable. In the outlook it is concluded that current drivers seem insufficient to create a strong move of particularly the small and medium-sized enterprises in the direction of sustainability, and a need for stronger legislation and for education and attitude building among future citizens and engineers is identified.

The Waitakere NOW Home was Beacon's first live research project, designed and built to show that a sustainable house could be built now using materials and products available today. By using simple, proven designs and technologies in combination, the Waitakere NOW Home addressed the sustainability of the whole house including energy efficiency, water, indoor environment, waste and material selection. The home was extensively monitored, over a two year period, while tenanted by a young family. Data was collected on energy use, water use, rainwater collection, temperature, indoor air quality, and humidity and moisture levels. It has provided sound scientific proof of the benefits of living in a sustainable home. Social research captured the story of the tenants' experience and has shown a wide range of social, health and emotional benefits beyond the immediate financial and resource savings (Drysdale and Nebel 2009).

Research by Roger Ulrich consistently shows that passive viewing of nature through windows or even surrogate contact (through posters or videos) promotes positive moods and reduces stress. Similarly, research by Rachel Kaplan found that workers with window views of trees had a more positive outlook on life than those doing similar work but whose window looked out onto a parking lot. Her study also found that workers with the nature view had lower stress scores and were more satisfied with their jobs. In addition to the psychological and emotional benefits, connection to nature also provides mini mental breaks that may aid the ability to concentrate according to research by Stephen Kaplan. Terry Hartig and colleagues report similar results in a field experiment. People in their study who went for a walk in a predominantly natural setting performed better on several tasks requiring concentration than those who walked in a predominantly built setting or who quietly read a magazine indoors. In the absence of windows or other direct contact with nature, workers frequently decorate their walls with nature décor as was found in a study by Judith Heerwagen and Gordon Orians.

Strongly connected with the Life Cycle Assessment is an issue of the Life Cycle Costs. The LCC is used to help making decisions in all the phases of building's life. The LCC method is often thought to be difficult and complicated. Sometimes, the idea of carrying out the LCC analysis is given up because of too time-consuming approach and too big expanses. Nevertheless, in long-term thinking such an attitude is much stronger justified. Construction costs are only the beginning, and there should also be taken into consideration operation and management costs, or even special costs as for example taxes. Structures, bridges, and other buildings, are designed and built with intent for a long service life, many of them are meant to exist for over 50 or even 100 years. Such a attitude assumes that a significant attention is paid on the performance of an engineered system over its life span. oreover, there are some trends that are becoming more and more common (Zimoch 2012):

- minimizing energy use through changes in building technologies,
- changing fashion affects on more flexible buildings with replaceable fixtures and fittings,
- attitude to recycling, reuse and deconstruction of buildings,
- requirements for change of use, adaptation and conversion during life of buildings,
- increase in technology used in households.

According to Thinkstep, the desire for healthier buildings, more sustainable products, and beautiful, engaging spaces now permeates design culture.

As example, next is follows facilities management quantitative and qualitative analyses aspects.

Facilities management is a stage of the lifecycle of the built environment. It is briefly discussed below.

Scholars from different countries understand facilities management as an object differently quite frequently. For example, German scientists hold the opinion that the environment, infrastructure, buildings and the equipment, installations and furnishings within comprise the facilities management object. The main objective of facilities management is the supply of a set of services that a client needs encompassing rational planning and implementing operations in the buildings, adapting to ever-changing needs and pursuing formation of good conditions for the development of effective organizational operations. This way the value of the real estate also increases. Such a perspective does not establish any strict boundaries between the objects and their functions of facilities management and of real estate management. There is a belief in the Netherlands that the main purpose of a facilities manager for assuring the effective operations of an organization is to determine the needed set of services and quality and capacity considerations and to provide them by the agreed time for the agreed price. Meanwhile a real estate manager endeavors to gain profits from the building under exploitation. An analogical opinion has taken hold in Great Britain as well.

Facilities management consists of four composite parts: the supervision of space (of the facilities), administration, technical and other services. A deliberation of these composite parts follows.

Space supervision is understood as the supply of services attempting to form effective organizational work condition. Space supervision encompasses:

- Space planning and adaptation to ever-changing needs
- Equipment (cleaning, loading, warehousing), installations (machine tools, software), furnishings, analysis of inventory requirements and supply
- Services supply provided for the building, facilities, property security, reception area duty, telephone links, mail, central archives, couriers, reproduction services (copying machines, scanners), cleaning (floors, windows, rooftop), snow removal, supervision of the environment, care of building plants, environmental protection, business travel handling, organization and maintenance of parking spaces, public food provisions organization (breakfast, lunch, number of coffee vending machines including the determination and layout of sites), trash removal and other sorts of services.

Administration supervision encompasses:

- Building use control: budget handling and optimization, coordination of provided services, contract obligations monitoring, building transferring and receiving, supervision of the building and parking spaces, documents handling, announcements handling, image improvements.
- Accounting of leases, supplemental income, taxes and the like.
- Transactions supervision: transactions drafting, insurance agreements drafting.
- Personnel acceptance and subcontractor control.
- Supervision of leases and leases with options to purchase (developing a concept and its practical implementation).

Technical supervision (control) encompasses:

- Systems and installations exploitation, inspectorate, maintenance; emergency services involving gas, water supply, sewage, heating, water heating, ventilation, electricity, lightening protection, elevators, transporters and warehouses, automated doors and gates; building and facilities security; measurements and control; cable and network communications; laundry and dry cleaning; medical and laboratory equipment and other equipment and systems.
- Building constructions and exploitation of elements, inspectorate and maintenance.
- Energy supervision.

Other services supervision encompasses special services according to client requests: computers and their networks, Internet connection, introduction and supervision of information technologies, building modeling, consultations on energy savings and such

Space, administration, technical and other services can be supervised in the following stages: consulting, planning, supplying, implementing, supervising and controlling.

The variety of facilities management will be illustrated next applying the example of workplaces supervision in Europe.

The understanding of a workplace has been changing as information technologies and communications develop. Some of the personnel spend time in several places for various reasons. An effective workplace is frequently not at the traditional site of an employer. It can also be found at a client's place, at home, while traveling and other places. For example, a good deal of work can be performed while traveling by train by using a laptop computer containing an Internet link. The work that can be done includes calculations, estimates, report writing, order placement and transmitting information by Internet to a client or to one's colleagues. A workplace has been named in exotic ways: satellite, non-territorial, virtual, "hotel-type" workplace and the like. Facilities management faces numerous new assignments requiring resolution as understandings about job sits change.

The features of a workplace largely depend on the type of work the organization does. Nonetheless, the comfortableness and effectiveness of workplaces at organizations engaged in similar areas in various European countries differ. These differences depend on more than merely the economic situation of an organization. In the opinion of Van Meel (2000), factors other than simply the operations of an organization influence the differences in the workplace in Europe: market differences, the organizational view regarding real estate, the architectural view regarding design, laws and culture. Broader analyses of these factors follow.

Economical buildings with strong exploitation features enjoy demand in the real estate market in the United Kingdom. There is less attention paid to consumer needs in such cases. Therefore economically rational buildings with average work conditions are built frequently. An analogical albeit often inferior situation is found in Eastern Europe. Meanwhile buildings are built at a higher standard with well-equipped workplaces in markets, where consumers predominate, such as in the Netherlands and Germany.

Organizational viewpoints on real estate as a means to increase the effectiveness of the company's operations differ in different countries. Attention in Eastern and Central Europe is primarily directed towards the fundamental operations of an organization, not towards rationalizing facilities management. Consequently business faces additional problems. Numerous Western European organizations assess real estate not only by price but also from the perspective of increasing the effectiveness of their organizations.

Whether the architectural view of a building is as a piece of art or as a discussion on the utilization of the designated unit depends on the effectiveness of the workplace. A variety of architectural traditions predominates in Europe; thus these and other architectural views differ. In France, for one example, architecture closely relates with art. Meanwhile Scandinavian architects traditionally pay more attention to the practical needs of consumers and try to create an environment that is comfortable and encourages effective work. Often it happens that more of the implemented ideas come from the architects while they are designing a building, not from the organization that is about to inhabit the building.

Although the European Union seeks harmonized workplaces by its laws, such implementation has not been fully successful to its finality. The differing climatic, economic, social security and other conditions preclude that. The valid laws of the Netherlands and Germany, as example, raise high demands on space, convenience and comfortableness. However, in the United Kingdom, it is economically unsound to have such laws, because they would require tremendous investments to reorganize workplaces. This is partly due to the relationships between employers and employees. To illustrate, labor unions are very influential in Scandinavian countries, where it took lengthy negotiations to achieve compliance of their workplaces with European standards. However, in the United Kingdom and Southern Europe, labor unions are less influential, because here company managements make the primary decisions. This causes workplaces to be of a rather poor quality. Still, in this case, the positive feature is that workplace innovations can be implemented quickly, without long-lasting negotiations.

Every organization retains certain values, which are upheld in daily activities. Such an influence on the effectiveness of workplaces will be briefly illustrated next by employing examples of employee selection, planning and layout of workplaces.

As mentioned previously, a workplace does not have to be at the job site. All that’s needed is a powerful laptop computer and a link into Internet, and one can work while travelling to see clients. There are many more such "virtual" employees in Northern Europe than there are in Southern Europe. The explanation for this is the common culture and the level of trust in one another. These "virtual" employees can only appear where there is a sufficient level of trust. Therefore, to provide an example, there are many less “virtual” employees in France and Italy than there are in Germany and the Netherlands.

The planning of workplaces is also not the same throughout Europe. In the United Kingdom, they are installed in huge, common work areas, whereas, in Northern Europe, they are in separate rooms. The employees of Northern European organizations actively participate in reaching decisions that affect them. Thus the workplaces in these countries are of a higher standard, generally consisting of separate rooms. Separate rooms provide employees with greater personal freedom and control over their environments. Meanwhile the employees in the United Kingdom usually work in cramped facilities without any windows or natural ventilation.

The size and quality of a workplace often depends on the position its employee holds in the organization. A person at a higher position has a more spacious workplace with a better view of the environment and greater privacy. The lower level workers are found either in smaller rooms in one, large common area with poorer conditions of comfort. This is the custom in France, Italy, Germany, Sweden and Denmark, whereas, in the Netherlands, the workplace depends more on the kinds of activities being executed, rather than by the position held.

The assortment of services provided by facilities management expands as time passes. Meanwhile clients raise greater demands for the building and its environment as a singular system, and laws raise greater demands for health and environmental protection. Generating more effective conditions for a company’s operations and improving the quality of work conditions are important factors, increasing the competitiveness of a company, which is vitally important for battling in an area with ever-growing competition.

The effort to resolve issues stemming from the building industry requires information and experience in management, economics, technology and psychology. Only a "hybrid" manager who is a qualified manager, economist, technologist and psychologist can fully understand the unfolding problems and find effective decisions for resolving them. The ability to interact and gain needed information is one of the most important qualities of a manager. Effective feedback assures an organization of always knowing consumer needs and the levels of their satisfaction, along with new wants that arise consequently. This assists in guaranteeing the supply of the required quality and prices at full capacity on a timely basis at the desired site of delivery.

Many organizations understand that their human resources are among the most important factors for effective organizational activities. The effort to attract highly qualified specialists requires not only paying them suitably high salaries but also providing them with comfortable work condition.

The effectiveness of organizations providing facilities management services can be evaluated from different perspectives. Various stakeholders assess organizational objectives, duties, operations and their final results from their own reference points. Such groups include clients, the personnel, stockholders, creditors, suppliers, the media and other means for mass information, municipalities and the like. The evaluations of such stakeholders do not always coincide. This is entirely understandable, because different stakeholders assess the effectiveness of the organization's operations by factors of greatest concern to themselves, resulting in different criteria systems for the evaluation. Organizational effectiveness can be described as having good relationships internally as well as with other stakeholders. An organization must have the ability to improve quality and increase capacity, expand the assortment of supplied services, augment the relationship between benefit and price, lower risk and adapt to its external, ever-changing environments involving the economy, laws, politics and the society. The most advanced organizations consider facilities management a composite part of the process of seeking increased competitiveness as they restructure their companies.

All the stages of a building's life cycle are interrelated. Therefore facilities management specialists must interact with stakeholders over the entire life cycle of a building.

Facilities management is pushed by all the aforementioned reasons and other trends to become a more complex and dynamic organism. Therefore its complexity and expenses rise. On the other hand, the indicators of such an organization's operations, such as the income to expense ratio, for one, tend to improve, along with the effectiveness of the workplaces and the production process and the like.

Obviously every specific organization does not require all the aforementioned services. The requirements for assortment, capacity and quality can be established by questioning clients based on the experience of other organizations providing similar services. The assortment, capacity and quality of services depend on the needs of the organization, its financial capabilities and most importantly – on its prices and abilities to increase the effectiveness of its organizational operations. Such a case can be resolved as a multicriteria assignment: the variations of possible alternative services are compiled, and the most rational is selected according to a certain system of criteria.

It is not always clear who can supply various services more rationally: the organization internally or one or several external organizations working jointly. An assessment of the effectiveness of alternative provided services by organizations is accomplished by a price comparison of their provided services either per square meter or price per year. A rational variation can be selected by calculating these indicators as well as assessing other factors. Several questions should be answered before coming to a final decision regarding the services that the organization should provide internally. Does the organization internally have all the required technology, economic conditions, managerial knowledge, equipment and documents, which will be essential for providing services effectively? Will the internal organization care about the continual training of the personnel and about taking over its best practices? Will it exploit the latest technologies effectively? Generally organizations do not have required expertise internally. One of the advantages of external organizations is their ability to offer an enlargement or a reduction in assortment and capacity in consideration of existing needs.

1.4.2. Micro, meso and macro level environment

European Commission (2010) details the ISO 14044 provisions and differentiates them for the three main types of questions that are addressed with LCA studies:

- Micro-level decision support: Life cycle based decision support on micro-level, i.e. typically for questions related to specific products. “Micro-level decisions” are assumed to have limited and no structural consequences outside the decision-context, i.e. they are supposed not to change available production capacity. Micro-level decision support covers among others the LCA applications listed below:
  - Identification of Key Environmental Performance Indicators (KEPI) of a product group for Ecodesign / simplified LCA;
  - Weak point analysis of a specific product;
  - Detailed Ecodesign / Design-for-recycling;
  - Comparison of specific goods or services;
  - Benchmarking of specific products against the product group's average;
  - Development of life cycle based Type I Ecolabel criteria;
  - Development of the 'Carbon footprint', 'Primary energy consumption' or similar indicator for a specific product;
  - Greening the supply chain;
  - Providing quantitative life cycle data as annex to an Environmental Technology Verification for comparative use.
- Meso/macro-level decision support: Life cycle based decision support at a strategic level (e.g. raw materials strategies, technology scenarios, policy options). “Meso/macro-level decisions” are assumed to have structural consequences outside the decision-context, i.e. they are supposed to change available production capacity. Meso/macro-level decision support covers among others the LCA applications listed below:
  - Policy development: Forecasting & analysis of the environmental impact of pervasive technologies, raw material strategies, and related policy development;
  - Policy information: Identifying product groups with the largest environmental improvement potential;
  - Development of specific, average or generic unit process or LCI results data sets.
- Accounting: Purely descriptive documentation of the system's life cycle under analysis (e.g. a product, sector, or country), without being interested in any potential

additional consequences on other parts of the economy. Accounting may cover the LCA applications listed below:

- Monitoring environmental impacts of a nation, industry sector, product group, or product;
- Policy information: Basket-of-products (or -product groups) type studies;
- Policy information: Identifying product groups with the largest environmental impact;
- Corporate or site environmental reporting including indirect effects under Environmental Management Systems;
- Certified supply type studies or parts of the analysed system with fixed guarantees along the supply-chain.

The LCA methodology as it relates to the building industry can be pictured as operating at one of four levels: material, product, building, or industry (Bayer et al. 2010):

Material Level. At its core, process-based LCA is defined at the material level. In the United States, the primary source for information about the environmental impact of materials is the LCI (life cycle impacts) database managed by the National Renewable Energy Laboratory or NREL.

- Product Level. At the product level, an LCA is calculated as a collection of materials, which are assembled into a final (or intermediate) product. A quantity takeoff of the product is completed, and the emissions from each component of the products are summed. The product LCA of a heat pump would include the production of the pre-cursor materials—steel, copper, aluminum, plastics, refrigerants—plus emissions from galvanizing processes, painting, metal fabrication, welding, etc. Completion of the heat pump LCA might be made easier if the LCA of a particular component, say an electric motor, is already available.
- Building Level. Building LCA, or whole-building LCA, can be thought of as a product LCA writ large, where the product is the building. In this case, the architect can be the LCA expert, as the architect understands how the building is constructed, how building materials and products flow to the jobsite, and how the building is going to be operated over time. In North America, three tools exist to support the whole-building LCA process: Athena Eco-Calculator, BEES, and Athena Impact Estimator.
- Industry Level. At the building industry level, the Economic Input-Output (EIO) based LCA method is probably the best tool for completing an LCA. Instead of completing a process-based LCA of every building in the portfolio—not a realistic approach—an LCA at the building industry scale is completed by examining industrial production and economic output data. And so, for example, to characterize the environmental impact of the residential housing industry, surveys of homebuilders, housing start data, income of wood-products suppliers, property tax rolls, and construction employment data could be collected and analyzed to predict the amount of green-field land, non-renewable materials, and energy are directed into residential construction on a national or regional basis each year. In this way, an LCA of an entire segment of the AEC industry is created, but with little of the specificity found in process-based LCAs. The EIO LCA method has been used in the

building industry to quantify the impacts of cement and steel production, suburban sprawl and urban densification, and changes in land use, for example.

When performing a LCIA, it is important to consider how the results of the life cycle inventory affect the world around us. Below are several categories along with their associated impacts (Williams 2009):

- Global impacts
  - Global warming (polar melt, soil moisture loss, longer seasons, forest loss/change, wind and ocean pattern changes)
  - Ozone depletion (increased ultraviolet radiation)
  - Resource depletion (decreased resources for future generations
- Regional impacts
  - Photochemical smog (smog, decreased visibility, eye irritation, respiratory tract and lung irritation, and vegetation damage)
  - Acidification (building corrosion, water body acidification, vegetation and soil effects)
- Local impacts
  - Human health (increased morbidity and mortality)
  - Terrestrial toxicity (decreased production and biodiversity, decreased wildlife populations)
  - Aquatic toxicity (decreased aquatic plant and insect production, decreased biodiversity, decreased fish populations).
  - Rønning and Brekke (2014) discuss possibilities and limitations of life cycle assessment (LCA) in the building sector. Through standardisation, LCA has gained global support as a most important tool for furthering more environmentally friendly choices in the sector. However, there are several limitations of LCA at a macro level such as choice of unit of analysis and at a micro level related to methodological and practical matters. Overall and inherent possibilities and limitations in the steps of LCA analyses are scrutinised. The flexibility of the method gives LCA the power to inform decision makers and the public about the environmental performance of buildings and building products (Rønning and Brekke 2014).
  - Sustainability assessment is increasingly being viewed as an important tool to aid in the shift towards sustainable urban ecosystems. An urban ecosystem is a dynamic system and requires regular monitoring and assessment through a set of relevant indicators. An indicator is a parameter which provides information about the state of the environment by producing a quantitative value. Indicator-based sustainability assessment needs to be considered on all spatial scales to provide efficient information of urban ecosystem sustainability. The detailed data is necessary to assess environmental change in urban ecosystems at local scale and easily transfer this information to the national and global scales (Dizdaroglu 2015). Dizdaroglu (2015) proposes a set of key micro-level urban ecosystem indicators for monitoring the sustainability of residential developments. The proposed indicator framework measures the sustainability performance of urban ecosystem in 3 main categories including: natural environment, built

environment, and socio-economic environment which are made up of 9 sub-categories, consisting of 23 indicators. Dizdaroglu (2015) also describes theoretical foundations for the selection of each indicator with reference to the literature.

- Huppes and Ishikawa (2009) look at the compatibility between technological improvements at the micro-level and sustainability at the macro-level. The two main approaches to prevent environmental degradation are technological improvement and economic de-growth. How do we establish the sustainability of technological options? LCA-type analysis of the technology system, combined with economic cost analysis, offers a first integrated eco-efficiency score. However, such a technology analysis focuses on micro-level technology relations only, is usually too optimistic and ignores other constraints implied in a choice. Fitting more comprehensive knowledge into the sustainability evaluation of options requires a unifying systematic framework, which is worked out in the present research as a ten-step procedure. The integrative framework for empirical analysis is ultimately a comparative-static systems analysis at macro-level, not in a deterministic dynamic mode, which is impossible, but as a knowledge-fed scenario analysis. The analysis shows the change in society's overall eco-efficiency, combining total value creation with total environmental impacts. Possible domains of application include not only technology choices like those in eco-innovation, including changed consumption styles and volumes, but also changes in policies regarding technologies and markets, whether direct policy shifts or indirect changes through institutional adaptations. Ultimately, such a framework also allows culturally framed questions about the type of society we would like to live in, to be analysed in terms of their economic and environmental consequences (Huppes and Ishikawa 2009).

1.4.3. Model for a complex analysis of the life cycle of the built environment

A thorough built environment's life cycle (brief; design; raw material extraction, transport and processing; construction materials production and distribution; construction; use, repair and maintenance; demolition; disposal, reuse, or recycling) analysis is quite difficult to undertake, because a buildings and its environment are a complex system (technical, technological, economical, social, cultural, ecological, etc.), where all sub-systems influence the total efficiency performance and where the interdependence between sub-systems play a significant role.

In order to develop a high-quality built environment, it is necessary to take care of its efficiency from the brief to the end of service life, demolition; disposal, reuse, or recycling. The entire process must be planned and executed with consideration of goals aspired by participating stakeholders and micro, meso and macro level environment. In order to realize the above purposes an original Model of a Complex Analysis of the life cycle of the built environment (see Figure 1.2) was developed enabling to analyze life cycle of the built environment, the parties involved as well as its micro, meso and macro environment as one complete entity.

A Model was being developed step by step as follows (see Figure 1.2): a comprehensive quantitative and conceptual description of a research object; multivariant design of life cycle of the built environment; multple criteria analysis of the life cycle of the built environment; selection of the most rational version of life cycle of the built environment; development of rational micro, meso and macro level environment. The above Model will be now described in more detail.

For more comprehensive study of a research object and methods and ways of its assessment major constituent parts of the above object will be briefly analyzed. They are as follows: life cycle of the built environment, the parties involved and micro, meso and macro environment having a particular impact on it.

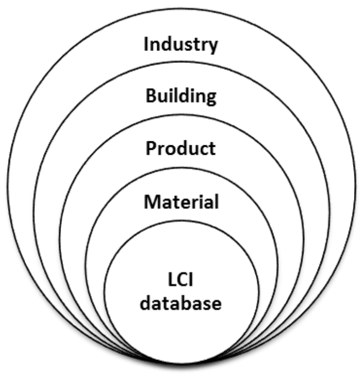

Figure 1.2. The entire process must be planned and executed with consideration of goals pursued by participating stakeholders at industry, building, product and material levels

Figure 1.2. The entire process must be planned and executed with consideration of goals aspired by participating stakeholders and industry, building, product and material levels

Life cycle of the built environment in turn consists of eight closely interrelated stages, such as brief; design; raw material extraction, transport and processing; construction materials production and distribution; construction; use, repair and maintenance; demolition; disposal, reuse, or recycling.

At the stage of brief the stakeholders state major requirements and limitations regarding the built environment in question.

Built environment is being designed with account of the stakeholders' needs as well as the possibilities of designers, constructors, suppliers, facilities managers, etc. At the design stage life cycle of the built environment multivariant design and multiple criteria analysis should be carried out taking into account the experience gained in realizing similar projects and seeking to harmonize the activities of various stakeholders. At a design stage, the strategy and means of its realization related to maintenance, facilities management, demolition, disposal, reuse, or recycling should be defined. These should ensure that maintenance, facilities management, demolition, disposal, reuse, or recycling problems are continually dealt with, starting from the brief stage. Since the rationality of various aspects of project often depends on a particular interested party only complex design of a life cycle process of built environment involving close collaboration of major stakeholders can lead to good results. Various parties are involved in the brief; design; raw material extraction, transport and processing; construction materials production and distribution; construction; use, repair and maintenance; demolition; disposal, reuse, or recycling of built environment, their cooperation taking rather long period of time.

Life cycle efficiency of built environment depend to a very great extent not only on the selected most rational processes and solutions, the interest level of the concerned parties involved in the project, expressed as the effectiveness of their participation in the process, but also on the micro, meso and macro level factors. As can be seen from Figure 1.2 the object of investigation is rather complicated involving not only life cycle of the built environment and its stages but also including stakeholders and micro, meso and macro environment factors having impact on the former. To select a rational alternative a new Model of a Complex Analysis of the life cycle of the built environment was developed. Based on this Model, professionals involved in design and realization of life cycle of the built environment can develop a lot of the alternative versions as well as assessing them and making the final choice of the most efficient variant. A practical realization of a Model is presented in Figure 1.4.

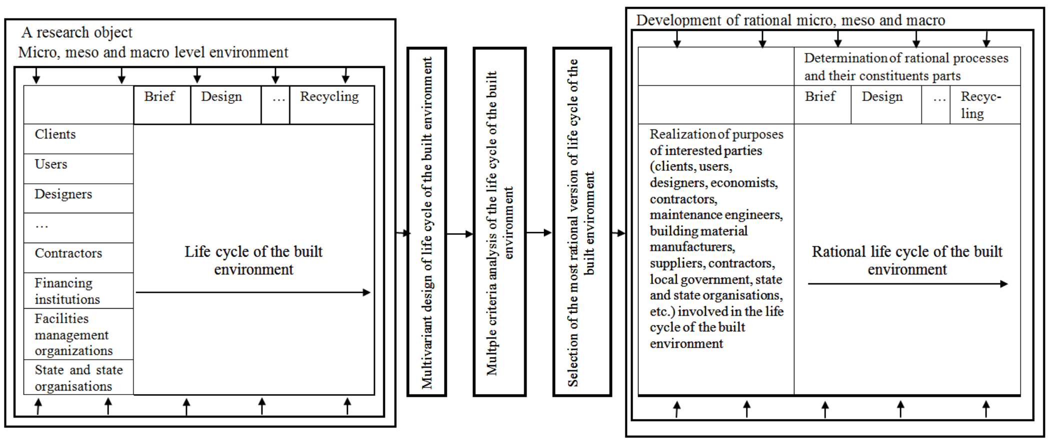

Figure 1.3. Model for a Complex Analysis of the Life Cycle of the Built Environment

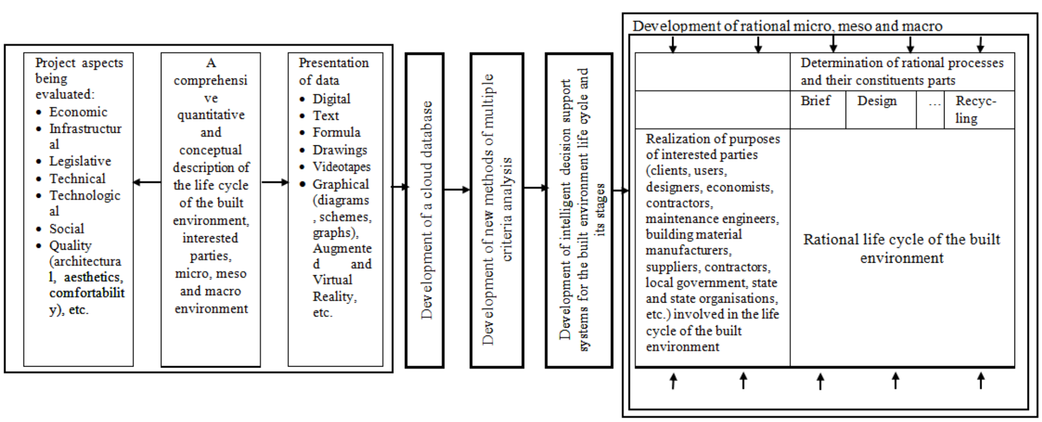

Figure 1.4. Practical realization of Model for a Complex Analysis of the Life Cycle of the Built Environment

1.4.4. Model for a complex analysis of the life cycle of the built environment

By modelling and forecasting future perspectives and trends of life cycle of the built environment, it is possible to get ready to respond to the variation of micro, meso and macro-level variables. Model for a Complex Analysis of the Life Cycle of the Built Environment suggested by this research is based on presumption that the built environment depends on many micro, meso and macro-level variables. The presence of specific micro, meso and macro-level variable factors right away imposes objective limitations for efficient life cycle of the built environment.

Therefore, basing oneself on main worldwide development trends and best practices, it is possible to issue recommendations on the increase of efficiency of life cycle of the built environment in specific country. When rational variable micro, meso and macro-level factors determine for specific country have been realized, they should create better and more favourable conditions for efficient realization of life cycle of the built environment would be created.

The research aim was to produce a Model for a Complex Analysis of the Life Cycle of the Built Environment in specific country by undertaking a complex analysis of micro, meso and macro-environment factors affecting it and to give recommendations on the increase of its competitive ability.

The research was performed by studying the main worldwide development trends and best practice, taking into consideration specific countries' history, development level, needs and traditions. Simulation was undertaken to provide insight into creating an effective environment for the life cycle of the built environment by choosing rational micro, meso and macrofactors. The most of stakeholders cannot correct or alter the micro, meso and macro-level variables, but they can go into the essence of their effect and take them into consideration when realizing various activities. Stakeholders, knowing the micro, meso and macro-level factors affecting the activities being realized, can organize their present and future activities more successfully.

To design and achieve effective built environment life cycle a complex analysis of its stages as well as stakeholders, their aims and potentialities is needed. The effect of micro, meso and macro environmental factors should also be taken into account.

Dozens of millions of built environment life cycle alternatives can be obtained. The diversity of solutions available contributes to more accurate evaluation of economical, technological, social, cultural, climatic and other conditions, risk exposure, as well as making the project cheaper and better satisfying different stakeholders requirements. This also leads to better satisfaction of the needs of all parties involved in the project design and realization.

Various stakeholders are involved in the life cycle of the built environment, trying to satisfy their needs and affecting its efficiency. The level of the efficiency of life cycle of the built environment depends on a number of variables, at three levels: micro, meso and macro level.

The problem is how to define an efficient built environment life cycle when a lot of various stakeholders are involved, the alternative project versions come to hundreds million and the efficiency changes with the alterations in the environment conditions and the constituent parts of the process in question. Moreover, the realization of some objectives seems more rational from the economic perspective thought from the other qualitative perspectives they have various significance. Therefore, it is considered that the efficiency of a sustainable built environment life cycle depends on the rationality of its stages as well as on the ability to satisfy the needs of the stakeholders and the rational character of micro, meso and macro environment conditions.

Formalized presentation of the research shows how changes in the micro, meso and macro environment and the extent to which the goals pursued by various stakeholders are satisfied cause corresponding changes in the value and utility degree of a sustainable built environment life cycle. With this in mind, it is possible to solve the problem of optimization concerning satisfaction of the needs at reasonable expenditures. This requires the analysis of built environment life cycle versions allowing to find an optimal combination of goals pursued and finances available.

The research object is a built environment life cycle, stakeholders striving to attain their goals and micro, meso and macro environment making an integral whole.

Model for a Complex Analysis of the Life Cycle of the Built Environment was developed with the goal of integrating different quantative and qualitative aspects of the process over the life of the built environment. This six-stage model is presented in brief heretofore:

Stage I. Comparative description of the life cycle of the built environment basing oneself on main worldwide development trends and best practices:

- Determining a system of criteria characterizing the efficiency of a life cycle of the built environment by employing relevant literature and expert methods.
- Describing, per this system of criteria, the present state of the life cycle of the built environment in countries under consideration in conceptual (textual, graphical, numerical, virtual and augmented reality and such) and quantitative forms.

Stage II. Comparison and contrast of the life cycle of the built environment in countries under consideration:

- Identifying the global development trends (general regularities) of the life cycle of the built environment.
- Identifying the differences in life cycle of the built environments in countries under consideration.
- Determining the pluses and minuses of these differences.
- Determining the best practice for the life cycle of the built environment in countries under consideration as per actual conditions.
- Estimating the deviation between the knowledge stakeholders have of worldwide best practices and their practice-in-use.

Stage III. Development of certain general recommendations on how to improve the knowledge levels of stakeholders.

Stage IV. Submission of certain recommendations to stakeholders including several particular alternatives for each general recommendation proposed.

Stage V. A multiple criteria analysis of the composite parts of a life cycle of the built environment and selection of the most efficient versions – henceforth interlinking the received compatible and rational composite parts into a full life cycle of the built environment process.

In order to assure the efficiency of a project, it should be executed within certain bounds which are determined by the built environment. The fact is that these factors are different in each country, so also the possibilities for efficient realisation of projects (see Figure 1.5) will also vary.

Figure 1.5 indicates diagrammatically the factors at micro, meso and macro level which may impinge upon the efficiency of the built environment. This means that to be efficient the built environment must operate within certain boundaries imposed by the micro, meso and macro factors. Recognising that in each country the factors will be different, this diagram will vary accordingly. It is necessary to utilise knowledge and experience about the micro, meso and macro level factors, so as to increase the efficiency level in each country under consideration. This will be done by analysing the worldwide experience, knowledge and best practices and applying this to specific country.

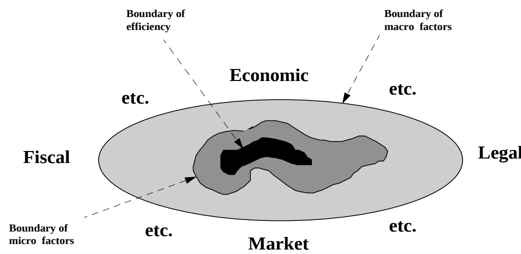

Figure 1.5. Micro, meso and macro factors that influence the efficiency of the life cycle of the built environment

Using carbon tax as an example of this, it can be appreciated that if the level of carbon tax is high, national firms could either go bankrupt because of increased tax liabilities, or they could decrease efficiency in the face of a lack of competition from international companies who will not attempt to enter the local market. Similarly, if the carbon tax level is lowered, this may cause national firms to lose market share to international companies entering the local market, or to force them to increase efficiency in the face of such competition.

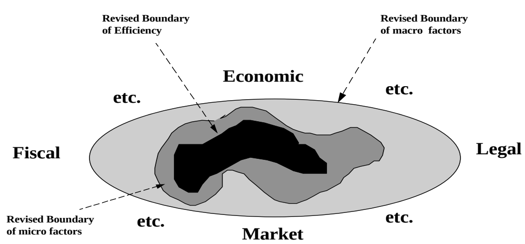

Figure 1.6. Fluctuation of efficient boundary of micro, meso and macro environment

Such changes in taxation will alter the boundary of efficiency of the built environment. Similar built environment changes can shift this boundary (the area within boundary of efficiency expresses the total satisfaction level of needs of all stakeholders). For example, the specific country government (in order to solve the most important problems for specific country society) may abolish VAT on new passive houses in order to promote investment in passive housing. Thus the boundary of efficiency is extended to include this new development from the former situation. After development of the specific country built environment the boundary will alter again (Figure 1.7 illustrates a revised level of efficiency as an example of how to take account of these alterations).

Figure 1.7 graphically illustrates interrelationships between macro-level factors and the built environment. The area inside the ellipse represents the positive action of specific macro-level factors on the efficiency of the built environment. The area outside the ellipse represents the negative effect of the macro-level factors on the efficiency of the built environment. Where the macro-level factors overlap a better environment for the built environment is created. In this case the optimum environment for the built environment is when all four ellipse areas are overlapping (i.e. economic, fiscal, legal and market). The greater the common overlapping area (taking into account the significance of the factors), the greater will be the efficiency level of the built environment. Having investigated the effects of the micro, meso and macro variables affecting built environment by using best practices, differences have been identified between these and specific country. On the basis of these differences, the main implications for specific country can be identified. Studying only some worldwide experience, knowledge and best practices could lead to any inferences being purely subjective. However, by studying a number of countries any bias can be diminished. In other words, the presence of specific micro, meso and macro-level variable factors immediately imposes objective limitations on the efficient activities of stakeholders. The stakeholders, in the presence of these objective limitations, try to perform their activities in a more rational way.

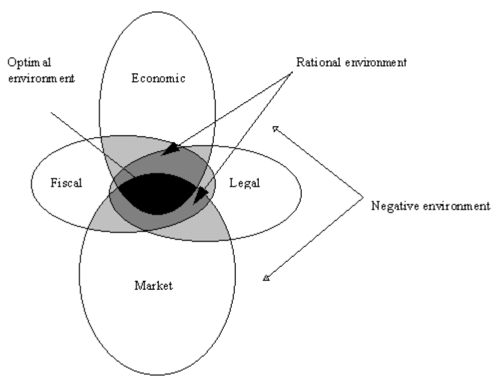

Figure 1.7. Determination of optimal, rational and negative environment for the built environment

Based on the above considerations, it is possible to propose a Model for a Complex Analysis of the Life Cycle of the Built Environment on the basis of the performed search for a rational variable environment for specific country (i.e. seek to explore ways of harmonising the relationship between the specific country built environment and its micro, meso and macro environment). Upon completion of such a model, the stakeholders by taking into consideration existing limitations of micro, meso and macro-level environment and existing possibilities, will be able to use their resources in a more rational manner.

One of the major tasks of an organization is to carry out its activities under the most favourable micro, meso and macro-level conditions. Efforts are made to ensure that the structure, goals, output, efficiency and quality of production of the organization would be in maximum conformity with the existing environmental conditions. The pursuit of impracticable goals, for instance, trying to realize projects which surpass the organization's capabilities or the environment (economical, social, legal, political, competitive and technological conditions) is adverse, may cause undesirable consequences.

In order to assure the efficiency of a project, it should be executed within certain bounds which are determined by micro, meso and macro-level factors.

Model for a Complex Analysis of the Life Cycle of the Built Environment was developed with the goal of integrating the environmental, energetic, political, economical, legal/regulatory, infrastructural, technical, technological, pollution, health, quality of life, social, cultural, ethical, psychological, emotional, religious, ethnic and other aspects of the process over the life cycle of the built environment.

It can be noticed that researchers from various countries engaged in the analysis of the life cycle of the built environment but its stages did not consider the research's object as was analyzed by the authors of the present investigation. A life cycle of the built environment may be described as follows: the stakeholders involved in its life cycle as well as the micro, meso and macro environments, having a particular impact on it and making an integral whole.

1.5. STAKEHOLDERS IN VARIOUS STAGES OF THE LIFE CYCLE OF THE BUILT ENVIRONMENT

Establishment of rational stakeholders is one of the more important assignments regarding upgrading quality in a built environment's process of life cycle. Every interest group understands the degree of quality of any project as the relationship between the degree of its own contribution and the goals achieved due to it (amount of a received salary, risk and the like). In other words, a project's increased effectiveness due to the efforts of each interest group must be directly proportional to the achievement of their own goals and needs satisfaction. The understanding that generally predominates is like that, as stakeholders consider their "slice of pie" (final benefit of a joint project, compensation for a job done) to be a set size.

Stakeholders attempt to increase a project's effectiveness, wanting to increase the size of their "slice of pie". Thereby the slicing of the "pie" (including its increase) can be considered a positive problem. It means, this is a way to generate a more effective system for organizing stakeholders.

Everyone who is related to the project, i.e., everyone who makes a contribution and receives a benefit is interested. The efforts and the received “pie” can be either tangible or intangible. An interest group can be described from different perspectives:

- Temporary (design and construction process) or permanent (exploitation process).
- Main sphere of an interest group's activities.
- Suitable time when an interest group must enter into an ongoing process.
- The contribution and received “pie” of an interest group is monetary (yes/no).
- Degree of influence stakeholders have on a project.
- Dependency of stakeholders on a project (Zavadskas et al. 1992).

Stakeholders are rarely established at once while a project is being compiled. It is additionally characteristic for them to join a project during its implementation process. Despite this, it is very important to establish the stakeholders that greatly influence a project or greatly depend on it as soon as possible.

"Brain storming" (a specific means of problem solving, where everyone participates in a free-for-all discussion) is a suitable method to foresee and select rational stakeholders. One means to apply this method is "snow cards", which is a small card for a person under questioning to write down only one interest group and the reasons why, in that person's opinion, this is a rational interest group. The person under questioning can fill out as many cards as he/she deems necessary. The "snow card" method can be applied at large meetings (with hundreds of participants), where groups consisting of 3-6 people work together filling out these cards. Afterward, project management can process, distribute and select rational stakeholders according to the functions they perform by utilizing a criteria system of their meanings and significances (Zavadskas et al. 1992).

Next, an example is briefly provided regarding the establishment of stakeholders. A bridge must be constructed to cross the river. It is easy to establish that the stakeholders are the owner, consumers, project designer, contractors, neighbors and those who sail under the bridge. So, what about the fish swimming in that water? It could be their spawning zone. Construction materials (sand and stones) are in a different place, where other fish spawn or where the best fishing areas are found. How can an interest group be established in an early stage of the project, while it is still possible to control and correct this process (Zavadskas et al. 1992)?

There are quite a few areas requiring coordination of interest group interests:

- Selection of a construction site.
- Organizational and pubic interests.
- The construction lot environment (before and after construction, internal and external).
- Aesthetics.
- Functionality.
- Longevity.
- Reliability.
- Risk (technical/financial/political).
- Applicability.
- Duration of construction.
- Construction methods.
- Project price.
- Exploitation expenses and the like.

Each one of the mentioned project areas can be deliberated by various aspects, e.g., selection of the construction site determines numerous factors (Zavadskas et al. 1992):

- Price of a lot.
- The boundaries of the "geographical" market of the owner's company.
- Financing possibilities.
- Economic, political and other conditions for organizational activities.
- Amount of designated taxes.
- Living expenses.
- School, health protection, social and other administrative offices.
- Ability to shop.
- Conditions for spending free time.

- Workplaces of suppliers.
- Energy supply.
- Other types of supplies.
- Postal, telegraph, port, railroad, roads, airport.
- Life cycle (distance to them).
- Suitability of a construction site for construction.
- Price of the labor force.
- Means for digging a foundation pit and so forth.

The needs of stakeholders expand and change over the long term, and new stakeholders join as a project is being implemented. A project that is large and complicated and has many stakeholders participating becomes difficult or impossible to handle without the assistance of computers and different methods to operatively and rationally formulate, coordinate and manage its own requirements.

One of the major assignments when aiming for effective design planning and implementation of a project involves having an alternative design and quality analysis over the entire process of the project's life cycle, when an objective is to satisfy maximally all the goals of stakeholders participating over the entire process.

The previously described process of the life cycle of a project cannot be implemented effectively without the maximal satisfaction of all the goals of all stakeholders (clients, buyers, construction and design organizations, suppliers, lawmakers, governmental bodies, consumers and others). A brief discussion on certain stakeholders follows.

The concept of a buyer encompasses all persons or companies, both external and internal, using the production of the organizations under discussion. "External buyers" (client, owner, media, local residents, local government and such) do not belong to an organization under discussion but they are associated with its production in one way or another. All these "external buyers" want something specific from the organization under discussion: the client wants good quality, low-priced production; the owner – income, stability; the media – advertising orders, valuable information or news, local residents – jobs and taxes and the local government – upholding the laws. Analogically the organization under discussion is also attempting to get something from the "external buyers": from the client – income and respect, from the owner – broad-based support, from the media – a good reputation and advertising dissemination, from local residents – employees and from the local government – protection, peace and quiet, legal guarantees and various services. The concept, "average buyers", denotes persons or companies that are part of the organization under discussion. There are numerous "average buyers" (suppliers) in a large organization. Here a spiral takes shape, where some subsidiaries are the "average buyers" of different subsidiaries of the same organization.

Construction organizations implement a project for all practical purposes by using different materials, equipment, energy, financial resources, labor force and the like. A good deal of responsibility of assuring an effective construction process falls on suppliers. The dependency between a construction organization and suppliers is one of the most obvious examples of how an environment directly impacts an organization. Gaining construction resources from other parties can be beneficial to a construction organization and future consumers from the perspective of prices, quality or quantity. However, the State may not be interested in such supply, since it may cause an increase in the number of unemployed and currency fluctuations, which could cause political instability. At times all the construction organizations in a region negotiate with one or practically with one supplier and all depend on that one supplier equally. For example, all organizations receive electricity at a price set by the State, and an alternative supplier rarely appears, even if an organization believes that the price of electricity in this case is too high. Therefore, in certain cases, the effectiveness level of an organization (e.g., when selling production in a foreign market) could depend on the overly centralized pricing policies of the State.

The outlook of a State on some specific activity (by various laws and resolutions, the work of governmental institutions and the like) also greatly impacts the operations of organizations. The mutual contact between a client and contractor winds up in the regulatory sphere of legal relationships in many cases. Every construction organization has a certain legal status, which establishes the kinds of activities in which an organization engages and its taxes. However, some laws are very complicated and not particularly expedient.

The most important goal of every organization is to satisfy consumer needs maximally and, by that, to implement its own objectives. To put it another way, the capability of an organization to survive and develop effectively depends on its ability to find a consumer within the sphere of its own interests and abilities who satisfies its demands maximally. Consumers determine the most effective direction for development among competing organizations in consideration of the results of their activities as they decide the kinds of goods and services they need according to a desirable price. In this instance, consumer needs are being satisfied and this has a determining influence on the relationships between contractors, suppliers and other stakeholders. It is expedient for an organization to orient its production to the large-scale consumer groups, and it primarily depends on these groups.

Competitors constitute an extremely important external factor. They greatly influence one another. The management of every company understands that, if the consumer demands are not met as effectively as competitors do, the company will not survive for long. Many times it is not the consumers who establish what production can be sold at what price but specifically the level of competition that does this. Consumers are not the only targets of an organization’s competition. A competitive battle can break out over work resources, materials, capital and the right to exploit innovations. Most internal factors of an organization also depend on the level of competition: work conditions, salaries, the relationship between a boss and subordinate and other matters.

Certain stakeholders, such as project design and construction organizations and suppliers, are selected on the basis of competitive bids. The hiring person leads the negotiations with them. The stakeholders must identify the areas where their goals are suitable or unsuitable during the negotiations. Afterwards the reason for any mismatch of interests must be discovered. Disagreements that arise are usually resolved in three ways:

- dominating;
- compromising;
- constructively.

The previous discussion was about the effectiveness of the process of the life cycle of the built environment and how it depends on various decisions, processes and stakeholders. A multicriteria analysis of all operable factors endeavoring to achieve the best, comprehensive result is necessary when aiming to better design and implement the life cycle process of a built environment. Performance of a multicriteria analysis of alternatives under discussion permits establishing the rational goals and effective strategies of stakeholders. These issues are further discussed as organizational examples. The principles that are laid out are also partly applicable for other stakeholders, as well.

Every organization (design, construction, suppliers and such), the same as every one of its employees, is seeking numerous, economic, social, moral, legal and other kinds of goals at the same time.). Some are easier to achieve than others are and, besides that, they are not all equally important. Thus, even if stakeholders do not achieve all the goals they might desire, they can still be satisfied having their most important goals satisfied. In such a case, it is highly beneficial to apply the interdependent principle of substitutability and total needs satisfaction.

It is very difficult to formulate the goals an organization is seeking to achieve, because nearly every one of its employees has his/her own opinion. This process can be accomplished more objectively by applying experimental and multicriteria evaluation methods. Organizational goals can only be implemented effectively, if they are correctly, unambiguously and clearly formulated. Meanwhile the employees must be informed about the goals, thereby raising their interest in them. The rationality level of company goals depend on how much they, along with the means for their implementation, correspond with the surrounding environment, as well as the desire of the stakeholders to participate in the process.

The effort to increase organizational effectiveness must include improvements in the mental systems of the employees. It is also possible to learn from past mistakes. Experience provides and organization with an opportunity to correctly adjust the direction of its activities, work more professionally and forecast the future effectively. The surrounding environment and the dynamic nature of the organization must be considered when selecting the different elements of a company's activities, as well as the company as a comprehensive entity, for analysis. This makes the analysis of this complex process much more difficult.

The general goals of a company are formulated and, step by step, they become entrenched based on the foundation of the organization's value orientations. The pursued goals must be described on the basis of numerous quantitative and qualitative characteristics. Descriptions of some of them appear below.

Above all else, goals must be specific. They should be expressed in numbers. One of the most important goals for some organizations is the satisfaction of their employee needs. Goals might be expressed as, for example, increase employee on-the-job satisfaction by 10 percent in a year, promote 15 percent of the employees on a career track and decrease employee turnover by 10 percent. Such specific numbers illustrate rather accurately what awaits employees in the future. The organization generates a terrific foundation of mutual interestedness and accountability by expressing its rules with specific indicators. In this sort of case, middle management gains a decent orientation on different issues requiring resolution (including upcoming concentrations required for employee education and training, or where, and other issues). Additionally it will be easier to determine, to what degree the organization has implemented its goals and, consequently, how much the company's effectiveness increases. A company's executive policies can change, once the final results become known.

It is necessary to define exactly, what the organization wants to implement, along with exactly, when it must be begun, when it should be achieved and what its intermediate and final results should be. Goals are usually defined in the short term and in the long term. The long term time for planning is approximately five years, sometimes more. Short term goals usually have to be implemented within a year. The average goal planning time lasts from one to five years. Long term goals tend to be quite abstract. An organization formulates these first. The average term and short term goals are defined next. Generally the sooner is the time of implementation, the more specific the goal is. For example, long term goals can be formulated such as, “Increase overall work capacity by 25 percent over the next 5 years.” Then, accordingly, an organization can establish that work capacity must increase by 10 percent over the first two years. Furthermore short term goals are defined for specific areas, such as the price of material resources, upgrading employee qualifications, company modernization, more effective utilization of manufacturing resources and such. This group of goals is meant to help implement the long term goals, which are directly related to the group, as well as other organizational goals of construction. Essentially all the goals orient to increasing organizational effectiveness.

The pursuit of unrealistic goals can cause undesirable consequences. Such goals might include an effort to implement a project that either is greater than the capabilities of the organization or the surrounding environment does not form the conditions for it (due to imperfect laws, overly powerful competitors, poor demand to supply ratio for the offered production and such). Additionally an organization’s level of goal achievement destines its employee interrelationships, because the future goals of the employees often closely relate to the organization’s goals. When goals of an organization remain unachieved, certain employee goals remain correspondingly unachieved. Thereby the future perspectives of the employees shrink, and work motivation. A person tries to shoot as many rabbits as possible with one shot in everyday life. For example, it is a pleasure to comprehensively relate to receiving a good salary, holding an interesting and creative job and being promoted on-the-job. Unachieved employee goals can actually harm an organization. An organization’s level of competitiveness can decrease, as employee motivation weakens.

Stakeholders are the core of all processes. The entire life cycle of the built environment and its constituent parts revolve around them, as planets orbit the sun. A brief overview follows.

CASBEE is the first building environmental assessment method developed in Japan for the promotion of sustainable building practices. Since the release of the first CASBEE tool in 2002, only limited studies have been conducted to understand the perspectives of CASBEE's stakeholders. In the Japanese building market where numerous sustainable building policies and schemes coexist, CASBEE's status and practicality have yet to be validated. This study examined four aspects of the project stakeholders' perspectives – perceptions, motivations, incentives and barriers – towards the adoption and promotion of CASBEE. Data were collected through surveys administered to CASBEE Accredited Professionals and local governments. The findings show that CASBEE's adoption is limited in the Japanese building market and also point toward the underdevelopment of a favorable business environment for CASBEE's dissemination. Substantial gaps in perspectives exist between the local governments and their building community; in particular, the reward systems for promoting CASBEE appear to be missing or misplaced. With regard to the perspectives of building community, this study has revealed significant differences between building sectors (residential versus non-residential) and between regions. This study contributes to the policymaking for the Japanese sustainable building market by providing recommendations for the development and implementation of CASBEE. It also provides a reference for other countries or markets that are considering building environmental assessment methods for sustainable building policies (Wong and Abe 2014).

Building stakeholders cannot easily quantify the environmental impacts of buildings as they accrue during construction. The goal of this work is to demonstrate a method to measure and manage the cradle-to-gate life cycle environmental impacts by linking environmental targets with modern construction management methods, to enable buildings to meet sustainable target values (STV). In this work, a construction activity-based computational framework was developed to enable stakeholders to reliably and efficiently construct cradle-to-gate life cycle models capturing environmental impacts including carbon and energy associated with material extraction, manufacture, transport to site, and construction. These models allow stakeholders to measure and manage impact accrual so as to not exceed STVs; without this framework, construction managers and other building stakeholders do not possess adequate environmental management tools to deliver projects consistently at or below STV. Specifically, the components developed are: (1) time dependent impact accrual budgets during construction and (2) impact measurement during construction. These benchmarks are used to determine whether a specific project is above or below target values, similar to methods for cost and schedule variance analysis. Two case studies were used to test this framework. This integration provides a life cycle assessment (LCA) modeling platform for management of environmental footprint during construction (Russell-Smith and Lepech 2015).

Stakeholders are concerned with increasing the sustainability of their existing buildings from social, environmental, economic, and technical perspectives. Several studies indicate that conflicting stakeholder requirements are a main barrier in implementing sustainable retrofits with the decision often made based purely on short-term economic grounds. However, most studies did not take into account the important role that different stakeholders can play in determining the type and extent of any retrofit measures, or develop methodologies that integrate social, environmental, economic, and technical concerns. In this research, a House of Quality (HOQ) model is developed that synthesizes differences among the stakeholders and integrates their competing objectives to establish hierarchy of retrofits that meet the stakeholder requirements in using the existing building. The developed model is tested on a decision to sustainably retrofit an existing US Navy case study building. The HOQ analysis revealed that the stakeholder type for this case study did not affect the ranking of their requirements, and in general, all 5 of the main groups of stakeholders involved in this study, agreed without persuasion that the primary reasons for implementing sustainable retrofits in each of the four main systems are to save energy, reduce costs, and adhere to policy (Menassa and Baer 2014).

Research on the barriers for building renovation in Denmark has revealed that an important obstacle is a lack of simple and holistic tools that can assist stakeholders in prioritisation and decision-making during the early stages of building renovation projects. The purpose of this research is to present a tool – RENO-EVALUE, which can be used as decision support for sustainable renovation projects, and for evaluation, during and after building renovations. The tool is a result from the European Eracobuild project ACES – “A concept for promotion of sustainable retrofitting and renovation in early stages” (Jensen and Maslesa 2015). Jensen and Maslesa (2015) present the main result of a work package concerning benefits of renovation. RENO-EVALUE has been developed from four case studies on renovation projects in Denmark, tested and validated on the cases and in a Delphi study. The tool is value based by focusing on the different interests and values of the main stakeholders involved in building renovation. It is meant as a basis for dialogue among building professionals and building users and supports formulation of objectives for renovation projects. RENO-EVALUE can also be used for comparing alternative project proposals and to follow-up on a project and assess the results. The tool covers the four main parameters: Stakeholders, Environment, Organisation, and Economy. The evaluations are collected from different stakeholders by use of standardised information and interview templates. The test results of one case study of a social housing estate are presented (Jensen and Maslesa 2015).

Göçer et al. (2015) provide a review of the improvements in the evaluation of building performance and introduces a new method for post-occupancy evaluation (POE) to complete the missing link in the building design process. Existing studies were reviewed to understand the possible reasons for the missing link of "building performance feedback". The intention of Göçer et al. (2015) research is to set out a new vision for how future post-occupancy evaluation can close the building performance feedback loop to better inform building design. The spatial mapping method adopted extends the use of building information modeling (BIM), which has shown great potential for the future of the Architecture, Engineering and Construction (AEC) industry, and uses geographical information systems (GIS), which is a powerful tool for analyzing and visualizing relationships between geographical units and their data. This study explores how to establish a communication platform for different stakeholders in order to engage them in the collaborative effort of continuous building performance improvement by using the results of POE embedded into BIM. In Göçer et al. (2015) research, the experiences of a POE study of a LEED® Platinum building and a historical building on a university campus are reported as examples to illustrate the proposed new method.

The building sector accounts for nearly 41% of U.S. primary energy use. Various tools have been developed for estimating the embodied energy during the design and construction phase of a building. However, there is a lack of a comprehensive mechanism which can measure and control the energy flow occurring during the operation phase of a building. Loss of efficiency of building systems and deterioration of various building components can collectively reduce the performance of a building, which eventually results in more energy flow into a building in the form of more maintenance and replacement requirements, as well as, increased operational energy demand. This research analyses a building's deterioration mechanism and presents a system dynamics simulation based "Life Cycle Energy Framework" that couples material performance and energy simulation to arrive at an optimal maintenance and replacement cycle for major materials over the entire operation period of a building. The case study results indicate that the proposed framework can help various building stakeholders in understanding and limiting the energy usage of the building from the design phase until the end of life phase (Thomas et al. 2015).

Narrowing the performance deficit between design intent and the real-time environmental and energy performance of buildings is a complex and involved task, impacting on all building stakeholders. Buildings are designed, built and operated with increasingly complex technologies. Throughout their life-cycle, they produce vast quantities of data. However, many commercial buildings do not perform as originally intended (Corry et al. 2015). Corry et al. (2015) present a semantic web based approach to the performance gap problem, describing how heterogeneous building data sources can be transformed into semantically enriched information. A performance assessment ontology and performance framework (software tool) are introduced, which use this heterogeneous data as a service for a structured performance analysis. The demonstrator illustrates how heterogeneous data can be published semantically and then interpreted using a life-cycle performance framework approach (Corry et al. 2015).

Häkkinen et al. (2015) evaluate the current methods as support for the design of low-carbon buildings and the significance of different design phases from the perspective of embodied carbon. Through evaluation of relevant literature, interviews with practicing architects, and a building case study, Häkkinen et al. (2015) recommend to proceed gradually across all design phases for achieving low-carbon building design. This should take place in a systematic way that describes the status, coverage, and accuracy of GHG assessments in each design stage. Furthermore, Häkkinen et al. (2015) outline the framework with the use of the Royal Institute of British Architects (RIBA) stages of design, and for each stage, Häkkinen et al. (2015) identified the objectives, typical deliverables, and milestones necessary for ensuring carbon efficiency. This will require integration of the roles and responsibilities of the relevant stakeholders, including the client, project manager, architect, structural engineer, and Heating Ventilation and Air Conditioning (HVAC) engineer (Häkkinen et al. 2015).

Many tools have been developed to support the Front End of Eco-Innovation (FEEI) to design more radical product/service concepts. Although it is widely recognised that designers need to extend the consideration of key stakeholders in the value chain, few studies analyse the impact of the integration of the 'stakeholder' notion into eco-innovation practices (Tyl et al. 2015). Tyl et al. (2015) aim at understanding how the 'stakeholder' perspective can usefully be integrated into eco-innovation sessions. In addition to an extended literature review of existing eco-innovation tools with a stakeholder perspective, this research adopts an original “research scenario” perspective through a collection of case studies, with various participants, studyal backgrounds, and industrial or academic contexts. Through a Strengths, Weaknesses, Opportunities, and Threats (SWOT) framework, the Tyl et al. (2015) analyse the strengths, weaknesses, opportunities and threats of the integration of the stakeholder notion into eco-innovation tasks. Tyl et al. (2015) highlight the different ways to consider stakeholders at the FEEI stage, from stakeholder identification to the analysis of the different types of stakeholder value. Moreover, the need to adapt the stakeholder approach according to the type of FEEI tool user is emphasised. Stakeholder typologies can be reduced to a few key unfamiliar stakeholders during the ideation process with industrialists, while the number of stakeholders can be more exhaustive in an educational approach (Tyl et al. 2015).

In the design phase of a high-rise residential building, stakeholders should adopt the proper external wall system by considering energy performance and IEQ as well as construction cost and structural stability. The energy related performance and construction cost of external walls affect the life cycle cost. Therefore, also a value analysis of the LCC in terms of the energy performance is required. The purpose of this study was to evaluate the energy related performance and construction cost of external walls in high-rise residential buildings, which are the currently staple external walls, using reinforced concrete (RC), glass fiber reinforced concrete (GFRC) and cellulose fiber reinforced cement (CFRC). All the wall systems have the same doors and windows in their bodies for equal comparison of energy efficiency and construction cost. The energy efficiency of the CFRC external walls was high while the construction cost for RC external walls was low. The value assessment considering the LCC and the residents’ health revealed that RC external walls were most satisfactory up to 6 years after construction, GFRC from 6 years to 26 years, and CFRC thereafter, respectively. The findings of this research will be valuable for stakeholders deciding on an external wall system (Lee et al. 2015).

Currently the construction and demolition (C&D) waste collection system in Spain is managed in a decentralized manner by each sub-contracted company. This lack of comprehensive strategy for C&D waste management causes a confusing and sometimes individual attitude regarding the different measures for C&D waste. Therefore effective waste management should be enforced. Construction stakeholders have wide range of best practices in C&D waste management that can be implemented, so they need to be assessed for their effectiveness. The aim of this research study is to assist construction stakeholders in making a decision on C&D waste management (Saez et al. 2013). Saez et al. (2013) carry out a survey conducted among the construction agents in order to evaluate the effectiveness of 20 best practice measures regarding C&D waste management, identifying the most suitable types of building constructions to implement these practices and also the advantages and drawbacks of their performance in a building construction project. Results of this study show that among the highly effective best practices are: the use of industrialized systems and the contract of suppliers managing the waste. In addition, distributing small containers in the work areas is also another high valued practice, although only 36% of respondents usually implement this measure in their works (Saez et al. 2013).

Conceptual design decision-making plays a critical role in determining life-cycle environmental impact and cost performance of buildings. Stakeholders often make these decisions without a quantitative understanding of how a particular decision will impact future choices or a project's ultimate performance. The proposed sequential decision support methodology provides stakeholders with quantitative information on the relative influence conceptual design stage decisions have on a project's life-cycle environmental impact and life-cycle cost. A case study is presented showing how the proposed methodology may be used by designers considering these performance criteria. Sensitivity analysis is performed on thousands of computationally generated building alternatives. Results are presented in the form of probabilistic distributions showing the degree to which each decision helps in achieving a given performance criterion. The method provides environmental impact and cost feedback throughout the sequential building design process, thereby guiding designers in creating low-carbon, low-cost buildings at the conceptual design phase (Basbagill et al. 2014).

An extensive growth in pavement life cycle assessment studies is noticed in recent years. Current literature in pavement life cycle assessment demonstrates a wide range of implications on environmental burdens associated with the pavements. However, immature parts still remain, needing further research, in the next years, in different stages of pavement life cycle assessment. Most of these papers focused on the implementation of new technologies on pavements construction, the use of recycled materials, and the investigation of various phases of the pavement life cycle rather than improving the applicability and the adequacy of life cycle assessment methodology to the pavement problems. These stages are based on ISO 14040 and 14044 frameworks: the goal and scope definition, the inventory analysis, the life cycle impact assessment and interpretation. In this research, a comprehensive review (i.e. a critical review and research gaps investigation) of life cycle assessment studies on pavements was conducted. The presentation comprises (not an extensive list) inventory analysis such as surface roughness, noise, lighting, albedo, carbonation, and earthwork in addition to locally applicable data collection, consequential and temporal consideration of pavement life cycle, and sensitivity analysis. Addressing these inadequacies will permit enhanced pavement life cycle assessment studies. This will then be useful for policy makers, project managers, construction engineers, and other stakeholders in identifying prospective in sustainable development of the pavement sector (Jafari et al. 2015).

Currently, the construction industry is turning towards sustainability. Nevertheless, in order to achieve a sustainable performance, a balance between environmental, social and economic criteria has to be created. There are already different tools available which have the potential to reach this goal. It is necessary to identify them as such and find out how they can be integrated to obtain synergies and contribute to sustainable construction. These tools have to be implemented in early design phases so as to add value to the project. In the present research, two powerful methods, namely BIM and LCA, will be highlighted. Such methods can be of great assistance in the context of sustainability. On the one hand, BIM supports integrated design and improves information management and cooperation between the different stakeholders throughout the different project life-cycle phases. On the other hand, LCA is a suitable method for assessing environmental performance. Both LCA and BIM should be integrated in the decision-making process at an early stage with a view to achieving a holistic overview of the project, including environmental criteria, from the beginning (Antón and Díaz 2014).

After many years of stagnant growth in geothermal power generation, development plans for new geothermal plants have recently emerged throughout Japan (Kubota et al. 2013). Through a literature review, Kubota et al. (2013) investigated the relationships between the principal barriers to geothermal development and Kubota et al. (2013) thereby analyzed the deciding factors in the future success of such enterprises. The results show that the societal acceptance of geothermal power by local stakeholders is the fundamental barrier as it affects almost all other barriers, such as financial, technical, and political risks. Thus, Kubota et al. (2013) conducted semi-structured interviews with 26 stakeholders including developers, hot spring inn managers, and local government officials. Some hot spring inn managers and local government officials noted that they have always been strongly concerned about the adverse effects of geothermal power generation on hot springs; their opposition has delayed decision-making by local governments regarding drilling permits, prolonged lead times, and caused other difficulties. A key reason for opposition was identified as uncertainty about the reversibility and predictability of the adverse effects on hot springs and other underground structures by geothermal power production and reinjection of hot water from reservoirs. Therefore, Kubota et al. (2013) discuss and recommend options for improving the risk management of hot springs near geothermal power plants.

According to the targets set for sustainability, integrating the principles of sustainable development into country policies and programs is one of the main goals for development projects. A major challenge in the development field is cross-sectoral integrated planning and achieving multi-stakeholder consensus for collaborative joint projects, especially when sustainability is a goal. This increases the complexity of the multi-stakeholder interaction in decision making and requires enhanced mechanisms for stakeholder participation, coordination, and commitment beyond narrow self-interest. A critical aspect in the decision making process is to enable stakeholders to not only interpret and make decisions based on expert judgments, but also to appropriately involve the relevant parties in the research and decision making process. Therefore, scientific analyses in multi-stakeholder contexts have to be more transparent, participatory, and stakeholder-based in order to provide useful information to assist responsible decision making (Thabrew et al. 2009). Thabrew et al. (2009) present an outline of a stakeholder-based life cycle assessment approach that can be used to support sustainable decision making in multi-stakeholder contexts. The framework is discussed and compared to other common methods used to support environmental decision making in development projects. Thabrew et al. (2009) argue that the fundamental concept of life cycle thinking can be effectively used to incorporate stakeholders in the research and decision making process, which can lead to more comprehensive, yet achievable assessments in collaboration with stakeholders. Life cycle thinking is not just a way to examine environmental impacts of activities, but also a way to comprehend and visualize a broader set of upstream and downstream consequences of decisions in development planning and implementation. A life cycle framework including the mapping of stakeholder involvement at each activity in upstream and downstream stages would give stakeholders a holistic view that they otherwise may not have (Thabrew et al. 2009).

Green Public Procurement (GPP) is a significant policy tool for reducing the environmental impacts of services and products throughout their whole life cycle. Scientific and easily verifiable environmental criteria, based on a life cycle approach, should be developed and used within procurement procedures. In this research, Life Cycle Assessment (LCA) is applied to wood windows showing how it can support the criteria definition. After a foreword on GPP development in Italy, the evaluation features of the environmental performances of building materials and components are outlined. The LCA case study is then presented, describing the use of the analysis results to define the environmental criteria. LCA allowed to identify the main impacts and the critical processes of the window life cycle, giving a scientific framework to discuss GPP criteria with manufacturers associations and stakeholders. Nevertheless, it couldn't help neither in identifying detailed criteria for GPP nor to define numerical thresholds to be used as reference in procurement procedures. The appropriate strategies should be selected taking into account the technical status of the market, the standard development and the voluntary industry commitments, involving manufacturers associations. Finally, some elements to develop a structured approach for GPP of construction materials are presented (Tarantini et al. 2011).

The building industry in China has huge potential capacity for energy/resources conservation and pollutants reduction to achieve sustainable development. However, stakeholders are hardly able to reach a consensus on preferential needs and effective solutions, which was a difficulty faced by policy makers. To better identify the common interests on sustainable development in this field, the Sustainability Solutions Navigator (SSN) was adopted in China for the first time to assess the sustainability needs and practices. Based on the participation of stakeholders from the government, businesses, academia, and non-government organizations, prioritized needs and practices were identified using SSN, and gap analyses were conducted for comparison to global benchmarks. According to the results, the top needs were mainly focused on improving government efficiency and implementation, maintaining healthy indoor environments and obtaining adequate funds; priority practices were mainly focused on governmental action, renewable energy development and pollutant source reduction. The gap analysis indicated that the government efficiency and performance had the largest gap to the benchmark. By using a simple interactive tool to bring different stakeholders into policy making process, this study produces all-around information for decision makers. The results imply that the sustainability of the building industry in China has a much better expectation than governmental performance (Yang et al. 2013).

1.6. CRITERIA SYSTEM TO SYSTEMATICALLY DESCRIBE THE LIFE CYCLE OF THE BUILT ENVIRONMENT

The thoughts of other authors served as basis for compiling a criteria system describing the life cycle of the built environment. This relates to the considerable subjectivity, in a certain sense, of a criteria system that would actually define the goals of interest groups. Therefore the ideas of experts in this field based the compilation of a criteria system to define built environment aiming to increase the objectivity level of this analysis. The criteria system or its subsystems describing the life cycle of the built environment has been published in publications.

For example, the criteria system can be conditionally subdivided into four Level 1 subsystems:

- Criteria subsystem describing the impact of macro-level factors on built environment effectiveness.
- Criteria subsystem describing the impact of meso-level factors on built environment effectiveness.
- Criteria subsystem describing the impact of micro-level factors on built environment effectiveness.
- Criteria subsystem describing the impact of interest groups on built environment effectiveness.
- Criteria subsystem describing the impact of different building life cycle process stages on built environment effectiveness.

Each one of these Level 1 criteria subsystems based on the principle of a tree diagram can be discussed in much greater detail. To illustrate, the life cycle of the built environment described according to an example of the i^{th} level criteria subsystem could be a construction resources supply criteria subsystem.

For the sake of clarity, the impact of the micro-, meso- and macro-level factors that describe the Level 1 criteria subsystem on built environment effectiveness will be briefly discussed next along with the i^{th} level criteria subsystem describing the supply of resources for construction.

1.6.1. Level 1 criteria subsystems

This subsection contains a brief discussion of Level 1 criteria subsystems, which describe the impact of the micro-, meso- and macro-level factors on built environment effectiveness.

The macro-level is the highest level on which the effectiveness of the built environment depends. The following macro-level factors impact the effectiveness of the built environment:

- The level of a country's economic, political, legal and institutional and cultural development.
- Social, ethnic and religious environment.
- Technological and technical level.
- Government's policies including regional support programs, regulation of competitiveness, governmental orders, grants, subsidies, social policies and taxation system.
- Legal documents and standards relevant to the built environment.

- Interest rates.
- Inflation.
- The market.
- Insurance systems.
- Fluctuations of currency rates.
- Customs duties.
- Unemployment level.
- Labor force qualifications.
- Level of work compensations.
- Labor laws.
- Environmental protection.
- Customs and traditions
- Life cycle of local resources and so forth.

A complex analysis of a built environment on the macro-level scope (city, country) is recommended basing it of the following system of criteria (Masure 2003; Raipa 2007; Sinkienė 2008; McAvoy 2002; Cheshire and Hay 1989; Webster and Muller 2000):

- Political, legal and institutional factors such as work cooperation between municipalities, effectiveness of city administration, the image of a city, the programs of different political parties, the governmental position with respect to certain areas of city operations (taxes, means for regulating the labor market and the like), effectiveness of the legal base of a built environment and the application of electronic democracy and electronic municipal governing. National and EU policies also require analysis, because it is essential for city heads and interest groups to understand the intentions of national governance (along with supranational governance, such as the European Commission) in the context of city evolvement and the means the government uses to implement its policies. Legal factors are distinguished on the basis of an analysis of the laws and standardized acts. These assist in establishing the limits of allowable operations and applicable methods to represent the interests of one's own city at different levels. Political factors are notable for their dynamism, whereas the legal ones, by stability, and these assure the continuity of the main rules for city development independently of changes in the dominating political forces occurring in the city.
- Analysis of economic factors in the external environment that include international competitiveness for capital, labor force, institutions, arranged events and the like; unemployment levels, growth in the number of jobs and attracted investments; the business environment; productiveness of companies; capability of exploiting macro-level conditions better than the capabilities of other cities with similar natural, human, technological and other resources; governmental policies (taxes and their benefits, grants, subsidies), interest rates, inflation, currency exchange rates and documents regulating a built environment; national tax policies; tariffs and macro-economic and industrial initiatives; structure of the country's economic operations; level of innovations and application of electronic business. These factors assist in understanding the macro-economic indicators of the country or the broader region, growth trends of the external economy, fiscal and monetary policies and the specifics of corporate management as well as in evaluating the existing conditions of

transportation, communications and other parts of the infrastructure with possible changes in the near future.

- Analysis of social, cultural, ethnic and religious factors that include memberships in networks, quality and knowledge of human resources, changes with respect to the rational expectations of the public regarding the city and the services it provides, rational city development that does not cause huge conflicts between interest groups for resources (land, money and others), political influence, development of human resources, educational level of the work force, capabilities and generation of innovations by joint work and expansion of networks, demographic changes in the country and region, the dominant family and community relationships, the situation in the area of equal opportunity and discrimination, features of the society's life style and their changes along with aspects of health and education, work and income and the criminological situation. An analysis of cultural factors concentrates on changes in the mobility of the country's or region's residents, the outlook on the major issues regarding city operations and development (forthrightness, insularity, rationality, cosmopolitism and the like).
- Analysis of technological and technical factors permits a timely determination of the operations opportunities and threats for that city, which outcrop due to new technologies and the conditional methods for their operations. They also condition the formation of rules regarding the directions of strategic technological breakthroughs for a certain city or the social and economic backwardness of a city due to a technological lag. In the case of a city analysis, it is also appropriate to analyze the development of informational and communications technologies operating beyond city borders, consolidation of new industrial branches, advancement in manufacturing technologies, the international and national policies for technological development and the like.
- Review of the state and tendencies of natural and ecological environments and structures as well as their possible consequences. Essential analyses involve indicators of the broader region (country, continent, world) for air quality, emissions, water quality of drinking water and open reservoirs, refuse handling, the condition of living nature, risk of natural disasters, physical expansion of city boundaries as well as the goals and means of national and international policies for regulating these areas.

The impact of the aforementioned macro-level factors on the effectiveness of the built environment must be expressed by the Level 2 and other level criteria subsystems that thoroughly describe such factors to achieve a comprehensive evaluation of them. The market is used as an example to illustrate this.

Market research is one of the most important issues that organizations must resolve, because their level of effectiveness depends on it. Numerous criteria can provide the basis for evaluating the market:

- Demand level (more information about this indicator can be gained by answering questions such as what kinds of users and why, how much, when and how they purchase the production offered by the organization under discussion and other similar sorts of production).

- Supply level (more information about this indicator can be gained by the availability of data about direct and indirect competitors and their strategies).
- Price levels of the production manufactured by the organization under discussion and its competitors.
- Market size (what share of the market belongs to the organization under discussion).
- Trends in market changes (What are the growth opportunities? How will the market share of the organization under discussion change, if the market should expand?).
- The strengths and weaknesses of the organization under discussion and its competitors.
- Analysis of the production buyers by their different personalities (age, sex, nationality or ethnicity, favored pursuits, education, life style, social status, standard of living, profession, marital status and the like).
- Production buyers (of various organizations) analysis (involving the buyer's sphere of activity, job, structure, production sales level, distribution channels, number of employees).
- The individual who makes the final decision regarding purchases of the production.
- Opportunities for disseminating information and advertising about the manufactured production.

These criteria describing the market can be analyzed in even greater detail. Here the supply and demand of construction production will serve as an example.

Demand for construction production depends on the following factors:

- Prices
- Interest rates
- Prices of other products/services
- Income
- Population numbers
- Interests
- Governmental policies
- Future perspectives

Prices change, whenever the aforementioned factors of demand change.

The supply of production from the construction sector depends on numerous factors:

- Expenses (construction costs).
- Technology improvements causing lower production prices and higher quality.
- Interrelated product prices that can replace or supplement each other while under production (for example, cheaper window alternatives lower the price of a building's revitalization).
- Other factors on which supply and demand depend: political shakeups, wars, strikes, policies on interest rates and such.

Criteria subsystems can be compiled analogically to the aforementioned macro-level factors describing them to achieve comprehensive definitions of those factors.

Level 2 factors, which impact the effectiveness of the built environment, can be categorized at the micro and meso-level. These factors depend on the macro-level factors (various laws regulating construction sector operations, normative documents and the like). For example, it might be noted that, if the tax level becomes sufficiently high, then national companies could bankrupt due to the huge tax load or their effectiveness could drop (the number of international companies that want to enter the local market and competition will drop as taxes increase). Contrariwise, as taxes decrease, the international companies entering the local market can either push national companies out of their respective market share, or the national companies that face such competition will be forced to increase their effectiveness. Various areas could feel the consequences from such a process, including the unemployment rate, changed level of tax collection and such).

The effectiveness of the micro- (house, project) and mezo-levels (region, organization) of a built environment can be evaluated according to the following system of criteria (Jacobs 1970, 2000; Castells 1989; Storper 1997; Sinkienė 2008; Hall 1998; Storper, Scott 2003; Petrakos, Economou 2000; Florida 2002):

- Physical factors referencing the supply and demand of land and facilities, prices of land and facilities, selection of an area of operations, quality of the residential environment including its pollution (hard particles, noise and so forth), infrastructure of the construction site, quality of life, geographical situation of the city and its accessibility, resources of the city's natural environment, territorial assets, advantages of the physical location, the dwelling and its location and image, size of the city or its status as capital and the city's geographical situation: Is it centrally located or in the peripheries of a country? In reference to the city's geographical situation in Europe – is it northerly, southerly or otherwise?
- Human resources referencing effective interest groups (residents, media, clients, consumers, project designers, construction materials manufacturers, suppliers, contractors, building utilization organizations) and an active and conscientious local community that is integrated, not splintered by social conflicts; a city like the locales distinguished for the greatest competitiveness, where companies and people want to invest and to reside; strong personal contacts of the leaders and direct contacts; a capability for attracting good employees; the qualification levels of the work force along with its innovativeness and exceptional knowledge and abilities; application of advanced techniques and technology and organizational management; opportunities for life-long learning and studying; the demographic situation along with the national and religious composition of the residents as well as the creativity, talent, tolerance, culture, traditions and the like of the residents.
- National and EU institutions, societies and social and political organizations referencing effective public organizations, political parties, financial institutions, municipalities and State; the numbers of national and EU institutions and the effectiveness of their operations; joint work between cities; development of public, social and strategic networks; public and private partnerships; the vision and strategy for development of the area and so forth.
- Economic factors referencing application of advanced economic propagation methods, services provided by the city, ability to exploit the micro- and mezo-level conditions better than other municipalities or regions can, structure of the economy, operations generating high added value, local tax system, city's levels of economic compensations, accessibility of capital in the city, the city's institutions for education and research and for experimental development, the city's industrial clusters and the like.

Different micro and meso-level factors affect project effectiveness:

- Prices of land lots and buildings.
- Infrastructure of the construction site.
- Informational systems for construction.
- Organizational mergers in the construction sector.
- Selection of the type of operations.
- Project planning integrated with the life cycle process of a built environment.
- Effectiveness increases in process of supplying construction materials and products by using Internet.
- Lifelong learning.
- Financing for organizations.
- Type of contract.
- Goal determination process.
- Project planning process.
- Construction process.
- Exploitation process.
- Facilities management and so forth.

The impact of the aforementioned micro and meso-level factors on built environment and construction effectiveness is next illustrated in brief by the green buildings examples.

Vučićević et al. (2014) present a method for selecting and calculation indicators of sustainable development, needed for determining the level of sustainable development, expressed through sustainability index of residential buildings. It is important to verify procedure for determining economic, social and environmental sub-indicators based on consumption of final energy (used to meet space heating, hot water generation and household cooking needs, as well as for operation of various household electrical appliances, indoor temperature and humidity). It was done for representative sample of Belgrade buildings stock. Different dwelling types constructed in two different periods and heated by electricity, district heating and fossil fuels were analysed. Multi-criteria analysis was used to evaluate residential buildings sustainability. The results showed that the best building options, constructed in the period 1981–2006, are: the apartment buildings and single family houses (electricity for space heating) when economy indicator has priority; the apartments connected to the district heating system when environmental indicator has priority; and single family houses connected to the district heating system when social indicator has priority. Implementation of proposed methodology is beneficial when evaluating and comparing sustainability of different residential buildings, enabling decision makers to more easily reach decisions on the issues related to energy policy and environmental protection (Vučićević et al. 2014).

As Malaysia moves towards a sustainable lifestyles and development, the need to prepare for the change is imperative. Sustainability has become an important initiative discussed and undertaken not only by private buildings but also by public buildings dealing with residential, office, commercial as well as hospital. Building is known as human habitat. The way people design, construct and operate the building has a profound impact on people health and the environment. Compared to other building types, healthcare buildings have an especially large impact on the environment for the 24/7 use. Thus, the development of green hospital is important as it requires strict cleaning procedures and frequent air changes, which increase the already-high energy costs of the 24/7 operations and sophisticated medical equipment that make hospitals among the greatest energy consumers of any institution. The primary aim for this research is to investigate green assessment criteria for public hospital building development in Malaysia. It compiles the essential criteria of existing green rating systems for healthcare buildings worldwide and presents the difference between each criteria compared to Malaysian green rating system. Existing tools and guidelines are reviewed, analysed and grouped according to the main criteria. The assessment criteria from each rating systems are divided into similar category covers all aspect of building design, construction and operation. Results from the analysis show the important assessment criteria of green public hospital building correspond to Malaysia. The research intended to produce initial guideline as a starting point for Malaysian public hospital in the most consistent and systematic way in practicing green (Sahamir and Zakaria 2014).

The construction and building process depends on substantial consumption of natural resources with far-reaching impacts beyond their development area. In general, a significant portion of annual resource consumption by the building and construction industry is a result of applying traditional building strategies and practices such as designing and selecting types of development (e.g. multi-unit condo and single-family house, etc.), building materials and structure, heating/cooling systems, and planning renovation and maintenance practices. On the other hand, apart from structural suitability, building developers mostly consider the basic requirements of public owners or private occupants of the buildings, where the main criteria for selecting building strategies are costs, and long-term environmental and socio-economic impacts are generally ignored. The main purpose of this reseaerch is to develop an improved building sustainability assessment framework to measure and integrate different sustainability factors, i.e. long-term environmental upstream and downstream impacts and associated socio-economic costs, in a unified and quantitative basis. The application of the proposed framework has been explained through a case study of single-family houses and multi-unit residential buildings in Canada. A comprehensive framework based on the integration of emergy synthesis and life cycle assessment (LCA) has been developed and applied. The results of this research prove that the proposed emergy-based life cycle assessment (Em-LCA) framework offers a practical sustainability assessment tool by providing quantitative and transparent results for informed decision-making (Reza et al. 2014).

Green building assessment is currently being introduced into Serbian building practice. Since there is no Serbian certification system which could support building assessment, and especially lighting design evaluation, this research analyzes and compares the lighting design criteria of three international certification systems, LEED, BREEAM and CASBEE. Specific requirements for each considered criterion, as well as the grading structure and stringency of these systems, are also analyzed. Based on the conclusions of these analyses, a new set of criteria, some of which are original, are offered in order to be incorporated into the future Serbian certification system. Taking into account that the structure of the future system is unknown, the basic applied principle was simplicity for application and, therefore, a single requirement is defined for each criterion. Finally, a hierarchy within the new set of criteria is established for both indoor and outdoor lighting. Mandatory criteria are selected first, while the remaining criteria are divided into two groups based on their relevance. Although predominantly intended for the improvement of Serbian building practice, the proposed set of assessment criteria is general and can be used throughout the world (Stankovic et al. 2014).

Communication about very complex problems like household sustainable consumption in simple terms is still a major challenge. Despite the diversity of tools to measure household consumption, clearer indicators are needed to more effectively communicate with the general public. The main objective of this research was to develop an approach to define the main procedures and criteria to built household sustainable consumption assessment tools based on indicator sets. A review of available household sustainable consumption assessment metrics and related initiatives was conducted; this included a comparative analysis of the different approaches. The review revealed that the majority of these initiatives are focused upon specific domains (e.g. energy or waste), but none used an integrated approach in the sustainable consumption domains. Furthermore, it was found that few methods used indicators to measure and assess household sustainable consumption. Principal components and a checklist of key good-practice factors that a household sustainable consumption indicator system should include were developed. Due to the need to communicate effectively, to engage stakeholders and to address the complexity involved in the measurement and assessment of household sustainable consumption, the proposed integrated approach was designed to evaluate household sustainable consumption (Caeiro et al. 2012).

The built environment is recognized as a major hotspot of resource use and environmental impacts. Life cycle assessment (LCA) has been increasingly used to assess the environmental impacts of construction products and buildings during the last 25 years. A new trend stems in the application of LCA to larger systems such as urban islets or neighborhoods. This review aims at compiling all papers related to LCA of the built environment at the neighborhood scale. A focus is carried out on 21 existing case studies which are analyzed according to criteria derived from the four phases of LCA international standards. It sums up current practices in terms of goal and scope definition, life cycle inventory (LCI) and life cycle impact assessment (LCIA). The results show that the case studies pursue different goals. They are either conducted on existing or model neighborhoods with an aim at building knowledge to feed urban policy making. Or they are conducted on actual urban development projects for eco-design purpose. Studies are based on different scopes, resulting in the selection of different functional units and system boundaries. A comparison of data collection strategies is provided as well as a comparison of LCIA results for cumulative energy demand and greenhouse gases emissions. Methodological challenges and research needs in the field of application of LCA to neighborhood scale assessment are identified, such as the definition of the functional unit and the need for contextualization methodologies aligned with data availability at the design stages of a neighborhood development project (Lotteau et al. 2015).

As, fossil energy resources are closer to their exhaustion, global warming in raise, and more catastrophic weather extremes are occurring worldwide, there are more and more warnings that the risks to the Earth humanity survival are also in growth. The Earth/humanity as a whole is becoming more complex system than ever. Trying to find a way to make a turn from the current one-way irreversibility to sustainability, it is necessary to find universal schemes, quantities, indicators and criteria relevant for the Earth and humanity's resilience and sustainability. Presented is a review of the multi-criteria sustainability analysis methods (intrinsic thermodynamic based on energy, exergy, sustainability index, analytic hierarchy process, etc.). It has been shown that crucial sensitivity of all methods is related to the selected sets of energy criteria (economical, social and environmental) and to the mathematical algorithms for the determination of the weighted factor and sub-indicators agglomeration. Also, shown is that concerning buildings sustainability is missing indicator relevant to the indoor comfort and people health, accompanied with a comprehensive, physically sound assessment methodology for building's synergetic environmental performance – twofold metrics with the reference to outdoor and indoor built environment concerning people health and comfort. A scheme of a structure and spatio-temporal vision of the Global sustainable development is presented – showing that the approach to the global sustainable development can be reliable only if it is based on a system of real human and ethical values applicable to every social, studyal and economic situation (Kim and Todorovic 2013). Finally Kim and Todorovic (2013) summarize needs for future multidisciplinary, inter- and cross-disciplinary study on healthy sustainable buildings, interwoven with harmony and holistic people health and well-being research. That research is to be physically sound – intrinsic thermodynamic, harmonious green, and relevant metrics is to be free of the short-term politically shaped and quasi-economically distorted approaches, because the world is to get what is painfully missing – a standard metrics of the sustainability index, universally acceptable (Kim and Todorovic 2013).

da Graça et al. (2007) present a method for evaluating and optimising environmental comfort parameters of school buildings during the preliminary stages of design. In order to test the method, 39 existing public school building designs in the State of São Paulo, Brazil, had their plans analysed and characterised in relation to their influence on environmental comfort. Four aspects of comfort were considered: thermal, acoustic, natural lighting and functionality. Since the evaluation method is based on preliminary design information only, parameters that otherwise would be analysed quantitatively had to be assessed by interviews with specialists using a qualitative five-point semantic scale. For each aspect of comfort, possible design solutions were rated from 0 to 1, according to the fuzzy set theory. The final mean grades for each comfort stated the building's average performance. Although conflicts between different comfort parameters are apparent, results show that multi-criteria optimisation can be applied as a design tool during the creative process. Maximisation of various aspects of comfort simultaneously was shown to be impossible, but compromise solutions could be found (da Graça et al. 2007).

Emphasizing that sustainable development, health, social security and renewable energy sources implementation are inextricably linked, research examines the state of the art of building's health and sustainability relevant technologies. Sustainability definitions, relevant criteria and indicators related to healthy buildings have been searched and studied. Reviewed is the wide range of physically sound interdisciplinary research, results of which are new knowledge and developed synergetic analytical/experimental methods that lead to a sustainable, healthy, comfortable/productive indoor and outdoor environment. Research and knowledge based building intelligence and e-automation are elucidated as crucial technologies and techniques for design, construction and operation of sustainable buildings (Todorovic and Kim 2012). Todorovic and Kim (2012) show, that qualitative relations and relevant comparative evaluation methods between indoor environmental quality and work performance or health, and further relation of both to the energy and energy efficiency, are not enough neither known nor searched. Initiated research is devoted to the healthy and sustainable buildings relevant performance modeling, evaluation methods and metrics investigation, and determination of all relevant interdependent relations, as well as determination of the relevant synergetic sustainability criteria and indicators. Initial results of related research are presented. Further research needs are outlined, drawing the attention on the role of harmony and interdisciplinarity in synergetic buildings health/sustainability study (Todorovic and Kim 2012).

Proietti et al. (2013) present the results of a detailed LCA study of a low-energy consumption building (thermal energy for heating equal to 11 kWh/m2 year) located in Perugia, Italy, according to European ISO 14040 and 14044. The building matches the criteria of environmental sustainability and bio-architecture, complying with the “PassivHaus” standard. All life cycle phases were included in the research: acquisition and production of materials, on-site construction and use/maintenance, demolition and material disposal (100% landfilling and demolition with waste recycling). A life span of 70 years was considered. The research was therefore focused on cradle-to-grave life, based on data collected by authors, integrated with data from the literature. In particular the study was carried out to analyze: the benefits due to the use of recycled materials, a solar PV (during the utilization years) and the final demolition of the building. The LCA modeling was performed using the SimaPro software application, connected to the ecoinvent database. The results show that applying energy saving measures (highly insulated building envelope and passive-house standard, solar PV, waste recycling and recycled products in pre-production phase) could significantly decrease the impact of modern dwellings, with the consciousness that new ways of building do not always provide a positive environmental outcome (Proietti et al. 2013).

Scientific evidence suggests important discrepancies between simulated and real energy performance of buildings. This is exacerbated in developing countries, such as Saudi Arabia, by the reliance on leading international building environmental and sustainability assessment schemes (e.g. BREEAM and LEED). The paper proposes to test the overarching hypothesis that the leading international environmental and sustainability assessment schemes are not adapted to the Saudi built environment, with a focus on the residential sector (Alyami et al. 2013). Alyami et al. (2013) aim to (a) test the applicability of international leading schemes such as BREEAM and LEED for the assessment of Saudi's built environment, and (b) identify applicable building assessment categories and criteria for Saudi's built environment. As building assessment methods involve multi-dimensional criteria, a consensus based approach is used to conduct the research. Hence, the Delphi technique is selected and conducted in three successive consultation rounds involving world leading experts in the domain of environmental and sustainable assessment schemes, as well as professionals and highly-informed local experts from academia, government and industry. The results reveal that international assessment schemes are not fully applicable to the Saudi built environment, as reflected in the development of a new building environmental and sustainability assessment scheme (Alyami et al. 2013).

The post-industrial European city is characterized by dispersed urbanization, resulting in increased travel, substantial use of land, social disparities and costs that are unsustainable in the long term. Consequently, most European countries have set the goal of limiting urban sprawl by prioritizing increased density in already built-up areas. To achieve this goal, it is not enough to build new buildings in the urban lots that are still available. Efforts to increase the density of existing neighborhoods are also needed. These actions represent an important opportunity for ensuring sustainability through the simultaneous integration of socio-studyal, economic, and environmental criteria in our cities (Pérez and Rey 2013). Pérez and Rey (2013) present the evaluative approach applied to a case study carried out in the Fleurettes neighborhood, located near the train station in Lausanne, Switzerland. It demonstrates how carrying out a structured sustainability assessment of an existing neighborhood as well as a multi-criteria comparison of three possible scenarios using a tool recently developed known as SméO may truly help the decision-making process when choosing an operational strategy (Pérez and Rey 2013).

Many ways, tools and concepts have been developed to determine performance indicators and criteria for healthy and comfortable buildings, focusing in general on the prevention of health and comfort problems. Perhaps the most important observation in these ways, tools and concepts is the fact that because dose-response relations in general are incomplete, most indicators do not seem to be useful. A second observation is the fact that interactions occurring at different levels (at human level, parameters of the indoor environment and at building level) are not taken into account. Moreover, the timeframe taken is often static (at a certain point in time) and not dynamic. Comparing static performance indicators with a dynamic process (being exposed in a building) will therefore most likely result in a non-valid outcome. And last but not least it is observed that the perception of positive stimuli are in general not considered. There is a need for a different or at least an adapted approach towards evaluation of health and comfort of occupants in the indoor environment: an integrative multi-disciplinary approach taking account of positive and negative stimuli and concerned with "real" needs of people (Bluyssen 2010).

With the rapid development of China's urbanization, green has become the subject of modern architecture and equipment systems development. High-performance of green air conditioning system design, operation and management, and system evaluation is one of the key technologies of green buildings. Based on the analysis of domestic and international green building evaluation system, and the study of green air conditioning system diagnostic indicator system suitable for China, including the theory and principles of diagnosis, diagnostic criteria and diagnostic parameters and result indicates, established a multi-level, multi-target, multivariate diagnostic indicator systems suitable for China. Expect to provide technical support for green technology development and application air-conditioning equipment systems (Yu 2010).

The existing office building stock is a key target for energy retrofits to substantially reduce adverse impacts on the environment, human health, and the economy. Success of an energy retrofit project is tied with the assessment and selection of energy efficiency measures that can satisfy stakeholders' diverse, and often conflicting requirements (Shao et al. 2014). Shao et al. (2014) establishe a model-based method to support design teams in making informed multi-criteria decisions for energy-efficiency solutions at the early design stage. The key feature of the hybrid framework is the integration of an analysis procedure carried out by a design team and a numerical procedure of optimization carried out by computer. Such an interaction is necessary as building design and retrofit requires many qualitative aspects that require human judgment. In contrast to previous approaches, this study provides a basis for embedding multi-objective optimization into the decision making on energy retrofit solutions, which considers the important role of stakeholders by carrying out the analysis procedure. An office building in Germany needing an energy retrofit serves as a case study to demonstrate the feasibility of the proposed model (Shao et al. 2014).

The effectiveness of every micro and meso-level factor can be assessed by basing it on the adequately described Level 2 or lower criteria subsystems.

1.6.2. The i^{th} level criteria subsystems

This subsection discusses in brief the ith level criteria subsystem describing the supply of resources for construction.

A company must consider how to organize its operations effectively after it has selected a specific market and nomenclature of offered production. This depends on the decisions made regarding construction materials and goods, personnel and construction machinery. A company's level of competitiveness depends on the decisions made in these regards. These issues will be next analyzed briefly.

The effectiveness of construction machinery can be evaluated on the basis of the following nth level criteria subsystem:

- Price.
- Exploitation expenses.
- Repair (ongoing and capital) expenses.
- Productivity.
- Number of performed operations.
- Reliability.
- Comfortableness.
- Physical and moral longevity.
- Weight.

Making huge investments into construction machinery is risky, because losses can be suffered when work capacity lessens. Profits could be down to a minimum, if the need for construction machinery and its manner of acquisition (rental, buyout lease or purchase) turn out to be wrong.

The larger companies and those that make greater profits can get a bank loan to purchase their construction machinery, which is more advantageous than renting or leasing with a buyout clause. Even though considerable money is invested for purchasing construction machinery, the buyout period is just a few years. Such an investment is unjustified, if the construction machinery will be used insufficiently intensely. Owners of construction machinery in Western Europe gain many benefits by purchasing, like tax advantages, which they do not receive by renting construction machinery or leasing it with a buyout option. Additionally, once the value of the construction machinery reaches zero due to amortization deductions, the machinery will still have scrap value or it can be resold.

The rationality of renting, leasing and purchasing construction machinery can be evaluated on the basis of the following indicator subsystem:

- Price of renting, leasing or purchasing construction machinery.
- Duration of time the construction machinery is to be used and intensity of its use.
- Physical and moral durability of the construction machinery.
- Financial situation of the organization.
- Tax advantages.
- Inflation level.

The effectiveness of construction materials and goods can be evaluated on the basis of the following nth level criteria subsystem:

- Price.
- Technical characteristics.
- Physical and moral longevity.
- Heat conductivity.

- Sound conductivity.
- Harmfulness to health.
- Assessment of the aesthetic view (assuming the construction materials and goods will be seen in the building to be constructed).
- Weight.

The prices of construction materials and goods constitute a good portion of the price of the building. Therefore all constructions that are trying to increase their profits also try to minimize the prices they pay for construction materials and goods while assuring the necessary level of quality at the same time. The larger construction organizations that seek to minimize the prices they pay for construction materials and goods usually hire experts on a full-time basis. Such experts analyze all the alternative sources for supplying construction materials and goods and their conditions for acquisition and then they select the most effective alternatives. The supply of construction materials and goods involves attempting to deliver the required amount and nomenclature of resources at the desired level of quality at the right time to the right place. Contractors generally request delivery of the needed amount of resources at the time they are needed in construction (avoiding shortages on one end and surpluses on the other). Construction materials and goods that are delivered before they are needed must be safeguarded from spoilage and thefts. Warehousing requires a special place and increased expenses for storage and insurance, so turnover capital is frozen. If resources are delivered too late, the construction may be stalled (laborers have no work to do) and its completion time, causing all the related consequences (paying fines to the client and greater interest fees to the bank on borrowed capital). Sometimes the delivered resources could be defective or at the wrong nomenclature and quantity. That is why construction materials and goods must be delivered to the construction site somewhat in advance of the work.

The prices of construction materials and goods depend on quality. Contractors often try to use cheaper materials during the construction, and the quality of the project suffers as a result. However, there is a sufficiently large choice of resources at the same level of quality. Additionally, over time, many alternative construction materials and goods are developed that have the same features as the traditional ones albeit at a lower per unit price.

Most large-scale contractors try to acquire construction materials and goods directly from their manufacturers: they get a lower per unit price when purchasing large quantities at a time. The prices for construction materials and goods can fluctuate depending on various offered discounts (for stability of purchases, timely payments and other conditions). Other conditions relevant to deliveries of construction materials and goods also interest buyers, such as credit availabilities (maximally saving turnover capital), reliability (upholding contractual terms defined in a contract maximally accurately), on-time deliveries, competitiveness of the supplied resources, quality of the delivered materials, good service, a level of joint work and mutual trust that would result in needed changes in the supply process whenever changes appear in the project and other similar circumstances. Sometimes clients are prepared to pay a slightly higher price for the same construction materials and goods, so long as the supplier satisfies the named conditions.

Supplier selection can be made on the basis of the following n^{th} level criteria subsystem:

- Price and quality of the supplied materials and goods (considering technical characteristics, physical and moral durability, heat and sound conductivity and harmfulness to health).

- Guality of supplied materials and goods (considering technical characteristics, physical and moral durability, heat and sound conductivity and harmfulness to health).
- Provided discounts.
- Reliability.
- Repayment and payment procedures.
- Credit opportunities.
- On-time deliveries.
- Good service.

The goals employees and employers have do not always coincide. Employees want as high a salary as possible, whereas employers are trying to save that money to increase the competitiveness and profits of the organization. Nonetheless, there are quite a few interests in common as well. Construction is becoming more and more mechanized and technically complicated, demanding more highly qualified personnel. Thus organizations find themselves needing to hire more qualified and trustworthy employees who are versed in the latest technologies and able to work effectively with the most modern equipment. Employee compensations and opportunity for a stable job highly depend on the effectiveness of an organization's operations. Therefore most employees are interested in working constructive with their employers.

Insufficiently qualified personnel can negatively affect the effectiveness of the construction process. Money is spent for staff training, and employees must designate their spare time to it. However, once employees advance, they will work more effectively and earn more themselves. Meanwhile the organization will be earning more and more profits. A lack of mastery increases the prices of performed jobs and the difficulties of introducing new technologies. It lowers the quality of the construction. Firms encourage their employees to improve their mastery by offering them higher salaries. However, the increased salaries raise prices leading to a drop in demand for the work the organization performs. Meanwhile the supply of a qualified labor force increases as compensations increase. Conversely, lowering salaries will cause the best employees to leave the company, and the competitiveness of the company drops. Therefore the hiring of personnel with differing levels of qualification along with opportunities for advancing qualifications need to be considered.

1.7. THE QUALITY OF LIFE AND THE BUILDING LIFE CYCLE

1.7.1. Vision for Lithuania

The life cycle of the built environment can be assessed taking into account many quantitative and qualitative criteria. One of them is 'Quality of Life in a Built environment' discussed further as a Vision for Lithuania.

Vision entitled "Quality of Life in a Built environment" seeks radical reductions in the negative effects of a built environment's lifecycle on the environment. Furthermore this vision pursues preservation of resources and a guarantee of a good quality of life by broadly applying technical, technological, social, cultural, ICT, organizational, managerial, economic, business, work safety and other innovations. It bases significant economic prosperity on a social agreement between all levels of society. This vision is broken up further into five subtopics.

One subtopic of this vision is titled “Indoor Microclimate, Morbidity, Quality of Place for Work and Studies”. The goal here is to develop a lifecycle of healthy, comfortable and aesthetic premises for people using innovative solutions.

Another subtopic is “Work Safety and Creation of Attractive Work Conditions”. Here the desired goal is to make a construction site a safe, attractive workplace based on modern innovations (technical, technological, ICT, organizational, managerial, economic, business, social, work safety and such).

“Reduction of the Effect on the Environment” is a subtopic of the vision endeavoring to implement a radical reduction in the negative effects of a built environment’s lifecycle on the environment by an effective use of resources and wasteless and other innovative technologies and restoration of a desolated environment and ecosystem.

The subtopic “Reduction of Natural and Technogenic Dangers” is the part of the vision pursuing an evaluation at the EU level about the effects of natural and technogenic dangers on a built environment and preparation of normative documents on a built environment’s lifecycle to reduce natural and technogenic dangers in various areas (resistance of buildings and the infrastructure to earthquakes, excessive rainfall, storms, floods and erosion of river and coastal systems, whirlwinds, landslides, explosions, fires, climatic and geologic changes and others).

“Transformation of the Construction and Real Estate Branch” is the subtopic aiming for transformations in the construction and real estate branch (including all its stakeholder groups) in order to make it more creative, flexible, innovative, knowledge-based, open to new business opportunities and a source of attractive jobs. The process will help:

- To achieve more transparency and justice in the branch and a more comfortable and safe built environment, better health and increased mobility.
- To achieve increasing value and importance of the branch to the urban and regional economy locally and to remain an important employer to urban and rural people.

A certain strategic research program must be implemented to bring life to this vision. An analysis must be made on how this program can be effectively implemented in practice, i.e. to include these measures in practical business solutions.

Implementation of this vision’s goals – guarantee of an indoor microclimate, reduction of morbidity and improvement of the place for work and studies – requires the following accomplishments:

- Making an integrated analysis of life quality by applying various sciences such as environmental protection, economics, management, organizational behavior, architecture, law, engineering, ethics, aesthetics, psychology, sociology, professional medicine and ergonomics.
- Paying special attention to satisfying consumer needs, i.e., implementing consumer oriented knowledge and device-based transformation of a built environment’s lifecycle.
- Expressing requirements and needs of stakeholder groups, including persons with various disabilities, and requirements of the indoor environment by quantitative and qualitative indicators.

- Developing relevant knowledge and a device-based intelligent decision support system for accumulating, processing and analyzing the aforementioned types of information.
- Making decisions and offering recommendations on requirements and needs.
- Creating a healthy, comfortable and safe environment by using innovative construction materials and products that do not emit pollutants indoors, sensors, intelligent systems, engineering systems and facility management methods.
- Constructing more social housing units.
- Creating new technologies for minimizing negative effects of construction sites, such as dust and noise, on the health, safety and life quality of neighborhood residents.
- Minimizing use of harmful construction materials and products in construction.
- Adapting a built environment for disabled and elderly people.
- Increasing the safety of a built environment (including home, work, recreational and other facilities as well as the travel between such sites) with non-skid stairs and floors and the like
- Providing rational thermal comfort, lighting, humidity and noise reductions.
- Reducing effects of the sick building syndrome and incidences of respiratory diseases and allergies as well as improving environmental conditions for work and studies.
- Optimizing a healthy and comfortable indoor environment in an integrated manner and a sustainable low energy built environment.
- Reducing social problems in a built environment.
- Applying intelligent e-democracy systems for resolving issues relevant to quality of life.

Implementation of this vision's goals – work safety and creation of attractive work conditions – requires the following accomplishments:

- Installing automated production lines for construction materials and products by moving more and more construction processes to factories, thus minimizing construction processes at a construction site.
- Adapting construction materials and products to producing semi-manufactures in factories along with a larger variety of modular products for productivity and work safety improvements.
- Intellectualizing machinery and equipment to industrialize and mechanize construction processes.
- Reducing the number of accidents in construction using the newest technologies including 3D and 4D modeling, intelligent devices, equipment and clothing.
- Minimizing the number of accidents and professional diseases.
- Integrating the latest knowledge in all construction processes.
- Using the latest knowledge and device-based intelligent systems in all construction processes.
- Improving the image of the construction branch to attract the maximum number of qualified employees, women among them, thereby minimizing the unqualified work force.
- Increasing the responsibility of each employee and encouraging effective teamwork.

- Creating conditions for employees to advance their qualifications while actively working.
- Improving work relations along a vertical management hierarchy, thereby improving career opportunities.

The following accomplishments are required to implement a reduction of effects on the environment for this vision:

- Rationalizing the planning of various city functions by geographic locations (residential, work, recreation, industrial areas, highways, green zones).
- Urban planning and management from the lifecycle theory perspective of a city, block, district or building to reduce the negative effects of the lifecycle of a city's block, district or building on the environment and restoring the desolated environment of green areas and such.
- Organizing construction for reductions of negative effects on the environment and energy consumption to a minimum during a building's lifecycle (i.e., setting goals and designing; manufacturing construction products including recycling and recycled materials and products; construction; commissioning; facility management and demolition).
- Designing and constructing a building for reducing noise to residents and preventing harm to their health, thereby allowing decent conditions for work and rest.
- Improving protection of people, animals, plants and the ecosystem from the effects of pollution on the surrounding environment (prevention of air, soil and water pollution).
- Regenerating polluted soil.
- Developing soil and water quality monitoring systems (chemical sensors providing real time information about ground water quality and integrated technologies for protection of soil and water from critical situations or drastic changes, etc.).
- Conducting studies and implementing innovative solutions to reduce energy consumption and its negative effects on the environment (e.g., CO_2 emissions) by:
    - installation of low energy and renewable energy technologies;
    - development of new technologies for production of efficient and clean energy;
    - development of technologies for efficient energy management in a built environment;
    - development of construction products that drastically reduce the heating needs of new and renovated buildings;
    - construction of new buildings able to generate energy without CO_2 emissions.
- Conducting studies and implementing innovative solutions to improve the system of public transport by developing:
    - personalized public transport accessible to all, including the disabled;
    - a logistic system with centers at the edges of urban areas integrated with main highways, thereby avoiding heavy vehicles in a city's centre;
    - innovative and more efficient public transport.
- Utilizing waste from various construction organizations.

- Manufacturing construction products and increasing waste recycling to save resources and energy for improving manufacturing processes of construction materials and products.
- Planning in the early designing stages for building construction, demolition/disassembling, utilization and reuse of construction materials and products that will aid more efficient use of waste produced by building construction, demolition/disassembly and utilization and exploitation of unused resources (while designing a construction site, working at it and such).
- Integrating systems to analyze the effect of a building's lifecycle on the environment (traffic noise, vibrations and air, soil and water pollution, etc.), thereby enabling such systems to model and forecast the negative effects of a built environment on the environment.
- Developing intelligent teamwork systems involving all stakeholder groups.

Implementation of a reduction of natural and technogenic dangers to realize the vision requires the following actions:

- Harmonizing EU scientific research on new construction products, sensor technologies, mathematical models, computer modeling methods and natural research with normative documents from various fields relevant to reducing natural and technogenic dangers, such as resistance of buildings and the infrastructure to earthquakes, excessive rainfall, storms, floods and erosion of river and coastal systems, whirlwinds, landslides, explosions, fires, climatic and geologic changes and the like.
- Analyzing the effect of climatic changes on a built environment to evaluate any increasing effect of floods, excessive rainfall, storms, coastal erosion, etc.
- Developing advanced integrated methods, models and systems to monitor, evaluate, forecast, determine and notify early, manage, prevent and analyze risk and reduce natural and technogenic dangers by employing methods, models and systems that must include information to the society on preparation for unforeseen cases, analysis of the effects on business processes, distribution of roles and responsibilities during crises, training and competence, quality and performance management.
- Reducing natural and technogenic dangers with stakeholder group participation (end users, policy makers, practitioners) by applying interdisciplinary knowledge.
- Informing the society about existing and forecasted situations by developing a system for lifelong e-education and training of the society.

This vision also requires implementation of the transformation of the construction and real estate branch by accomplishing the following:

- Reforming branch management by applying more efficient and simpler management systems, thereby reducing the time and resources required for management.
- Determining how the state should regulate the construction business (from maximum state involvement to unlimited market forces) and how regulations should change over time.
- Aiming for legal acts and normative documents that regulate the construction business to create good conditions for innovative organizational development in construction by applying innovative activities more broadly.

- Creating a legal environment that facilitates and encourages development of innovative practices and stimulates interest among employees and companies to improve the quality of the work force.
- Reviewing documents on construction related regulations issued by ministries, counties and municipalities for creating a uniform system of national, technical and building safety requirements that is free of duplicated, unimportant or ambiguous documents.
- Improving employer-employee relations in the entire sector.
- Developing a consumer-oriented, innovative lifecycle of a built environment.
- Transforming the construction and real estate branch into a knowledgeable and device-based sector covering the entire value chain, from a client to a rank and file worker.
- Developing an integrated knowledge system of a built environment's lifecycle.
- Applying knowledge, information, communication, satellite technologies and electronics during the entire lifecycle of a built environment.
- Developing "intelligent products" (identification devices, sensors, diagnostic tools) that are able to disseminate information about a construction process condition involving deviations from the work schedule, supply of construction materials and such, the microclimate, conditions supporting constructions and other aspects.
- Constantly evaluating and monitoring the quality of a built environment in a transparent process reflecting a new image of innovations, creating new business opportunities and offering good work conditions for all.

1.7.2. The quality of life, the building life cycle and its constituent parts

Construction process is the broad mechanism for the realization of human settlements and the creation of infrastructure that supports development. This includes the extraction and beneficiation of raw materials, the manufacturing of construction materials and components, the construction project cycle from feasibility to deconstruction, and the management and operation of the built environment In Greece, the complex problems shared by cities are evidence of the impacts of urban sprawl (Vatalis et al. 2013). Vatalis et al. (2013) aim to investigate the sustainability components affecting decisions for green building projects. The research method is based on a questionnaire survey of thirty two participants who asked to assess nine sustainability components namely: Life cycle assessment, energy efficiency and renewable energy, water efficiency, environmentally preferable building materials and specifications, waste reduction, toxics reduction, indoor air quality, smart growth and sustainable development and environmentally innovative projects, which affect the decisions for green building projects. The respondent results indicate how participants prioritized the sustainability components ensuring a better quality of life inside buildings based on the principals of "green" buildings economy. Energy efficiency and renewable energy is considered of high priority followed by the reduction of toxic materials, indoor pollution and water saving (Vatalis et al. 2013).

The sustainability of housing units can be improved by integrating green building equipment and systems such as energy-efficient HVAC systems, building envelopes, water heaters, appliances, and water-efficient fixtures. The use of these green building measures often improves the environmental and social performances of housing units; however they can increase their initial cost and life cycle cost (Karatas, El-Rayes 2015). Karatas, El-Rayes (2015) present a multi-objective optimization model that is capable of optimizing housing design and construction decisions in order to generate optimal/near-optimal tradeoffs among the three sustainability objectives of maximizing the operational environmental performance of housing units, maximizing the social quality of life for their residents, and minimizing their life cycle cost. The model is designed as a multi-objective genetic algorithm to provide the capability of optimizing multiple housing objectives and criteria that include minimizing carbon footprint and water usage during housing operational phase, maximizing thermal comfort, enhancing indoor air and lighting quality, improving neighborhood quality, and minimizing life cycle cost. An application example is analyzed to illustrate the use of the developed model and evaluate its performance. The results of this analysis illustrate the novel capabilities of the model in generating 210 near-optimal tradeoff solutions for the analyzed housing example, where each represents an optimal/near-optimal and unique tradeoff among the aforementioned three sustainability optimization objectives of maximizing the operational environmental performance of housing units, maximizing the social quality of life for their residents, and minimizing their life cycle cost. These novel capabilities of the developed model are expected to improve the design and construction of housing units and maximize their overall sustainability (Karatas, El-Rayes 2015).

Masotti et al. (2011) present low-tech and low-cost solutions such as, in particular, self-help retrofitting technologies, to improve the quality in spontaneous settlements (favelas) which arise close to the major Brazilian towns. In particular, a critical analysis of the favela Vila Novo Ouro Preto in Belo Horizonte has been elaborated, highlighting both social, studyal and technical aspects to design suitable technological components to be adopted in order to improve environmental comfort. The study has been developed in order to meet people needs and expectations so as to guide planning and design perspectives aiming at improving the quality of life in a sustainable socio-studyal way. The contribution suggests a selection of interesting techniques and processes achievable in self-help construction; some of them are quite innovative since they use in a new and different way recycled materials and products, thus boosting economic growth and social development (Masotti et al. 2011).

The problem of the quality of life is a multidimensional and complex issue. It concerns the members of more than one profession such as planners, designers, architects, economists, lawyers and design-makers. Although it is not easy to find the most suitable indicators for the measurement of the quality of life, appropriate definitions can be made depending upon the goals of the researcher. The relationship between the quality of life and the environment has become an important subject for study for the last several decades. Numerous publications are produced in the academic circles. In addition, organizations like the United Nations, it specialized agencies, the European Union and the Council of Europe contributed greatly to the progress of environmental thought which keeps the phenomenon of the quality of living constantly in the agenda (Keles 2012).

Our environment is an important resource, not only for use in development, but to conserve. In the 1990s, the importance of our environment became underscored for conservation efforts in many areas. Among them, the building construction industry had played a role in impoverishing the environment, for the sake of improving our quality of life, but at a great cost of impact to the environment. It is therefore incumbent upon the industry to endeavor to mitigate effects from building constructions to our environment. During the life cycle of a building, it consumes energy and other natural resources. But it is difficult to evaluate their effects on the environment during the entire course of a building's life span, without much time and effort. An easy to handle program is necessary for the calculation of effects to the environment during the life cycle of a building. Many of the software programs developed for these kinds of assessments can only be used with significant restrictions because of their differences in design for scope and content (Lee et al. 2009). Lee et al. (2009) present foundations for the development of a Life Cycle Assessment (LCA) program for buildings, focusing on their energy consumption and carbon dioxide emission levels, with a comparison of domestically and foreign designed programs.

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Building renovation is a real opportunity to meet current challenges of primary energy reduction and global warming. But it is not sufficient in terms of sustainable development and sustainable retrofitting of buildings. Sustainable building renovation is primarily an opportunity to improve comfort, wellbeing and quality of life of users while lowering environmental impact of buildings. This contribution, studied in one of the subtasks in IEA SHC Task 47 - Solar Renovation of Non-Residential Buildings – Subtask D; “Environmental and Health Impact Assessment”, aims to broaden the vision of designers and building owners to other environmental and health issues in the context of advanced renovation of non-residential buildings (Trachte and Salvesen 2014).

The environmental movement has emerged as a response to society's concerns about the sustainability of Earth's natural resources and the effects of human activity on the environment and on society's well-being. Effects such as deforestation, air and water pollution, and resource depletion have shown to cause a decline in the quality of life of humans. In response, concerned citizens, non-governmental organizations, and governments have started initiatives to ensure the responsible utilization of our natural resources. Two of these initiatives in particular are relevant for U.S. hardwood products manufacturers: forest certification systems and green building standards. The former are standards created with the purpose of ensuring the sustainable utilization of the forest resource. Most forest certification systems also offer a chain-of-custody certification, to assure customers that label-carrying products indeed originate from certified forests. Green building standards were created to reduce the environmental impact caused by building construction and use (Espinoza et al. 2012).

1.8. CRITICISM OF BUILDING LCA

Studies of the same product often are giving yield different results. The boundaries that are established for a study, the functional unit that is assessed, the impact measures that are reported, and even the extent to which all lifecycle stages are taken into account can be different from one study to another. In recent years, there has been a concerted international effort to ensure that such differences are either eliminated in comparative studies or the reasons clearly delineated in reports. LCA is not a method that results in a simple score; it is one that requires users to read the report and understand what has been done and why. The next look at some of the specific aspects that can lead to this kind of criticism (Trusty 2010b):

- The Study or Tool Doesn’t Deal with the Whole Life Cycle. Not all studies deal with the full life cycle because for many products the manufacturer simply has no way of knowing exactly how the product will be used, maintained and treated at the end of its service life.
- The Study Doesn’t Show Human Health or Ecotoxicity Impacts. As LCA evolved over the years, not only were different impact measures developed, but there were also different methods developed for calculating the measures. The types of impact measures basically subdivide into two main categories: mid-point and end-point. Mid-point measures can be thought of as measures of environmental loading; for example, the release of greenhouse gases. End-point measures are essentially measures of ultimate impacts on human and ecosystem health. There are also measures that are simply aggregations of Life Cycle Inventory (LCI) data; energy use for example. Uncertainty increases as one moves from LCI data aggregations to mid-point and then to end-point measures. In 2005, the United Nations Environment Program (UNEP) commissioned a study to examine the issue and found a huge uncertainty range across seven different methods for calculating end-point impacts. As a result, such end-point measures as human cancerous and non-cancerous health effects and ecotoxicity have been dropped, or are in the process of being dropped, and a scientific consensus model – USEtox – is being adopted. USEtox contains only the most influential model elements and significantly reduces the uncertainty level, but is still not a recognized impact measure in the standards and should be treated with caution.
- LCA doesn’t Include Social Effects or Land Use. No tool should be criticized for not doing things it was never intended to do, and we have to think instead in terms of a toolkit stocked with complimentary tools. For example, work is under way to develop a social impact version of LCA, but it will undoubtedly be in a separate category complimentary to environmental LCA. Land use effects and issues such as biodiversity related to resource extraction are unquestionably important. However, they are very site specific and not readily handled at the level of product groups, or even at the level of one company if it has multiple extraction sites in different regions. This is much better handled through complimentary tools such as resource extraction certification systems. Similar comments can be made about risk analysis

related to toxic inputs and outputs in a production process. There are better methods for tracking and assessing the risks of such flows.

- Different Tools Give Different Answers. For example, there are two prominent LCA tools in use in the United States that are intended for different purposes. Both are aimed at the building community as opposed to LCA practitioners. One deals with complete building assemblies and the other with individual products; one covers maintenance and replacement over a 60-year-assumed service life and the other doesn't. The reality is that they are complimentary tools intended to serve different functions in the decision process. Similarly, there are different tools in the market intended for use by LCA practitioners. They come with data that the user can change, and it is essential that the user be trained in their use.
- There is No Consistent, Readily Available Data. The Life Cycle Inventory (LCI) is at the heart of any LCA analysis, and how well the data represents reality strongly influences the value of LCA results. However, data collection is also the most time consuming and costly part of the process. As the LCA method developed over the years, the absence of national comprehensive databases led to using whatever data was easily available; this in turn led to inconsistencies, which further supported arguments put forward by those opposed to LCA. Now, however, industry associations and their members are increasingly recognizing the importance of making data public by submitting it to national databases – the U.S.

1.9. FUTURE INCENTIVES FOR BUILDING LCA

Perera et al. (2010) establishes that, though many procurers have begun to use LCC as a decision-making tool, its use is still far from being systematic and the calculation methodologies are sometimes far from robust. Often, it is limited to quantifying the monetary value of selected costs; in most countries, nonfinancial elements are only now entering the discussion.Moreover, procurers tend not to be able to use LCC to inform bigger, more strategically advantageous decisions. For these reasons it is clear that the current sustainable public procurement model is not delivering the best value for tax payers' money. Perera et al. (2010) believe this needs to change. Perera et al. (2010) report also highlights a lack of motivation to use LCC because, often, the financial gains or longterm benefits will not flow back to the original decision-maker; the long-term financial benefits are beyond the scope (or term of office) of the decision-makers working on the initial procurement proposal; and the consideration of future issues is beyond the scope of responsibility of the decision-maker/procurer. It follows that better value for tax payers'money is delivered when life cycle costing or "whole life value thinking" is applied at the level of resource allocation. We should be focusing our attention on those who allocate budgets and scrutinize the use of public funds rather than on those who are able to make procurement decisions only within strict budgetary and financial limits (Perera et al. 2010). Next, Perera et al. (2010) present a few recommendations for future incentives for building LCA:

- Recommendation 1: LCC should be part of public expenditure policy—including procurement policy—and thereby should be integrated into sustainable public procurement policies. LCC, or whole life value thinking, will then be an integral part of the resource allocation process. Since resource allocation and budget setting is undertaken at a much higher level in the organization than routine procurement decision-making, "whole life value thinking" will begin to permeate all public spending decisions.

- Recommendation 2: LCC should be made a necessary component in sustainable public procurement policies and those responsible for public expenditure policy should provide the necessary tools, platforms, budgets and expertise to perform this analysis in a cost-effective manner. Many of the best cases of sustainable procurement are to be found where new funding models have been applied. This might be described as sustainable procurement being delivered in spite of, rather than because of, the resource allocation systems in place in many organizations.
- Recommendation 3: Alternative models of asset design and delivery, such as energy performance contracting agreements, need to be promoted as efficient means of implementing sustainable public procurement policies.
- Recommendation 4: Organizations should be enabled to retain at least a proportion of savings achieved through sustainable procurement to "pump-prime" initiatives with higher upfront investment costs.
- Recommendation 5: Alternative models of asset ownership, such as private finance initiatives and such other private-public partnership, need to be explored to provide more efficient models for delivering LCC efficient public procurement. So it also follows that:
- Recommendation 6: LCC should be promoted more as a tool for showing value for money, rather than simply a method for calculating the costs of purchasing environmentally and socially preferable good, services and assets.
- Recommendation 7: Clear guidance should be provided on how and when organizations should capture and report benchmark data used in life cycle costing exercises. This will help raise the standard of life cycle costing overall, as well as improve the quality of data. Indirectly, it is also likely to contribute to better management information systems and more effective reporting.

Future incentives for using the LCA methodology can be anticipated, given the evolution of current rating systems and the emergence of green building codes (Bayer et al. 2010).

The reality is that most building products have both positive and negative aspects when it comes to environmental performance. The task is to balance the pros and cons, understand the trade-offs in terms of true environmental performance measures, and use materials to their best advantage, recognizing that all buildings typically incorporate a wide range of materials. LCA is no panacea, but it is the best method we have right now to shift away from simple labels and a focus on single attributes to true environmental performance measures. The integration of LCA in Green Globes and LEED is most certainly a step in the right direction, leading on a path that should and must be improved and made progressively easier to tread (Trusty 2009).

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Chapter 2

2. BUILDING LCA DATABASES AND TOOLS

2.1. LCA DATABASES

2.1.1. Development, review, documentation, management, and dissemination of datasets contained in life cycle databases

Obtaining necessary data for a life cycle analysis can be a difficult task. Sometimes companies are willing to provide available data in order to assist with a life cycle analysis. However, longstanding confidentiality agreements often present unforeseen difficulties in obtaining necessary and required data. To obtain needed data, several extensive databases and software applications are available and may be used. They include data based on observations, quantitative research, and manufacturer information to calculate national averages. Using a software package can be a convenient way to obtain data for a life cycle analysis, but software packages can also introduce errors into the process. For example, if the LCA observes a national trend, then the available software programs will provide sufficient data. Conversely, if the LCA is specific to a manufacturer or region, then the averaged data used in a software program will most likely not be detailed enough. Because data acquired during this process may include gaps due to lack of information, it is necessary to explain these gaps in the final report (Williams 2009).

Data collection is closely linked to validation. The validation process starts from data as they are used in the process model. Results of the validation process may lead to the conclusion that further data are needed, or that the data used are insufficient. Validation at the dataset level serves to ensure that the model represents the actual process. The additional data may add complexity to the LCA model structure and process modelling, and may require additional data collection. Therefore, the value of the additional information has to be balanced against the costs of generating, collecting, and maintaining it (Global Guidance 2011).

LCI data are at the heart of any LCA analysis. Several organizations and LCA tool developers have developed LCI databases that contain material and energy use data as well as emissions data for commonly used products and processes. These databases contain elementary flows (inputs and outputs) for each unit process for a product system and are specific to countries and regions within countries. The LCI data are region-specific because the energy fuel mix and methods of production often differ from region to region. The data can be based on industry averages or could be supplier-specific (Bayer et al. 2010).

It is important to not only consider the data source, but also consider its validity. The data used in a LCA should be current. Because many manufacturing processes change frequently, the data must reflect the current process. It may be necessary to complete additional research to fill data gaps. Surveys sometimes provide enough information to fill the current data gaps. Some examples of common data gaps that might be filled by conducting a survey include: product turnover rates; maintenance frequency and need; changes in manufacturing processes;

and using a product for something other than its intended purpose. Data availability also varies by region, country, and continent. In general, the United States, Canada, Western Europe, and Japan have the most readily available and accurate current statistical information. In regions and countries where data is unavailable, it may be acceptable to draw a comparison in data between similar countries that are not on the same continent. However, it is very important to make the assumptions reasonable. For example, just because there is a lack of data on Chinese manufacturing and a wealth of data from European manufacturing, one cannot conclude that industries in China and Europe are comparable or even similar to each other. Each location has drastically different attitudes toward and laws governing the manufacture and disposal of materials, which makes such a substitution unrealistic. When comparing two or more sets of data, it is important that the sets are equivalent to one another. If the available data is not equivalent to one another, it cannot be correctly compared and analyzed. When evaluating data equivalency, it is necessary to consider the data source, age, and type. If there is detailed quantitative data for one process or product, but there is minimal data on another process which will be used for comparison, the analyst has to decide whether to omit data from the first data set in order to ensure data quality equivalence for both sets. The analyst can also report all of the data available, but only use equivalent data to make a quantitative comparison (Williams 2009).

Databases may contain industry averages or product-specific data. Industry averages make more sense in whole-building LCA tools, as these tools are designed to be used by architects to make decisions about assemblies at the schematic design stage. A specific supplier is not usually identified in early-stage design. At the specification and procurement stages, if the supplier-specific data are available, a decision to select the most environmentally sensitive supplier for a specific product could be assisted by the use of LCA. It may be necessary to engage an LCA practitioner at this stage, as LCA tools for architects may not have supplier-specific capabilities (Bayer et al. 2010).

Data sources for LCIs can include (Williams 2009):

- Equipment meter readings
- Operating logs and journals
- Industry and manufacturer reports and databases
- Test results
- Government reports, databases, and documents
- Publically available data and reports
- Published documents (journals, articles, books, references, encyclopedia, patents)
- Related previous tests and LCAs
- Government, process, and equipment specifications and requirements
- Previous experience
- Surveys and audits.

Life cycle assessment (LCA) provides a holistic, science-based analysis method for decision-makers in all sectors concerning policies, product purchases, process performance, and education systems. The use of LCA for product and service analysis is increasing and the demand for life cycle inventory (LCI) data is growing. The U.S. LCI Database was created and has been publicly available at www. nrel.gov/lci since 2003. The advantages of such a data source include (U.S. Life Cycle Inventory Database 2012):

- It provides comprehensive information for policy makers to make consistent comparisons between policy options regarding environmental decisions.
- It enables better evaluation of environmental opportunities and trade-offs of alternative product systems.
- Indirect sources of environmental impacts can be addressed in the redesign of products for better overall environmental performance.
- Legitimate, verifiable environmental market claims can be better substantiated based on quality LCI data.
- Environmental hotspots can be identified and targeted for improvement.
- It provides input to measure and monetize environmental externalities through, for example, a cap-and-trade system.

Also, other different built environment life-cycle inventory analysis databases can be found on the Web (Hossain 2013): EPA TRACI (http://www.epa.gov/nrmrl/std/traci/traci.html), Green Footsteps (http://greenfootstep.org/), NREL LCI Database (https://www.lcacommons.gov/nrel/search), Pharos Framework (http://www.pharosproject.net/framework/index/), ecoScorecard (http://ecoscorecard.com/), CORRIM (http://www.corrim.org), University of Bath, Inventory of Carbon & Energy (Hammond, Jones 2008).

Next, we present a few available LCA Databases as an example.

Comparability of life cycle assessment (LCA) results based on different background data has long been debated. This is one of the main issues in building LCAs since buildings are complex products, which require multiple material data for the assessment. The objective of this study was to investigate numerical and methodological differences in existing databases related to building LCAs. The five databases selected were compared in terms of greenhouse gas (GHG) emission values in the material production phase of the three reference buildings, two wooden buildings with different frame types and a precast concrete framed building. The results demonstrated that the databases show similar trends in the assessment results and the same order of magnitude differences between the reference buildings are shown by all the databases. It was also revealed that the numerical differences between the databases are quite large at some points and the differences originate from multiple data elements. The findings indicate the importance of the number of data and a clear statement of the bases of the values for comparative assessment. It would be more realistic to develop a reporting and communication system for LCAs rather than trying to unify the methodologies among the databases. An optimization of open information is significant for further development of LCA databases (Takano et al. 2014).

Use of exterior shading systems is important to increase energy savings in residential sector, mainly in warmer climates exposed to direct sunlight. These types of shades can keep inside temperatures cooler and consequently reduce cooling loads and costs. This research employs Life Cycle Assessment (LCA) to compare the effects of three different shading materials on building energy consumption and their impacts to the environment within five major climate zones defined by American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). To achieve this objective, A Life Cycle Inventory (LCI) is used to quantify the energy and emissions of the exterior shading systems during the manufacturing process, in-service and end of life. The Building for Environmental and Economic Sustainability (BEES) model and SimaPro 8.0 software (Ecoinvent 3.0 database) were employed to develop the life cycle inventory of the shadings through all life cycle stages (Babaizadeh et al. 2015).

Life-cycle analysis of a Concentrating Photovoltaic (CPV) for building-integrated applications is conducted. Two configurations (with and without reflective film) are examined: based on embodied energy/embodied carbon, multiple scenarios and databases (Lamnatou et al. 2015).

The purpose of this research is to apply life cycle assessment (LCA) methodology for green building certification in South Korea. The method of environmental assessment in the field of building materials was examined using United States' LEED, and the United Kingdom's BREEAM building certification systems. Life cycle data and assessment methods were established on major categories of materials thorough theoretical consideration on life cycle assessment. Building materials, assembly methods, and building use considerations were used to develop an assessment model to evaluate the environmental performance of a building. Numeric values for use in the developed model were established for concrete, rebar, gypsum board, steel, cement brick, glass, and insulation materials to potentially reduce greenhouse gas (GHG) emissions by 95% or more. An assessment method and LCA database were established (Gong et al. 2015).

This research presents a framework for LCA-based environmental decision making for commercial buildings at the conceptual design phase, compares it to the currently available LCA tools and data bases, and identifies the "next steps" in developing a comprehensive LCA standard for assessing whole building life cycles to support environmental decision making in design and construction. Findings and contributions were achieved as follow: 1) Current LCA tools are balkanized and usually address only one life cycle stage, material or system in a building. 2) LCA-related databases normally only address materials and product; they do not address construction activities or building operations. 3) LCA tools and databases generally require a completely separate activity, data input and expertise; they are not integrated into routinely used architecture, engineering, and construction (AEC) tools, methods or best practices. 4) LCA based decision-making will not become an AEC best practice until it is fully integrated, comprehensive, standardized, affordable, and demanded by customers and municipalities (Means and Guggemos 2015).

The Municipality of Città della Pieve in central Italy, promoted the creation of a "Renewable Energy Park" in a deprived area of its territory, to provide a space where the main technologies for the production of green energy could be installed. An educational/demonstration "zero energy consumption" building for multifunctional activities will also built with the most innovative techniques to save energy. This research presents the results of the life cycle assessment (LCA) of the "zero energy consumption" building for a useful life of 50 years. All life cycle phases were included in the research: acquisition and production of materials, on-site construction and use/maintenance, demolition and material disposal. Moreover, a few different disposal scenarios were considered. The LCA modeling was performed using the SimaPro software application, connected to the Ecoinvent database. The environmental impact of the zero energy consumption building was assessed by using specific indicators (Desideri et al. 2014).

Environmental criteria have to be taken into account when it comes to selecting a specific building component among a set of candidates with the same function. This article presents a methodological approach – based on both Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA) – for the selection of building components according to their environmental impact efficiency. A three-step LCA + DEA approach is proposed and tested through a case study for 175 external walls. The three steps of this approach involve data collection, life cycle impact assessment, and DEA of the sample of building components using environmental impacts as DEA inputs. Overall, from the availability of multiple data on the material and energy flows of each building component, the method provides decision makers with eco-efficiency scores and environmental benchmarks. A cautious definition of the set of candidates is critical, as relative efficiency scores are calculated. Data availability and functional homogeneity regarding the building components evaluated are the key requirements for the general use of the method. The three-step LCA + DEA approach proposed is proven to be a useful method to enhance decision making and environmental benchmarking in the building sector (Iribarren 2015).

The built environment is recognized as a major hotspot of resource use and environmental impacts. Life cycle assessment (LCA) has been increasingly used to assess the environmental impacts of construction products and buildings during the last 25 years. A new trend stems in the application of LCA to larger systems such as urban islets or neighborhoods. This review aims at compiling all papers related to LCA of the built environment at the neighborhood scale. A focus is carried out on 21 existing case studies which are analyzed according to criteria derived from the four phases of LCA international standards. It sums up current practices in terms of goal and scope definition, life cycle inventory (LCI) and life cycle impact assessment (LCIA). The results show that the case studies pursue different goals. They are either conducted on existing or model neighborhoods with an aim at building knowledge to feed urban policy making. Or they are conducted on actual urban development projects for eco-design purpose. Studies are based on different scopes, resulting in the selection of different functional units and system boundaries. A comparison of data collection strategies is provided as well as a comparison of LCIA results for cumulative energy demand and greenhouse gases emissions. Methodological challenges and research needs in the field of application of LCA to neighborhood scale assessment are identified, such as the definition of the functional unit and the need for contextualization methodologies aligned with data availability at the design stages of a neighborhood development project (Lotteau 20015).

The present research is a life cycle analysis of a patented building-integrated solar thermal collector which was developed/experimentally tested at the University of Corsica, in France, with the concept "integration into gutters/no visual impact". Three configurations (reference and two alternatives) are evaluated. The life-cycle impact assessment methodologies of embodied energy (EE)/embodied carbon (EC), two databases and multiple scenarios are adopted. The results reveal that the reference system can considerably improve its environmental performance by utilizing collectors connected in parallel. The Energy Payback Time of the reference system decreases to less than 2 years by parallel connection while it is around 0.5 years if recycling is also adopted. The EE of the systems is around 3 GJprim/m2 and it is reduced to around 0.4–0.5 GJprim/m2 by recycling. The EC of the configurations is approximately 0.16 t CO2.eq/m2 without recycling and around 0.02–0.03 t CO2.eq/m2 with recycling. CO2.eq emissions are strongly related with electricity mix. A reduction 28–96% in CO2.eq emissions of the systems is achieved by adopting configurations with "double collector surface/output". Concerning indicator of sustainability, the system with parallel connection shows a value of 0.78. The findings of the present investigation could be utilized for the design of building-integrated solar thermal systems as well as for research purposes (Lamnatou et al. 2014).

The aim of this research is to improve the contribution of the Life Cycle Assessment (LCA) methodology to setting up a cradle to cradle (C2C) life cycle of building materials. For this, the rules included in the most recent European Standards for the environmental assessment of the waste flows in the life cycle of these materials were taken into account. The paper starts with the identification of the waste flows that can be generated or used throughout the life cycle of building materials. Standardized calculation rules for the evaluation of the environmental impacts and benefits of these flows are then described and analysed in detail. Finally, a summary of the information available in LCA databases related to the end-of-life of construction materials is presented, and selected case studies are examined to provide an overview of the contribution of the LCA approach described in European Standards to close the loop in the life cycle of building materials (Silvestre et al. 2014).

Comparisons of buildings in similar climates built in accordance with different regional construction practices and building rating systems can provide useful insights in sustainable design practices. The objectives of this study were: (1) to perform energy related life cycle assessments of a typical LEED-H (Leadership in Energy and Environmental Design for Homes) single-family home in New Jersey (US), and a typical Minergie-P single-family home in Chur, Switzerland; and (2) to assess the effect of rating systems and construction practices on the buildings' environmental impacts. Inventory data was obtained from the Ecoinvent 2.2 database with a replacement of the Western European electricity mix with the US or New Jersey electricity mix for the New Jersey home. The Swiss building performed better regarding non-renewable energy consumption, Global Warming Potential and Acidification Potential mainly due to the geothermal heat pump and the Swiss electricity mix while there was less of a difference regarding Ozone Layer Depletion Potential and Eutrophication Potential. The influence of electricity sources exceeded the effects of longer building life time or the removal of the Swiss basement. Regional building practices, local codes and environmental policies should take the electricity mix into account because it is so important (Mosteiro-Romero et al. 2014).

Small and medium-sized commercial buildings can be retrofitted to significantly reduce their energy use, however it is a huge challenge as owners usually lack of the expertise and resources to conduct detailed on-site energy audit to identify and evaluate cost-effective energy technologies. This study presents a DEEP (database of energy efficiency performance) that provides a direct resource for quick retrofit analysis of commercial buildings. DEEP, compiled from the results of about ten million EnergyPlus simulations, enables an easy screening of ECMs (energy conservation measures) and retrofit analysis. The simulations utilize prototype models representative of small and mid-size offices and retails in California climates. In the formulation of DEEP, large scale EnergyPlus simulations were conducted on high performance computing clusters to evaluate hundreds of individual and packaged ECMs covering envelope, lighting, heating, ventilation, air-conditioning, plug-loads, and service hot water. The architecture and simulation environment to create DEEP is flexible and can expand to cover additional building types, additional climates, and new ECMs. In this study DEEP is integrated into a web-based retrofit toolkit, the Commercial Building Energy Saver, which provides a platform for energy retrofit decision making by querying DEEP and unearthing recommended ECMs, their estimated energy savings and financial payback (Lee et al. 2015).

Life Cycle Energy Analyses of buildings provide useful information for achieving sustainability. However, care must be taken when interpreting previous studies because of different life cycle stages included. Other problems found include the use of different types of areas and quality of data. This research presents an audited database of Life Cycle Energy Analyses of buildings. A Literature Based Discovery method has been adopted to analyze 38 research works consisting of 206 cases. The average initial embodied energy for offices is found to be 10.47 GJ/m2 and that of residential property is 4.10 GJ/m2. When the initial embodied energy is expressed as number of years of heating and cooling energy, the range is very wide. However, when it is expressed as number of years of operational energy, the results are consistent (7.8 years for offices and 7.5 years for residential buildings). It is expected that the audited information on the energy requirement of buildings will provide valuable information for designers and decision makers (Yung et al. 2013).

The evaluation of the environmental performance of energy systems used in residential buildings by applying the principles of the Life Cycle Analysis is an established methodological approach. Applying it in practice presents, however, significant interest, as a lack of available data has to be overcome. The research results include the analysis of the production, disposal and transportation of the materials used for the manufacturing processes of the building's energy systems, which include an oil and a gas fired boiler, split unit air conditioners, mono-Si and poly-Si PV arrays, flat plate and evacuated tube solar thermal collectors and their auxiliaries. The data needed for the analysis were taken from audits in the industries producing those systems, from related studies already published and from publicly available databases, when no other source was available. In this way, a comprehensive and fully adjustable database of the systems' environmental impact has been created. This database can be a part of an integrated dynamic decision support tool, or it can be used in combination with tools commercially available. It can therefore assist prospective users in the selection of the appropriate energy systems that will lead to the minimization of the total environmental impact of new and existing buildings. The results are applied to a representative residential building and its systems are evaluated and analyzed for several scenarios (Anastaselos et al. 2015).

A screening of Life Cycle Assessment for the evaluation of the damage arising from the production of 1 kg of recycled Polyethylene Terephthalate (RPET) fibre-based panel for building heat insulation was carried out according to the ISO 14040:2006 and 14044:2006. All data used were collected on site based on observations during site visits, review of documents and interviews with technical personnel and management. These data were processed by using SimaPro 7.3.3, accessing the Ecoinvent v.2.2 database and using the Impact 2002 + method. The study showed damage to be equal to 0.000299 points mostly due to the: 1) PET thermo-bonding fibre supply from China by means of a freight-equipped intercontinental aircraft; 2) production of bottle-grade granulate PET; 3) medium voltage electricity consumption during the manufacturing of RPET fibre panel. It was also highlighted that there were environmental benefits due to recycling through mainly avoiding significant emissions and reduced resource consumption. An improvement assessment was carried out to find solutions aimed at reducing the damage coming from the most impacting phases. Furthermore, the environmental impacts due to the production of the analysed RPET fibre-based panel were compared to other materials with the same insulating function, such as polystyrene foam, rock wool and cork slab. Finally, the environmental benefits of the recycling of PET bottles for flake production were highlighted compared to other treatment scenarios such as landfill and municipal incineration (Ingrao et al. 2014).

Energy efficiency in new building construction has become a key target to lower nation-wide energy use. The goals of this research are to estimate life-cycle energy savings, carbon emission reduction, and cost-effectiveness of energy efficiency measures in new commercial buildings using an integrated design approach, and estimate the implications from a cost on energy-based carbon emissions. A total of 576 energy simulations are run for 12 prototypical buildings in 16 cities, with 3 building designs for each building-location combination. Simulated energy consumption and building cost databases are used to determine the life-cycle cost-effectiveness and carbon emissions of each design. The results show conventional energy efficiency technologies can be used to decrease energy use in new commercial buildings by 20–30% on average and up to over 40% for some building types and locations. These reductions can often be done at negative life-cycle costs because the improved efficiencies allow the installation of smaller, cheaper HVAC equipment. These improvements not only save money and energy, but reduce a building's carbon footprint by 16% on average. A cost on carbon emissions from energy use increases the return on energy efficiency investments because energy is more expensive, making some cost-ineffective projects economically feasible (Kneifel 2010).

Narrowing the performance deficit between design intent and the real-time environmental and energy performance of buildings is a complex and involved task, impacting on all building stakeholders. Buildings are designed, built and operated with increasingly complex technologies. Throughout their life-cycle, they produce vast quantities of data. However, many commercial buildings do not perform as originally intended. This research presents a semantic web based approach to the performance gap problem, describing how heterogeneous building data sources can be transformed into semantically enriched information. A performance assessment ontology and performance framework (software tool) are introduced, which use this heterogeneous data as a service for a structured performance analysis. The demonstrator illustrates how heterogeneous data can be published semantically and then interpreted using a life-cycle performance framework approach (Corry et al. 2015).

In this research the concept of a stochastic material database for probabilistic building performance simulation was developed and illustrated. The source of uncertainty in the material data was addressed and uncertainty in different data levels was analyzed. In addition to specific materials, generic materials which have the common characteristics of one type of specific material were also included in the database, to take into consideration the situations in which the specific materials of concern are not well known. It is essential that when performing data sampling the correlations between material parameters and the interrelations between material parameters and material functions are taken into account. Probability distributions of material properties in different material categories were analyzed with statistical tests (Zhao et al. 2015).

Life Cycle Assessment (LCA) is currently used to a very limited extent in the building sector, for several reasons. Firstly, making an LCA evaluation of a building demands a specific tool to handle the large dataset needed and this tool has to be adaptable to the different decisions taken throughout the life cycle of the building. Such tools have been developed in a few countries, but they are exceptions. However, useful experience has been gained in these countries, providing a valuable source of data for developing guidelines for application in other countries. Since the results of a building LCA may contain complex information, the great challenge is to devise efficient ways for communication of the results to users and clients (Scarpellini et al. 2011).

2.1.2. Vision and roadmaps

Global Guidance (2011) document can be considered as a first step towards a world with interlinked databases and overall accessibility to credible data, in line with the established vision of global LCA database guidance, that is, to:

- provide global guidance on the establishment and maintenance of LCA databases, as the basis for future improved interlinkages of databases worldwide;
- facilitate additional data generation (including for certain applications such as carbon and water footprint creation) and to enhance overall data accessibility;
- increase the credibility of existing LCA data, through the provision of such guidance, especially as it relates to usability for various purposes; and
- support a sound scientific basis for product stewardship in business and industry and life cycle-based policies in governments, and ultimately, to help advance the sustainability of products (Global Guidance 2011).

Life cycle approaches have got relevance not only in the business world where sustainability is emerging as a megatrend, but has also gained stronger political dimension by being included in sustainable consumption and production policies around the world. Global coordination among LCI dataset developers and LCA database managers, together with capacity building and data mining, have been identified as priorities in the move towards a world with interlinked databases and overall accessibility to credible data. There is a need for global coordination among LCI dataset developers and LCA database managers. The coordination exercise could lead to a widely accepted global dataset library. Furthermore, processes at various levels could be set up to facilitate direct interlinkages between databases. Important elements of such a process would be (Global Guidance 2011):

- recognition of differences between existing LCA databases;
- analysis of the sources of these differences, which may lead to an understanding that the differences are mainly due to different system boundaries and allocation rules, plus different geographic and related technical conditions, different “histories,” organizational preferences, etc.; and
- adoption of the same system boundaries and allocation rules to facilitate interlinkages, and promote construction of adaptable datasets that can meet requirements of multiple databases.

A strengthened coordination could also lead to an improved alignment of data formats which result in better-functioning data format converters or even a common data format worldwide. Capacity building concerning global guidance on LCA databases has been identified as another priority to ensure overall accessibility to more credible data (and its use). Capacity building is particularly relevant in emerging economies and developing countries where LCA databases have yet to be established. With regard to capacity building, the strengthening of existing and the development of new regional and national life cycle networks is important (Global Guidance 2011).

There are huge amounts of relevant raw data and even developed LCI datasets available that currently are not easily accessible for LCA studies. LCA database managers, and also

LCA practitioners for particular studies, should mine data by working with actors who routinely collect data about the inputs and outputs of unit processes (not necessarily for LCI) and related information to characterize the life cycle. Several important pathways for access to data and datasets should be considered. Governments maintain vast numbers of databases, some of which contain portions of the data needed to create a unit process dataset. Such data are distributed across many external databases, often managed by different agencies. Governments and international agencies are rapidly making more of their databases available for use. Moreover, numerous research projects with public funding have generated a huge amount of relevant raw data and also a fairly significant number of unit process and aggregated datasets and will continue to do so in the future. Public funding agencies are encouraged to ensure that the data and datasets resulting from research projects are publicly available for future use in LCA databases. These various possible roadmaps have been put together to highlight how life cycle experts could contribute to moving forward towards the vision of a world with coordination between LCA databases and broad accessibility to credible LCI datasets (Global Guidance 2011).

Information technology will bring new ways to access the information in LCA databases, which may not change where the data are generated or stored, but the way in which users access the data. While not a radical departure from the status quo, the infusion of new technologies into existing database applications is occurring now and will continue into the near future (Global Guidance 2011).

2.2. LIFE CYCLE ASSESSMENT SOFTWARE AND DATABASES

By LCA tool, Trusty et al. (1998) mean a model that develops and presents life cycle inventory (LCI) and perhaps life cycle impact assessment (LCIA) results through a rigorous analytical process that adheres closely to relevant ISO standards and other accepted LCA guidelines. Key features certainly include system-wide, cradle- to-grave coverage of a full range of environmental inputs and outputs. But the most important distinguishing feature is the one set out in a recent international work group report on LCIA and summarized in SETAC News. The work group also emphasized the LCA focus on relative comparisons of whole systems in terms of resource use and emission loading. Absolute measures are allocated and normalized to some defined functional unit to provide relative or comparative results for the purpose of decision-making (Trusty et al. 1998). The most basic LCA *tool* takes inputs in the form of material take-offs (in area or volume) and converts it into mass. Then it attaches this mass value to the LCI data available from an LCI database and other sources (Bayer et al. 2010).

LCA *tool*s can be classified based on their ability to analyze building *system*s (for building-specific *tool*s) and based on the required user skill to use the *tool* (Bayer et al. 2010):

- Based on different levels of LCA application. For *tool*s that focus on the building industry, three main types of LCA *tool*s can be identified (the classifications are not exact; that is, some *tool*s have characteristics of more than one class):
- *Building Product LCA Tools.* Within building product *tool*s, the products themselves are the smallest element of analysis. Individual materials are not modeled within the *tool*s by the user (but the *tool*s are based on underlying material data). These *tool*s evaluate and compare competing building products. Such *tool*s can provide a

valuable service if they compare products that are sufficiently similar in their basic composition as well as in their function within a building context and they are legitimate substitutes. These *tool*s could provide a good framework for supplier-to-supplier comparisons as opposed to material-to-material comparisons. BEES® (Building for Environmental and Economic Sustainability) is an example of a building product LCA *tool*.

- *Building Assembly LCA Tools.* A building assembly is a group of interdependent building components that make up a *system* within a building. For example, a wall is made up of several elements, all of which are needed to build, weather-proof, and finish a wall. Building assembly *tool*s evaluate complete assemblies for their environmental footprint by considering the combined effect of all the products. These *tool*s are even wider in scope (and less specific in analysis results) than building product *tool*s. ATHENA® EcoCalculator is an example of a building assembly LCA *tool*.
- *Whole-building LCA Tools.* Whole-building LCA *tool*s assess the environmental impact of bringing together all the *system*s and assemblies. These *tool*s are generally capable of comparing several design options for a building program and are generally helpful during initial design. Example: ATHENA® Impact Estimator is a whole-building LCA *tool* that takes input in terms of building geometry and building assemblies. The result is aggregated for the entire building and presented in the form of environmental impacts due to different life-cycle stages or the contribution of the building towards a particular impact.
- Based on required user skills. LCA *tool*s can be categorized as *tool*s for LCA practitioners and *tool*s for general users (for example, architects):
- *Tools for LCA Practitioners.* These *tool*s help in structuring the analysis; linking user-defined or pre-defined unit processes; making it easy to take into account standard transport, energy production, and other common datasets; and providing necessary analytical and computational frameworks. These provide databases that can be adjusted or replaced by the user. These *tool*s may facilitate an LCA of individual products and relatively complex components like window assemblies. Carrying out an LCA of a whole building using these *tool*s can be a strenuous task. The analogy here would be to imagine creating an energy model of a building directly in the underlying simulation *tool* (e.g., DOE2) without using one of the modeling *tool*s that act as a front-end to the *software* (e.g., eQUEST). The real use for LCA practitioners' *tool*s in the building industry is to use these *tool*s to build product and assembly LCAs, which can then be embedded in building-specific *tool*s like BEES® and ATHENA® Eco-Calculator.
- *Tools for General Users. Tool*s for general users, such as architects, have all the basic LCA work done in the background. In most cases, databases are locked and cannot be modified by the user. Thus it can only be used for the building products, materials, and activity stages for which it has data (often a serious drawback). These *tool*s have a user-friendly interface in which the user is prompted for inputs and need not structure the analysis. The *tool* may ask for a building location region to determine aspects like electrical grid, source of building products, and transportation modes and distances. The model breaks down the selected assemblies into their

respective products, converts it onto a bill of quantities, and applies LCI databases to it to get the inventory of consumed resources and emissions. For some *tool*s, this is followed by impact assessment. It is essential for the user to understand the basic working of the *tool* to get an idea about the precision of the expected results.

- Based on Region. Some LCA *tool*s have an LCI database locked to them and are not compatible with other databases. Since LCI databases are region-specific *tool*s. For example, ATHENA® Impact Estimator has the ATHENA® and US LCI databases embedded in it, which are specific to North America so, at present, it can only be used for building locations in Canada and the United States. Other *tool*s, like SimaPro, are more adaptive in their linkages to different databases and thus are not region-specific.
- Based on Its Application to a Design Stage. The classification of *tool*s based on their application to a design stage is dependent on two factors: (1) the amount of information available for the project during that stage (2) the type of *decision*s taken during that stage. During pre-design stage, basic information like building form, gross building area, and schematic floor plans is available for a number of design options. Thus a *tool* from the simplified whole-building LCA *tool* category can be used at this stage to assess the impact of a specific form or structure *system*. Examples of such *tool*s are Envest, ATHENA® Impact Estimator, ATHENA® EcoCalculator, and Eco-Quantum. During the detailed design stage, more accurate information is available and *decision*s regarding building *system*s and products are taken. Thus product LCA *tool*s are the *tool*s suitable for the detailed design stage.
- Based on Life-Cycle Phases Included. Not all the LCA *tool*s are capable of conducting a cradle-to-grave LCA analysis. Cradle-to-gate LCA *tool*s will only account for impacts due to material manufacturing and the building construction phase, whereas cradle-to-grave LCA *tool*s like BEES® & ATHENA® Impact Estimator account for all life-cycle stages.

Athena Institute developed a simple LCA *tool* classification *system*, which contemplates the following three main levels of *tool*s: Level 1 – Product Focus: *1A – For LCA practitioners* SimaPro, GaBi, Umberto *1B – LCA in the background* BEES (NIST); Level 2 – Assembly Focus Athena EcoCalculator; Level 3 – Whole Building Athena Impact Estimator. The Level 1A *tool*s are designed for use by LCA practitioners, offering flexibility in terms of the data that are used and various steps in the LCA process, but requiring considerable expertise in the subject. In contrast, the Level 1B, 2, and 3 *tool*s have the LCA in the background to make LCA more accessible to the building community; design teams can input design options at the product, assembly, or building level and get back instant LCA results to help make final choices. The Level 2, assembly focused *tool* is especially relevant here because it is the starting point for the integration of LCA in the rating *system*s. The EcoCalculator provides instant LCA results for hundreds of common building assemblies, including exterior walls, roofs, intermediate floors, interior walls, windows, and columns and beams. The information embedded in the *tool* is based on detailed assessments completed with its parent *software*, the Athena Impact Estimator for Buildings (Trusty 2009).

International LCA tools designed to analyze building systems and their constituent parts (Bayer et al. 2010) are introduced below:

- EQUER (http://www.cenerg.ensmp.fr/english/logiciel/indexequer.html). Developed by the Center for Energy and Processes in Paris, the life cycle simulation *tool* EQUER is based on a building model structured in objects, this structure being compatible with the thermal simulation *tool* COMFIE. The functional unit considered is the whole building operated over a given duration. Impacts due to the activities of occupants (e.g., home-to-work transportation, domestic waste production, and water consumption) may be taken into account according to the purpose of the study: this possibility is useful, e.g., when comparing various building sites with different home-to-work distances, waste collection *system*, water network efficiency, etc.
- LCAidTM (http://buildLCA.rmit.edu.au/CaseStud/Buxton/BuxtonPS_LCAid_use.html). LCAid™ is computer *software* developed by DPWS Environmental Services with computer programming by Dr. Andrew Marsh of the University of Western Australia Department of Architectural Science. It is a user-friendly *decision*-making *tool* for evaluating the environmental performance and impacts of designs and options over the whole life cycle of a building, object, or *system*. It is well integrated with other environmental *software*—it can work on a 3D model created in *software* such as ECOTECT or Autocad. ECOTECT has been developed to interface with LCAid™ using building geometry as a bridge to incorporate LCA data into the design *tool*. It is possible to read other sets of LCA data from SimaPro or other LCA models.
- Eco-Quantum (http://www.ivam.uva.nl/index.php?id=373&L=1). Developed by IVAM, Eco-Quantum is an LCA *tool* to analyze residential projects. Eco-Quantum's VO *Tool* is for use during the provisional design phase. First a type of building is selected. Then the materials to be used are specified. Clients and local planning *author*ities can use Eco-Quantum as a policy *tool* to define the environmental specifications for a house-building program. And the built-in VO *Tool* for provisional design provides architects with a clear picture of their building's sustainability from early in the design phase, thus helping them to improve its environmental performance while it's still on the drawing board.
- LCA in Sustainable Architecture (LISA) (http://www.lisa.au.com/). LISA is a streamlined LCA *decision* support *tool* for construction. It includes construction and operation impacts. The *tool* was developed keeping in mind the specific needs of architects and other industry professionals who require a simplified LCA *tool* to assist in green design. Bill of materials and quantities, work schedules, fuel consumption by construction equipment, and utilization schedules are required as input. Output is produced in both graphical and tabular format showing the environmental impact of each stage in terms of: resource energy use in GJ, greenhouse gas emissions in metric tons of equivalent CO2, SPM, NMVOC, water, NOx, and SOx.
- Envest (http://envestv2.bre.co.uk/account.jsp) Developed by BRE, the Web-based *tool* Envest has been designed to simplify the process of designing environmentally friendly buildings. It allows both environmental and financial tradeoffs to be made explicit in the design process, allowing the client to optimize the concept of best value according to their own priorities.[51] It has been developed for use during the

early design stage. It allows large design companies to store and share information in a controlled way, enabling in-house benchmarking and design comparison. Two versions of the *tool*s are available: Envest 2 estimator and Envest 2 calculator.

- SBi LCA *tool* (http://www.en.sbi.dk/). Developed at the Danish Building Research Institute (SBi), this LCA *tool* consists of a database and an inventory *tool* for the calculation of the potential environmental effects for buildings and building elements. It differs from most other LCA *tool*s currently available by the *method* it uses to handle uncertainty.
- GaBi (http://www.GaBi-*software*.com/). Developed at the IKP University of Stuttgart in cooperation with PE Product Engineering GmbH and distributed by PE Product Engineering GmbH, GaBi is a generic LCA *tool* applicable to any industrial product or process. It is very popular in the automobile industry. The GaBi 4 *software* is one of the leading expert *system*s for balancing complex and data-intensive process networks. Other than LCA, GaBi has the capabilities to assist in greenhouse gas accounting, life cycle engineering, design for environment, substance flow analysis, strategic risk management, and total cost accounting. GaBi enables the user to develop the product *system* for analysis. Since the product *system* is user-defined and not fixed, as in other building product and whole-building LCA *tool*s, it is presumed that there are no *tool* assumptions.

Some A few examples of application of life cycle assessment software in use are follows.

SimaPro and GaBi are the leading *software tool*s used for life cycle assessments. Assessing product *system*s applying the exact same unit process foundation would be expected to yield comparable result sets with either *tool*. The *software* performances are compared based on a random sample of 100 unit processes. The research question investigated here is; can there be a difference between SimaPro and GaBi influencing the results and the *decision*s based on them? In many cases the results are identical between SimaPro and GaBi or nearly so, but in other cases the results reveal differences. Some of these differences are so large that they could influence the conclusions. For some of the 100 unit processes, six elementary flows were inventoried differently in SimaPro and GaBi, with an extreme maximum comparative ratio of 109. The implementation of the impact assessment *method*ologies shows notable differences. For the same life cycle inventory the maximum result ratio for the characterized results is 0.0076 for Terrestrial Ecotoxicity Potential. The observed differences appear to originate primarily from errors in the *software* databases for both inventory and impact assessment. SimaPro and GaBi are used by many Life Cycle Assessment (LCA) practitioners worldwide as a *decision*-support *tool*; if the results of the present analysis are representative of the differences obtained when using either one or the other, then the implications of this research are worrying. It is clearly in the interest of both *software* developers and LCA practitioners that the observed differences be addressed, for example through ring tests comparing the *tool*s (Herrmann, Andreas Moltesen 2015).

Use of exterior shading *system*s is important to increase energy savings in residential sector, mainly in warmer climates exposed to direct sunlight. These types of shades can keep inside temperatures cooler and consequently reduce cooling loads and costs. This study employs Life Cycle Assessment (LCA) to compare the effects of three different shading materials on building energy consumption and their impacts to the environment within five major climate zones defined by American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). To achieve this objective, A Life Cycle Inventory (LCI) is used to quantify the energy and emissions of the exterior shading *system*s during the manufacturing process, in-service and end of life. The Building for Environmental and Economic Sustainability (BEES) model and SimaPro 8.0 *software* (Ecoinvent 3.0 database) were employed to develop the life cycle inventory of the shadings through all life cycle stages. The LCA framework used in this study was based on a life cycle *method*ology that follows the International Organization for Standardization (ISO) 14040 standard for Life Cycle Assessment and the ASTM standard for *Multi*-Attribute *Decision* Analysis. Based on the analysis conducted for wood, aluminum, and polyvinyl chloride (PVC) shadings, it may be concluded that the use of external shadings on residential window panes, in most cases, carries a positive effect on fossil fuel depletion impact, while it increases environmental loads in other environmental impact categories. Among the three aforementioned materials, wood and PVC shadings are the most and the least environmentally-friendly materials, respectively (Babaizadeh et al. 2015).

Building design is an iterative process from the conceptual design up to the final process, so the use of computer-based *tool*s here is vital. The purpose of this research was to investigate the most popular *tool*s for building design and present a framework of an optimization model for building envelope, without compromising on energy efficiency, *comfort*, cost, and environment. The combination of simulation *tool*s DesignBuilder, SimaPro and the *method* of *multi*ple *criteria* complex proportional assessment (COPRAS) were not implemented in researches yet (Lapinskiene and Martinaitis 2013). Following the model, Lapinskiene and (Martinaitis 2013) determine the values, which are usually chosen as the optimization *criteria*: energy demand (heating, cooling, electricity), *comfort* parameters (PVM, PPD values, dis*comfort* hours, daylight), embodied, operational energy, CO2 emission, investment and exploitation cost.

A screening of Life Cycle Assessment for the evaluation of the damage arising from the production of 1 kg of recycled Polyethylene Terephthalate (RPET) fibre-based panel for building heat insulation was carried out according to the ISO 14040:2006 and 14044:2006. All data used were collected on site based on observations during site visits, review of documents and interviews with technical personnel and management. These data were processed by using SimaPro 7.3.3, accessing the Ecoinvent v.2.2 database and using the Impact 2002 + *method*. The study showed damage to be equal to 0.000299 points mostly due to the: 1) PET thermo-bonding fibre supply from China by means of a freight-equipped intercontinental aircraft; 2) production of bottle-grade granulate PET; 3) medium voltage electricity consumption during the manufacturing of RPET fibre panel. It was also highlighted that there were environmental benefits due to recycling through mainly avoiding significant emissions and reduced resource consumption. An improvement assessment was carried out to find solutions aimed at reducing the damage coming from the most impacting phases. Furthermore, the environmental impacts due to the production of the analysed RPET fibre-based panel were compared to other materials with the same insulating function, such as polystyrene foam, rock wool and cork slab. Finally, the environmental benefits of the recycling of PET bottles for flake production were highlighted compared to other treatment scenarios such as landfill and municipal incineration (Ingrao et al. 2014).

The purpose of this research is to examine the building's environmental performance through the insulation's material selection. Contemporary insulation materials achieve thermal conductivity values of less than 0.04 W/mK, whilst a plethora of materials, which fulfil specific requirements like mechanical and physical features according to the object specific specifications, can be found in the market. Still, the latter is dominated by inorganic fibrous materials and organic foamy ones, which were the subject of this study. The two materials' production process was registered and evaluated based on environmental *criteria* with Life Cycle Analysis' implementation, which was supported by the GEMIS model. The results obtained were used to set operating performance indicators and environmental condition indicators based on the ISO 14031 standard and accomplish the Environmental Performance Evaluation for the two materials. Moreover, insulation materials' life cycle correlation to building's life cycle examined and expressed with energy consumption indicators (Papadopoulos and Giama 2007).

LEGEP is a *tool* for integrated life-cycle analysis. It supports the planning teams in the design, construction, quantity surveying and evaluation of new or existing buildings. The LEGEP database contains the description of all elements of a building (based on DIN 276); their life cycle costs (LCC) based on DIN 18960 and on the calculation rules of the German DGNB and BNB Sustainability Certification. All information is structured along life cycle phases (construction, maintenance, operation, cleaning, refurbishment and demolition). LEGEP establishes the energy needs for heating, warm-water, electricity and their costs (following EnEV 2009 and EN 832). The environmental assessment comprises the material flows (input and waste) as well as an effect oriented evaluation based on DIN EN ISO 14040 – 44. LEGEP is organised along several *software tool*s, each with it's own database. The *method* is based on cost planning by "elements". The database is hierarchically organised, starting with the LCI-data at the bottom, building material data, work-process description, simple elements for material layers, composed elements like windows, and ends with macro-elements like building objects. The data are fully scaleable and can be used either "bottom-up" or "top-down". Elements at each level contain all necessary data for cost, energy, and mass-flow and impact evaluation. A building can be described using either preassembled elements or defining elements from scratch. The user can also define a specific composition by exchanging layers or descriptions of the element. The advantage of the top down approach is its completeness: if an element is not explicitly changed or eliminated it will remain in the calculation. The costs of the elements are established by the SIRADOS database, which is published each year. There are about 6.000 elements "ready for use" for the building fabric, technical equipment and landscape work. The LC Inventories are based on the German Ökobau.dat, used for the German DGNB and the BNB Sustainability Certification (LEGEP).

ENVEST (see: http://clarityenv.com.au/envest/) is a life cycle environmental impact assessment based design *tool* for use through the earliest phases of commercial/mixed use building design. The ENVEST *tool* is completely unique. It simultaneously reveals both the operational impacts and the materials impacts of a building as the design evolves. In doing so, it reveals the key design trade-offs to minimise greenhouse gas emissions and other impacts over the life of the building. ENVEST simultaneously estimates construction $ cost and whole of life $ cost. As these parameters are adjusted in ENVEST so the average building morphs into one meeting the client brief:

- Specifying location changes the climate data and solar gains, changes the connected electricity grid, changes the transport distances for materials used, changes the foundation design for typical ground conditions in that area.
- Specifying type of building changes the assumptions for lighting, occupant loads, internal partitioning requirements, floor loadings and spans.

- Specifying floor area changes the building dimensions to provide the required floor area – this in-turn changes the depth of plan and assumptions about structural *system*s, day-lighting and artificial lighting.
- Specifying occupancy changes the computer assumptions, lighting assumptions and consequential cooling and heating loads, water consumption and requirements for access and egress to meet code.
- Quality grade influences assumptions about finishing materials and frequencies of retrofit likely to be required over the building's life.
- This bland default design is then locked in – the effect of all design *decision*s from now on will be compared to this default.

As the team experiment by substituting the default values with design choices for plan shapes, numbers of storeys, orientation, glazing areas, atria, ENVEST provides instantaneous graphical feedback, revealing how the changes are affecting the environmental performance, construction and operating costs for the building. The team can very quickly test a wide range of alternatives before settling on the design. ENVEST potently communicates the effect of every choice and *decision* with a sweet spot plot of cost and environmental impact compared to the default design revealing the merits or problems with every *decision*. Graphs reveal the tradeoffs implicit in every *decision* – the impacts from materials, heating, cooling, lighting, ventilation, hot and cold water including greywater reuse are revealed, helping the design team spot synergies indesign *decision*s and avoid perverse outcomes. The building can be spun on its axis and a radar plot of performance generated to identify the best orientation. Generate context relevant reports at any level of detail. As the team continue, they could change controls and set-points, add heating *system*s, cooling *system*s, ventilation *system*s, lighting fixtures and office equipment (ENVEST).

In this research, a Life Cycle Analysis (LCA) from "cradle to gate" of one anhydrous ton of ammonia with a purity of 99% was achieved. Particularly, the energy and environmental performance of the product (ammonia) were evaluated. The eco-profile of the product and the share of each stage of the Life Cycle on the whole environmental impacts have been evaluated. The flows of material and energy for each phase of the life cycle were counted and the associated environmental problems were identified. Evaluation of the impact was achieved using GEMIS 4.7 *software*. The primary data collection was executed at the production installations located in Algeria (Annaba locality). The analysis was conducted according to the LCA standards ISO 14040 series. The results show that Cumulative Energy Requirement (CER) is of 51.945 × 103 MJ/t of ammonia, which is higher than the global average. Global Warming Potential (GWP) is of 1.44 t CO2 eq/t of ammonia; this value is lower than the world average. Tropospheric ozone precursor and Acidification are also studied in this research, their values are: 549.3 × 10−6 t NMVOC eq and 259.3 × 10−6 t SO2 eq respectively (Makhlouf et al. 2015).

Although wind technology produces no emissions during operation, there is an environmental impact associated with the wind turbine during the entire life cycle of the plant, from production to dismantling. A life cycle assessment is carried out to quantify the environmental impact of two existing wind turbines, a 1.8 MW-gearless turbine and a 2.0 MW turbine with gearbox. Both technologies will be compared by means of material usage, carbon dioxide emissions and energy payback time based on the cumulative energy requirements for a 20 year life period. For a quantitative analysis of the material and energy balances over the entire life cycle, the simulation *software* GEMIS® (Global Emission Model of Integrated *System*) is used. The results show, as expected, that the largest energy requirement contribution is derived mainly from the manufacturing phase, representing 84.4% of the total life cycle, and particularly from the tower construction which accounts for 55% of the total turbine production. The average energy payback time for both turbines is found to be 7 months and the emissions 9 gCO2/kWh. Different scenarios regarding operation performance, recycling of materials and different manufacturing countries such as Germany, Denmark and China are analysed and the energy payback time and carbon dioxide values obtained. Finally, the wind energy plant is compared with other renewable and non-renewable sources of energy to conclude that wind energy is among the cleanest sources of energy available nowadays (Guezuraga et al. 2012).

Traditionally, building rating *system*s focused on, among others, energy used during operational stage. Recently, there is a strong push by these rating *system*s to include the life cycle energy use of buildings, particularly using Life Cycle Assessment (LCA), by offering credits that can be used to achieve higher certification levels. As LCA-based *tool*s are evolving to meet this growing demand, it is important to include *method*s that also quantify the impact of energy being used by eco*system*s that indirectly contribute to building life cycle energy use (Srinivasan et al. 2014). Using a case-study building, Srinivasan et al. (2014) provide an up-to-date comparison of energy-based indicators in *tool*s for building assessment, including those that report both conventional life cycle energy and those that also include a wider *system*s boundary that captures energy use even further upstream. Srinivasan et al. (2014) apply two existing LCA *tool*s, namely, an economic input–output based model, Economic Input–Output LCA, and a process-based model, ATHENA® Impact Estimator, to estimate life cycle energy use in an example building. In order to extend the assessment to address energy use further upstream, Srinivasan et al. (2014) also tests the Ecologically based LCA *tool* and an application of the emergy *method*ology. All of these *tool*s are applied to the full service life of the building, i.e., all stages, namely, raw material formation, product, construction, use, and end-of-life; and their results are compared. Besides contrasting the use of energy-based indicators in building life cycle *tool*s, Srinivasan et al. (2014) uncovered major challenges that confront stakeholders in evaluating the built environments using LCA and similar approaches.

Steen (2001) provides an overview of the life cycle assessment *tool* (LCA). It is used to evaluate the environmental consequences of an industrial ventilation project. LCA is a compilation and evaluation of inputs, outputs, and the potential environmental impacts of a product *system* throughout its life cycle. LCA serves several purposes in industry. It is a good learning process and a *method* of *system*atically handling and processing environmental information related to products. The application of LCA to accounting may also be used for *decision*-making in various situations, such as purchasing, product development, or the development of a company's environmental strategy. The use of LCA for communicating environmental achievements to interest groups is an important option. Some other environmental assessment *tool*s are: risk assessment, cost–benefit analysis, and environmental impact assessment (Steen 2001).

den Boer et al. (2007) outline the most significant result of the project ‘The use of life cycle assessment *tool*s for the development of integrated waste management strategies for cities and regions with rapid growing economies’, which was the development of two *decision*-support *tool*s: a municipal waste prognostic *tool* and a waste management *system* assessment *tool*. den Boer et al. (2007) focuse on the assessment *tool*, which supports the adequate *decision* making in the planning of urban waste management *system*s by allowing the creation and comparison of different scenarios, considering three basic sub*system*s: (i) temporary storage; (ii) collection and transport and (iii) treatment, disposal and recycling. The design and analysis options, as well as the assumptions made for each sub*system*, are shortly introduced, providing an overview of the applied *method*ologies and technologies. The sustainability assessment *method*ology used in the project to support the selection of the most adequate scenario is presented with a brief explanation of the procedures, *criteria* and indicators applied on the evaluation of each of the three sustainability pillars (den Boer et al. 2007).

The main aim of this study was to evaluate the costs and environmental impacts induced by a fixed model of MSW kerbside separate collection *system* for communities up to 10,000 inhabitants, in order to evaluate the convenience for the smaller municipalities to unite and form more economically and environmentally sound *system*s. This topic is important not only due to the large number of small municipalities (e.g. in Italy 72% of the municipalities has less than 5000 inhabitants) but also to the fact that separate collection *system*s are typically designed to take into account only the technical and economic aspects, which is a practice but not acceptable in the light of the sustainable development paradigm. In economic terms, between 1000 and 4000 inhabitants, the annual per capita cost for vehicles and personnel decreased, with a maximum at approximately 180 €/inhabitants/year; while, from 5000 up to 10,000 inhabitants, the annual per capita cost was practically constant and equal to about 80 €/inhabitants/year. For the municipalities of less than 5000 inhabitants, from an economic point of view the aggregation is always advantageous. The environmental impacts were calculated by means of the Life Cycle Assessment *tool* SimaPro 7.1, while the economic-environmental convenience was evaluated by combining in a simple *multicriteria* analysis, the annual total per capita cost (€/inhabitants/year) and the annual total per capita environmental impact (kEco-indicator point/inhabitants/year), giving the same importance to each *criteria*. The analysis was performed by means of the Paired Comparison Technique using the Simple Additive Weighting *method*. The economic and environmental convenience of the aggregation diminishes with the size of the municipalities: for less than 4000 inhabitants, the aggregation was almost always advantageous (91.7%); while, for more than or equal to 5000 inhabitants, the aggregation was convenient only in 33.3% of the cases. On the whole, out of 45 cases examined, for the municipalities from 1000 to 9000 inhabitants, the aggregation was both economically and environmentally convenient in 60.0% of the cases (De Feo and Malvano 2012).

The increasing use of recycled materials in asphalt pavements calls for environmental assessment of such impacts as the energy input and CO2 footprint. Life cycle assessment (LCA) is being accepted by the road industry for such purpose. It aims to quantify and collate all the environmental impacts from the life time of the product or process. This research reviews relevant LCA resources worldwide, identifies the knowledge gap for the road industry, and describes the development of an LCA model for pavement construction and maintenance that accommodates recycling and up-to-date research findings. Details are provided of both the *method*ology and data acquisition. This is followed by a discussion of the challenges of applying LCA to the pavement construction practice, and recommendations for further work. In the case study, the model is applied to an asphalt paving project at London Heathrow Terminal-5 (LHR), in which natural aggregates were replaced with waste glass, incinerator bottom ash (IBA) and recycled asphalt pavements (RAP). Production of hot mix asphalt and bitumen was found to represent the energy intensive processes. This is followed by data analysis and sensitivity check. Further development of the model includes expanding the database to accommodate the recycling and maintenance practice in the UK, and taking into account the effect that roadwork has on traffic emissions. The LCA model can be further tested and calibrated as a *decision* support *tool* for sustainable construction in the road industry (Huang et al. 2009).

In France, where a division by 4 of the greenhouse gases emissions is aimed from 1990 to 2050, technical solutions are studied in order to reduce energy consumption while providing a satisfactory thermal *comfort* level in buildings. A two-dwelling passive building has been carried out in Formerie (North-West of France), complying the "Passivhaus" standard. This building, not yet monitored, has been modeled using the dynamic simulation *software* COMFIE, which is dedicated to building eco-design. In order to account for the implemented ventilation *system*, including a heat recovery unit and an earth-to-air heat exchanger, a specific model has been developed and integrated to COMFIE as a new module. In this research, this model is described first. In order to quantify the benefits brought by a passive design, the simulation results are presented for the passive house and a reference house complying with the French thermal regulation for buildings. The heating load and thermal *comfort* level of both houses are compared, showing for the passive design a tenfold reduction of the heating load and a clear reduction of summer dis*comfort*. Finally, the environmental assessment – carried out with the life cycle assessment *tool* EQUER – shows the reduction in primary energy consumption, global warming potential and other impacts brought by the passive house design. Passive house appears to be an adequate solution to improve the environmental performances of buildings in the French context (Thiers and Peuportier 2008).

Bribián et al. (2009) present the state-of-the-art regarding the application of life cycle assessment (LCA) in the building sector, providing a list of existing *tool*s, drivers and barriers, potential users and purposes of LCA studies in this sector. It also proposes a simplified LCA *method*ology and applies this to a case study focused on Spain. The thermal simulation *tool*s considered in the Spanish building energy certification standards are analysed and complemented with a simplified LCA *method*ology for evaluating the impact of certain improvements to the building design. The simplified approach proposed allows global comparisons between the embodied energy and emissions of the building materials and the energy consumption and associated emissions at the use stage. The results reveal that embodied energy can represent more than 30% of the primary energy requirement during the life span of a single house of 222 m2 with a garage for one car. The contribution of the building materials decreases if the house does not include a parking area, since this increases the heated surface percentage. Usually the top cause of energy consumption in residential building is heating, but the second is the building materials, which can represent more than 60% of the heating consumption (Bribián et al. 2009).

Global climate change is one of the most significant environmental impacts at the moment. One central issue for the building and construction industry to address global climate change is the development of credible carbon labelling schemes for building materials. Various carbon labelling schemes have been developed for concrete due to its high contribution to global greenhouse gas (GHG) emissions. However, as most carbon labelling schemes adopt cradle-to-gate as *system* boundary, the credibility of the eco-label information may not be satisfactory because recent studies show that the use and end-of-life phases can have a significant impact on the life cycle GHG emissions of concrete in terms of carbonation, maintenance and rehabilitation, other indirect emissions, and recycling activities. A comprehensive review on the life cycle assessment of concrete is presented to holistically examine the importance of use and end-of-life phases to the life cycle GHG quantification of concrete. The recent published ISO 14067: Carbon footprint of products – requirements and guidelines for quantification and communication also mandates the use of cradle-to-grave to provide publicly available eco-label information when the use and end-of-life phases of concrete can be appropriately simulated. With the support of Building Information Modelling (BIM) and other simulation technologies, the contribution of use and end-of-life phases to the life cycle GHG emissions of concrete should not be overlooked in future studies (Wu et al. 2014).

Two scenarios are assessed in a new life cycle assessment model, ROAD-RES, developed at the Technical University of Denmark for road construction and recycling of residues. The scenarios concern a 1 km asphalted road in Denmark with a service life of 100 years: Scenario A was a road with natural materials only, while Scenario B was a similar road, where municipal solid waste incineration bottom ash is used as sub-base layer replacing gravel beneath the lanes. The assessment included resource and energy consumption, and emissions associated with production of road's materials, transport, construction of the road and operation and maintenance of the road during the roads life as well as leaching of heavy metals and salts from the bottom ash, and salts used for road salting. The assessment showed that the difference between the scenarios was marginal in terms of environmental impacts and resource consumption. The majority of the environmental impacts were related to emissions from combustion of fossil fuels. Potential pollution of groundwater due to leaching of salts appeared to be important potential resource consumption, primarily due to road salting (Birgisdóttir et al. 2006).

Pollution prevention (P2) strategy is receiving significant attention in industries all over the world, over end-of-pipe pollution control and management strategy. This research is a review of the existing pollution prevention frameworks. The reviewed frameworks contributed significantly to bring the P2 approach into practice and gradually improved it towards a sustainable solution; nevertheless, some objectives are yet to be achieved. In this context, the research has proposed a P2 framework 'IP2M' addressing the limitations for *system*atic implementation of the P2 program in industries at design as well as retrofit stages. The main features of the proposed framework are that, firstly, it has integrated cradle-to-gate life cycle assessment (LCA) *tool* with other adequate P2 opportunity analysis *tool*s in P2 opportunity analysis phase and secondly, it has re-used the risk-based cradle-to-gate LCA during the environmental evaluation of different P2 options. Furthermore, in *multi*-objective optimization phase, it simultaneously considers the P2 options with available end-of-pipe control options in order to select the sustainable environmental management option (Hossain et al. 2008).

Herva and Roca (2013) review the advantages of combining complementary environmental evaluation *tool*s – ecological footprint, life cycle assessment and environmental risk assessment – that were identified as encompassing the most significant features that should be considered in corporate-related appraisals. Together, these *tool*s evaluate key aspects of environmental sustainability, such as depletion of resources, environmental impacts and human *health* preservation, and their combined application was found to produce more comprehensive analyses and ensure that relevant issues were not being disregarded. The joint application of complementary *tool*s implies a set of indicators for which a compromise solution must be found. In this respect, the applicability of *multi-criteria* analysis in *decision support system*s was also reviewed, restricting the areas of application to the following 4 categories: 1) industry-related applications, 2) energy *decision* making, 3) waste management and treatment and 4) wastewater treatment. Outranking *method*s were identified as those more widely employed in environmental problems when users were asked to select from a number of discrete alternatives. The incorporation of fuzzy reasoning in *decision* making has increased significantly in most recent applications, revealing the need to incorporate such features in a problem characterized by imprecision and subjectivity. Although not always conducted, sensitivity analyses were also essential to enhancing the robustness and reliability of such studies. It was concluded that *multi-criteria* analysis would benefit from the previous application of standardized *method*ologies as those proposed in this review to derive *criteria*. Hence, the most relevant environmental burdens and their severity would be identified and characterized in a previous step, helping to reduce the complexity of the *decision*-making problem and the possibility of duplicating effects. The scientific basis would be enhanced, making the selection of *criteria* and establishment of weights less arbitrary (Herva and Roca 2013).

2.3. MULTI VARIANT DESIGN AND ANALYSIS OF THE BUILDINGS LIFE CYCLE AND THE SELECTION OF THE MOST EFFICIENT OPTIONS

2.3.1. Analysis of the building life cycle and the selection of the most efficient options

Many studies (Fouquet et al. 2015, Kreiner et al. 2015, Caliskan 2015, Kursun et al. 2015, Luo et al. 2015, Wallhagen et al. 2011, Uihlein et al. 2010, Lacirignola et al. 2013, Zhang et al. 2015, Salpakari and Lund 2016, Marques et al. 2015, Gil-López et al. 2012, Langdon 2007, Ibn-Mohammed et al. 2014, Nemry et al. 2010, Marszal et al. 2012, Chau et al. 2012, Gu et al. 2012, Wang et al. 2010, Rezaie et al. 2013) dealing with the analysis of building life cycle options and the constituent parts of this process have been performed worldwide. Some of them are briefly overviewed below.

For example, solid wastes are generated during the resource extraction, manufacturing and on-site construction stages of the life cycle; significant air emissions are generated during all of the intermediate transportation steps; and toxic releases to water and air are almost entirely a function of product manufacturing as opposed to building operations. Moreover, energy itself requires energy for its production and transportation, which can result in a full range of emissions (known as “precombustion effects”). To the extent possible, we should consider and balance all of these effects throughout the full life cycle of a product or building. And we should bear in mind that material choices directly influence the operating effects for a building (e.g., the thermal properties of envelope materials). When we take a full life cycle approach, we may find that accepting a penalty in one stage of the life cycle, or with regard to specific measures such as initial embodied effects, may yield overriding benefits. It is also important to note that the LCA of a product should take account of the production and use of other products required for cleaning or maintaining the product during its use phase (Trusty 2009).

In LCA, we use the term “functional equivalence” when referring to the problem of ensuring that two or more products provide the same level of service and that comparisons are fair from that perspective. Ensuring functional equivalence is not as easily accomplished in building applications as might be supposed because the choice of one product may lead to, or even require, the choice of other products. For that reason, comparisons may have to be made in a building systems context rather than on a simple product-to-product basis. In general, product-to-product comparisons are more likely to be misleading when dealing with structure and envelope materials, where the systems context is key. In a similar vein, we should be careful to take account of all the components that may be required during building construction to make use of a product. Mortar and rebar go hand in hand with concrete blocks, just as fasteners, tape, and drywall compound are integral to the use of gypsum wallboard. The final point to note about LCA is that it is not the same as life cycle costing (LCC). The two methodologies are complementary, but LCC focuses on the dollar costs of building and maintaining a structure over its life cycle, while LCA focuses on environmental performance measured in the units appropriate to each emission type or effect category. For example, global warming gases are characterized in terms of their heat trapping effects compared to the effects of carbon dioxide (CO2), and so global warming potential is then measured in equivalent amounts of CO2 (Trusty 2009).

All buildings reflect the use of a wide range of materials and that all materials or products have pros and cons from an environmental perspective. There is no environmentally perfect material and the task is to use each to best advantage. Certainly, choices have to be made among directly competing materials for specific functions, but the answer ultimately depends on the circumstances. One material may be selected on environmental grounds in one situation and another in a different situation. Moreover, there are usually tradeoffs in terms of specific environmental impacts. One product may have lower global warming potential but a higher water consumption impact, and these tradeoffs must be weighed in context. How one material fares relative to others is also very much a function of the scope of the LCA itself. Direct product-to-product comparisons can lead to a different answer than a whole building-to-building comparison. In the latter, a negative result at a material level for a given material may be relatively insignificant in the context of a whole building, or outweighed by other environmental effects. For example, a given insulation material may have a relatively poor environmental footprint from a manufacturing perspective, but have such a long service life or insulating quality that the negatives are outweighed by the positives over the whole building service life when operating effects are taken into account (Trusty 2010a).

The Options for Incorporating LCA There are three basic options for bringing LCA into building design decisions: at the product level, the assembly level or the whole building level. The product or material level involves comparing alternative products for fulfilling a given function. We can only do that effectively if the LCAs for the alternatives are comparable in scope and rigor and use equivalent functional unit definitions. We can certainly require that a specific brand of a given product group meet or exceed the average for that group, but that doesn’t help when we are comparing alternative materials – steel vs. wood vs. concrete, for example. As well, we should take into account the fact that one product type may require the use of, or typically lead to the use of, other products. For example, gypsum wallboard requires the use of fasteners, tape and mud. Those products are integral to the use of that type of wallboard, but not to other wallboards, and must therefore be taken into account. The next level is the assembly (an exterior wall assembly, for example), where we do take account of the full set of materials or products used to construct and maintain one type of assembly vs. another. We can define and assess various assemblies using LCA, and can generate averages for different categories of assemblies – exterior walls, interior walls, roofs, intermediate floors and so on. Now, requirements can be set out in a code in terms of the performance of selected assemblies relative to the averages (Trusty 2010a).

That problem is addressed at the highest level of whole building LCA. At this level the selected materials, related materials, operating energy, maintenance, replacement and ultimate disposal can all be incorporated in the analysis. The trick at this level is to define what we mean by a whole building from an LCA perspective. Obviously, we have to take account of structural systems and the thermal envelope, but what about the interior finishes, for example, floor and wall covering, or the escalators, elevators, HVAC equipment and plumbing fixtures? At the same time, whole building LCA will still be the most critical approach. It ties together the material interrelationships and the operating energy side, promoting optimization of building environmental performance from a full life cycle perspective (Trusty 2010a).

Traditional approaches to sustainable design are limited by incomplete information and a lack of a framework to assess decisions within a consistent, holistic context. By providing a rational and validated basis for decisions, LCA equips sustainable designers with a better toolkit. For example, consider this scenario: a designer wants to select the best environmental choice between two competing products. Product One has high recycled content. Product Two is locally sourced. Which one is better? It’s impossible to say given our limited data set here – all we have is a percent recycled content and a distance traveled, neither of which tells us anything about actual environmental performance. When we are forced to make a guess, there is a good chance that we end up with a greater environmental burden altogether, or the burden is unintentionally shifted to other life cycle stages or impacts of concern. The alternative is to eliminate the guesswork by reviewing LCA data for both products. This allows objective comparison of quantified environmental performance for various metrics like kg CO2e global warming potential (O’Connor and Bowick 2014).

While useful in product comparisons, LCA is much more valuable to a designer when applied at the level of the whole building. Products with a heavy environmental burden can be balanced out by other building elements. In addition, the environmental performance of individual products is properly considered within the context of the whole building – this is an issue of scale. Traditional sustainability metrics don't provide any indication of the relative scale of impact. For example, Product One might have much lower environmental burdens than Product Two, yet choosing Product One could have a negligible impact on total building performance. If Product Two has other product advantages, it would likely be the better choice, and a designer would look elsewhere for environmental improvements in the building. LCA is particularly useful for identifying hotspots, in other words, the biggest contributors to the environmental footprint of the building. By focussing attention on the hotspots, we can make meaningful and efficient improvements to the overall building footprint. Contribution analysis will indicate, for example, where in the building, or when in the building’s life cycle, we are most likely to find opportunities for impact reduction (O’Connor and Bowick 2014).

Identification of alternative options is generally linked to one of the following two scenarios (Langdon 2007):

- Identification of options relating to the constructed asset itself. This typically relates to the early project stages where strategic decisions are taken, such as: alternative uses of an asset; alternative investment options; whether to refurbish/adapt an existing asset or to construct a new one; scope of proposed refurbishment/remodelling/adaptation; choice between alternative scheme designs or configurations for the asset. By definition, LCC analysis of the above options is most likely to occur during strategic business case preparation or at the early stages of a project before detailed designs and cost breakdowns are available. Reliance is therefore likely to be placed on historic or benchmark data and on high level analysis. As the project proceeds, more detailed LCC models can be developed and early assumptions tested and refined.
- Identification of options for components, materials or assemblies within the asset. This typically relates to the detailed design stages where decisions are made on the components, materials and assemblies that will make up the asset. Examples of the identification of options might include: alternative strategic options (e.g. district v localised heat generation); alternative HVAC system options (e.g. natural cooling v air conditioning; alternative plant options (e.g. gas or biomass heating plant); alternative materials (e.g. softwood, hardwood, aluminium or PVC windows).

Clearly it would be impractical (and unnecessary) to carry out a detailed LCC analysis of alternative options for every component, material or assembly within an asset. Unless otherwise specified by the client, attention should be focused on those parts of an asset that are likely to have the greatest impact on its future costs and performance. Selection criteria might include the likely magnitude of life cycle/FM/operational costs, likely use of energy/natural resources, potential effects of failure (including any financial penalties or consequences of loss of function). Historic/benchmark information and the experience of the project team and operational managers are typical key inputs to this process. Once the components, materials and assemblies to be included in the LCC analysis have been selected, alternative options for each of these must be identified. This may be achieved in a number of different ways, including by the client, by the project team, as a result of a sustainability analysis or from a design review/value management workshop. In some cases the client's brief will specify particular options to be considered. In others, it is the responsibility of the project team and/or the LCC consultant to identify options. On large or complex projects it is common for options to be identified in a formal workshop setting involving all project stakeholders including the client, design team, FM/operational staff and the end users of the asset. Various structured methods can be used for evaluating alternative options, typically consisting of the following steps (Langdon 2007):

- Identification of the parts of the asset (i.e. components, materials and assemblies) that are to be subject to LCC analysis
- Identification of evaluation criteria (e.g. functional performance, aesthetics, ease of future maintenance, environmental impact), capital/life cycle/operational/utility costs)
- Weighting of evaluation criteria in terms of relative importance
- Brainstorming to identify long-list of alternative options for each part of the asset
- Scoring of long-list options against the weighted criteria
- Identification of short-list of options for further detailed LCC analysis.

The concept of a Net Zero Energy Building (Net ZEB) encompasses two options of supplying renewable energy, which can offset energy use of a building, in particular on-site or off-site renewable energy supply. Currently, the on-site options are much more popular than the off-site; however, taking into consideration the limited area of roof and/or façade, primarily in the dense city areas, the Danish weather conditions, the growing interest and number of wind turbine co-ops, the off-site renewable energy supply options could become a meaningful solution for reaching ‘zero’ energy goal in the Danish context (Marszal et al. 2012). Therefore, Marszal et al. (2012) deploys the life cycle cost analysis and takes the private economy perspective to investigate the life cycle cost of different renewable energy supply options, and to identify the cost-optimal combination between energy efficiency and renewable energy generation. The analysis includes five technologies, i.e., two on-site options: (1) photovoltaic, (2) micro combined heat and power, and three off-site options: (1) off-site windmill, (2) share of a windmill farm and (3) purchase of green energy from the 100% renewable utility grid. The results indicate that in case of the on-site renewable supply options, the energy efficiency should be the first priority in order to design a cost-optimal Net ZEB. However, the results are opposite for the off-site renewable supply options, and thus it is more cost-effective to invest in renewable energy technologies than in energy efficiency (Marszal et al. 2012).

The use phase of buildings, dominated by the energy demand for heating is by far the most important life cycle phase for existing and new buildings. The environmental impacts were allocated to single building elements. Ventilation, heat losses through roofs and external walls are important for a majority of single- and multi-family houses. Three improvement options were identified: additional roof insulation, additional façade insulation and new sealings to reduce ventilation. The measures yield a significant environmental improvement potential, which, for a majority of the buildings types analyse represent at least 20% compared to the base case. The major improvement potentials at EU-level lie with single-family houses, followed by multi-family houses. Smaller reductions are expected for high-rise buildings due to the smaller share in the overall building stock. For both roof insulation and reduced ventilation, the measures were shown to be economically profitable in a majority of buildings (Nemry et al. 2010).

In the UK, 87% of dwellings and 60% of non-domestic buildings that will be standing in 2050 have already been built. Therefore, the greatest energy savings and emissions reductions will be achieved through retrofit of existing buildings. This usually involves decision-making processes targeted at reducing operational energy consumption and maintenance bills. For this reason, retrofit decisions by building stakeholders are typically driven by financial considerations. However, recent trends towards environmentally conscious design and retrofit have focused on the environmental merits of these options, emphasising a lifecycle approach to emissions reduction. Building stakeholders cannot easily quantify and compare the sustainability impacts of retrofit options since they lack the resources to perform an effective decision analysis. In part, this is due to the inadequacy of existing methods to assess and compare the cost, operational performance and environmental merit of the options. Current methods to quantify these parameters are considered in isolation when making decisions about energy conservation in buildings. To effectively manage the reduction of lifecycle environmental impacts, it is necessary to link financial cost with both operational and embodied emissions (Ibn-Mohammed et al. 2014). Ibn-Mohammed et al. (2014) present a robust Decision support system which integrates economic and net environmental benefits (including embodied and operational emissions) to produce optimal decisions based on marginal abatement cost methods and Pareto optimisation.

In Caliskan (2015) study, the biomass, solar, and electrical energy options based building heating are investigated and compared along with energy, exergy, sustainability, environmental, exergoenvironmental, enviroeconomic and exergoenviroeconomic analyses. All of the analyses are presented gradually to show the complete energy and exergy based advanced analyses. Eight different reference temperatures are considered which are varying from 4 °C to 7.5 °C with a temperature interval of 0.5 °C. The most efficient and sustainable energy option of the building is found to be solar energy, while biomass energy is the second one. Furthermore, according to environmental analysis, maximum 0.1599 kg-CO2 is released in a day for the solar energy option, while this value is 0.6082 kg-CO2 for the biomass energy, and 29.614 kg-CO2 for the natural gas fired electrical energy 4 °C reference temperature. In addition, among the energy options, solar and biomass energies have the best exergoenvironmental results in which exergetic results are taken into account. Finally, the maximum released CO2 prices in a day are determined at 4 °C reference temperature to be 0.0088 $, 0.0023 $, and 0.4294 $, while the corresponding exergoenviroeconomic results are found as 0.0040 $, 0.000933 $, and 0.4294 $ for the biomass, solar, and electrical energy options, respectively (Caliskan 2015).

The building sector, as one of the major energy consumers, demands most of the energy research to assess different energy options from various aspects (Rezaie et al. 2013). In Rezaie et al. (2013) research, two similar residential buildings, with either low or high energy consumption patterns, are chosen as case studies. For these case studies, three different renewable energy technology and three different hybrid systems are designed for a specified size. Then, the environmental impact indices, renewable energy indices, and the renewable exergy indices have been estimated for every energy options. Results obtained show that the hybrid systems (without considering the economics factors) are superior and having top indices. The importance of the energy consumption patterns in buildings are proven by the indices. By cutting the energy consumption to about 40% the environment index would increase by more than twice (Rezaie et al. 2013).

Buildings are long-lasting products which have huge impacts on the environment during their whole lives. The design of buildings should take into consideration long-term environmental and economic benefits. A life cycle assessment approach is developed and demonstrated in a case study—the strategic design of a Flagship Store in Shanghai. Industrial practitioners were invited to the feasibility study. Their opinions were included in the life cycle assessment for the first time. The economic analysis takes account of not only the capital costs of the design options but also the running costs during the building's economic life cycle. The methodology adopted is an integrated life cycle assessment process including life cycle costing, multi-criteria decision making and group decision making methods. The top 10 sustainable design options after the life cycle assessment process were chosen by the practitioners as the compulsory design strategies in their global environmental development agenda, whilst the other 32 design options as optional design solution for the international retailer's future stores. The life cycle assessment tool demonstrated by a case study was proven to be a simple and efficient design tool in practice, and therefore it can be adopted in other projects to assist the decision makers (Wang et al. 2010).

As a well-known technique for rational use of energy, the combined cooling, heating and power (CCHP) system is paid more and more attention in building energy conservation activities (Gu et al. 2012). In Gu et al. (2012) research, the performances of typical CCHP systems are investigated for a high-rise residential building, which is experiencing rapid expansion in China. Based on the building's energy consumption, four types of CCHP technologies have been assumed following three design and management modes, namely, heat tracking mode, electricity tracking mode and energy island mode. In order to have a comprehensive understanding of the performance of the assumed CCHP systems, besides the separated energy, economic and environmental assessments, an integrated assessment framework is proposed. According to the simulation results, gas engine and fuel cell based CCHP systems are feasible options from the energy and environmental viewpoints, but at the cost of poor economic performance. From an integrated viewpoint, the gas engine system is the most attractive option if economic performance is taken into account; otherwise the fuel cell system is the best choice (Gu et al. 2012).

Chau et al. (2012) applied the Monte Carlo method to generate probabilistic distributions for describing the CO2 footprint of the superstructure of a high-rise concrete office building. The distribution profile was constructed with the material use data collected from thirteen high-rise office concrete buildings in Hong Kong. Our results indicate that the superstructure of an office building (i.e. it does not embrace foundation or basement), on average, had a footprint of 215.1 kg CO2/m2. External walls and upper floor construction had the highest CO2 footprint, followed by suspended ceilings and finishes. These three elements altogether accounted for an average of 84.2% of the CO2 footprint associated with the superstructure. Furthermore, this study also evaluated the emissions reduction impacts of five different material use options over a 60-year lifespan. Among all the studied options, the most effective option is to maintain 15–30% of the existing structural and non-structural building elements as it can reduce the CO2 footprint by 17.3%. Diverting construction wastes to recycling can reduce the CO2 footprint by 5.9%. Reusing resources and importing regional materials can each only reduce the CO2 footprint by 3.2% and 3.1% respectively. In contrast, the CO2 footprint will be increased by 5% if off-site fabricated materials are used in facades, slabs and partition walls (Chau et al. 2012).

The EU-27 residential building stock offers high potential for energy efficiency gains. The policies already in place or proposed to improve the energy efficiency and thus the environmental performance focus on new buildings and major renovations of existing buildings. However, there might be additional measures that could lead to further energy efficiency improvements. In particular, the installation of roofs or windows that show a high thermal efficiency outside major renovations offer a large improvement potential (Uihlein et al. 2010). In Uihlein et al. (2010) research, the potential environmental and economic impacts of two types of such policy options were analysed: first, measures that require high energy efficiency standards when roofs or windows have to be replaced; and, second, measures that accelerate the replacement of building elements. The results suggest that the two policies offer the potential for substantial additional energy savings. In addition, the installation of energy efficient building elements comes at negative net cost. When the replacement of building elements is accelerated, however, the additional costs do not outweigh the energy cost savings (Uihlein et al. 2010).

2.3.2. A method of multiple criteria multivariant design of a building life cycle

A lot of data had to be processed and evaluated in carrying out multivariant design of a building life cycle. The number of feasible alternatives can be as large as 100,000. Each of the alternatives may be described from various perspectives, e.g. by conceptual and quantitative information. The problem arises how to perform computer-aided design of the alternative variants based on this enormous amount of information. To solve this problem a new method of multiple criteria multivariant building life cycle design was developed. According to the above method multiple criteria multivariant design is carried out in 5 stages (Fig. 2.1.) which are briefly described below.

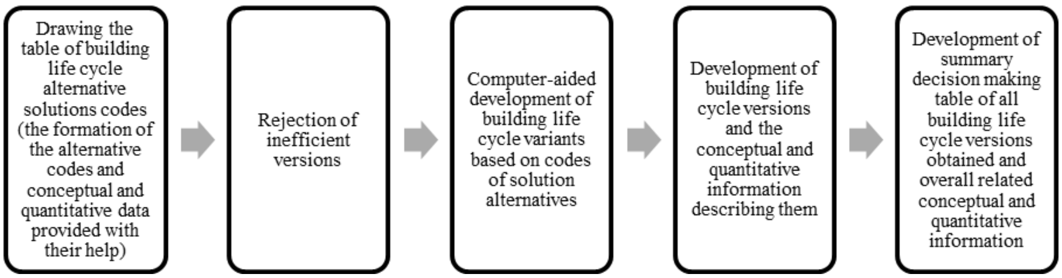

Figure 2.1. Main stages of multiple criteria multivariant design of a building life cycle

In order to reduce the amount of information being used in computer-aided multivariant design the codes of the alternative solutions are used. In this case, any i solution of j alternative is given aij code providing thorough quantitative (system of criteria, units of measure, significances, values, as well as a minimizing or maximizing criterion) and conceptual (text, drawings, graphics, video tapes) information about the alternative being considered (see Table 2.1). Thus, the use of codes of the alternative solutions in computer-aided multivariant design reduces the volume of information to be processed providing better insight into a physical meaning of computations.

Codes, with conceptual and quantitative information provided, are used for describing all available alternative project solutions. The total number of these codes makes the table of codes of building life cycle alternatives allowing to get the alternative versions in a more simple way (see Table 2.1). As can be seen from Table 2.1, it contains c solutions of a building life cycle (plots, buildings, contractors, maintenance process, etc.) of the ni alternative versions codes. Any i line of the code table represents the codes of Ai solution aij alternatives. If the information relating to the solutions in the code table of building life cycle alternatives is represented by codes, then the code contains quantitative and conceptual information (see Table 2.1). In this case, ni alternatives of any i solution are being considered in developing the alternative versions of a building life cycle. Thus, the maximum number of the projects obtained may be computed as follows:

$$k = \prod_{i=1}^{c} n_i \, , \qquad (2.1)$$

where c is the number of solutions considered in determining a building life cycle; ni - is the number of i solution alternatives to be used in developing a building life cycle.

For example, if in determining possible building life cycle alternative versions 10 alternatives are considered for any of 10 solutions, then, according to equation 1.1 maximum ten billion such variants will be obtained. It is evident that in this and similar cases it is hardly possible and reasonable to analyze all the versions from various perspectives. Therefore, it is advisable to reduce their number as follows. If a project of c solutions having ni alternatives allows k combinations (equation 2.1) then, by using multiple criteria analysis methods, p most efficient versions should be chosen from every solution for further consideration (see Table 2.2). In this way, inefficient variants are being removed. The best solutions alternatives obtained are then grouped according to priority considerations. In Table 2.2 ai1 is a code of the best variant of i solution, while aip is a code of its worst version.

Table 2.1. Codes of building life cycle alternative solutions with conceptual and quantitative information

Solutions considered	The codes of the alternative solutions considered						
	1	2	3	...	j	...	n_i
1. Plot variants	a_{11}	a_{12}	a_{13}	...	a_{1j}	...	$a_{1\,n1}$
2. Building variants	a_{21}	a_{22}	a_{23}	...	a_{2j}	...	$a_{2\,n2}$
...	...	...	...	...	...	...	...
i. Well-being variants	a_{i1}	a_{i2}	a_{i3}	...	a_{ij}	...	$a_{i\,ni}$
...	...	...	...	...	...	...	...
c. Maintenance variants	a_{c1}	a_{c2}	a_{c3}	...	a_{cj}	...	$a_{c\,nc}$

The information provided by code a_{ij} of *i* solution *j* alternative

Conceptual information (text, drawings, graphics, videotapes)	Quantitative information					
	Cost, X_1	Aesthe-tics, X_2	Comfortabi-lity, X_3	...	X_j	...	Means of transport, X_n
K_{ij}	$x_{ij\,1}$	$x_{ij\,2}$	$x_{ij\,3}$	...	$x_{ij\,j}$	...	$x_{ij\,n}$
Units of measure	Lt	Points	Points	...	...	...	Points
Significance	$q_{i\,1}$	$q_{i\,2}$	$q_{i\,3}$	...	$q_{i\,j}$	...	$q_{i\,n}$
*	$z_{i\,1}$	$z_{i\,2}$	$z_{i\,3}$	...	$z_{i\,j}$	...	$z_{i\,n}$

∗ - Signs zij (+ (−)) mean, that corresponding higher (lower) value of the criterion better satisfies the client's needs

Table 2.2. Most efficient solution alternatives set according their priorities

Solutions considered	Priority of the best alternative solutions						
	1	2	3	...	j	...	p
1. Plot variants	a_{11}	a_{12}	a_{13}	...	a_{1j}	...	a_{1p}
2. Building variants	a_{21}	a_{22}	a_{23}	...	a_{2j}	...	a_{2p}
...	...	...	...	...	...	...	...
i. Well-being variants	a_{i1}	a_{i2}	a_{i3}	...	a_{ij}	...	a_{ip}
...	...	...	...	...	...	...	...
c. Maintenance variants	a_{c1}	a_{c2}	a_{c3}	...	a_{cj}	...	a_{cp}

Then, project variants are being developed based on the efficient p alternatives of c solutions chosen. At the beginning, this process should involve the codes of the alternative solutions. The first building life cycle variant is obtained by analyzing the best solution variants according to the priority order (see Table 1.2 and 1.3). The last variant is based on solution versions from the bottom of priority table, while intermediate variants are obtained with account of the versions found in the middle of this table. For example, the first building life cycle version is based on a11 plot, a21 building, ai1 well-being, ac1 maintenance, etc. variants. The last building life cycle version takes into account a1p plot, a2p building, aip well-being, acp maintenance, etc. variants. In this case, combinations are obtained by using p alternatives from any c solutions. Therefore, the maximum number of the projects obtained may be determined from the following expression:

$$K = \prod_{i=1}^{c} p \quad , \tag{2.2}$$

where c is the number of solutions used in determining a building life cycle; p is the number of the best variants of every solution used in developing a building life cycle.

While in Table 2.3 the development of building life cycle alternatives was based on codes of solution alternatives, Table 2.4 presents conceptual and quantitative information about the variants instead of the codes. When a particular building life cycle is being considered the values relating to various solutions but based on the same criterion are recalculated into a single reduced value.

Table 2.3. Computer-aided development of building life cycle variants based on codes of solution alternatives

Solutions considered	Development of building life cycle variants based on codes of solution alternatives											
	1	2	3	...	p	p+1	p+2	p+3	...	2p	...	K
1. Plot variants	a_{11}	a_{11}	a_{11}	...	a_{11}	a_{11}	a_{11}	a_{11}	...	a_{11}	...	a_{1p}
2. Building variants	a_{21}	a_{21}	a_{21}	...	a_{21}	a_{21}	a_{21}	a_{21}	...	a_{21}	...	a_{2p}
…	...	...	...	...	...	...	...	...	...	...	...	...
i. Well-being variants	a_{i1}	a_{i1}	a_{i1}	...	a_{i1}	a_{i1}	a_{i1}	a_{i1}	...	a_{i1}	...	a_{ip}
…	...	...	...	...	...	...	...	...	...	...	...	...
c-1	$a_{c-1\,1}$	$a_{c-1\,1}$	$a_{c-1\,1}$	...	$a_{c-1\,1}$	$a_{c-1\,2}$	$a_{c-1\,2}$	$a_{c-1\,2}$	...	$a_{c-1\,2}$	...	$a_{c-1\,p}$
c. Maintenance variants	a_{c1}	a_{c2}	a_{c3}	...	a_{cp}	a_{c1}	a_{c2}	a_{c3}	...	a_{cp}	...	$a_{c\,p}$

The reduction of the same criterion (e.g. cost, comfortability) values of various solutions (plot, building, well-being, maintenance) to a single one it is necessary to appraise significances of these solutions. For example, noise level within and outside the building is not of the same significance to its inhabitants. The same applies to paying the money (it depends on whether – this should be done at the present moment or in some years). The above significances of the solutions are determined by using expert, financial analysis and other methods. The significances should be made compatible in two directions: horizontally (among criteria) and vertically (among solutions). In this way, Table 2.4 may be transformed into a summary decision making table (see Table 2.5) containing all building life cycle versions and overall related information.

Table 2.4. Development of building life cycle variants and related conceptual and quantitative information

Solutions used in developing building life cycle variants	Information related to building life cycle versions							
	Concep-tual	Quantitative						
		Cost, X_1 (Lt)	Aesthetics, X_2 (Points)	Comforta-bility, X_3 (Points)	…	X_j	…	Means of transport, X_n (Points)
	Information related to life cycle of 1-st building							
1. Plot, a_{11}	K_{11}	$x_{11\,1}$	$x_{11\,2}$	$x_{11\,3}$	…	$x_{11\,j}$	…	$x_{11\,n}$
2. Building, a_{21}	K_{21}	$x_{21\,1}$	$x_{21\,2}$	$x_{21\,3}$	…	$x_{21\,j}$	…	$x_{21\,n}$
...		...	...	...	…	...	…	...
i. Well-being, a_{i1}	K_{i1}	$x_{i1\,1}$	$x_{i1\,2}$	$x_{i1\,3}$	…	$x_{i1\,j}$	…	$x_{i1\,n}$
...		...	...	...	…	...	…	...
c. Maintenance, A_{c1}	K_{c1}	$x_{c1\,1}$	$x_{c1\,2}$	$x_{c1\,3}$	…	$x_{c1\,j}$	…	$x_{c1\,n}$
	Information related to life cycle of 2-nd building							

1. Plot, a_{11}	K_{11}	$x_{11\,1}$	$x_{11\,2}$	$x_{11\,3}$	…	$x_{11\,j}$	…	$x_{11\,n}$
2. Building, a_{21}	K_{21}	$x_{21\,1}$	$x_{21\,2}$	$x_{21\,3}$	…	$x_{21\,j}$	…	$x_{21\,n}$
...		...	...	...	…	...	…	...
i. Well-being, a_{i1}	K_{i1}	$x_{i1\,1}$	$x_{i1\,2}$	$x_{i1\,3}$	…	$x_{i1\,j}$	…	$x_{i1\,n}$
...		...	...	...	…	...	…	...
c. Maintenance, a_{c2}	K_{c2}	$x_{c2\,1}$	$x_{c2\,2}$	$x_{c2\,3}$	…	$x_{c2\,j}$	…	$x_{c2\,n}$
...	...	...	...	...	.	...	.	...
	Information related to life cycle of p-th building							
1. Plot, a_{11}	K_{11}	$x_{11\,1}$	$x_{11\,2}$	$x_{11\,3}$	…	$x_{11\,j}$	…	$x_{11\,n}$
2. Building, a_{21}	K_{21}	$x_{21\,1}$	$x_{21\,2}$	$x_{21\,3}$	…	$x_{21\,j}$	…	$x_{21\,n}$
...		...	...	...	…	...	…	...
i. Well-being, a_{i1}	K_{i1}	$x_{i1\,1}$	$x_{i1\,2}$	$x_{i1\,3}$	…	$x_{i1\,j}$	…	$x_{i1\,n}$
...		...	...	...	…	...	…	...
c. Maintenance, a_{cp}	K_{cp}	$x_{cp\,1}$	$x_{cp\,2}$	$x_{cp\,3}$	…	$x_{cp\,j}$	…	$x_{cp\,n}$
...	...	...	...	...	.	...	.	...
	Information related to life cycle of the last (K) building							
1. Plot, a_{1p}	K_{1p}	$x_{1p\,1}$	$x_{1p\,2}$	$x_{1p\,3}$	…	$x_{1p\,j}$	…	$x_{1p\,n}$
2. Building, a_{2p}	K_{2p}	$x_{2p\,1}$	$x_{2p\,2}$	$x_{2p\,3}$	…	$x_{2p\,j}$	…	$x_{2p\,n}$
...		...	...	...	…	...	…	...
i. Well-being, a_{ip}	K_{ip}	$x_{ip\,1}$	$x_{ip\,2}$	$x_{ip\,3}$	…	$x_{ip\,j}$	…	$x_{ip\,n}$
...		...	...	...	…	...	…	...
c. Maintenance, a_{cp}	K_{cp}	$x_{cp\,1}$	$x_{cp\,2}$	$x_{cp\,3}$	…	$x_{cp\,j}$	…	$x_{cp\,n}$

Table 2.5. Summary decision making table of all building life cycle versions obtained and overall related conceptual and quantitative information

Building life cycle (BLC) versions obtained	Information related to building life cycle versions							
	Conceptual	Quantitative						
		Cost, X_1	Aesthe-tics, X_2	Comfor-tability, X_3	…	X_j	…	Means of transport, X_n
1 BLC version	K_1	x_{11}	x_{12}	x_{13}	…	x_{1j}	…	x_{1n}
2 BLC version	K_2	x_{21}	x_{22}	x_{23}	…	x_{2j}	…	x_{2n}
3 BLC version	K_3	x_{31}	x_{32}	x_{33}	…	x_{3j}	…	x_{3n}
...		...	...	...	…	...	…	...
i BLC version	K_i	x_{i1}	x_{i2}	x_{i3}	…	x_{ij}	…	x_{in}
...		...	...	...	…	...	…	...
K BLC version	K_K	x_{K1}	x_{K2}	x_{K3}	…	x_{Kj}	…	x_{Kn}
Significances of criteria		q_1	q_2	q_3	…	q_j	…	q_n
Measuring units of criteria		Lt	Points	Points	…	…	…	Points

2.4. THE VISION OF ICT IN THE LIFE CYCLE OF THE BUILT ENVIRONMENT

The vision in the built environment of information and communications technologies (underground construction, cities and buildings, materials, networks and infrastructure, cultural heritage, quality of life, Eurocodes and compilation of national annexes) — this involves radically reducing the negative effects of the lifecycle period of a built environment, saving resources, assuring the quality of life and widely introducing information, intelligent and telecommunications technologies that maximally satisfy the needs of all interest groups. Further the main benchmarks, such as information and communications technologies, are drawn for an integrated introduction at the built environment level (underground constructions, cities and buildings, materials, networks and infrastructure, cultural heritage, quality of life, Eurocodes and compilation of national annexes) for the purpose of increasing its effectiveness.

Five major directions for implementing the vision of information and communications technologies in built environment are deliberated next, as follows:

- Lithuanian built environment transformation.
- Construction materials, equipment and machinery.
- Construction process.
- Built environment and its management.
- Training, education and experience transference.

The following major objectives are sought for executing the transformation of a Lithuanian built environment:

- Wider use of information technology opportunities at three levels (national, organizational and projects levels).
- Development of the analysis, modeling and forecasting of the construction and real estate branch based on an intelligent decision support system.
- Development and practical application of new business and joint cooperation models in the ICT area among interest groups.
- Transformation of the construction and real estate branch into a sector that is based on know-how and instruments in which the entire chain of values rests on knowledgeability (from a client to a run-of-the-mill employee).
- Development of a base of tacit and explicit information held by Lithuania's construction and real estate experts and an information system.
- Expressed demands by interest groups and the needs and demands of information and communications technologies as quantitative and qualitative indicators along with the development of an intelligent decision support system grounded on the applicable storing, processing and analyzing of such information by the information and instruments for decision-making and for providing recommendations.
- Retention of closer contacts with residents via electronic discussion forums, electronic forms and direct access to files by eventually going over to new, democratic expressions by developing means for interacting with politicians who represent users and by organizing electronic discussion forums in which residents and politicians can discuss specific matters, for example, like forming plans for building up micro-regions and allocating financing for alternative municipal projects.
- Development of construction and real estate intelligent decision support systems grounded on knowledge and instruments.
- Development of auctions grounded on electronic information.
- Development of a catalogue of Lithuania's construction and real estate directives containing the information of interest to the organizations in the entire construction and real estate branch.
- Integration of an information system for Lithuania's construction and real estate industry such as electronic sales of construction products, exports of construction products and services, public purchases and other activities of interest.
- Development of work systems involving intelligent groups consisting of all interest groups.

- Development of advanced and integrated methods, models and systems for the observation, evaluation, forecasting, early establishment and warning, management, prevention and risk analysis that encompass public information and readiness relevant to unexpected events, analysis of their impact on business processes, allocation of their roles and responsibilities in the event of a crisis, relevant training and competence upgrades and the management of quality and results.
- Utilization of knowledge, information, telecommunications and satellite technologies and electronics over the entire lifecycle process of a built environment.
- Integration of a virtual environment of construction and facilities management (3D and 4D models) with developed information and instruments grounded on systems like a digital home or city model containing a virtual walk through a house or city, modeling levels of street pollution, virtual design of a building, means for analyzing various technological processes by their suitability for a specific project in virtual reality, virtual exploitation of buildings and facilities modeling and analysis as well as on other types of virtual modeling (indoor climate of a building, features of a fire, energy use, sound insulation as well as a management system for work safety).
- Integration of planning a virtual lifecycle for a building (involving integrated virtual systems for determining the purposes of a building, project planning, construction, exploitation and facilities management), preparing applications for competitive bidding and construction management (compiling estimates during the time of virtual planning, calculating expenses for the exploitation of a building, applying for a competitive bid and correlating planned expenses and those actually incurred during construction and others).

The following recommendations reference advanced construction materials, equipment and machinery incorporated during the time of construction:

- Incorporate automated production lines of construction materials and goods in an effort to transfer more construction processes into plants, thus minimizing the construction processes at construction sites. Semi-manufacturing of construction materials and goods can be produced at plants. The variety of modular types of products can be increased by applying industrialized construction processes. Thereby productivity and safety at work will increase. Application of such innovations permits revitalizing buildings faster. Work safety will increase at the construction site, and the number of accidents will decrease.
- Develop new construction materials using nanotechnologies that reduce defects in constructions to a minimum by adapting to the climate (climate control) and lengthening the duration of use to the time when capital renovation is required.
- Develop a subsystem of intelligent, electronic construction materials and goods for export involving market research, searches for transactions and business partners, financial information, legal and technical information, information about commercial events, special tips and factors operating in the construction and real estate environment.
- Industrialize and mechanize construction processes maximally.
- Develop intelligent, robotized construction equipment, machinery and systems of a new class grounded on interactive information and sensors (cranes, excavators, pipe fitting equipment, automated welding aggregates and the like).

- Develop "intelligent products" such as identification instruments, sensors, and diagnostic tools, which can transmit information about the state of the construction process (including deviations from the work completion schedule or supplies of construction materials and similar situations), the microclimate, condition of retentive constructions and the like.

There can be a goal to support exports of construction products and services from an information and analytical perspective. Then the recommendation is to develop a subsystem of export products and services stemming from the system of information on Lithuania's construction. This would assist in generating conditions needed for construction to compete more effectively in world markets, thereby creating new jobs. A construction products and services export subsystem would assist in accomplishing the following:

- Registering and organizing the documents relevant to exporting construction products and services.
- Performing different calculations.
- Conducting an analysis of various export stages and composite parts (goods and services, sectors, markets, investments, suppliers, disseminators and so forth) and establishing effective alternatives.
- Searching for alternative credit loans, performing their analysis and establishing the most effective ones.
- Drawing up orders, selecting the means for payments, transferring orders, paying for orders and double-checking payments.
- Finding needed information.
- Finding new and expanding existing markets for Lithuania's goods and services.
- Attracting more investments to Lithuania.
- Reducing business expenses by increasing its effectiveness and quality.
- Entering global markets for goods and services and for credit provisions.

The rational actions to take in the effort to increase the effectiveness of the construction process would be the following:

- Assure applications in common of construction standards, norms and rules by exchanging electronic information and their legal validities.
- Develop an information system on Lithuania's construction.
- Form an intelligent, electronic subsystem on public purchasing.
- Form an intelligent system for modeling Lithuania's construction exports and penetrating foreign markets.
- Form an information system on construction permits intended to supply public services using a computer and other IT networks (application admissions, issuance of construction permits, issuance of permits to continue suspended construction, issuance of approval acts for suitable use of a structure, issuance of incomplete construction certificates and others). Then gather, accumulate, process, systematize, store, use data on the state of construction and state administration of construction in the country from the signing of the code on designing conditions for preparing the structure project up to the point when the structure is approved for use. It is also possible to supply data to governmental institutions and offices as well as to legal entities and physical persons. Formation of the following basic, functional and information subsystems are expected: organization of data on construction permits,

compilation and storage of projects for legal acts, organization of documents and their data, accounting, data provisions to users, systems administration, regulation of classifiers and data exchanges.

- Implement the accumulating of electronic data at the construction site along with their analysis, processing, monitoring and control as well as recommendation provisions.
- Establish real-time monitoring systems of the construction process based on sensors that generate the conditions to know, analyze and monitor the actual construction situation and deviations from the work schedule and that provide reports and recommendations in real time in order to complete the construction on time.
- Generate virtual construction environments. Use the latest technologies (3D and 4D modeling, intelligent instruments, equipment and clothing) to reduce the number of accidents during construction.
- Install the use of satellites and other communications technologies as quickly as possible at the construction site.
- Utilize robotic technologies.
- Integrate the latest information into all construction processes.
- Use intelligent systems based on the latest information and tools in all construction processes.
- Increase the responsibility of every employee and encourage effective team work.

The following primary goals are sought while executing a transformation in a built environment and its management:

- Special attention must be paid to satisfying user needs, i.e., execution of a transformation of a built environment's lifecycle process must be oriented towards users and grounded on information and instruments.
- The production and incorporation of intelligent sensors for all built environment elements generate the conditions needed always to have full historical information covering all needs.
- An intelligent decision support system must be formed that is grounded on information and instruments in an effort to model the effects of pollution on public health and on the built environment.
- A system must be formed to observe the quality of the soil and waterways (chemical sensors providing real time information about the quality of the groundwater, the integrated protection of the ground and water from any critical situation or technologies for drastic changes and so forth).
- An integrated system of analysis must be formed regarding the lifecycle effects of structures on the environment (noise and vibration pollution caused by traffic on the air, soil and water and the like). Such analyses should be able to model and forecast the negative effects of a built environment on the overall environment.
- Systems grounded on information and instruments are constructed in the effort to improve the lifecycle of a built environment. These utilize the experiences of numerous experts and the information gained by a full array of sensors. Consultants on information will assist in implementing a process of a built environment lifecycle more effectively.

- An open digital administration is installed when the residents consuming its services have an opportunity to send official documents electronically. They are able to watch their own movements through the necessary institutions, learn post-haste about problems arising and the chances for resolving them and repeatedly utilize the personal information gained from various databases (by using a digital signature) and repeatedly use the most reliable information.
- Participation by members of the society in decision-making processes relevant to land use, territorial planning and project designing and land regeneration and development must be implemented.
- An intelligent subsystem must be formed for issuing electronic land lot zoning permits, changing land designation permits and electronic construction permits.
- A multi-functional, computerized, information search system – a Multiple Listing Service [MLS] – must be installed that encompasses the entire real estate market for sale or for lease within some specific area (a city, region or country).
- Real estate transactions can be formed for full or partial implementation in virtual space using an electronic signature and virtual documentation arranging technologies.
- A "smart" (or intelligent) home idea for people with serious physical disabilities must be implemented at the scope of the entire country of Lithuania. This would provide such people with an opportunity to have greater independence, thereby bettering their quality of life.
- Mounted implants or small micro chips should be used in the constructions and elements of structures, which receive and transmit digital information about the status of some certain element of the building, into the network of the main computer of the home. Such a system of a structure's self-control would permit noticing malfunctions in time for appropriately eliminating them.
- A system of integrated knowledge about the lifecycle process of a built environment must be developed.

Societal agreement is needed for implementing an intelligent built environment transformation. The rational, preparatory work that needs to be done to realize this purpose is to educate the public-at-large and the experts in this field. Then the following tasks must be executed:

- Learning and demonstration centers must be established, where employees of small and average-sized companies can become familiar on a practical level with the capabilities of the latest information and Internet technologies.
- An intelligent system for lifelong learning must be developed providing employees in the construction and real estate sector with opportunities to better their qualifications.
- An intelligent system for lifelong learning must be developed providing employees in the construction and real estate sector with opportunities to better their their qualifications by using diverse tools: electronic books, audio and visual materials, computerized teaching systems, software for a specialized field, electronic assignments and jobs, a testing system and the like. Numerous alternative study programs can be compiled for learners by selecting the most rational teaching materials.

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Chapter 3

3. INTELLIGENT DECISION SUPPORT SYSTEMS AND THEIR REVIEW

3.1. INTRODUCTION

The term of intelligent decision support systems (IDSS) describes DSS that make extensive use of artificial intelligence (AI) techniques. Some research in AI, focused on enabling systems to respond to novelty and uncertainty in more flexible ways has been successfully used in IDSS. For example, data mining in AI that searches for hidden patterns in a database has been used in a range of decision support applications. The data mining process involves identifying an appropriate data set to mine or sift through to identify relations and rules for IDSS. Data mining tools include techniques like case-based reasoning, clustering analysis, classification, association rule mining, and data visualization. Data mining increases the “intelligence” of DSS and becomes an important component in designing IDSS (Yang et al. 2012).

Text and data analytics, text, data and process mining, expert and advisory systems, neural networks, intelligent software agents, natural language processing, voice recognition, speech understanding, language translation, robotics and sensory systems, computer vision, fuzzy logic, rough sets, case based reasoning and genetic algorithms become important components in designing IDSS.

DSS user interfaces have evolved over time. As DSS migrates to mobile computing environments, user interfaces will continue to evolve. For example, mobile computing environments, such as phones or other devices provide smaller screens and have different keyboard and other human computer interfaces (O'Leary 2008). Some examples of the latest types of computer human interfaces (gesture, voice and wearable hybrid interface interfaces, etc.) are also provided in this chapter.

Thanks in part to the Nintendo Wii, the Apple iPhone and the iPad, many people now have some immediate experience with gesture-based computing as a means for interacting with a computer. The proliferation of games and devices that incorporate easy and intuitive gestural interactions will certainly continue, bringing with it a new era of user interface design that moves well beyond the keyboard and mouse. While the full realization of the potential of gesture-based computing remains several years away, especially in education, its significance cannot be underestimated, especially for a new generation of students accustomed to touching, tapping, swiping, jumping, and moving as a means of engaging with information. At MIT, researchers are developing inexpensive gesture-based interfaces that track the entire hand. Elliptic Labs recently announced a dock that will let users interact with their iPad through gestures. Gestural interfaces can allow users to easily perform precise manipulations that can be difficult with a mouse, as the video editing system Tamper makes plain (Johnson et al. 2011).

In-vehicle music retrieval systems are becoming more and more popular. Previous studies have shown that they pose a real hazard to drivers when the interface is a tactile one which requires multiple entries and a combination of manual control and visual feedback. Voice interfaces exist as an alternative. Such interfaces can require either multiple or single conversational turns. In this study, each of 17 participants between the ages of 18 and 30 years old was asked to use three different music retrieval systems (one with a multiple entry touch interface, the iPod™, one with a multiple turn voice interface, interface B, and one with a single turn voice interface, interface C) while driving through a virtual world. Measures of secondary task performance, eye behavior, vehicle control, and workload were recorded. The multiple turn voice interface (B) significantly increased both the time it took drivers to complete the task and the workload (Garay-Vega et al. 2010).

Kim et al. (2014) propose a wearable hybrid interface where eye movements and mental concentration directly influence the control of a quadcopter in three-dimensional space. This noninvasive and low-cost interface addresses limitations of previous work by supporting users to complete their complicated tasks in a constrained environment in which only visual feedback is provided. The combination of the two inputs augments the number of control commands to enable the flying robot to travel in eight different directions within the physical environment. Five human subjects participated in the experiments to test the feasibility of the hybrid interface. A front view camera on the hull of the quadcopter provided the only visual feedback to each remote subject on a laptop display. Based on the visual feedback, the subjects used the interface to navigate along pre-set target locations in the air. The flight performance was evaluated by comparing with a keyboard-based interface (Kim et al. 2014).

Gesture-based computing moves the control of computers from a mouse and keyboard to the motions of the body via new input devices. Depicted in science fiction movies for years, gesture-based computing is now more grounded in reality thanks to the recent arrival of interface technologies such as Kinect, SixthSense, and Tamper, which make interactions with computational devices far more intuitive and embodied. Publishers are beginning to explore richly visual interfaces that include multimedia and collaborative elements (Johnson et al. 2011).

The integration of artificial intelligence (AI) and database management systems (DBMS) technologies promises to play a significant role in shaping the future of computing. AI/DB integration is crucial not only for next generation computing but also for the continued development of DBMS technology. The motivations driving the integration of these two technologies include the need for (a) access to large amounts of shared data for knowledge processing, (b) efficient management of data as well as knowledge, and (c) intelligent processing of data (Nihalani et al. 2009). One of the major types of integrations of AI and DBMS technologies in decision making support systems (DSSs) are intelligent databases. Current intelligent databases using artificial intelligence (data mining, etc.) components can discover relevant patterns in the data, assist users in performing searches and knowledge representation. Furthermore intelligent databases are able to manage and merge data, text, charts, images and multimedia. Examples of such intelligent databases are submitted next.

An “intelligent database” is one in which the ocean of data is collected, distilled, and classified in a comprehensive and systematic way. An intelligent database of infectious diseases was envisioned as a map of the knowledge domain of the most important infectious diseases in the world. The content of an intelligent database would include the following categories of infections: arthropod-borne, bioterrorism, childhood, community-acquired, food borne, gastroenteritis, localized, sapronoses, sexually-transmitted, and zoonoses (Brown 2008). In Brown's (2008) opinion, an intelligent database is an effective tool for developing and updating a decision-support system. Such a system could help medical practitioners to access information and improve the diagnosis of infectious diseases.

Many decision support systems for the analysis of the life cycle of the built environment have been developed worldwide:

- Citizen participation in locally unacceptable land use decision-making (Padgett 1993).
- Public participation in a spatial decision support system for public housing (Barton et al. 2005).
- Simulation and decision support tool for citizens and policy makers (O'Looney 2001).
- Measuring resilience on communalities involved in flooding river (Scarelli, Benanchi 2014).
- Holistic modelling of socio-technical systems (Wu et al.2015).
- Social acceptance motivated decision support system for subsurface activities (Os et al. 2014).
- Energy and climate policy (Oikonomou et al. 2010).
- Climate change impact assessment and adaptation (Pyke et al. 2007).
- Economic modelling of the capture–transport–sink scenario of industrial CO2 emissions (Shogenova et al. 2011).
- Building energy performance (Kabak et al. 2014).\
- Building renovation and energy performance improvement (Juan et al. 2010).
- Solar energy planning in urban environments (Rylatt et al. 2001).
- An adaptable energy retrofit façade system for residential buildings (Ochoa, Capeluto 2015).
- "Green" buildings (Dagdougui et al. 2012).
- Visualisation of urban greening in a low-cost high-density housing settlement (Donaldson-Selby et al. 2007).
- Environmental assessment in construction (Ruiz, Fernández 2009).
- Integration of environmental interests in urban planning (Stigt et al. 2013).
- Ecosystem variables for retrofitting of drainage systems (Uzomah et al. 2014).
- Land use planning (Witlox et al. 2009).
- Land use impacts in life cycle assessment (Cao et al. 2015).
- Selection of a new site for municipal solid waste disposal (Suthar, Sajwan 2014).
- Land-use decisions in site redevelopment (Wang et al. 2013).
- Welfare town planning for persons with disabilities (Koga et al. 2014).
- Modeling emergency evacuation of individuals with disabilities (Manley, Kim 2012).
- Assessment of underground spaces – public transport stations (Durmisevic, Sariyildiz 2001).
- Intelligent transport systems deployment (Nwagboso et al. 2004).

- Integrated transport-land use model for the activities relocation in urban areas (Brandi et al. 2014).
- Sustainable transportation (Kim, Lee 2014).
- Urban freight systems (Comi, Rosati 2015).
- Traffic management (Wismans et al. 2014).
- Optimizing high-speed rail routes (Kim et al. 2014).
- Road safety analysis (Fancello et al. 2015).
- Evaluating pedestrian crashes in areas with high low-income or minority populations (Cottrill, Thakuriah 2010).
- Response to extreme events (Mendonça 2007).
- Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards (Tralli et al. 2005).
- Fire incident (Salter et al. 2013).
- Crime prevention (Moon et al. 2014).
- Decision-making to resolve boundary conflicts (Kamruzzaman, Baker 2013).
- Coastal and marine ecosystem services valuation for policy and management (Luisetti et al. 2011).
- Integrated coastal zone management (Sardá et al. 2005).
- Evapo-transpiration in basin (Moges et al. 2003).
- Complex situations (Petkov et al. 2007).
- Complex cultural heritage systems (Oppio et al. 2015).
- Municipal infrastructure maintenance management (Michele, Daniela 2011).
- Housing condition assessment and refurbishment strategies (Juan et al. 2009).
- Optimal roofing material selection (Rahman et al. 2012).
- Building model (Binbasioglu 1996).
- Construction cost management (Zou, Wang 2002).
- Bridge information modelling (Markiz, Jrade 2014)
- Safety with access scaffolds (accident analysis) (Whitaker et al. 2003).
- Rural industry knowledge acquisition (Miah et al. 2008).

The following is a short description of some of the Web-based decision support that is provided.

Energy consumption of buildings accounts for around 20–40% of all energy consumed in advanced countries. Over the last decade, more and more global organizations are investing significant resources to create sustainably built environments, emphasizing sustainable building renovation processes to reduce energy consumption and carbon dioxide emissions (Juan et al. 2010). Juan et al. (2010) develop an integrated decision support system to assess existing office building conditions and to recommend an optimal set of sustainable renovation actions, considering trade-offs between renovation cost, improved building quality, and environmental impacts. A hybrid approach that combines A* graph search algorithm with genetic algorithms (GA) is used to analyze all possible renovation actions and their trade-offs to develop the optimal solution. A two-stage system validation is performed to demonstrate the practical application of the hybrid approach: zero-one goal programming (ZOGP) and genetic algorithms are adopted to validate the effectiveness of the algorithm. A real-world renovation project is introduced to validate differences in energy performance projected for the renovation solution suggested by the system. The results reveal that the proposed hybrid system is more computationally effective than either ZOGP or GA alone (Juan et al. 2010).

When dealing with cultural built heritage, the enhancement strategies are generally rooted on the history and based on the embedded values of cultural goods themselves, rather than on the multiplicity of their tangible and intangible values. Furthermore, the current state of the art in cultural heritage management lacks of an appropriate legislation and adequate instruments to be used by decision makers in order to achieve a holistic vision of the problem. Traditionally, decisions are made just by allocating resources case by case and by adopting policies based on simplifications of reality. In addition to dissipation of resources and unsuccessful results, this approach highlights the need of using an evaluative framework starting from the early stages of the decision-making processes (Oppio et al. 2015). In the above perspective, Oppio et al. (2015) explore the use of multicriteria-spatial decision support systems (MC-SDSS) in order to define enhancement strategies for cultural built heritage. The integration among different evaluation methodologies (SWOT analysis and analytic network process) and tools with spatial analysis strengthens the explorative role of this kind of approaches. In this research the MC-SDSS has been applied to a system of thirteen castles in a mountainous region in the North of Italy. The study has been carried out with a special attention to the mutual relationship among this system of goods and the surroundings, according to a multidimensional structure of analysis (Oppio et al. 2015).

Since crime has damaged citizens' lives and properties, establishing a safe urban environment has been a crucial social issue. New approaches using big data and ICT prove to reduce crime rates (Moon et al. 2014). Moon et al. (2014) report the results of big data analyses, which includes not only real crime data, but also urban attributes such as land use, and pedestrian flows, etc. A 'Ubiquitous Crime (U-Crime) prevention system (UCPS)' operating on the web is proposed. The results can be used as a guideline for system development and a decision support system for establishing security policies (Moon et al. 2014).

O'Looney (2001) describes a project, and computer application of the same name, called Sprawl Decisions. The purpose of Sprawl Decisions is to design, build, and test (in both laboratory and real-world settings) simulations and decision support technologies to overcome perceptual, social-psychological, organizational, and technological barriers to achieving effective urban design and environmental negotiations and decisions. The key goal of the project is to develop decision support technologies that can assist citizens to be more knowledgeable and effective spokespersons for their interests in a sustainable built environment. A prototype application that links land use planning choices with cost estimations, and environmental, resource, and visual impacts is described (O'Looney 2001).

Sewers, water pipes, and streets are elements of our civil infrastructure, the supporting structure of society. Infrastructure is a complex technical system that provides us with a varied range of essential services; a storehouse of resources and wealth that each generation inherits, uses, and passes on to succeeding generations. The asset management has a big influence on infrastructure development and use: undertaken and executed without fully recognizing the complexity, diversity, and social and technological evolution of the system almost inevitably squander economic, environmental, social, and cultural resources. The challenges of managing these assets most effectively are substantial: the inefficiencies are widespread and really easy to see: jammed traffic on roads designed to carry only a fraction of the current demand, newly-resurfaced city streets open to repair aged subsurface pipes, basements flooded in case of insistent heavy rain, etc. In existing asset management systems often information is not efficiently used in decisional process, which results in much waste in time and effort. It is necessary to develop life-cycle management systems of infrastructure to overcome this problem. The system must integrate geographic information, design data, inspection and maintenance data. Emphasis is placed on development of decision-support tools for municipal infrastructure management (Michele, Daniela 2011).

Michele and Daniela (2011) identify the challenges for maintenance, repair and renewal planning faced by asset owners and managers. Integration with existing systems such as Computerized Maintenance Management Systems, Geographic Information Systems, is seen as the largest challenge for developing and using decision-support tools in the area of asset management (Michele, Daniela 2011).

Assessing and adapting to the impacts of climate change requires balancing social, economic, and environmental factors in the context of an ever-expanding range of objectives, uncertainties, and management options. Most climate-related decision support resources implicitly assume that decision making is primarily limited by the quantity and quality of available information. However, a wide variety of evidence suggests that institutional, political, and communication processes are also integral to organizational decision making. Decision support resources designed to address these processes are underrepresented in existing tools. These persistent biases in the design and delivery of decision support may undermine efforts to move decision support from research to practice. The development of new approaches to decision support that consider a wider range of relevant issues is limited by the lack of information about the characteristics, context, and alternatives associated with climate-related decisions (Pyke et al. 2007). Pyke et al. (2007) propose a new approach called a decision assessment and decision inventory that will provide systematic information describing the relevant attributes of climate-related decisions. This information can be used to improve the design of decision support resources, as well as to prioritize research and development investments. Application of this approach will help provide more effective decision support based on a balanced foundation of analytical tools, environmental data, and relevant information about decisions and decision makers (Pyke et al. 2007).

Decision support systems for preparing legal documents need to consist of technical, software and organizational system components, which can ease all the stages of the life of a legal document. At the initiation stage, this system must assure and regulate the continuity of document initiation. If there is a positive reply, it must also provide the support needed for recording the fact of initiation and perform all possible preparatory jobs. The system must provide initiators with an opportunity to become familiar with the analogical and related documents of other parties, permit modeling situations, forecast consequences and evaluate the results. Such a system must assure support for all subjects involved in preparing the document, while a legal document is still under preparation. Then the system performs commutative functions among all the participants. In this case, participants can be commissions, ministries, administrative offices, specialized work groups, departments and other governmental and managerial structures. The system assures them with an interlink to already existing databases of legal acts, provides support in analyzing analogical legal documents belonging to other parties and assures the provision of other economic and social information needed for the preparation of the legal document that will be provided to those who compiled this legal document. At this stage, the system must allow the modeling of situations, forecast consequences and perform other support and expertise functions.

The system must assure protection of all the versions of this coordination, as it coordinates the pieces of the legal document, all the changes made and all the commutative functions. The evolvement of the legal document's coordination, the supervision regarding the legality of the changes and other functions, which will differ at different levels of this system, are also possible. As the system approves a legal document, it must assure support when legally recording the initiation of the process and provide assistance at the time of considerations and of approval.

The system must assure that the standards and symbol conventions cover the scope of the entire country and that the classification and other legal and legally recorded document requirements are met, while an already approved legal document is being recorded. At the stage of disseminating the legal document, the system must assure that the dissemination is in accordance with the obligatory addresses for a specific document. These can be objects within the country, administrative offices of neighboring countries or world organizations and libraries. It is possible to make use of e-mail or other commutative means for this purpose. Control and feedback are very important for each valid document. Unless these are assured, such a system cannot be sufficiently effective effective.

Expert systems are created for expert services. Every such system is a set of technical, informational and software tools based on specialized databases of informational components of artificial intellect, which ease the work of various governmental and managerial advisors and experts.

An expert system must provide users with the kind of advice that experts or specialists of a certain specific field generally provide. The principles of the software expert systems and other aforementioned systems essentially differ. The components of artificial intelligence that are usually implemented in expert systems are software (nucleus) for independent use and the facts and rules of specific areas of expertise used by expert systems (information bases) for making decisions. Derivation rules and information about the experiences of people, which are accumulated for some specific field, are stored in bases named informational bases. The informational bases of worthwhile systems also collect information relevant to earlier resolutions of assignments. Expert systems differ from the rest in that the rules by which derivations are gained from available facts are recorded into an informational base. The rules of other systems by which results are derived from primary data are recorded in applied programs, not in a database or file.

A decision support system is an informational system that accumulates data and information from various sources and processes them. It utilizes various mathematical and logical models and provides a decision-maker with information needed for analyzing, compiling and assessing possible alternative resolutions. It can make a decision, derive the received results and safeguard them. Thus a decision support system, which can be based on data from various sources, must allow users to transform a huge amount of unprocessed data into an analysis of a problem under consideration along with informational announcements necessary for decision-making.

Four major composite parts must make up the decision-making support system under development: data (databases and their management system), models (model bases and their management system) and the the system's interface with users and other systems (their data and information bases) the user interface and the system regulating electronic mail.

The first three composites, as discussed, are always within a decision support system (DSS) in one form or another. Meanwhile a system regulating electronic mail can be included, but not necessarily. This subsection contains a brief discussion about the composite parts of a decision support system. The broader discussion is found in other sections.

The data of a decision support system play very meaningful roles. Decisions are based on such roles. The more comprehensive the accumulated data are about an object under consideration, the more effective the decision made can be. For example, various economic, social, legal, technical, technological and other factors from the external environment impact some sector of construction. The possible operations of an organization objectively change for better or for worse, as external conditions change. Usually an organization can organize its operations for more than one market. Therefore it is very important to understand and evaluate the constantly changing external environment and its impact on an organization's operations in different markets. The external and internal environments of an organization's operations can be described for each time period by basing it on specific information. Organizations must react to a fluctuating external environment by making adequate strategic, tactical and operative decisions on the basis of such specific information. Since decision-making is an informational process, all of its stages, from the time of setting objectives to the ending of their implementation and evaluating their consequences, must be substantiated by searching for, visualizing, processing and analyzing necessary data.

Every individual, group of people and the entire society have specific goals that they endeavor to implement in their everyday activities and attempt to satisfy their corresponding needs as best as possible. Many decisions involve the interests of other people, because the effectiveness of alternatives can be evaluated from the positions of economic, legal, social, aesthetic, technical, political, ethical and other perspectives. An effort to describe an alternative under discussion comprehensively often requires portrayals based on economic, legal, social, aesthetic, technical, technological, political, ethical and other kinds of qualitative and quantitative data. Therefore a decision support system database must contain both quantitative and qualitative data comprehensively characterizing the object under consideration.

Problems arise, when the available data inadequately describes the alternative under analysis or when there is a shortage of data to make effective decisions. In other words, the comprehensiveness and level of accuracy of the available data primarily determine the effectiveness of the decision made. Such data must be provided to the user in a form that is well understood. Thus a decision support system must have the means to submit the data comprehensively describing the object under consideration in various forms.

Data, which are necessary for making decisions, can be submitted in a numerical, textual and graphic (drawings, graphs, diagrams, sketches, blueprints) forms or in terms of formulas, photographs, audio recordings and visuals or some other kind of form. These various forms for submitting data in various ways present information about the same object. The selection of a single-family home can be discussed as an example. A person who wants to purchase a home evaluates its price, size, aesthetics, comfortableness, number and sizes of rooms, environmental pollution, the infrastructure, neighbors and other qualities. Generally various alternative variants are considered before purchasing a house and these are usually found in different places. Therefore real estate agencies keep thorough information in their offices to save time, both for themselves and for their clients. This information is provided in different means of expressions. For example, it is rational to express the price of the building, its age, area, number of floors and rooms, size of the land lot and heat resistance and sound conductivity of the walls in numbers; the condition of the building – in words and trends in building price fluctuations – by graphs. Video equipment and photographs can best show visions of the building's exterior and interior, the general planning layout, architecture of the neighboring houses and landscape. Here, as an example, the aesthetic view of the building's exterior not only depends on its architecture but also on the quality of the windows, doors and trim, including the degree of overall deterioration and the like. A description of the building's exterior walls would include their heat resistance, sound conductivity, harmfulness to health and longevity. It is rational to express the aesthetic view of the building's exterior and its exterior walls by various forms, including numbers, photographs, video equipment, graphs and other means.

The database designated for supporting decisions could contain a great deal of related data that is being stored with the rest. Databases describing the object under consideration can be in different sites, as well as in the Internet. An DSS can provide information about an object arranged by various aspects after it submits a questionnaire to a user. The management system of the databases must contain applicable means for this. Such systems, being powerful means for software programs, generally comprise an opportunity for a user to manage numerous data in an appropriate form for analyzing an object without needing any programming efforts by a user. The system for regulating databases also eases linking the data from various sources. Usually decision-makers do not enter data or enter very little data while using the system and most often use the existing databases.

The Model bases management system (MBMS) performs a similar role with models, as the databases management system does with data. The models applied during the use of the Model bases management system as per a user's needs include decision alternatives along with other expert assessments; statistical analyses; econometrics; artificial, legal and dynamic programming; network planning and management and such. The results gained during the user's work session can become the preliminary data for other models. Data gained while realizing some of the models also function in the entire system, and others use them as well. They must be submitted in a specific format, and the models are highly interrelated. Quantitative and qualitative models are equally used in decision-making systems. The system analyzes quantitative data with the help of quantitative models (interest rates, subsidy fluctuation over time), which can be sized objectively. Qualitative models assist in decision-making, when there is no single measure reflecting the advantage of some alternative. In such a case, alternatives are evaluated by several criteria in consideration of information from experts. Although such evaluations are usually subjective, they can assist in discovering more advantageous decisions, since specialists, who are experts, are providing them.

A user's use of DSSes with automatic generation of alternative variants, their analysis and consequent decision-making due to having distinguished the best decisions in a relevant situation not only saves time but also opens up new, qualitative opportunities to use. The object under consideration can be reviewed in a three-dimensional space, and an alternative variant can be analyzed by different traits separately or comprehensively and the like.

The e-mail management system forms opportunities for utilizing the results of e-mail and electronic discussion group activities as data sources. Thereby it is obvious that an DSS with flexible data and model bases management systems as well as a convenient interface assists users in receiving data by means of a dialogue that thoroughly describes decision alternatives, formulates them, analyzes various aspects and evaluates and interprets the received results. A user thereby receives needed help in decision-making.

Decisions can be made by one person or by a group of people. Specialist groups are more qualified than other groups and have more experience and information about the problem under analysis. People with expertise can analyze problems comprehensively and objectively, continuously generate more effective alternatives and then select the best one. Nevertheless, group decision-making is more complicated, because the decisions of the group's members must be coordinated to unearth the judgments-in-common. However, there are also other shortcomings. The specialists must meet in one place to make such a decision. Then, before the most appropriate decision can be selected, the members of the group meet, compose various alternatives, analyze them comprehensively, argue different issues and process the received results. All this takes considerable time, some of which is wasted. Various subjective factors impact the decisions passed at the time of such a meeting – people's characters and temperaments, positions held at work and friendships that can negatively affect the objectivity of the decision taken. Special methods are devised to eliminate the shortcomings of group decision-making and to strengthen the positive features on the foundation of a decision support system. This book goes on to analyze this more broadly.

The application of DSSes in practice rarely reduces the expenses of decision-making. Ordinary situations might make it seem that decisions made without the help of such systems could cost less. However, such systems become more useful in the more complicated situations when many, complicated decisions must be made. Other factors also encourage introducing such systems into practice, such as receiving data about an object under consideration, processing the data, forming and analyzing alternative variants as well as the speed, comprehensiveness and accuracy of the decision being made and the like. Additionally time is saved during this process, and the reactions to some situation that have formed become faster and more adequate. For example, it is especially rational to use an DSS, when some typical problem must be decided numerous times or when quite much time is wasted analyzing the available data in electronic formats.

3.2. ASSESSMENT OF DECISION-MAKING ALTERNATIVES

Most decision-makers endeavor to discover the most economical decision possible; i.e., most aim for economic goals alone. Therefore many decision support systems (DSSes) only process and provide economic information and apply economic models for decisions. For example, the description of a dwelling includes the price for it with its land lot, exploitation expenses, insurance expenses, taxes, interest rate (if a loan is involved) and similar economic indicators (by data). This data can be broken down in even greater detail. Credits for a dwelling come from various sources, and the competition for them is with other people and with financial offices in local and foreign markets.

Nonetheless, supplemental information about alternative possibilities and conditions for getting a loan is often important for a decision-maker along with the technical indicators describing the structure (data on the overall and the useable area of the structure; room height, number and measurements; the kinds of materials used for construction of the structure, technical characteristics of the engineering systems and such).

Legal issues arise when buying or selling a dwelling, registering it and giving it to another party. The legal system attempts to reflect the existing social, economic, political, technical condition with respect to the demands raised by economic, market requirements.

The object under consideration from a social perspective can affect society, different groups of people and separate individuals. For example, underprivileged dwellings are unaesthetic, uncomfortable and unhygienic, which can spread different diseases or aggravate social problems (filthy environment, drunkenness, presence of hoodlums and so forth). This affects the surrounding residents in different ways. A government resolves such problems in two ways: by passing minimal standards for dwellings and their surroundings and by providing subsidies to residents who are unable to achieve the required standards on their own accord. Thereby, by resolving the issue of underprivileged housing, a certain sort of social harmony is reached. Currently the low-income people of Lithuania (pensioners, members of large families or the unemployed) are often unable to pay for utility services, such as heating or hot water, without governmental support. The majority political party can lose a solid chunk of votes if it does not resolve this problem on a national scale. Thus this is also a political problem, not only a social one. An analogical problem arises, when a government becomes involved in financial markets attempting to win more advantageous conditions for long term mortgages or when a government seeks to reduce the government's housing expenses directly.

This all illustrates that there are numerous such situations, when decision must be made, not only by quantitative assessments but by qualitative ones as well. This is the case, when the evaluation being sought for a decision is banned or impossible to measure accurately or when several (or many) factors must be considered among those that are incompatible or when decisions require optimal criteria. Thus, at first, not many decisions may be distinguishable from all those possible, but their variants (alternatives) could be truly appropriate. A few or several features evaluate each such alternative. It is possible to make use of specialists in the applicable field as experts, wanting to evaluate decision alternatives according to all criteria, and receive their qualified albeit subjective evaluations. The evaluations themselves can be as much quantitative as qualitative. Decisions are made from the alternatives by selecting out the most appropriate in regards to the raised requirements – the one that is the best according to the selected criteria for evaluation. The data necessary for such decisions can be presented in tables where the rows contain the distinguished alternatives and the columns – the parameters (criteria) for evaluating the alternatives. A search is made for the optimal decision upon compiling such a table by analyzing possible answers that are gained by applying the optimally most appropriate criteria for the existing situation.

Decisions can be arranged and optimal alternatives selected by the following sequence: distinguishing decision alternatives (variants from which a final selection is made, eliminating the others as not being any better); describing the distinguished alternatives and selecting the evaluation parameters (separating out the suitability of the evaluation criteria) for the evaluation of the decision alternatives for the situation under consideration; evaluating the parameters of all the alternatives and presenting the data in a table and evaluating all the alternatives according to the selected optimal criteria. Then the received results are analyzed, and the most appropriate (optimal) decision is derived upon determining the most appropriate principle (criteria) for selecting an alternative that is optimal for the situation under consideration along with the fundamentals for the selection of such criteria.

A conclusion can be reached on the basis of the ideas that have been laid out – an DSS must generate conditions for a decision-maker to derive exhaustive quantitative and qualitative evaluations from various perspectives for resolving a problem with the support of databases and model bases, thereby allowing a flexible analysis of them leading to making the most appropriate decisions.

3.3. INFORMATION, DATA AND THEIR MANAGEMENT SYSTEMS

3.3.1. Utility of information characteristics

The need for information is constantly growing. There is additional information found nearly every day that is needed for making some specific decision in this age of information (e.g., for electronic communications means and in the media). This information must be received, processed and saved in a database for its appropriate usage.

A good deal of funds is needed to find, process and store information (data) in a database of a decision support system (DSS) that is directly accessible to a user. Therefore issues regarding the utility and value of data (their worth and prices) traditionally come up when compiling databases. It is necessary to establish how valuable different information is for making a beneficial decision as well as the price of utilizing such information wanting to rationally resolve these issues.

The evaluation of information being compiled for decisions can be associated with the direct effects of corresponding informational announcements, which can assist in arranging, making or even realizing appropriate decisions. For example, information can be evaluated from the perspective of the time it was received: when it is received on time and when all the information needed for decision-making has arrived; i.e., its timeliness, comprehensiveness, reliability and utility.

Timeliness indicates that the instance of receiving information coinciding with the instance of its utilization for decision-making. New information that is appropriate for some specific DSS appears nearly every day. Such information is frequently meaningful for making everyday decisions. Thus it would be rational to process its most important part as quickly as possible and enter it into the database. Timeliness of information is especially important when it is being utilized for making operative decisions, the kind that depend on information received as fast as possible regarding any deviation from a normally operating process (foreseen in advance) to be effective and other similar situations.

Comprehensiveness indicates that the defined essence of appropriate information depicts the degree of sufficiency. Information used for decision-making can be insufficient, sufficient or excessive. For example, the information utilized for forecasting is usually incomplete; thereby decisions are made in uncertainty. However, the demands raised for making operative decisions are probably stricter in terms of comprehensiveness. The data stored in a database must provide sufficient information about the object under consideration. A different example involves establishing the value of some specific dwelling, and it is necessary to know the prices of analogical facilities for sale. Obviously the value of one analogical sale is insufficient to establish the realistic value of the dwelling under consideration. When there is no chance of receiving sufficient, needed information for making decisions, forecasts of a more general nature can be performed. Models can be used that utilize information lacking comprehensiveness or conditions can be partly, not fully, described.

Reliability of the information can be determined by its actuality meeting up with the characteristics of objectively defined situations in which appropriate decisions are made.

Information can be unreal from its very appearance or from the instant it was created. Its actuality can also lessen if it is transferred, stored and processed. Actuality can also be lost on purpose, when information is consciously distorted. Such purposeful distortion can be undertaken by certain interested persons who want to hide an existing situation or provide incorrect information aiming for a beneficial result. The organization of decision-making technologies involves paying much attention to the retention of the actuality of information by applying various methods for the control and security of the actuality.

The usefulness of information can be determined by its particularity, clarity, comprehensiveness, ratio of data utility to price (value), comparability, reliability, provision of digital information, suitability of the form for data provision and such.

Particularity involves the degree of data detail. These can be in great detail or aggregated (summed up). The head of a construction organization, for example, in practice is usually interested in all the indicators of the organization's operations as well as the project designers, architects and estimators along with specific indicators of a project and the like. This can be laid out according to the information tree principle, so every user can find or readily receive the information of interest to him/her and either particularize or aggregate it while analyzing it.

Clarity in how the database presents information is important for understanding, so it would not be comprehended ambiguously and differently. It may be rational to use an electronic dictionary for this purpose. It can serve as a basis for a user to explain the ambiguities that arise while working on-the-job (decoding, explaining and describing various abbreviations).

Comprehensiveness is important, because the data in a database has to thoroughly describe an object under consideration. Otherwise, as an example, a user would have a difficult time selecting an effective variant by relying on information from a database containing only technical and economic indicators (building and land price, their dimensions and such) without any of the qualitative characteristics (the external, aesthetic view of the building, its comfortableness and an evaluation on the level of infrastructure). Therefore the more thorough and objective the data are in the database, the greater the probability that users will effectively implement their desired goals. Qualitative data are usually subjective. They must be processed by expert methods to be more objective. The established meanings and significances of these qualitative criteria must be comprehensively explained and substantiated. In addition an opportunity must be provided in decision-making for changing the significances of the criteria and meanings of qualitative criteria in consideration of consumer needs. Additionally a way must be provided to introduce any criteria deemed lacking (in the opinion of users) with their descriptive information.

Comparability is also essential, because the effectiveness of any project can only be assessed by comparing it with analogical projects. Thus information stored in a database of alternative projects has to be compared. It is recommended to pay attention to the essential information on the variants while establishing the conditions for comparability (projects meeting such conditions can be compared): functional purpose and power of the object and the standardization of methods applied for calculating criteria and such. Other conditions might be disadvantageous, such as those involving contractors, suppliers, construction methods, rationality level of engineering equipment, effectiveness of the exploitation process and so forth. This is due to the fact that all compared projects always have positive and negative features, so the factors of one project can compensate for others without compromising the effectiveness of the entire project. In other words, it is not advisable to include criteria expressing the efficiency of construction and exploitation processes, building comfortableness, level of engineering equipment and the like.

Reliability must define the information in a database. Such information can be either unreliable from the very start (unreliable primary data) or it can become an DSS. Reliability depends on the hardware and software as well as on the work quality of the users (operators and others). Generally an information system is reliable if it is in working condition at the instances when a user needs it and if it safeguards the established performance indicator values as it executes its assigned functions. Technical devices running trouble-free and programming, which could lower the probability of accurate results, running error-free determine the degree of reliability. Programming errors are made at the time programs are under development or design, i.e., project planning errors lessen the reliability of a utilized program. However, such errors can be noticed, discovered and corrected. Software that is in use does not wear out and mistakes become less frequent. Therefore, as time goes by, the reliability of software programs actually increases rather than decreases.

Submitting digital information is rational when wanting to express needed information in numbers. In this case, it is easier to process such information at different levels, relate it in conjunction with other data and perform various calculations and analyses.

Suitability of the form for submitting data is also a factor, because the information in a database can be presented in different ways: in a digital form, textually, by a graph or formula, as a video or an audio piece and jointly using several manners. The most effective format must be chosen, because the same object can be represented differently by these different data formats.

Ratio of data usefulness to price regards the information needed in a database. A database must contain the kind of data that will result in a payback when used for making decisions. It is necessary to consider the needed costs, time and qualifications of specialists when creating or supplementing a database in light of the benefits potentially received (additional profits, reduced costs or time saved). Overloading a database with information that is unnecessary for considering the target object is not worthwhile.

The usefulness of the information used for making decision can be linked with the search for optimal decisions and their optimization. The characteristics of optimized information can be analogically understood as a characteristic of effectiveness. Here the information that can be named as optimal is that, which is gained by an optimization method (the type of information that defines an optimal decision under certain circumstances). This requires a good deal of computer time.

More characteristics of managerial decision-making can be distinguished as well. Nevertheless, some of these can relate to those already distinguished, or explicit requirements can be raised for regarding them. For example, the adequacy of the information can be defined to some extent by its certainty, because this can be measured by the degree or level that it pertains to the actual situation or process. Adequacy can also relate to timeliness: the adequacy and timeliness of such information decreases as the time period between the processes that are actually happening and receipt of the information defining such processes increases.

The issue of assessing the expenses of the information can be linked with the receipt of the same information as a suitable resource. In that sense, time and money can only be discussed as expenses for gaining initial information, storing it in a database and processing it with the selected technology in the effort to receive informational announcements needed for decision-making. These issues relate to the system's effectiveness and they are dealt with separately.

The actual information or the provision of informational services must also be priced from the consumer's perspective when seeking to assess the information (informational services) thoroughly. This means establishing the benefits of achieving a positive result by utilizing that information. The necessity of such information can be judged by comparing the benefits of achieving it (getting the respective information) with the required expenses. Here the issues arise of measuring and evaluating the effect of this information (its usefulness and value) on the results of the respective human activities. The evaluation of the information must closely interrelate with the other managerial and administrative work regarding improved operations.

3.3.2. Databases

A database (DB) can be considered in several ways. A database is a collection of stored, interrelated data, i.e., an entity consisting of an informational object designated for processing by a computer. The second concept of a database is broader. It identifies a database with data and a set of programs performing processing operations of that data. Information technology standards reference a database as a set of data organized according to a conceptual structure that describes the characteristics of that data and the relationships between their respective entities upholding one or several fields of application. Database management systems (DBMS), based on applicable software designated for data entering, editing, searching and the like, are being created for defining, developing organizing and monitoring, regulating and utilizing databases. Still others perceive databases almost as independent systems or as data banks: a database is referenced as a system of informational, mathematical, linguistic, organizational, programmatic and technical measures when evaluating stored data and the personnel involved in the technological process – a system designated to store the data in a centralized fashion in order to receive information needed at the time.

Since databases are informational models of some specific field, they are independent of any specific decision support system. Various decision support systems can make use of the same databases found in different sites (possibly at distances of many kilometers from one another). The data can be internal, external and/or personnel.

Internal data describes an organization's operations and the projects it executes. They can involve the capacity of the work performed by the organization, its profits and expenses, the technical and economic characteristics of the project it is executing and the like.

External data encompasses all the appropriate database that exist globally and the information found in Internet, books, magazines, governmental documents, laws, standards, newspapers and other such sources. All such data must be in an electronic form, and a decision support system (DSS) must have a comparatively simple access to them. An DSS can not only use the data found in Internet but also by its analytical instruments therein. For example, analytical instruments in the Internet can supply information about loan provision opportunities and conditions offered by different financial institutions. There are those that calculate interest rates as well. Additionally Internet has analytical tools providing information on the fluctuations of different currencies over recent decades.

Many organizations also have private data that is not publically revealed. As an example, such data might involve information providing them with a strategic advantage over their competitors.

3.3.3. Database structures and management

Special software is needed for a user of a computer to work and interact with databases. Such software, which is designated for creating databases, storing them and processing them in various ways, is called a Database Management System (DBMS). The most important functions of a DBMS are designing the structure of a database; loading, accumulating and editing a database; reviewing, searching, sorting and other arranging of the data; creating user application programs and compiling reports.

Architects, designers, estimators and other specialists can use the same DSS for planning the same building, even if they are located in different places at the same time and are using database services. Therefore it is easier to establish the designation of a building and to design it. Analogical work can also be performed by a team of specialists at constructing and exploiting buildings.

An analysis regarding the adequacy of database structures for decision decision support systems has to define the type of problem under consideration to determine their different levels of effectiveness. There are three fundamental database structures: hierarchical, network and relational.

The structure of a hierarchical database is a tree structure oriented to its roots, where the data at the lowest level are subordinate to the data at the next higher level. To illustrate, say, the data in a database is about the employees of a construction company (Figure 3.1). It is easy to receive information about every employee in this company by using this base. However, it is not easy to find the horizontal links between the different data in this database. Take, for example, a decision-maker who wants to gather a group to work abroad. These people have to be experts in construction engineering and know English. This sort of information would not be found readily in a database with a hierarchical structure.

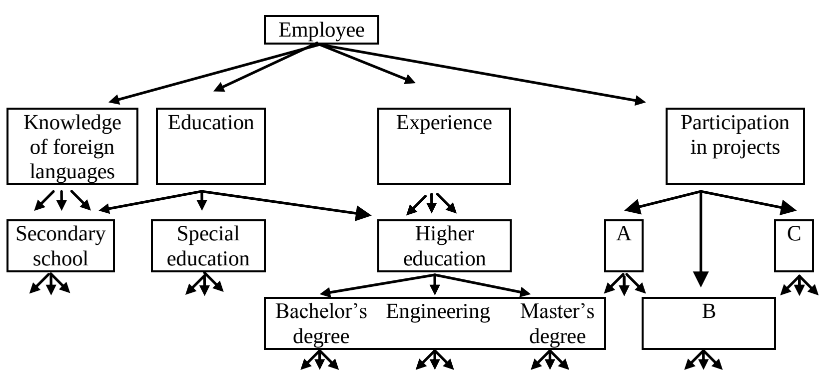

Figure 3.1. Structure of a hierarchical database

The structure of a network database is more flexible than that of a hierarchical database. The structure of a network database is a structure consisting of data expressed by an orientation graph in which each node can contain more than one connection. Assume for discussion's sake that a database contains information about two project planning groups at an organization who are designing three houses (Figure 3.2). Figure 3.2 shows that two project planning groups (A1 and A2) are designing three houses (P1, P2 and P3). Each project planning group has three employees (A11, A12, A13, A21, A22 and A23). Project planners A11 and A21 are designing House P1, planners A12 and A22a – House P2 and planners A13 and A23 – House P3. Connections between two data types are possible within the structure of a network database (in this example, it is between the projects and the project planning groups). The dependency could analogically be between suppliers and products but not between suppliers, products and databases.

	Project planning group A_1	Project planning group A_2
Project P_1	A_{11}	A_{21}
Project P_2	A_{12}	A_{22}
Project P_3	A_{13}	A_{23}

Figure 3.2. Structure of a network database

Presently the structure of relational databases is the most appropriate in light of the requirements raised by DSSs. A relational database stores information in tables. Every table is given a name for storing it in the external memory of the computer as a separate file. The indexes common for this table are logically interconnected. Thereby the entirety of the logically interrelated table comprises the model. A relational fragment of a database relevant to walls can serve as an example (Figure 3.3). The first table in Figure 3.3 shows the alternative walls under consideration that define the meanings of the quantitative and qualitative indicators. The second table presents the data on the compatibility of the walls under consideration with other decisions for the construction. The third table presents the information about the manufacturers and sellers of these walls. The wall indexes link all these three tables. This makes it easy to use these tables, for example, when wanting to select the most effective walls for some specific house being designed.

Database management systems are not isolated from each other or from other application programs. There are various tools that help different DBMSs interact with one another and maintain a connection with other programs and systems. A DBMS can be subdivided by capacity into large (highly complex) systems, average (less complex) and small systems.

Indicator meanings defining alternative wall variants

Wall	Price	Heat	Sound	Materials	Aesthet	Durabil	Comfortab

indexes		conductivity	insulation	harmful to health	ics	ity	leness
001	k_1	$š_1$	g_1	m_1	e_1	i_1	f_1
002	k_2	$š_2$	g_2	m_2	e_2	i_2	f_2
...	...	...	...	...	...	...	...
00n	k_n	$š_n$	g_n	m_n	e_n	i_n	f_n

Wall compatibility with other structures

Wall indexes	Windows				…	Roof			
	l_{11}	l_{21}	...	l_{m1}	…	t_{11}	t_{21}	...	t_{m1}
001	l_{12}	l_{22}	...	l_{m2}	…	t_{12}	t_{22}	...	t_{m2}
002	...	...	...	...	…	...	...	...	...
...	l_{1n}	l_{2n}	...	l_{mn}	…	t_{1n}	t_{2n}	...	t_{mn}
00n									

Data on the suppliers and sellers of the walls under consideration

Wall indexes	Manufacturers				Suppliers				Sellers			
001	g_{11}	g_{21}	...	g_{m1}	t_{11}	t_{21}	...	t_{m1}	d_{11}	d_{21}	...	d_{m1}
002	g_{12}	g_{22}	...	g_{m2}	t_{12}	t_{22}	...	t_{m2}	d_{12}	d_{22}	...	d_{m2}
...	...	...	...	...	...	...	...	...	...	...	...	...
00n	g_{1n}	g_{2n}	...	g_{mn}	t_{1n}	t_{2n}	...	t_{mn}	d_{1n}	d_{2n}	...	d_{mn}

Figure 3.3. Relational database structure on walls, a fragment

3.3.4. Assessment criteria of possible alternatives

This book analyzes the composite parts and application possibilities of decision support systems (DSSes). An example of a building (built or being designed) is used for the purpose of this discussion.

Many people who wish to purchase a house primarily look at price, while others – at the building’s exploitation expenses, consisting of heating, exploitation, upkeep, insurance and different taxes and fees. Still others are interested in the infrastructure of the site (schools, hospitals, theaters, concert halls, stores and communication lines), its level of development, level of air and environmental pollution and the neighbors. Then there are the people who pay most attention to the comfortableness of the house. The concept of comfortableness for many relates to the number of rooms, their sizes and heights, the design, functional convenience, proportions of the facilities, kitchen size, overall area of the housing, absence of harmful materials, heat and sound insulation of the external walls, level of engineering equipment and the like. Nevertheless, buyers most often try to evaluate the positive and negative features of the house in a composite manner. Attention must also be paid to the fact that different people are often guided by different criteria systems when choosing a home, based on their own needs and possibilities. Therefore these people ascribe different meanings and significances to the same criteria.

An DSS must have comprehensive information, encompassing the experiences of exploiting, not only the same sorts of buildings but also analogical buildings, endeavoring to provide a user with serious help in selecting an effective house. Data can be either objective or subjective. Objective data includes the price of the building, its measurements, the year it was constructed, interest rates on the loan taken for purchasing or building the house, heat and sound insulations of the external walls and harmfulness of materials to the residents and its level of change over the years. Subjective data includes the aesthetic look of the building's exterior, comfortableness, the environment and the neighbors. People's opinions often differ, and quite sharply, regarding subjective issues. Over time such opinions can change. This is not a bad thing, because these opinions reflect what these people are striving for, their goals and the opportunities they want.

A user should have the opportunity of operatively receiving thorough information (quantitative and qualitative criteria including their meanings and significances with explanations), which defines the object under consideration when analyzing alternative variants. For example, a user should receive the latest, comprehensive information about materials that are harmful to human health and the change in their affect over time; the materials used for trimming the building's external walls and their price, quality and durability; possible variants for insuring the building from different insurance companies and the like. Additionally a user must have a chance to adjust or supplement the criteria defining the alternatives under consideration as well as the meanings and significances of such criteria, based on the user's own experience, needs and available resources.

Thus users are obviously able to compile and thoroughly analyze alternatives under consideration (i.e., comprehensively assessing the criteria system defining them along with the meanings and significances of such criteria) and make decisions by using the digital, textual, graphic, audio and visual information along with the model bases management system, supplied by a database management system.

3.4. Base of Models and Management

3.4.1. Model dimensions

Models can be subdivided as quantitative and qualitative by their presentations. Qualitative models (multicriteria, based on expertise) are based on subjective opinions, experiences and assessments by experts. However, when different experts assess the same characteristics of an object, the derived results are often different. This occurs due to the different experiences, educational levels, purposes, available opportunities and the like of different experts. The derived data can be made more objective by applying the expertise of assessment methods. Quantitative models (statistical, accounting) reflect the objective features of the objects under consideration, independently of the subjective assessments by experts. Such features of an object can be expressed directly by physical units of measurement (monetary units, kilograms, meters, degrees, percents, ratios and such). Qualitative models have as many positive and negative features as quantitative models have. Objects being considered by quantitative models are objectively but often not comprehensively reflected. Contrariwise, qualitative models reflect reality subjectively and comprehensively. Therefore the rationality of applying quantitative and qualitative methods often depends on specific, decision-making situations. Frequently decision-making requires a comprehensive application of quantitative and qualitative models. For example, it is best to apply qualitative research methods when analyzing the overall level of a building's comfortableness. However, when analyzing how much money will be spent over the entire process of this building's existence, such as the costs of its purchase or construction, exploitation, maintenance upkeep, insurance expenses, taxes and the like, the application of quantitative methods is better.

Models are subdivided as static and dynamic according to the dimension of time. Models are considered static, when the features of the object under consideration do not change over time. Meanwhile the changing features of the object under consideration over time are considered for dynamic models.

Models are also subdivided by methodology: complete list, algorithmic, heuristic, modeling and analytical.

Application of the complete list method involves gathering and assessing information about all the objects under consideration. This method requires a great deal of work and monetary resources. It is applied at the time of a population census. Additionally, with neural networks, it can be applied for establishing stolen credit cards. For example, people generally purchase typical products or services with credit cards. Assuming, all of a sudden, the use of a credit card involves purchases of other sorts of products, in principal, for untypical prices or untypical services. Then it is possible to verify that the credit card is stolen by the complete list method via the neural networks and thereby, annul its validity. Frequently the neural network system manages to establish the fact of a credit card theft before the card owner notices it.

Algorithmic models (for example, operations research methods) are applied for calculating from the start to the end (from the initial dates of data entries to the result under search or until the pursued goal has been attained). Repeated calculations on the basis of these models establish the best meanings of the specific characteristics (goal functions) of the object under consideration and the modeling parameters given the time and monetary resources as well as the technical and other sorts of limitations.

Heuristic (artificial intelligence) models are applied for problems that cannot be solved algorithmically. Heuristic models help to reduce the number of search variants in the effort to submit either a decision or conclusions. Heuristics is the most important part of artificial intelligence and expert systems.

Problems that are resolved by modeling are those, which cannot be investigated accurately on the basis of a mathematical analysis. The application of these models creates an adequate, typical situation regarding the object under consideration. Experimentation is possible by repeating the states of the object, thereby revealing ways to improve the system's operations. This sort of modeling is often applied for examining problems relevant to the storage and servicing of inventories.

A general analysis of the object under consideration is performed at the start of analytical modeling. Next, this object is broken up into parts, and the composite elements are examined separately. Afterwards the dependencies and the connections of the object's composite elements are established. A statistical analysis provides a good example of analytical modeling.

3.4.2. Model base management system

The model bases management system forms good conditions for a user to use a library of models. This library provides a user with the opportunity to use a wide spectrum of statistical, financial, managerial and other models for solving specific problems. A user can select a definite model with a mouse, thereby activating the pictogram of the needed model. Every model has its own menu of commands, the same as the model bases management system has. The list of commands in the menu is often subdivided into command groups by meaning and by actions performed.

Further the model bases management system will be discussed with the example suggested by the author Multicriteria DSS for revitalizing heat in buildings. The multicriteria, DSS model bases management system on Building heat revitalization contains the following models, as recommended by the author:

- External building barrier structure alternatives model.
- Initial criteria significances (applying expert assessment methods) model.
- Criteria significances establishing model.
- Building revitalization designing project variants model.
- Project multicriteria analysis and priority setting model.
- Degree of project usefulness setting model.
- Recommendations submission model.

These models allow automatically compiling tens of thousands alternatives for consideration. Furthermore multicriteria analyses can be performed on such alternatives and the most effective variant can be selected. The Model bases management system library is presented in Figure 3.4.

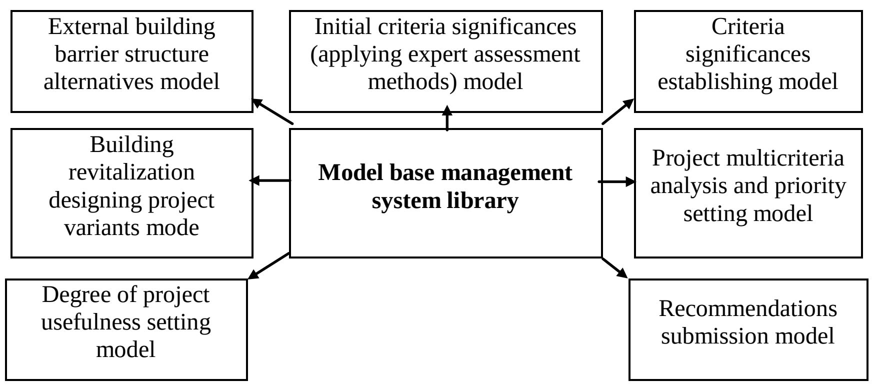

Figure 3.4. Building revitalization, multicriteria, DSS model base management system library

Various models are applied according to user needs by using the model bases management system. Use of the model bases management system involves the following: the calculation results of some models (determination of the significances of initial criteria) become the initial data for other models (multicriteria analyses of planning variants for building revitalization projects). Meanwhile the results of these models become the baseline data for still other models (determination of the degrees of project usefulness and presentation of recommendations).

The models in the aforementioned model base management system library will be presented next, in brief, as per the example of the External building barrier structure alternatives model.

3.4.3. External building barrier structure alternatives model

The External building barrier structure alternatives model forms variants (decision-making matrixes) on the basis of five stages. These stages are next presented briefly.

1. A building's external barrier structures, which can be used for the building's heating revitalization, are presented on the display screen.

External walls	Windows	Roof	Cellar ceilings	Cellar walls

Figure 3.5. External barrier structures menu for a building

A user is asked what external barrier structures he/she would like analyzed for accomplishing the heating revitalization of a building. Assume the user wants to analyze all the external barrier structures that are found in the database. In this case, the DSS assists the user in forming possible external barrier structures in order of priority (starting with the external structures and ending with the walls of the cellar).

Next, information is compiled (Figure 3.6) that thoroughly defines each external barrier structure under consideration for the building until Stage 4. These stages are next presented in brief under consideration of the alternatives for forming the external walls, as an example.

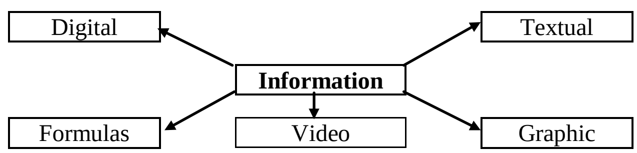

Figure 3.6. Dialogue between DSS and a user as quantitative and conceptual information forms to comprehensively define a building's external barrier structures

2. The display screen presents the criteria system defining the external walls and the explanations of each criterion (which features of this criterion are under consideration) in a conceptual form (digital, text, formula, video or graph) [Figure 3.7]).

Criteria system defining external walls	Conceptual information defining criteria
• price (x_1),	$\check{z}_1$
• payback period (x_2),	$\check{z}_2$
• heat resistance (x_3),	$\check{z}_3$
• sound insulation (x_4),	$\check{z}_4$
• aesthetic view evaluation (x_5),	$\check{z}_5$
• harmful to health (x_6),	$\check{z}_6$
• durability (x_7),	$\check{z}_7$
• exploitation expenses (x_8),	$\check{z}_8$
• comfortableness (x_9)	$\check{z}_9$

Figure 3.7. Criteria menu defining external walls

A user selects the most appropriate criteria system for further analysis. If needed, a user can enter supplemental criteria. The computer's memory stores the selected criteria system (xm).

3. The display screen presents the initial units of measure and significances of these criteria. The reasons why these specific significances and units of measure were determined are also indicated (Figure 3.8).

Criteria names	Criteria units of measure	Initial criteria significances as per expert opinions	Reasons for determining these units of measure and significances
x_1 x_2 ... x_m	d_1 d_2 ... d_m	q_1 q_2 ... q_m	s_1 s_2 ... s_m

Figure 3.8. Criteria significances and units of measure menu

A user is able to adjust the initial criteria significances and units of measure, if so desired. A user can enter supplemental criteria and, if so, the user then provides each supplemented criterion with a unit of measure and an initial significance. The computer's memory stores this information.

4. The display screen presents the graphic (visual) part (Gi) of the external wall alternative variants, the meanings (xij) of the criteria defining those variants and the reasons (pij) affecting the determinations of qualitative criteria meanings (Figure 3.9).

Names of alternative variants	Graphic (visual) part of the alternative variants (G_i)	Meanings of criteria defining alternative variants (x_{ij})	Reasons affecting determinations of qualitative criteria meanings (p_{ij})
x_1	G_1	x_{11} x_{21} ... x_{n1}	p_{11} p_{21} ... p_{n1}
x_2	G_2	x_{12} x_{22} ... x_{n2}	p_{12} p_{22} ... p_{n2}
...	...	... ...	... ...
x_m	G_m	x_{1m} x_{2m} ... x_{nm}	p_{1m} p_{2m} ... p_{nm}

Figure 3.9. Alternative variants and criteria meanings menu graphically (visually)

Users select alternative variants in consideration of their needs and possibilities and examine these further. A user also considers the objectives and means being pursued along with the explanations presented (reasons for ascribing certain specific meanings to the qualitative criteria). Thus the user is able to change the meanings of the qualitative criteria. If a user enters supplemental criteria, that user also enters the meanings defining the criteria. The computer's memory then stores this table.

5. A user compiles in the computer's memory in 1-4 stages all the digital, textual, graphic, visual and formulas information that comprehensively defines the alternative variants of specific external barrier structures under consideration. Thereby a decision-making matrix is formed of specific external barrier structures under consideration (Figure 3.10).

Quantitative information defining external barrier structures									
Criteria considered	*	Significance	Unit of measure	Alternatives considered					
				x_1	x_2	...	x_j	...	x_n
Quantitative criteria	$ž_1$ $ž_2$ ... $ž_i$	q_1 q_2 ... q_I	d_1 d_2 ... d_i	x_{11} x_{21} ... x_{i1}	x_{12} x_{22} ... x_{i2}	... ...	x_{1j} x_{2j} ... x_{ij}	... ...	x_{1n} x_{2n} ... x_{in}

	...	...	...	...	...	...	...	...	...
	$ž_t$	q_t	d_t	x_{t1}	x_{t2}	...	x_{tj}	...	x_{tn}
Qualitative criteria	$ž_{t+1}$	q_{t+1}	d_{t+1}	$x_{t+1\,1}$	$x_{t+1\,2}$	...	$x_{t+1\,i}$	...	$x_{t+1\,n}$
	$ž_{t+2}$	q_{t+2}	d_{t+2}	$x_{t+2\,1}$	$x_{t+2\,2}$	...	$x_{t+2\,i}$	...	$x_{t+2\,n}$
	...	...	...	...	...	...	...	...	...
	$ž_i$	q_I	d_i	x_{i1}	x_{i2}	...	x_{ij}	...	x_{in}
	...	...	...	...	...	...	...	...	...
	$ž_m$	q_m	d_m	x_{m1}	x_{m2}	...	x_{mj}	...	x_{mn}
Conceptual information defining external barrier structures									
K_k	$K_ž$	K_q	K_m	K_1	K_2	...	K_j	...	K_n

∗ - The sign $ž_i$ (+ (−)) indicates that a respectively greater (lesser) criterion meaning better corresponds to user demands.

Figure 3.10. External barrier structures decision-making matrix

Assume a user enters supplemental alternative external barrier structure variants (that were not already in the database). Then that same user must enter the conceptual and quantitative information thoroughly defining those variants into a decision-making matrix.

6. Analogically (Stages 1–5) decision-making matrixes are formed of other external barrier structures under consideration.

3.4.4. Intellect and a decision support system

Systems that imitate traits of human intellect are called artificial intelligence systems. They include, on the basis of certain rules, the information and accumulated experiences of experts in some field. This way, possibilities are increased for systems to evaluate accurately features of assigned tasks and make effective decisions.

Expert systems constitute one of the trends for artificial intelligence systems. They consist of informational bases with a set of rules and provider mechanisms for generating conclusions and recommendations. They recognize a situation based on sets of initial data and rules, diagnose it, formulate a decision and recommend selecting certain actions. An expert system generally resolves the sorts of assignments that usually require human expertise by imitating the work of experts or consultants. Additionally, just like an expert, it executes numerous secondary functions like posing questions, explaining its own reasoning, processing symbolic expressions and reasoning on their bases, substantiating conclusions and so forth. Current expert systems usually help free professional people from having to decide certain difficult albeit clearly formulated assignments.

Lately there is an effort to apply the best artificial intelligence, expertise and hybrid systems as well as features of neural networks to a decision support system. The use of DSS by artificial intelligence does not change the decision-maker; however, it helps the decision-maker make better use of the opportunities DSS provides.

3.5. USER INTERFACE

User interface is one of the most important parts of a decision support system (DSS). Frequently a user decides about the effectiveness of an actual DSS based on the opportunities provided by the user interface. The user interface assists in using the data and models effectively, increases the efficiency as well as frequency of some specific use of the DSS. A user interface can be analyzed on the basis of its components – working language, presentations language and base of information – as well as its manner of interaction. These components are briefly analyzed here.

The working language for the user interface identifies the inputs that decision-makers enter into an DSS and the form of the requirements for the outputs from the DSS. Various exchanges of information are possible between users and the DSS. Five types of working languages are historically used for an DSS:

- menu;
- commands;
- answers to questions;
- input/output;
- natural speech.

When an interface is used as a menu, the display screen provides a list of possibilities (functions, commands, operations, regimes, tips, results) from which system users can make a choice for their work. The list of commands in the menu is usually divided up into command groups by meaning and by actions performed. It can be a window, contextual, tools or managerial menu. Users using an interface in the form of a menu can select various ways of activating the system: with a mouse, a pointer and an “Enter” key, pressing the letter of the first command letter, speaking into a microphone that is connected to the computer and, with certain types of sensorial terminals, using a finger or a pen. Then there is also the voice input system activated by speaking into a microphone that is connected to the computer. The use of a menu could involve hundreds of possible choices, which must be organized to permit their presentation in understandable sizes. For example, the organization of a hierarchical menu is by hierarchy, and this menu switches to another menu for each unit chosen, which belongs to a secondary group. Use of a multi-window system can circumvent certain problems in moving through the menu structure. The menu window can be open alongside another window showing the hierarchy of the menu. Not only is it important to have the chance to establish one’s own location within the hierarchy of the menu, moving forward must also be a possibility for a user upon indicating what other menu must be shown. This way, wide leaps can be taken from one level to another in the hierarchy.

The commands interface demands a user to input a text command into the system. The command can be in the form of a question or an input into some command subsystem or it can call up a sequence of other commands. The commands interface is irrational for inexperienced users, because a comparatively lengthy time is required to learn the language of commands. Therefore an interface grounded on a menu (or, at times, a natural speech interface) is the best type of interface for inexperienced users. An experienced computer user sometimes gives priority to the commands interface, since it helps to interact with a computer faster. Generally commands interfaces are not used singularly in an DSS. They are usually used jointly with a menu interface. Thus, in this case, there is a rational combination between the flexibility, power and ease of use of the interfaces employed

Use of the question and answer format involves a user’s answers to the questions posed by the DSS, which then directs the dialogue in the desired direction. The user is also able to pose questions.

The input/output format can provide a user with many forms on the display screen. These have been filled out in certain places, while other places are highlighted for the user to fill out (Figure 3.11). For example, the project designer who has planned out a building with the help of the DSS needs to order required materials and structures for the construction of the building. Now this user is able to take the necessary information from this project's specifications and submit it on an order form that is acceptable to a specific supplier for the needed materials and structures. This form is filled out and sent directly from the computer to the supplier. Generally the submission of completed forms for ordering construction materials and structures directly relates to the work of a building project planner. The data on the order form automatically change relevant to the required structures and materials, as decisions change regarding the planning and make-up of the building. Project designers and architects can perform analyses of the quality to price ratio of various variants relevant to make-ups and planning, structures and other decision alternatives with the DSS quite effectively. These players are more likely than the rest to value materials and structures according to their better quality to price ratios; therefore, the DSS serves them well in performing and selecting the most effective decisions in their work. Furthermore this system provides information about needed materials and structures that do not appear automatically on the order form.

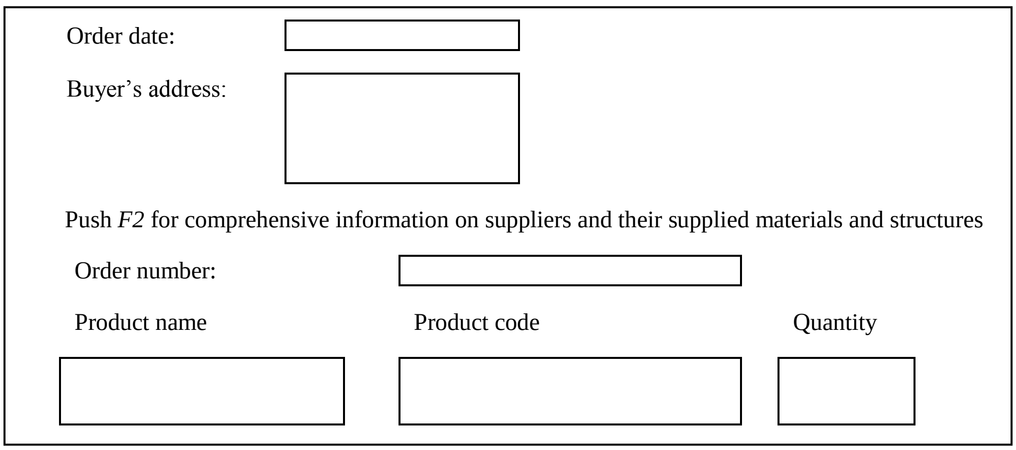

Figure 3.11. Input /output format fragment

The natural speech interface provides the opportunity for a user to interact with the DSS in a natural voice. Different difficulties can arise, however, when a user expresses unusual terminology or has an accent (for example, when the system is used in an international range). Nevertheless, the natural speech interface can be most beneficial to user who are unable to make use of other input devices or who face a situation making use of other devices irrational.

The language the computer uses to submit the results of the analyses the DSS has performed is in a form that is acceptable to the user, if that user had used working speech to interact with the computers. The essential results of an DSS analysis are provided meaningfully and attractively at the beginning of the analysis and at its end presenting the results of intermediary calculations. Some results are more rationally submitted as a table, while others as a graph, diagram, text, video or some other form.

Use of different windows for presenting different results increases the effectiveness of the language used by the DSS for presentations. The layout of windows that are open at the same time can be changed automatically by using the menu. This menu offers a layout of windows arranged in a way, so the name of every window is visible, all the windows are reduced to the size of pictograms or the buttons on the tasks bar and such. The recommendation for easing the work of users with the DSS is to position the information of the same type of graphics, tables, warnings, help or other typical forms, colors and lettering in the same place on the display screen. In this instance, users intuitively find the type of information they need faster so they save time and achieve greater clarity about using the DSS. Users point their cursor on the pictogram or button on the task bar to select the desired program or operation for performing the analysis of some specific problem. An analysis of the same problem can be performed in different ways; thus different possibilities for accomplishing an analysis of different problems must be foreseen.

The language used to present information to a user must be objective. The degree of objectivity of an analysis lessens, when a user does not receive all the factors defining some problem under consideration. Often the objectivity level of the information presented to users depends on the applied method. For example, the manager of two identical cement mixer manufacturing plants analyzed the effectiveness of the plants based on average capacity rates. The first plant produced 8,300 cement mixers in a year, whereas the second plant, 6,000 units. The derived difference was rather large. Nonetheless, the difference in capacity does not seem so great, when it is considered that the permissible deviation is 2,500 and that the second plant is undergoing a restructuring. Therefore the data the DSS presents on the display screen about the capacity levels of these two plants should also familiarize a user with the supplemental information regarding possible deviations in capacity along with the ongoing reorganization at the second plant. Information presenting the operations of analogical plants in the country and beyond its borders, existing demand and supply, competitors and other similar information additionally increases the objectivity of the provided information. Application of more appropriate models for the analysis might also increase its objectivity. Obviously various factors can affect the objectivity level of a problem's analysis over the entire period under analysis.

Instructions are necessary for a user's interaction with the system that are used from the initiation of beginning jobs for selecting and changing options until the ending of the work by the DSS. Such instructions are provided for users in different ways. One of the most popular teaching tools is learning by example. In this case, the screen presents the entire process, with all its possibilities, for making some specific decision on the screen for that user. The effort is to demonstrate all the possibilities of the DSS to a user thoroughly. For example, a good portion of users are not experts about different models (statistical, financial, mathematical programming and such). In this case, the DSS helps a user use these sorts of models practically.

The demands different users have for a user interface vary. Users would like for a user interface to help them accomplish analyses of problems maximally for them to make decisions. For example, physicians would rather have the DSS screen remind them of a treatment diagram that they traditionally use. Thus the essential needs of a user have a determining influence on the project planning for a user interface. Metaphors picture essential concepts and expressions such as, for example, a red cross to associate with medical care. Such visuals are used to signify different procedures in the effort to ease a user's work with the DSS. Use of different colors on a computer affects people of different cultures and countries differently. Red is one example of a color that is very meaningful for some nationalities, but other nationalities are completely indifferent to it. It is obvious that the means of interactions between users and an DSS must be carefully planned.

3.6. TEAMWORK

Teamwork becomes effective, when all members of the group receive thorough and integrated information. All information is stored in one site that is easily accessible to every team member. There is no more need for any verbal explanations – every employee knows his/her rights obligations, duties and the basic principles for the division of labor. Therefore there is no need to organize additional meetings and conferences for no reason. Instead, the leader of a group can effectively regulate and adjust the activities of his/her subordinates. Integrated work procedures allow allocating jobs among team members in a way for all to engage in interesting activities for which he/she has the most experience and qualification.

There are quite a few publications worldwide about the duration of a team's life – from the beginning of its formation to the end of its activities. Tuckmann (Europulsas 2006) holds the opinion that small groups go through five stages during the evolvement of a team:

- Formation – a team forms during this stage as well as learns what behavior is acceptable to the group. Groups establish essential and non-essential rules. This is a time of acclimatization and orientation.
- Storm – once team members begin feeling better within the group, they might disagree with the structure of the group under formation. They often resist the rules established during the first stage.
- Normalization – this period is for resolving the conflicts that arose in the previous stage. The group unifies, because certain members establish common goals, standards and fundamental rules. Members begin declaring a common opinion, and close relationships begin unfolding.
- Activities – the issues about the structure have already been resolved, and the team begins to work like a singular unit. Now the formed group designates all its efforts for conducting common activities, not for resolving problems amongst each other.
- End of teamwork – now temporary teams, like those for implementing some specific project, complete their activities. Meanwhile the attitudes of the members range from excitement to depression (Europulsas 2006).

The working atmosphere generates the overall effectiveness of such a division. What can be done with employees who perform their work beautifully but, apparently, are incapable to finding agreements with their colleagues? The division's employees usually sense a nervous tension due to the ongoing disagreements. The sum total of the results coming from a well-working person who is frequently angry with surrounding people could be zero or negative, taking into consideration the work performed along with the nervous tension generated causing a drop in the productivity of others on the team. The measurement of success in an organization is not only by the specific work performed by a person on the job but also by balancing the damage done, e.g., by ignoring company rules, work procedures and policies, against the benefits gained. For example, morally trampling coworkers by constantly bragging, hurting the sensibilities of others or demeaning authority, causes their productivity to drop, burdens interactions among coworkers and lowers work effectiveness. This is the reason organizations issue job descriptions for specific work duties. Companies describe their expectations regarding how results should be sought. Such job descriptions can discuss teamwork, skills for getting along with others, interactions with stockholders along with other skills and behaviors (Joan Lloyd & Associates 2010).

Many situations in teamwork repeat thousands of times. A boss behaves inappropriately with a subordinate. Coworkers do not agree on various issues. Different means of resolution are available. How should one act in such a situation? What kind of a decision would be more rational? These and other practical issues on teamwork can be resolved by making use of typical recommendations and rules suggested by various authors (About.com 2010; 3M. Innovative Technologies 2010).

It is also rational to compose typical situations, their resolutions (possible alternatives, the criteria system describing them and their values and significances) and a database of rules for typical decision-making. One can apply such a database, when needed, for resolving practical problems. For example, the conclusion possibly drawn based on the "Righteousness is a subjective matter" rule is that it is recommended to associate with persons whose views coincide with one's own, who retain similar values, unite with similar goals and have compatible characters and temperaments. Thereby objective conditions will form in which fewer ethical problems of all sorts will come up.

Several typical rules appear next to assist in strengthening teamwork and making it more effective (About.com 2010):

- Do not personalize. Use the words we, ours or we, but not you when talking with members of the personnel about goals or duties.
- Do not play the game of the favorites and the unpopular. Delegate interesting assignments to all members of the personnel that provide chances for sharpening skills.
- Recognize and reward team efforts. Establish the group's goals and celebrate when the team reaches them.
- Establish the importance of each person to the team. Show the personnel that they truly mean a lot; i.e., publicly recognize their experience and performed work.

The teams that will meet with success are those with the capabilities to change constantly by reacting to the ever-changing needs of the group and the environment more flexibly. Organizations need employees who are capable of reacting to the changes happening flexibly and quickly adapting to the ever-changing conditions. Such changes can cause stress and feelings of insecurity for many employees.

The sources of stress related to work are two: personal and conditional to the environment. Factors arising from the environment include the work schedule, pace of the work, sense of insecurity about the job, travel to and from work, noise at the work place and the number of visitors along with the behavior of the visitors. Work related stress could cause serious consequences to an employee as well as to the entire team. The outcomes of stress include anxiety, depression, anger, various health maladies (headaches, insomnia, fatigue) and accidents. Stress can also do a good deal of harm to the organization as well, for example, a worsening of work quantity and quality, more frequent employee turnover and an onslaught of complaints. However, stress is not always damaging. For example, certain people work more effectively under mild stress.

The recommendations for reducing stress include planning the jobs for each day rationally, performing a delegated job on time, not exceeding one's own limits, maintaining friendly relationships with employees, superiors and visitors and jointly resolving problems and disagreements that arise in a friendly manner. Stressful situations depend more on a boss than on an employee. A superior is able to provide more freedom for employees for accomplishing their jobs, lessen bureaucracy, promote achieved wins and consult people on issues of concern.

Stressful situations can lower the effectiveness of teamwork in various ways, i.e., due to absences, reduced productivity, employee turnover, accidents and such. Symptoms of stress can be grouped into three general categories: physiological, psychological and behavioral. Stress can cause a more rapid heart rhythm and breathing rate, high blood pressure, headaches and even a heart attack. Psychological symptoms are even more important. Since stress can cause dissatisfaction, work related stress could cause dissatisfaction with work. Displeasure with one's work is simply the most obvious psychological symptom of stress. However, stress also announces itself by other sorts of psychological states, for example, tension, anxiety, irritability, boredom and procrastination. Behavioral symptoms caused by stress include a changed level of productivity, absences, employee turnover and impatience.

Employee selection should be the starting point in any discussion relevant to reducing stress caused by teamwork. There needs to be an explanation regarding the suitability of the employee's capabilities for fulfilling the job requirements. Employees usually suffer from a good deal of stress, when the assignments they get are more than they can handle. Good team intercommunications can lessen stress caused by unclearness to a minimum. Responsibly composed, detailed job descriptions should clearly delineate an employee's duties and operational goals, thereby lessening the number of unnecessary conflicts. A reorganization of the work process might also lessen stress. A rearranged work process could lessen boredom as well as the workload. In other words, a rearrangement of jobs should make them more interesting while reducing the load of unnecessary work. Providing employees with possibilities for shared decision-making and needed support results in stress reduction.

Teams can improve effectively by having the ability to make use of their employees' teamwork experiences and knowledge rapidly and effectively. For example, when employees undertake a new project, they do not have to start "from zero", if they are able to make use of the experiences of other team members.

Recently the application of teamwork using Internet technologies is used more and more often around the world for operations such as industry, health care, agriculture, environmental protection, construction, real estate, consulting services, insurance, trade, travel/tourism services, job market, sales of stocks and bonds as well as products, banking and financial services. The next several examples are from the automotive field.

Ford engineers design automobile motors in common although they are located in various countries around the world. Use of special Internet design software and data and knowledge bases are for performing this design process. Everything being designed is visible to all the other participants of the project who are able contribute actively to this process.

Daimler-Chrysler, General Motors and Ford are the major giants in the automobile manufacturing industry. They are jointly creating a system for sales of electronics. This system will provide an opportunity to rationalize the purchasing and supplying of raw materials and parts, which will result in price reductions of automobiles under manufacture. Other companies and suppliers in the automobile-makers industry can participate in this project. Other companies in the auto industry that do not want to lag behind the competition are also creating similar systems in the electronics business.

Traditionally strong supplier contacts have evolved in Europe's automobile industry. The variety of the product assortment makes it sufficiently difficult to rationalize this supply process more than it already is. Orders can involve over 30 000 combinations for every automobile model, because different chassis styles, motors, finishing, colors and other features of an automobile have been designed. Therefore it is especially important to have a strong contact for information across the entire supply chain. The required qualitative information and knowledge must circulate unhindered over the supply chain and provide timely satisfaction of all interest group needs, from the development of the product idea to the design stage and onward to the manufacturing logistics and sales up to the time product use ends (Single European... 2002).

The governments of numerous developed countries pay much attention to assuring provision of social and other kinds of services by electronic means to the public of today. This would provide residents and companies an opportunity to submit their declarations, applications and other documents electronically via Internet. Currently the governments of developed countries are making scant use of the vast opportunities for information and contact technologies for increasing the effectiveness of their operations.

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Chapter 4

4. APPLICATIONS OF IDSSS AND THE IOT FOR VARIOUS STAGES OF THE LIFE CYCLE OF THE BUILT ENVIRONMENT AND ITS ASSESSMENT

This chapter will present a brief analysis of the use of intelligent decision support systems (IDSSs) and the IoT in the life cycle of a building and its assessment. The chapter will focus on IDSSs integrated into the systems developed by the author and his colleagues presented in Chapter 5.

4.1 RECOMMENDER, ADVISORY AND EXPERT SYSTEMS AND THEIR INTEGRATION WITH VARIOUS STAGES OF THE LIFE CYCLE OF A BUILDING AND ITS ASSESSMENT

The two terms — recommender systems and advisory systems — are very often used as synonyms in literature.

Recommender Systems are software tools and techniques providing suggestions for items to be of use to a user. The suggestions provided are aimed at supporting their users in various decision-making processes, such as what items to buy, what music to listen, or what news to read. Recommender systems have proven to be valuable means for online users to cope with the information overload. Development of recommender systems is a multi-disciplinary effort which involves experts from various fields such as Artificial intelligence, Human Computer Interaction, Information Technology, Data Mining, Statistics, Adaptive User Interfaces, Decision Support Systems, Marketing, or Consumer Behavior (Ricci et al. 2011).

Advisory systems provide the advices and assist for solving problems that are normally solved by human experts. They can be classified as a type of expert systems (ElAlfi and ElAlami 2009). Both advisory systems and expert systems provide expertise to support decision making in a myriad of domains. Expert systems are used to solve problems in well defined, narrowly focused problem domains, whereas advisory systems are designed to support decision making in more unstructured situations which have no single correct answer (Beemer and Gregg 2008).

Both advisory systems and expert systems are problem-solving packages that mimic a human expert in a special area. These systems are constructed by eliciting knowledge from human experts and coding it into a form that can be used by a computer in the evaluation of alternative solutions to problems within that domain of expertise. Advisory systems do not make decisions but rather help guide the decision maker in the decision-making process, while leaving the final decision-making authority up to the human user (Turban and Aronson 2001).

The next paragraphs describe in detail the integration of recommender, advisory and expert systems with various stages of the life cycle of a building.

Sustainability has become an important initiative discussed and undertaken, not only by private buildings, but also by public buildings which both dealing with residential, office, commercial as well as hospital. Sustainable building is the practice of designing, constructing, operating, maintaining, and removing buildings in ways that conserve natural resources and reduce pollution. Rating systems provide effective framework for assessing building environmental performance and they measure a building's sustainability by applying a set of criteria organized in different categories. A good Green Building Rating System (GBRS) should cover key indicators reflecting a building's characteristics and keep their performance in balance. This paper proposed a knowledge-based expert system as a tool to assess the performance level of a green building based on assessment factors of green building rating systems. Analytic Hierarchy Process (AHP) and fuzzy logic is adopted in order to develop the knowledge-based expert system. The data for this research collected from the experts in the field via pair-wise and Likert-based questionnaires. Using AHP, the most important parameters of rating systems according to their weights selected to be incorporated in the Fuzzy Inferences System (FIS) of fuzzy logic model. The fuzzy rules (knowledge) discovered from the collected data for FIS to assess the performance level of the green buildings from the Environmental, Social and Economical perspectives denoted as SE2. The outcome of this research is accordingly a performance assessment tool that analyzes the effect of factors in developing the sustainable building (Nilashi et al. 2015).

Nilashi et al. (2015) discussed an efficient expert system developed for performance assessment of a green building system with adopting Analytic Hierarchy Process (AHP) and fuzzy logic denoted as (fuzzy-AHP). Using these approaches, the system is constructed based on three main assessment dimensions in green buildings are Social, Environmental, and Economical denoted as SE2. These three main dimensions have been widely used in the most of the current rating systems. In this research, an effort has been made to develop an expert system to assess the performance level of green buildings using AHP and fuzzy logic approaches. The assessment criteria have been selected from the literature based on the three main dimensions of assessment, Social, Economical and Environmental denoted as SE2 in this research work. The data for this research has been collected from the experts in the field via pair-wise and Likert-based questionnaires. The results of proposed expert system showed the ability of fuzzy logic in evaluating the performance level of green building. In addition, the evaluation results also demonstrated that the Environmental dimension is more important for performance level in relation to the Social and Economical dimensions based on the experts knowledge. The main objectives of this research are twofold (Nilashi et al. 2015):

1. Evaluating and weighting the criteria for green buildings from the SE2 perspectives.
2. Developing a new knowledge-based expert system for assessing the performance level of green buildings from the SE2 perspectives.

A very large percentage of the European residential building stock is ageing and does not comply with current energy regulations. The need to complete short-term energy upgrading on these buildings in order to improve performance and meet current regulations poses a considerable challenge. Consistent energy methodologies are needed for mass application of suitable technologies in sensitive points such as the façade, saving time by guiding designers on use of preferred climatic design strategies for each situation and with economic feasibility (Ochoa and Capeluto 2015). Ochoa and Capeluto (2015) present a methodology with integrative approach between energy and economic aspects, using an inference system to overcome uncertain or unknown information found at the start of the project. Components used in the analysis are studied from a programmatic point of view (input, decision process and output). The methodology is suitable for early stages of the design process and its products enable continuation into more advanced ones. The methodology can form the basis for a software program using either its own databases or integrated energy simulation engines. This work is based on research for a European project concerning energy retrofit of residential building facades, but can be extended to other zones or end-uses having similar approaches. An assumption made in the methodology is that the system will be applied on the entire building facade (i.e., all apartment inhabitants and owners have an agreement on its common use). Due to the repetitive nature of the problem, the methodology is also suitable to become the basis for automated expert systems diagnosing the best alternatives, either as a standalone tool or integrated in a CAD system (Ochoa and Capeluto 2015).

The methodology presented here outlines the procedures for adequate selection and application of adaptable modular systems for energy retrofitting. It summarizes and directs many combined efforts such as energy modelling, economic forecasting, and design specification. As such, it can be used as the basis for expert system software or as guideline for extremely complex renovation projects that have to consider energy efficiency among other aspects. Since a large number of buildings in Europe will need to be retrofitted in order to achieve policy goals for reduced energy consumption and emissions, it is expected that demand for complete retrofit systems will increase. To meet deadlines and for correct application, expert systems using methodologies like the one presented here will be extremely relevant (Ochoa and Capeluto 2015).

Rodger (2014) addresses the problem of predicting demand for natural gas for the purpose of realizing energy cost savings. Daily monitoring of a rooftop unit wireless sensor system provided feedback for a decision support system that supplied the demand for the required number of million cubic feet of natural gas used to control heating, ventilation, and air conditioning systems. The expert system was modeled with artificial neural networks (ANNs). Data on the consumption of the system were collected for 111 days beginning September 21, 2012. The input/output data were used to train the ANN. The ANN approximated the data very well, showing that it can be used to predict demand for natural gas. A fuzzy nearest neighbor neural network statistical model consisting of four components was used. The predictive models were implemented by comparing regression, fuzzy logic, nearest neighbor, and neural networks (Rodger 2014). In addition, to optimize natural gas demand, Rodger (2014) used the fuzzy regression nearest neighbor ANN model cost function to investigate the variables of price, operating expenses, cost to drill new wells, cost to turn gas on, oil price and royalties.

Ekici and Aksoy (2011) present Adaptive Network Based Inference System (ANFIS) model to forecast building energy consumption in a cold region. The objective of this research is to examine the feasibility and applicability of ANFIS in building energy load forecasting area. Different combinations of building samples formed by using three different form factors (FF 1/2, FF 1/1 and FF 2/1), nine azimuth angles varied 0o–80o, three transparency ratios of 15%, 20%, 25% and five insulation thicknesses of 0, 2.5, 5, 10 and 15 cm. Finally, it is observed that ANFIS can be a strong expert tool with the 96.5 and 83.8% for heating and cooling energy prediction in pre-design stage of energy efficient buildings for choosing the best combinations (Ekici and Aksoy 2011).

A brief discussion is presented of the increasingly important role being played by informatic techniques in the building sector. Computer aided design packages for the architect have existed for some time, but other types of software are also needed now. The profusion and complexity of norms and standards, together with the large number of technical solutions available, make it very difficult to master all the knowledge required for building design and retrofit without informatic help. This is particularly true in building energy auditing, which is an essential prelude to the retrofitting of older buildings. To illustrate the way ahead, an expert system being developed by the Joint Research Centre is described. This system, known as BEAMES, employs a neural network allowing the system to "learn" from the experience of past audits (Caudana et al. 1995).

Doheny and Monaghan (1987) describes the development of an expert system which carries out the preliminary stages of the concept design of energy systems for buildings. The concept design is based on the optimal search of a space, which includes all possible solutions, using heuristic knowledge about the problem. Problem knowledge is divided into five categories: domain knowledge; constraint knowledge; procedural knowledge; analysis algorithms and solution knowledge. This knowledge has been represented in an expert system, written in OPS5 and accessing FORTRAN-coded analysis and graphics routines. Domain, constraint and procedural knowledge have been implemented in a hierarchical manner using production rules and linked data structures (Doheny and Monaghan 1987).

The growing demand for air-conditioned buildings and the resultant demand for electrical energy has prompted research into passive cooling, such as the European Union funded PASCOOL programme. One of the tasks in this programme is to develop comfort criteria appropriate to free-running non air-conditioned buildings, where environmental conditions are likely to vary much more widely than mechanically controlled buildings. Conventional comfort theory has criteria which are more appropriate to controlled buildings. These criteria fail to account for the adaptive behaviour of the occupants to improve the thermal conditions actually experienced (Baker and Standeven 1996). Baker and Standeven (1996) briefly summarise the results of the comfort monitoring surveys, conducted within the research programme during 1993 and 1994, which have provided information on room and local thermal conditions, and simultaneous subjective responses. Although limited in scope, the results show clearly that the subjects were exercising a considerable amount of adaptation both in regard to their person and their immediate surroundings during the surveys. More discursive comment is made on adaptive behaviour such as metabolic rate adjustment, followed by speculative comments on the nature of environmental tolerance. Finally, an outline for an expert system to assess thermal satisfaction is proposed (Baker and Standeven 1996).

4.2. Data Mining Research

Data mining is applied often enough in fields such as decision support system, analytics, predictive analytics, data analysis, data warehouse, business intelligence, exploratory data analysis and web mining. The beginning of this section will present a short analysis on how data mining can enlarge the opportunities for intelligent decision support systems and their interdependencies as well as the technologies being used. This section will close by providing practical examples for the use of data mining in intelligent decision support systems and by describing what sorts of additional data mining opportunities could be applied in the future while developing IDSS.

Decision support systems (DSS) are a specific class of computerized information system that support business and organizational decision making activities. On the other hand, data mining extends the possibilities for decision support by discovering patterns and relationships hidden in the data and therefore enabling an inductive approach to data analysis (Khademolqorani and Hamadani 2013).

Data mining processes data from different perspectives into useful knowledge, and becomes an important component in designing intelligent decision support systems (IDSS) (Yang et al. 2012).

It has been estimated that the amount of stored information doubles every twenty months. Data mining is a term coined to describe the process of sifting through large databases for interesting patterns and relationships. Given the recent growth of the field, it is not surprising that a wide variety of data mining methods is now available to the researchers and practitioners. No one method is superior to others for all cases (Maimon and Rokach 2010).

Data mining research for the various phases of the life cycle of a building can be summarized as follows.

The construction industry has been increasingly adopting green building because of its advantages over conventional building. However, implementing successful green building projects entails difficulties in terms of cost performance. The objective of this study is to identify the critical factors that affect the cost performance of green building projects during their pre-project planning phase. This study validates the relationship between certain critical factors and the cost performance of green building projects. Support vector machine-recursive feature elimination (SVM-RFE), a data mining-based feature selection method, is applied to a data set comprising 53 green building projects. The results of the study show that 10 out of 64 project definition rating index (PDRI) factors exert most of the influence on the cost performance of the green building projects. These results will help the project stakeholders deliver green building projects more successfully in terms of cost performance (Son et al. 2015).

Developed by the USGBC, LEED is currently the most widely adopted credit-based green building rating program worldwide. Buildings can be graded as Platinum, Gold, Silver, or Certified depending on the number of LEED credit points achieved. Selection of LEED credits is an important step in LEED certification planning and application. The relationships between LEED credit achievement and project factors like budget and schedule have already been studied. Apart from these, climate factors such as temperature and precipitation can also affect the selection of green building technologies and therefore the LEED credits achieved. However, study on the relationships between LEED credit achievement and the climate of the building location is lacking (Cheng and Ma 2015). Cheng and Ma (2015) investigate the relationship between climate factors and LEED credits using data mining techniques. The LEED credits achieved and the local climate conditions of 912 LEED certified existing building projects were collected and analyzed. By setting the climate factors as variables and the credit achievements as the targets, 26 classification models were built using the Random Forests classification algorithm. The variable importance for each credit was then calculated based on the contribution to the classification performance. For the models with high AUC performance, high importance climate factors were identified and discussed. The results show that some climate factors, such as diurnal temperature range, have a notable correlation with the achievement of certain LEED credits (Cheng and Ma 2015).

Early prediction of the performance of green building projects using pre-project planning mining approaches is an important and challenging issue. The aim of this study was to develop a model to predict the cost and schedule performance of green building projects based on the level of definition during the pre-project planning phase. To this end, a three-step process was proposed: pre-processing, variable selection, and prediction model construction. Data from 53 certified green buildings were used to develop the models. After balancing the data set with respect to the proportion of cases in each of the outcome categories by pre-processing, the number of input variables was reduced from 64 to 13 and 7 for cost and schedule performance prediction respectively, using the ReliefF-W variable selection method. Then, cost and schedule performance prediction models were constructed using the selected variables and four different classifiers: a support vector machine (SVM), a back-propagation neural network (BPNN), a C4.5 decision tree algorithm (C4.5), and a logistic regression (LR). The classification performance of the four models was compared to assess their applicability. The SVM models exhibited the highest accuracy, sensitivity, and specificity in predicting both the cost and schedule performance of green building projects. The results of this study empirically validated that the cost and schedule performance of green building projects is highly dependent on the quality of definition in the pre-project planning phase (Son and Kim 2014).

The occupants' health, comfort, and productivity are important objectives for green building design and operation. However, occupant behavior also has "passive" impact on the building indoor environment by generating heat, CO2, and other "disturbances". This study develops an "indirect" practical data mining approach using office appliance power consumption data to learn the occupant "passive" behavior. The method is tested in a medium office building. The average percentage of correctly classified individual behavior instances is 90.29%. The average correlation coefficient between the predicted group schedule and the ground truth is 0.94. The experimental result also shows a fairly consistent group occupancy schedule, while capturing the diversified individual behavior in using office appliances. Compared to the occupancy schedule used in the Department of Energy prototype medium office building models, the learned schedule has a 36.67–50.53% lower occupancy rate for different weekdays. The heating, ventilation, and air conditioning (HVAC) energy consumption impact of this discrepancy is investigated by simulating the prototype EnergyPlus models across 17 different climate zones. The simulation result shows that the occupancy schedules' impact on the building HVAC energy consumption has large variations for the buildings under different climate conditions (Zhao et al. 2014).

Kim et al. (2011) intend to address why delivery of an energy efficient building is not just the result of applying one or more isolated technologies. Rather, it can best be obtained using an integrated whole building process throughout the entire project development process, which leads building designers to generate a large amount of data during energy simulations. Kim et al. (2011) observed that even a simple energy modeling run generated pages of data with many different variables. The volumes of energy modeling data clearly overwhelm traditional data analysis methods such as spreadsheets and ad-hoc queries with so many factors to be considered. An integrated or whole building design process involves studies of the energy-related impacts and interactions of all building components, including the building location, envelope (walls, windows, doors, and roof), heating, ventilation and air conditioning

(HVAC) system, lighting, controls, and equipment, which shows why it is so difficult to find the correlation between different systems. The objective of this research is to develop an energy efficient building design process using data mining technology which can help project teams discover important patterns to improve the building design. This paper utilizes the data mining technology to extract interrelationships and patterns of interest from a large dataset. Case study revealed that data mining based energy modeling help project teams discover useful patterns to improve the energy efficiency of building design during the design phase. The method developed during this research could be used to guide designers and engineers through the process of completing an early design energy analysis based on energy simulation models (Kim et al. 2011).

Yu et al. (2011) report the development of a new methodology for examining the influences of occupant behavior on building energy consumption; the method is based on a basic data mining technique (cluster analysis). To deal with data inconsistencies, min–max normalization is performed as a data preprocessing step before clustering. Grey relational grades, a measure of relevancy between two factors, are used as weighted coefficients of different attributes in cluster analysis. To demonstrate the applicability of the proposed method, the method was applied to a set of residential buildings' measurement data. The results show that the method facilitates the evaluation of building energy-saving potential by improving the behavior of building occupants, and provides multifaceted insights into building energy end-use patterns associated with the occupant behavior. The results obtained could help prioritize efforts at modification of occupant behavior in order to reduce building energy consumption, and help improve modeling of occupant behavior in numerical simulation (Yu et al. 2011).

With the advances of information technologies, today's building automation systems (BASs) are capable of managing building operational performance in an efficient and convenient way. Meanwhile, the amount of real-time monitoring and control data in BASs grows continually in the building lifecycle, which stimulates an intense demand for powerful big data analysis tools in BASs. Existing big data analytics adopted in the building automation industry focus on mining cross-sectional relationships, whereas the temporal relationships, i.e., the relationships over time, are usually overlooked. However, building operations are typically dynamic and BAS data are essentially multivariate time series data (Fan et al. 2015). Fan et al. (2015) present a time series data mining methodology for temporal knowledge discovery in big BAS data. A number of time series data mining techniques are explored and carefully assembled, including the Symbolic Aggregate approXimation (SAX), motif discovery, and temporal association rule mining. Fan et al. (2015) also develop two methods for the efficient post-processing of knowledge discovered. The methodology has been applied to analyze the BAS data retrieved from a real building. The temporal knowledge discovered is valuable to identify dynamics, patterns and anomalies in building operations, derive temporal association rules within and between subsystems, assess building system performance and spot opportunities in energy conservation (Fan et al. 2015).

4.3. DATA ANALYTICS IN VARIOUS STAGES OF THE LIFE CYCLE OF A BUILDING

Lately data analytics has been becoming more and more popular. However, data analytics are rarely used as composite parts of IDSS. Predictive analytics is the branch of data mining concerned with forecasting probabilities. The technique uses variables that can be measured to predict the future behavior of a person or other entity. Multiple predictors are combined into a predictive model. In predictive modeling, data is collected to create a statistical model, which is tweaked as additional data becomes available (Matlis 2006).

Kwon et al. (2014) define big data analytics as technologies (e.g., database and data mining tools) and techniques (e.g., analytical methods) that a company can employ to analyze large scale, complex data for various applications intended to augment firm performance in various dimensions.

A few examples of data analytics in use in various stages of the life cycle of a building are presented below.

Buildings consume more than one-third of the world's primary energy. Reducing energy use in buildings with energy efficient technologies is feasible and also driven by energy policies such as energy benchmarking, disclosure, rating, and labeling in both the developed and developing countries. Current energy retrofits focus on the existing building stocks, especially older buildings, but the growing number of new high performance buildings built around the world raises a question that how these buildings perform and whether there are retrofit opportunities to further reduce their energy use. This is a new and unique problem for the building industry. Traditional energy audit or analysis methods are inadequate to look deep into the energy use of the high performance buildings (Hong et al. 2014). Hong et al. (2014) aim to tackle this problem with a new holistic approach powered by building performance data and analytics. First, three types of measured data are introduced, including the time series energy use, building systems operating conditions, and indoor and outdoor environmental parameters. An energy data model based on the ISO Standard 12655 is used to represent the energy use in buildings in a three-level hierarchy. Secondly, a suite of analytics were proposed to analyze energy use and to identify retrofit measures for high performance buildings. The data-driven analytics are based on monitored data at short time intervals, and cover three levels of analysis – energy profiling, benchmarking and diagnostics. Thirdly, the analytics were applied to a high performance building in California to analyze its energy use and identify retrofit opportunities, including: (1) analyzing patterns of major energy end-use categories at various time scales, (2) benchmarking the whole building total energy use as well as major end-uses against its peers, (3) benchmarking the power usage effectiveness for the data center, which is the largest electricity consumer in this building, and (4) diagnosing HVAC equipment using detailed time-series operating data. Finally, a few energy efficiency measures were identified for retrofit, and their energy savings were estimated to be 20% of the whole-building electricity consumption. Based on the analyses, the building manager took a few steps to improve the operation of fans, chillers, and data centers, which will lead to actual energy savings. This study demonstrated that there are energy retrofit opportunities for high performance buildings and detailed measured building performance data and analytics can help identify and estimate energy savings and to inform the decision making during the retrofit process. Challenges of data collection and analytics were also discussed to shape best practice of retrofitting high performance buildings (Hong et al. 2014).

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Standardisation, archiving, and digital access of spatial data pertaining to built-up environments is an area acquiring increasing attention amongst several interest groups: policy makers, designers and planners, civil engineers, infrastructure management and public service personnel, building users. Initiatives such as the Building Information Model (BIM), Industry Founda- tion Classes (IFC), and CityGML are creating the information-theoretic backbone that guides the crucial aspects of quality, exchange, and interoperability of spatial data at the environmental and urban scale. However, due to the inherent scale, com- plexity, and detailed geometric character of building information data, extracting useful semantic and qualitative knowledge for accomplishing high-level analytical tasks is still an extremely complex and error prone process involving data intensive computing (Schultz and Bhatt 2013). Schultz and Bhatt (2013) propose a uniform spatial data access middleware that can provide a combination of high-level, multi-modal, semantic, and quantitative-qualitative spatial data access and analytical capability. Schultz and Bhatt (2013) present the core computational capabil- ities for the proposed middleware and present an overview of the high-level spatial model and its compliance with the industry standard IFC. A key theoretical contribution is a framework for investigating the computational complexity of deriving spatial artefacts within the context of building informatics. Additionally, Schultz and Bhatt (2013) empirically investigate the feasibility and practicality of the derivation of spatial artefacts by conducting experiments on seven industry-scale IFC models.

4.4. DSSs FOR THE LIFE CYCLE OF A BUILDING AND ITS ASSESSMENT

There are various classifications of decision support systems (DSS). This Sub-chapter is based on the traditional DSS classification, according to which DSS are sorted out into decision support systems, group decision support systems, expert systems and neural networks. All the systems taken together get into the artificial intelligence sphere. This subchapter analyses in detail these systems for the life cycle of a building and its assessment.

The evaluation of the environmental performance of energy systems used in residential buildings by applying the principles of the Life Cycle Analysis is an established methodological approach. Applying it in practice presents, however, significant interest, as a lack of available data has to be overcome. The research results presented in this research include the analysis of the production, disposal and transportation of the materials used for the manufacturing processes of the building's energy systems, which include an oil and a gas fired boiler, split unit air conditioners, mono-Si and poly-Si PV arrays, flat plate and evacuated tube solar thermal collectors and their auxiliaries. The data needed for the analysis were taken from audits in the industries producing those systems, from related studies already published and from publicly available databases, when no other source was available. In this way, a comprehensive and fully adjustable database of the systems’ environmental impact has been created. This database can be a part of an integrated dynamic decision support tool, or it can be used in combination with tools commercially available. It can therefore assist prospective users in the selection of the appropriate energy systems that will lead to the minimization of the total environmental impact of new and existing buildings. The results are applied to a representative residential building and its systems are evaluated and analyzed for several scenarios (Anastaselos et al. 2015).

A prototype energy signal tool is demonstrated for operational whole-building and system-level energy use evaluation. The purpose of the tool is to give a summary of building energy use which allows a building operator to quickly distinguish normal and abnormal energy use. Toward that end, energy use status is displayed as a traffic light, which is a visual metaphor for energy use which is substantially different from expected (red and yellow lights) or more or less the same as expected (green light). Which light to display for a given energy end-use is determined by comparing expected energy use to actual energy use (Henze et al. 2015). As expected energy use is necessarily uncertain, Henze et al. (2015) cannot choose the appropriate light with certainty. Instead the energy signal tool chooses the light by minimizing the expected cost of displaying the wrong light. The expected energy use is represented by a probability distribution. Energy use is modeled by a low-order lumped parameter model. Uncertainty in energy use is quantified by a Monte Carlo exploration of the influence of model parameters on energy use. Distributions over model parameters are updated over time via Bayes' theorem. The simulation study is devised to assess whole building energy signal accuracy in the presence of uncertainty and faults at the submetered level, which may lead to tradeoffs at the whole building level not detectable without submetering (Henze et al. 2015).

The economic and environmental benefits of building retrofits have been acknowledged. However, there is a series of barriers that threaten to impede implementing successful retrofit projects such as: lack of funding, lack of interoperability, and unstructured decision making (Woo and Menassa 2014). Woo and Menassa (2014) aim to address these barriers by providing the framework of the Virtual Retrofit Model (VRM), an affordable computational platform that supports streamlined decision making for building retrofit projects. An occupant survey was implemented to identify the primary requirements and perceptions from different types of stakeholders of the buildings. The responses were analyzed to identify the most important criteria of the future retrofit projects to focus on if it were to be renovated in the future. A case study approach was used to describe the outcomes from a year-long demonstration project that has been conducted at an aging commercial building. The research activities focused on integrating theories and technologies of Building Information Modeling (BIM), energy simulation, agent-based modeling, multi-criteria decision support system, and software application that can be employed and adopted in building retrofit projects. The software prototype is designed to connect buildings to a smart grid environment where building energy data should be shared for intelligent decision making (Woo and Menassa 2014).

Lifecycle building performance assessment (LBPA) practices are being increasingly applied on existing buildings to ensure that performance requirements are fulfilled during building service-life. LBPA is a multi-disciplinary and information-intense process that requires computational tools for information management and decision support (Dino and Stouffs 2014). Dino and Stouffs (2014) have previously developed a computational reference model (CLIP-Core) that supports various component-based LBPA practices. When CLIP-Core is considered to be used, it needs to be adapted to the specific context it addresses. Dino and Stouffs (2014) developed two such domain models, CLIP EPI-CREM and CLIP-CMU, for two existing LBPA practices. Dino and Stouffs (2014) addresses the evaluation of CLIP-Core and its potential in supporting various requirements.

In the UK, 87% of dwellings and 60% of non-domestic buildings that will be standing in 2050 have already been built. Therefore, the greatest energy savings and emissions reductions will be achieved through retrofit of existing buildings. This usually involves decision-making processes targeted at reducing operational energy consumption and maintenance bills. For this reason, retrofit decisions by building stakeholders are typically driven by financial considerations. However, recent trends towards environmentally conscious design and retrofit have focused on the environmental merits of these options, emphasising a lifecycle approach to emissions reduction. Building stakeholders cannot easily quantify and compare the sustainability impacts of retrofit options since they lack the resources to perform an effective decision analysis. In part, this is due to the inadequacy of existing methods to assess and compare the cost, operational performance and environmental merit of the options. Current methods to quantify these parameters are considered in isolation when making decisions about energy conservation in buildings. To effectively manage the reduction of lifecycle environmental impacts, it is necessary to link financial cost with both operational and embodied emissions (Ibn-Mohammed et al. 2014). Ibn-Mohammed et al. (2014) present a robust Decision Support System which integrates economic and net environmental benefits (including embodied and operational emissions) to produce optimal decisions based on marginal abatement cost methods and Pareto optimisation. The implication of the DSS within the current climate change policies is also discussed. Overall, the methodology developed provides stakeholders with an efficient and reliable decision process that is informed by both environmental and financial considerations (Ibn-Mohammed et al. 2014).

Decision support tools for energy management in public buildings using future scenarios of market and technological developments would be beneficial. The aim of this paper is to discuss the drivers and uncertainties in the recent and future energy market trends and prices, including technological progress and developments in fossil-fuel markets. This discussion is relevant for researchers and policymakers in general, and in particular, as an input for scenarios used in the development of decision support systems (Egging 2013).

Juan et al. (2010) develop an integrated decision support system to assess existing office building conditions and to recommend an optimal set of sustainable renovation actions, considering trade-offs between renovation cost, improved building quality, and environmental impacts. A hybrid approach that combines A* graph search algorithm with genetic algorithms (GA) is used to analyze all possible renovation actions and their trade-offs to develop the optimal solution. A two-stage system validation is performed to demonstrate the practical application of the hybrid approach: zero-one goal programming (ZOGP) and genetic algorithms are adopted to validate the effectiveness of the algorithm. A real-world renovation project is introduced to validate differences in energy performance projected for the renovation solution suggested by the system. The results reveal that the proposed hybrid system is more computationally effective than either ZOGP or GA alone. The system's suggested renovation actions would provide substantial energy performance improvements to the real project if implemented (Juan et al. 2010).

Europe is facing one of its most challenging crises since Great Depression and the construction sector is one of the worst affected. Refurbishment is therefore often suggested as one of the most useful solutions for the current real estate crisis in consolidated areas like the EU. On the other hand, it is imperative to construct buildings according to sustainable principles regarding economic, environmental and social issues. Therefore, proper decision-support methods are needed to help designers, investors and policy makers to choose the most sustainable solution for a refurbishment project, especially for energy retrofit works (Ferreira et al. 2013). Ferreira et al. (2013) review the works relating to sustainable refurbishment decision-support tools which have already been developed. For this purpose Ferreira et al. (2013) have analysed and classified 40 different methods, with particular focus on their main common aims. They are also compared with other classifications proposed. Ferreira et al. (2013) further highlights the role of energy as a driving factor and discusses what other research developments are needed to create related tools for the future that could respond to actual construction requirements.

The complexity of environmental problems makes necessary the development and application of new tools capable of processing not only numerical aspects, but also experience from experts and wide public participation, which are all needed in decision-making processes. Environmental decision support systems (EDSSs) are among the most promising approaches to confront this complexity. The fact that different tools (artificial intelligence techniques, statistical/numerical methods, geographical information systems, and environmental ontologies) can be integrated under different architectures confers EDSSs the ability to confront complex problems, and the capability to support learning and decision-making processes. In this paper, we present our experience, obtained over the last 10 years, in designing and building two real EDSSs, one for wastewater plant supervision, and one for the selection of wastewater treatment systems for communities with less than 2000 inhabitants. The flow diagram followed to build the EDSS is presented for each of the systems, together with a discussion of the tasks involved in each step (problem analysis, data collection and knowledge acquisition, model selection, model implementation, and EDSS validation). In addition, the architecture used is presented, showing how the five levels on which it is based (data gathering, diagnosis, decision support, plans, and actions) have been implemented (Poch et al. 2004). Finally, Poch et al. (2004) present opinion on the research issues that need to be addressed in order to improve the ability of EDSSs to cope with complexity in environmental problems (integration of data and knowledge, improvement of knowledge acquisition methods, new protocols to share and reuse knowledge, development of benchmarks, involvement of end-users), thus increasing our understanding of the environment and contributing to the sustainable development of society.

In an effort to tackle climate change most countries utilize renewable energy sources. This is more pronounced in the building sector, which is currently one of the major consumers of energy, mostly in the form of heat. In order to further promote the use of domestic solar hot water systems in buildings, an ontology-based decision support tool has been developed and is presented in this paper. The proposed tool aids non-technical consumers to select a domestic solar hot water system tailored to their needs, containing up-to-date information on its components and interrelationships, installation costs etc., in the form of an ontology formulated in OWL (Web Ontology Language). The optimum system configurations are computed based on various specific parameters, such as number of occupants, daily hot water requirements and house location. The backbone of the proposed system is an ontology that represents the application domain and contains information regarding the various domestic solar hot water system components along with their interrelationships. Ontologies are a rapidly evolving knowledge representation paradigm that offers various advantages and, when deployed specifically in the domestic solar hot water systems domain, deliver improved representation, sharing and re-use of the relevant information (Kontopoulos et al. 2015). As a conclusion, Kontopoulos et al. (2015) present an ontology-driven decision support system for facilitating the selection of domestic solar hot water system, which delivers certain advantages, such as sustainability of the decision support system itself, due to its open and interoperable knowledge-base, and its adaptability/flexibility in decision making policies, due to is semantic (ontological) nature.

Ruiz and Fernández (2009) propose a Spatial Decision Support System based on the Geographical Information System (GIS) to evaluate the environmental performance in construction. The system has been designed to add a spatial component to the current tools for the inspection and management of the sustainability of buildings and to assist the planners in their decision-making. The multi-criteria evaluation method developed in the Green Building Challenge and implemented in the software SbTool has been used as a reference. The evaluation method presents a hierarchical structure of criteria and variables which is applied to buildings spatially indexed in GIS and the environmental data of the buildings comes from an external data-base developed in Access. In order to validate the system, the environmental assessment of a group of residential, industrial and public service buildings during the phases of operation was simulated. The application of this tool in the inspection and environmental assessment of buildings allows the geographical scale of analysis to be extended to a group of buildings within the area of interest and consequently to extend the limits of its usefulness within the field of planning and environmental assessment (Ruiz and Fernández 2009).

Life Cycle Assessment (LCA) is a methodology to generate environmental impact estimates associated with the life cycle stages of a product or process. The approach facilitates a more comprehensive outlook of the end-of-pipe process impacts, in which wastewater treatment plants (WWTPs) are included (Garrido-Baserba et al. 2014). Here Garrido-Baserba et al. (2014) describe the implementation of the LCA methodology within a knowledge-based Decision support system (DSS) in order to include the environmental criteria to the decision making process when selecting the most appropriate process flow diagrams for specific scenarios. A sample group of 22 actual operating facilities in Spain, corresponding to five different typologies were assessed by two relevant impact categories within the system: Eutrophication Potential (EP) and Global Warming Potential (GWP). DSS includes useful tools that support a user in choosing a consistent, near optimum solution for an environmental impact specific problem in a reduced time frame. The synergistic combination of the two methodologies to address the design and assessment of treatment facilities can serve to identify the most sustainable options, embracing simultaneously a wide variety of analysis criteria, and enhancing the calculation of environmental savings. Results of averaged paired-comparison ratios between DSS estimates and facilities operations empirical data showed up to 70% and 95% EP and GWP, respectively. Interestingly, when unbiased operational efficiencies for existing facilities were discarded, the matching ratios increased substantially, up to 99% in both cases. The in-depth analysis of different output data gathered during the conceptual design and simulation of operating facilities using DSS identified the best performing facilities; and was used to improve the environmental performance of WWTPs, even during preliminary design of new facilities. Results demonstrated that combined LCA and DSS implementation is a suitable tool to assess WWTP design during the decision-making process. Following this procedure, a reliable interpretation and discussion of the results can be performed (Garrido-Baserba et al. 2014).

4.5. APPLICATIONS OF THE IOT FOR VARIOUS STAGES OF THE LIFE CYCLE OF A BUILDING

Today computers — and, therefore, the Internet—are almost wholly dependent on human beings for information. Nearly all of the roughly 50 petabytes (a petabyte is 1,024 terabytes) of data available on the Internet were first captured and created by human beings — by typing, pressing a record button, taking a digital picture or scanning a bar code. The problem is, people have limited time, attention and accuracy—all of which means they are not very good at capturing data about things in the real world (Ashton 2009).

There is no commonly recognized definition of ”Internet of Things”. Internet of Things can be defined in several ways:

- The concept goal of the Internet of Things is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any path/network and any service. Internet of Things is a new revolution of the Internet. Objects make themselves recognizable and they obtain intelligence thanks to the fact that they can communicate information about themselves and they can access information that has been aggregated by other things. For example - alarm clocks will go off early if there’s traffic; plants will communicate to the sprinkler system when it’s time for them to be watered; running shoes communicate time, speed and distance so that the wearer can compete in real time with people on the other side of the world; medicine containers tell your family members if you forget to take the medicine. All objects can play an active role thanks to their connection to the Internet (Friess et al. 2012).
- Internet of Things (IoT) is an integrated part of Future Internet including existing and evolving Internet and network developments and could be conceptually defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network (Vermesan et al. 2014).
- International Telecommunication Union (ITU) defines the Internet of Things as a ”global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things, based on existing and evolving interoperable information and communication technologies.” ITU’s foundational definition, published on 4 July 2012, offers useful insight and a sound springboard for further analysis and research into the Internet of Things. Importantly, ITU points out that the Internet of Things is a ”vision”, not a single technology, and that it has ”technological and societal implications” (Louchez 2013).
- The Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment (Gartner).

The IoT has many potential applications for various stages of the life cycle of a building. Libelium has released the document “Top 50 Internet of Things Applications”. Based on Libelium (2014), below is an overview of the applications used in various stages of the life cycle of a building:

- Domotic & Home Automation: Energy and Water Use (Energy and water supply consumption monitoring to obtain advice on how to save cost and resources), Remote Control Appliances (Switching on and off remotely appliances to avoid accidents and save energy), Intrusion Detection Systems (Detection of windows and doors openings and violations to prevent intruders), Art and Goods Preservation (Monitoring of conditions inside museums and art warehouses).
- Smart Cities: noise urban maps (sound monitoring in bar areas and centric zones in real time), eletromagnetic field levels (measurement of the energy radiated by cell stations and and WiFi routers), smart lighting (intelligent and weather adaptive lighting in street lights), waste management (detection of rubbish levels in containers to optimize the trash collection routes).
- Smart Environment: forest fire detection (monitoring of combustion gases and preemptive fire conditions to define alert zones), air pollution (control of CO2 emissions of factories, pollution emitted by cars), landslide and avalanche prevention (monitoring of soil moisture, vibrations and earth density to detect dangerous patterns in land conditions), earthquake early detection (distributed control in specific places of tremors).
- Smart Water: potable water monitoring (monitor the quality of tap water in cities), chemical leakage detection in rivers (detect leakages and wastes of factories in rivers), swimming pool remote measurement (control remotely the swimming pool conditions), pollution levels in the sea (control realtime leakages and wastes in the sea), water leakages (detection of liquid presence outside tanks and pressure variations along pipes), river floods (monitoring of water level variations in rivers, dams and reservoirs).
- Smart Metering: smart grid (energy consumption monitoring and management), tank level (monitoring of water, oil and gas levels in storage tanks and cisterns), photovoltaic installations (monitoring and optimization of performance in solar energy plants), water flow (measurement of water pressure in water transportation systems), silos stock calculation (measurement of emptiness level and weight of the goods).
- Security & Emergencies: perimeter access control (access control to restricted areas and detection of people in non-authorized areas), liquid presence (liquid detection in data centers, warehouses and sensitive building grounds to prevent break downs and corrosion), radiation levels (distributed measurement of radiation levels in nuclear power stations surroundings to generate leakage alerts), explosive and hazardous gases (detection of gas levels and leakages in industrial environments, surroundings of chemical factories and inside mines).

The growth in energy monitoring and management requires integration of energy consumption data in several tools to support energy-aware decision-making, such as energy efficiency KPIs (e-KPIs), visualization energy and visualization e-KPIs, energy simulation KPIs, energy-decision support system (e-DSS) and optimization tools. The integration of energy data into production management decisions also requires an e-DSS to support energyaware decision-making. Such systems provide several benefits for the factories. The first benefit is providing solutions and mechanisms to support production processes to be more energy and cost efficient. The second benefit is the rapid response to production processes needs, such as faster response to changes in energy prices (i.e. demand response) (Shrouf and Miragliotta 2015).

In today's manufacturing scenario, rising energy prices, increasing ecological awareness, and changing consumer behaviors are driving decision-makers to prioritize green manufacturing. The Internet of Things paradigm promises to increase the visibility and awareness of energy consumption, thanks to smart sensors and smart meters at the machine and production line level. Consequently, real-time energy consumption data from manufacturing processes can be collected easily, and then analyzed, to improve energy-aware decision-making (Shrouf and Miragliotta 2015). Relying on a comprehensive literature review and on experts' insight, Shrouf and Miragliotta (2015) contribute to the understanding of energy-efficient production management practices that are enhanced and enabled by the Internet of Things technology. In addition, it discusses the benefits that can be obtained thanks to adopting such management practices. Eventually, a framework is presented to support the integration of gathered energy data into a company's information technology tools and platforms. This is done with the ultimate goal of highlighting how operational and tactical decision-making processes could leverage on such data in order to improve energy efficiency, and therefore competitiveness, of manufacturing companies. With the outcomes of this research, energy managers can approach the Internet of Things adoption in a benefit-driven manner, addressing those energy management practices that are more aligned with company maturity, measurable data and available information systems and tools (Shrouf and Miragliotta 2015).

The Water Framework Directive and the European Union carbon emission reduction target by 2020 set out the strategic context for the EU FP7 iWIDGET (Improved Water efficiency through ICT for integrated supply-Demand side manaGEmenT) project (http://www.i-widget.eu/) deployment. The goal of this project is to provide a webbased platform – the iWIDGET system, targeting both the household and water utilities end-users, capable of offering near real-time (at sub-daily intervals) information about water consumption (and energy use, in specific conditions) and a set decision-support tools aimed to promote water and related energy efficient use behaviors. The main scientific challenges of the iWIDGET system are the management and extraction of useful information from vast amounts of high-resolution consumption data, the development of customized interventions to influence behavioral change, and the integration of iWIDGET concepts into a set of decision-support tools for water utilities and consumers, applicable in differing local conditions (Ribeiro et al. 2015).

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Chapter 5

5. WEB-BASED INTELLIGENT DECISION SUPPORT SYSTEMS DEVELOPED BY THIS AUTHOR WITH HIS COLLEAGUES

5.1. INTRODUCTION

The decision support systems described in this monograph are understood to be an object (with its composite parts) for managing and investigating data, information and expressed and unexpressed knowledge. This is a modeling system, which accumulates data and information from various resources and processes them by employing various mathematical, logical and informational models. It provides a user with data and information needed for analyzing, forming and assessing possible decision-making alternatives and for making a decision as well as for obtaining and saving results. A decision support system must permit a user to transform a huge amount of data and information from necessary informational publications for analyzing possible problem resolutions and making decisions. Modeling an object (with its composite parts) by a decision support system shows how an object under investigation, or its composite parts, changes as the surrounding environment changes. A decision support system permits simulating and visualizing an object under investigation, along with its composite parts, individually or in groups. Expressed and unexpressed information and practices accumulated by experts and users in some certain objective area are stored and developed in the information bases of a decision support system. Their use is for analyzing and modeling an object (with its composite parts) under investigation. The results from a decision support system analysis can be submitted in digital, textual and graphic forms (schematics, graphs, diagrams) and as formulas, blueprint drawings, videotapes and other forms.

Today universal decision support systems are rapidly expanding throughout all spheres of the life cycle of the built environment. Thousands of top-notch experts pass on their experiences and expertise through the Internet for a comparatively low price. These comprise the basis for large amounts of stored data, information and knowledge that form databases. Applications of decision support systems offer thousands of various unique services. These include "Green" buildings (Dagdougui et al. 2012), visualization of urban greening in a low-cost high-density housing settlement (Donaldson-Selby et al. 2007), environmental assessment in construction (Ruiz & Fernández 2009), integration of environmental interests in urban planning (Stigt et al. 2013), ecosystem variables for retrofitting drainage systems (Uzomah et al. 2014), land use planning (Witlox et al. 2009), land use impacts in life cycle assessment (Cao et al. 2015), new site selection for municipal solid waste disposal (Suthar & Sajwan 2014), land-use decisions in site redevelopment (Wang et al. 2013), welfare town planning for disabled persons (Koga et al. 2014), modeling emergency evacuation of disabled persons (Manley & Kim 2012), energy and climate policy (Oikonomou et al. 2010), climate change impact assessment and adaptation (Pyke et al. 2007), economic modeling of the capture–transport–sink scenario of industrial CO2 emissions (Shogenova et al. 2011), building energy performance (Kabak et al. 2014), building renovation and energy performance improvement (Juan et al. 2010), solar energy planning in urban environments (Rylatt et al. 2001), adaptable energy retrofit facade system for residential buildings (Ochoa & Capeluto 2015), municipal infrastructure maintenance management (Michele & Daniela 2011), housing condition assessment and refurbishment strategies (Juan et al. 2009), optimal roofing material selection (Rahman et al. 2012), building model (Binbasioglu 1996), construction cost management (Zou & Wang 2002), bridge information modeling (Markiz & Jrade 2014), accident analysis on safety with access scaffolds (Whitaker et al. 2003), rural industry knowledge acquisition (Miah et al. 2008), citizen participation in locally unacceptable land use decision-making (Padgett 1993), public participation in a spatial decision support system for public housing (Barton et al. 2005), simulation and decision support tool for citizens and policy makers (O'Looney 2001), measuring resilience on communalities involved in river flooding (Scarelli & Benanchi 2014), holistic modeling of socio-technical systems (Wu et al. 2015), social acceptance motivated decision support system for subsurface activities (Os et al. 2014), assessment of underground spaces – public transport stations (Durmisevic & Sariyildiz 2001), intelligent transport systems deployment (Nwagboso et al. 2004), integrated transport-land use model for activity relocations in urban areas (Brandi et al. 2014), sustainable transportation (Kim & Lee 2014), urban freight systems (Comi & Rosati 2015), traffic management (Wismans et al. 2014), optimizing high-speed rail routes (Kim et al. 2014), road safety analysis (Fancello et al. 2015), evaluating pedestrian crashes in areas with high low-income or minority populations (Cottrill & Thakuriah 2010), response to extreme events (Mendonça 2007), satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards (Tralli et al. 2005), fire incident (Salter et al. 2013), crime prevention (Moon et al. 2014), decision-making to resolve boundary conflicts (Kamruzzaman & Baker 2013), coastal and marine ecosystem services valuation for policy and management (Luisetti et al. 2011), integrated coastal zone management (Sardá et al. 2005), evapo-transpiration in basin (Moges et al. 2003), complex situations (Petkov et al. 2007) and complex cultural heritage systems (Oppio et al. 2015).

The first decision support system developed by this author was as early as in 1984 in a monograph on analyzing calculations for foundations and their effectiveness on planning variants for underground foundations of farming structures in tri-hinged concrete frames and their multi-criteria analyses along with analyses of various foundation types [Zavadskas & Kaklauskas 1988a and 1988b and Zavadskas & Kaklauskas 1991]). The decision support systems developed from then on continued to encompass more and more complex objects for research, for example, planning the process of existence of agricultural production buildings and single-family homes as well as their respective multi-criteria analyses (Zavadskas, Kaklauskas & Bejder 1992a and 1992b). Later monographs by Zavadskas et al. in 1994, 1995, 1996 and 1999 described other decision-making support and expert systems developed by this author with his colleagues, including subcontractor analyses, renewals of residential buildings, multi-criteria analyses of construction projects, planning and multi-criteria analyses of monolithic building alternatives, project quality analyses and other like projects). One of the monographs (Zavadskas, Kaklauskas & Banaitienė 2001) specifically earmarked the highly popular topic on the multi-criteria analysis of the life cycle process of a building.

The efforts of the author of the monograph on developing decision support systems received much attention. Development of an automated planning system for a single-family residence merited a silver medal in 1988 at the All Union Exhibition of Economic Achievements by the People in Moscow (acronym VDNCH). This was a tremendous accomplishment in those times. The Central Planning Institute in Moscow signed quite a solid contract for those times immediately afterwards, in 1989, to develop a multi-variant automated planning system for small residential unit buildings by designing the best building alternatives, sectionals, facades and perspectives (Zavadskas & Kaklauskas 1991). As of 1989, a contract for a decision support system to develop monolithic buildings as well as single unit residences has been under execution in Lithuania developing recommendatory systems along with systems establishing market values of projects (Zavadskas & Kaklauskas 1990a, b and c). The author of the monograph have published some 200 articles in the field of intelligent and biometric systems.

Numerous results of scientific investigations for developing decision support systems by the monograph's author in conjunction with his colleagues appeared in reviewed publications containing the Web of Science Core Collection citation index:

- Planning Alternative Building Life Cycle Processes and Multi-criteria Analysis Decision-making Support System SPS (Zavadskas et al. 2005)
- Planning Alternative, Information Grounded Building Renewal and Multi-criteria Analyses SPS (Kaklauskas et al. 2005a)
- Internet Real Estate Intelligent SPS (Kaklauskas et al. 2005b)
- Ethics Multi-criterion SPS (Kaklauskas & Pruskus 2005; Kaklauskas et al. 2009)
- Planning of Alternative, Information and Device Grounded Building Renewal and Multi-criteria Analyses SPS (Zavadskas et al. 2006)
- Intelligent Teaching System (Kaklauskas et al. 2006b)
- Internet, multi-criteria, decision-making support system in construction (Kaklauskas et al. 2007)
- Multi-criteria Analyses of Innovations SPS (Kaklauskas and Zavadskas 2007)
- Planning Alternative Building Management and Multi-criteria Analysis System (Lepkova, Kaklauskas & Zavadskas 2008)
- Student Learning Evaluation Applying the Voice Analysis Biometric System (Kaklauskas et al. 2010a)
- Student Learning Evaluation Applying the Self-analysis Biometric System (Kaklauskas et al. 2010a)
- Pledged Intelligent Environment SPS (Kaklauskas et al. 2010b)
- Crisis Management in the Construction and Real Estate Sector SPS (Kaklauskas et al. 2011)
- Negotiations System (Urbanavičienė et al. 2009)
- Energetics Systems Multi-criterion SPS (Šliogerienė et al. 2009)
- Facilities Microclimata Analysis SPS (Lepkova, Kaklauskas & Zavadskas 2008)
- Pledged and Humanized Environmental Renewal SPS (Tupėnaitė et al. 2010)
- Export Modeling SPS (Kaklauskas & Zavadskas 2002) and others.

The monograph's author and his colleagues employed three of their own new, multi-criteria, decision-making methods for developing biometric and decision support systems:

- A criteria weight establishment method and model — these constitute a new method for the complex determination of a criterion weight taking into account its quantitative and qualitative characteristics that allow calculation and co-ordination of the weight of quantitative and qualitative criteria, according to these named characteristics.
- A multiple criteria analysis and priority setting method and model — these constitute a new method for the multiple criteria, complex, proportional evaluation of alternatives enabling a user to obtain a reduced criterion determining, complex (overall) efficiency of suggested alternatives. This general criterion is directly proportional to the relative effect of the criteria values and weight considered regarding the efficiency of an alternative.
- A utility degree and market value determination of alternatives method and model — these were developed to find the price that would make an alternative value competitive on the market. The method suggests determining the utility degree and market value of alternatives based on the complex analysis of all their benefits and drawbacks. This method considers the utility degree and the market value of an alternative under estimation as directly proportional to the system of the criteria adequately describing alternatives along with the values and weights of those criteria.

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

The following major principles and methods constituted the bases for developing the Web-based decision support systems by the author and his colleagues:

- Complex Analysis Method permits economic, technical, qualitative, technological, environmental, managerial and other optimizations throughout the life cycle of a project.
- Functional Analysis Method involves determining expenditures associated with project functions by considering the benefits of a function and the cost of its realization.
- Cost-benefit Ratio Optimization Principle optimizes the cost-benefit ratio by the efforts required for maximum economic, qualitative, environmental and social, legal and such benefits using minimum expenses over a project's life cycle.
- Interrelations of Various Sciences Principle considers a successful resolution for a cost-benefit ratio that requires interrelating the achievements of various sciences in management, economics, law, engineering, technology, ethics, aesthetics, psychology and other areas.
- Multi-variant Design and Multiple Criteria Analysis Methods allow considering quantitative and qualitative factors, as well as cutting the price of the project, for better satisfaction of the needs of all interested parties.
- Close Interrelation Principle holds that a project's efficiency closely relates to the interested parties and their aims.

An integrated analysis of a built environment involves economic, technical, technological, corporate, managerial, utility, comfort and other kinds of optimizations throughout the life cycle of the built environment under analysis. Another aim is maximum goal achievement for any stakeholder who is involved in or who affects the project. An integrated analysis is a means to fine-tune stakeholder goals and, at the same time, to implement a rational life cycle of a built environment. Improved performance of a single phase alone, however, cannot be an absolute success because it may undermine the performance of other phases. In this case, the end result of a built environment assessment must consider the interrelation and significance of goals for the built environment, along with the resources used to achieve such goals.

Employment of the functional analysis method is for examining a set of functions under implementation of a planned project. Anticipated expenditures are usually determined by considering the efficiency of functions by their costs and benefits for implementation.

There is always the issue of the ratio between inputs and outputs used to produce a project. The anticipation is always for maximum goal achievement while using the least resources, i.e., a more advantageous benefit-cost ratio. Entities try to cut costs over an entire lifetime of a built environment, so they seek any savings potential, from the moment the goals for the built environment are set until the very end. All stakeholders need to strengthen the benefits a built environment offers throughout its lifetime; however, the understanding of what constitutes the benefits of the built environment often differs among stakeholders. They are seeking multiple economic, social, legal, moral and other goals, at one and the same time. Some goals are easier to achieve than others are, and the significances of goals are different as well.

The only way to resolve the benefit-cost ratio issue of a built environment successfully is to interlink various scholarly disciplines, such as management, economics, law, engineering, organizational studies, technology, ethics, aesthetics, psychology and others. These other sciences are capable of estimating the benefits and related costs over different parts of the life cycle of a built environment.

Multivariate design and multiple criteria analysis methods can mathematically show the changes in the efficiency and costs of a built environment as the level of goal achievement is changing. Thereby it is possible to resolve the issue of optimizing goals and the financing required to implement them. This means that the most rational combination of the benefit-cost ratio of the built environment can be determined after an analysis of all the possible variants of its life cycle is completed. The author (Kaklauskas 1999) has developed methods to accomplish such by employing multivariate design, multiple-criteria assessment, utility degree and market value determinations of a built environment. Another tool is use of intelligent decision support systems based on these methods.

A study in brief of some of the above-named, developed, Web-based Decision Support Systems (DSSs) follows.

5.2. DECISION SUPPORT SYSTEM FOR ANALYZING THE MARKET VALUE OF REAL ESTATE, POLLUTION AND HEALTH EFFECTS

5.2.1. Introduction

Certain groups of patients such as those suffering from asthma, atopic allergies, emphysema and bronchitis, heart conditions and strokes and diabetes as well as pregnant women, the elderly and children, who are especially sensitive to the health effects of outdoor air toxicants, have been studied (American Lung Association 2005). An estimated, around 20% of the US population suffers from asthma, emphysema, bronchitis, diabetes and/or cardiovascular disease and these people are thus especially susceptible to outdoor air pollution (American Lung Association, 2005). Outdoor air quality plays an important role in human health. Air pollution causes large increases in medical expenses, morbidity and causes an estimated 800,000 or so annual premature deaths worldwide (Cohen et al. 2005). There have been numerous publications issued in the last decade, much research (Atkinson et al. 2001, Brook et al. 2004 and Grossman et al. 2007) and digital maps and standards (Environmental Management Centre 2006, Hubbell et al. 2005 and US Environmental Protection Agency (EPA) 1987) on the respiratory, cardiovascular, cancerous, reproductive and developmental, neurological, infectious and other health effects as well as on mortality due to outdoor air pollution. Levels of priority air pollutants often exceed these limits in many parts of the world, especially in large cities.

The problems named above and others relate to the air pollution, premises microclimate, health effects, real estate market value and such of a built environment. However, the Real Estate Market Value, Pollution and Health Effects Analysis Decision Support System (RE-MVPHE-DSS) can analyze the above factors in an integrated manner. This is the first attempt of this kind to consider the above-named integration function. The author of this research participated in the project Framework 6 *Intelligent Cities* (INTELCITIES) and the Lincoln Institute of Land Policy Fellowship *Development of Market-Based Land Mass Appraisal Online System for Land Taxation*. One of the respective project goals (on the Lithuanian side) was development and improvement of the Real Estate Market Value, Pollution and Health Effects Analysis Decision Support System (RE-MVPHE-DSS) for use of best practices as well as explicit and tacit knowledge.

5.2.2. Real Estate Market Value, Pollution and Health Effects Analysis Decision Support System

The author of this book in conjunction with his colleagues (E. K. Zavadskas, I. Jackute, J. Cerkauskas, A. Banaitis, V. Trinkunas and L. Bartkiene) developed the Real Estate Market Value, Pollution and Health Effects Analysis Decision Support System (RE-MVPHE-DSS). The constituents of the RE-MVPHE-DSS are analyses of Market Value, Air Pollution, Premises Microclimate (Kaklauskas et al. 2006), Health Effects, Voice Stress and Cooperative Decision-making along with Multiple User Subsystems. More detailed descriptions of the Air Pollution, Health Effects, Voice Stress and Cooperative Decision-making Analyses as well as the Multiple User Subsystems will follow.

The Air Pollution Subsystem accumulates information about pollution (carbon monoxide, noise, particle pollution, volatile organic compounds, nitrogen dioxide, etc.) and develops digital maps (see Figure 5.1).

The Antakalnis and Zirmunai districts of Vilnius located alongside the river were chosen to develop pollution digital maps. Means of transport are the greatest environmental pollution sources in the areas under analysis. Morbidity due to chronic bronchitis is 72% higher among residents of polluted compared to non-polluted districts. Morbidity due to other respiratory system diseases is noted for a better comparison of such areas. Another important trend is the relation between air pollution and morbidity due to acute myocardial infarction. Studies of environment pollution show that higher concentrations of CO, NO_2 and SO_2 determine higher rates of morbidity in respiratory system and other diseases.

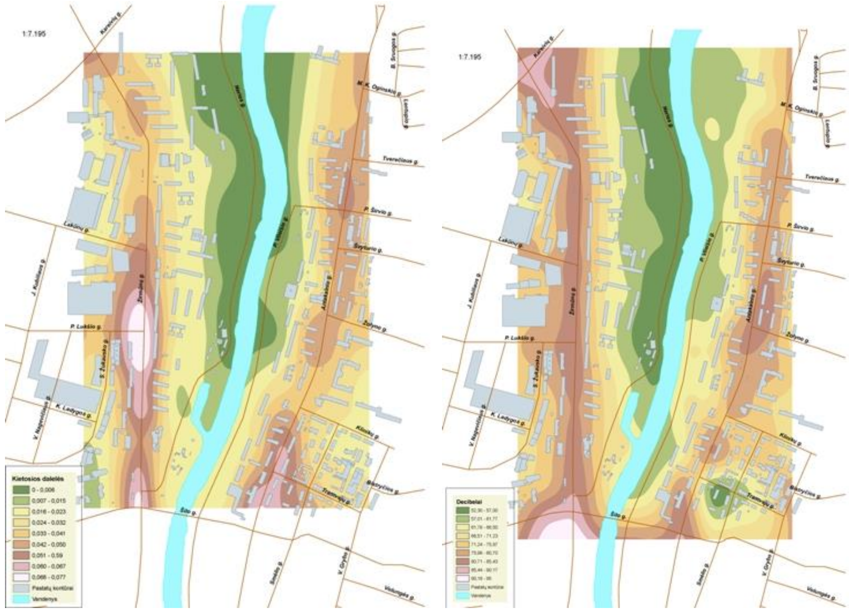


Figure 5.1. Concentration level of particle pollution (left) and noise level in the Antakalnis-Zirmunai Districts (right)

The level of carbon monoxide should not exceed 5 mg/m^3. However, the CO concentration exceeds the normative requirements in Silo Street at the crossroads of Antakalnio and Zirmunai Streets by reaching 7.15 mg/m^3. Volatile organic compounds are vapors of any composition emitted by oil-based products. The highest allowed concentration in the air of a residential environment is 5 mg/m^3. An analysis shows levels excessive of the norm at the crossroads of Zirmunai and Kareiviu Streets and parts of Antakalnio Street where traffic is more intensive.

The Health Effects Subsystem received information from the Air Pollution Subsystem about pollution (carbon monoxide, noise, particle pollution, volatile organic compounds, nitrogen dioxide, etc.) and developed digital maps on the respective health effects (see Figure 5.2).

The EU pays considerable attention to preservation of the environment. It is recognized that environmental pollution affects the development, health and efficiency of humans negatively, and negative effects are evaluated in billions of Euros. Morbidity due to chronic bronchitis is 72% higher among residents of polluted compared to non-polluted districts in Vilnius. Morbidity due to other respiratory diseases is noted for a more similar comparison. Studies on environmental pollution show that higher CO, NO2 and SO2 concentrations determine higher rates of morbidity due to respiratory system and other diseases.

Compilation of the above digital pollution maps employed several initial digital maps of respiratory disorders and asthma as its basis. These Digital maps show clear zones of pollutant concentrations that are dangerous to people with respiratory disorders and asthma. The digital maps show the zones with dangerous concentration of CO and NO_2 (marked in red). Such concentrations of pollutants can cause respiratory disorders and asthma (see Figure 5.3).

Figure 5.2. Zones of NO2 concentration (left) pollutions dangerous to people with respiratory disorders and asthma and the pollution effect on human health (right)

The Voice Stress Analyzer (VSA) Subsystem measures stress in a human voice. The VSA Subsystem is for analyzing different situations in a built environment (work of brokers, analysis of the subjective opinions held by stakeholders about pollution and health effects, etc.). Development of a statistical information database is necessary to use the VSA Subsystem efficiently in practice.

An analysis in brief is next presented on the practical application of the Voice Stress Analyzer (VSA) Subsystem in real estate sales. The situation selected is a typical first visit to an apartment. There was a recording made of the discussion between the seller and the broker inspecting the apartment for sale (with mutual consent). The conversation consisted of standard questions. The unit’s advantages and disadvantages were noted, and the sales price was established, along with the amount of the broker’s commission. and negotiations on conclusion of a mediation agreement. A VSA Subsystem recording shows the vibration curve of a sound document, which indicates the sound frequency in real time. If a sound frequency is high, the oscillation of the sound curve is denser. A density of oscillations in a sound curve shows that a person is unsure of the correctness of his/her statement or is concealing some truth. For example, it was noticed that a sound vibration curve is typically very dense, when a client speaks about the brokering contract. The evidence the VSA Subsystem provides can indicate, whether a client's statement is false or doubtful.

The research determined that people are usually unsure or partially conceal truth when speaking about brokering contract, exact floor area of an apartment, furniture for sale with the apartment, the sales price of the apartment, remuneration to a broker and other topics. All these criteria are essential in the activities of a broker. False information may leave a broker without remuneration for the work. Knowledge that a client is lying when he/she speaks about such things can also protect a broker against fraud. Currently, when sufficient statistical information is not available yet, it would be wrong to rely on evidence provided only by the VSA Subsystem. However, it can help to avoid a number of misunderstandings and other problems.

A company can use the VSA Subsystem for its specific purposes, e.g., at conferences, during reports to a top manager and at other kinds of meetings. This way the head of a company will have an opportunity to analyze the information, requests, opinions and such provided at a meeting and to make decisions based on the evidence provided by the VSA Subsystem as well as the manager's logical thinking. Such an application of the system would not be difficult, because internal regulations of a company allow a head to collect and use information about the company's personnel. Besides, the obtained information would help to meet client needs and the company's employee needs in better ways.

As an example, Figure 5.4 shows the relationship between the difference of the true area of a housing unit and the increase in its size as deliberately misrepresented by a seller (by percentage) and the average microtremor frequency of the seller's voice while claiming the greater floor area. The x-axis represents the percent of divergence of the claimed area from the true area of the housing unit. The y-axis shows the average microtremor frequency noted in the seller's voice during the conversation. Figure 5.4 clearly shows the relationship between the level of untruth told by a seller and the average microtremor frequency of his/her voice. The higher the average microtremor frequency, the greater the size will be that has been added to the actual area of a unit.

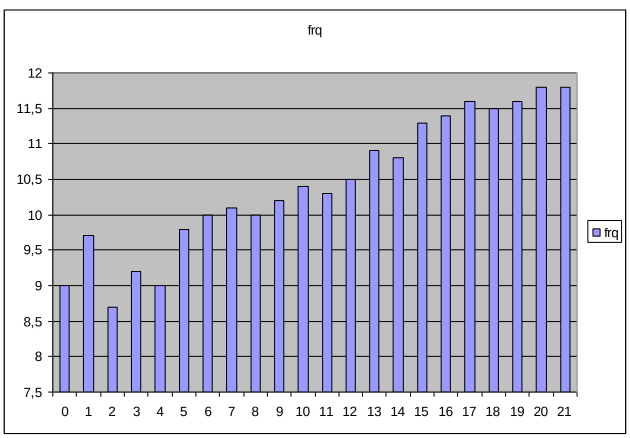


Figure 5.4. Relationship of the deliberate divergence in truth about the actual area of a real estate unit (by percent) and the average microtremor frequency of the seller's voice while making a false claim

In the future, it will be automatically possible to assess the correctness of provided information (by percent) by using the VSA Subsystem based on accumulated, historical statistical data and a pre-determined regression equation. For example, the VSA Subsystem would automatically convert a seller's answer regarding a unit's floor area into a frequency and specify the actual floor area along with the percentage of deviation from the actual area as specified.

The Cooperative Decision-making (CDM) Subsystem has taken on more and more worldwide importance. Cinderby and Forrester (2005) report on a novel empirical approach to capturing and analyzing the understanding of a non-professional public about spatially related environmental issues and its representations of local knowledge about air pollution and related problems. Public participation is an essential part of sound, legitimate, political decision-making. Awareness of environmental problems by potential investors and by the public may have a significant effect on environmental protection in the area (Peterlin et al. 2005). Air pollution in an environment impacts public health, vegetation, property deterioration and causes other harm (Pummakarnchana et al. 2005).

Currently intelligent systems for real estate have been mostly viewed from a single-broker perspective, where only the purposes of a single client are taken into account. The Cooperative Decision-making Subsystem considers a group planning a real estate purchase in common, whereby many potentially conflicting objectives must be analyzed. The Cooperative Decision-making Subsystem allows different stakeholders (e.g., family members) to resolve common tasks in cooperative manners (e.g., development of a joint criteria system as well as estimation of criteria weights and qualitative criteria values). The RE-MVPHE-DSS can assist a group of buyers in achieving a cooperative decision regarding a Web-based, real estate search, analysis, negotiation and decision-making. This is done by transforming individual buyer models to a mutual (medium) buyer model (decision-making matrix) This model can be used to mediate a type of group discussion with the goal of reaching a compromise that is acceptable to all group members. The Cooperative Decision-making Subsystem allows stakeholders to share ideas and to vote, so a joint selection is possible for the most acceptable real estate alternative, i.e., the one with the most votes. This will reduce problems involving mistrust. Furthermore the multiple criteria methods developed by this author with his colleagues can be applied.

The Multiple User (MU) Subsystem stores individually specific data. Its use is to accumulate information about the requirements, preferences and needs of some real estate buyer, his/her financial capabilities and the like. Thus the MU Subsystem accumulates information on a buyer's aggregate requirements for real estate. It starts by gathering a buyer's needs and knowledge of the required real estate, i.e., what a buyer already wants and knows. Sometimes buyers do not know or fully understand the importance of certain information characterizing real estate, e.g., surrounding pollution and noise and/or the internal microclimate. The MU Subsystem uses such data to represent a buyer's requirements and knowledge and represents the client's knowledge in terms of deviations from an expert and a typical real estate seeker's knowledge. On the basis of these deviations this sort of information makes it possible to decide what criteria or what criteria weights and values should be added to the specific buyer's decision-making matrix. Brokers and buyers may have different perspectives on issues but must reach an agreement during an e-negotiation process since they must have mutual understanding regarding searching for and analyzing real estate alternatives. It is considered that a constituent part of the MU Subsystem includes the real estate alternatives discovered according to a set of search parameters. The measures on the significance of real estate alternatives under analysis for a buyer are priority, utility degree and market value of each alternative under consideration. Additionally, the MU Subsystem’s research focuses on the statistically generated Statistical Model and finds average criteria system and criteria weights. Buyers are particularly able to study and utilize the typical real estate seeker model (typical criteria system and criteria weights) by allowing interfaces regarding inferences about a buyer from the typical real estate seeker model. Development of the MU Subsystem involves a systematic process for continually improving the typical real estate seeker model by learning from the different navigational and decision-making activities engaged by buyer/users. New knowledge is incorporated, thereby gaining credible statistical information, and historical experiences modify buyer activities.

The Statistical Model has accumulated information in recent years about user navigational activities and decision-making. It collected concrete statistics on the level of real estate, navigational activities engaged by users (number of visitors at some concrete real estate alternative and time for analyzing this alternative) and decision-making (selection of a criteria system and criteria values and weights). This is the statistical information the author with his colleagues used to determine the most marketable real estate as well as the most important criteria and their weights. The received statistical information reflects the navigational purposes of users. The ability to measure the navigational activities by users statistically allows statistically generating the average criteria system and criteria weights relevant for a typical real estate seeker. This resolution improves the accuracy of the development of the criteria system and criteria weights for a user. The Statistical Model submits proposals for developing a decision-making matrix by using statistical information from historical buyers, according to how well the real estate properties satisfied buyer preferences. The Statistical Model integrates concrete statistics on a level of real estate with navigational activities, as per the typical real estate seeker model. Another use for such statistical information is supplementing the MU Subsystem to better adapt the search process to user needs.

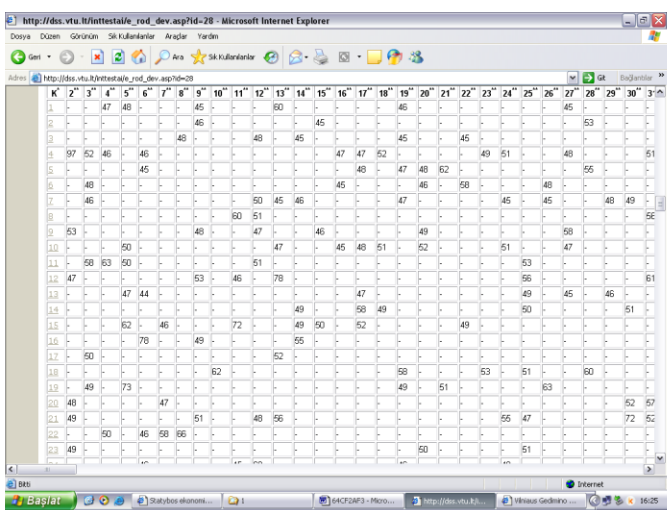


Figure 5.5. Time (by seconds) for analyzing real estate alternatives by different buyers

All members of a real estate market can use this developed system. It is recommended to members to rely on their own knowledge as much as possible before making final decisions. For example, the requirements of buyers, sellers, brokers, financial institutions, neighbors and other stakeholders should be estimated and submitted in a quantitative form to perform the multiple criteria analysis of some real estate alternative.

5.3. COOPERATIVE INTEGRATED WEB-BASED NEGOTIATION AND DECISION SUPPORT SYSTEM FOR REAL ESTATE

5.3.1. Integrating Decision Support and Knowledge Systems

Integration of neural networks, multimedia, knowledge-based, decision support and other systems in the construction and the real estate sectors has a very promising future in scientific research. Recently much effort has been made to apply the best elements of multimedia, neural networks and knowledge-based and other systems to decision support systems. For example, the use of artificial intelligence in DSS systems does not influence people who make decisions; however, it allows optimization of DSS possibilities.

Scientists and practitioners refer to an integrated, knowledge-based and decision support system as intelligent DSS, knowledge-based management support systems, expert DSS, expert support systems and knowledge-based DSS. Various forms for integrating these systems were investigated and several system architectures offered. Some scholars have suggested the idea to integrate knowledge-based and decision support systems. All these systems have a typical and common feature, i.e., the knowledge-based part of integrated systems performs an auxiliary and advisory role and chooses decision alternatives, data and their sources and problem solution tools, methods and models and organizes a flexible interaction between a user and the system. Knowledge-based and decision support systems are related but they treat decisions differently. For example, previously obtained knowledge and rules for problem solving provide the basis for knowledge systems, and a decision support system leaves much room for a user's intuition, experience and outlook. Knowledge systems form a decision trajectory themselves, while decision support systems perform a passive auxiliary role. However, a situation might occur when decision support systems might suggest further actions to the decision maker.

Calculation and analytical DSS models are applicable for processing the information and knowledge stored in the knowledge base. For example, some DSS models are applicable for preparing recommendations by referring to the knowledge in the knowledge base. Decision support systems can also facilitate the search, and an analysis and distribution of the explicit knowledge.

A Cooperative Integrated Web-based Negotiation Decision Support System for Real Estate is considered as an example for demonstrating the integration decision support and knowledge systems in the construction and real estate sector.

5.3.2. Cooperative, Integrated, Web-based, Negotiation Decision Support System for Real Estate

The Negotiation Decision Support System for Real Estate (NDSS-RE) is a Cooperative, Integrated, Web-based, Negotiation Decision Support System for Real Estate. It is found at the following web address: http://dss.vtu.lt/realestate/. The NDSS-RE consists of a Decision Support Subsystem (DSS-RE) and Expert Subsystem (ES-RE). The DSS-RE consists of a database, database management system, model base, model base management system and user interface (see Figure 5.6).

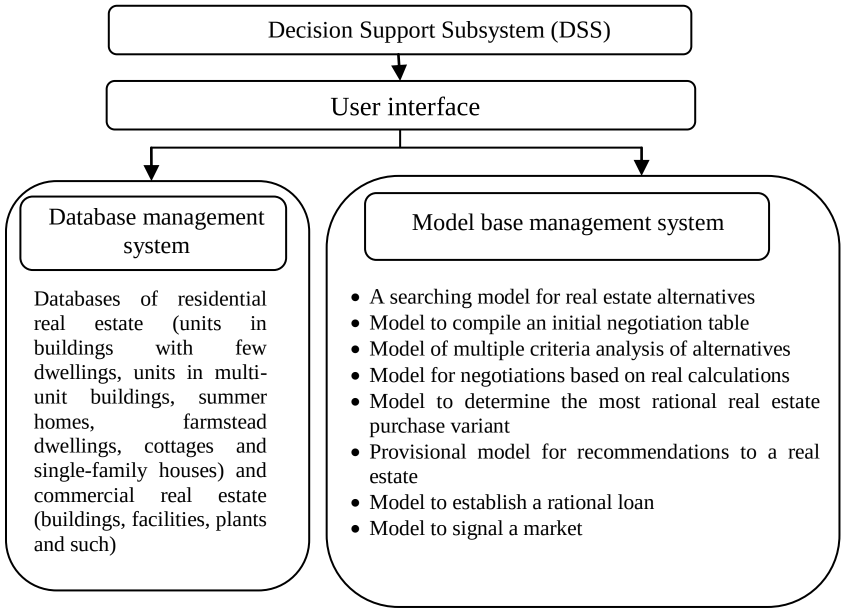


Figure 5.6. Decision Support Subsystem components

Real estate listings act as an interface prompting sellers to post listings. The system provides forms for sellers or brokers of real estate to fill out with information about their property on sale. A DSS-RE administrator provides permissions to brokers wishing to present information on their real estate properties. This permit allows a broker to enter all the necessary information about real estate objects under sale in the DSS-RE databases, according to the system's requirements (i.e., system of criteria and values and weights of criteria). Only a broker and a DSS-RE administrator have access to the databases personally developed by brokers. Presently the developed DSS-RE allows performance of the following five main functions: search for real estate alternatives, finding alternatives and compiling a table for initial negotiations, analysis of alternatives, negotiations and an ultimate determination of the most rational variant for a purchase of real estate property. More detailed descriptions of some of the aforementioned subsystem functions are presented next to illustrate the DSS-RE better.

A buyer may perform a search for real estate alternatives from databases from different brokers. This is possible due to the provision of standardized forms of data submissions at some specific level. Such standardization creates conditions that can be applied to special intelligent agents that are performing a search for the required real estate in various databases, and the gathering information/knowledge.

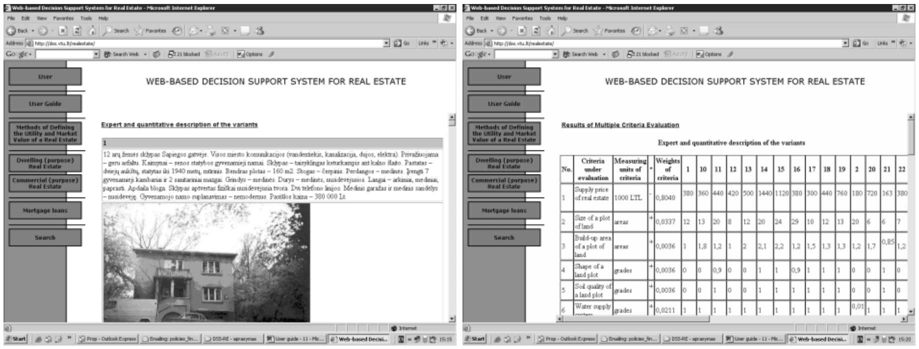


Figure 5.7. Search result submissions for specific real estate information in textual, photo/video and graphic forms (*left*) and expert and quantitative descriptions of real estate alternatives (initial negotiation table) (*right*)

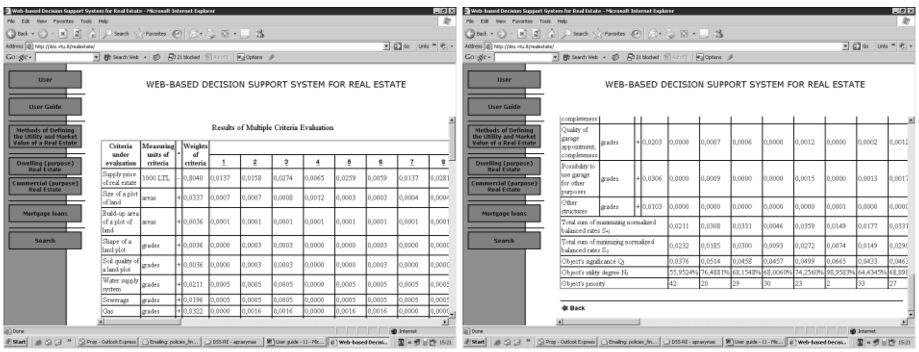


Figure 5.8. Multiple criteria assessment results of single-family home alternatives: upper matrix for obtained results (left)lower matrix for obtained results (*right*)

Interested parties specify requirements and constraints, and the system searches information on a specific real estate property from a number of online brokers. The system performs the tedious, time-consuming and repetitive tasks of searching databases, retrieving and filtering information/knowledge and feeding it back to the user. Search results for information on alternatives for a unit of specific real estate property appear in textual, photo/video and/or graphic forms and there is a display of an initial negotiation table (see Figure 5.7), which may include direct links to a Web page of brokers. Such a display can more effectively support the multiple criteria comparisons. A click on the link "Expert and quantitative description of variants" (see Figure 5.7 [*left*]) displays a presentation on expert and quantitative descriptions of single-family home alternatives (see Figure 5.7 [*right*]). The quantitative information for each alternative described (system of criteria and weights and values of criteria) has a number (see Figure 5.7) that coincides with the verbal and photographic information describing the mentioned alternative (see Figure 5.7).

A buyer should examine numerous alternatives over the course of the purchasing decision process. Each alternative involves a considerable amount of information/knowledge that includes economic, quality-architectural, aesthetic, technical, legal, technological and other factors as well as comfort and infrastructure. A multiple criteria analysis follows, from the gathered information and knowledge. This analysis, involving use of multiple criteria methods developed by this author (Kaklauskas et al. 1999), facilitates determining the initial priority, utility degree and market value of the real estate alternatives under analysis by the buyer (broker). A click on the link “Results of Multiple Criteria Evaluation” (see Figure 5.7 [*left*]) displays the results of the multiple criteria evaluation of single-family home alternatives (see Figure 5.8). The lower part of the matrix of obtained results displays the calculated significances of real estate alternatives, their priority and their utility degrees (see Figure 5.8). The upper part of the matrix of obtained results shows the priority numbering of the real estate alternatives (see Figure 5.8 [*left*]). A click on these blue, underlined numbers permits calculating the market value of a certain alternative (see Figure 5.9). The table presented in Figure 5.9 (*left*) shows the iterations made during the calculation of the market value. Figure 5.9 (*right*) presents the same information, only now in graphic form. A move with the mouse above any column of the graphic presentation provides the numerical value of the column. For example, it took 15 calculation iterations to arrive at the market value of the eighth alternative (see Figure 5.9 [left]).

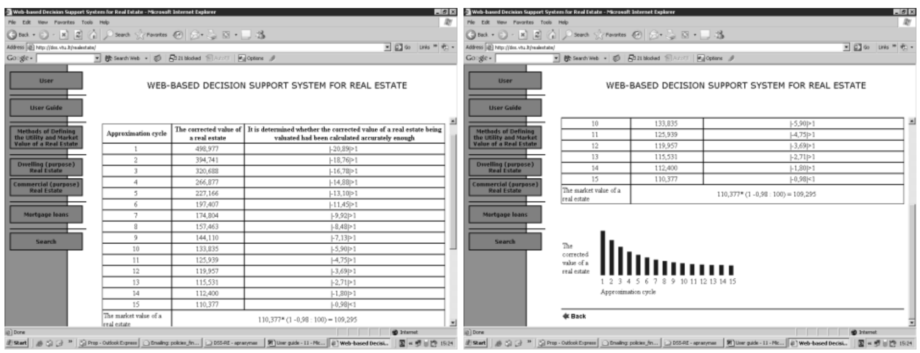


Figure 5.9. Market value calculation presentations: numerical form (*left*) and graphic form (*right*)

A buyer performing a multi-criteria analysis of all real estate alternatives selects the objects for starting negotiations by clicking the respective box with the mouse (see Figure 5.10 [*left*]). Then the Letter Writing Subsystem generates a negotiations e-mail and sends one to all real estate sellers upon a click on *Send*.

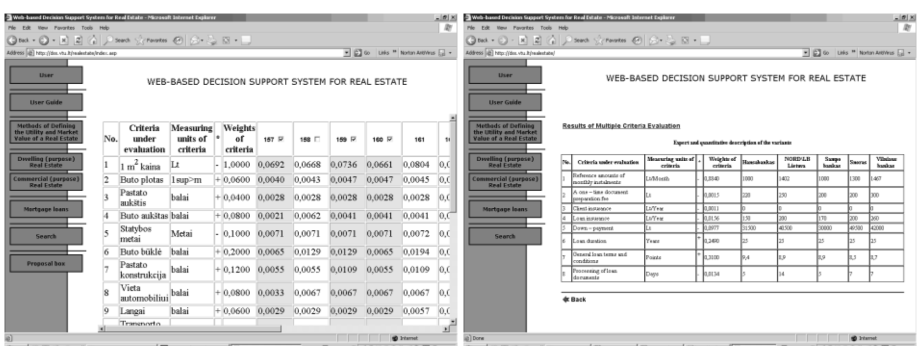


Figure 5.10. Automated selection of real estate properties for negotiations (*left*) and analysis of offered bank loan alternatives (*right*)

The DSS-RE helps the buyer and seller perform real calculations (utility degree, market value and purchase priorities) of the real estate during negotiations. The characteristics describing the real estate alternatives obtained during negotiations (explicit and tacit criteria system, criteria values and weights) serve as the basis for performing such calculations. The results received constitute the basis for developing the final comparative table. Use of the DSS-RE assists in next performing the multiple criteria analysis and selection of the best real estate buying version from the developed, final comparative table.

Usually a buyer must receive a loan from a bank upon selecting a real estate variant. Development of the Loan Analysis Subsystem was for this purpose (see Figure 5.10 [*right*]).

There are two main categories of rules and procedures in the Expert Subsystem:

- Expert Subsystem rules develop suggestions on useful brokers and reasons for further negotiations after determining the sequence of priority, utility degree and market value of the real estate alternatives with DSS-RE assistance.
- The Expert Subsystem generates a comprehensively reasoned negotiation e-mail for each selected brokers using information taken from the calculations and predefined rules and procedures previously generated by the DSS-RE. The e-mail reasonably suggests decreasing the price of the offered real estate property and references the calculations performed by the DSS-RE.

5.3.3. Testing the System

Master degree students studying for their final semester in the Real Estate Management and Evaluation program at Vilnius Gediminas Technical University collected more than 250 listings to test the usefulness of this system. These students work as brokers for different real estate companies in Vilnius. They placed information into the database about real estate properties they were selling at the time. Eighteen students tested this system for areas possibly needing improvement, e.g., the process, interface, navigation, search for alternatives from databases of other brokers, multiple criteria assessments, market value calculations and negotiations. The testing of the NDSS-RE also involved a questionnaire designed for administration to four real estate broker organizations in Vilnius. The letter attached to the questionnaire read, “We would like you to draw on your experience and expertise to help us test, whether the NDSS-RE can also meet your needs as a user. Please read through the following questions and circle your response.” A more comprehensive study is underway to gauge user satisfaction and the current survival means employed by real estate agents. It should also gauge why people are not using such an approach, should they so report.

The first functional NDSS-RE prototype was developed in 2003, using existing information in order to start testing the main characteristics of the System together with prospective user groups in order to determine. Real estate brokers performed tests to ensure the desired results are achieved. When additional or improved modules were ready, they were included/exchanged in the NDSS-RE.

There are lessons to learn about the social impacts of implementing such kinds of e-broker systems. Several experts from Vilnius broker companies estimated that about forty percent of employees in real estate broker firms could lose their jobs.

The most important issues outlined for further exploration are for gaining knowledge needed for developing NDSS-RE subsystems as follows:

- A model for analyzing buyer needs is still under development for the NDSS-RE for providing recommendations to a real estate broker. The purpose of such a subsystem is to accumulate information about the popularity of real estate property alternatives entered into the database. The number of buyers analyzing some certain property and the time they spent observing it serve as the basis for establishing the popularity of a piece of property. This information also lets a seller know whether to reduce or increase the price of the real estate property under sales. Other types of advice will also be provided.
- There is still a need for provision of a Market Signaling Subsystem that would link to sites with exhaustive information and analytic reviews about the Lithuanian real estate market situation and perspectives about its development. In the future, this Subsystem could send selected messages with required information to subscribers.

5.4. Virtual and Augmented Realities along with Intelligent Systems

5.4.1. Augmented Reality

Augmented reality (AR) is a live, direct or indirect, view of a physical, real-world environment. Computer-generated sensory input, such as sound, video, graphics or GPS data augment (or supplement) its elements. This relates to a more general concept called mediated reality, in which a computer modifies a view of reality (possibly even diminishes rather than augments it). As a result, the technology functions by enhancing one's current perception of reality (Graham 2012). By contrast, virtual reality replaces the real world with a simulated one (Steuer 1993). Augmentation is conventionally in real-time and in semantic context with environmental elements. Information about the surrounding real world of the user becomes interactive and digitally manipulative with the help of advanced AR technology (e.g., by adding computer vision and object recognition). Artificial information about the environment and its objects can be overlaid on the real world (Chen 2009).

Rice (2011) classified AR into the following four levels:

- Level 0 — physical world hyper linking: A simple link from the physical world to the virtual world exists without involving any real time rendering and graphics. Examples include bar code and 2D image recognition.
- Level 1 — marker-based AR: These are 2D marker, AR based on PC and web cam. Level 1 AR is very challenging for mobile use due to the lack of robustness of markers and computing power.
- Level 2 — markerless AR: There is no requirement for markers for registration and tracking methods. The tracking is more robust, thus enabling the realization of mobile AR.
- Level 3 — This has augmented vision that is currently under development.

5.4.2. Housing Health and Safety Decision Support System with Augmented Reality

The author of this book developed the Housing Health and Safety Decision Support System with Augmented Reality in conjunction with his colleagues (E. K. Zavadskas, M. Krutinis, J. Cerkauskas, I. Jackute, A. Banaitis, V. Trinkunas, L. Bartkiene).

5.4.2.1. Housing Health and Safety Model

The groups of patients included in study by the American Lung Association are those who are especially sensitive to the health effects of outdoor air toxicants, such as asthmatics, atopic patients, patients with emphysema and bronchitis, heart and stroke patients, diabetics, pregnant women, the elderly and children (American Lung Association 2005). An estimate claims that about 20 percent of the population in the USA suffers from asthma, emphysema, bronchitis, diabetes and/or cardiovascular diseases and are thus especially susceptible to outdoor air pollution (American Lung Association 2005). Outdoor air quality plays an important role in maintaining good human health. Air pollution causes large increases in medical expenses and morbidity and an estimated about 800,000 annual premature deaths worldwide (Cohen et al. 2005). Much research has published on the health effects of outdoor pollution in the past decade (Atkinson et al. 2001, Brook et al. 2004 and Grossman et al. 2003) as well as digital maps and standards (Environmental Management Centre 2006, Hubbell et al. 2005 and US Environmental Protection Agency 1987). The health effects under discussion include respiratory, cardiovascular, cancer, reproductive and developmental, neurological, mortality, infectious and other health effects. Publications have covered outdoor air pollution, a premise's microclimate and dwelling valuations. These aforementioned and other problems relate to a built environment's air pollution, the microclimate of a premise, health effects, real estate market value, etc. Nonetheless, Housing Health and Safety Decision Support System with Augmented Reality (HUSSAR) analyzes the above factors in an integrated manner.

The Housing Health and Safety Rating System (HHSRS or Rating System) is the UK Government's new approach to the evaluation of the potential risks to health and safety from any deficiencies identified in dwellings. There are 29 hazards in dwellings. Four main groups constitute the arrangement for reflecting the basic health requirements. There are four subdivided groups according to the nature of their hazards (Operating Guidance - Housing Act 2004):

- Physiological Requirements, including Hygrothermal conditions and Pollutants (non-microbial)
- Psychological Requirements, including Space, Security, Light, and Noise
- Protection against Infection, including Hygiene, Sanitation and Water Supply
- Protection against Accidents, including Falls, Electric shock, Burns and Scalds and Building related Collisions

For example, the databases of Protection against Infection contain the following information:

- Domestic hygiene, pests and refuse. Poor design, layout and construction, such that the dwelling cannot be readily kept clean and hygienic; access into and harborage within the dwelling for pests and/or inadequate and unhygienic provision for storing and disposal of household waste. Health effects include stomach and intestinal diseases, infections, asthma, allergies, food spoilage, disease from rats and birds and physical hazards.

- Food safety. Infections threaten, when there are poor provisions and facilities for storing, preparing and cooking food. Health effects include stomach and intestinal diseases, diarrhea, vomiting, stomach upsets and dehydration.
- Personal hygiene, sanitation and drainage. Threats of infection and threats to mental health associated with personal hygiene, including personal and clothing washing facilities, sanitation and drainage. Health effects include stomach and intestinal diseases, including dysentery, skin infections and depression.
- Water supply for domestic purposes. The quality and adequacy of the water supply within dwellings for drinking and domestic purposes including their threats to health from contaminations by bacteria, protozoa, parasites, viruses and chemical pollutants. Health effects include dehydration, fatigue, headaches, dry skin, bladder infections, stomach and intestinal diseases, respiratory disorders and Legionnaires' disease.

One of the priorities of the Europe 2020 Strategy is smart growth driven by complex interactions between technical, social, economic and human factors. The design of the project - Learning Augmented Reality Global Environment (LARGE) - is to produce a new type of learning environment that supports educational/training institutions in delivering their curriculum in the most attractive and effective way for learners. The aim of LARGE is to build a global environment based on this technology by simplifying the process of augmented reality content creation and allowing all educational/training institutions to benefit from its undoubted advantages. This Global Environment consists of a platform that is the basis for the system and an integrated content development tool allowing development of appropriate educational/training AR content by the target groups. An AR system generates a composite view for the user, which combines the real scene and the virtual scene generated by the computer that then augments the scene with additional information. The Learning Augmented Reality Global Environment superimposes graphics, audio, video, 3D objects and other enhancements from computer screens to real time environments expanding user knowledge, skills and experiences.

The main aim of project "Development of National Housing Health and Safety Certification Model" is to improve the quality of public healthcare services and to improve the management of the residential environmental health risk factor. The goal of the mentioned project was to create tools for residential environmental health risk factor management.

The bases for the development of the National Housing Health and Safety Certification Model was an analysis of worldwide literature on healthy housing (Battersby 2011, Davidson et al. 2010, English Housing Survey 2010, Department for Communities and Local Government 2006, Living in Wales Survey 2006, Office of the Deputy Prime Minister 2006, Scottish House Condition Survey 2011 and Wales - Housing Demolitions... 2011) and an analysis of healthy housing models (Csóka et al. 1993, Hashim & Dawal 2012, Hayashi et al. 2001, HHSRS worked examples 2007a, 2007b and 2007c, Howarth & Reid 2000, Kaklauskas et al. 2012, Laporte et al. 2003, Mahdavinejad & Mansoorim 2012, Office of the Deputy Prime Minister 2006 and Schoenwetter 1997). The latter may be described as consisting of a life cycle of housing health and safety, the parties involved in its design and realization as well as the micro, meso and macro environments having a particular impact on it making an integral whole. The methods multiple criteria project analysis, developed by this author (1999), aided performance of a complex analysis of the formulated research object.

5.4.2.2. Housing health and safety decision support system with augmented reality

An analysis of existing expert support system (Botia et al. 2012 and Soyguder & Alli 2009), decision support system (Ahmed et al. 2001, Chlela et al. 2009, Körner & Van Straten 2008, Parker 2009, Thiers & Peuportier 2008, Wang & Gwilliam 2009 and Yakubu 1996) and knowledge support system (Fazio et al. 1989 and Matsumoto & Toyoda 1994) served as the bases for developing the Model, Housing Health and Safety Rating System. The most efficient versions of the HoUsing Health and Safety Decision Support System could be determined with the development of augmented reality (HUSSAR 2013).

Dwelling listings are an interface for a seller to post listings. The system provides forms for sellers or brokers to fill in information about their offered dwellings. A HUSSAR administrator issues permits to brokers who wish to present information on their properties. This permit allows a broker to insert all the necessary information about dwelling properties under sale in the HUSSAR databases, according to the system's requirements (i.e., system of criteria and values and weights of criteria). The ability to access databases developed personally by brokers is only available to the broker and to the HUSSAR administrator. The presently developed HUSSAR allows for the performance of the following six main functions:

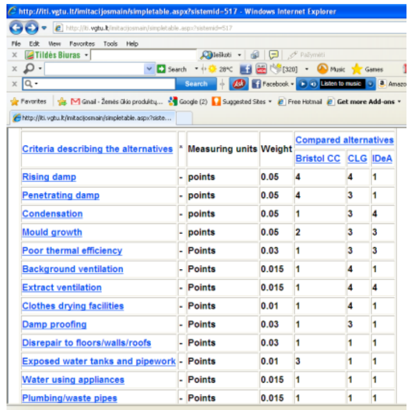
- search for dwelling alternatives
- finding alternatives and compiling an initial negotiation table
- analyzing alternatives; negotiating
- determining the most rational dwelling purchase variant
- performing statistical analysis
- groupware decision-making

More detailed descriptions of some of the above-mentioned subsystem functions follows to illuminate the HUSSAR better.

A buyer may perform a search for dwelling alternatives from databases from different brokers. This is possible due to the standardization of the data submission forms at a specific level. Such standardization creates conditions applicable to special intelligent agents that are performing a search for some required dwelling in various databases and gathering information/knowledge. The Physiological Requirements databases of housing health and safety assessments contain the following kinds of evaluation data on buildings:

- Damp mould growth. Health threats due to dust mites, mould or fungal growths including mental and social well-being health threats associated with damp, humid and moldy conditions. Health effects are allergies, asthma, effects of toxins from moulds and fungal infections.
- Excess cold. Sub-optimal indoor temperatures cause health threats. Healthy indoor temperature is approximately 21°C. Health effects include respiratory illnesses (flu, pneumonia and bronchitis), cardiovascular conditions (heart attacks and strokes), thermoregulatory system impairment (body temperature control) and such.

- Excess Heat. Excessively high indoor air temperatures cause health threats. Health effects include dehydration, trauma, stroke and cardiovascular, respiratory and genitourinary disorders.
- Asbestos and Manufactured Mineral Fibers (MMF). Presence of and exposure to asbestos fibers and MMF within dwellings can cause negative health effects such as pleural disease, lung cancer and mesothelioma. NOTE: Attempting to remove asbestos that is in good condition and not likely to be disturbed is significantly more hazardous than not removing it. A contractor licensed by the Health and Safety Executive should perform work involving asbestos.
- Biocides. Threats to health from chemicals used to treat timber and mould growth can cause negative health effects via risks from inhalation, skin contact and ingestion (eating or drinking the chemical).
- Carbon monoxide and fuel combustion products. Hazards result from the presence of excess levels of carbon monoxide, nitrogen dioxide or sulfur dioxide in the atmosphere and smoke within the dwelling. Health effects involve dizziness, nausea, headaches, disorientation, unconsciousness, respiratory disorders, bronchitis and breathlessness.



Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives		
				Bristol CC	CLG	IDeA
Rising damp	-	points	0.05	4	4	1
Penetrating damp	-	points	0.05	4	3	1
Condensation	-	points	0.05	1	3	4
Mould growth	-	points	0.05	2	3	3
Poor thermal efficiency	-	Points	0.03	1	3	3
Background ventilation	-	Points	0.015	1	4	1
Extract ventilation	-	Points	0.015	1	4	4
Clothes drying facilities	-	Points	0.01	1	4	1
Damp proofing	-	Points	0.03	1	3	1
Disrepair to floors/walls/roofs	-	Points	0.03	1	1	1
Exposed water tanks and pipework	-	Points	0.01	3	1	1
Water using appliances	-	Points	0.015	1	1	1
Plumbing/waste pipes	-	Points	0.015	1	1	1

Figure 5.11. Search results for a specific dwelling submitted in textual, photo/video and graphic information (*left*); fragment of expert and quantitative description of the dwelling's (damp and mould growth criterion) alternatives (*right*) (HHSRS worked examples 2007a, 2007b and 2007c)

The Psychological Requirements databases contain the following information:

- Lead. Lead ingestion causes a health threat. Lead sources are paint, water pipes, soil and fumes from leaded petrol. Health effects include lead poisoning, nervous disorders, mental health, blood production issues and behavioral problems in children.
- Radiation. Health threats come from radon gas and its primarily airborne daughters but also from radon dissolved in water. Health effects of expressed concern are about possible electromagnetic fields (EMFs) and leakage from microwave ovens (rare). Health effects include lung cancer caused by exposure to radon gas. Risk increases with greater dose and duration of exposure.

- Incombustible fuel gas. This threat is from fuel gas escaped into the atmosphere within a dwelling. Health effects are suffocation.
- Volatile organic compounds. These are a diverse group of organic chemicals, including formaldehyde, which are gaseous at room temperature. They are present in a wide variety of materials in the home. Health effects include allergies; irritations to eyes, nose, skin and respiratory tract; headaches; nausea; dizziness and drowsiness.

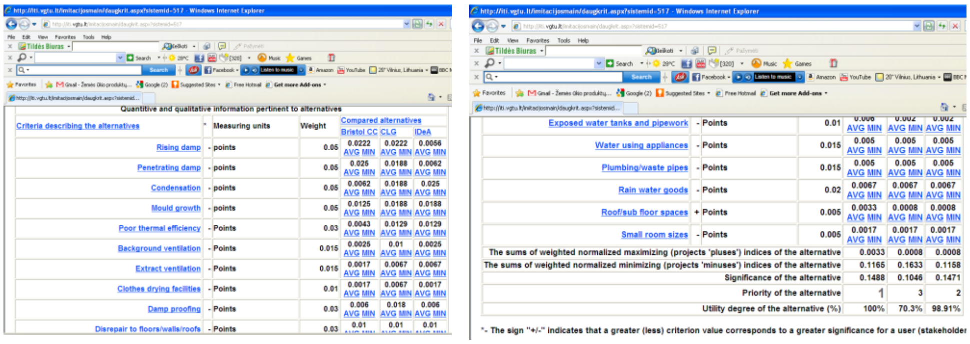


Figure 5.12. Fragment of multiple criteria evaluation results of dwelling alternatives (damp and mold growth criterion): upper matrix for obtained results (left); lower matrix for obtained results (*right*)

Buyers specify requirements and constraints, and the system queries information on a specific dwelling from a number of online brokers. The system performs the tedious, time-consuming and repetitive tasks of searching databases, retrieving and filtering information/knowledge and delivering it back to the user. Search results for a specific dwelling are submitted as textual, photo/video and graphic information relevant to dwelling alternatives (see Figure 5.11), which may include direct links to a Web page of brokers. Such a display, when submitted, can provide effective support for multiple criteria comparisons. A click on the link “Expert and quantitative description of variants” presents the expert and quantitative descriptions of single-family home alternatives (see Figure 5.11 [right]). Each alternative described by quantitative information (system of criteria, weights of criteria and values) has a number (see Figure 5.11) that coincides with the verbal and photographic information describing the mentioned alternative (see Figure 5.11).

A buyer should examine numerous alternatives over the course of the purchasing decision process. Each alternative involves a considerable amount of information/knowledge pertinent to factors like physiology (hygrothermal conditions and pollutants), psychology (space, security, light and noise), protection against infection (hygiene, sanitation and water supply), protection against accidents (falls, electric shock, burns and scalds and building related collisions), economic factors, quality-architecture, aesthetics, comfort, infrastructure as well as technical, legal, technological and other factors. The multiple criteria analysis is conducted with respect to the gathered information and knowledge.

Use of the multiple criteria methods developed by this author (1999) permits a buyer (broker) to determine an initial priority, utility degree and market value of the dwelling alternatives under analysis. A click on the link “Results of Multiple Criteria Evaluation” prompts a demonstration of the multiple criteria evaluation results on single-family home alternatives (see Figure 5.12). The lower matrix presents obtained results on the calculated significances of the dwelling alternatives, their priority and utility degrees (see Figure 5.12). The upper matrix presents obtained results for numbering the dwelling alternatives (see Figure 5.12 [left]). A click on these blue underlined numbers makes it possible to calculate the market value of a certain alternative (see Figure 5.13). The table presented in Figure 5.13 (*top*) shows the iterations made for calculating a dwelling's market value. The same information, only in graphic form, appears as presented in Figure 5.13 (*bottom*). A move of the mouse above any column of the graphic part displays the numerical value of the column. For example, it took 15 iterations to calculate the market value of the eighth alternative (see Figure 5.13 [*top*]).

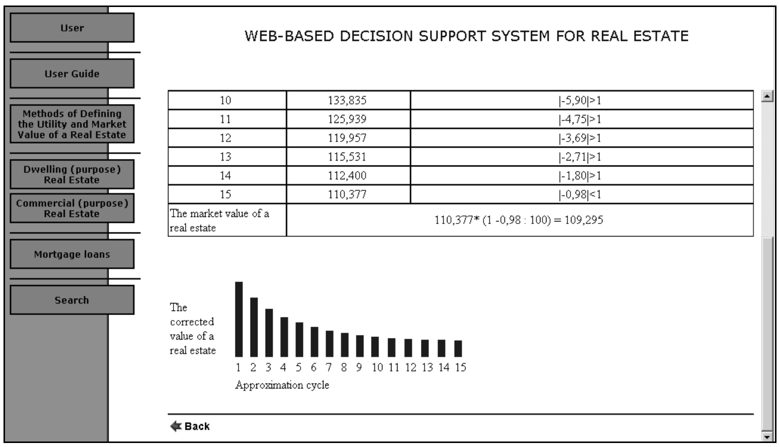
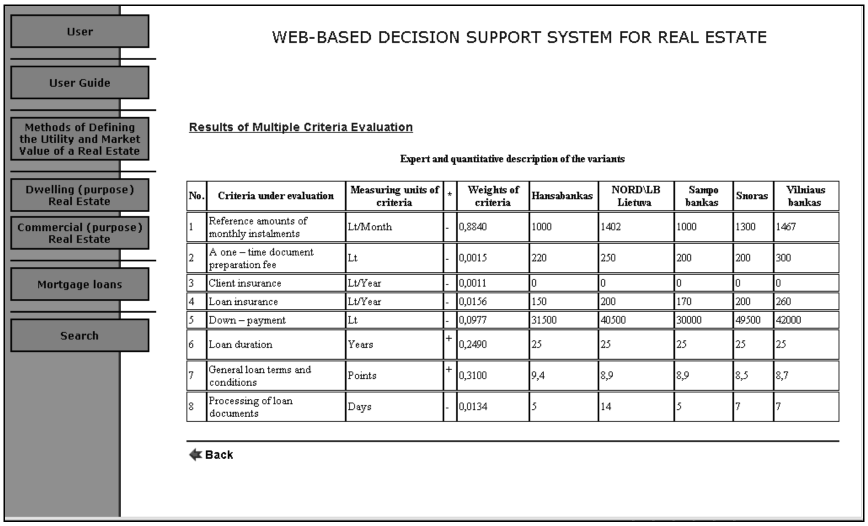


Figure 5.13. Market value calculations: presentation in numerical form (*top*) and in graphic form (*bottom*)

A buyer performing a multi-criteria analysis of all dwelling alternatives selects the objects for starting the negotiations. For that purpose, he/she marks (clicks a box with a mouse) the desirable negotiation objects (see Figure 5.14). The Letter Writing Subsystem generates a negotiations email and sends one out to all dwelling sellers, following the selection of desired objects. Then the buyer clicks *Send*. The buyer and seller may perform real calculations (the utility degree, market value and purchase priorities) of a dwelling with the help of HUSSAR during their negotiations. Characteristics that describe a dwelling's alternatives that are obtained during negotiations serve as the bases for performed calculations (explicit and tacit criteria systems and criteria values and weights). The received results are then compiled into a final comparative table. Next, the multiple criteria analysis is performed with the assistance of HUSSAR. The selection is then made of the best dwelling alternative for purchase.

A purchaser usually must borrow part of the needed money from a bank after selecting one of the alternatives for a dwelling. Development of the Loan Analysis Subsystem occurred for this purpose (see Figure 5.14).

The Statistical Model has accumulated information about client navigational activities and his/her decision-making over the past three years. The Statistical Model collects concrete statistics about navigational activities by one's clients — the number of concrete real estate alternative visitors, time spent analyzing this alternative and the decision-making for the selection of a criteria system and the criteria values and weights. It is possible to use the statistical information to determine the most marketable real estate and the most important criteria along with their weights. The received statistical information reflects the navigational purposes of clients. The ability to measure the navigational activities by clients statistically allows generating statistically the average criteria system and criteria weights for a typical real estate seeker. This solution improves the accuracy of the development of the criteria system and criteria weights for a client. The above statistical information is also applicable to adapt the searching process better to client needs.



No.	Criteria under evaluation	Measuring units of criteria	*	Weights of criteria	Hansabankas	NORD\LB Lietuva	Sampo bankas	Snoras	Vilniaus bankas
1	Reference amounts of monthly instalments	Lt/Month	-	0,8840	1000	1402	1000	1300	1467
2	A one – time document preparation fee	Lt	-	0,0015	220	250	200	200	300
3	Client insurance	Lt/Year	-	0,0011	0	0	0	0	0
4	Loan insurance	Lt/Year	-	0,0156	150	200	170	200	260
5	Down – payment	Lt	-	0,0977	31500	40500	30000	49500	42000
6	Loan duration	Years	+	0,2490	25	25	25	25	25
7	General loan terms and conditions	Points	+	0,3100	9,4	8,9	8,9	8,5	8,7
8	Processing of loan documents	Days	-	0,0134	5	14	5	7	7

Figure 5.14. Analysis of loan alternatives offered by certain banks

Currently intelligent systems for real estate are mostly viewed from the perspective of a single-buyer, thus the purposes taken into account are also for a single client alone. Meanwhile, the Cooperative Decision-making Subsystem considers the circumstances, when a group of interested parties is planning a common real estate development, purchase and/or other activities (with a special emphasis on pollution and health effects). Now many potentially conflicting objectives must be analyzed and dealt with; thus, these must be included in the system. The Cooperative Decision-making Subsystem allows different stakeholders to resolve their common tasks together in a cooperative manner, e.g., developing a joint criteria system and estimating criteria weights and qualitative criteria values. For example, HUSSAR can help interested parties achieve a cooperative decision on a Web-based, real estate search, analysis, negotiations and decision-making. This is done by transforming individual client models (an individual decision-making matrix) to a cooperative (medium) client model (a mutually integrated decision-making matrix) and to mediate a group discussion by using the cooperative client model for arriving at a compromise that is acceptable to all group members. The Cooperative Decision-making Subsystem also allows stakeholders to develop a cooperatively integrated decision-making matrix by using expert methods. The developed, integrated, cooperative, decision-making matrix helps to decrease mistrust between stakeholders and to select most appropriate solution to satisfy all interested parties.

A number of academics and practitioners worldwide (Sara 2010, Webb 2013 and Wiggers 2012) use the Augmented Reality Subsystem in real estate.

Home Spotter is an augmented reality real estate platform that allows brokers to find properties in a neighborhood that are for sale along with descriptive details of the properties, such as the number of bedrooms, square footage and price. Then the system can provide a “radar view” of others for sale in the neighborhood, wherever a user points their mobile phone cameras. A version for homebuyers is in the works (Webb 2013).

Sawbuck Reality's Homesnap, an app launched on iOS in 2012 on Android, seeks to make some aspects of home searching a bit more fun. Homesnap seems simple on the surface: take pictures of the houses you want to know more about and compare them side-by-side. Beneath the surface, though, things are quite complicated. The app relies on in-phone sensors like the GPS, magnetometer, accelerometer and gyroscope. With these Homesnap is able to figure out where your phone is pointing the moment you take a picture. After snapping the picture, the app uses a number of advanced algorithms to serve up additional data, such as the value and for-sale status of nearby properties. An Explore tab provides information about nearby homes, neighborhood price trends and even the quality of surrounding schools. The interface is not anything to write home about — it is identical to the iOS version — but the functionality is impressive. Layar is derived from location-based services; it works on mobile phones that include a camera, GPS and a compass. Layar is first available for handsets with the Android operating system. It works as follows: Starting up the Layar application automatically activates the camera. The embedded GPS automatically knows the location of the phone and the compass determines in which direction the phone is facing. Each partner provides a set of location coordinates with relevant information that forms a digital layer. The user easily switches between layers by tapping the side of the screen. This makes Layar a new type of browser combining digital and reality, which offers an augmented view of the world (Wiggers 2012).

Sara is the world’s first augmented reality architecture application, which the Netherlands Architecture Institute (NAI) developed in partnership with IN10 Communicative and Layar. Users of the technology simply hold up their smartphone to see photos, video, 3D models, scale models and other details about buildings currently in site, as well as those from the past and any planned for the future. Those with the app can view a 3D model of how a building will look once it is finished, although currently it is still under construction. SARA also allows users to add their own information about any building or to take map tours of their favorite architecture. The launch of this technology was on December 2009 on the Layar platform; it will be downloadable from the Apple App Store and Android Market beginning next month. The world’s first building to appear in three dimensions on the smartphone via augmented reality is the eye-catching Market Hall, which is currently under construction in Rotterdam’s Blaak area. SARA is expected to evolve into a complete national architecture guide within the next 5 years (Sara 2010).

Any user with a Google account may access Google Maps at https://maps.google.com/. The site’s feature My Places lets you personalize its maps with your information. Use the Placemarks tool to mark a location defined by specific coordinates in a map (e.g., to mark a building). Each placemark may have a unique title and may link to additional information, such as URLs, photos, HTML code and the like. The titles named here refer to a building’s address or a company that uses the building for its business. The additional information provided here is a link to the initial data matrix with the multiple criteria analysis pertinent to the building’s properties for refurbishment (see Figure 5.11-5.17) and the building’s photo.

Google's Street View technology lets you take a virtual tour and explore the building's environment.

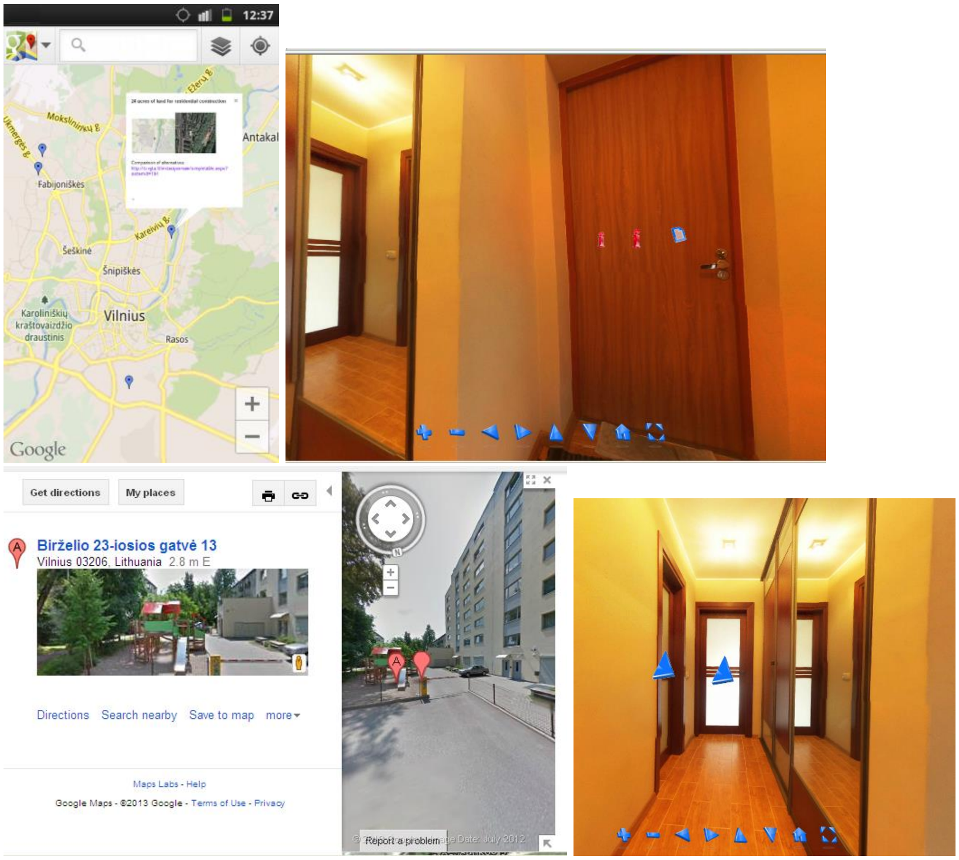


Figure 5.15. Links to the multiple criteria analysis matrix comparing alternatives created with Google Maps tools; a Google Street View image of the location is shown alongside the virtual tour.

The Augmented Reality Subsystem offers real-time additional information about a piece of property (see Figure 5.12, 5.16 and 5.17). All property details in the databases link to the Google Maps service. The digital map is a convenient tool to display the pieces of property of interest to users and make intuitive choices of a property for further analysis. Once a user has selected the property of interest, the Decision Support Subsystem opens up. A user equipped with GPS coordinates and a palmtop may retrieve information about the object in which the user is presently located and compare it with other alternatives pinned in the digital map.

The "My places" Google Maps tool is used to pin in a map the address of each piece of property with a marker. Each marker shows some extra information about the property, such as its name, address, image and a link to the Decision Support Subsystem that compares alternative variants of the properties marked in the map.

A mobile device with Android OS and the Maps application offers access to the map in Google Maps. An active GPS receiver in the mobile device pins the user's actual location on the map. Thus any nearby alternative variants of real estate objects are shown in the map with some extra information about them. Street View, a service by Google Maps, offers a possibility to take a virtual tour to check out what is in the vicinity of a piece of property.

Using the Google Maps mapping tool, the location of each alternative described in the initial-data **table** for the multiple criteria analysis is marked on the map. Each property is pined on the city's map (blue markers on the map). A click on its marker will provide a view of the details of a property of interest (a link to the Decision Support Subsystem, the property's image, a link to Google Street View).

5.5. ADVISORY, NEGOTIATION AND INTELLIGENT DECISION SUPPORT SYSTEM FOR LEADERSHIP ANALYSIS

5.5.1. Introduction

Leadership, according to Uhl-Bien & Russ Marion (2009), is multi-level, processable, contextual and interactive. Today's organizational leaders face unprecedented complexity in the wake of increasing globalization (Youssef & Luthans 2012).

Various systems are under development globally for leadership analysis. These systems include information (Cho et al. 2011 and Dimitrios et al. 2013), intelligent (Seah et al. 2010 and Rao et al. 1994), knowledge (Chun & Tak 2009 and McKenna et al. 2009), expert (Lehner 1992 and Oliveira et al. 2012) and decision support (Rees & Koehler 2000 and Lim et al. 1994).

The aforementioned systems analyze their managerial, organizational, technical, technological, economic, legal/regulatory, innovative and similar aspects. However, there is generally no attention paid at all to the integrated economic, legal/regulatory, technical, technological, organizational, managerial, quality of life, social, cultural, political, ethical or psychological aspects.

`There is agreement in common that a better integration of advisory, negotiation and decision support systems would significantly improve the value of decisions made. The objective for integrating advisory, negotiation and decision support systems is to improve the quality and efficiency of decision-making support. An Advisory, Negotiation and Intelligent Decision Support System for Leadership Analysis will be considered as an example to demonstrate the integration of advisory, negotiation and decision support systems.

5.5.2. Leader Model for Quantitative and Qualitative Analyses

Development of the Leader Model for quantitative and qualitative analyses was on the basis of a conducted analysis of worldwide leadership models (Kim 2012, Vargas & Torres 2008, Chen et al. 2013, Day & Sin 2011, Tavakoli & Vahidi 2010, Liu et al. 2007, Ashtiani et al. 2013, Six 2007 and Sense 2003). A description of this model could be as the life cycle of a leader and the parties involved in this leader's life cycle as well as the micro-, meso- and macro-environments with impact on making an integral whole. Application of multiple criteria, project analysis methods aided the complex analysis for the formulation of the research object (Kaklauskas 1999 and Kaklauskas, Zavadskas and Raslanas 2005a). These methods included CODEC (COmplex DEtermination of Criteria weight method including quantitative and qualitative characteristics), COPRAS (COmplex PRoportional ASsessment Method), DUMA (Defining a project's Utility Degree and MArket value method) and DAM (multiple criteria multivariant Design of Alternatives Method) (Kaklauskas 1999 and Kaklauskas, Zavadskas and Raslanas 2005a).

The goal for developing this Model was to integrate the managerial, organizational, technical, technological, economic, legal/regulatory, innovative, social, cultural, ethical, psychological, religious, ethnic and other aspects of the process over the life of a leader. This six-stage model appears below in brief.

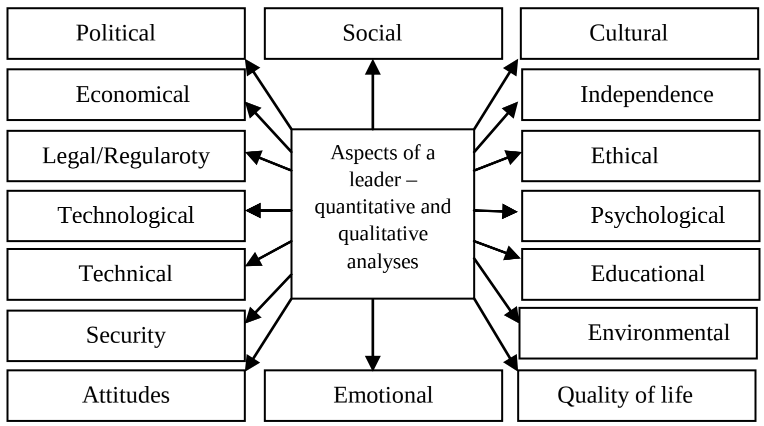


Figure 5.16. Aspects of a leader – quantitative and qualitative analyses

Stage I. Comparative descriptions of a leader in developed countries and in Lithuania (by economic, legal/regulatory, technical, technological, organizational, managerial, quality of life, social, cultural, political, ethical, psychological and other aspects) are compiled for:

- Determining a system of criteria characterizing the efficiency of a leader by employing relevant literature and expert methods
- Describing the present state of a leader in developed countries and in Lithuania per this system of criteria in conceptual (textual, graphic, numerical and such) and in quantitative forms

Stage II. Comparison and contrast of a leader in developed countries and in Lithuania are compiled for:

- Identifying global development trends (general regularities) of the leader
- Identifying the differences in leaders between developed countries and Lithuania
- Determining the pluses and minuses of these differences for Lithuania
- Determining the best practices for a leader in Lithuania as per actual conditions
- Estimating the deviation between the knowledge stakeholders have of worldwide best practices and their practice-in-use

Stage III. Development of certain general recommendations on how to improve the knowledge levels of stakeholders is accomplished.

Stage IV. Submission of certain recommendations to stakeholders including several particular alternatives for each general recommendation proposed is completed.

Stage V. A multiple criteria analysis of the composite parts of a leader and selection of the most efficient life cycle for the project are completed.

Stage VI. Transformational learning and the redesign of mental and practical behavior are executed.

A partial description of the Stage I (Leader socio-cultural aspects) follows to illustrate the above-presented Model. Representatives of different cultures have ambiguous views towards a leader. A great many socio-cultural factors influence such outlooks. *Social, emotional, cultural, ethical, psychological, religious/spiritual, traditional and the like* are among the most important. A brief presentation of these follows.

5.5.3. Advisory, Negotiation and Intelligent Decision Support System for Leadership Analysis

The author of this book in conjunction with his colleagues (R. Gudauskas, S. Jokubauskienė and L. Budrytė) developed the Advisory, Negotiation and Intelligent Decision Support System for Leadership Analysis. First, there was an analysis of the existing different intelligent systems. These included information systems (Cho et al. 2011 and Dimitrios et al., 2013), intelligent systems (Seah et al. 2010 and Rao et al. 1994), knowledge systems (Chun & Tak 2009 and McKenna et al. 2009), expert systems (Lehner 1992 and Oliveira et al. 2012) and decision support systems (Rees & Koehler 2000, Lim et al. 1994, Kaklauskas 1999 and 2015, Kaklauskas et al. 1999, Kaklauskas et al. 2011 and 2012, Šliogerienė et al. 2012, Brauers et al. 2013 and Gudienė et al. 2013) plus developed multiple criteria methods — CODEC, COPRAS, DUMA and DAM (Kaklauskas 1999 and Kaklauskas, Zavadskas & Raslanas 2005a). The purpose was to determine the most efficient Advisory, Negotiation and Intelligent Decision Support System for Leadership Analysis (ANDES) to analyze a leader's life cycle. This developed support system consists of a database, database management system, model base, model base management system and user interface (Figure 5.17).

ANDES is an information system that accumulates data and information from various sources and processes them by extensive use of artificial intelligence techniques. It utilizes various multiple-criteria and artificial intelligence models and provides a decision-maker with data, information and knowledge needed for analyzing, compiling and assessing possible alternative resolutions. It can make a decision, derive the received results and safeguard them. Thus the ANDES can be based on data from various sources and allow users to transform a huge amount of unprocessed data, information and knowledge into an analysis of a problem under consideration.

The authors have been developing decision support and recommender systems for leader analysis for many years. Aalborg University in Denmark published their first findings on the topic, which had a focus on civil engineering (Zavadskas & Kaklauskas 1991 and Zavadskas, Kaklauskas & Bejder 1992a). Later a number of publications discussing the research findings of these authors on the multiple criteria analysis of leaders followed (Zavadskas, Peldschus & Kaklauskas 1994; Zavadskas & Kaklauskas 1996; Jokūbauskienė 2013; Tampieri & Bianchi 2013 and others). The first decision support and recommender systems for leader analysis by the authors of this work were offline systems.

Development of the initial version of the Advisory, Negotiation and Intelligent Decision Support System for Leadership Analysis was in 2004. The testing of the System has been ongoing since then. A total of 176 distance-learning students tested this system. The continuous testing results resulted in improvements to the System. The testing of the System was the subject of some 18 final master theses.

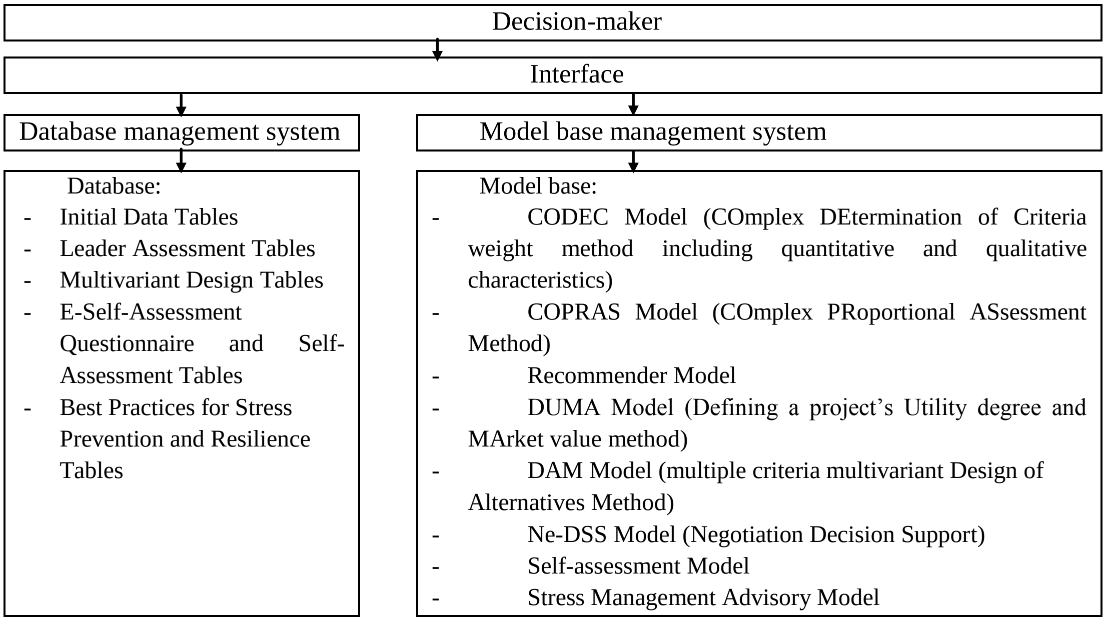


Figure 5.17. ANDES components

5.5.3.1. Database

Presently the structure of relational databases is the most appropriate in light of the requirements raised by ANDES. A relational database stores information in tables. Every table has a name ascribed for storing it in the external memory of the computer, as a separate file. The indexes common for this table are logically interconnected. Thereby the entirety of the logically interrelated table comprises the model.

The data play very meaningful roles. Data constitute the basis for decision-making. The more comprehensive the accumulated data are about an object under consideration, the more effective the decision made can be. For example, various economic, social, legal, technical, technological and other factors from the external environment influence knowledge management. The possible operations of an organization objectively change for better or for worse, as external conditions change. Usually an organization can organize its operations for more than one market. Therefore it is very important to understand and evaluate the constantly changing external micro, meso and macro environments and their impacts on organizational operations in different markets. The bases for descriptions of the external and internal environments of organizational operations for each time period comprise specific data, information and knowledge. Organizations must react to the fluctuating external environment by making adequate strategic, tactical and operative decisions based on such specific information. Since decision-making is an informational process, all of its stages, from the time of setting objectives to the ending of their implementation and evaluating their consequences, must be substantiated by searching for, visualizing, processing and analyzing necessary data, information and knowledge.

A leader interacts with a number of interested parties, all of whom are pursuing various goals and all of whom have different potentials, educational levels and backgrounds of experience. Therefore all the aforementioned parties in the field approach decision-making in various ways. It is often necessary to define these players in terms of their economic, legal/regulatory, technical, technological, organizational, managerial, quality of life, social, cultural, political, ethical and psychological aspects along with other types of information. The purpose for this is to analyze the available alternatives thoroughly and to obtain an efficient compromise solution. Such information needs to appear in as much of a user-oriented manner as possible.

The presentation of information in ANDES, which is needed for decision-making, may be in conceptual (digital, numerical), textual, graphic (diagrams, graphs, drawing, etc), photographic, audio (sound), visual (video) and quantitative forms. The presentation of quantitative information involves criteria systems and models, units of measurement, values and initial weights, which fully define the variants provided. Conceptual information conceptually describes alternative solutions, criteria and ways used to determine the values and weights of the criteria and the like. Upon demand the ANDES provides conceptual information (images, audio, video, and so on), which aids users to get a better understanding of the alternatives in question and their defining criteria.

This way ANDES provides a decision-maker with different conceptual and quantitative information about a leader from a database and a model base. It allows the decision-maker to analyze the above factors and determine an efficient solution.

An analysis of database structures in decision support systems by the type of problem they resolve reveals their various utilities. There are three basic types of database structures: hierarchical, network and relational. ANDES has a relational database structure, when the information is stored in the form of tables. These tables contain quantitative and conceptual information. Each table has a given name for saving it into the computer's external memory, as a separate file. Logically linked parts of the table constitute a relational model. The ANDES database consists of the following tables:

- Initial Data Tables. The data cover general facts about the leader under consideration. The leader's requirements and their significances, as well as an intended salary, are included.
- Leader Assessment Tables. Quantitative and conceptual information about alternative leaders on the ANDES website (http://iti.vgtu.lt/imitacijosmain/simpletable.aspx?sistemid=518) shows the input data for the multiple criteria analysis in ANDES.
- Multivariant Design Tables. These contain quantitative and conceptual information on the interconnecting elements in the life cycle of a leader in the organization, their compatibilities and possible combinations, as well as data for the complex multivariant design of the elements previously described herein.
- E-Self-Assessment Questionnaire and Self-Assessment Tables.

An analysis of the available alternatives is necessary for designing and realizing an effective leader's life cycle. A computer-aided, multivariant design requires the availability of tables containing data on the interconnecting elements of the life cycle of a leader in the organization, along with their compatibilities, possible combinations and a multivariant design.

The development of possible variants is possible using the aforementioned tables as the basis for a multivariant design of a leader's life cycle. The development of millions of alternatives of a leader's life cycle (including the project on the life cycle of the leader in the organization) is possible by using a multivariant design method. The capacity of these versions to meet various requirements is checked. Alternative versions that are unsatisfactory in terms of the requirements raised are excluded from further consideration. A problem involving the significance of criteria compatibilities arises in the process of designing a number of variants of a leader's life cycle. Thereby the performance of a complex evaluation of the alternatives determines that the value of a criterion weight is dependent on the overall criteria under assessment, as well as on their values and initial weights.

Numerous studies have been conducted worldwide analyzing the reliability of self-assessments. This is quite a controversial issue. A great many researchers attained reliable results proving that self-assessments are sufficiently reliable. Our investigations also demonstrate that self-assessments are sufficiently reliable. The basis for the *E-Self-Assessment Questionnaire and Self-Assessment* ***Table****s* is the presumption that it is possible to determine a leader's level of stress rather accurately by assigning questions for leaders according to some certain methodology and then processing them in accordance with a certain algorithm.

5.5.3.2. Model base

ANDES models are subdivided as quantitative and qualitative by their presentations. The bases for the qualitative models (multicriteria, based on expertise) are subjective opinions, experiences and assessments of experts. However, when different experts assess the same characteristics of an object, the derived results are often different. This occurs due to the different experiences, educational levels, purposes, available opportunities and the like of different experts. Application of the expert methods can make the derived data more objective. Quantitative models (i.e., text analytics) reflect the objective features of the objects under consideration, independently of the subjective assessments by experts. The direct expressions of such features of an object can be in physical units of measurement, such as monetary units, degrees, percents, ratios and such. Qualitative models have as many positive and negative features as quantitative models have. Objects being considered by quantitative models are objectively but often not comprehensively reflected. Contrariwise, ANDES qualitative models reflect reality subjectively and comprehensively. Therefore the rationality of applying quantitative and qualitative methods often depends on specific, decision-making situations. Frequently decision-making requires a comprehensive application of quantitative and qualitative models. For example, it is best to apply qualitative research methods when analyzing the qualitative leadership characteristics (emotions, culture, religious, traditions, ethical leader behaviors, psychological capital). However, the application of quantitative methods is better, when analyzing how much money will be spent over the entire process of an office's life cycle, such as the costs of its purchase or construction, exploitation, maintenance upkeep, insurance expenses, taxes and the like.

A determination regarding the efficiency of alternative leaders often takes into account economic, legal/regulatory, technical, technological, organizational, managerial, quality of life, social, cultural, political, ethical, psychological and other factors. Therefore the model base of the ANDES should include models enabling a decision-maker to analyze the available variants comprehensively and arrive at a suitable choice. The intention for the following models of the model base is to perform this function (Kaklauskas 1999):

- CODEC Model (Complex Determination of Criteria Weight Method including quantitative and qualitative characteristics)
- COPRAS Model (Complex Proportional Assessment Method)
- Recommender Model
- DUMA Model (Defining a Project's Utility Degree and Market Value Method)
- DAM Model (Multiple Criteria, Multivariant Design of Alternatives Method)
- Ne-DSS Model (Negotiation Decision Support)
- Self-Assessment Model
- Stress Management Advisory Model
- Text Analytics

Development of the CODEC Model (Complex Determination of Criteria Weight Method including quantitative and qualitative characteristics) allows for the calculation and coordination of the significances of the described quantitative and qualitative characteristics of the criteria.

Development of the multiple criteria COPRAS Model (Complex Proportional Assessment Method) enables a user to obtain a reduced criterion for determining the complex (overall) efficiency of alternatives. This generalized criterion is directly proportional to the relative effect of the values and weights of the criteria under consideration regarding the efficiency of the alternatives.

The DUMA Model determines the utility degree and market salary of leaders. It establishes the competitive salary for a leader on the market. The basis for this model is a complex analysis of all the benefits and drawbacks of a leader. A leader's utility degree and the estimated market salary of a leader are directly proportional to the system of the criteria, which adequately describe them, and the values and weights of those criteria, according to this Model.

Development of the DAM Model of a multiple criteria, multivariant design of a leader's life cycle enables a user to design, with the aid of a computer, up to 100,000 alternative versions. Quantitative and conceptual information are the bases for any life cycle variant obtained in this way.

The bases for the ANDES are the models described above. ANDES can generate millions of alternative versions of leader life cycles (including a project for determining the life cycle of the current leader in the organization). ANDES performs a multiple criteria analysis of a leader's life cycle, determines a leader's utility degree and selects the most beneficial variant for a leader.

A model base management system can provide various models according to user needs. The results of its obtained calculations become the initial data for some other models when using some certain model. Such a model could be for determining the initial weights of the criteria, for designing a leader's life cycle in a multivariant method (including a project on the life cycle of the current leader in the organization), for analyzing by multiple criteria and for setting priorities. Meanwhile the results of the latter, in turn, are acceptable as the initial data for some other models (such as for determining the leader utility degree, for providing recommendations and for other undertakings).

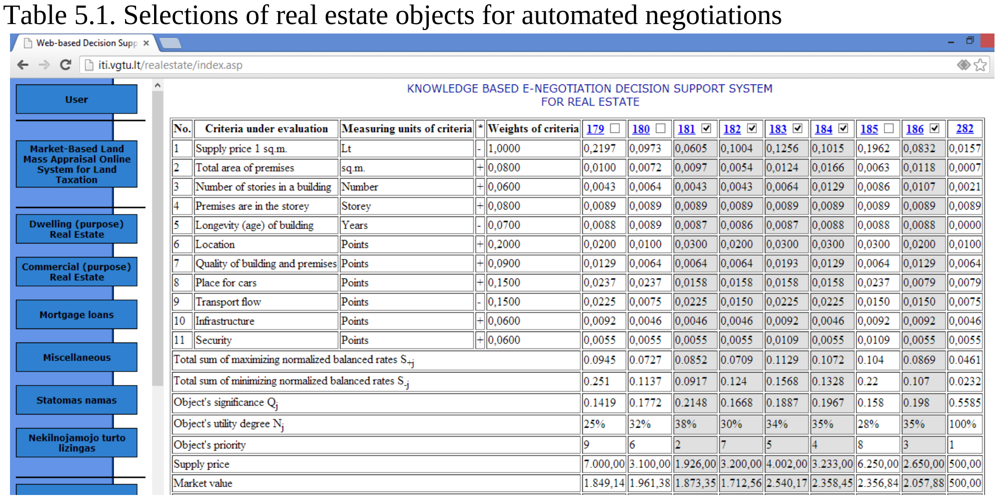
The Negotiation Decision Support Model (Ne-DSS) is for use by leaders engaged in different negotiation circumstances. One such example could be the purchase of office premises. A leader performing a multi-criteria analysis of all real estate alternatives selects objects for starting the negotiations. The leader marks (clicks a box with the mouse) the desirable objects for negotiation (see Table 5.1). The Letter Writing Model generates a negotiations e-mail after the selection of the desired objects. It then sends the e-mail to all real estate sellers once the user clicks “Send”. The buyer and the seller may perform real calculations (the utility degree, market salary and purchase priorities) of the real estate with the help of ANDES during negotiations. The bases for these calculations are the characteristics describing the real estate alternatives, obtained during negotiations (explicit and tacit criteria system and criteria values and weights). Development of the final comparative table is in accordance with the received results. Use of ANDES permits the performance of the multiple criteria analysis and selection of the best real estate for purchase version, following the development of the final comparative table.

There are two main categories of rules and procedures in the Ne-DSS Model:

- It compiles suggestions for leaders to employ along with the reasons for the recommended further negotiations with a particular leader.
- It composes a comprehensive, negotiation e-mail for each of the selected broker leaders. The Ne-DSS uses information inherited from the previous ANDES calculations and predefined rules and procedures and composes a negotiation e-mail for each of the selected broker leaders. The e-mail includes a reasonable suggestion for a decrease in the price of the real estate. The e-mail also references the calculations performed by ANDES.

Development of the Self-assessment Model took place while analyzing similar studies conducted worldwide. Areas of special attention were the criteria systems used, integration of such criteria into one general assessment, use of aggregation methods, reliability level of the results and tendencies of the results. This author in conjunction with his colleagues based their work on the aforementioned and other studies.

Table 5.1. Selections of real estate objects for automated negotiations



KNOWLEDGE BASED E-NEGOTIATION DECISION SUPPORT SYSTEM
FOR REAL ESTATE

No.	Criteria under evaluation	Measuring units of criteria	*	Weights of criteria	179 ☐	180 ☐	181 ☑	182 ☑	183 ☑	184 ☑	185 ☐	186 ☑	282
1	Supply price 1 sq.m.	Lt	-	1,0000	0,2197	0,0973	0,0605	0,1004	0,1256	0,1015	0,1962	0,0832	0,0157
2	Total area of premises	sq.m.	+	0,0800	0,0100	0,0072	0,0097	0,0054	0,0124	0,0166	0,0063	0,0118	0,0007
3	Number of stories in a building	Number	+	0,0600	0,0043	0,0064	0,0043	0,0043	0,0064	0,0129	0,0086	0,0107	0,0021
4	Premises are in the storey	Storey	+	0,0800	0,0089	0,0089	0,0089	0,0089	0,0089	0,0089	0,0089	0,0089	0,0089
5	Longevity (age) of building	Years	-	0,0700	0,0088	0,0089	0,0087	0,0086	0,0087	0,0088	0,0088	0,0088	0,0000
6	Location	Points	+	0,2000	0,0200	0,0100	0,0300	0,0200	0,0300	0,0300	0,0300	0,0200	0,0100
7	Quality of building and premises	Points	+	0,0900	0,0129	0,0064	0,0064	0,0064	0,0193	0,0129	0,0064	0,0129	0,0064
8	Place for cars	Points	+	0,1500	0,0237	0,0237	0,0158	0,0158	0,0158	0,0158	0,0237	0,0079	0,0079
9	Transport flow	Points	-	0,1500	0,0225	0,0075	0,0225	0,0150	0,0225	0,0225	0,0150	0,0150	0,0075
10	Infrastructure	Points	+	0,0600	0,0092	0,0046	0,0046	0,0046	0,0092	0,0046	0,0092	0,0092	0,0046
11	Security	Points	+	0,0600	0,0055	0,0055	0,0055	0,0055	0,0109	0,0055	0,0109	0,0055	0,0055
Total sum of maximizing normalized balanced rates S_{+j}					0.0945	0.0727	0.0852	0.0709	0.1129	0.1072	0.104	0.0869	0.0461
Total sum of minimizing normalized balanced rates S_{-j}					0.251	0.1137	0.0917	0.124	0.1568	0.1328	0.22	0.107	0.0232
Object's significance Q_j					0.1419	0.1772	0.2148	0.1668	0.1887	0.1967	0.158	0.198	0.5585
Object's utility degree N_j					25%	32%	38%	30%	34%	35%	28%	35%	100%
Object's priority					9	6	2	7	5	4	8	3	1
Supply price					7.000,00	3.100,00	1.926,00	3.200,00	4.002,00	3.233,00	6.250,00	2.650,00	500,00
Market value					1.849,14	1.961,38	1.873,35	1.712,56	2.540,17	2.358,45	2.356,84	2.057,88	500,00

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