Integrated lighting system assisant : design of a decision support system for integrating daylight and artifical lighting in the early design stage of office rooms

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Integrated Lighting System Assistant

Design of a decision support system for

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PROEFONTWERP

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Elisabeth Heiltje de Groot

geboren te Asperen

Dit proefontwerp is goedgekeurd door de promotoren:

prof.ir. P.G.S. Rutten

en

prof.dr. H.J.P. Timmermans

Copromotor:

dr.ir. H.M.G.J. Trum

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Summary

Wicked problems - The aim of the design project described in this thesis is to *design* a tool to support the building *design* process. Developing a design is considered to be a *wicked problem* because it goes beyond reasonable or predictable limits. Consequently, in this design project we address two wicked problems simultaneously: a *double wicked problem*.

The first wicked problem concerns the design of Design Decision Support System [DDSS]. Initially, an interactive computer-based system to support the design of energy efficient buildings was considered. Later, the tool was further developed to support building designers at the energy efficient use of daylight and artificial lighting systems in office buildings.

The second wicked problem concerns the conceptual design of office lighting systems. In conceptual design, the functional brief is translated into a schematic design. The decisions made in this design stage cover issues which often are directive and, at the same time, restrictive and irreversible. The decisions are based on available information which may be incorrect, incomplete, (e.g. potential maintenance costs), or overly complex (e.g. code requirements).

Method to address wicked problems - To get a handle on the first wicked problem, two workshops were organised to meet the possible future users and to create a common basis for the tool to be developed. At the first workshop 29 building experts identified barriers that prevent buildings to be more energy efficient under three categories: Design Process, Today's building technologies, and Dutch regulation. After most barriers were identified, the attendees where invited to indicate whether a Knowledge Based System [KBS] could overcome these barriers in their work situation. From analysing this discussion, specifications for such a KBS came forward. A demonstration tool was developed according to the identified specifications focusing on lighting system design. It was presented during a second workshop in which 14 of the same building experts that attended the first workshop were present.

To tackle the wickedness of the second problem, an office lighting model and performance evaluation method were developed. The lighting model was validated and adapted by five lighting experts and one architect. The evaluation method is based on a psychophysical approach: lighting experts were asked to judge the influence of the various variables in the lighting model on the overall performance of a lighting system. The revised lighting model and evaluation method were implemented in a new prototype computer system: Integrated Lighting System Assistant [ILSA] and were validated during a third, and final, workshop.

Results of the three workshops - During the first workshop, the attendees agreed that poor communication between the building team members is one of the most important problems. Further, they recognised that the building industry is not willing to use innovative solutions because of the high risks involved. Another issue raised was that the building team focuses on low initial costs, and not on low operating or life cycle costs. Furthermore, an interesting issue was raised leading to the notion that regulations make designs less creative. All the participants agreed that a KBS would assist in overcoming most of the identified barriers. The KBS specifications drawn up in the workshop were, however, at a high level of abstraction.

During the second workshop, the enthusiastic response of participants made it clear that the demonstration tool was a good basis for further development. However, much effort was needed in order to realise a final, operational system: an information and decision support system for the design of energy efficient buildings. Further, it was found that application by two possible kinds of end-users could be identified: the architect, who uses the tool to design a standard workplace, and the consultant, who uses the tool to design a part of a complex workplace. It was decided to focus initially on the architect as future user of the tool.

During the third workshop, the validation of the lighting model, revised by six experts during interviews, indicated that the eighteen variables within the implemented lighting model of ILSA correspond well with daily practice. The validation of the performance evaluation method showed that attendees did not initially agree on the proposed individual lighting variables. However, agreement was reached later in workshop when the evaluation method was validated using two complete cases of office lighting systems.

Conclusions and future projects - The workshops have proven to be a good source of feedback and an essential link to daily practice. Although the final ILSA-prototype has not been applied in real projects, we are convinced that a DDSS in which the developed lighting model and performance evaluation method are implemented can support architects in making decisions for the early design stage in the field of integrating daylight and artificial lighting.

The ILSA prototype shows that it is possible to implement the lighting model and evaluation method into a working prototype, but the area in which ILSA can be applied is still very limited. Only office environments that meet a certain brief can be evaluated in relation to certain reference concepts and the number of implemented lighting concepts is limited, as well. However, if necessary it is possible to add more lighting concepts to choose from and to select other reference concepts by adapting the implemented performance values.

In the future it is needed to test the prototype in real lighting design projects. Further, more DDSS’s should be developed to cover the whole building, involving other architectural scales, building systems, and performance indicators, than those that were considered in this design project.

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Chapter 1

INTRODUCTION

If somebody is commissioned to design something s/he is confronted with a 'wicked problem' that goes beyond reasonable or predictable limits. According to Gero (1998) building design in general meets the three main criteria of a wicked problem identified by Rittel and Webber (1973):

1. There is no definitive formulation of a wicked problem. The information needed to understand the problem depends upon one's ideas for solving it. Formulating a wicked problem *is* the problem.
2. Wicked problems have no stopping rule. Because solving the problem is identical to understanding it, there are no criteria for sufficient understanding and therefore completion.
3. Solutions to wicked problems are not true-or-false, but good-or-bad. Many parties may make (different) judgements about the quality of the solution.

Rittel and Webber argue that the system analysis approach of defining and analysing a problem, and then producing a solution, simply does not work. They argue that one of the most intractable problems is defining the problem. The aim of the project described in this thesis is to *design* a tool to support the building *design* process. In a way, that is addressing two wicked problems simultaneously: a *double* wicked problem.

The design process takes place in the design stage of the building life cycle. This is one of several stages that a building undergoes in its life cycle from the first day somebody starts asking himself or herself whether the world needs this building (Feasibility stage) until somebody else decides it is not needed anymore (Demolition stage, figure 1.1). This period can be as long as a few months, such as most of the buildings constructed for the world exhibition of the year 2000 in

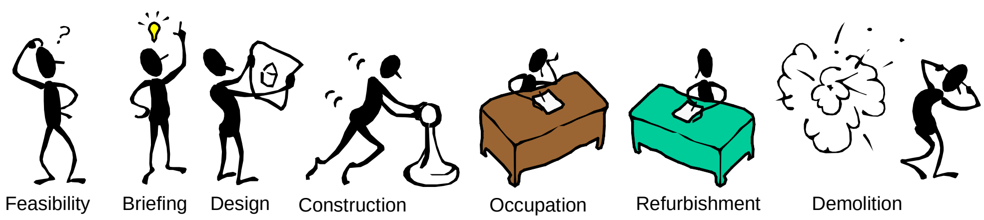


Figure 1.1: The stages in a building life cycle.

Hannover, to several thousands of years, as is the case with the pyramids in Egypt. These stages do not have to follow each other sequentially; in fact it would be better if the processes within, at least, the first three stages would be conducted iteratively, because it would improve the appropriateness of the decisions made in these stages.

The decisions made during the first three stages of the building life cycle, *Feasibility*, *Briefing*, and *Design,* are crucial; especially in these stages many important decisions are made with a potentially large impact on the final result in terms of building flexibility, efficiency and effectiveness. The decisions made by the project team during *Feasibility* cover the viability of the project. During *Briefing* the client expresses his or her demands and decisions are made to translate these into requirements for the building. During *Design* decisions are made to translate the requirements, laid down in *Briefing*, into solutions.

The stage *Design* can be subdivided further into: 'Conceptual design', 'Preliminary design', 'Final design', 'Specification', and 'Tender/ Award contract'. The design project described in this thesis focuses on decision making during the conceptual design stage. This is the stage in which the *Functional Brief* is translated into a *Schematic Design* and in which the objectives of the design are being weighed against each other. The reason for focussing at this stage is that in our opinion the need in this area is the largest, because the decisions in this stage cover conceptual design issues which often are directive and, at the same time, restrictive and irreversible, (Rutten and Trum 1998). The decisions are based on available information which may be incorrect, incomplete, (e.g. potential maintenance costs), or overly complex (e.g. code requirements), (De Groot et al 1999). This is one of the reasons that makes the design of a building a wicked problem. Therefore, it has been recognised that it is desirable to structure the available knowledge, and to develop a system to support designers in making decisions, either computer based or paper based. Nevertheless, it should be realised that doing this successfully does not solve the wicked problem; it only facilitates insightful communication among designers and therefore reduces the risks involved in the decisions made in the early stages of the building life cycle.

1.1 Design context

In this section the context of the design project is described. Firstly, the development time frame is considered, including a description of the preliminary system as established during a preliminary study: the TIE system. Further, the position of this project within Eindhoven University of Technology [TUE] is introduced. This has had a large influence in deciding for the final field of study and thus the outcome of the project. Finally, we elaborate further on the long-term project of which the design project has been part.

1.1.1 Time frame

The project described in this report builds on the experience achieved by developing the knowledge-based TIE-system (Thermal Indoor office Environments system). The design of this system is related to the graduate course OPB, (Ontwerp, Planning en Beheerstechnieken van Bouwen en de gebouwde omgeving = Design, Planning and Maintenance of Building and the Built Environment) of the Stan Ackermans Institute of Eindhoven University of Technology, (De Groot 1996) and (De Groot & Louwers 1996). The goal of the TIE-project was to determine whether it was possible to collect, structure and implement all of the relevant knowledge on thermal indoor environments of office rooms. The TIE-system predicts the thermal sensation of people in an office room easier and faster than by using traditional methods, and can be used to support decision making in the design and management of office building environments. This one-year project was followed by the three-year Ph.D. project, described in this thesis. After the decision was taken to focus on lighting systems, the main interest became visual comfort, and no longer thermal comfort.

1.1.2 Position within TUE

This design project is part of a larger research program within the Eindhoven University of Technology called the “Building Evaluation Project”. The Building Evaluation Project is supported by two sections of the faculty of Architecture: Building Physics (Indoor Climate program) and Design Systems (DDSS research program). Within the Building Physics section research is conducted on, among other things, heat and mass transfer, acoustics and lighting. Thus, the study must focus on one of these areas with only a limited consideration of the overall building domain.

The Design Systems section has experience with various programming languages and tools. One of these is the software development environment Delphi of the Borland Company. Therfore, Delphi was a practical choice for developing the prototype.

The design team consisted of the following people each contributing in their specific fields of expertise:

- Prof.ir. P.G.S. Rutten is promoter and supervisor of the design project.
- Prof.dr. H.J.P. Timmermans is second promoter and advisor in the field of Design & Decision Support Systems.
- Dr.ir. H.M.G.J. Trum is senior lecturer in the Building Physics section and advisor in the field of design methodology.
- Ir. R.H.M. van Zutphen is senior lecturer in the Design Systems section and advisor in the field of system development.
- Drs. L. Zonneveldt is lighting researcher and advisor in the field of integrating daylight and artificial lighting.

- Ir. A.J. Jessurun is programmer in the Design Systems section. He developed the component that visualises the performance values, set up the World-up virtual reality model of the office room to visualise the design decisions, and generally supported the programming of the tools.

- Ir. T.M.J. Raijmakers, acoustics consultant, made figures 2.2 and 2.3, and together with dr.ir. B. de Vries, senior lecturer in the Design Systems section, developed the input for the World-up model.

- S.M. Mallory-Hill, M.Arch., B.E.S. is a fellow research assistant also working in the Building Evaluation Project doing her own Ph.D. research on Case Based Design Assistants.

1.1.3 Position within Building Evaluation Project

The design project described here is one of two pilot projects of the long-term Building Evaluation Project. The hypotheses that is tested in this long-term project is, (De Groot et al 1999) and (Rutten and Trum 1998):

> *A smart, interactive, and easy-to-use computer system, that provides a way of viewing the potential consequences of design decisions of all participants involved in early design, will help them making decisions.*

During this long-term project the goal is to apply Information and Communication Technology [ICT] techniques to build a tool that:

1. Improves communication between members of a design team,
2. Improves knowledge transfer from research departments to building practice,
3. Improves knowledge transfer from the occupation stage to the design stage, and
4. Introduces a new approach for strategic performance based design and evaluation.

The first objective aims at addressing the problem that not all participants involved in early design are able to understand the impact of their design decisions; not only on their own design task in the following stages of the process, but also on other participants' field of work. For example, the architect wants to make the building look more transparent and therefore increases the window area in the façade. This may increase the cooling load in summer and thus the building service engineer should be contacted about this change in the design, because s/he may need to increase the capacity of the cooling system. If this impact is estimated well and the communication is done properly there may not be a problem. If not, this small change early in the building life cycle can cause much work later, when the building is constructed and something must be done to decrease the temperatures in summer. Then building elements, for example sun shading devices, must be added or modified at high costs.

The second objective must address the problem that people working in the building industry do not know about the newest innovations found at research departments of universities, research institutes, and suppliers of building materials, elements or systems. The building design team has no easy access to this new information that may help them making decisions.

The third objective recognises the fact that sometimes the same mistake is being made over and over again, because the building design team does not realise that a particular solution is not working well enough in practice. In (Hill 1997) a reference is made to the traditional procurement model and the same model with feedback cycles as was introduced by Nelson in 1996. This model is shown in figure 1.2 and describes an ideal situation, which unfortunately does not exist in reality: the feedback loop that transfers knowledge acquired during Post Occupancy Evaluations [POE] often is missing. Many designers do not know how their design solutions are appreciated in use. This objective is not considered during by this particular design project, but in the other pilot project.

The fourth objective is special for this Building Evaluation Project. In the new approach for strategic performance based design and evaluation future use of the building is in focus. The goal is to design for adaptability of the building. The approach will be introduced in section 2.1 as part of the method to structure design knowledge and information in a three-dimensional model. The knowledge domain of the design projects has been positioned within this 3D-model.

In relation to the use of ICT in building science, Oxman (1995) writes that in the past decade building design has become one of the sub-fields of artificial

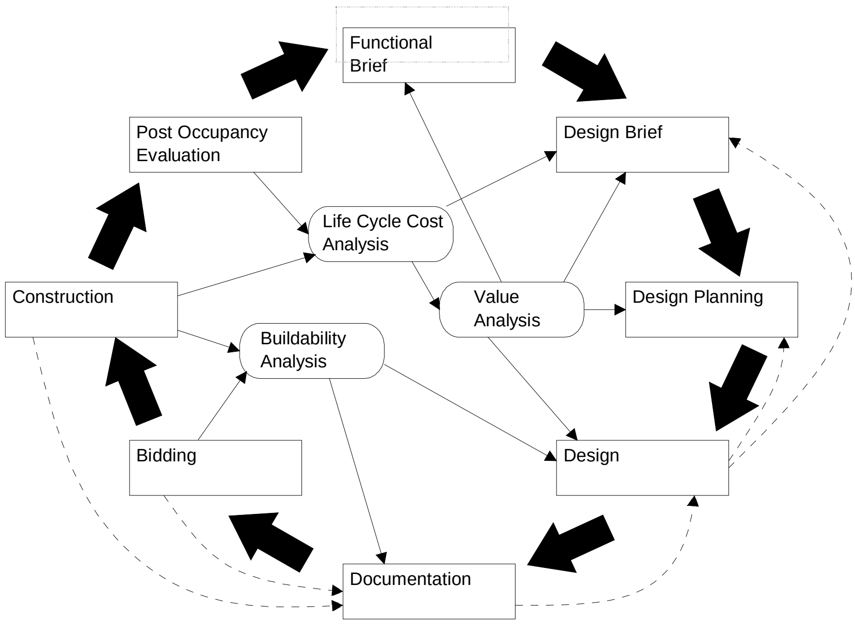


Figure 1.2: Traditional Procurement model with Feedback Cycles (Nelson 1996).

intelligence. It is obvious that ICT has provided a wide variety of tools and systems, which support the decision-making process. Nevertheless, in the field of building industry they are still very rarely used. According to Timmermans (1993) this is partly the result of its idiosyncrasies, but also because their proponents merely seek to replace well understood and perfectly acceptable practices or media with new computer technologies which are not necessarily providing better quality or greater flexibility. Nevertheless, the ability to use ICT is vastly enhanced by the application of fourth-generation languages (4GLs). Because at the same time computers became more powerful, it has been possible to write instructions in a more programmer friendly manner, (although this is at the same time less computer efficient). 4GLs make it very easy for people to use computers and to develop software.

1.2 Design task

1.2.1 Goal and objectives

In the beginning of the project reported in this thesis, the goal was defined as *to develop a Design Decision Support System [DDSS] that will assist designers in the early stages of design*. Early in the project it became clear that a choice had to be made between either researching the total building domain and developing a model on paper, or researching a small part of the total building domain and developing a prototype computer system for this small part. The second option has been chosen for this project, because it provides the possibility to combine this project with the EIKS project, a project sponsored by the European Committee that aimed at developing an Energy Impact Knowledge-based System (further described in section 2.3.1 and chapter 4, *Design of the DDSS; EIKS*). The objective of the EIKS project, and thus also initially of this project, was that all energy-related aspects relevant for commercial buildings in Europe needed to be considered throughout the whole building life cycle.

This design project has been one of two pilot projects of the Building Evaluation Project, introduced in section 1.1.3. Therefore, the goal of the project must fit within the framework and objectives of both EIKS and the Building Evaluation Project.

Therefore, the goal of the design project has been initially to apply ICT-techniques in order to:

> *Design an interactive computer-based system to help building designers use data on energy efficiency and an integrated building model to address the problem of designing a building as energy efficient as possible.*

During the EIKS project, the consortium concluded that a smaller part of the total building design domain should be taken into account. Therefore, it was decided to focus on the integration of daylight and artificial lighting in office buildings:

> *Design an interactive computer-based system to help building designers use data on energy efficient use of daylight and artificial lighting and an integrated lighting system model to address the problem of selecting office lighting concepts.*

The design of this tool was continued after the conclusion of the EIKS project and later became ILSA: Integrated Lighting System Assistant. Because of this change of focus, interference between aspects, such as the impact of lighting on the cooling load, would be lost. Nevertheless, it is hypothesised that when the methodology is valid for this small part, it may be applicable for other parts as well.

1.2.2 State of the art

Several research groups are also developing tools for the early stages of the building design process. Only the few groups that also focus on energy related issues will be discussed and evaluated here.

One of these groups is Lawrence Berkeley National Laboratory. Their most interesting projects are called ‘Building Design Advisor’ [BDA] and ‘Energy 10’. Another group is Carnegie Mellon University, whose most interesting project is ‘SEMPER’, and a mutual project with University of Adelaide is called ‘SEED’.

BDA (Lawrence Berkeley National Laboratory) - According to (LBNL 1999), (Papamichael et al. 1998), and (Papamichael, LaPorta & Chauvet 1997), the Building Design Advisor (BDA) is a software environment that supports the integrated use of multiple analysis and visualisation tools throughout the building design process, from the initial, schematic design stages to the detailed specification of building components and systems. BDA uses an object-oriented representation of the building and its context, and acts as a data and process controller to allow designers to benefit from the capabilities of multiple tools.

While BDA is still under development, so far two simulation tools, originally developed for the detailed design stage, are linked to the BDA: an energy estimation tool and a daylight simulation tool. The Graphical User Interface [GUI] of BDA consists of two elements: the Decision Desktop and the Building Browser. The Decision Desktop provides any of the input and output parameters addressed by the simulation tools linked to BDA for each alternative design solution under consideration by the designer. The Building Browser allows BDA users to navigate through the building representation and view the objects and parameters, along with their values.

Energy 10 (Lawrence Berkeley National Laboratory) - At the National Renewable Energy Laboratory of Lawrence Berkeley Laboratory ‘Energy 10’ has been developed. According to (NREL 1997), this is a design tool for Low-Energy Buildings. It is intended to assist architects, engineers, consultants, students, and energy specialists design buildings that integrate day lighting, passive solar heating, and low-energy cooling strategies with energy-efficient shell design and mechanical equipment. The program focuses on special features that facilitate the making of key decisions that effect energy performance early in the design process.

SEMPER (Carnegie Mellon University) - According to (SEMPER 1997) and (Mahdavi et al. 1997), "SEMPER" is an active multi-aspect computational tool integrating building performance simulation (energy analysis, thermal comfort, air-flow modelling), in computer-aided architectural design environments. It incorporates an object-oriented, space-based shared building representation, with dynamic links to different building performance evaluation applications. The performance simulation modules in SEMPER employ detailed techniques and algorithms consistently across various stages of the design process. It incorporates a CAD tool that allows for the semantic modelling of building elements, such that the building data and representations needed for the simulation modules can be automatically derived from the CAD tool. SEMPER provides active design support within selected simulation modules. The energy analysis provides the designer with energy loads and spatial temperature profiles. Modules for lighting, acoustics, and life-cycle assessment are under development.

SEED (University of Adelaide, Carnegie Mellon University) - SEED (Software Environment to support Early stages in building Design) aims at providing computational support for the early stages in building design in all aspects that can benefit from such support, (SEED 1997). It intends to encourage an exploratory mode of design by making it easy for designers to generate and evaluate alternative design concepts and versions. The objective is to develop an object database that allows designers to store and retrieve different design versions, alternatives and designs that can be reused and adapted in different contexts (case-based design).

Evaluation - The tools considered above are evaluated in respect of three criteria: 'User friendliness', 'Applicability for the conceptual design', and 'Level of decision support'. The results are summarised in table 1.1.

Table 1.1: Results of evaluation of tools to support early energy design, (++: very good, +: good, 0: neutral, -:bad, --: very bad).

Criteria	**BDA**	**Energy 10**	**SEMPER**	**SEED**
User friendliness	-	-	+	++
Conceptual design	+	-	-	+
Decision support	+	+	+	--

To be able to use BDA in the conceptual design stage, many default parameters are set. The user may change these parameters, but it would be an enormous task to find the matching defaults for each specific building design, especially because American defaults and units are implemented. Further, entering the geometrical data currently is complicated.

The user interface of Energy 10 has been designed for engineers and may not appeal to architects. This tool may be of use in the early schematic design stage, but not for the conceptual design stage. Many details are required to perform an accurate estimation of the interactions between acoustics, lighting and temperature.

SEMPER is an interesting tool although it is not developed to support the conceptual design. Evaluation on almost all physical aspects of building will be possible in the future, but again many details are needed. The user interface is CAD oriented, which makes it user friendly, because users are familiar with this environment.

SEED acts as a web browser and will be useful in education and for generating ideas, but it is too general to support decisions in the conceptual design stage.

Summary - The tools described above either rely on detailed information that might be available in the final design stage, but not yet in the conceptual design stage, or are too general to support the decisions in this particular stage.

For the design project described here we choose not to use tools or calculation methods that are supposed to support detailed design, as some of the other research groups did. They used defaults on places where otherwise detailed information would go. In this way the results of the calculations cannot be accurate, although these results might be useful if two or more alternative solutions are compared. Another reason not to use these detailed calculation procedures is that often much of the user's time is required, both for entering the parameters (even if defaults are used) as for calculating the results, which often is precious in this stage.

1.3 Outline of the thesis

In the two previous sections the *Design Context* and the *Design Task* are described. These provide the environment in which the project is executed and the goal and objectives of the project. The following six chapters describe the design process, that has led to the design of the Design Decision Support System prototype ILSA, and results and conclusions that were acquired during the process.

The *Design Problem* described in chapter 2 begins with a brief description of the new three-dimensional model to structure design knowledge and information developed at TUE. Within this model the knowledge domain of the design task has been projected. Also, an overview is given of similar tools in the field of lighting system design and this chapter ends with the planned design trajectory, as well as the followed design trajectory.

The first task within a design project is to identify the user requirements, the functions of the design to be developed, and the structure of the design. These are provided in chapter 3, *Structure of the Design.*

Because this project involved two types of designs, two design structures are discussed:

- The *Design Decision Support System*, consisting of four components: Data Management, Knowledge Management, Models for Analysis, and User Interface.
- *Office Lighting Systems*, consisting of three sub-systems: Daylight, Artificial Lighting, and Controls. In this part the developed lighting model is described, as well as the performance evaluation method implemented in the DDSS.

The first design process is described in chapter 4, *Design of the DDSS: EIKS*. This chapter covers the first half of this three-year project when the tasks were related to the *EIKS* project. The results of the two workshops that were organised are reported and a description of the developed demonstration software tool is given.

The second design process is described in chapter 5, *Design of Office Lighting Systems*. This chapter covers the second half of the design project, in which a new lighting model and performance evaluation method were developed. The model was validated with lighting experts during interviews. The revised lighting model and the newly developed evaluation method were implemented into the new *ILSA* prototype and validated in a third, and final, workshop.

In chapter 6, *DDSS for Office Lighting: ILSA*, the results of the two previous chapters are integrated. The functions and user interface of the *Integrated Lighting System Assistant* are described.

The final chapter, chapter 7, *Conclusions and Recommendations* summarises the conclusions and provides recommendations for future design and research projects. The design process is evaluated and some possible future developments are indicated.

Chapter 2

DESIGN PROBLEM

This chapter consists of a brief description of the new approach for strategic performance based design and evaluation as a method to structure design knowledge and information. Using this method the knowledge domain of the design project is visualised. An overview is given of similar tools in the field of lighting system design. Finally, the design trajectory that was planned is described, as well as the followed design trajectory.

2.1 Structuring design knowledge and information: 3D model

To deal with the complexity and to structure the knowledge and information relevant to a particular building stage a three-dimensional model has been developed at TUE. This 3D model captures the relevant knowledge and information of the whole research field of building science, and therefore can be seen as a 'total building design domain', see figure 2.1. This 3D model has not been a subject of the design project. The 3D model has been applied as a communication tool within the Building Evaluation Project and as a tool to position the knowledge domain of the design task. In relation to this, a brief description of this 3D model is given below, while an elaborate description can be found in (Hill 1997) and (Mallory-Hill 2000).

Within the 3D model three different *levels* are projected along the axes:

Scale-axis	projects five architectural system levels that will be explained in section 2.1.1.
Demand-axis	projects six human system levels that will be explained in section 2.1.2.
Supply-axis	projects six building system levels that will be explained in section 2.1.3.

Projecting these three levels in this manner provides 180 cubes, each representing a sub domain within the total building domain. This provides the possibility to point out the field of study for each research or design project executed at TUE or elsewhere. The cubes can be subdivided further if necessary or desirable. This will be done in section 2.1.4 for the design project.

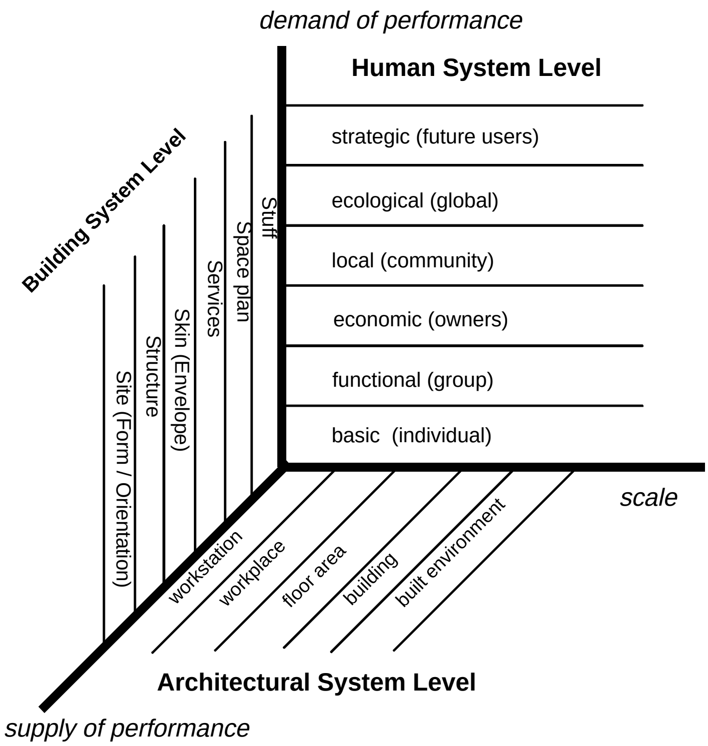


Figure 2.1: 3D model for the total building domain, (Hill 1997).

2.1.1 Architectural system levels

During the design of each building, decisions are being made on different architectural levels: the Architectural System Levels, [ASL's]. ASL's reflect the architectural scales that increase from the workstation level (micro), through workplace, floor area, and building scale to the built environment (macro). Figure 2.2 shows the five relevant architectural levels.

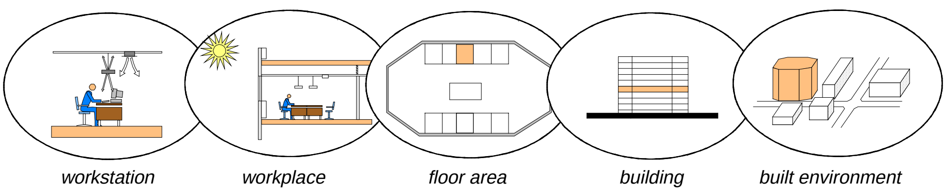


Figure 2.2: Architectural system levels.

2.1.2 Human system levels

All different users of a building, stakeholders so to say, have different interests, demands and expectations towards the building. Rutten (1996) and Hill (1997) have introduced a new approach of looking at the demand of building performances. Six Human System Levels, [HSL's] have been distinguished and visualised in figure 2.3: *Basic value* (Individual), *Functional value* (Organisation), *Local value* (Community), *Ecological value* (Environment), *Strategic value* (Future user), and *Economic value* (Owner). These HSL's can be subdivided in performance indices, each having a performance value. This value gives, in a way, a measure of extent to which the supply of performance meets the demand.

The individual who occupies the building demands basic values, such as shelter, protection, and comfort. The organisation, of which employees occupy the building, demands support for production, manageability and maintainability. The community demands it to fit within the built environment aesthetically. The environment demands low energy use and low emissions. The future user demands the building to be easy to change. Finally, the owner demands low initial and operating costs.

This HSL-model has been applied successfully in a graduation study by Jacobs, see (Jacobs et al. 1999) and during the design stage of the new office building for the Océ-company in Venlo, see (Océ 1999).

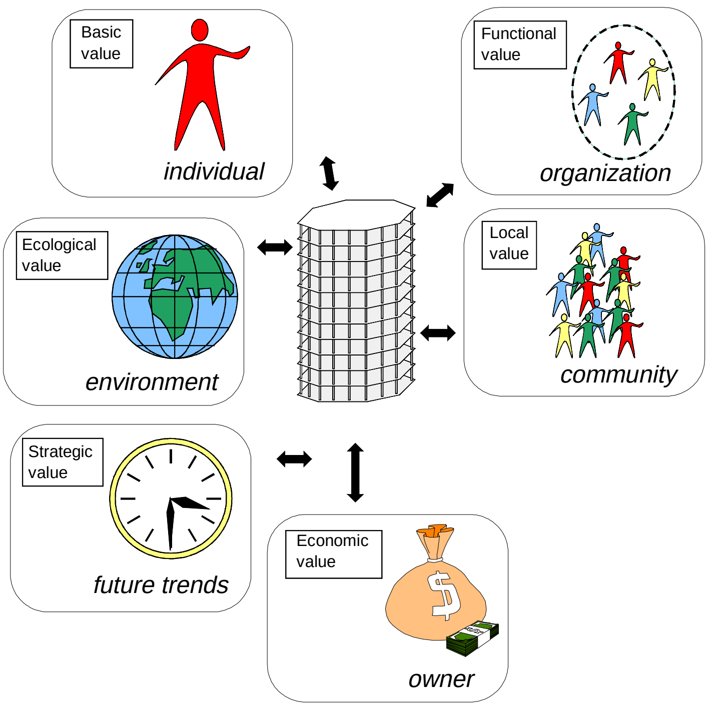


Figure 2.3: Human system levels, (Hill 1997).

2.1.3 Building systems levels

At each ASL different building system levels are important: the Building System Levels, [BSL's]. These BSL's supply the performance with which the demands of the users can be met. A building can be divided into sub-system concepts. Hill (1997) categorises these different systems based on Brand's "six S's" model (Brand 1994). In this model Brand represents the various layers of the building in terms of how often they are changed: *Stuff* (furniture and equipment), *Space plan* (lay out of the floor plan), *Services* (HVAC-systems, lighting systems, etc.), *Skin* (façade), *Structure* (construction), and *Site* (form and orientation of the building).

Each of these BSL's can be subdivided into smaller systems. For example the BSL 'Services' contains the Heating Ventilation and Air Conditioning [HVAC] system, the Artificial lighting system, the Control system, the Domestic water system, and the Elevators and escalators. One part of the BSL 'Skin' consists of the façade systems, including the Daylight system (fenestration system, sun shading system, and all elements added to redirect the sunlight) and the Non transparent system (Brick wall or other kind of outside wall material). The other part of 'Skin' may comprise the roof system and the foundation system.

2.1.4 Design project's knowledge domain

Within this 3D model we have visualised the knowledge domain for this design project in figure 2.4.

- *One ASL*: Workplace, (for only one building type: an office building). As the project is executed in the Indoor Climate Group of the Building Physics Section within the faculty of Architecture, the main interest is focused towards this ASL. Most physical indoor climate aspects, such as lighting, acoustics, air temperature, and air quality play major roles at this level.

- *Three building sub-systems*: Daylight system (as part of the BSL Skin), Artificial lighting system (as part of the BSL Services), and Control system (as part of the BSL Services). Due to time constraints and availability of expert knowledge, the above mentioned building systems were considered instead of all energy related building systems.

- *Five performance indices*: Energy efficiency (as part of the HSL Ecological value), Visual comfort (as part of the HSL basic value), Initial costs and Operating costs (as part of the HSL Economic value), and Flexibility (as part of the HSL Strategic value). Energy efficiency has been in focus all along the design project. After it was decided to continue the project focusing on Daylight and Artificial lighting, the four other performance indices were added. These were considered most relevant for these particular building-systems.

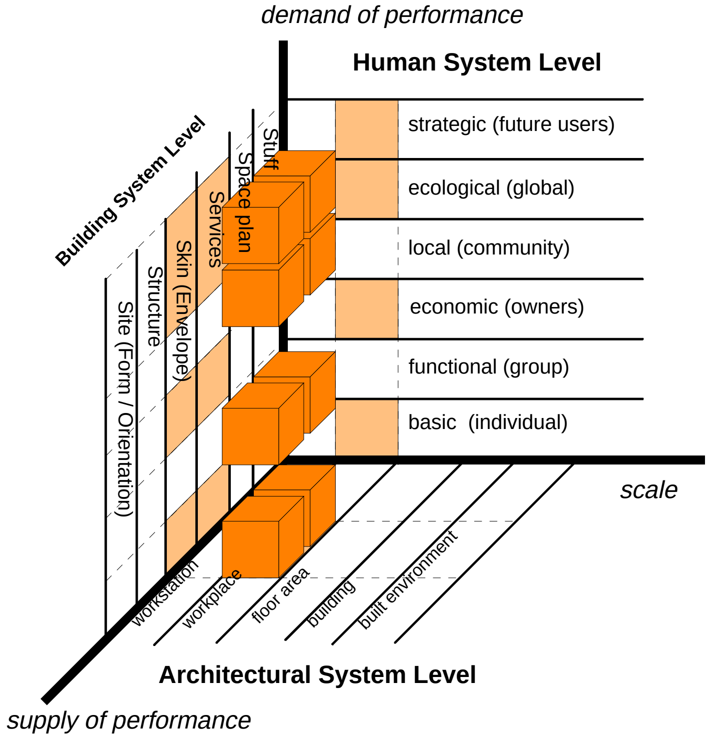


Figure 2.4: Design task, after (Hill 1997).

2.2 Examples of tools related to lighting

In literature several computer tools are described that have been developed to support building designers in making decisions on lighting. The most interesting tools are described below.

2.2.1 Leso-DIAL - Labatoire d'Energie Solaire

In Lausanne at the Laboratoire d'Énergie Solaire et de Physique du Bâtiment [LESO-PB; Solar Energy and Building Physics Lab] Leso-DIAL is under development, (Paule et al. 1998). Their aim is to give the architect relevant information regarding the use of daylight, at the very first stage of the design process. They try to simultaneously provide help at the beginning of the design process, handle concrete objects, and improve the architects' knowledge.

2.2.2 Office Environment Designer - Building Research Establishment

According to (OED 1997) the Office Environment Designer [OED] enables architects and building engineers to design naturally ventilated offices that optimise the use of daylight without overheating or requiring the use of cooling. This tool predicts maximum and average temperatures in summer, and estimates daylight penetration to allow optimisation of glazing. Simple data entry routines are provided for specifying office and glazing types.

2.2.3 Manufacturer's guides: CALCULUX

As an example of manufacturer's guides the Philips-tool CALCULUX, (Philips 1993), has been studied. CALCULUX has been developed at the Philips Lighting Design and Application Centre [LiDAC] and is a lighting design program for personal computers. It consists of three lighting design programs: Indoor, Area and Road, and a luminaire database management program. The package is intended for use by lighting engineers to carry out simple artificial lighting design calculations. The Indoor-program calculates the light distribution based on the reflection factors, the specific (Philips) luminaires and light sources that are applied, and the room dimensions.

2.2.4 Simulation tools: Adeline

Radiance, (Radiance 1999), and Superlite, (Superlite 1996), both developed and freely distributed by Lawrence Berkeley National Laboratory, are excellent tools to simulate daylight and artificial lighting situations. Radiance uses ray-tracing techniques and provides photo-realistic pictures of the building model, illuminance levels, daylight factors and visual comfort calculations. Superlite delivers illuminance and daylight factor distributions on work surfaces, but has no luminance visualisation possibility. Before, it was very cumbersome to model a building in these programs, but this disadvantage has been overcome with the new version of Adeline's graphical user interface, (Erhorn et al 1998) and (Adeline 1996).

2.2.5 Evaluation of the tools related to lighting

The tools considered above are evaluated on five criteria: 'User friendliness', 'Applicability for the conceptual design', 'Level of decision support', 'Possibility to evaluate daylight systems', and 'Possibility to evaluate artificial lighting systems'. In table 2.1 the results of the evaluation of the described tools are summarised.

The BDA, described in section 1.2.2 is added with the results for the first three criteria from table 1.1. This tool also contains a daylight estimation tool, but is does not include sun shading devices, nor artificial lighting variables.

Leso-DIAL does not take artificial lighting into account, but covers all relevant daylight aspects from activities in the room to reflection factors of the surfaces, from window size to size of the light shelves. The interface is user-friendly: appealing graphics of the room to be designed with the possibility to change all dimensions easily.

Table 2.1: Results of evaluation of lighting tools, (++: very good, +: good, 0: neutral, -:bad, --: very bad, √: available).

Criteria	BDA	Leso-DIAL	OED	CALCULUX	Adeline
User friendly	-	++	+	0	+
Conceptual design	+	+	+	0	-
Decision support	+	++	+	--	--
Daylight	√	√	√		√
Artificial lighting				√	√

The user of OED is only required to enter the main design parameters for the office, the building and the windows. It is easy to adapt the design to achieve a specified performance. This tool supports conceptual design. It requires just enough input to be useful in this stage. Unfortunately, artificial lighting aspects are not taken into account. Further, it just provides the outcomes of calculations, with an indication on whether the outcomes are good or bad, but it does not tell how to improve the performance.

CALCULUX provides fast and accurate estimates of artificial lighting distribution for any rectangular shaped room. The exact type of luminaire must be selected, which makes it not very appealing for the conceptual design stage. Further, daylight aspects are not taken into account.

With Adeline it is possible to simulate daylight and artificial lighting situations, but detailed information on the design, some engineering skills, and much time is needed, and no decision support is given. Nevertheless, it can be useful to use these kinds of tools to simulate several typical situations and gather the results for example in a ‘handbook’.

2.2.6 Summary tools related to lighting

Very often tools that are developed for the detailed design stage are used in the conceptual design stage. This is also the method LBNL is using in their BDA. The simulation tools available in their institute are linked to the conceptual design tool by entering defaults on the places where detailed information is required. This provides a method to compare alternative solutions, although the numerical outcomes might not be realistic.

The tool to be designed will not use this approach. Human lighting experts, rather than simulation tools, will be the knowledge sources. This choice has been made because to our knowledge no performance estimation methods exist for the conceptual design stage of lighting systems. Especially the performance indices related to 'comfort' must be determined by human experts. Based on their experience they can predict the performance of conceptual design solutions.

2.3 Design trajectory

The planned design trajectory is determined in relation to the one-year Energy Impact Knowledge-based System [EIKS] project executed in 1997 and its follow-up project, EIKS (II), supposedly starting in the beginning of 1998. Figure 2.5 shows the planned and followed design trajectory. The numbers in the last column refer to the steps within the design itself as shown in figure 2.6 and explained further in section 2.3.3.

2.3.1 EIKS project

The Energy Impact Knowledge-based System [EIKS] project is funded by the Thermie-B programme of the European Union and is executed in a consortium consisting of eight research and construction companies from four different European countries: BRE and Haden, from United Kingdom, CSIC, from Spain, Villa Real, from Finland, and Tebodin, HBM, TNO Building and Construction and TUE from the Netherlands.

The objectives pursued by the Thermie programme are (Thermie 1997):

- to improve energy efficiency, in both demand and supply sectors;
- to promote a wider utilisation of renewable energy sources;
- to encourage a cleaner use of coal and other solid fuels;
- to optimise the exploitation of the EU's oil and gas resources.

EIKS meets the first objective; it has been directed towards overcoming some of the difficulties experienced by the design team in ensuring that the most effective use of energy is made throughout the life cycle of the building, (EIKS 1998).

Problem definition for the EIKS project - Two problems are recognised (EIKS 1998):

- *Lack of Communication.* It is believed that there is poor communication in respect of life cycle energy consumption between the members of the professional team during the design of the building. Because of that, the decisions made during the design process rarely result in the most effective building in relation to life cycle energy consumption and building cost.

- *Poor Knowledge Transfer.* There is much information available concerning energy related matters in research institutes, universities and the building industry. The transfer of this knowledge to and between the members of the design team is both poor and slow. This may be true for knowledge transfer between research and industry in general.

<table>
<tr><th>Planned design trajectory</th><th>Period</th><th colspan="2">Followed design trajectory, §2.3.3.</th></tr>
<tr><td>Investigate problem domain.</td><td>Nov-Dec 96</td><td colspan="2">Investigate problem domain.</td></tr>
<tr><td rowspan="7">EIKS project, §2.3.1.</td><td>Jan-Feb 97</td><td colspan="2">Propose requirements for tool to be developed: #1.</td></tr>
<tr><td>Mar-Apr 97</td><td colspan="2" rowspan="2">Organise the first Dutch workshops to validate requirements with future users: #2.</td></tr>
<tr><td>May-Jun 97</td></tr>
<tr><td>Jul-Aug 97</td><td colspan="2" rowspan="2">Develop demo DSS, EIKS, based on the validated requirements and get feedback during the second Dutch workshop (#3, #4, #5).</td></tr>
<tr><td>Sep-Oct 97</td></tr>
<tr><td>Nov-Dec 97</td><td colspan="2">Report on EIKS project.</td></tr>
<tr><td rowspan="9">EIKS (II) project, proposal rejected, §2.3.2.</td><td>Jan-Feb 98</td><td colspan="2" rowspan="4">Redevelop knowledge model and evaluation algorithm based on outcomes of second workshop: #6.</td></tr>
<tr><td>Mar-Apr 98</td></tr>
<tr><td>May-Jun 98</td></tr>
<tr><td>Jul-Aug 98</td></tr>
<tr><td>Sep-Oct 98</td><td colspan="2">Compare project fundaments with other design team at LBNL during study stay.</td></tr>
<tr><td>Nov-Dec 98</td><td colspan="2" rowspan="2">Validate redeveloped knowledge model with six lighting experts during interviews: #7.</td></tr>
<tr><td>Jan-Feb 99</td></tr>
<tr><td>Mar-Apr 99</td><td colspan="2">Redesign prototype, ILSA, (#8, #9).</td></tr>
<tr><td rowspan="3">Reporting on total project.</td><td>May-Jun 99</td><td rowspan="3">Reporting on total project.</td><td>Organise final workshop to get feedback on used evaluation method: #10.</td></tr>
<tr><td>Jul-Aug 99</td><td rowspan="2"></td></tr>
<tr><td>Sep-Oct 99</td></tr>
</table>

Figure 2.5: Planned and followed design trajectory, (# refer to figure 2.6).

Objective for the EIKS project - Develop a decision support and information system that can be used by all members of the team and that can alert the user to the impact of his design decisions. Such a system may be a part of a Knowledge Based System (KBS). A KBS is a computer program in which knowledge is contained explicitly and which also has an inference mechanism to use this knowledge in solving problems. Not only can a KBS significantly contribute in improving the communication between the members of a design team, it can also utilise the energy related knowledge from universities and other research institutes.

Planned Activities for the EIKS project - The steps involved in developing such a computer tool include:

- *Defining the building life cycle.* This will be diagrammatic in form and show the life cycle of a building from the initial conception to the time it is demolished and parts are removed for recycling.
- *Determining those topics having an important impact on the overall energy efficiency in buildings.* Clearly there are many operations that could affect the

energy efficiency of the building from inception to demolition.

- *Organising workshops.* The participation in workshops of those involved in the building process, to establish the barriers that prevent effective communication and knowledge transfer in relation to energy.
- *Developing a Knowledge Based System.* To identify and use the knowledge obtained above to structure a prototype KBS and to test the system in a workshop comprising all members of a building design team.

The fourth activity and the organisation of the Dutch workshops for the third activity were tasks executed as part of the design project. Other consortium members executed the two first mentioned activities, and organised the workshops in the three other European countries.

2.3.2 EIKS (II) project

Originally, the follow up project for EIKS should have been entered in the Thermie-A demonstration programme closing January 30, 1998. This programme supports demonstration-projects implementing innovative energy technologies (Thermie 1997). The objective was to use the tool developed during EIKS in this follow-up project, but in October 1997 the consortium realised that this has been an unrealistic objective and postponed this action until later notice.

Instead a proposal has been entered in Theme 2 of the European Strategic Programme for Research and development in Information Technology (Esprit 1999), called “Decision support system for conceptual building design”, (DECISION 1997). This three-year project was aiming at developing several prototype decision support systems and included further development of the EIKS demo. Unfortunately, this proposal has not been approved. The project should have been started in September 1998, and therefore no involvement with the design project was accounted for. It was decided to continue the design project within the TUE, outside any consortium. In March 1998 a definition report, (De Groot 1998), was presented that contained this independent planning, which has been followed accordingly since then.

2.3.3 Followed design trajectory

The followed design trajectory is shown in figure 2.5. The design project started with investigating the project domain in preparation to the EIKS project, the following year. During the EIKS project the basis for the design is laid down. The results of the several actions within the EIKS project are summarised in chapter 4, *Design of the DDSS: EIKS*, of this thesis. Results of the continuation after the EIKS project are described in chapter 5, *Design of Office Lighting Systems*, and chapter 6, *DDSS for Office Lighting: ILSA*.

Figure 2.6 shows the specific actions involved in the design of the tool. The first five actions relate to the EIKS project. The last five actions were executed to develop ILSA. The design process has been iterative. Within the process a loop can be recognised containing three steps: Definition, Development, and Validation.

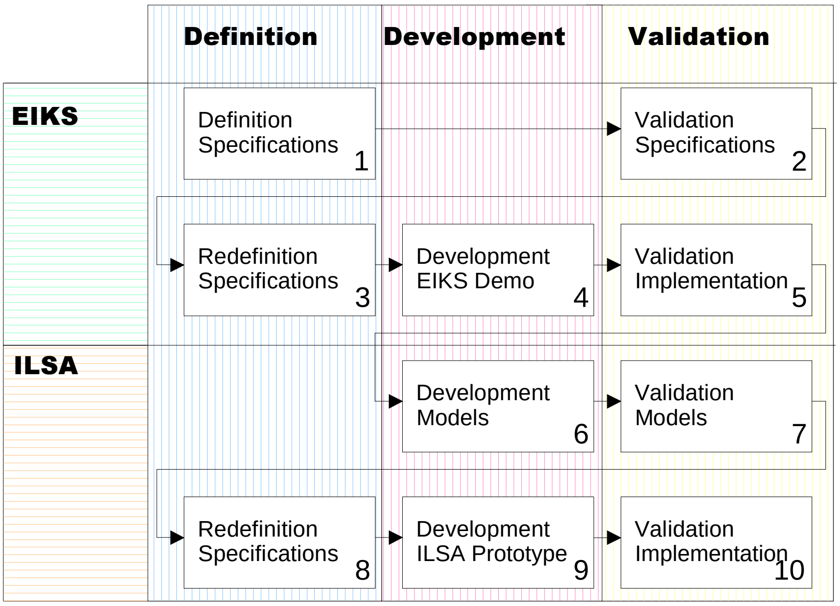


Figure 2.6: Specific actions involved in the design of the tool.

Together with the EIKS consortium specifications for the tool have been defined (action 1) and validated with building experts working in practice through workshops (action 2). Organisation of the two Dutch workshop sessions has been part of the design project, as well as the development of a demo software program (action 4). Before, the specifications were redefined in the consortium (action 3) according to the results of all European workshops, and it was decided to focus on integrated lighting systems; an energy efficient combination of daylight and artificial lighting. In follow-up workshops in all four involved countries, the EIKS demo has been presented to some of the same building experts that also came to the first workshop sessions (action 5). The scripts for this follow-up workshop and for the demonstration of the tool were developed as part of the design project. This completed the contribution to the EIKS project, (EIKS 1998).

After the conclusion of the EIKS project time has been allocated to study the underlying models of the EIKS demo, because during the EIKS project the development of the models has had no high priority. A revised integrated lighting design model and a performance evaluation method were developed together with a lighting expert (action 6). The model has been validated with four other lighting experts and one architect (action 7). Before implementation in the new prototype tool: Integrated Lighting System Assistant [ILSA], the specifications for the tool were redefined again (action 8). During the development of ILSA (action 9) building a Decision Support System [DSS], and not longer a Knowledge-Based System [KBS] has been pursued, because it was recognised that the members of the design team during the EIKS workshops preferred a DSS rather than a KBS. The main difference between these two systems is that a DSS *supports* and a KBS *replaces* (parts of) the decision making process. In chapter 3, *Structure of the*

Design, these differences are described more circumstantially. In the last validation action (action 10) ILSA has been presented to a group of thirteen, mainly, lighting experts to validate the implemented lighting model and evaluation method.

Within this design trajectory the Iterative Application Design [IAD]-approach of Cap Volmac, (Tolido 1996) can be recognised. The ‘I’ in this abbreviation may have three meanings:

Interactive - together with the user – we have had three workshops with possible future users in which we have got feedback on the design.
Iterative - developing in several loops – four loops can be identified if figure 2.6.
Incremental - developing in small steps, to increase the usability step by step – during the development first the overall layout was developed after which each small piece was filled in.

Chapter 3

STRUCTURE OF THE DESIGN

In chapter 1, *Introduction*, a design problem has been identified as a wicked problem. Consequently, the specific design problem described in this thesis has been recognised as addressing a double wicked problem, because it contains two design problems: the design of a tool and the design of (a part of) a building. In chapter 2, *Design Problem*, the tool and the part of the building to be considered were specified: the tool will be a decision support system and the part of the building will be office lighting systems.

This implies that we must consider two sets of user requirements and desired functions, and two sets of design components/ variables, as well. At the same time, the relation between the two designs must be considered, while the one comprises the other. The user requirements, functions, and structure of the design of the tool will be described in the first section of this chapter, section 3.1, *Design Decision Support System*, and those of the design of office lighting systems will be described in section 3.2, *Office Lighting Systems*.

3.1 Design Decision Support System

3.1.1 Introduction to Decision Support Systems

At first the design project was aiming at the development of a Knowledge Based System [KBS]. This would have been the follow up to the TIE-system, described in section 1.1.1, that was developed during the design course prior to the design project reported in this thesis. It would meet the objectives of the EIKS project described briefly in section 2.3.1. In literature various definitions of KBS's are found, e.g. (Kwee 1987), (Mars 1991), (Wognum et al. 1993), and (Lucardie 1994), but all resemble more or less the following definition:

> *KBS's are computer programs in which knowledge is contained explicitly and which also have a mechanism to apply this knowledge in solving problems.*

A KBS that gives answers in one specific area as well as human experts would, is called an artificially intelligent system, or an expert system. A computer program can be artificially intelligent in two different ways. Firstly, the computer program simulates human intelligent behaviour ⇒ artificially intelligent process. Secondly, the computer program provides the same results as those that can be reached using human intelligence ⇒ artificially intelligent product. According to (Olson and Courtney 1992) an expert system is used for repetitive tasks, and therefore could replace human judgement (for well-defined, specific applications).

By means of workshops, organised early in the project it became clear that architects, and other designers involved in the early design stages of buildings, have no desire for this kind of tool. In respect of addressing wicked problems, they want to be supported rather than replaced, and so the focus of the project was redirected towards Design Decision Support System [DDSS]. Moreover, it is believed that it is almost impossible to capture the creativity involved in the conceptual design stage into an artificially intelligent computer system, because of its wicked character. This belief has been recognised by (Roozenburg & Eekels 1998), and (Weggeman 1997). DSS's are meant to support rather than to replace human judgement, by providing computerised tools to aid human learning. Unlike expert systems, DSS's are applied to cope with unstructured problems involving specific decisions. Therefore, DSS's are able to respond to changes in problem formulations, requirements, and functions.

DSS's were proposed in the early 1970s as assist managers in semi-structured tasks, with the intent of supporting rather than replacing managerial judgement, (Olson & Courtney 1992). Olson and Courtney use the following definition:

> *DSS's are interactive computer-based systems to help decision-makers use data and models to solve unstructured problems.*

In our opinion unstructured problems in this definition can be interpreted as being wicked problems, and thus we have used this definition to specify our design goal in section 1.2.1. 'Decision-makers' has been replaced by 'building designers', 'data' is specified as being 'data on energy efficient use of daylight and artificial lighting' and 'models' as 'an integrated lighting system model', and 'to solve unstructured problems' is 'to address the problem of selecting office lighting concepts'.

Bidgoli (1989) describes that a DSS has appeared in a variety of disciplines, which can be categorised under the following major functions:

What-if analysis — All the preferences of the variables are set and the result is determined. One of the variables can be changed to illustrate the effect of this change on the result determined before.

Goal seeking — The reverse of what-if analysis. The goal is set and then the necessary changes are returned to the user. For example, the user asks for the most energy efficient solution and the DSS specifies the solution that meets this goal.

Sensitivity analysis — The impact of a variable on the result is illustrated. It enables the user to perform optimisation analyses

	applying different variables. For example, the most inexpensive solution can be found that is still energy efficient.
Exception reporting	The performance of variables that are outside a predefined range are monitored. For example, all the variables that do not meet one of the requirements can be found.

The DDSS described in this thesis will contain the first three mentioned functions. These three functions will support the wicked design problem by illustrating the effects of changing variables or goals. The fourth function is not useful because all the implemented variables will meet the pre-set standard brief, as will be explained in section 3.2.3.

3.1.2 User requirements for the DDSS

Target user - The DDSS must assist all designers, engineers, and building operation managers involved in office building design, but especially architects. It is realised that each possible group of future users will need their own specific approach; this is particularly the case for the user interface and the built-in help-function. During the design project several occasions were created to obtain feedback from the future user group.

Platform - The DDSS should work in the software environment that is used most often by our target user. This platform can be described as an IBM compatible PC with minimum specifications according to almost the latest standard: Pentium-Pro processor 200 Hz, with 64 MB RAM internal memory, 600x800 pixels screen size, and Windows NT 4.00 or Windows 95/98 control system.

Functions - At the beginning of the project only some general functions for the DDSS were known. These were similar to the goals of the long-term project described in section 1.1.3. The DDSS will:

1. Improve communication between members of a design team,
2. Improve knowledge transfer from research departments to building practice,
3. Improve knowledge transfer from the occupation stage to the design stage, and
4. Introduce the new approach for strategic performance based design and evaluation.

These general functions where introduced to a group of building experts during the first EIKS workshops in four European countries. They specified the functions and added more specifications. The results of the Dutch workshops will be discussed in chapter 4, *Design of the DDSS: EIKS*.

Risks involved - It is unlikely that all relevant building performance indices can be captured in one prototype. Focusing on a small applicable research field, whether this is all energy-related issues or only daylight and artificial lighting issues, implies irrefutably that other related issues are not taken into account, and thus the model is incomplete. However, one must keep in mind that this is only one of the two first prototypes, and that, if the results of this project and of the other pilot project will turn out to be positive, more research will be conducted in the field of DDSS's. In the end all DDSS's should melt together into one integrated network of design decision support systems.

Another risk is that it may not be possible to find a performance evaluation method that is accepted by all designers, because each and every designer has its own subjectively determined important issues. For example, esthetical issues may be judged differently by all individual designers.

3.1.3 Knowledge in the DDSS

At this point we want to elaborate on some aspects of knowledge. The first aspect is knowledge acquisition, followed by knowledge classification, knowledge representation, and finally knowledge handling.

Knowledge acquisition - For knowledge acquisition (McGraw & Harbison-Briggs 1989), (Mars 1991), (Mastrigt et al. 1987), and (Witte & Kwee 1988), all suggest three different methods:

- Consulting handbooks,
- Re-using knowledge stored elsewhere, and
- Retrieving knowledge from human experts.

The latter method can consist of interviewing experts (asking how experts handle different domain-specific problems), or protocol-analysis (experts think aloud while solving a domain-specific problem and a knowledge engineer writes down the process). Already in 1970 protocol-analysis was used by Eastman, (Eastman 1970), and later for example by Macmillan and Mezughi, (Macmillan & Mezughi 1996), as a framework for examination of interaction between thinking and drawing. Their objective was to investigate the conceptual association that marks the creative process of architectural design.

According to (Schraagen & Schaafstal 1998), interviews are suitable for acquiring facts and strategies and protocol analysis is suitable for acquiring heuristics (approaches to proceed to a solution). Disadvantages of interviews can be that the reliability of the results is uncertain, that some experts are incapable to explain their knowledge understandably or to make their knowledge explicitly available, and that the process is time-consuming. Protocol analysis can also be very time consuming. Further, it is uncertain whether the aloud thinking disturbs the performance and velocity of the execution of the task.

Nevertheless, retrieving knowledge from human experts has been the method used in this project, because the knowledge needed to support the conceptual lighting design stage cannot be found in handbooks or elsewhere. Two workshops were organised with building experts from practice. This is reported in chapter 4, *Design of the DDSS: EIKS*. To validate the implemented knowledge interviews took place with five lighting experts and one architect and one workshop was organised with mainly lighting experts. This is reported in chapter 5, *Design of Office Lighting Systems*.

Knowledge classification - To classify knowledge two sets of definitions were found: the definition of McGraw & Harbison-Briggs (1989) and of Anderson (1987). MacGraw & Harbison-Briggs describe four different kinds of knowledge:

Informal knowledge	Learned by imitation and observation. Difficult to represent, because how one executes a task is unknown.
Formal knowledge	Consists of natural laws and rules.
Technical knowledge	Also called *domain knowledge*. Adopted from mathematical and physical theories.
Strategic knowledge	Knowledge about how one uses technical knowledge to solve problems.

The knowledge of experienced human experts consists of a combination of technical knowledge and strategic knowledge. Anderson (1987) has other names for these two kinds of knowledge: declarative knowledge and procedural knowledge. Declarative knowledge is ‘knowing what’, for example facts or estimation calculations. This is similar to the earlier mentioned technical knowledge. Procedural knowledge is ‘knowing how’; how do you apply knowledge, how do you use knowledge. This is similar to the earlier mentioned strategic knowledge. These two kinds of knowledge should be represented in a DSS.

Knowledge representation – Anderson (1987) provides three possibilities for knowledge representation:

Production rules	Main rules, causal relations, and prescripts.
Semantic network	Objects connected by relations.
Frames	Knowledge in modules handling the same characteristic or object.

The different representations can be combined. In (Nguyen, Ha & Bédard 1996) a knowledge based design system is described that allows designers to perform architectural and structural design processes as well as code compliance checking. The building codes are translated into rules, though the building itself is described by using frames. In (Anderson 1987) the simulation model uses a semantic network to represent declarative knowledge and production rules to represent procedural knowledge.

The technical and strategic knowledge in this project has been positioned using the 3D model described in section 2.1. For the DDSS described in this thesis the technical or declarative knowledge consists only of objects (concepts) with properties (performance values), and is stored in tables within a database. The strategic or procedural knowledge consists of rules that are hard coded inside the prototype, i.e. written in between the code of the prototype as opposed to collected in a separate rule base, see section 3.2.6 and appendix A.

Knowledge handling - Three different ways for knowledge handling are known:

KADS	Knowledge Acquisition and Documentation System; the DDSS is not developed further until all relevant knowledge and methods for solving problems are carefully collected.
Rapid Prototyping	In an early stage of knowledge acquisition a prototype DDSS is built. After that, the knowledge is continuously expanded and validated.
Mechanical learning	Inference rules are generated automatically from reliable examples of desirable behaviour.

For our project we used workshops and interviews to acquire knowledge from human experts and rapid prototyping with regularly confrontations with experts to validate the methodology and implemented knowledge.

3.1.4 Components of the DDSS

In general, a (Design) Decision Support System consists of four major components: database management, knowledge management, models for analysis, and user interface, see figure 3.1 (after Van Zutphen 1999). These components and their functions will be discussed below. Most of the time a DSS is linked with other DSS's, databases, or other facilities. An example of a project, that clusters different knowledge based systems within multimedia instructional servers, is described in (Vásquez de Velasco de la Puente 1996).

Database management - The database management component enables the DSS to perform any type of data analysis operation and can include both internal and external databases, (Bidgoli 1989). A database is simply a collection of relevant data stored in a central location. Databases are utilised even in manual systems, for example a file cabinet. Bidgoli states that in computer terminology, a database is defined as a series of integrated files, (such as descriptions of all available artificial lighting components: light sources, luminaires, control device, etc.). A file is a series of related records, (such as descriptions of all available light sources: fluorescent tubes, incandescent lamps, halogen lamps, etc.). A record is a series of related fields (such as descriptions of all relevant specifications of one specific light source: power consumption, dimensions, etc.). A field is the place where one piece of data is stored (for example: power consumption is 25 Watt).

Usually the database is organised according to a specific procedure for creating, representing, organising, and maintaining data in a computer system: a data model. A data model may include three elements:

Data structure	Including relations, hierarchies, networks, and records.
Integrity rules	Defining the boundaries of a database, including maximum and minimum values, different constraints, and different types of access procedures of related fields.
Operations	Offered by a data model, including a variety of operations such as database creation, update, and query.

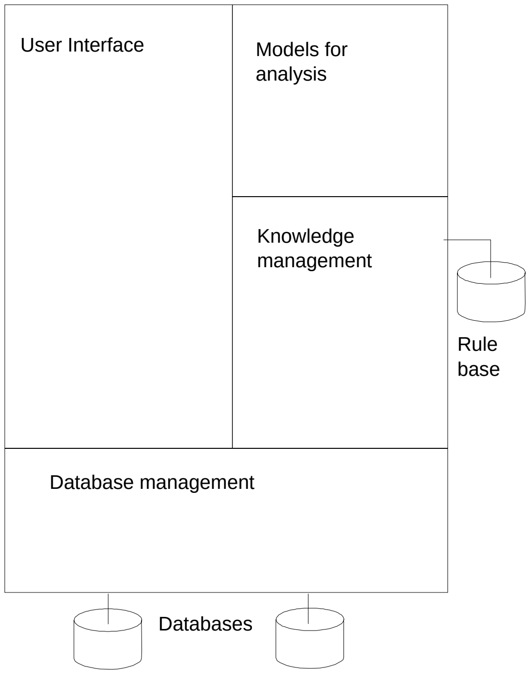


Figure 3.1: Components of DSS, (after Van Zutphen 1999).

The database management component is associated with the data model. Through the available data structures and integrity rules, and through the possible operations, the database management component is able to retrieve the right data at the right time and present it at the right place, if the database contains the right information. For example, it can retrieve all luminaires for fluorescent tubes of which the power consumption is 30 Watt. That is if the database contains files on luminaires and light sources, if the power consumption for all light sources is known, and if for each luminaire is known for which light sources it is designed.

There exist different data models that can function in a DSS environment: a flat-file model (no relations between the files), a relational model (files can be related on basis of a common field), a hierarchical model (connection between records is hierarchical: files are related as the branches of a tree), and a network model (enhanced version of a hierarchical model), (see Bidgoli 1989). The data on daylight and artificial lighting systems for our project has been expressed in a hierarchical model, see chapter 5, *Design of Office Lighting Systems*.

Knowledge management: Rule based approach - The knowledge management component is complementary to the database management component. It is able to operate computations, deductions and explanations with the data retrieved by the database management component. For our project a rule-based approach has been considered. Using this approach, the knowledge is stored either within the management component or in an external rule base. The knowledge is described as sets of rules, which may be conditional (the power consumption of an energy efficient lighting system is less than 50 W/m^2) or unconditional (the colour of an energy efficient lighting system can be anything). The rule based knowledge model not only provides data queries but also provides explanation capabilities and sometimes contains artificial intelligence.

Through the available knowledge rules, the knowledge management component is able to retrieve the right knowledge at the right time and present it at the right place. For example, it can retrieve all possible combinations of lighting system components that meet all the requirements for being energy efficient, but only if there exists a set of rules describing the requirements that a lighting system must meet to be energy efficient. The rules implemented in our DDSS can be found in appendix A and are explained in section 3.2.6.

Models for analysis: Multicriteria evaluation methods - The models for analysis component includes mathematical and statistical models, which enable the DSS to perform modelling analysis. This component interprets the requests from the user and translates his or her question into queries and actions. For example, if the user requests to find the most energy efficient lighting system, the DSS uses its models for analysis to find the requirements for such a lighting system. With these requirements the knowledge management component and the data management component are able to find the lighting system elements that together constitute to the most energy efficient lighting system.

As already discussed in chapter 1, *Introduction*, in the early design stage decisions are being made that are based on various criteria. Some of these criteria may be demands; a solution is only valid if these demands are met. Other criteria may be desires; a solution is preferred over another when this solution satisfies these desires better. This implies that the models of analysis within the DDSS to be developed must contain a method to check whether a solution meets the demands, as well as a multicriteria evaluation method to evaluate which solution satisfies the desires better. During the design project we focus on the latter item, and introduce only solutions that meet the demands of a specific brief for a particular office workplace environment. These demands will be explained in section 3.2.3.

According to Voogd (1982), who researched multicriteria evaluation for urban and regional planning activities, multicriteria evaluation methods are a means:

- To arrive at a surveyable classification of factual information.
- To get better insight into the various value judgements.
- To arrive at substantially better considered decisions.
- To incorporate differences in interest and/or political views in an analytical research framework.
- To give more substance to the notion of openness of a planning process.
- To arrive at a reduction of the available information.
- To arrive at a better position of the expert in a planning process.
- To account for or justify policy decisions.
- To structure research contributions in a planning process.

These points illustrate that this method is not only interesting for urban planning but for building design as well. Especially the first three points make this method useful for our project. The first point originates from the fact that this method increases the possibility to get a better insight into the problem under consideration. The second point originates from the fact that the method makes it possible to take different opinions of the experts involved in the design process into account. The third point originates from the fact that designers using this method are confronted with a large number of different dimensions of a decision, which prevents them to only focus on those aspects, which are conceived as bottlenecks.

According to Voogd (1982) multicriteria evaluation methods can be helpful in the investigation of phenomena where a number of choice possibilities must be tested against multiple criteria with conflicting priorities. A multicriteria evaluation method can be helpful if an inventory must be made or if the available information concerning choice-possibilities must be classified, analysed and conveniently arranged. A characteristic of these multicriteria methods is that they start from a number of explicitly formulated criteria (or standards of judging).

Multi-attribute utility theory - Winterfeldt and Fischer (1975) introduce a multi-attribute utility theory, which classifies decision situations according to three salient aspects of choice: uncertainty, time-variability, and multi-dimensionality. Veldhuisen and Timmermans (1981a, 1981b) describe the judgement of residences and shopping centres as being a multi-dimensional problem that is not uncertain, nor variable in time. These are the conditions under which three measuring methods are applicable. The methods can be used to derive the method that individuals use to combine the performance of the variables into a judgement towards a situation as a whole:

Psychophysical method	The performance of each variable is determined. The overall performance is estimated by determining the average of the performances of these variables, taking the relative importance of each variable into account.
Conjunctive method	Situations (e.g. certain combinations of variables) are ranked from worse to best.
Functional method	Situations are ranked on a numerical scale.

With the psychophysical method providing data is easiest for the subjects, but selecting the right numerical scale is difficult. This makes validation of the psychophysical method almost impossible. The conjunctive method uses a relatively simple method that, nevertheless, is laborious and time consuming for the subjects if more than five combinations need to be ranked, or if more than ten variables are involved. Statistical testing of the results is not possible, because only the order of the successive solutions is known and not the distances between them. These distances are known if the functional method is used. For the subjects this method is even more laborious and time consuming, but statistical testing is possible and weights can be retrieved as well.

The decision making process of a lighting expert, in which s/he selects the combination of concepts that forms an office lighting system, is also considered multi-dimensional, not uncertain, nor variable in time. After all, a typical combination of concepts provides *the same* overall performance *every time* it is established for a certain situation. Therefore, it is postulated that these multi-attribute utility theories are applicable for conceptual office lighting design, as well.

In their common practice lighting experts estimate the performance of the total lighting system based on their experience with the performance values of the separate variables. This is a complicated procedure in which these lighting experts combine their judgements towards the lighting system's variables into a judgement towards the total lighting system. For this design project we have used the psychophysical method to derive the overall performance of an office lighting system from the separate performance values of its variables. First, the variables influencing the performance of an office lighting system that are important in the conceptual design stage are derived in consultation with lighting experts. Then performance values are allocated to these variables of which three sets of values are validated with the same group of lighting experts. The overall performance of the office lighting system itself is estimated by determining the average of the performance values of the variables, assuming that no second order effects exist.

For each performance index the average performance value is determined to estimate this performance for the office lighting system:

$$P_i = \frac{1}{n}\sum_{j=1}^{n} p_{i,j} \qquad (3.1)$$

where P is the performance value of the office lighting system, p is the performance value of a variable, *i* indicates a specific performance index, *j* indicates a specific variable, and *n* is the total number of variables.

This method is similar to the weighted summation method, except for the fact that weights are not taken into account explicitly. The difference in importance is expressed implicitly in the separate performance values per variable.

User interface - The user interface component provides the DDSS user with various interface procedures that enable him or her to access the DDSS. From the user's point of view, this is probably the most important part. It is imperative that this component must be as flexible (easy to apply by different users under different circumstances and on different computer systems) and as user-friendly (easy to use and to learn) as possible.

Designing a good user interface requires understanding on how to present information visually to enhance human acceptance and comprehension, and on how physical actions must flow to minimise the potential for fatigue and minor injuries (head ache, muscular ache).

According to (Bidgoli 1989) the criteria for user-friendliness are:

Simplicity	Dialog should be straightforward with a minimum amount of computer jargon.

Consistency	Different parts of the system should utilise the same command for a specified task.
Familiarity	The system prompts should be designed to match a user's established thought pattern.
Informativeness	The user should be informed if s/he makes a mistake; the source should be indicated and remedies suggested.
Flexibility	A good dialog should help the user navigate through the system in any direction.

Galitz (1994) describes that when designing a Graphical User Interface [GUI] it is important to understand the user and the application. After this the method of showing information must be chosen, as well as the layout of windows and the colours used. The messages, feedback and guidance to the user should be properly provided.

Eberts (1994) describes that there exist four approaches to design and evaluate a human-computer interface:

Empirical	A conceptual GUI design is tested among possible users, and after that modified and again tested.
Cognitive	A GUI design is made according to an accurate, consistent, and complete description of the computer system and knowledge on how humans perceive, store, and retrieve information from short-term and long-term memory.
Predictive modelling	A GUI design is made according to the predicted performance of humans interacting with computers.
Anthropomorphic	A GUI design is made according to the process of human-human communication.

Our approach has been a mixture of the predictive modelling approach and the empirical approach. On the one hand, the user interface is designed to match the 'Microsoft appearance', because this is the environment that is common to the target users. Information is also provided to the user in a way that s/he is familiar with (drawings, textual information, qualitative expression, etc.). On the other hand, there have been several occasions where some of the possible future users gave feedback on, among other things, the user interface.

3.2 Office lighting systems

3.2.1 Introduction to office lighting

According to the Lighting Handbook of the Illuminating Engineering Society of North America (Rea 1993) offices are designed to house working people engaged in thought and in a number of forms of communication. Office lighting should enable workers to perform these tasks effectively. It provides for visibility of the visual tasks to be performed, and it affects the appearance of the space and its occupants, mood, and productivity level. Both visibility values and aesthetic values must be considered in lighting the environment. These aspects must work together to provide both a stimulating and comfortable environment and good visibility.

There are many different types of office environments. For example, Duffy (1997) distinguishes four types, based on the differences in autonomy and interaction of the organisation: *Hive*, *Cell*, *Den*, and *Club*. *Hives* are typically uniform, screened, and impersonal open-plan work environments that house individual, routine-process work with low levels of interaction and low autonomy. *Cells* are individual workplaces accommodating individual, concentrated work with little interaction. *Den* offices are associated with group work, such as group meetings or group presentations. Den offices typically are highly interactive but not necessarily highly autonomous and are arranged in an open-plan office or in group-rooms. Work in organisations that use *Club* offices is both highly autonomous and highly interactive because of the considerable judgement and intelligence involved, such as project meetings and workshops. The innovative office layout involved in the *Club* office contains a wide variety of time-shared task-based settings serving both the concentrated individual and group interactive work. All different types of office areas need different lighting systems, as is described in (Wouters & Van Bommel 1998) and (Wouters 1998). During this design project we focus on a cell office.

3.2.2 Performance-based design

In 1969 Archer introduced a performance-based method to structure the design process. He describes that the optimum solution can be selected if the demands and performances of the properties are known. Performances are defined as the relationships between varying states of the properties and the varying degrees of fulfilment of their respective objectives. Demands are defined as the limiting and ideal states of the properties, and hence the domain of acceptability implied by the objectives. In (AIC 1999) contributions of universities in Pittsburgh, Berkeley, Strathclyde, Prague, Milan, Haifa, Ottawa, Hong Kong can be found on this topic, showing that nowadays this topic still is investigated.

In (Rutten and Trum 1998) the principle of performance based design has been explained with an example. A similar example will be given here, though adapted to a lighting topic: the selection of a light source to illuminate our task. It is presumed that this can be done by all available light source concepts, e.g. incandescent and halogen bulb lamps, long and compact fluorescent lamps, and high pressure metal halide and sodium lamps. Which lamp is the best choice? To being able to make this decision, we must compare the performances of each light source concept in relation to our demands. For this example we are looking for a light source that produces warm white light, e.g. the colour temperature of the light must be between 2900 and 3300 K, and the costs must be low, e.g. less than 1 Euro per lm/W. The performance index for costs is estimated as follows:

$$P_{costs} = \mathrm{Costs} / \frac{\phi}{P} = \frac{\mathrm{Costs} \cdot P}{\phi} \qquad (3.2)$$

in which P_{costs} is the performance index for costs expressed in Euro per lumen per Watt [€·W/lm], Costs is costs per lamp expressed in Euro [€], the light flux, Φ, is

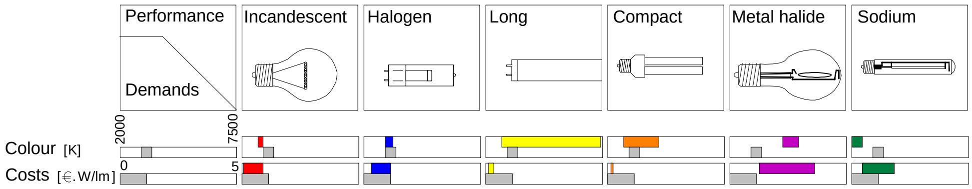


Figure 3.2: Performance concept, after (Rutten & Trum 1998).

expressed in lumen [lm] and the power consumption, P, is expressed in Watt [W]. For the values of these parameters the bandwidth was determined from the values found in an arbitrarily chosen manufacturers guide: (Philips 1997), see figure 3.2 and table 3.1. The performance values per concept for light colour were found in the same guide. These performance values depend on the exact light source type within each concept, and therefore the performance values are given in bandwidths. Also our demands can be expressed in bandwidths and those will form the slots in the filter for the choice of a lighting source concept. In our example the *Halogen*, the *Long fluorescent*, and the *Compact fluorescent* prove to meet both demands.

Table 3.1: Performance values for light source concepts.

Philips (1997), Rae (1993)	Classictone incandescent		Halotone halogen		TL long fluorescent		PL compact fluorescent		metal halide		sodium	
	min	max	min	max	min	max	min	max	min	max	min	max
P_{Cost} [€.W/lm]	0.07	0.94	0.34	1.11	0.10	0.36	0.11	0.27	1.28	3.67	0.47	1.84
P_{Colour} [·1000K]	2.7	2.9	2.9	3.2	2.7	7.4	2.7	4.1	4.2	5.0	1.9	2.5

In the design project described in this thesis the energy efficiency of lighting systems was the most important performance index to be considered, because of the requirements set in the EIKS project. After the consortium decided to focus on lighting systems, four performance indices were added and represented in the EIKS-demo: ‘Visual comfort’, ‘Costs’, ‘Installation aspects’, and ‘Maintenance aspects’. After redevelopment and validation of the lighting model with lighting experts the final set of performance indices to be evaluated in the ILSA prototype are 'Visual comfort', 'Energy efficiency', 'Initial costs', 'Operating costs', and 'Flexibility':

Visual comfort - Visual comfort is a subjective performance index, which is interpreted differently by each individual. Known causes of discomfort are glare, caused by luminaires or windows, especially when computer monitors are used, presence of shadows, lack of control over the illuminance or shading devices.

Energy efficiency - Energy efficiency includes the costs involving the use of energy by the lighting system but also the savings that result from the installation of particular lighting system concepts.

Initial costs - Initial costs include material costs and installation costs of the lighting system.

Operating costs - Operating costs include only costs due to damage to and replacement of the lighting system concepts. As opposed to what is done normally, energy costs are not included in operating costs; these are considered in the 'Energy efficiency index', in order to make this performance index explicit.

Flexibility - Flexibility expresses the ease (in time and costs) with which changes can be made to the lighting system in case changes in the organisation require other specifications of the lighting system.

3.2.3 User requirements for office lighting

The design project is focusing on the early building design stage, or conceptual design stage. In chapter 1, *Introduction*, is described that for this stage the input is provided by the functional brief. Another project within the Building Evaluation Project will focus on the briefing stage. This project will start in the near future and can build on the experience that was achieved during the development of BFIM (Bouw Fysisch Informatie Model = Building Physical Information Model, Van Luxemburg et al. (1989)) and IBT (Intelligent Briefing Tool, Van Luxemburg. (1999)). The result will be a computer tool that supports the briefing process, and that delivers a functional brief. This tool will be able to deliver the input, a functional brief for office lighting designs, for the DDSS described in this thesis.

For the time being we must work with a specific brief for a specific office lighting design. We chose to base this brief on the requirements that were set for the refurbishment of three cellular office rooms located on the tenth floor of the main building of the TUE, (see also (Zonneveldt & Mallory-Hill 1998)). The brief consists of general workplace requirements and additional lighting requirements, both daylight and artificial lighting, presented below. The elements of the brief are in line with the descriptions on programming and schematic design in (Rea 1993).

General workplace requirements - The general workplace requirements describe a cellular room in an office building in Eindhoven, the Netherlands, and are presented in table 3.2. Only one employee, between 45 to 50 years old, occupies the room performing administrative tasks using a PC. The room has one window orientated to the west. According to (NEN 1890) the luminance ratio (luminance on task: surrounding: periphery) must be 10:3:1 and the standard illuminance for this workplace must be between 400 and 800 lux.

Table 3.2: General workplace requirements.

Requirement	Value
Country	NL
Location	Eindhoven
Building type	Office
Room type	Cell: 3.60 x 5.40 x 2.80 m^3
Orientation	West
Obstruction	None
Number of people	1
Average age	45-50 year
Activities	Administration, PC
Luminance ratio	10:3:1 (NEN 1890)
Standard illuminance	400-800 lux (NEN 1890)

Additional lighting requirements - The additional lighting requirements can be divided into requirements for the appearance of the room, daylight requirements, and artificial lighting requirements. Most of the requirements are qualitative, and thus translation into technical requirements may be needed. For example, if the choice for the wall colour is light, the tool must determine the reflection factor of the walls at 60% to 70%. Not all these qualitative aspects can be translated into numbers. This is not problematic, because when using rules the computer can reason with qualitative values as well. For example:

if View **=** very important **then** Elements outside **or** Elements inside ≠ roller blind (3.3)

This rule prescribes that if the client expresses the view out of the window to be very important, that roller blinds may not be applied as sunshields. If another rule may conflict with this one, the system should warn the user, so that s/he can decide which rule is more important.

The requirements for the appearance of the room are presented in table 3.3 and describe the atmosphere, the location of the workplace, and the colours of the surfaces in the room.

Table 3.3: Additional requirements for apperance of the room.

Requirement	Value
Atmosphere	Professional
Location workstation	Window side
Colour walls	Light
Colour ceiling	Light
Colour floor	Medium

A ‘professional’ atmosphere implies that effort must be put in making the room look sophisticated (chic and stylish, as opposed to common if a ‘general’ atmosphere is preferred). The location of the workstation at the ‘Window side’ means that the desk is located less than 5 m away from the window, determined by using the method in Appendix B (Zonneveldt & Mallory-Hill 1998). For ‘Light’ walls a colour will be used with a reflection factor between 60 and 70%, as opposed to a ‘Light’ ceiling of which the reflection factor will be between 70 and 80%. A ‘Medium’ floor colour will have a reflection factor between 20 and 30%.

The daylight requirements are presented in table 3.4. The requirements describe that ‘Maximum’ use should be made of daylight and that both view and avoidance of reflectance of the window in the computer screen are ‘Important’. This implies that these aspects must be taken into consideration during the design.

Table 3.4: Additional requirements for daylight in the room.

Requirement	Value
Use of daylight	Maximum
View	Important
Avoidance of window reflectance	Important

The artificial lighting requirements are presented in table 3.5 and describe that the colour of the light should be ’Warm white’. Therefore, a light source providing light with a colour temperature between 2900 and 3300 degrees Kelvin must be applied. ‘Natural colours’ should be rendered properly, implying a Rendering factor Ra between 80 and 90%. The evenness of light on the work plane must be ‘High’, therefore no shadows or direct sunlight may fall onto the desk. Furthermore, it is considered ‘Important’ to shield the luminaire, which has an impact on which optic types can be selected; only luminaires with a shielding angle higher than 30°.

Table 3.5: Additional requirements for artificial lighting in the room.

Requirement	Value
Light colour	Warm white
Colour rendering	Natural colours
Evenness of light on work plane	High
Shielding of luminaire	Important

3.2.4 Variables of office lighting

For this design project a lighting model has been developed consisting of eighteen variables that were considered important in the conceptual design stage of office lighting systems. The variables are divided among the following three categories:

1. Daylight variables, relevant for the daylight system.
2. Artificial lighting variables, relevant for the artificial lighting system.
3. Control variables, relevant for the control possibilities of the daylight and artificial lighting systems.

We choose to allow approximately three possible concepts for each of the variables in order to keep the model manageable. This provides enough concepts to change the lighting system completely and still does not make the database extremely large. For the time being, the choice of the concepts is based on common practice in the Netherlands, and on the fact that we wanted to be able to represent the three earlier mentioned cases (refurbished at TUE). The user of the system may add concepts, and also delete concepts if s/he prefers to do so. This characteristic has been successfully applied during the EIKS project, when the Finish consortium member asked us to add ‘triple-glazing’ to the set of concepts for ‘window type’.

The lighting model has been validated by means of six interviews and a workshop with thirteen mainly lighting experts. The results of these validations are reported in chapter 5, *Design of Office Lighting Systems*.

Daylight variables - Nine daylight variables have been identified. Four variables describe the façade itself (1 to 4), three describe possible adaptations to the façade (‘features’, 5 to 7), and the last two describe elements that can be added (‘elements’, 8 and 9). Table 3.6 presents the implemented concepts.

1. *Façade type* - Type of outside wall construction. This is important to determine which adaptations to the façade and which additional elements will be possible.
2. *Window area* - The percentage of the outside wall that is transparent. This determines the amount of daylight that can enter the room.
3. *Window orientation* - The way the window is positioned in the wall. This expresses the preference for ‘light’ (vertical) or ‘sight’ (horizontal).
4. *Glazing type* - Type of glazing that is applied in the window. Especially non-transparent glazing will implicate a discoloration of the outside world.
5. *Features outside* - The adaptations made to the outside of the construction. These will influence the amount of daylight entering the room.
6. *Features façade* - The changes to the façade itself, made to increase the amount of daylight entering the room.
7. *Features inside* - The changes made at the inside of the construction in order to bring the daylight deeper into the room.
8. *Elements outside* - Shading devices attached to the outside of the window. In case of the active wall, or ventilated wall these shades will be applied in between the two sheets.
9. *Elements inside* - Shading devices attached to the inside of the window.

Artificial lighting variables - Six artificial lighting variables have been identified. Three variables relate to the amount and distribution of artificial light (1 to 3), and three are related to the luminaire (4 to 6). *Target illuminance* (2) has been added in pursuance of what has been mentioned during the interviews. One of the variables has been divided into two sub-variables (6). Table 3.7 presents the implemented concepts.

1. *Light direction* - The direction in which most of the light leaves the luminaire.
2. *Target illuminance* - The illuminance as designed within the legislative boundaries: 400-800 lux.
3. *Light distribution in room* - The way in which artificial lighting is distributed qualitatively in the room.
4. *Light source* - Type of lamp.
5. *Luminaire position* - The position in the room where the luminaire is attached.

6a. *Luminaire type direct* - The kind of shielding implemented in the luminaire for direct light direction.

6b. *Luminaire type indirect* - The kind of shielding implemented in the luminaire for indirect light direction.

Control variables - Three control variables have been identified. One variable relates to the daylight control (1), and the other two relate to the artificial lighting control (2 and 3). Table 3.8 presents the implemented concepts.

1. *Daylight control* - Type of control of shading devices. Distinguished by the level of automation in control.
2. *Artificial lighting control* - Type of control of the artificial lighting system. Distinguished by the area that is controlled.
3. *Control option* - Type of control of the artificial lighting system. Distinguished by the type of device.

Table 3.6: Daylight concepts.

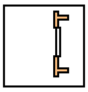
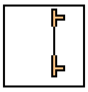
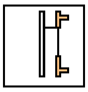
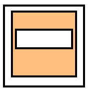
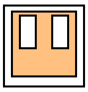
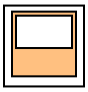
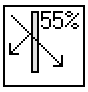
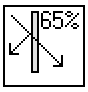
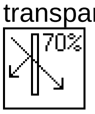
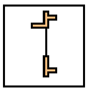
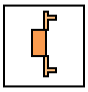
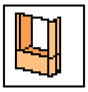
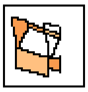
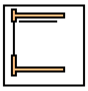
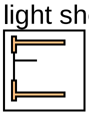
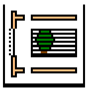
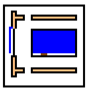
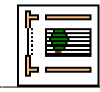
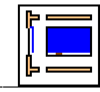
Daylight variables	**Concepts**				**Explanation**
Façade type	active wall 	double glazing 	ventilated wall 		Profiles of façade.
Window area	60%	50%	40%	30%	Percentage of façade.
Window orientation	horizontal 	vertical 	combination 		Outside view on façade.
Glazing type	heat absorbing 	heat reflecting 	transparent 		Percentage of transmission.
Features outside	none	horizontal 	vertical 		Profile of façade.
Features façade	none	bevelled edge 	reflectors 		3D view of façade
Features inside	none	mirrors 	light shelves 		Profile of room.
Elements outside	none	venetian blind 	roller blind 		Profile of and inside view on façade.
Elements inside	none	venetian blind 	roller blind 		Profile of and inside view on façade.

Table 3.7: Artificial lighting concepts.

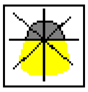
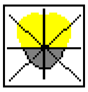
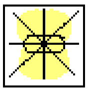
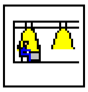
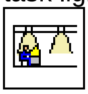
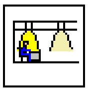
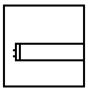
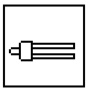
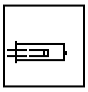
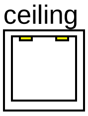
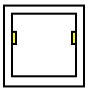
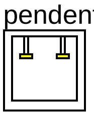
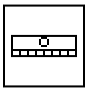
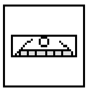
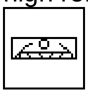
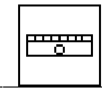
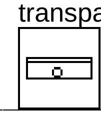
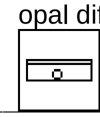
Artificial lighting variables	**Concepts**			**Explanation**
Light direction	direct 	indirect 	combination 	Profile of luminaire with light rays.
Target illuminance	400 lux	500 lux	800 lux	Amount of lux.
Light distribution room	ambient 	task light 	zoned 	Profile of room.
Light source	fluorescent tube 	compact fluorescent 	halogen 	Profile of light source.
Luminaire position	ceiling 	wall 	pendent 	Profile of room.
Luminaire type direct	louvered 	matte reflecting 	high reflecting 	Profile of luminaire.
Luminaire type indirect	louvered 	transparent 	opal diffuser 	Profile of luminaire.

Table 3.8: Control concepts.

Control variables	**Concepts**		
Daylight control	per room manually	per room light sensor	central light sensor
Artificial lighting control	per room	central	zoned
Control option	switch on/off occupancy sensor	dimmer daylight and occupancy sensor	daylight sensor

Schematic conceptual design or detailed conceptual design - Until now, a limited list is given of only eighteen variables in only three categories (daylight, artificial lighting, and control). As long as the amount of variables is this limited, until maybe up to 25, it is possible to sum up the situation. When, in the future the number of variables will increase, further classification is necessary to enable the designer to make choices on different levels of detail. In this way s/he can still keep track of the decisions made, and increase the level of detail step by step.

Especially, if several building systems must be integrated, more than one level of detail is needed. The designer will make less detailed designs of all systems to be integrated first, based on a global choice of concepts, and then integrate them one by one, increasing the level of detail at the same time. In relation to this strategy, Bouten (1995) describes a method to categorise characteristics of HVAC-systems. He distinguishes three categories:

Intrinsic values	Independent of the building, characteristics of the HVAC system itself.
Integrating values	Dependent of the building, the HVAC-system fit into the building.
Dimensioning values	Dependent of the capacity and dimensions of the HVAC-system.

According to these categories we also can distinguish different levels in our set of eighteen variables: Number 2 and 3 of the daylight variables can be considered dimensioning, the other variables, 1 and 4 – 9 are intrinsic. Number 2 and 3 of the artificial variables are actually specifying the elements of the brief, while number 5 can be considered integrating and 1, 4 and 6 intrinsic. Of the control variables 1 and 2 are integrating and 3 is intrinsic. This categorising can be helpful in the future when more and more systems need to be integrated.

Table 3.9: Two levels of detail applied in the model.

Detail level 1; Outline conceptual design	**Detail level 2; Conceptual design**
Daylight	
Façade type	Façade type
Window area	Window area
Window orientation	Window orientation
Glazing type	Glazing type
	Features outside
	Features façade
	Features inside
	Elements outside
	Elements inside
Artificial lighting	
Light direction	Light direction
Light source	Light source
	Target illuminance
	Light distribution in room
	Luminaire position
	Luminaire type
Controls	
Daylight control	Daylight control
Artificial lighting control	Artificial lighting control
	Control option

For the time being we will only make a division into two levels of detail, shown in table 3.9. An outline conceptual lighting design may by influenced by only eight variables of the previously mentioned eighteen variables: the first four daylight variables, the first and fourth artificial lighting variable, and the first two control variables. Together with the other ten variables the design will be influenced in more detail. What should be taken into account is that these 'less important' variables still can have a large impact on the overall performance of the lighting design.

Further, when in the future not only conceptual design is considered, but also the successive preliminary and final design stages, more levels of detail are necessary, as well. Then working with bandwidths, as has been shown in section 3.2.2, is not longer enough. Depending on the project these bandwidths must become smaller, as the project progresses.

3.2.5 Application of psychophysical method for performance evaluation

The psychophysical multi-attribute utility theory, described in section 3.1.4, is applied to establish the performance values of the separate variables. According to this theory, for each lighting system variable the separate performance values p_j are determined for each of the considered performance indices and implemented in the DDSS in the table structure, presented in table 3.10.

Table 3.10: Table structure for the psychophysical method.

Lighting system variable j	$p_{j,\text{ visual comfort}}$	$p_{j,\text{ energy efficiency}}$	$p_{j,\text{ initial costs}}$	$p_{j\text{ operating costs}}$	$p_{j,\text{ flexibility}}$
Alternative 1 Alternative 2 . . Alternative n					

Equation 3.1 has been used to formulate the five performance values for the office lighting system:

$$P_i = \frac{1}{18}\sum_{j=1}^{18} p_{i,j} \tag{3.4}$$

where P is the performance value of the total lighting system, p is the performance value of the variable, *i* is a string from the set {visual comfort, initial costs, operating costs, energy efficiency, flexibility}, and *j* indicates one of the 18 variables.

3.2.6 Rules

The rules that are hard coded inside the prototype, (i.e. written in between the code of the prototype as opposed to collected in a separate rule base), can be found in the Appendix A. Seven topics are concerned:

Link light direction to luminaire type – This rule links the variables 'Luminaire type' and 'Light direction'. If the light direction is direct, only the luminaires for direct light are enabled. If the light direction is indirect, only luminaires for indirect light are enabled. If the concept for combined light direction is selected all luminaires are enabled. The user is invited to select the luminaire that fits the main light direction.

If artificial lighting control central only switch – This rule enables only the concept 'Switch on/off' of the variable 'Control option' if the artificial lighting is controlled centrally. All the other concepts for this variable are disabled, because a central daylight or occupancy sensor has not been taken into account.

Only reflecting with façade type double glazing – This rule allows the user only to select the concept 'Reflectors' of the variable 'Features façade' if for the façade type the cavity wall with double glazing has been selected. With the other façade types this special feature of the façade cannot be applied in practice.

Only bevelled edges if window orientation is vertical – This rule allows the user only to select the concept 'Bevelled edge' of the variable 'Features façade' if a vertical window orientation has been selected. For horizontal window orientation or for combination of horizontal and vertical it is not possible to bevel the frames.

If glass %=60 then window orientation is combination, else it is horizontal or vertical - This rule implies that if the concept '60%' of the variable 'Window area' is selected, the window orientation becomes the combination of vertical and horizontal, implying a façade filling glazing area. If a lower percentage is selected only vertical or horizontal orientation can be selected.

No indirect luminaire if ceiling mounted – This rule implies that if the concept 'Ceiling' of the variable 'Luminaire position' is selected, only direct luminaire types are allowed.

No other features if the façade is reflecting – This rule disables all other features inside (except mirrors on the ceiling), outside, or to the façade if the concept 'Reflectors' of the variable 'Features façade' is selected.

Chapter 4

DESIGN OF THE DDSS: EIKS

The previous chapter described the general structure of a Design Decision Support System. The design of such a system is considered a wicked problem, and thus has no true or false solution. To handle some of the wickedness it is important that a common basis for this solution is created together with possible future users. During the first year of the design project this was addressed by organising two workshops, imbedded in the European EIKS project. This chapter describes the results starting with an introduction to the EIKS project first in section 4.0.

The EIKS tasks executed as part of the design project consisted of organising the two workshops and developing a demo version of a Knowledge Based System [KBS]. The objectives, results and conclusions of the EIKS project are published in a final report (EIKS 1998). This chapter is based on the EIKS sub-reports that are part of the final report. A summary of the Dutch tasks of the EIKS project is provided in (De Groot & Pernot 1998). The outcomes of the first Dutch workshop are presented in section 4.1, from *Proceedings EIKS Workshop Nederland* (De Groot 1997a). A description of the demo KBS is given in section 4.2, from *Task III Information and Decision Support System; Definition report* (part of EIKS 1998). Finally, the outcomes of the second Dutch workshop are presented in section 4.3, from *Proceedings EIKS Follow-up Workshop* (De Groot 1997b) and *Task III Information and Decision Support System; Evaluation report* (part of EIKS 1998). The recommendations from the EIKS project for the continuation of the design project are presented in section 4.4.

4.0 Introduction to the EIKS project

The Energy Impact Knowledge-based System [EIKS] project is an EU-funded project that was executed in 1997 in a consortium consisting of eight European building research and construction companies, see section 2.3.1. The Annex 1 of the Thermie-B proposal for the EIKS project (EIKS 1998) describes the aim and objective as follows:

> *The EIKS initiative …. is aimed at overcoming barriers in the current building process that hinder the realisation of optimal energy efficiency in buildings. By developing a knowledge-based assistive information and decision support system that will guide*

> *designers, engineers, building operation managers etc. to the application of best practices and best available technologies.*
>
> *The objective is to determine - in consultation with the European building sector - aforementioned energy related barriers, best building practices and best technological knowledge. Hereto the proposed preparatory action includes a number of international thematic workshops that are going to take place in four different EU regions. The workshop outcomes will be applied in a pilot version of the information and decision support system.*

The building experts, who have been invited to the workshops, are also possible future users. Therefore, an additional benefit of these workshops has been that we had a change to validate the project's goal, and create a common basis on the specifications of the tool to be designed. This is a very important aspect in addressing wicked problems that is reflected in the third criterion of a wicked problem, (see chapter 1, *Introduction*): Solutions to wicked problems are not true-or-false, but good-or-bad. Addressing wicked problems is fundamentally social and therefore it is important to come to an agreement. Getting the right answer is not as important as having stakeholders accept whatever solution emerges, (see also Conklin & Weil (1997)).

4.1 EIKS Netherlands Workshop

4.1.1 Workshop script

The EIKS proposal defined the organisation of twenty workshops with experts from the European building sector. The idea behind this was to determine energy-related barriers, best building practices and best technological knowledge. This form of knowledge acquisition has been chosen because of the possibility to emphasise group working and debate. The workshops must have a highly interactive character, with all participants making a positive contribution. All building professions must be represented.

The definition of the script for all workshops was a task of one of the British partners in the EIKS consortium. During the try-out workshop in London it became clear that the developed script did not cover all of the objectives: it only allowed the participants to define the barriers to energy efficient integrated design and to specify the role of the knowledge based system in overcoming these barriers. As opposed to what had been described in the EIKS proposal, no time was allocated to gather information on best building practices and best technological knowledge.

In order to be able to compare the results of the workshops of all four European countries it was decided not to change the workshop script completely. Only a few adaptations were made to the themes of the brainstorm session on barriers and to the workshop setting. Originally, the barriers had to be categorised in three themes: 'Design Process', 'Technical Understanding', and 'Communication'. For

Figure 4.1: Picture taken during the first EIKS workshop.

the two Dutch workshops the 'Design Process' and 'Communication' were combined because it was felt that during the pilot workshop in London both had provoked similar responses. Further, the category 'Dutch building regulations' was added because in our opinion this might potentially act as a large barrier in the Netherlands. A last catch-all category was added to provide the participants with the possibility of contributing their own thoughts.

For the two Dutch workshops we chose to use the electronic meeting facilities at the Faculty of Systems Engineering, Policy Analysis and Management at the Delft University of Technology. The two Group Decision Rooms can each contain a maximum of 17 attendees, including the facilitator who manages the software during the meeting process. Every workstation has a computer, with which the attendees can enter group discussions electronically by using the software: "GroupSystems" developed by the University of Arizona. The facilitator's computer can be connected to a projector that can be used to execute an electronic presentation.

According to De Vreede (1995) four advantages exist of using this electronic meeting facility instead of the traditional workshop format. The first advantage is that the participants can contribute anonymously. This increases the quality of the meeting results and the satisfaction of the participants with the meeting itself. By being able to enter ideas, comments, and votes anonymously, silent or shy participants are more encouraged to enter ideas. Ideas appear to be judged on their merit, not on the personality or position of the participant that has entered it. Another advantage is that parallel information gathering is supported, which yields increased group productivity and satisfaction. This implies that participants do not have to listen to others before they can submit their own views, nor have to remember their ideas and criticisms until they have the attention, and therefore spend more time on generating new ideas. Further, voting techniques can be supported, which make it possible to quickly determine which of the issues identified during a brainstorm session are considered important by the group. Finally, all ideas, comments, and votes that are entered during a meeting are stored electronically, which decreases the amount of time needed to produce the meeting results.

A disadvantage that is often mentioned according to De Vreede (1995) is that electronic meeting facilities lacks social cues. Since information is only communicated electronically, certain types of information, such as ironic remarks, may be interpreted out of context. Further, the advantage of anonymity sometimes is considered a disadvantage, as well, if generated ideas or voting results need clarification.

4.1.2 Participants

The EIKS proposal prescribed that all building professions must be represented. Altogether 76 people were invited, 60 people responded positively but not everybody was available on the specific day, in the end 29 top-level expert participants from various companies and organisations were present. They were divided among two Group Decision Rooms, as shown in table 4.1.

Table 4.1: Participants to the Dutch EIKS workshop.

Participants Workshop group 1			Participants Workshop group 2		
Owner	1	(8%)	Owners	0	(0%)
Users/building manager	1	(8%)	Users/building managers	2	(12%)
Architect	1	(8%)	Architects	2	(12%)
Authorities	2	(15%)	Authorities	3	(19%)
Constructors	1	(8%)	Constructors	1	(6%)
Project manager	1	(8%)	Project manager	0	(0%)
Consultants	2	(15%)	Consultants	4	(25%)
Building service engineers	1	(8%)	Building service engineers	1	(6%)
Researchers	3	(22%)	Researchers	3	(19%)

4.1.3 Timetable

The same timetable was given to both groups of building experts, shown in figure 4.2.

After a short presentation on the EIKS project and the goals and objectives of the workshop, there was an introduction on the Group Decision Room system by the facilitator. After this the first brainstorm session started and the attendees had to identify barriers that prevent improving energy efficiency of buildings. They had to provide answers in one of the four provided categories: design process, today's

Timetable:

9:00	Introduction	
9:15	Instruction on "How to discuss in a Group Decision Room"	
9:30	Brainstorm: **"Which barriers do you recognise in improving energy efficiency of buildings?"**	
	Answer in 4 categories:	• design process, • today's building technology, • Dutch building regulations, • other topics.
10:30	Coffee break	
10:45	Voting on 3 most important items per category	
11:30	Presentation on Knowledge-Based System [KBS] + example	
11:45	Brainstorm: "**Do you think a KBS can be helpful to you in overcoming the stated barriers?"** **"If yes, when and how?"** "**If not, why not?"**	
12:30	Short presentation on the results and closing	
12:45	Lunch	
13:30	Evaluation	
15:30	End	

Figure 4.2: The timetable of the Dutch workshops of the first series EIKS workshops.

building technology, Dutch building regulations, and other topics. The last category was added to provide the attendees with the possibility of creating their own categories.

All the discussions started at the same time. Every attendee could respond to items from any topic area that appeared on his or her screen. In the first workshop room the facilitator then selected important issues from the discussions. These were discussed orally with the group afterwards. The group selected the three most important items per category using the voting facility of the GroupSystems software. In the second workshop room the voting was done on all items and their related discussions. Again, the three most important items were chosen for each category. The results of the voting were shown to the attendees.

The next topic on the agenda was a presentation on Knowledge-Based Systems [KBS]. Both rooms were provided with an explanation on KBS's. An example was also shown, so that the attendees could get an idea of the appearance of a KBS.

A second brainstorm session took place in both rooms following the presentation. The three most important barriers, determined during the earlier session, for each category were shown on each screen. The attendees were asked to indicate for each item whether they thought a KBS could help overcome this barrier in their work situation. If yes, they were asked to indicate when and how they would use it. If not, they were asked to indicate why not.

After this last brainstorm session was completed a summary was given to the attendees. The last activity on the agenda was the evaluation of both workshops by all present EIKS consortium members.

4.1.4 Results workshop group 1

Below the results of the first workshop session are presented: per category the top three of the identified barriers with a summary of the electronic discussion that took place.

Thirteen building experts have voted on the three main items per category. The total amount of votes is shown between brackets. For some items the percentage of the participants that agreed that a KBS could assist in solving this specific problem is shown. Unfortunately, not for all the top three items, identified during the vote, this percentage is known. This problem is caused by a technical problem that allowed the participants during the second brainstorm session to work with the three first mentioned items of the original list, instead of the three most important items identified during the vote.

Design process

1. *No clear briefing (9)* – The brief, including budget and accessory technical requirements, must be clear and requirements that prevent a building to be energy efficient should be adapted. For example, if the design contains an atrium the brief must prescribe a maximum heat loss or cooling load caused by this atrium. – 80% of the participants agreed that a KBS could assist in solving this problem by preventing that essential items are forgotten.

2. *Co-operation between building team members should be better (7)* – Already in the early stages of the design, the co-operation of the architect with the rest of the building team is not optimal. All members of the building team should know how their decisions impact on the work of others. – 90% of the participants agreed that a KBS could assist in solving this problem by identifying the consequences of design decisions on other knowledge fields.

3. *There should be a judgement on integrated design approach (6)* – Building and building services should be designed at the same time and integrally. An integral management can be helpful, if not only the budget and the planning are managed, but also the functionality. – no percentage available.

Today's building technology

1. *Because of competitive bidding "real new technology" is not stimulated (10)* – In general, designers must deliver as much output as possible and therefore choose for routine solutions, because of lack of time and money, and risk involved with advanced solutions. – 100% of the participants agreed that a KBS could assist in solving this problem by providing alternative solutions.

2. *More attention should be given to technology that gives the user feedback on his or her behaviour and on the working of the building services (9)* – This application is limited because the users, who benefit from it, are not involved in the design and construction of their building. – no percentage available.

3. *The building industry is too afraid of taking risks (7)* – The design must be based on solid facts and the designer should take care if it does not fulfil all expectations yet. – no percentage available.

Dutch regulation

1. *Existing regulations include insufficient values on performance (7)* – Performances are only included in the Dutch Energy Performance Norm if residences and utility buildings are considered. Maybe the additional performance based requirements will appear in relation to sustainability. – no percentage available.

2. *More funding for new technology is needed (6)* – The government should take actions in the field of building innovation. The funding should support new energy efficient technologies. – 40% of the participants agreed that a KBS could assist in solving this problem by providing up-to-date information on funding possibilities.

3. *Regulations make creativity less important (5)* – Regulations make designing buildings less creative, but it improves energy efficiency. – 100% of the participants agreed that a KBS could assist in solving this problem by identifying solutions that meet the standards.

Other topics

1. *Costs and profits are not for the same party (11)* – The parties involved in the design of the building are not involved in the exploitation. The new building must not exceed the budget (initial costs), and therefore proposed investments to make the building more energy efficient (lower operating costs) will not be approved even though they might be profitable. – no percentage available.

2. *Project developers only are interested in short-term profit (8)* – Project developers are only interested in a low rent per square meter prize. The energy account is paid by the renter and is not important. – 100% of the participants agreed that a KBS could assist in solving this problem by providing initial costs and estimated saving on operating costs of innovative energy efficient solutions.

3. *Project developers transport their investments to the exploitation stage (6)* – This can only be prevented by regulations. – 50% of the participants agreed that a KBS could assist in solving this problem by showing the project developer how much easier it is to let an energy efficient building.

3. *Saving energy and (thermal) comfort do not belong together (6)* – A better

thermal comfort is much more important economically than a low energy bill. A problem is that an increase in productivity because of a good balance between energy use and comfort cannot be measured. – no percentage available.

4.1.5 Results workshop group 2

Below the results of the second workshop session are presented: per category the top three of the identified barriers with a summary of the electronic discussion that took place. Unfortunately, the discussion items on ‘Dutch regulation’ were lost during the workshop, due to a technical problem.

Sixteen building experts have voted on the three main items per category. The total amount of votes is shown between brackets. During this workshop the three items that were identified as most important were transferred to the second brainstorm session. For the two categories where a joint finish occurred, only the first item has been transferred to limit the time needed for this session. Thus for almost all items the percentage of the participants that agreed, that a KBS could assist in solving this specific problem, is shown.

Design process

1. *Consultants cannot break away from using standard solutions (12)* – Clients should allow money and time to investigate new solutions. – 70% of the participants agreed that a KBS could assist in solving this problem by providing alternative solutions.

2. *Because of competitive bidding design costs must stay low (6)* – This implies that alternative solutions are not tested, because more work and time is involved. – 80% of the participants agreed that a KBS could assist in solving this problem by providing initial costs and estimated saving on operating costs of innovative energy efficient solutions.

3. *The energy costs are very low compared to cost of personnel (4)* – Energy costs cover less than 1% of the personal costs. Saving money on this account does not make sense. – 60% of the participants agreed that a KBS could assist in solving this problem by providing initial costs and estimated saving on operating costs of innovative energy efficient solution.

3. *Building team members do not have the same objectives (4)* – There is no good building co-ordination and the building team members do not start at the same time. It is very important that the different parties inform each other well, but unfortunately this is not the case. Each discipline designs his or her solution that might not fit with the other solutions. Tuning of the various sub-designs is necessary. – no percentage available.

3. *Designers think in solutions, instead of performances (4)* – Especially in the conceptual design stage, designers should think in concepts and not in solutions. – no percentage available.

Today's building technology

1. *A separation between thinking in building concepts and building services concepts exist in the design process (11)* – Most of the time the consultants are involved in the project after the building design is finished. Then they can only develop a solution that fits the building design instead of a solution that fits the brief. – 80% of the participants agreed that a KBS could assist in solving this problem by identifying the consequences of the design decisions of each other's work.

2. *Building industry is not willing to innovate because of high risks (8)* – Priority is with efficiency in investment, not in energy. The building industry only thinks in short-term profit, not in long-term investments. – 80% of the participants agreed that a KBS could assist in solving this problem by providing information on innovative energy efficient solutions.

3. *Availability of good design tools is insufficient (5)* – Sometimes checking whether a solution is optimal is not carried out because it takes too much time. – 100% of the participants agreed that a KBS could assist in solving this problem by providing access to other available design tools.

3. *Often the things that seem possible at the beginning of the project turn out to be too expensive (5)* – At the beginning of the project it is the responsibility of the designing party to estimate the costs of each possible measure or demand. – no percentage available.

3. *Building for eternity and conceptual thinking do not belong together (5)* – During the conceptual design stage, aspects of the occupation stage and demolition stage should be taken into account. – no percentage available.

Dutch regulation (no data on the discussion available)

1. *Not the rules but the thinking needs to be changed (9)* – 70% of the participants agreed that a KBS could assist in solving this problem by identifying solutions that meet the standards and thus teaching the user how s/he can be creative within the legislative boundaries.

2. *Regulations should be more stringent if people want to save energy (8)* – 60% of the participants agreed that a KBS could assist in solving this problem by providing up-to-date information on regulations.

3. *Regulations are too complex (6)* – 90% of the participants agreed that a KBS could assist in solving this problem by identifying solutions that meet the standards.

Other topics

1. *The knowledge level of the decision-makers is too low (9)* – The client should

have the knowledge to judge whether the solution proposed by the consultants meets the goals of the project. The client should allow time and money for evaluating alternative solutions. – 90% of the participants agreed that a KBS could assist in solving this problem by providing a mechanism to match the brief with the proposed design and by providing information on all building topics.

2. *Often consultants are being introduced to the design when the shape of the building is almost completed (8)* – One solution for this problem can be that the designers involved early in the design project have access to enough information on energy efficiency. – 60% of the participants agreed that a KBS could assist in solving this problem by identifying the consequences of design decisions on other knowledge fields.

3. *Investors should be stimulated to spend more money on the building to have less exploitation costs in the future (4)* – 80% of the participants agreed that a KBS could assist in solving this problem by providing initial costs and estimated saving on operating costs of innovative energy efficient solutions.

4.1.6 Conclusions of the EIKS Netherlands workshop

There was no large difference between the results of the two workshops groups. Probably, the homogenous distribution of building experts over both rooms has caused this similarity.

During the first brainstorm session similar barriers were identified in both workshop groups, but not always in the same category. For example, Workshop group 2 Design process: *Because of competitive bidding design costs have to stay low* and Workshop group 1 Today's building technology: *Because of competitive bidding "real new technology" is not stimulated*. In the first category, 'Design Process', many of the issues we identified for the Building Evaluation Project are reflected in the contributions of the participants. They agree with us that poor communication between the building team members is one of the most important problems. In the second category, 'Today's building technologies', both groups recognised that the building industry is not willing to use innovative solutions because of the high risks involved. An issue that was raised is the fact that the building team focuses on low initial costs, and not on low operating costs. In the first workshop group during the third category, 'Dutch regulation', an interesting issue was raised, indicating that regulations make designing less creative. It is believed that the opposite is true; it requires more creativity to design a building within the legislative boundaries unless regulations are too prescriptive in respect of the design. Nevertheless, five participants out of thirteen agreed with this contribution.

The barriers that were identified were generally known and not new, as expected. However, the aim of this workshop item was to make the attendees aware of them and use them in the next workshop item, when the attendees where invited to provide specifications of a Knowledge Based System [KBS] that could overcome these barriers.

During the second brainstorm session all the participants agreed that the KBS to be developed would assist in solving most of the identified barriers. Although in the first workshop group not the most important items were discussed, more or less the same issues came up as in the second workshop group. Therefore, it can be concluded that the technical problem, causing a departure of the original script had no large impact on the overall results. The following guidelines for the KBS came forward from analysing the discussions of both workshop groups:

- Be cheap to use, and easy to learn.
- Have an up-to-date knowledge base that is maintained on a daily basis.
- Be such that it is very attractive for companies to give away their knowledge.
- Provide access to, or at least provide information on, other design tools.
- Generate and compare alternative solutions (energy use and economics).
- Show the consequences of the choices of the user on other discipline's work.
- Teach different disciplines about each other's work, without giving the illusion they do not need each other anymore.
- Have data on experience from practice, so it can be used as a learning tool for novices. Also an example-base should be linked to the KBS.
- Show possibilities and restrictions of the building codes.
- Support the briefing process.
- Include rules of getting funding.
- Allow the feedback of knowledge from the occupation stage.
- Provide turnkey calculations and estimations of future energy use.

These specifications have a high level of abstraction. The same kind of results was found in the other European workshops, (EIKS 1998).

4.2 EIKS-Demo

4.2.1 Requirements of the EIKS-demo

The EIKS consortium members involved in organising the European workshops identified the items considered most important by their participants. From these lists a summary has been made taking into account items that were on more than one list, and considered the functionality of the tool to be developed:

- Support decision-making.
- Be a communication tool, not a design tool; act only as a design assistant.
- Provide various levels of detail, depending on the viewpoint of the disciplines involved.
- Serve the expectations of owner/developer and user.
- Contain experience gained from good projects and also what not to do.
- Generate and compare alternative solutions.
- Provide warnings and highlight problem areas.
- Allow checking against rules and regulations.
- Be able to make approximations based on the preliminary information available.

The first two items show that the participants ask for a design decision support tool, rather than a knowledge based system. They are looking for a tool that supports the decision making process, helping the different parties involved in the design understand each others discipline. With this observation in mind, the EIKS-demo was designed and developed.

4.2.2 Information

During the EIKS project Integration DEFinition language 0 [IDEF0] diagrams have been used to define the functions needed to program the EIKS-demo. The software tools used to make the diagrams are called ERwin and BPwin. A brief description of the IDEF0 method can be found in Appendix C, the diagrams and the definitions used can be found in Appendix D. The following tables provide the information that was implemented; the functions between brackets in this section refer to the functions in the IDEF0 models. The user requirements for office lighting and the variables influencing the performance of office lighting, described in sections 3.2.3 and 3.2.4, were developed based on the EIKS brief and preliminary lighting model described in this section.

General brief - We assume that a briefing action outside the EIKS-demo has provided a list of demands relevant to lighting (function A1.1.1), see table 4.2.

Table 4.2: Briefing elements in EIKS.

Requirements	Value
General	
Project	CBO TNO-TUE
Country	The Netherlands
Location	Eindhoven, city centre
Building type	Office building
Space related	
Space type	Single cell office
Façade orientation	West
Obstruction from other buildings	None
Number of people	1
Average age	25-30
Type of activities	Administration
Building codes	
National requirements lighting	NEN 1890, NEN 3087
Illuminance	400 - 800 lux
Preferred horizontal luminance-ratio:	
Task-surrounding-periphery	10: 3: 1
National requirements energy use	NEN 2916
Dutch Energy Performance Norm	< 1.9

This list is based on the requirements that were set for the refurbishment of three cellular office rooms on the tenth floor of the main building of the TUE. With these ‘results’ the requirements for visual comfort and energy efficiency are set, (the legislative boundaries to the solution, function A1.1.2), also shown in table 4.2 under Building codes. The building code prescribes the illuminance to be between 400 and 800 lux, the preferred horizontal luminance-ratio between the task, the immediate surrounding, and the farther periphery to be 10 to 3 to 1, and the Dutch Energy Performance Norm to be less then 1.9. It also presents the code names for further reference.

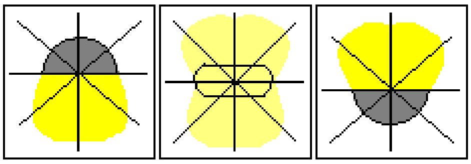
Additional lighting requirements - The program user must then provide characteristics relating to the client's requirements for lighting concerning the appearance of the space, daylight and artificial lighting (functions A1.2.1 and A 1.2.3) chosen from the concepts available as presented in table 4.3.

Table 4.3: Lighting requirements in EIKS.

Additional requirements	**Possible values**		
Appearance of the space			
Atmosphere	professional	general	not important
Locations of workplaces	window side	central	corridor side
Finish walls	light	medium	dark
Finish ceiling	light	medium	dark
Finish floor	light	medium	dark
Daylight			
Use of daylight	maximum	take into account	not important
Importance of view	very important	important	not important
Glare control	very important	important	not important
Artificial lighting			
Colour of lighting	warm white	white	cool white
Colour rendering	exact colour	natural colour	not important
Indirect/ direct lighting	indirect	indirect/direct	direct
Shielding	very important	important	not important
Energy efficiency	ideal	good	sufficient

These provide the client's boundaries to the solution that are translated into technical requirements by the EIKS-demo. Some examples of rules are provided by the EIKS-demo and are explained below.

Appearance of the space – For 'Atmosphere' the value 'professional' means a sophisticated appearance, and may imply that no cheap looking lighting concepts must be chosen (e.g. simple louvered luminaire). The value 'general' may imply that no fancy, expensive lighting concepts, nor cheap looking lighting concepts must be installed. The qualitative values of 'Locations of workplaces' can be expressed in meters away from the window, but is not applied in the EIKS-demo. If the choice for Finish wall is light, in the EIKS-demo the reflection factor of the walls then is between 60% and 70%, while medium implies 50 to 60%, and dark implies 40 to 50%. For the ceiling a light finish implies a reflection factor between 70% and 80%, medium implies 60 to 70% and dark implies 50 to 60%. If the colour of the floor is light this implies a reflection factor of only 30 to 40%, medium implies 20 to 30%, and dark implies 5 to 20%.



direct **indirect/direct** **indirect**

Figure 4.3: Lighting direction.

Daylight – 'Use of daylight', 'Importance of view', and 'Glare control' have no rules attached to it in the EIKS-demo.

Artificial lighting – The 'Colour of lighting' is made quantitative by using the colour temperature [T_{colour}] of the light produced by the light source. If 'warm white' is chosen T_{colour} must be between 2900 and 3300 Kelvin, 'white' implies a T_{colour} between 3300 and 5000 Kelvin, and 'cool white' implies a T_{colour} of more than 5000 Kelvin. For 'Colour rendering' the rendering factor R_a is used. If the exact colours must be visible, R_a must be between 90 and 100%. For natural colours R_a can be between 80 and 90%. The choice for 'Indirect/ direct lighting' restricts which luminaires can be installed, depending on where the light actually exits the luminaire, see figure 4.3. However, in the EIKS-demo no division is made in direct or indirect luminaires. The 'Shielding' could be expressed in the angle of the light exiting the luminaire, but this is not included in the EIKS-demo. Finally, the values for 'Energy efficiency' of the artificial lighting system are translated into numbers: 'ideal' (installed power then is between 0 and 10 Watt/m^2), 'good' (installed power then is between 10 and 20 Watt/m^2), or 'sufficient' (installed power then is between 20 and 50 Watt/m^2).

Daylight system - The daylight system can now be established. The EIKS-demo only provides concepts that meet both client's and legislative requirements, together with textual information on the energy performances and sometimes a drawing of these concepts to support the user's selection. The user can select from the total daylight system examples (function A2.1.2) or from windows (A2.1.3.1), architectural features (A2.1.3.2), and additional elements (A2.1.3.3) to 'compose' their own total daylight system, see table 4.4.

Artificial lighting system – To the selected daylight system, an artificial lighting system must be added. The user can either select a total artificial lighting system (function A2.2.2) or compose one by selecting the lighting distribution (A2.2.3.1), the lighting source (A2.2.3.2) and the luminaire (A2.2.3.3), see table 4.5.

Integration of both systems - To integrate the two selected systems the user has to specify the control, maintenance, dimensions and materials (function A2.3.2). These depend on the selected daylight and artificial lighting system, see table 4.6.

Table 4.4: Daylight concepts in EIKS.

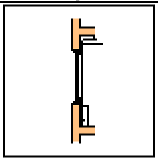
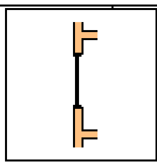
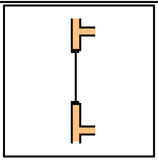
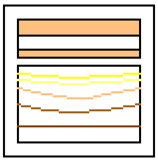
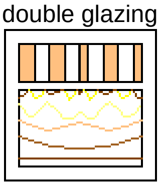
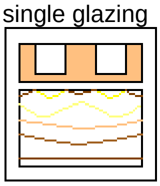
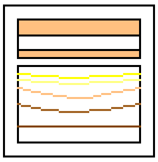
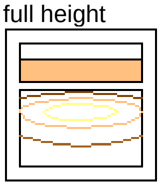
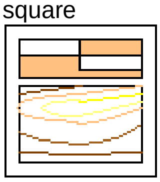
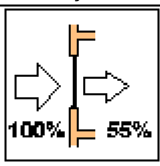
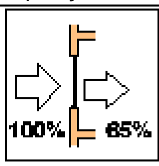
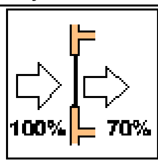
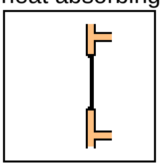
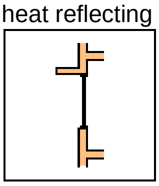
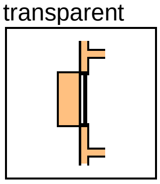
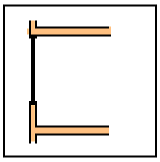
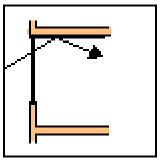
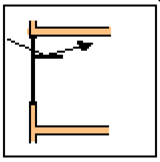
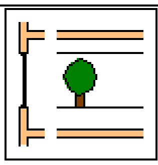
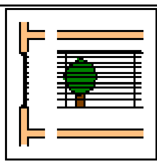
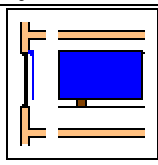
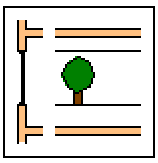
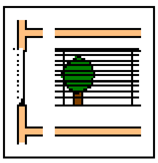
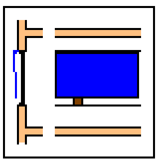
Variables	Concepts			Explanation
Windows				Profiles of façade.
Type	air exhaust	double glazing	single glazing	
				View on outside façade and light distribution on the floor.
Shape	full width	full height	square	
				
Position	mid façade	top façade	asymmetric	
Architectural features				Percentages indicate amount of light transmitted through glazing.
Glazing	heat absorbing	heat reflecting	transparent	
				Profiles of façade.
Outside	none	horizontal shading	vertical shading	
				Profiles of façade, indicating redirected light rays.
Inside	none	mirrors	light shelves	
Additional elements				Profiles and inside view of façade, visualising view out of window.
Inside	none	Venetian blind	roller blind	
				
Outside	none	Venetian blind	roller blind	

Table 4.5: Artificial lighting concepts in EIKS.

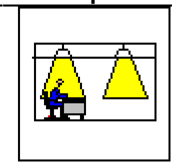
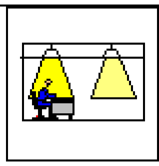
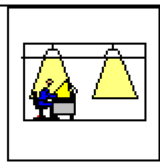
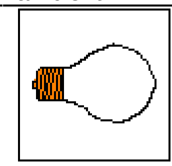
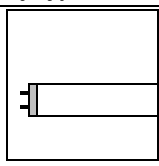
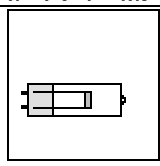
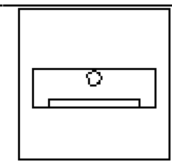
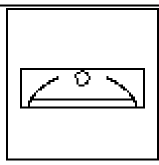
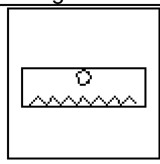
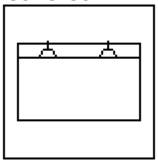
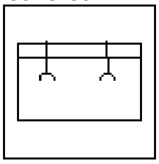
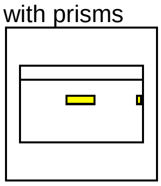
Variables	Concepts			Explanation
Lighting distribution	 ambient	 zoned	 ambient + task	Profiles of room, indicating distribution of light.
Lighting source	 incandescent	 fluorescent	 halogen	Profiles of light sources.
Luminaire Type	 louvered	 louvered + mirrors	 with prisms	Profiles of luminaires.
Position	 ceiling mounted	 pendent	 wall mounted	Profiles of room, indicating luminaire position.

Table 4.6: Integration concepts in EIKS.

Variables	Concepts		
Control			
Control automation	by hand	daylight control	Occupancy
Switch	switch	switch + dimmer	Dimmer
Position	local	local + central off	central on + off
Maintenance			
Relamping	Spot	group	spot + group
Cleaning	at relamping	every month	every 6 months
Dimensions			
Materials			

Evaluation - Finally, the results of evaluating the performance in providing visual comfort and energy efficiency, together with initial costs, installation aspects, and maintenance of the integrated lighting system are visualised (function A3.2). In the EIKS-demo this evaluation is based on calculating the average of randomly chosen values between -5 and +5 that were attached to each of the implemented concepts for the five performance indices considered in the EIKS-demo. It is possible to repeat the design process and compare the results of two different solutions. The implemented performance values in the EIKS-demo have not been validated with lighting experts, as opposed to the values in the ILSA-prototype.

4.2.3 Designing the user interface of the EIKS-demo

It is important that the user interface appeals to the user, (the architect, and structural or service engineer). Instead of numbers s/he should be provided with pictures and drawings etc. to visualise the consequences of design decisions. As visual information is regarded very important to the designer, the input has been visualised at every decision point in the EIKS-demo.

The top of figure 4.4 shows the main screen of the EIKS-demo that is divided into three summary boxes: design requirements, design decisions, and design performance evaluation. These summary boxes reflect the three main processes in the EIKS-demo as shown in the IDEF0 diagram A0: design requirements are the result of 'Determine lighting system requirements' (function A1), design decisions are the result of 'Establish total lighting design' (function A2), and design performance evaluation is the result of 'Evaluate (alternative) lighting system(s)' (function A3).

In IDEF0 diagram A1, the first process is subdivided into two sub-processes: 'Transform brief into requirements for visual comfort and energy efficiency' (function A1.1) and 'Determine lighting requirements' (function A1.2). Figure 4.5 reflects these two processes with two tab-forms: *External requirements from the brief*, determined outside the EIKS-demo but within an intelligent front-end and *Additional requirements*, determined within the EIKS-demo, and needed to specify the client's boundaries for the lighting design. The first tab-form provides a list with requirements relevant for lighting systems, including legislative requirements. The second provides a list of thirteen items for which a decision must be made. For

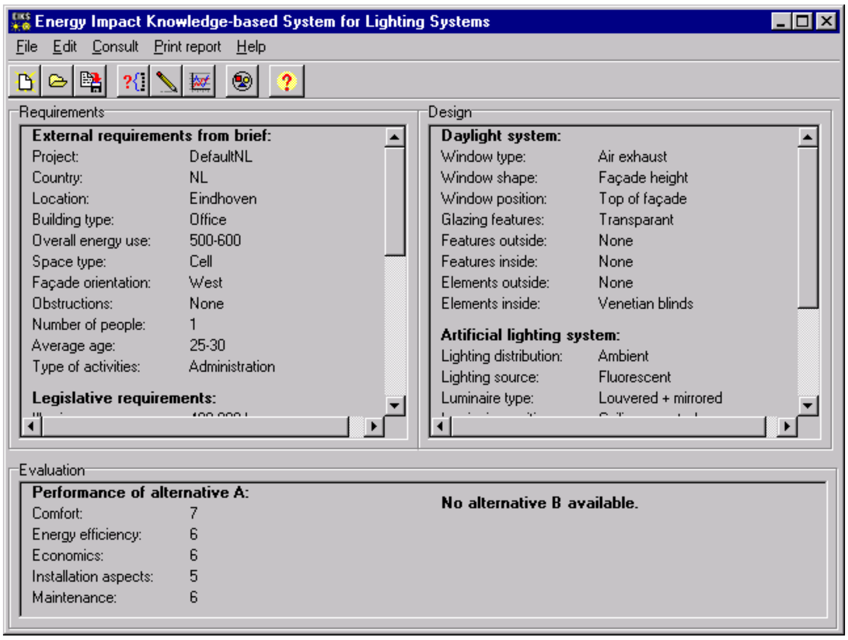


Figure 4.4: Main screen of EIKS.

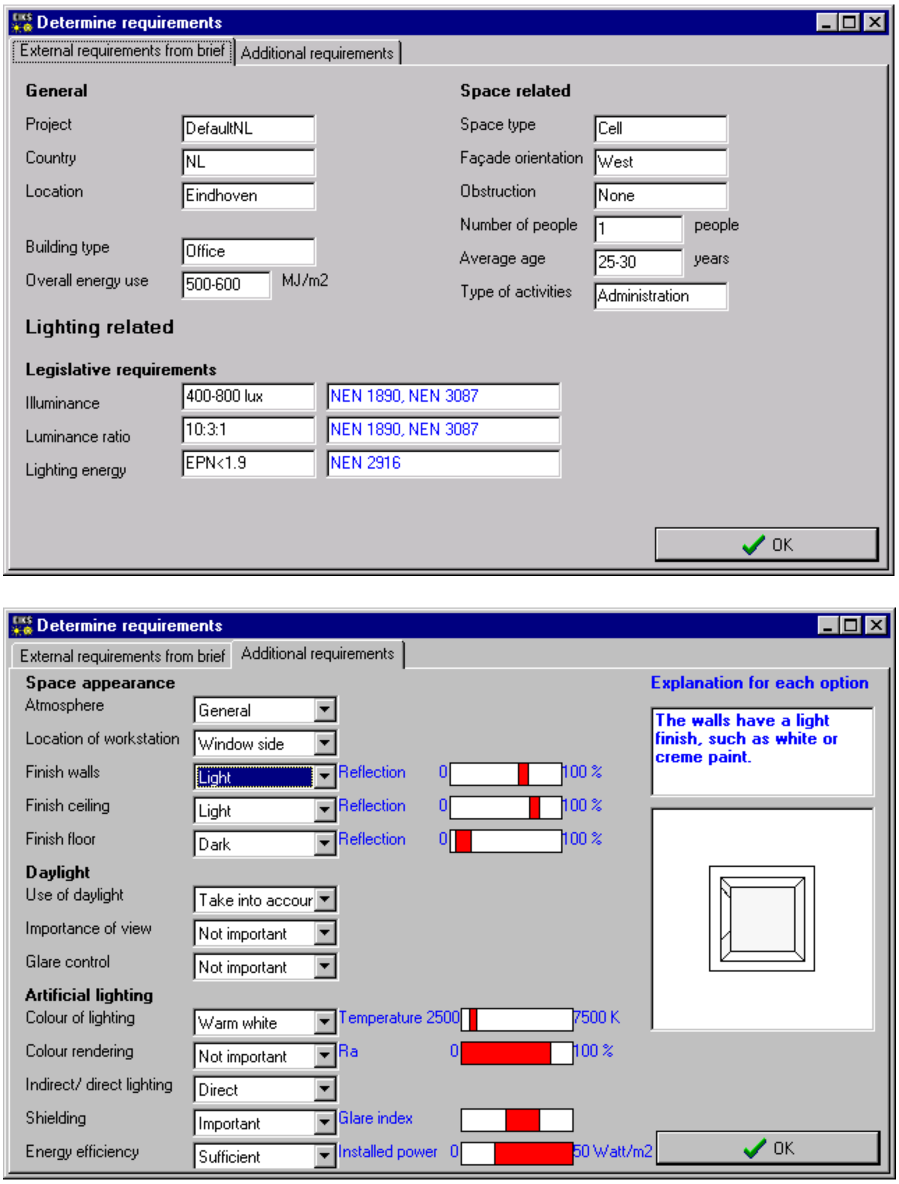


Figure 4.5: Requirements screens of EIKS.

seven of these the choice is translated into a number; for other six reasoning should be done with strings. For all of them an explanatory description is given.

In IDEF0 diagram A2 the second process is subdivided into three sub-processes: ‘Select daylight system’ (function A2.1), ‘Select artificial lighting system’ (function A2.2), and ‘Establish integrated lighting system’ (function A2.3). The EIKS-demo integrates a Daylight system and Artificial lighting system; these are the only two building systems that can be selected in the upper part of the screen in figure 4.6.

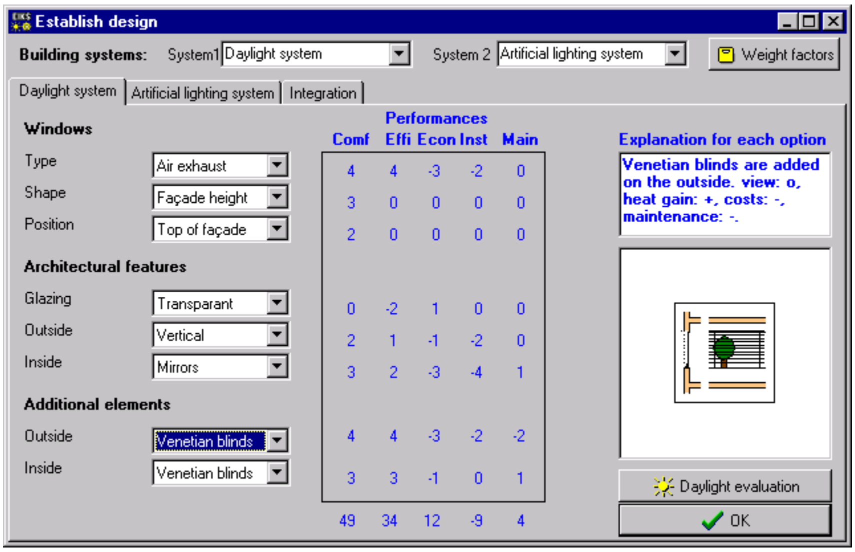


Figure 4.6: Design screen of EIKS.

Each of the three tab-forms reflects one of the sub-processes and consists of items for which a decision has to be made. For each concept five numbers are provided indicating the performance values for Comfort, Energy efficiency, Initial costs, Installation aspects, and Maintenance. The figures of each similar column on all three tab-forms are added at the bottom of the column. For all item-concepts a description and a figure are given. The weight factor for each performance index must be defined after all design decisions are taken.

The third process 'Evaluate (alternative) lighting system(s)' is provided in figure 4.7. The performance values of the integrated lighting system that is currently designed are shown in the field of 'Performance of alternative A'. If the user wishes to evaluate an alternative system s/he can copy the performances of the currently designed lighting system to the field of alternative B, save it, and change the decisions made. The performance of the new alternative is shown in the field of alternative A. In the lower part of the screen the performance is shown diagrammatically.

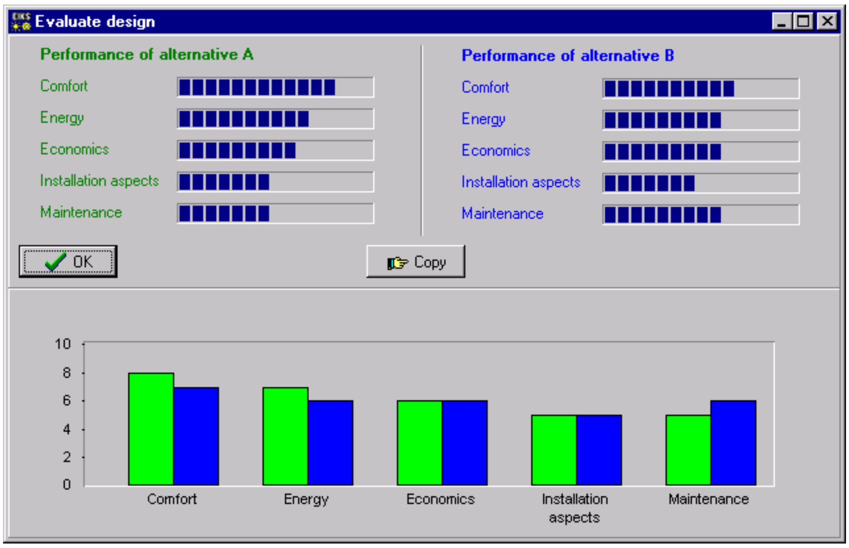


Figure 4.7: Evaluation screen of EIKS.

4.2.4 Implementation of workshop results

European workshop results that were considered most important by the consortium members have been presented in section 4.2.1. The information flows and user interface having been described in the previous sections, it is now possible to evaluate how these requirements have been implemented in the EIKS-demo. In this section an explanation is given whether and how these have been implemented.

Support decision-making - Support for decision making is provided by showing the consequences of the decisions at the stage of determining requirements for the brief and by showing the performance values of each concept when certain design decisions are made.

Be a communication tool, not a design tool; act only as a design assistant - At each design option, a description and sometimes an image explains briefly the type, function and impact of such a choice on the overall performance of the design.

Provide various levels of detail, depending on the viewpoint of the disciplines involved - This has not been taken into account in the EIKS-demo. The objective was to provide an assist-function of which the depth of the contents depended on the user's background. Each of the building team members would have his or her own help-file and user interface. Initially, it was decided to focus on the architect.

Serve the expectations of owner/developer and user, e.g. easy to understand - The user interface is very user friendly: it is designed according to the five criteria presented by Bidgoli (1989) described in section 3.1.4. A help-function can guide the user if needed.

Contain experience gained from good projects and also what not to do - The goal is to feedback experience gained from real projects. The project memory can be extended with cases from practice. Two Dutch cases are already available.

Generate and compare alternative solutions - Alternative concepts of solutions are given for each decision that is needed to determine the requirements or to establish the design, together with information on the consequences or the performance. Two complete lighting systems can be compared.

Provide warnings and highlight problem areas - This has not yet been included due to a lack of available knowledge. A survey is needed in the field of expertise on lighting systems, e.g. a workshop with lighting experts, to find solutions for one or more cases, indicating the problem areas.

Allow checking against rules and regulations - The legislative requirements for the particular project are determined. Only decision-concepts meeting these requirements are shown. In the future it may be possible to show all available concepts indicating (by using different colours) those which meet the requirements (green), which meet the requirements within a certain bandwidth (orange), and which do not meet the requirements (red).

Be able to make approximations based on the preliminary information available, e.g. "rules of thumb" - No suitable rules of thumb for lighting were found. Most of the calculations need detailed information that is not available in the conceptual design stage. Working with defaults as has been done by other researchers, for example Papamichael (1998), does not appeal because the choice of defaults may have a large impact on the evaluation. Instead the first steps towards an evaluation method for conceptual designs were implemented in the EIKS-demo. Here it is based on randomly determined performance values, but for ILSA this method will be improved, using the psychophysical multi-attribute utility theory.

4.3 EIKS-demo Evaluation Workshop

4.3.1 Problem and objectives

The objective of the follow up workshop was to have a discussion on the program's general structure and functionality and to evaluate the way the specifications were implemented, without looking in too much detail at the contents and operation. In each of the four participating countries a follow-up workshop has been organised with some of the same building experts that participated in the first workshops.

In this section only the results of the Dutch workshop are reported.

4.3.2 Participants

In total, fourteen building industry experts from different companies and organisations attended the workshop. For the discussion part of the workshop, the group was divided over two separate rooms:

Table 4.7: Participants to the Dutch follow-up workshop.

Participants Workshop group 1			**Participants Workshop group 2**		
User/ Building manager	1	(14%)	Users	0	(0%)
Architects	0	(0%)	Architect	1	(14%)
Constructor	1	(14%)	Constructor	1	(14%)
Consultants	2	(28%)	Consultant	1	(14%)
Building service engineers	2	(28%)	Building service engineers	2	(28%)
Researcher	1	(14%)	Researchers	2	(28%)

4.3.3 Timetable

Both discussion groups of building experts were given the timetable presented in figure 4.8.

The introduction reported on the progress of the EIKS project, provided a summary of the results of the earlier Dutch workshops, and presented the goals and objectives of these workshops. The EIKS-demo for lighting systems was demonstrated.

For the discussion period the group was divided over two separate rooms. Each discussion started with an introduction of each participant, which included their profession, company's background, and use of computers in the company. Further, a general opinion on the EIKS-demo was requested. The formal discussion topics were:

- disciplines within the building industry that will benefit from the tool

Timetable:	
9:30	Introduction
10:00	Demonstration EIKS-demo
10:30	Coffee & Tea
10:45	Discussion in two groups
11:45	Summary results per group
12:00	Lunch
13:00	Evaluation
15:00	End

Figure 4.8: Timetable of the Dutch workshops from the second series EIKS workshops.

- existing computer programs that should be linked to the tool
- functions of the tool
- conditions for using the tool

After the one-hour discussion the groups were reunited and the results were summarised.

4.3.4 Results workshop group 1

The disciplines in a building team that can benefit from the tool - All disciplines involved in the early stages of the design process can benefit from the tool. There are two possible uses: the first is when the architect uses the tool to design a standard workplace without having the other experts around; the second is when consultants use it to design their parts of a complex workplace. According to the discussion group, the tool should support both uses.

Existing programs that need to be linked to the tool - According to the discussion group, most relevant programmes commonly in use in practice should be linked to this tool to prevent entering the same data twice. The tool should, however, be able to perform some simple estimations itself. When input is missing the tool should indicate this and also provide methods to find the missing input (by referring to other computer programmes).

The functions of the tool - Regarding the visualisation of the requirements by using ranges or bandwidths, it is desirable to distinguish between good, better, and best concepts.

- It should be clear and traceable how the tool determines its results and recommendations. The user cannot trust results if s/he does not know how these were determined.
- The user should be able to expand and maintain the knowledge base. The general part can be maintained per specific knowledge field.
- More research is needed into which performance indices influence the design and each other. ‘Flexibility’ is one of the missing performances. The performance ‘comfort’ should be divided into comfort in summer and comfort in winter.

The conditions to use the tool - One of the conditions for use is that it should be possible to support the very preliminary up to, and including, detailed design. Therefore, it is important to identify different levels of detail.

4.3.5 Results workshop group 2

The disciplines in a building team that can benefit from the tool - The tool is very suitable for supporting the definition of a brief and conceptual design of lighting systems. It provides the possibility to compare various alternatives quickly, but roughly. Especially architects will use the tool, but they will still need advice from other experts to explain the exact consequences of their decisions.

The existing programs that need to be linked to the tool - It is not desirable to link component libraries and specialised tools to this system. It is found that for Dutch cases it is desirable to implement the Energy Performance estimation from the Dutch building code.

The functions of the tool

- The subjective performance indices, such as 'well-being', should get more attention, although these are difficult to implement.
- The behaviour of the occupants of the space should be taken into account.
- Warning flags when problems are anticipated are missing.
- Changes in the values of the default reference case should be made visible.

The conditions to use the tool

- The knowledge in the system should be kept up-to-date. It is suggested to make the new versions of the knowledge base available over the Internet.
- The time that is needed to establish a design must be short, e.g. in the order of a couple of hours. Using default reference cases helps to speed up the design process by reducing the amount of input required.

4.3.6 Conclusions of the follow-up workshop

Although in the EIKS proposal there was no time allocated to organise follow-up workshops, the consortium agreed to use this opportunity to show the EIKS-demo to some of the same building experts that participated in the first workshops and gather their feedback.

From the generally enthusiastic response of participants during the workshops it can be concluded that the EIKS-demo provides a good basis for further development. However, it was clear that much effort is needed in order to realise a final, operational system: an information and decision support system for energy efficient building. During the plenary discussion after the demonstration of the EIKS-demo, several points were mentioned that could be improved:

- Visualise the solution more clearly.
- Visualise the evaluation results more clearly, with for example a radar chart.
- Flexible evaluation of performance indices, to be selected by the user.

The system is designed to be used during the early stages in the design of utility buildings, mainly office buildings. During the workshops it was found that application by two possible types of end-users could be identified:

1. The architect, who uses the tool to design a standard workplace.
2. The consultant, who uses the tool to design a part of a complex workplace.

If both applications should be made possible, support should be provided for different levels of expertise. Expert level users will need linkages to specialised evaluation tools found in different fields of building engineering.

The functionality of the EIKS-demo is based on the findings of earlier workshops. What still is missing are warning flags to indicate area's where problems can be expected. It was also found that more performance indices of the lighting system should be evaluated such as: 'flexibility': how easy is it to adapt the lighting system to changing requirements, and 'well-being': not only the minimum requirements, but also the optimal requirements should be taken into account. This last issue implies that the user of the tool should be made aware of the fact that sometimes just meeting the requirements is not enough.

The most important issues surrounding the use of the tool in practice were found to be: 'the time needed to design' (with the tool) and 'maintenance of the tool' (keeping it up-to-date).

4.4 Further development of the tool

At the end of the EIKS-project it was decided to continue the design project outside any consortium, because at that time no immediate project was granted in which the design project could be incorporated, except of course the Building Evaluation Project at TUE. At this point, this long-term TUE project, described in section 1.1.3, is aiming at the design of a modular system that can communicate with all kinds of (already available or new) systems. In the system itself no calculations will be done (only estimations), but links to (existing) calculation and simulation packages will be developed. Each of the different professions in the building industry can benefit, because an intelligent front end to the network will guide them in the right direction, see also (DECISION 1997). In the Building Evaluation Project it was decided, for the time being, to focus on only one kind of user: the architect, and on only one function type: an office workplace.

For the design project it was decided that the EIKS-demo would be developed further to become one of the modules of this network, focusing on the conceptual design of office lighting systems and aiming at the architect as possible future user, as was described earlier in section 2.3. At the same time, another researcher in the team began to focus on the translation of the client's wishes into technical requirements, using the case-base approach, (Mallory-Hill 2000). This implied that to prevent that double work would be done, the briefing stage of the early design stages became no longer a topic of the design project and that the case base function in the EIKS-demo would no longer be a topic of further development. All these changes to the EIKS perspective made it necessary to continue the project with another name: ILSA, Integrated Lighting System Assistant.

For ILSA we presume that the brief is generated externally implying that no changes can be executed to the brief within ILSA. As the link with the briefing tool of the Building Evaluation Project not yet exists, we chose to work with a specific brief for a specific office lighting design. This brief is based on the requirements that were set for the refurbishment of three cellular office rooms located on the tenth floor of the main building of the TUE, as has been explained in section 3.2.3.

Further we developed and implemented the model for conceptual office lighting design, described in section 3.2.4 and a performance evaluation method based on the psychophysical method, described in section 3.2.5.

For the functionality and the user interface of ILSA the findings of the EIKS-demo evaluation were taken into account:

- A virtual reality viewer to visualise the solution has been developed.
- A radar chart to visualise the evaluation results has been developed.
- It has been made possible for the user to select the performance indices that are preferred for evaluation.

How this is done will be explained in the chapter 6, *DDSS for Office Lighting: ILSA.*

Chapter 5

DESIGN OF OFFICE LIGHTING SYSTEMS

At the end of the EIKS-project it was decided to continue the design project outside any consortium and continue the project in the Building Evaluation Project, as was explained in section 2.3.3 and 4.4. As opposed to the EIKS project this TUE project initially is focusing on only one kind of user: the architect, and on only one architectural system level: an office workplace. From then on, these formed the target area for the design project, as well. Further, the briefing stage of the early design stages was no longer topic of the design project and the case base function in the EIKS-demo was no longer topic of further development, because these research fields are being addressed by another researcher in the Building Evaluation Team, (Mallory-Hill 2000).

The models for EIKS were adapted according to these changes. The revised process and lighting model for the new tool, Integrated Lighting System Assistant [ILSA], are described and explained in the following sections 5.1 and 5.2. After the first revision, the lighting model was validated in consultation with six experts in the field of daylight and artificial lighting during face-to-face interviews. The results of this validation are presented in section 5.2.3. Further, the implementation of the evaluation method based on the psychophysical method is described in section 5.3, and the adaptations made to the user interface are described in section 5.4. Finally, the results obtained during the third, and final, workshop are presented in section 5.5. During this final workshop, for which again an electronic meeting room was used, the revised lighting model and the performance evaluation method were validated with thirteen, mainly lighting, experts.

5.1 ILSA Process model

During the EIKS project, preliminary process and data models were made with the software tools ERwin and BPwin, see section 4.2.2. For ILSA these models were translated and adapted in PowerDesigner 6.0, because the tools within this package, Data Architect and Process Analyst, were more user friendly than the software used earlier. Further, the package includes a tool, AppModeler, with which the models can be directly transferred into Delphi or other software environments. This characteristic has not been used in this design project, but may be useful in future projects.

The schematic diagrams of the ILSA process model are shown in figures 5.1 to 5.4. The processes that take place within ILSA are presented as circles. When a process name contains a '+', this process will be elaborated on in another schematic diagram. The user of ILSA and other means are projected as squares linked to ILSA, (solid lines). Dashed lines indicate future links. When links are split up into two links a small circle will appear to indicate the junction. Links to processes will appear as links to small diamonds with a circle inside. Links to other means will appear as links to an empty diamond.

The first diagram, figure 5.1, shows the first level of processes happening in ILSA. The main process is supporting the *User of ILSA* with the development of *Conceptual design of lighting system*. This process is supported by a *Design database*, that contains data on the performance values of all the possible concepts for all variables, and an *Example case base*, that contains examples of integrated daylight and artificial lighting systems. The process will be supported by an *Intelligent briefing tool* when this tool becomes available in the future. The *User of ILSA* can enter the *Conceptual design of lighting system* in the *Example case* base through a *Feedback of knowledge* process.

This first diagram is almost the same as the first diagram for EIKS in figure D.1. The main process, the *Design data bases*, and the *Example case base* are similar. Further, the *Intelligent briefing tool* in ILSA may be considered to be the provider of the *General brief* in EIKS. Different are the positions of the *User of the tool* and of the final result: *Conceptual design of lighting system*, and a new process appeared: *Feedback of knowledge*. As opposed to EIKS, for ILSA we presume that the user is working on a conceptual design and during this design process s/he is supported by ILSA and s/he can decide to store the result or not.

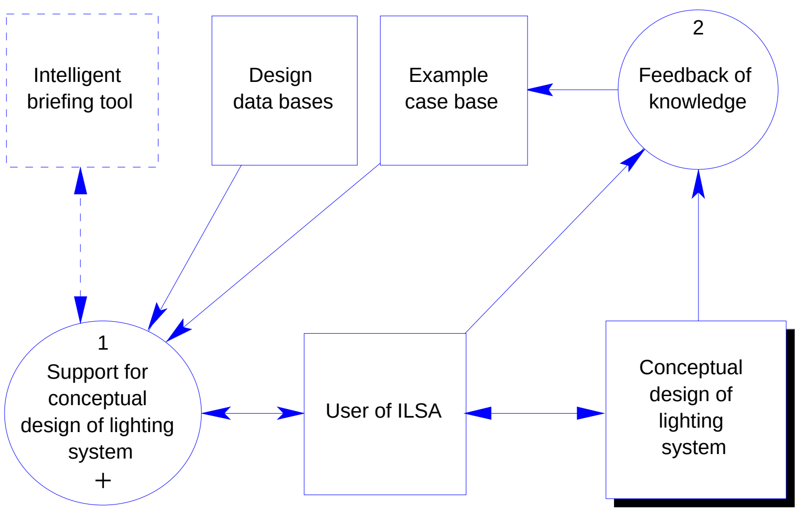


Figure 5.1: First level of the process model for ILSA.

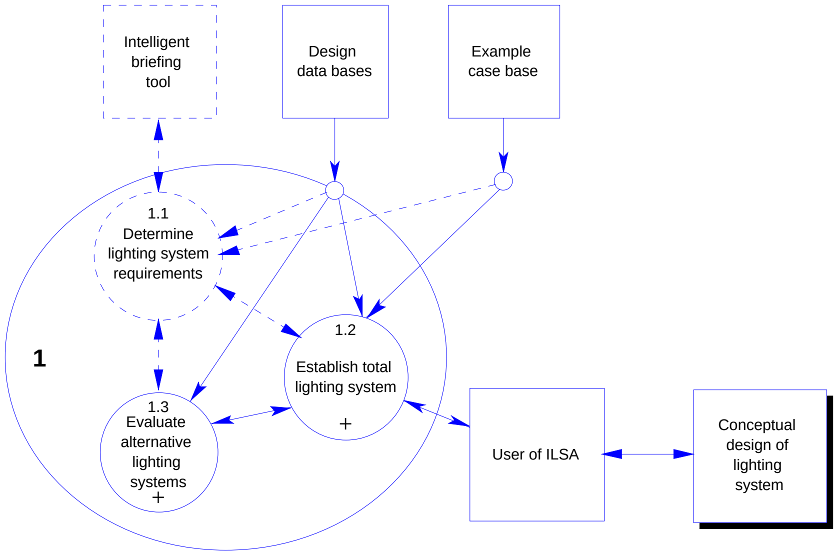


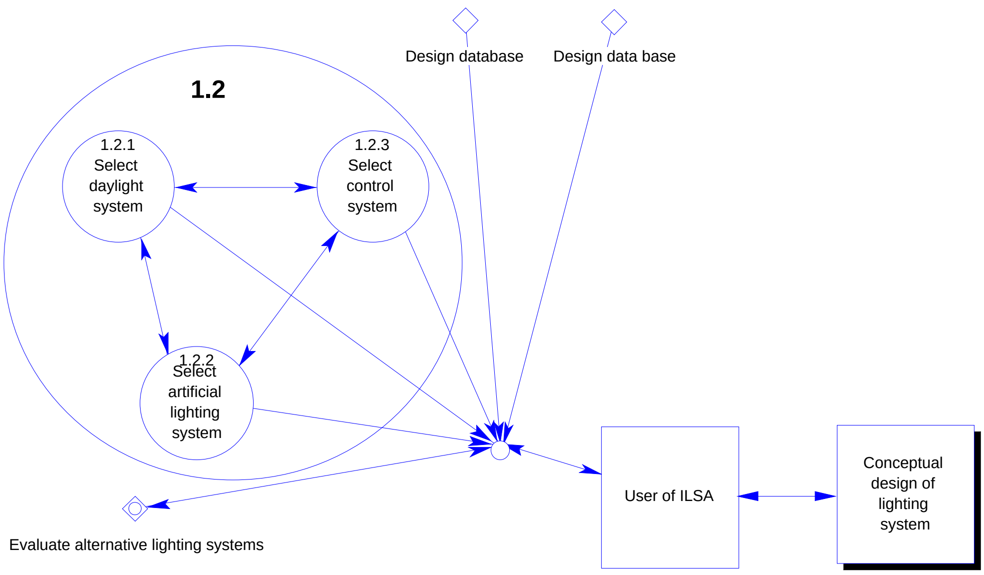
Figure 5.2: Second level of the process model for ILSA: 'Support for conceptual design of lighting system'.

Zooming in on the process: *Support for conceptual design of lighting system*, figure 5.2, three sub-processes appear: *Determine lighting system requirements*, *Establish total lighting design*, and *Evaluate alternative lighting systems*. This second ILSA diagram is almost the same as the subdivision of the first sub-process for EIKS in figure D.2. The three processes in both diagrams are identical. The differences mentioned before in the first model (position of the user and the final result) can be recognised in these diagrams, as well.

The first sub-process has not been implemented in ILSA, thus the IDEF0 diagrams A1, A1.1, and A1.2 of EIKS, figures D.3, D.4, and D.5, have not been revised.

The subdivision of the second sub-process for ILSA is shown in figure 5.3 and is almost similar to the second sub-process for EIKS in figure D.6. Only the third process, of the three processes within both diagrams, is called differently; for EIKS the third process aims at integrating the two designed systems, but in ILSA a third system is added: the control system. The subdivision of this process for ILSA is not shown in this thesis. However, the IDEF0 diagrams A2.1, A2.1.3. A2.2, A2.2.3, and A2.3 of EIKS, figures D.7 – D.11, have been implemented similarly in ILSA.

The subdivision of the third sub-process for ILSA is shown in figure 5.4 and is not similar to the subdivision of the third sub-process for EIKS in figure D.12. The evaluation method developed for ILSA is visualised in figure 5.4. Each of the values for the five performance indices is determined, and the values for alternative solutions are visualised, as well, in order to make comparison possible. At the time the EIKS diagrams were made this evaluation method was not developed yet, thus a more general description is given in IDEF0 diagram A3: *Retrieve specifications of the total lighting system*.



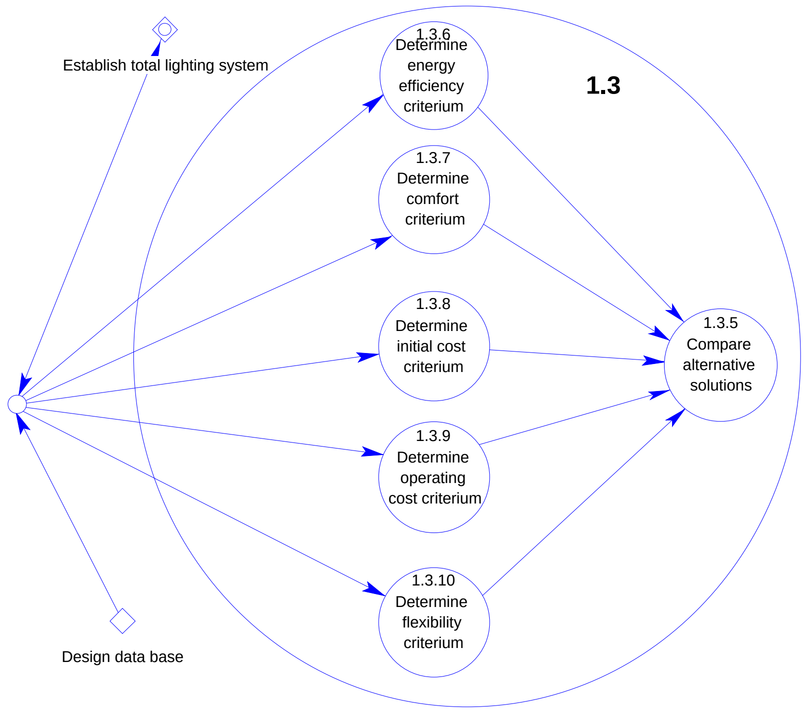


Figure 5.3: Third level of the process model for ILSA: 'Establish total lighting design'.

Figure 5.4: Third level of the process model for ILSA: 'Evaluate alternative lighting systems'.

5.2 ILSA Lighting model

5.2.1 Revised model

For this design project a lighting model has been developed consisting of all relevant variables that influence the performance of an office lighting system. The preliminary lighting model of the EIKS-demo has been derived from the information flows described in section 4.2.2 and was revised in consultation with one lighting expert. The differences between the EIKS model and the lighting model before the interviews are clarified in table 5.1.

Table 5.1: Differences in lighting model between EIKS and the model before interviews.

EIKS lighting model		**Lighting model before interviews**
Daylight	=	*Daylight*
Window type	=	Façade type
Window shape		
Window position	=	Window position
		Window area
Glazing type	=	Glazing type
Features inside	=	Features inside
Features outside	=	Features outside
		Features façade
Elements inside	=	Elements inside
Elements outside	=	Elements outside
Artificial lighting	=	*Artificial lighting*
		Light direction
Lighting distribution	=	Lighting distribution in room
Lighting source	=	Lighting source
Luminaire position	=	Luminaire position
Luminaire type	=	Luminaire type
Integration	≠	*Control & Maintenance*
		Daylight control (automation)
Control automation	}	Control option (switch)
Control switch		
Control position	=	Artificial control (position)
Maintenance relamping	=	Maintenance relamping
Maintenance cleaning		
Dimensions/ Materials		

The third category in EIKS was called *Integration* and involved ‘Control’, ‘Maintenance’, ‘Dimensional’, and ‘Material issues’. Following the proposals of the lighting expert, only the control issues and relamping remained because the other issues did not seem appropriate for the conceptual design stage. ‘Control automation’ and ‘Control switch’ are captured together in ‘Control option’ and ‘Daylight control’ (controls the shading devices) has been added. The variable ‘Window shape’ in the section *Daylight* has been removed, and ‘Window area’ and

‘Features façade’ have been added. The element ‘Light direction’, which was part of the brief in EIKS was added to the section *Artificial lighting*.

5.2.2 Interviews experts

Interview outline - The revised lighting model described in section 5.2.1 was validated with five lighting experts and one architect during face-to-face interviews. Each interview lasted approximately one-and-half-hour and consisted of three parts.

The first part involved a list of requirements for a particular workplace. The experts might add or adapt requirements to obtain a well-defined brief that would act as the boundary conditions for the design task of the second part.

During this second part the lighting model itself was validated by allowing the experts to select a concept for each of the eighteen defined variables and establish an office lighting system for the workplace that met the boundary conditions defined in the first part. The experts were invited to add additional variables.

For the third part the persons ranked visual comfort, energy efficiency, initial costs, and operating costs of their solution, in respect to a standard solution that was provided, see table 5.2. Further they explained how their solution could be made more energy efficient, and if and how visual comfort could be increased for their solution.

The functional brief - The standard brief that is implemented in ILSA is presented in table 5.2 and corresponds with the brief described in section 3.2.3.

Two requirements were added:

Luminance ratio – This prescribes the maximum luminance ratio: the luminance level on the task may be approximately three times higher than the luminance of the immediate surrounding and approximately ten times higher than the luminance of the periphery.

Flexibility of the artificial lighting system – This indicates how easy, (in time and costs), it will be to adapt the artificial lighting concepts in the future if required.

The last two mentioned requirements for artificial lighting in table 5.2, *energy use* and the just added *flexibility*, have not been included in ILSA as requirements, but as performance indices: the ‘overall energy efficiency’ and ‘flexibility of the total lighting system’. Other requirements that were mentioned by only one or two experts, such as ‘height of the work plane’, ‘vertical illuminance’, ‘exact orientation of the desk in relation to the window’, ‘relation between architecture and lighting’, ‘kind of ceiling’, and ‘colour of the window frames’, were not yet taken into account.

Table 5.2: Standard brief implemented in ILSA.

Requirements	Value
General	
Country	NL
Location	Eindhoven
Building type	Office
Room type	Cell: 3.60 x 5.40 x 2.80 m3
Orientation	West
Obstruction	None
Number of people	1
Average age	45-50 year
Activities	Administration, PC
Luminance ratio (added later)	10:3:1 (NEN 1890)
Standard illuminance	400-800 lux (NEN 1890)
Appearance of the room	
Atmosphere	Professional
Location workstation	Window side
Colour walls	Light
Colour ceiling	Light
Colour floor	Medium
Daylight	
Use of daylight	Maximum
View	Important
Avoidance of window reflectance	Important
Artificial lighting	
Light colour	Warm white
Colour rendering	Natural colours
Equality of light on the work plane	High
Shielding of luminaire	Important
Energy use (not included)	Minimum, meting other requirements
Flexibility (added later, not included)	Average

Lighting model - The changes made to the lighting model following the results obtained during the interviews are illustrated in table 5.3.

The lighting model now consists of three sub-systems, each of which is influenced by its variables. This has been done to make the structure match the 3D model described in section 2.1 more closely. The item relamping has been deleted, because this maintenance issue cannot be a part of a sub-system.

For several elements very relevant additional concepts were given, such as vertical blinds to be added to elements inside. Nevertheless, we chose to allow only three concepts per variable, with a few exceptions to this rule: control options, luminaire type, and window area type.

Daylight - The daylight section has not been changed, except for the variable ‘window position’ which was renamed to ‘window orientation’, because this name reflects the contents better. Two experts would like to determine the colour of the window frame to be able to influence the contrast within the surface of the façade. Both experts also selected the concept ‘Bevelled edges’ for ‘Features façade’, which also implies less contrast. Apparently, reducing contrast can be considered a main concern of those two experts. Nevertheless, determining the colours of the frames has not been added.

For their design solutions meeting the brief of table 5.2, four experts chose for the traditional cavity wall, with indoor venetian blinds. One of them added a reflecting ceiling, and another expert added bevelled edges.

Table 5.3: Differences in lighting model between the model before interviews and the model implemented in ILSA.

Lighting model before interviews		**ILSA lighting model**
Daylight	=	*Daylight variables*
Façade type	=	Façade type
Window position	=	Window orientation
Window area	=	Window area
Glazing type	=	Glazing type
Features outside	=	Features outside
Features façade	=	Features façade
Features inside	=	Features inside
Elements outside	=	Elements outside
Elements inside	=	Elements inside
Artificial lighting	=	*Artificial lighting variables*
Light direction	=	Light direction
		Target illuminance
Lighting distribution in room	=	Light distribution in room
Lighting source	=	Light source
Luminaire position	=	Luminaire position
Luminaire type	=	Luminaire type
Control & Maintenance	≠	*Control variables*
Daylight control	=	Daylight control
Control option	=	Control option
Artificial control	=	Artificial lighting control
Maintenance relamping		

Artificial lighting - To the artificial lighting section the variable ‘Target illuminance’ has been added. This is needed because the brief only provides the range in which the designer must select his or her preferred illuminance level. One of the experts indicated that the range that is given is extracted from Dutch regulation and soon all designs must meet the European regulations. The brief must be adapted when this occurs. A few experts would like to determine the orientation of the luminaires in respect to the window. Another suggestion, to add accentuating lamps, is not concretised, because this is not commonly applied in office rooms (and furthermore difficult to conceptualise). The concepts for lighting source were changed from three types of straight fluorescent lamps into straight and compact fluorescent lamps and halogen lamps. Also the set of luminaires has been increased, because luminaires for indirect light directions were missing.

For their design solutions, all experts chose for a straight fluorescent lamp inside a mirrored luminaire. Two of them chose for a direct light direction and three persons chose for a combined direct-indirect light direction.

Control - Because the item 'relamping' has been removed from the Control & Maintenance section, this section is renamed to Control section. One expert suggested adding the control option for pre-set dim-positions. This seems to be more relevant for multi-used rooms, such as conference rooms. As soon as these are considered, this must be taken into account.

For their design solutions, most experts chose for daylight control: per room manually, and for artificial lighting control: per room, daylight sensor. A few experts also added an occupancy sensor.

Ranking the solution - As was expected, ranking of solutions is found to be very subjective. Two almost identical solutions were ranked similarly on only two of the four performance indices. For the other two indices one solution was ranked two steps higher than the other solution. This indicates that one expert is more confident on the performance of his or her solution than the other. Two other rather similar solutions (although different in more variables than the other two) are ranked exactly the same for three performance indices. However, the performance value of the fourth index of one solution is ranked three steps higher compared to the other.

Conclusions of the interviews – The lighting model has been validated and adapted with five lighting experts and one architect. We found that only small adjustments had to be made to make them all agree on the final model. It is obvious that every expert uses his or her own approach when they design, and according to all of them the final model can be improved, but generally agreement has been reached.

Two items are added based on the results of the interviews. Luminance ratio is added to the brief, and flexibility of the lighting system is added as the fifth performance index.

The lighting model that is implemented in ILSA consists of eighteen variables influencing the overall performance of office lighting systems, divided among three categories (also described in section 3.2.4):

1. Nine daylight variables; projected on the left side in figure 5.5.
2. Six artificial lighting variables; projected on the right side in figure 5.5.
3. Three control variables; projected on the bottom side in figure 5.5.

Ranking solutions still is a difficult problem. To study this phenomenon more closely we have asked a group of thirteen experts to rank two solutions during the third and final workshop of which the results will be reported in section 5.5.6.

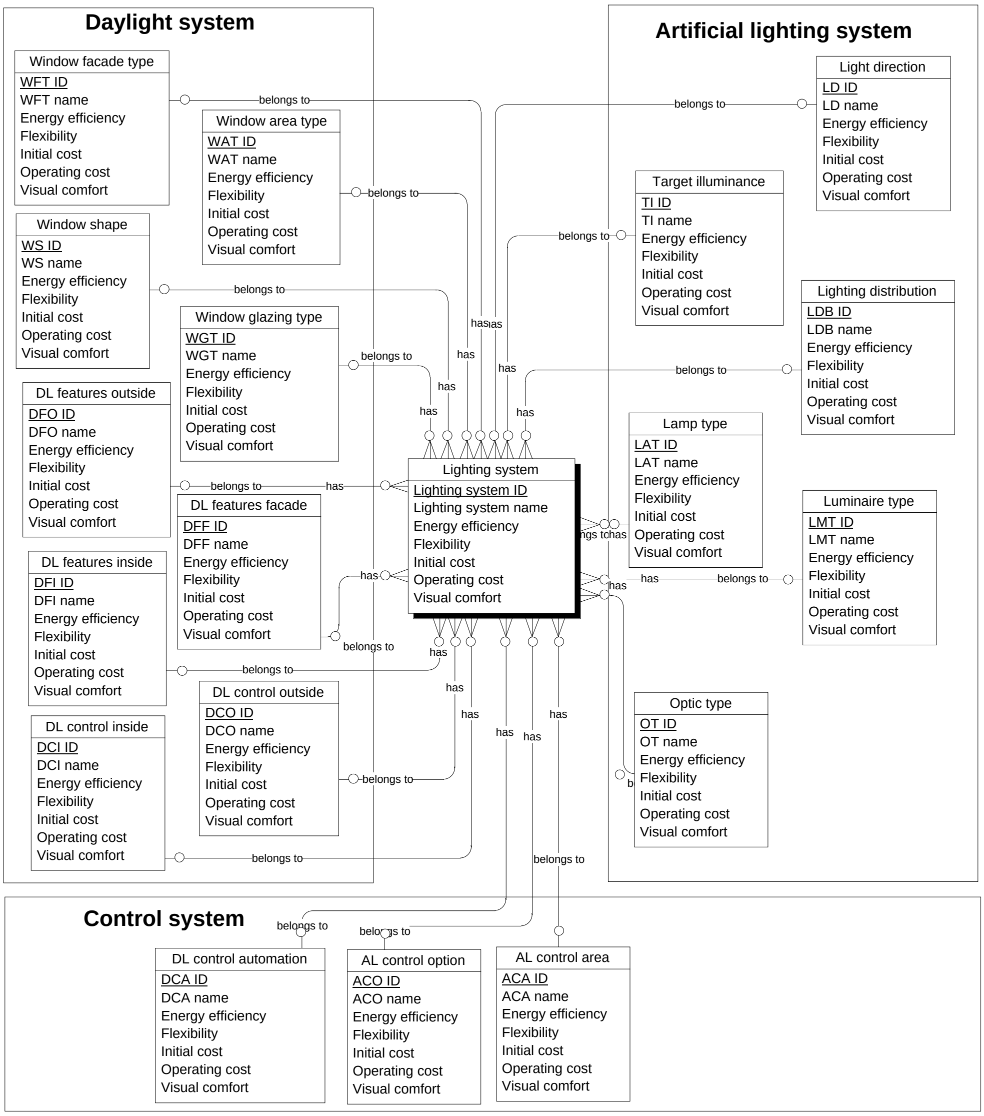
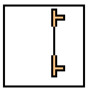
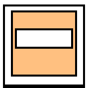
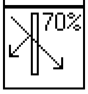
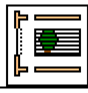
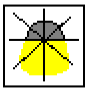
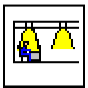
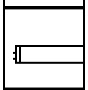
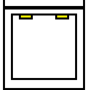
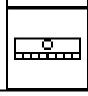


Figure 5.5: Conceptual data model for ILSA.

5.2.3 Reference solution

A reference solution has been composed based on common practice. From the concepts of each of the eighteen variables identified in section 3.2.4 the concept was selected that is typical in the Netherlands. It is also the solution that is often applied in the main building of the TUE and formed the starting point of refurbishment for three offices that can be visualised in ILSA, see table 5.4.

Table 5.4: Reference solution.

Elements	Concept	
Daylight variables		
Façade type	Cavity wall with double-glazing	
Window area	50%	
Window orientation	Horizontally oriented	
Glazing type	Transparent	
Features outside	None	
Features façade	None	
Features inside	None	
Elements outside	None	
Elements inside	Venetian blinds	
Artificial lighting variables		
Light direction	Direct	
Target illuminance	500 lux	
Light distribution in room	Ambient	
Light source	Fluorescent tube	
Luminaire position	Ceiling	
Luminaire type direct	Louvered	
Control variables		
Daylight control	Per room manually	
Artificial lighting control	Per room	
Control option	Switch on/off	

5.3 ILSA Evaluation method

The three methods of estimating magnitudes described in sections 3.1.4 and 3.2.5 all seem to be suitable to our problem. The 'Psychophysical approach' was implemented, because with eighteen variables the other two methods become very cumbersome and time consuming for the subjects. The physical parameters that are determined here are the five performance indices per concept. The values were estimated by the author and later validated on a 'psychological' basis in a workshop with lighting experts: the experts were asked to judge the different concepts based on their experience. Some of these values could have been estimated based on rules of thumb or other calculation methods used in the conceptual design stage, but no estimation methods exist that take all eighteen variables into account. The psychophysical approach provided the possibility to derive an evaluation method that estimates the influence of all variables simultaneously.

5.3.1 Performance values per concept

For each lighting system variable a reference concept has been chosen according to table 5.4. The reference concept is indicated with (ref.) in the following tables. The performance values of this concept are normalised as zero. The performance values of the alternative concepts for this variable are estimated in relation to the reference on a scale from –3 (performs much worse), through 0, (performs equally), to +3 (performs much better).

For example, the reference concept of the variable window façade type is a 'cavity wall with double-glazing'. The two alternatives are 'active wall' and 'ventilated wall'. The first alternative performs better on energy efficiency (less heat loss in winter and less cooling load in summer) and flexibility (people can sit closer to the window, without possible discomfort). This alternative performs worse on visual comfort (the additional construction parts involved in this solution are blocking daylight penetration and outside view), initial and operating costs (both costs are higher because of the higher initial prize of the concepts of this solution). The second alternative also performs better on energy efficiency and flexibility and worse on visual comfort and operating costs for the same reasons, but it performs much worse on initial costs, because the additional wall construction in this solution increases the initial costs significantly.

A few notes should be made in relation to this evaluation method. First, by expressing the performance values per index per concept in numbers it is assumed that all numbers correspond to the same scale. Consequently, the concepts that have a higher impact on the overall performance should be ranked higher on this scale to incorporate implicitly the weights of all different variables. Further, the method suggests that finding the overall performance can be conducted by just adding the separate performance values per concept. Thus second order effects are not taken into account. However, it is very likely that these exist in practice. For example, adding two good concepts of different variables together may form a worse solution because these concepts just be a match for, or even undermine, each others good qualities, (Archer 1969). Another example can be that constructing a solution of certain concepts may form a better solution than just the average would indicate. The second order effect, in general, has been topic of investigation during the final workshop, reported in section 5.5.

If necessary, the performance values can be adapted easily and new concepts can be added. If the new concepts perform even better that the best concept included in the model, the performance values may be added that are higher than +3. Further, if it is decided to allow the user to select his or her own reference concept per variable, all performance values per concept can be revised accordingly.

The implemented performance values are only valid if the conceptual lighting design is established for an office room that meets the requirements of table 5.2, because the performance of the concepts depends on the situation in which they are applied. For example, shading devices will perform differently depending on whether the orientation of the window is North, East, South, or West. Please note that the consequence then is that for each different situation all performance values per concept need to be revised accordingly.

Daylight variables

Table 5.5: Performance values per Daylight variable.

window façade type	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
active wall	-1	1	-1	-1	1
cavity wall/double glazing (ref.)	0	0	0	0	0
ventilated wall	-1	1	-3	-1	1
window area type	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
60%	-1	-1	-1	-1	-2
50% (ref.)	0	0	0	0	0
40%	1	1	1	1	1
30%	-2	2	3	1	2
window glazing type	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
heat absorbing	-3	-1	-2	0	0
heat reflecting	-2	-1	-2	0	0
transparent (ref.)	0	0	0	0	0
window shape	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
intermediate window	-1	1	0	0	0
horizontal window (ref.)	0	0	0	0	0
vertical aperture	-2	2	0	0	0
daylight features façade	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
none (ref.)	0	0	0	0	0
reflecting elements	1	2	-3	-2	-2
bevelled edges	3	0	-1	-1	-2
daylight features outside	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
none (ref.)	0	0	0	0	0
horizontal	-1	1	-1	-1	-1
vertical	1	1	-1	-1	-1
daylight features inside	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
none (ref.)	0	0	0	0	0
mirrors	1	1	-1	-1	0
light shelves	1	1	-1	-1	0

Continuation of table 5.5: Performance values per Daylight variable.

daylight control outside	visual comfort	energy efficiency	initial costs	operating costs	flexibility
none (ref.)	0	0	0	0	0
roller blinds	1	-3	-1	-2	0
venetian blinds	2	-1	-2	-3	0
daylight control inside	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
none	-2	1	-3	3	0
roller blinds	-1	-3	-1	1	0
venetian blinds (ref.)	0	0	0	0	0

Artificial lighting variables

Table 5.6: Performance values per Artificial lighting variable.

light direction	visual comfort	energy efficiency	initial costs	operating costs	flexibility
indirect	-1	-3	-2	-1	-1
direct (ref.)	0	0	0	0	0
combination	2	-1	-2	-1	-1
target illuminance	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
400 lux	-1	3	1	0	-1
500 lux (ref.)	0	0	0	0	0
800 lux	3	-2	-2	0	2
light distribution	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
ambient (ref.)	0	0	0	0	0
zoned	-1	1	1	0	-2
ambient & task lighting	-2	-1	-2	-2	3
lamp type	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
fluorescent tube (ref.)	0	0	0	0	0
compact fluorescent	0	0	-1	0	0
halogen	1	-2	-2	0	0
luminaire type	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
pendent direct	1	2	-1	0	-3
ceiling mounted (ref.)	0	0	0	0	0
wall mounted	-2	-1	0	0	-1
optic type	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
louvered (ref.)	0	0	0	0	0
matte Reflecting	1	1	-1	0	0
high Reflecting	2	2	-2	0	0
transparent Glass	-1	-1	0	-1	0
opal Diffuser	-1	-1	0	-1	0

Control variables

Table 5.7: Performance values per Contol variable.

daylight control automation	visual comfort	energy efficiency	initial costs	operating costs	flexibility
per room manually (ref.)	0	0	0	0	0
per room light sensor	2	1	-1	-1	0
central light sensor	-2	1	-2	-1	0
artificial lighting control area	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
per room (ref.)	0	0	0	0	0
per zone	1	2	-2	-1	3
central	-2	-2	2	3	-3
artificial lighting control option	**visual comfort**	**energy efficiency**	**initial costs**	**operating costs**	**flexibility**
switch on/ off (ref.)	0	0	0	0	0
dimmer	1	1	0	0	2
daylight sensor	2	1	-1	-1	1
occupancy sensor	0	1	-1	-1	1
occupancy/ daylight sensor	2	3	-2	-3	1

5.3.2 Performance of total lighting system

For each of the five performance indices the average performance is determined to estimate the particular performance value for the total lighting system with equation 3.4, introduced in section 3.2.5:

$$P_i = \frac{1}{18}\sum_{j=1}^{18} p_{i,j} \qquad (3.4)$$

where P is the performance value of the total lighting system, p is the performance value of the variable, *i* is a string from the set {visual comfort, initial costs, operating costs, energy efficiency, flexibility}, and *j* indicates one of the 18 variables.

5.4 Designing the user interface for ILSA

The user interface for ILSA was developed in co-operation with the Design Systems group at TUE, using the same set-up as for EIKS, see section 4.2.3. It was tried to fulfil the requests that were made during the plenary discussion after the demonstration of the EIKS-demo at the second EIKS workshop, see section 4.4. Several points were mentioned that could be improved:

- Visualise the solution more clearly.
- Visualise the evaluation results more clearly, with for example a radar chart.
- Flexible evaluation of performance indices, to be selected by the user.

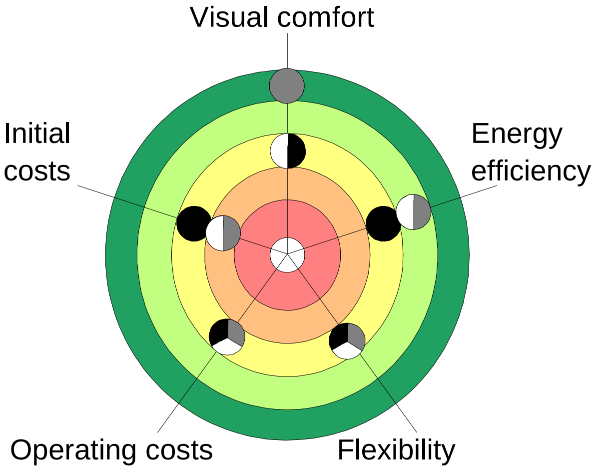


Figure 5.6: Radar chart to visualise performance values in ILSA.

In answer to the first point, a Virtual Reality component was added to provide a three-dimensional image of the design solution. For this purpose the freely distributed World Up Release 4 Player of Sense 8 has been used, (SENSE 1999).

For the second point, a Radar Chart component was designed and developed for this project. In figure 5.6 the radar chart is shown. This radar chart consists of five rings: the third ring is yellow and indicates a neutral performance, i.e. a performance as good as the performance of the reference solution. Moving away from the centre of the radar chart implies an improvement of the performance in relation to the reference solution; counting from the middle, the fourth ring (light green) indicates the proposed solution performs better, whereas the fifth ring (dark green) indicates a much better performance. Moving towards the centre of the radar chart implies a reduction of the performance; counting from the middle, the second ring (orange) implies the proposed solution performs worse. The first ring (red) implies a much worse performance. Each solution has its own set of dots printed on each performance index axis in one particular colour (the reference solution has black dots).

The third point was addressed by providing the user with the option to select the performance indices s/he wants to be evaluated. At the moment only five indices from all the possibilities that are captured in the human system levels, see section 2.1.2, are enabled: Visual Comfort, Energy Efficiency, Initial Costs, Operation Costs, and Flexibility.

5.5 Final workshop

5.5.1 Goal and objectives of the final workshop

The final workshop was organised together with Shauna Mallory-Hill, (De Groot & Mallory-Hill 1999). She presented her work in the morning session, while ILSA was presented in the afternoon session. Again a Group Decision Room [GDR] has been used, as was also done for the first EIKS workshop (see section 4.1.1). The goal of this workshop was to obtain feedback and to validate the implemented knowledge by a group of lighting experts.

The objectives of the ILSA session were to validate:

- The lighting model; are the 18 identified variables the right ones? Is the model complete?
- The evaluation method; is it possible to evaluate a lighting system based on the performance of each variable? Are there no second order effects?

5.5.2 Attendees

Thirteen attendees contributed to the workshop: ten lighting experts (six affiliated to artificial lighting producers and four lighting consultants), one building physics consultant, and two TUE building information technology lecturers. Among the lighting experts where also the five experts who had been involved in the interview-validation of the model.

5.5.3 Timetable

Figure 5.7 shows the timetable for the final workshop. The first item was a presentation in which the design project was introduced as well as the developed lighting model and the evaluation method. The ILSA prototype was used to visualise the model and method.

After this, during the first validation, the eighteen variables of section 5.3, that were identified and validated during the interviews, were checked on completeness and correctness. The attendees were asked to add more relevant variables to the

Timetable:

13:30	Introduction attendees and Group Decision Room
13:45	Presentation: Introduction ILSA
14:15	**Validation completeness Lighting model**
15:00	Coffee break
15:15	**Validation evaluation method per variable**
16:00	**Validation evaluation method per total solution**
16:30	Summary results

Figure 5.7: Timetable of the final workshop session.

eighteen variables during a brainstorm session and afterwards to select the ten most important variables of both original and newly identified variables.

The evaluation method described in section 5.3 was validated. The attendees were asked to estimate the performance of the concepts of three variables relatively to the reference concept for this variable. They did by indicating how the performances of the reference solution would change, if this particular concept would replace the reference concept. For example, the reference concept for the variable ‘Window area’ is *50%*. The attendees were invited to indicate in which direction the performance values would change (e.g. improve, reduce, improve much, reduce much, or stay the same) when this concept would be replaced by *60%, 40%* or by *30%*.

Further, of two complete lighting solutions, based on two refurbished offices at TUE presented in Appendix E, the performance was estimated similarly: the attendees indicated in which direction each of the five implemented performance indices would change relative to the reference solution.

5.5.4 Results validation completeness

During the brainstorm session twenty-five variables were added to the eighteen ILSA variables. After this all thirteen attendees voted on the ten variables that were most important, in their opinion, for the conceptual design of office lighting systems. Table 5.8 summarises the results of the vote. The original eighteen variables are printed in Italics.

We consider all variables that received three votes or more (the top 16), because we postulate that a good basis can be formed if three of thirteen experts (23%) agree that these items should be included in the lighting model. Only three of the considered items do not belong to the original set: ‘Reflection factors inside’, ‘Atmosphere’, and ‘Tasks executed in the room’. These three variables however, are included in the brief within ILSA. (Most of the other added variables can be found in ILSA’s brief, as well). Apparently, in practice decisions are made on these briefing aspects during the conceptual design stage.

Furthermore, it is noticeable that the three variables from the original model that were considered to be not important, are related to changes made to the construction, either inside, outside, or to the façade itself. This may be explained from the fact that most attendees are artificial lighting experts. Most probably they are rarely involved in this type of design decisions, related to the daylight system.

Table 5.8: Results of the lighting model validation (n=13).

	Variables in the lighting model	**number of votes**
1.	*Window area*	11
	Artificial lighting control	11
	Light source	11
4.	*Target illuminance*	10
	Luminaire type	10
6.	*Daylight control*	7
	Control option	7
8.	*Light distribution in room*	6
	Reflection factors inside	6
10.	*Elements inside*	5
	Glazing type	5
12.	*Window orientation*	4
	Atmosphere	4
14.	*Façade type*	3
	Luminaire position	3
	Tasks executed in the room	3
17.	*Elements outside*	2
	Light direction	2
	Type of activities	2
	Shielding angle luminaire	2
	Lamp ballast type	2
	Light colour	2
23.	*Features façade*	1
	Features inside	1
	Position of the monitor	1
	Location desk and meeting table, etc.	1
	Luminance ratio	1
	Allow possibility of different luminaires in one room	1
	Luminaire luminance	1
	Luminaire classification in relation to direct and reflected glare	1
	Window position	1
	View	1
	Distance of daylight penetration into the room	1
	Colour and material of window-frames	1
35.	*Features outside*	0
	Colour rendering index	0
	Allow reflections to increase amount of light	0
	Obstructions caused by buildings or vegetation	0
	Allow variation in tasks during the day	0
	Built environment (influence on daylight factor?)	0
	Sensor position (in case of automatic lighting control)	0
	Working time schedule	0
	Climate zone	0

Table 5.9: Results of validation variables: window area (ref.: 50%), window orientation (ref.: horizontal orientated), target illuminance (ref.: 500 lux). 'Mean' provides the average performance value. 'Mode' provides the performance value that received the majority of the votes. 'ILSA' provides the implemented values.

Window area	**60%**			**40%**			**30%**		
	Mean	Mode	ILSA	Mean	Mode	ILSA	Mean	Mode	ILSA
Visual comfort	0	-1	-1	0	-1 or 1	1	-1	-2	-2
Energy efficiency	-1	0	-1	0	0	1	0	0	2
Initial costs	0	0	-1	0	-1,0,1	1	0	-1	-3
Operating costs	-1	-1	-1	0	1	1	0	1	1
Flexibility	0	0	-2	0	0	1	-1	0	2

Window orientation	**Vertical oriented**			**Combination**		
	Mean	Mode	ILSA	Mean	Mode	ILSA
Visual comfort	0	-1	-2	0	-1	-1
Energy efficiency	0	-1 or 1	1	0	1	1
Initial costs	0	-2 or 0	0	-1	0	0
Operating costs	0	0	0	0	0	0
Flexibility	0	-2,-1,1	0	-1	-1	0

Target illuminance	**400 lux**			**500 lux**		
	Mean	Mode	ILSA	Mean	Mode	ILSA
Visual comfort	-1	-1	-1	1	2	3
Energy efficiency	1	1	3	-1	-1	-2
Initial costs	0	0	1	-1	-1	-2
Operating costs	1	1	0	-1	-2	0
Flexibility	-1	0	-1	1	1	2

Table 5.10: Results of validation evaluation method for total solution.

Performance indices	**Case 1**		**Case 2**	
	Workshop	ILSA	Workshop	ILSA
Visual comfort	1	2	0	0
Energy efficiency	1	1	1	1
Initial costs	-1	-1	-1	-1
Operating costs	0	0	0	0
Flexibility	0	0	-1	0

5.5.5 Validation of implemented evaluation method per concept

Of three of the eighteen variables in ILSA the implemented performance values were validated: Window area, Window orientation, Target illuminance. The attendees estimated the performance values on a quantitative scale from –3 (worse) through 0 (equal) to +3 (better) relative to the reference concept.

Tables 5.9 provide the results for the three validated variables. The results for each alternative concept are divided among three columns. The first column, *Mean*, provides the average performance value. The second column, *Mode*, provides the performance value that received the majority of the votes. The last column is added for comparison reasons and provides the values that are implemented in ILSA.

During this workshop item it became clear that large differences exist in voting behaviour among the attendees: often there were attendees expecting a positive change, as well as attendees expecting a negative change. Consequently, the Mean turns out to be close to zero for all validated variables. This kind of behaviour was expected for the subjective performance index visual comfort, but for the other performance indices more unanimity was expected. During the discussion of this phenomenon one of the attendees remarked that it maybe caused by the difference in voting behaviour of artificial lighting and daylight experts. Because of the anonymous character of the meeting this hypothesis could not be tested. Mostly, the Mode values resemble the implemented values in ILSA slightly better. This may imply that ILSA agrees with the majority of the attendees, but it is not possible to trace whether this majority consisted of the same people all the times.

5.5.6 Validation of implemented evaluation method per total solution

After validation of the evaluation method per concept two cases, containing total lighting system solutions were presented, (the composition of these cases is presented in Appendix E), and the attendees estimated the performance values. This time they had to express the performance values on a qualitative scale from ‘much worse’ (=-2) through ‘equal’ (=0) to ‘much better’ (=+2). The qualitative evaluation turned out to be less complicated; the matching with the estimates made by ILSA improved and also there was more conformity among the attendees, as can be seen in table 5.10 (results expressed in numbers).

5.5.7 Conclusions of the final workshop

The goal of this workshop was to obtain feedback and to validate the implemented knowledge by a group of lighting experts. The workshop has proven to be a good source of feedback. Validation of the implemented model and method was possible in a workshop set-up. More results can be found in Appendix E (for example, on the distribution of the votes).

Lighting model – One of the objectives was to validate the lighting model. The results of this part of the validation indicate that the eighteen variables within the implemented lighting model of ILSA correspond well with daily practice in design of office lighting systems. It is noticeable that of the twenty-five variables that were added during the brainstorm session many are incorporated in ILSA, not in the lighting model but in the specific brief to which the design must comply. This was brought to the attention of the workshop before the voting. Nevertheless, three 'briefing' variables showed up in between the sixteen variables that received three votes or more: *Reflection factors inside*, *Atmosphere*, and *Tasks executed in the room*. This indicates that many lighting experts make decisions for this kind of variables during the (conceptual) design stage.

Further, it is remarkable that almost no attendees voted for any of the features to the construction, applied to improve the use of daylight. Apparently, in their daily practice they do not consider the decisions related to the construction; other members of the design team do. ILSA is developed for architects, who will also take the façade construction into consideration. This is the reason why these variables have not been removed from the original lighting model within ILSA.

Validation evaluation method per variable – One part of the second objective of this workshop was to validate the evaluation method per concept. It was found that it is very difficult to reach agreement over the performance of each concept. During this workshop item the attendees estimated the performance values of three variables of the lighting model. Often, some of attendees expected a positive change and, at the same time, other attendees expected a negative change. This implied that all the average values turned out to be between –1 and +1, while in ILSA values are implemented between –3 and +3. Most of the Mode values agree slightly better with the values in ILSA. This makes it reasonable to presume that different sets of performance values can be distinguished: the values of the average artificial lighting expert, as well as the values of the average daylight expert. It might be necessary to develop these, and maybe more, sets of values, and to add those to the ILSA database. In this way the user can pick the set that appeals to him or her. During the design of ILSA in this design project it was not possible to proceed this activity but it can be considered for future work. For the time being the values implemented in ILSA will not be adapted, because during the last validation good agreement was found between the lighting experts average values and the values ILSA estimated based on the values per concept.

Validation evaluation method per complete solution – The other part of the second objective of this workshop was to validate the evaluation method per complete solution and to find out whether there are second order effects. Because the validation per concept did not deliver unambiguous values, no second order effects can be distinguished. However, the attendees do agree during this workshop item where the evaluation method is validated for two complete cases. The average values almost match the values estimated by ILSA, (although it should be mentioned that these are estimated with the proposed values per concept on which no agreement was found). One attendee pointed out that it would be useful if the user can adapt the reference case to his or her liking. Also into this topic more research is needed in future project.

5.6 Conclusions

The process model for ILSA is set up differently from the IDEF0 model for EIKS: the positions of the user of the tool and of the final result are different in the diagrams and a 'Feedback of knowledge' process is added. For ILSA we presume that the user is working on a conceptual design and during this design process s/he is supported by ILSA. Further, the subdivision of the sub-process 'Evaluate alternative lighting systems' is done according to the newly developed evaluation method.

The original preliminary lighting model applied in EIKS is not much different from the final validated lighting model implemented in ILSA. For ILSA we have divided the lighting system into three sub-systems, each influenced by variables for which different concepts can be selected. For EIKS we identified three sections: two sections for the aspects of the two sub-systems and one for the integration aspects for those two sub-systems. Nevertheless, the contents of the sub-systems in ILSA or the sections in EIKS are almost identical.

The evaluation method developed for ILSA applied the psychophysical method introduced in section 3.1.4. The validation per total solution was successful, which make us believe the evaluation method is applicable. Why the validation per concept was disappointing, can have various reasons. Maybe different sets of performance values must be distinguished: one for artificial lighting experts, as well as one for daylight experts, and maybe more. Another reason could be that for the experts estimating a quantitative value is more difficult than estimating a qualitative value.

Based on these results it is fair to postulate that a DDSS in which the lighting model and evaluation method are implemented can function as an assistant to architects to support their decision making in the early design stage in the field of integrating daylight and artificial lighting. One possible implementation will be provided in the next chapter, *DDSS for Office Lighting: ILSA*. During the development of the user interface of ILSA prototype the EIKS user interface has been the starting point. Further, the process model described in section 5.1 has been followed.

- Chapter 5 -

Chapter 6

DDSS FOR OFFICE LIGHTING: ILSA

In the two previous chapters the design process of the DDSS and of office lighting systems have been described. Chapter 4, *Design of the DDSS: EIKS*, described the process of defining requirements for the DDSS, validating them during workshops, designing a demo tool, and getting feedback on this tool in another workshop. Chapter 5, *Design of Office Lighting Systems*, described how the design process continued after the EIKS project ended, with the development of the lighting model and the performance evaluation method. The model and the method were validated during interviews and in a final workshop with experts. In this chapter the two designs will come together in a DDSS for office lighting: ILSA. The requirements for the ILSA prototype are described in the first section 6.1, the user interface is explained in section 6.2, and after that the implementation of the requirements are elaborated on in section 6.3.

6.1 Requirements of the ILSA prototype

6.1.1 Goal and objective of ILSA

The goal of ILSA is that the tool supports an architect during the conceptual design stage of office lighting design.

The objective of ILSA is that the tool estimates the performance of a proposed office lighting system solution. The calculation is based on the relative performance of each concept in relation to the performance of the reference solution. For each of the implemented concepts of the eighteen lighting system variables in the lighting model (introduced in section 3.2.3) this relative performance has been determined (presented in section 5.3). The overall performance is estimated by ILSA by calculating the average performance value from all performance values per selected concept for each performance index.

6.1.2 Required functions for ILSA

During the first EIKS workshop several required functions of the tool came forward. In the EIKS-demo these have been implemented up to a certain degree, see section 4.2.4. For ILSA, two of these functions became less relevant and thus have been removed from the list.

The requirements that were removed are:

- Serve the expectations of owner/developer and user.
- Contain experience gained from good projects and also what not to do.

The first requirement has been removed because ILSA has been designed for architects. This was decided in the Building Evaluation Project, in which ILSA was developed after the EIKS project ended. The second requirement that has been removed is related to the case-base function, which is addressed by another researcher in the Building Evaluation Team.

The requirements that remain are:

- Support decision-making.
- Be a communication tool, not a design tool; act only as a design assistant.
- Provide various levels of detail
- Generate and compare alternative solutions.
- Provide warnings and highlight problem areas.
- Allow checking against rules and regulations.
- Be able to make approximations based on the preliminary information available.

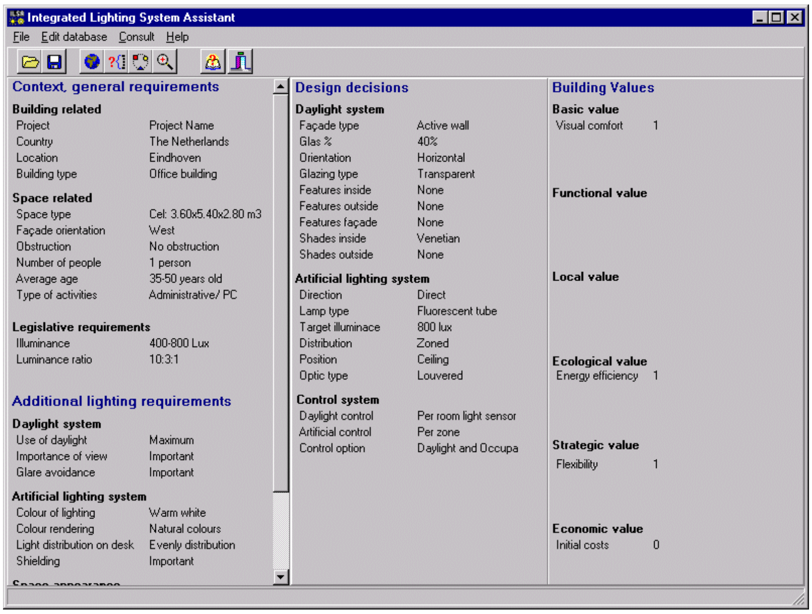
Three requirements were added according to the findings of the EIKS-demo evaluation during the second EIKS workshop, reported in section 4.3.6. These points were also mentioned in section 5.4:

- Visualise the solution more clearly than was done for the EIKS-demo.
- Visualise the evaluation results more clearly than was done for the EIKS-demo.
- Flexible evaluation of performance indices, to be selected by the user.

6.2 User interface of the ILSA prototype

6.2.1 Overview screen

Figure 6.1 shows the overview screen of the ILSA system. In this screen the results of all procedures within ILSA are summarised. On the left side the requirements are shown. These cannot be changed within ILSA, because the design project is focusing on the early building design stage, or conceptual design stage. As was explained in section 3.2.3, we work with a specific brief to a specific office lighting design. This brief consists of general workplace requirements and additional lighting, both daylight and artificial lighting, requirements, as can be seen in figure 6.2. The performance values, estimating in ILSA are only valid for a lighting design meeting these requirements. For each different situation, the performance values per variable need to be revised.



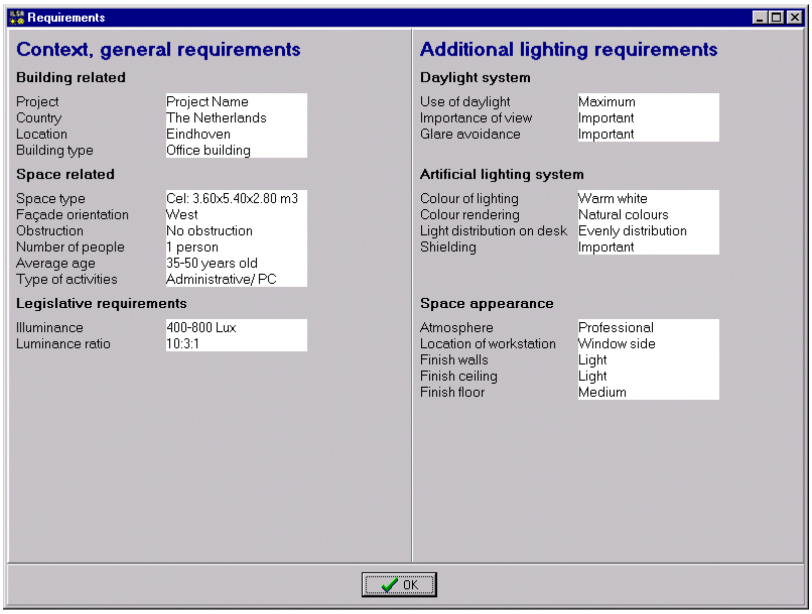


Figure 6.1: Overview screen of ILSA.

Figure 6.2: Requirement screen of ILSA.

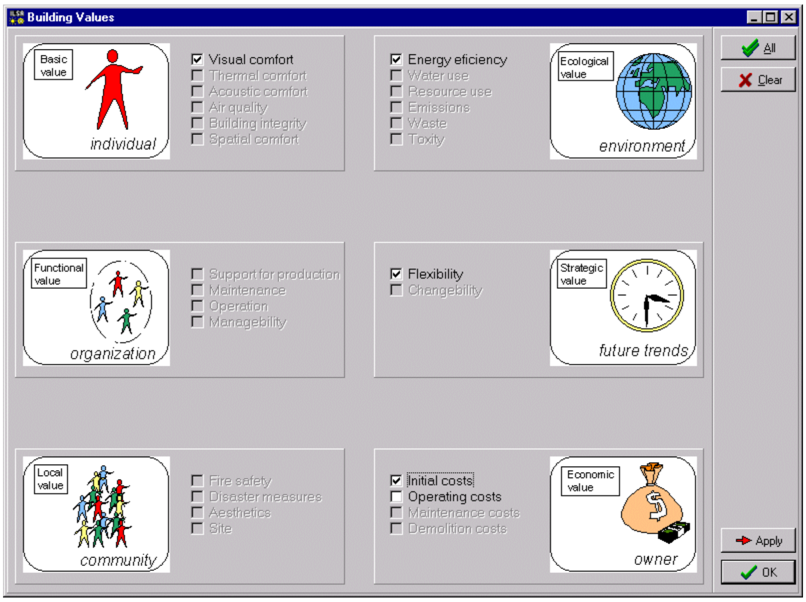


Figure 6.3: Building values screen of ILSA.

6.2.2 Building values screen

In ILSA the user can select which performance indices, or building values, within the Human System Levels s/he wants to evaluate. Figure 6.3 shows the building values screen of the ILSA system. At the moment only five performance indices are enabled: Visual comfort, Energy efficiency, Flexibility, Initial costs, and Operating costs. In the future also the other indices may be enabled. If the Apply-button in the lower right corner is clicked the selection will be applied in the rest of the program and the screen will remain visible. Clicking the OK-button will have the same effect but the screen will disappear. To select all enabled indices the All-button should be clicked, to deselect all indices the Clear-button should be clicked.

6.2.3 Design screens

ILSA contains two design screens that, when opened for the first time, show the choices made for the reference lighting system solution, (introduced in section 5.2.3). Both screens are shown in figure 6.4. The first screen to appear is the 'Design screen' that shows a 3D image of the solution in a VR-viewer and the calculated performance value for the selected performance indices in a radar chart. The second screen will appear if the Details-button is clicked. Both screens contain a triple tab-control with which the selected concepts of the reference solution can be adapted. The first screen contains the eight variables of the first level of detail presented in table 3.9, while the second screen contains the other ten variables that add up to the second level of detail.

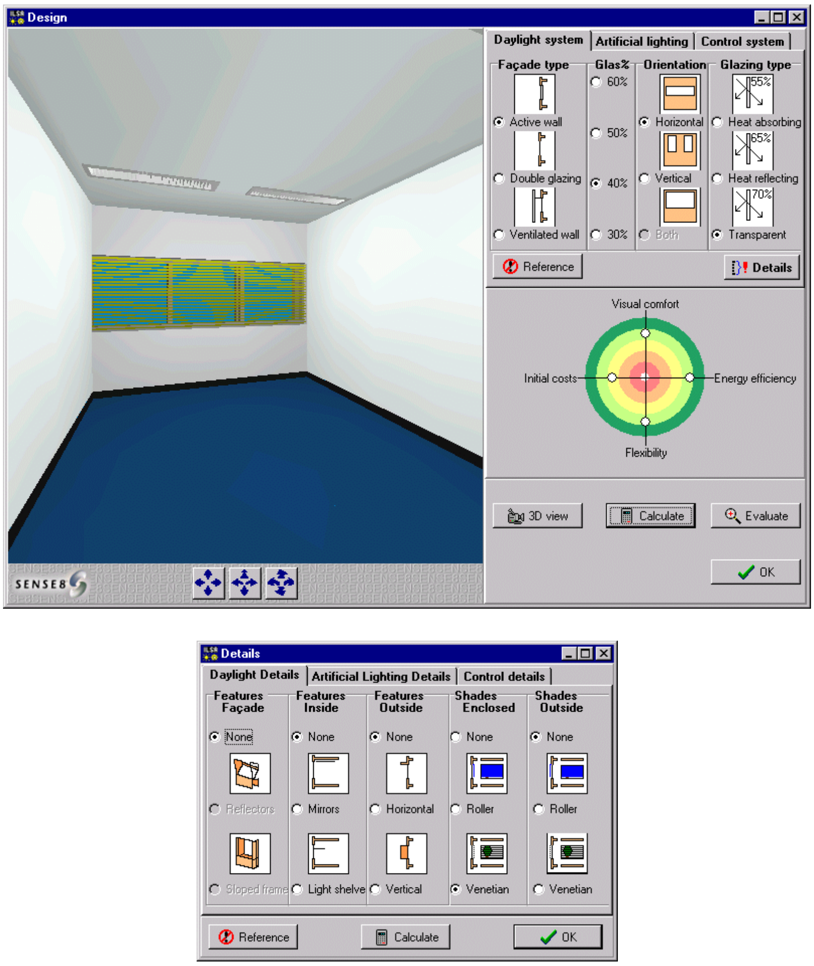


Figure 6.4: Design screens of ILSA.

The user may click the 3D view-button to get a 3D image of the new solution, or the Calculate-button to get an indication of how well this new solution performs in relation to the reference solution.

Inside the VR-viewer the user may click the right mouse button to move around or to stop at a certain position, and the left mouse button to make a specific tab-control for one of the three systems in the VR environment come to the front:

- clicking the window for the Daylight system,
- clicking the luminaires for the Artificial lighting system
- clicking the light switch next to the door for the Control system

The left mouse button can also be used to zoom in and the middle mouse button, if available, to zoom out inside the VR environment. It is not possible to go beyond the boundaries of the room.

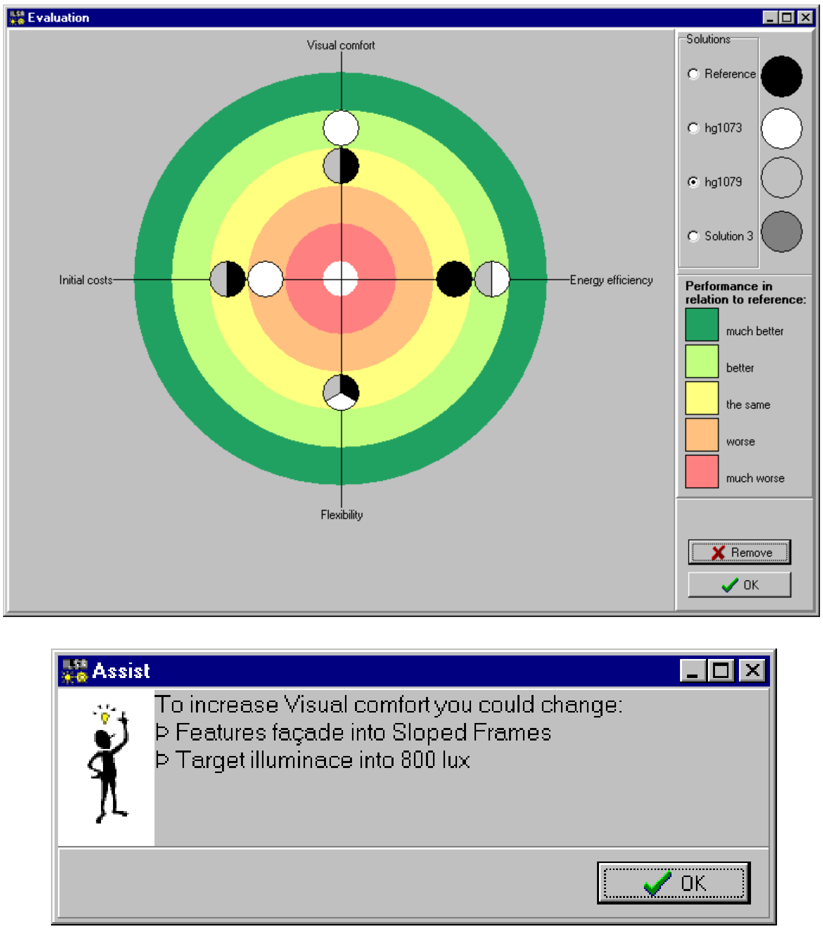


Figure 6.5: Evaluation and Assist screen of ILSA.

6.2.4 Evaluation screen

If the user clicks the Evaluate-button the evaluation screen will appear, see figure 6.5. This screen consists of a larger radar chart in which maximum three solutions can be compared to the reference solution. Each solution has its own set of dots printed on each performance index axis in one particular colour. The user can indicate what kind of change s/he wants by pulling one of the dots of the selected solution towards or from the centre. Next, an assist screen will appear explaining the user how this change can be achieved. An example of such a message is shown in figure 6.5. The content of this message is based on finding the concepts in the lighting model with the highest (or lowest) score for that particular performance index.

6.3 Implementation of the requirements

The EIKS requirements that were still relevant and the three newly found requirements have been presented in section 6.1.2. Having described the user interface it now is possible to evaluate how these requirements have been implemented in the ILSA-prototype. In this section an explanation is given whether and how these requirements have been implemented.

Support decision-making - ILSA indicates how a performance value can be increased or decreased by selecting other concepts. The mechanism behind this is based on finding the concepts that have the highest performance values for this particular performance index. It is not yet possible to increase (or decrease) the performance value even further, after the proposed changes are applied.

Be a communication tool, not a design tool; act only as a design assistant - The tool acts as an idea generator and a conceptual design evaluator that supports this conceptual design process.

Provide various levels of detail - Two levels of detail are introduced in table 3.9. A set of eight variables contributes to an outline conceptual design; ten more variables add up to influencing the design in more detail.

Generate and compare alternative solutions - Every time a concept has been changed the new performance can been estimated. In total four different solutions can be compared with each other; just enough to compare three new solutions with the reference solution and still keep an overview of what they are.

Provide warnings and highlight problem areas – All the concepts that are provided are meeting the requirements, thus serious problems are not to be expected by applying any of those. Further, rules are implemented that prevent impossible combinations to be applied, such as selecting a luminaire for direct artificial lighting when indirect lighting is selected as light direction.

Allow checking against rules and regulations - All possible concepts meet the demand list, standard available in ILSA, and so they meet the legislative requirements for the Netherlands (NEN 1890). What is evaluated is to what degree the client’s wishes are met.

Be able to make approximations based on the preliminary information available, e.g. “rules of thumb” - The approximations or estimations of the performance is based on the relative performance of each concept in relation to the alternative to this concept in the reference solution. No rules of thumb were available that comprise all eighteen variables that were considered important by a group of experts.

Visualise the solution more clearly - A virtual reality viewer was developed to visualise the solution in three dimensions. Not all the possible combinations can be visualised yet, because not all 3D drawings are provided. If a combination is selected of which no drawing was provided, a message appears informing the user about this.

Visualise the evaluation results more clearly, with for example a radar chart - A radar chart was developed to visualise the evaluation results. This radar chart enables ILSA to show the performance values of all selected performance indices in a dartboard like figure. This radar chart, developed especially for ILSA, has replaced the bar chart implemented in the EIKS-demo.

Flexible performances evaluation, to be selected by the user - We made it possible for the user to select the performance indices s/he prefers to evaluate. The user must indicate which of the performances s/he wants to be evaluated. Only five indices are being enabled at the moment, but in the future the other relevant indices can be enabled; the screen from which the indices are selected already provides their names.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

This last chapter summarises the conclusions of this design project. After the general conclusions on compliance with the original goal and objectives, the two wicked problems are addressed individually. The validation points are particularly elucidated. At these points potential future users and lighting experts from building practice were involved in the development process. Lastly, recommendations for future design and research projects are proposed.

7.1 Conclusions

7.1.1 Compliance with original goal and objectives

The goal of the project was *to develop a Design Decision Support System [DDSS] that will assist designers in the early stages of design* focusing on the integration of daylight and artificial lighting in office buildings. In trying to do this, the project was addressing a *double* wicked problem. ILSA shows that this problem was addressed successfully and that it is possible to implement a lighting model and performance evaluation method into a working prototype. We postulate that a DDSS in which the developed model and method are implemented can function as an assistant to architects. It can support their decision making in the early design stage in the field of integrating daylight and artificial lighting.

The objectives of the Building Evaluation Project that were considered during the project were:

1. Improve communication between members of a design team.
2. Improve knowledge transfer from research departments to building practice.
3. Introduce a new approach for strategic performance based design and evaluation.

All of these objectives have been addressed. Firstly, the communication between lighting experts and architects will be improved while both are involved and should stay involved in further development of ILSA; the lighting experts should input their knowledge into the system, and the architects should use it when making a conceptual office lighting design. Secondly, if the research departments together with lighting experts keep ILSA up to date by adding new innovative concepts for office lighting also the knowledge transfer between these researchers and designers will be improved. Thirdly, the developed performance evaluation method is based on the strategic performance based design and evaluation approach under development.

However, the area in which ILSA can be applied is very limited at the moment. Only for office environments that meet a certain brief performance values per concept have been implemented in relation to certain reference concepts. Thus only for a specific office environment can estimates be made for the values of five performance indices in relation to a certain reference solution.

Nevertheless, the knowledge acquisition method used here can be repeated to find the performance values in relation to other specific briefs, other reference solutions, and other concepts. Further it is hypothesised that it is also possible to use the same strategy to find performance values for knowledge fields other than office lighting systems.

7.1.2 First wicked problem: Design Decision Support System

At the start of the design project, emphasis was placed on the first wicked problem: the design of a design decision support system. To decrease the wickedness imbedded in this problem, two workshops were organised to meet possible future users and create a common basis for the tool to be developed.

Conclusions from the first workshop - At the first workshop 29 building experts identified barriers that prevent buildings to be more energy efficient for several categories. The barriers that were identified were generally known and not new. However, the aim of this workshop task was to make the attendees aware of them and use them in the next workshop task, when the attendees where invited to provide specifications of a Knowledge Based System [KBS] that could overcome these barriers. All the participants agreed that a KBS could assist in overcoming most of the identified barriers, but the specifications for the tool that came forward from the workshop had a high level of abstraction. This made it difficult to structure the development of the demonstration tool, and another workshop was needed to validate whether the implementation was done according to the attendees' expectations.

Conclusions from the second workshop - The demonstration tool, which was developed according to the identified specifications focusing on lighting system design, was presented during a second workshop. Fourteen of the same building experts who had visited the first workshop were present. From the enthusiastic response of participants it was concluded that the demonstration tool could be a good basis for further development. However, it was clear that much effort would be needed in order to realise a final, operational system: an information and decision support system for energy efficient building design.

7.1.3 Second wicked problem: Office lighting design

The second wicked problem concerned conceptual office lighting design. The performance based design approach used in this project emphasises that expert knowledge should be made available to support architects at making decisions during the early design stages. This project focused on the integrated design of daylight and artificial lighting systems for office environments. To handle the wickedness of this second wicked problem, a lighting model and a performance evaluation method have been developed and validated with lighting experts in interviews and during a third, and final, workshop.

Conclusions from the interviews – The lighting model for the design of integrated daylight and artificial lighting for office environments has been validated with five lighting experts and one architect, and adapted accordingly. Only small adjustments to the model had to be made to reach a consensus.

Conclusions from the third, and final, workshop – The revised lighting model and performance evaluation method were validated by thirteen, mainly, lighting experts. The validation of the lighting model indicated that the eighteen variables within the implemented lighting model of ILSA correspond well with daily practice in design of office lighting systems.

During the validation of the evaluation method the attendees often did not agree on the performance values per concept; some attendees expected positive values and, at the same time, other attendees expected negative values. This implied that the Mean values turned out to be between -1 and +1, while in ILSA values are implemented between -3 and +3. Most of the Mode values agree better with the values in ILSA. This result suggests that different sets of performance values can be distinguished; for example, different values for an artificial lighting expert as for a daylight expert. More agreement was found later during the workshop when the evaluation method was validated for two complete cases. The average performance values closely matched the values estimated by ILSA.

7.2 Recommendations

The limited area in which ILSA can be applied at the moment should be extended by using the same knowledge acquisition method. Different sets of performance values should be determined in consultation with lighting experts: sets in relation to other specific briefs, sets in relation to other reference solutions, and separate values for other not yet implemented concepts.

Further, the hypothesis that experts with a different background (daylight, artificial lighting, or other) prefer using other performance values should be tested, as well as the hypothesis that it is also possible to use the same strategy to find performance values for other knowledge fields than office lighting systems. The knowledge domain visualised in the 3D model of figure 2.1 is a large working field for the Building Evaluation Project at the TUE. An enormous amount of time and effort can be put into working out all the other sub-domains, involving other architectural system levels than ‘Workplace’ only, involving other building systems than ‘Daylight system’, ‘Artificial lighting system’, and ‘Control system’, and involving other performance indices than ‘Energy efficiency’, ‘Visual comfort’, ‘Initial costs’, ‘Operating costs’, and ‘Flexibility’. It is recommended to start with the other building physical aspects of indoor climates of building, because knowledge is available within the section where the Building Evaluation Project is executed.

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Indices

Subjects index

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Appendix A

Rules implemented in ILSA

Link light direction to luminaire type

```
procedure TDesignForm.LD_DClick(Sender: TObject);
    begin
        if LD_D.checked then
            with  DetailsForm do
                begin
                    OTI_L.enabled:=false;
                    if OTI_L.checked then OTD_L.checked:=true;
                    OTI_T.enabled:=false;
                    if OTI_T.checked then OTD_L.checked:=true;
                    OTI_O.enabled:=false;
                    if OTI_O.checked then OTD_L.checked:=true;
                end else
            with  DetailsForm do
                begin
                    OTI_L.enabled:=true;
                    OTI_T.enabled:=true;
                    OTI_O.enabled:=true;
                end;
        if LD_I.checked then
            with  DetailsForm do
                begin
                    OTD_L.enabled:=false;
                    if OTD_L.checked then OTI_L.checked:=true;
                    OTD_M.enabled:=false;
                    if OTD_M.checked then OTI_L.checked:=true;
                    OTD_H.enabled:=false;
                    if OTD_H.checked then OTI_L.checked:=true;
                end else
            with  DetailsForm do
                begin
                    OTD_L.enabled:=true;
                    OTD_M.enabled:=true;
                    OTD_H.enabled:=true;
                end;
        if LD_B.checked then DetailsForm.label7.visible:= true
        else DetailsForm.label7.visible:= false;
    end;
```

If artificial lighting control central only switch

```
procedure TDesignForm.ACA_CClick(Sender: TObject);
    begin
        if ACA_C.checked then
            with  DetailsForm do
                begin
                    ACO_D.enabled:=false;
                    ACO_DS.enabled:=false;
                    ACO_OS.enabled:=false;
                    ACO_DOS.enabled:=false;
                    ACO_S.checked:=true;
                end else
            with  DetailsForm do
                begin
                    ACO_D.enabled:=true;
                    ACO_DS.enabled:=true;
                    ACO_OS.enabled:=true;
                    ACO_DOS.enabled:=true;
                end;
    end;
```

Only reflecting with façade type double glazing,

```
procedure TDesignForm.WFT_AWClick(Sender: TObject);
    begin
        with DetailsForm do
            begin
                if WFT_AW.checked then
                    begin
                        DFF_R.enabled:=false;
                        if DFF_R.checked then DFF_none.checked:=true;
                    end else
                if WFT_VW.checked then
                    begin
                        DFF_R.enabled:=false;
                        if DFF_R.checked then DFF_none.checked:=true;
                    end else
                if WFT_DG.checked then
                    begin
                        DFF_R.enabled:=true;
                    end;
            end;
    end;
```

Only bevelled edges if window orientation is vertical

```
procedure TDesignForm.WS_VClick(Sender: TObject);
    begin
        if WS_V.checked then DetailsForm.DFF_SF.enabled:=true
        else with DetailsForm do
            begin
                DFF_SF.enabled:=false;
                if DFF_SF.checked then DFF_none.checked:=true;
            end;
    end;
```

If glass %=60 then window orientation is combination, else it is horizontal or vertical

```
procedure TDesignForm.WAT_60Click(Sender: TObject);
    begin
        if WAT_60.checked then
            begin
                WS_H.enabled:=false;
                WS_V.enabled:=false;
                WS_B.enabled:=true;
                WS_B.checked:=true;
            end else
                begin
                    WS_H.enabled:=true;
                    if WS_B.checked then WS_H.checked:=true;
                    WS_V.enabled:=true;
                    WS_B.enabled:=false;
                end;
    end;
```

No indirect luminaire if ceiling mounted

```
procedure TDetailsForm.LMT_CClick(Sender: TObject);
    begin
        if LMT_C.checked then
            begin
                OTD_L.enabled:=true;
                OTD_M.enabled:=true;
                OTD_H.enabled:=true;
                OTI_L.enabled:=false;
                if OTI_L.checked then OTD_L.checked:=true;
                OTI_T.enabled:=false;
                if OTI_T.checked then OTD_L.checked:=true;
                OTI_O.enabled:=false;
                if OTI_O.checked then OTD_L.checked:=true;
            end else
                begin
                    OTI_L.enabled:=true;
                    OTI_T.enabled:=true;
                    OTI_O.enabled:=true;
                end;
    end;
```

No other features if the façade is reflecting

```
procedure TDetailsForm.DFF_RClick(Sender: TObject);
    begin
        if DFF_R.checked then
            begin
                DFI_LS.enabled:=false;
                if DFI_LS.checked then DFI_none.checked:=true;
                DFO_H.enabled:=false;
                if DFO_H.checked then DFO_none.checked:=true;
                DFO_V.enabled:=false;
                if DFO_V.checked then DFO_none.checked:=true;
            end else
                begin
                    DFI_LS.enabled:=true;
                    DFO_H.enabled:=true;
                    DFO_V.enabled:=true;
                end;
    end;
```

Table A.1: List of abbreviations used in programming code.

Abbreviation	Variable	Concepts
ACA_C	Artificial lighting control	Central
ACO_D	Control option	Dimmer
ACO_DS	Control option	Daylight sensor
ACO_DOS	Control option	Daylight & Occupancy sensor
ACO_OS	Control option	Occupancy sensor
ACO_S	Control option	Switch on/off
DFI_LS	Features inside	Light shelve
DFI_none	Features inside	No features inside
DFF_none	Features façade	No features in the façade
DFF_R	Features façade	Reflectors
DFF_SF	Features façade	Bevelled edge
DFO_H	Features outside	Horizontal
DFO_none	Features outside	No features outside
DFO_V	Features outside	Vertical
LD_B	Light direction	Combination indirect/direct
LD_D	Light direction	Direct
LD_I	Light direction	Indirect
LMT_C	Luminaire position	Ceiling mounted
OTD_H	Luminaire type direct	High reflecting
OTD_L	Luminaire type direct	Louvered
OTD_M	Luminaire type direct	Matte reflecting
OTI_L	Luminaire type indirect	Louvered
OTI_T	Luminaire type indirect	Transparent cover
OTI_O	Luminaire type indirect	Opal diffuser
WAT_60	Window area	60% transparent
WFT_AW	Façade type	Active wall
WFT_DG	Façade type	Cavity wall with double glazing
WFT_VW	Façade type	Ventilated wall
WS_B	Window orientation	Combination horizontal/vertical
WS_H	Window orientation	Horizontal
WS_V	Window orientation	Vertical

- Appendix A -

Appendix B

Subdivision of a Room in Lighting Zones

The distribution of daylight in a side-lit room is defined in IEA task 21 'Daylight in Buildings'. A room is subdivided into three zones. The subdivision is determined as follows: First of all the 'effective glazing area' is determined. It is the net glazing area above the sill height (fixed to 0.9 meter as glazing below this height does not contribute on the horizontal working plane) times the transmission factor τ of the glazing (See figure D.1). Of course the glass maybe in more than one window in the façade. If the effective glazing area is less than 1/6 of the total façade area above 0.9 meters it is neglected. This means that small windows with low transmission (tinted) glazing are not seen as a useful source for lighting. From the effective window area the effective window height is determined. This is the effective window area divided by the width of the room.

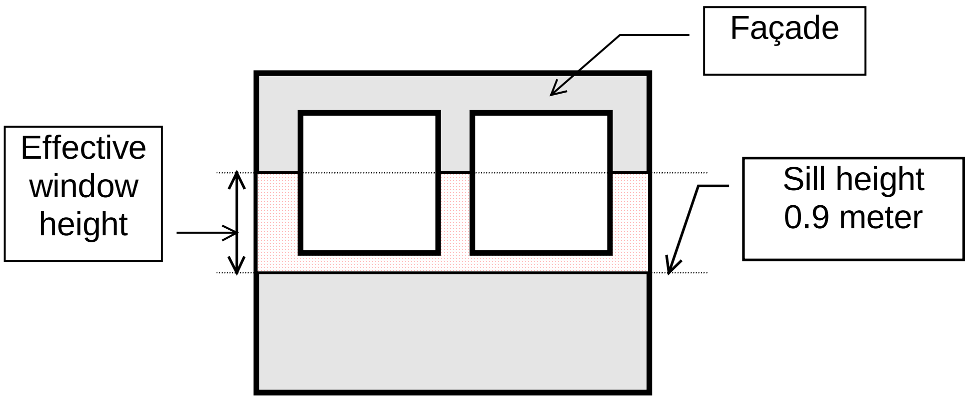


Figure B.1 Determination of the effective window height for a simple façade with two windows.

Based on the effective window height the three lighting zones are defined:

Daylight zone - In this zone next to the façade most of the time sufficient daylight is available. It has a depth of 2 times the effective window height. For most normal reading and writing tasks this zone offers potentially enough daylight. Solar shading and glare control may reduce this potential slightly. In this zone daylight responsive lighting maybe useful.

Intermediate zone - This is the zone adjacent to the daylight zone and has a depth of 1.5 times the effective window height. Here daylight and electric light have to co-operate to create an acceptable environment. Still daylight responsive controls will lead to significant energy savings.

Inner zone - This zone forms the rest of the room with little or no daylight. Here artificial light has to provide the working conditions so no savings from the utilisation of daylight can be achieved here.

Appendix C

IDEF0 Description

On the Internet (http://nemo.ncsl.nist.gov/idef/) a description was found of the IDEF0 approach. This text has been copied exactly for this appendix, except for the definitions on call-arrows, because these were not used for the EIKS model.

Introduction - IDEF0 (Integration DEFinition language 0) is based on SADT (Structured Analysis and Design Technique), developed by Douglas T. Ross and SofTech, Inc. In its original form, IDEF0 includes both a definition of a graphical modelling language(syntax and semantics) and a description of a comprehensive methodology for developing models.

IDEF0 may be used to model a wide variety of automated and non-automated systems. For new systems, IDEF0 may be used first to define the requirements and specify the functions, and then to design an implementation that meets the requirements and performs the functions. For existing systems, IDEF0 can be used to analyse the functions the system performs and to record the mechanisms (means) by which these are done.

As a function modelling language, IDEF0 has the following characteristics:

1. It is comprehensive and expressive, capable of graphically representing a wide variety of business, manufacturing and other types of enterprise operations to any level of detail.
2. It is a coherent and simple language, providing for rigorous and precise expression, and promoting consistency of usage and interpretation.
3. It enhances communication between systems analysts, developers and users through ease of learning and its emphasis on hierarchical exposition of detail.
4. It is well-tested and proven, through many years of use in Air Force and other government development projects, and by private industry.
5. It can be generated by a variety of computer graphics tools; numerous commercial products specifically support development and analysis of IDEF0 diagrams and models.

In addition to definition of the IDEF0 language, the IDEF0 methodology also prescribes procedures and techniques for developing and interpreting models, including ones for data gathering, diagram construction, review cycles and documentation.

Diagrams - IDEF0 models are composed of three types of information: graphic diagrams, text, and glossary. The diagrams are cross-referenced to each other. The graphic diagram is the major component of an IDEF0 model, containing boxes, arrows, box/arrow interconnections and associated relationships. Boxes represent each major function of a subject. These functions are broken down or decomposed into more detailed diagrams, until the subject is described at a level necessary to support the goals of a particular project. The top-level diagram in the model provides the most general or abstract description of the subject represented by the model. This diagram is followed by a series of child diagrams providing more detail about the subject.

Each model shall have a top-level context diagram, on which the subject of the model is represented by a single box with its bounding arrows. This is called the A-0 diagram (pronounced A minus zero). The arrows on this diagram interface with functions outside the subject area to establish model focus. Since a single box represents the whole subject, the descriptive name written in the box is general. The same is true of the interface arrows since they also represent the complete set of external interfaces to the subject. The A-0 diagram also sets the model scope or boundary and orientation.

The A-0 context diagram also shall present brief statements specifying the model's viewpoint and purpose, which help to guide and constrain the creation of the model. The viewpoint determines what can be "seen" within the model context, and from what perspective or "slant". Depending on the audience, different statements of viewpoint may be adopted that emphasise different aspects of the subject. Things that are important in one viewpoint may not even appear in a model presented from another viewpoint of the same subject.

The statement of purpose expresses the reason why the model is created and actually determines the structure of the model. The most important features come first in the hierarchy, as the whole top-level function is decomposed into sub-function parts that compose it, and those parts, in turn, are further decomposed until all of the relevant detail of the whole viewpoint is adequately exposed. Each sub-function is modelled individually by a box, with parent boxes detailed by child diagrams at the next lower level. All child diagrams must be within the scope of the top-level context diagram.

A parent diagram is one that contains one or more parent boxes. Every ordinary (non-context) diagram is also a child diagram, since by definition it details a parent box. Thus a diagram may be both a parent diagram (containing parent boxes) and a child diagram (detailing its own parent box). Likewise, a box may be both a parent box (detailed by a child diagram) and a child box (appearing on a child diagram). The primary hierarchical relationship is between a parent box and the child diagram that details it.

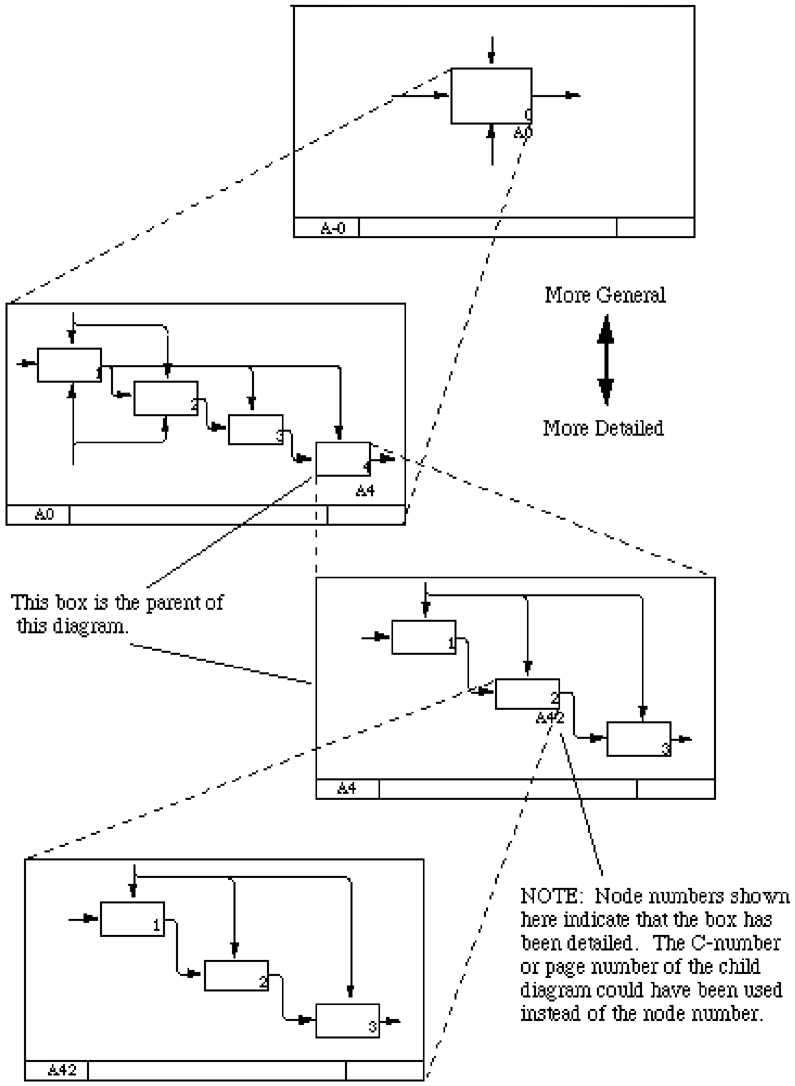


Figure C.1: Decomposition structure of IDEF0 diagrams.

Boxes and arrows - Box and arrow semantic rules:

- A box shall be named with an active verb or verb phrase.
- Each side of a function box shall have a standard box/arrow relationship:
  - Input arrows (what is transformed by the activity) shall interface with the left side of a box.
  - Control arrows (what influences the output of the activity) shall interface with the top side of a box.
  - Output arrows (what comes out of the activity) shall interface with the right side of the box.
  - Mechanism arrows (who of what is doing the activity) shall point upward and shall connect to the bottom side of the box.

- Arrow segments shall be labelled with a noun or noun phrase unless a single arrow label clearly applies to the arrow as a whole.
- "Squiggles" () shall be used to link an arrow with its associated label, unless the arrow/label relationship is obvious.
- Arrow labels shall not consist solely of any of the following terms: function, input, control, output, mechanism, or call.

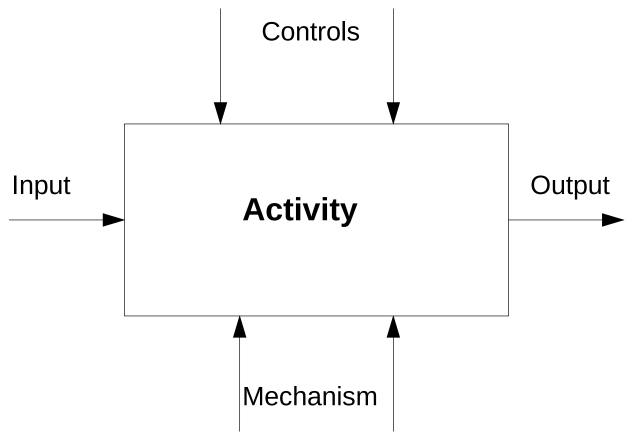


Figure C.2: Representation of an IDEF0 box.

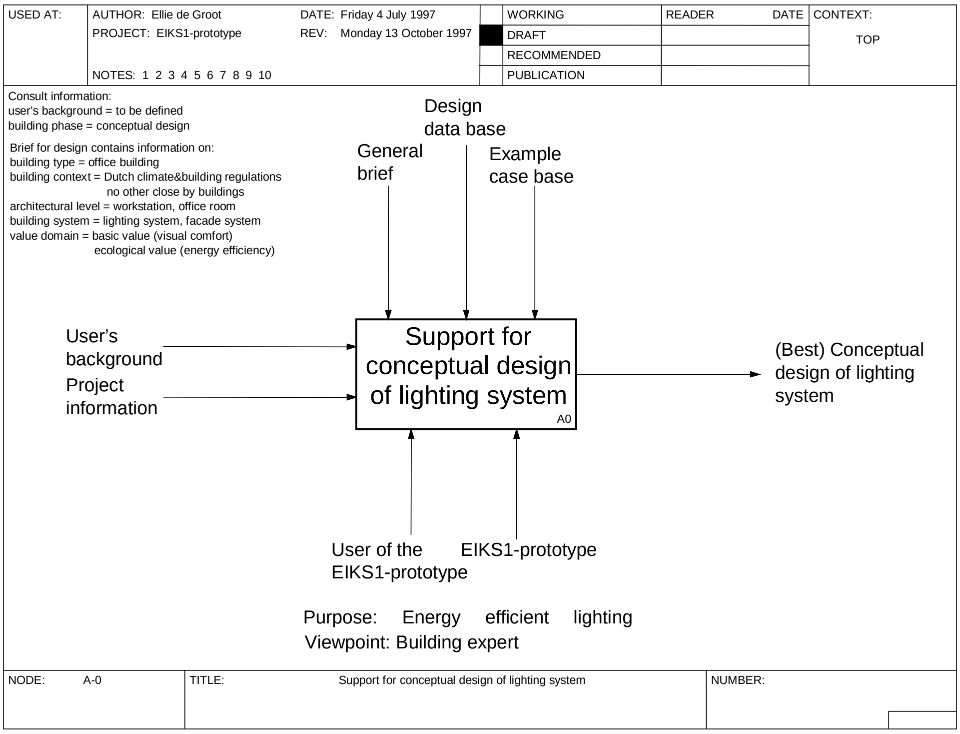
Since IDEF0 supports function modelling, the box name shall be a verb or verb phrase that is descriptive of the function that the box represents. The definitive step beyond the phrase-naming of the box is the incorporation of arrows (matching the orientation of the box sides) that complement and complete the expressive power (as distinguished from the representational aspect) of the IDEF0 box.

Standard terminology shall be used to ensure precise communication. Box meanings are named descriptively with verbs or verb phrases and are split and clustered in decomposition diagramming. Arrow meanings are bundled and unbundled in diagramming and the arrow segments are labelled with nouns or noun phrases to express meanings.
Arrow-segment labels are prescriptive, constraining the meaning of their segment to apply exclusively to the particular data or objects that the arrow segment graphically represents.

Each side of the function box has a standard meaning in terms of box/arrow relationships. The side of the box with which an arrow interfaces reflects the arrow’s role. Arrows entering the left side of the box are inputs. Inputs are transformed or consumed by the function to produce outputs. Arrows entering the box on the top are controls. Controls specify the conditions required for the function to produce correct outputs. Arrows leaving a box on the right side are outputs. Outputs are the data or objects produced by the function. Arrows pointing upward to the bottom side of the box identify some of the means that support the execution of the function. These may be inherited from the parent box.

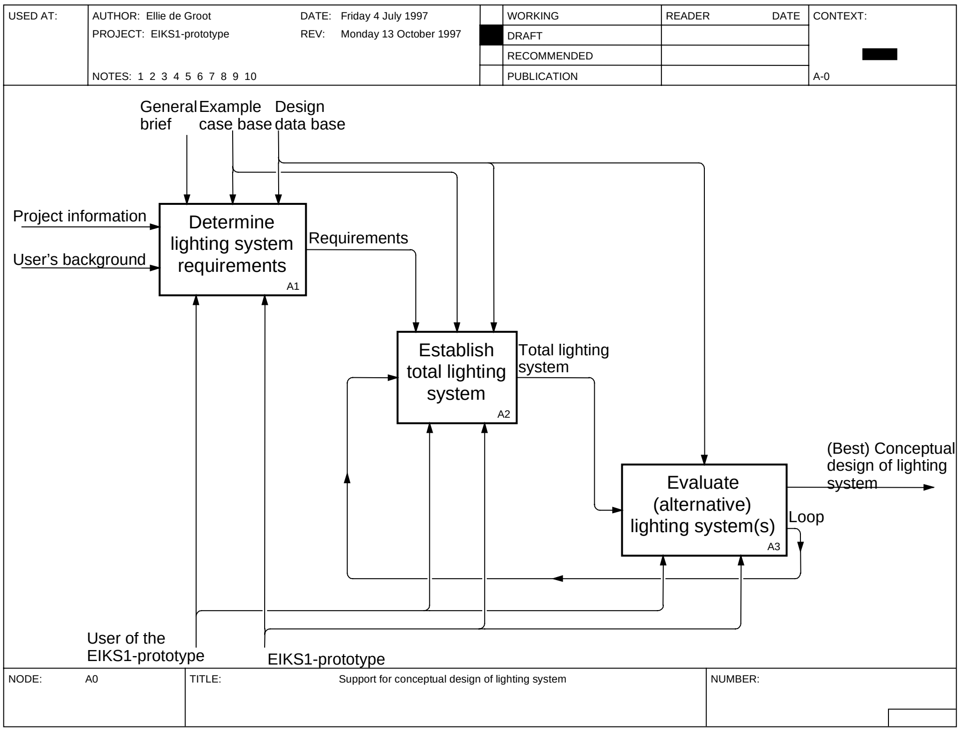
Appendix D

IDEF0 Diagrams for the EIKS-Demo



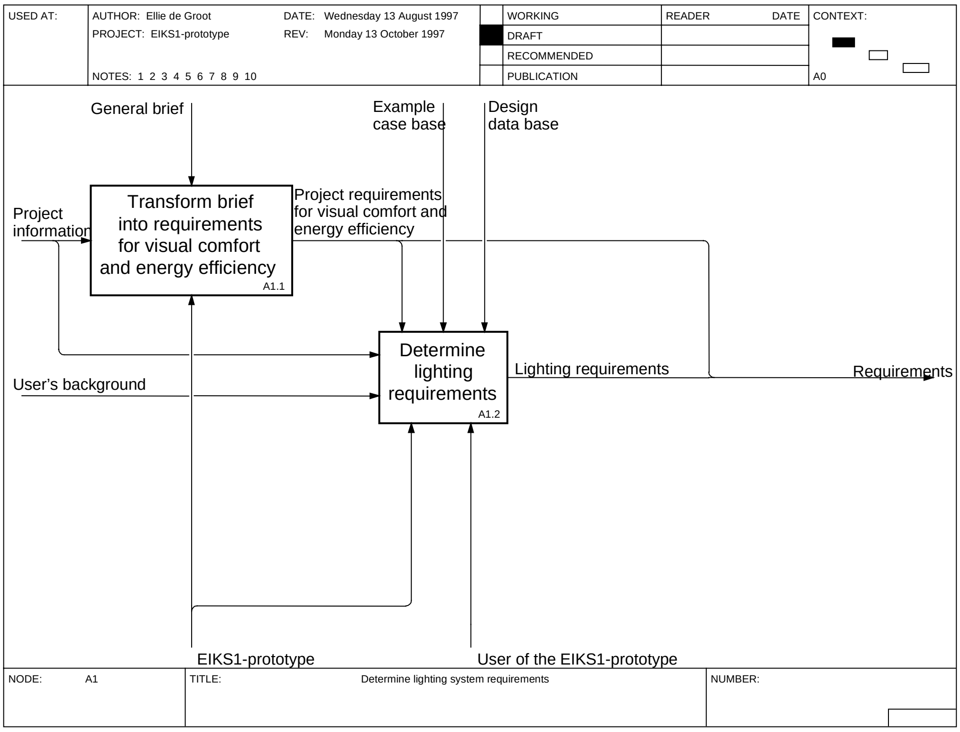
Activity or Arrow name	Definition
A0: Support for conceptual design of lighting system	Subdivided further, figure B.1 and B.2.
(Best) Conceptual design of lighting system	An integrated daylight/ artificial lighting system of which control, maintenance, dimensions and materials are adjusted to fit the project's requirements with the performances.
Design data base	Several data bases with data on products, theory, etc.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
General brief	The brief as formed during the briefing process of SBPPE. For the tool some characteristics will be provided.
Project information	Project specific information on the stage of the project, building surroundings, space characteristics, organisation characteristics.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.
User's background	Information on the user's background, important for the structure of the questions and the help-function.

Figure D.1: EIKS diagram A-0.



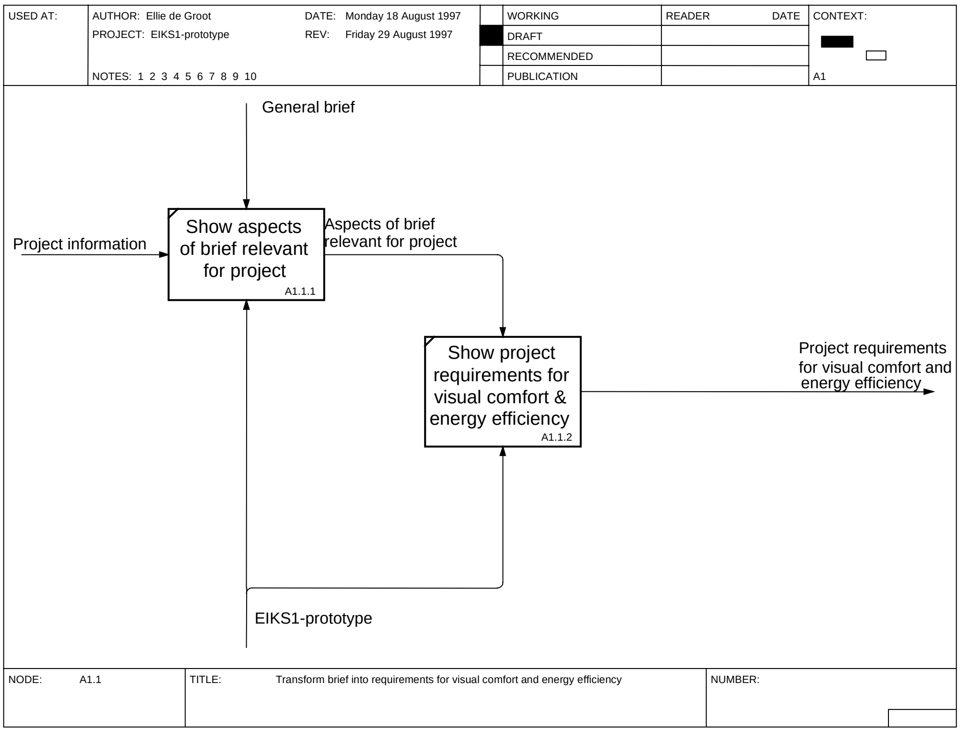
Activity or Arrow name	Definition
A1: Determine lighting system requirements	Subdivided further, figure B.3.
A2: Establish total lighting system	Subdivided further, figure B.6.
A3: Evaluate (alternative) lighting system(s)	Subdivided further, figure B.12.
(Best) Conceptual design of lighting system	An integrated daylight/ artificial lighting system of which control, maintenance, dimensions and materials are adjusted to fit the project's requirements with the performances.
Design data base	Several data bases with data on products, theory, etc.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
General brief	The brief as formed during the briefing process of SBPPE. For the tool some characteristics will be provided.
Loop	A redirection in the program.
Project information	Project specific information on the stage of the project, building surroundings, space characteristics, organisation characteristics.
Requirements	All requirements for visual comfort and energy efficiency and lighting requirements. These provide the boundaries to the solution.
Total lighting system	A combination of daylight and artificial light of which control, materials and dimensions are adapted to make the performance of it meet the requirements.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.
User's background	Information on the user's background, important for the structure of the questions and the help-function.

Figure D.2: EIKS diagram A0.



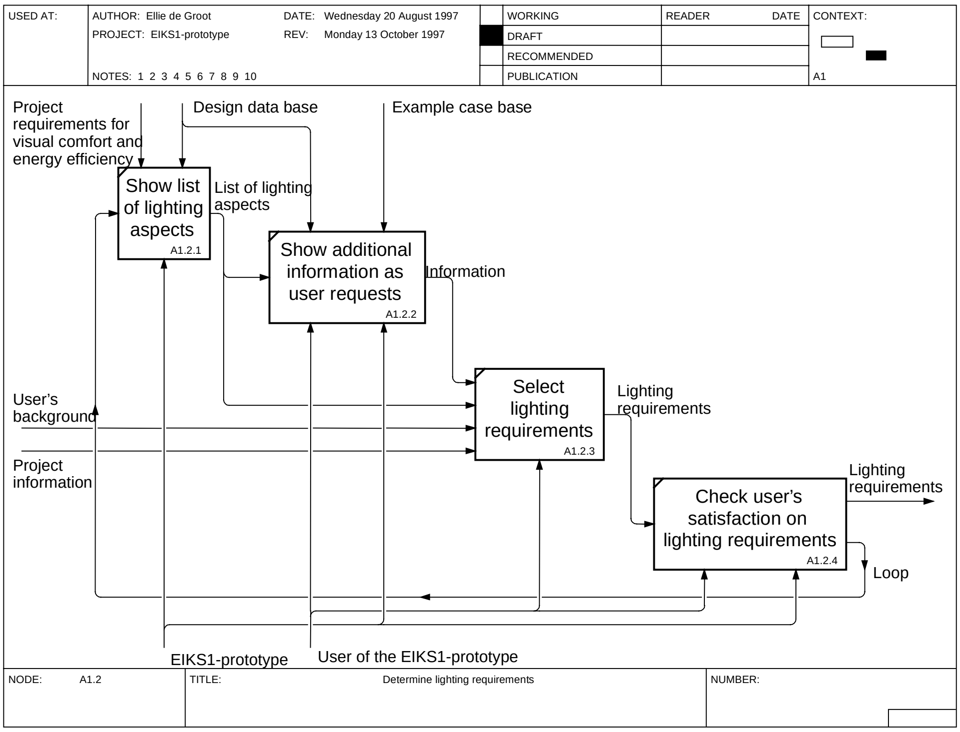
Activity or Arrow name	Definition
A1.1: Transform brief into requirements for visual comfort and energy efficiency	Subdivided further, figure B.4.
A1.2: Determine lighting requirements	Subdivided further, figure B.5.
Design data base	Several data bases with data on products, theory, etc.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
General brief	The brief as formed during the briefing process of SBPPE. For the tool some characteristics will be provided.
Lighting requirements	Requirements concerning: compatibleness with architecture, colour of light, glare, flexibleness, lighting control, maintenance. These provide the client's boundaries to the solution.
Project information	Project specific information on the stage of the project, building surroundings, space characteristics, organisation characteristics.
Project requirements for visual comfort and energy efficiency	Minimum requirements concerning: National lighting requirement for illuminance and luminance- ratio limits and for energy use and Local requirements. These provide the legislative boundaries to the solution.
Requirements	All requirements for visual comfort and energy efficiency and lighting requirements. These provide the boundaries to the solution.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.
User's background	Information on the user's background, important for the structure of the questions and the help-function.

Figure D.3: EIKS diagram A1.



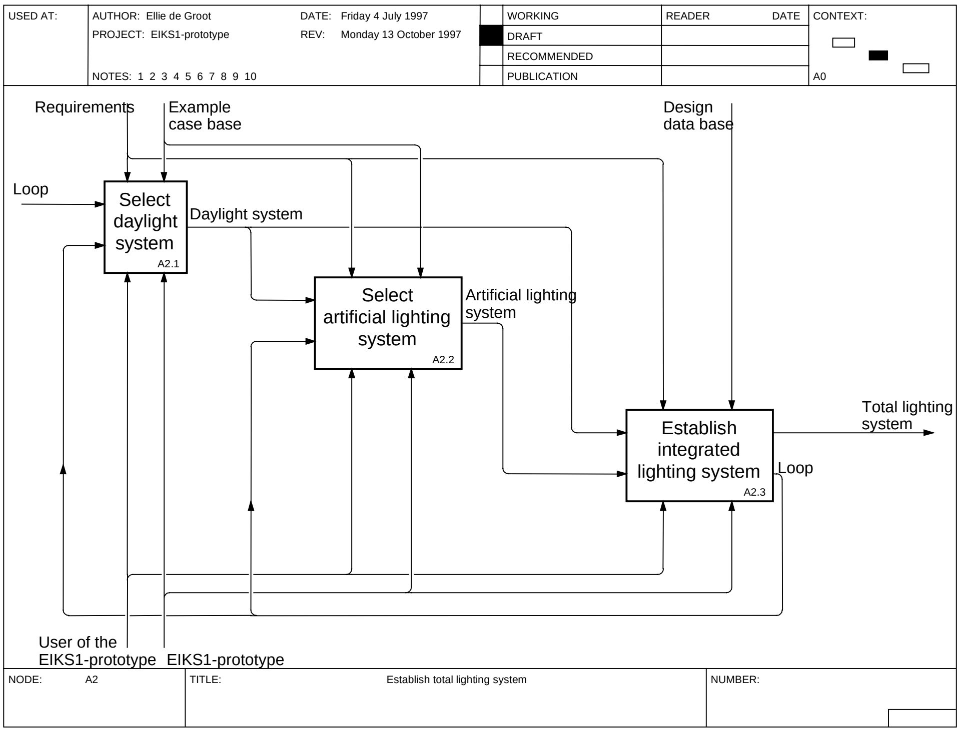
Activity or Arrow name	Definition
A1.1.1: Show aspects of brief relevant for project	These briefing results relevant for lighting contain information on Project new or old, Country, Location, Building type, Space type, Outside wall(s) orientation(s), Amount of people, Average age, Type of activities, Overall energy use.
A1.1.2: Show project requirements for visual comfort & energy efficiency	The requirements consist of National lighting requirement for illuminance and luminance- ratio limits and for energy use and Local requirements. These provide the legislative boundaries to the solution.
Aspects of brief relevant for project	Those aspects of the brief that are relevant for lighting: Project new or old, Country, Location, Building type, Space type, Outside wall(s) orientation(s), Amount of people, Average age, Type of activities, Overall energy use
EIKS1-prototype	The demo computer system itself.
General brief	The brief as formed during the briefing process of SBPPE. For the tool some characteristics will be provided.
Project information	Project specific information on the stage of the project, building surroundings, space characteristics, organisation characteristics.
Project requirements for visual comfort and energy efficiency	Minimum requirements concerning: National lighting requirement for illuminance and luminance- ratio limits and for energy use and Local requirements. These provide the legislative boundaries to the solution.

Figure D.4: EIKS diagram A1.1.



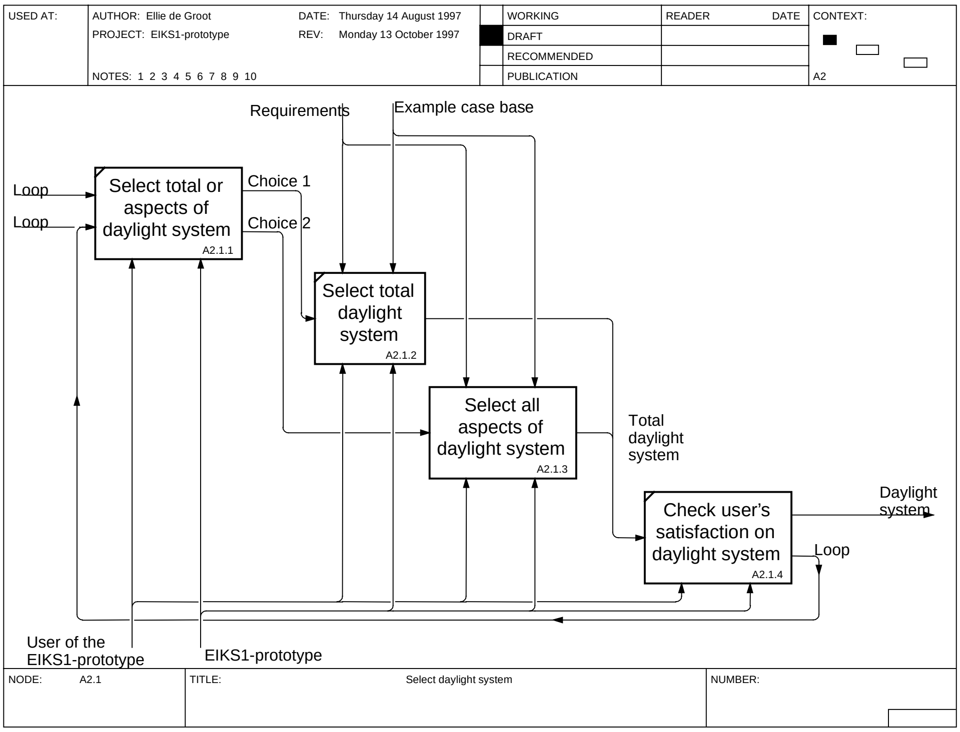
Activity or Arrow name	Definition
A1.2.1: Show list of lighting aspects	Aspects related to: Space appearance, Daylight, Artificial lighting, Control & maintenance.
A1.2.2: Show additional information as user requests	Theory and examples to explain every lighting aspect.
A1.2.3: Select lighting requirements	For each lighting aspect a value must be selected. These are lighting requirements and provide the client's boundaries to the solution.
A1.2.4: Check user's satisfaction on lighting req.	The user has to indicate whether he or she wants to continue or make some changes on the lighting requirements.
Design data base	Several data bases with data on products, theory, etc.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
Information	Information on theory and examples to explain the importance of every lighting aspect.
Lighting requirements	Requirements concerning: compatibleness with architecture, colour of light, glare, flexibleness, lighting control, maintenance. These provide the client's boundaries to the solution.
List of lighting aspects	Aspects related to: Space appearance, Daylight, Artificial lighting, Control & maintenance.
Loop	A redirection in the program.
Project information	Project specific information on the stage of the project, building surroundings, space characteristics, organisation characteristics.
Project requirements for visual comfort and energy efficiency	Minimum requirements concerning: National lighting requirement for illuminance and luminance- ratio limits and for energy use and Local requirements. These provide the legislative boundaries to the solution.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.
User's background	Information on the user's background, important for the structure of the questions and the help-function.

Figure D.5: EIKS diagram A1.2.



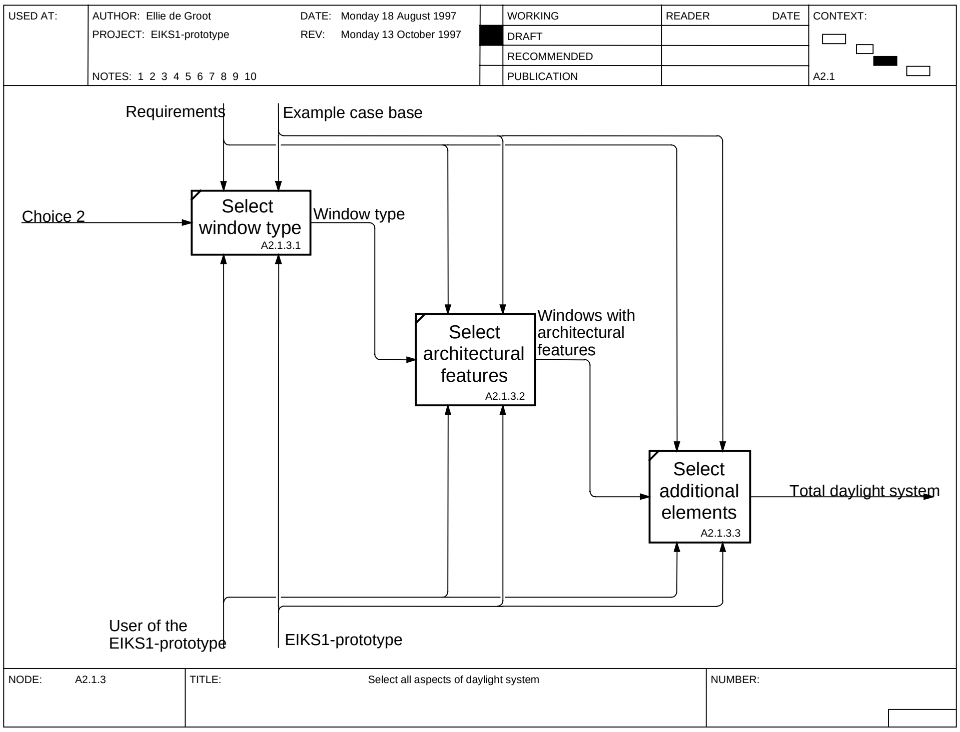
Activity or Arrow name	**Definition**
A2.1: Select daylight system	Subdivided further, figure B.7.
A2.2: Select artificial lighting system	Subdivided further, figure B.9.
A2.3: Establish integrated lighting system	Subdivided further, figure B.11.
Artificial lighting system	Combination of a distribution of lighting, lighting sources and luminaires for artificial lighting.
Daylight system	Combination of an opening in a façade or ceiling, architectural adjustments and additional elements for daylight.
Design data base	Several data bases with data on products, theory, etc.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
Loop	A redirection in the program.
Requirements	All requirements for visual comfort and energy efficiency and lighting requirements. These provide the boundaries to the solution.
Total lighting system	A combination of daylight and artificial light of which control, materials and dimensions are adapted to make the performance of it meet the requirements.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.

Figure D.6: EIKS diagram A2.



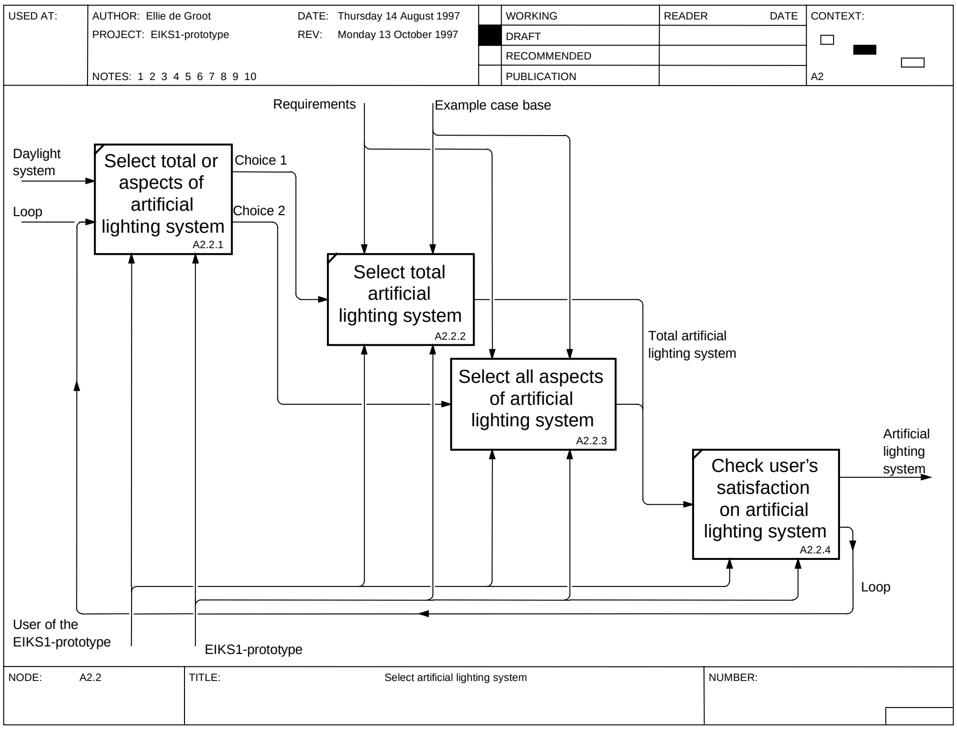
Activity or Arrow name	Definition
A2.1.1: Select total or aspects of daylight system	The user has to indicate whether he or she wants to select a total daylight system or the various parts one by one.
A2.1.2: Select total daylight system	The user has to pick the most appealing total daylight system from the examples meeting the requirements provided by the tool.
A2.1.3: Select all aspects of daylight system	Subdivided further, figure B.8.
A2.1.4: Check user's satisfaction on daylight system	The user has to indicate whether he or she wants to continue or make some changes on the daylight system.
Choice 1	First consult concept: selection of total day or artificial lighting system from example case base.
Choice 2	Second consult concept: selection of various parts of day or artificial lighting system from example case base.
Daylight system	Combination of an opening in a façade or ceiling, architectural adjustments and additional elements for daylight.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
Loop	A redirection in the program.
Requirements	All requirements for visual comfort and energy efficiency and lighting requirements. These provide the boundaries to the solution.
Total daylight system	A daylight system chosen from the example case base or built from window type/position/shape, architectural adjustments and added elements.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.

Figure D.7: EIKS diagram A2.1.



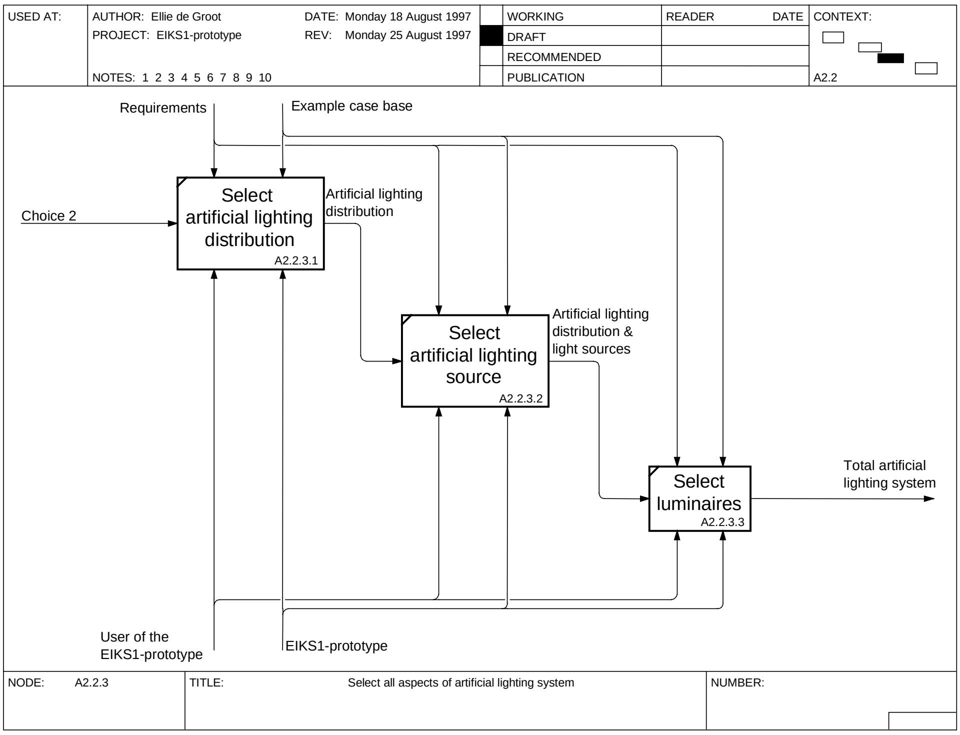
Activity or Arrow name	Definition
A2.1.3.1: Select window type	The user has to pick the most appealing window system from the examples meeting the requirements provided by the tool.
A2.1.3.2: Select architectural features	The user has to pick the most appealing architectural features from the examples meeting the requirements provided by the tool.
A2.1.3.3: Select additional elements	The user has to pick the most appealing additional elements from the examples meeting the requirements provided by the tool.
Choice 2	Second consult concept: selection of various parts of day or artificial lighting system from example case base.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
Requirements	All requirements for visual comfort and energy efficiency and lighting requirements. These provide the boundaries to the solution.
Total daylight system	A daylight system chosen from the example case base or built from window type/position/shape, architectural adjustments and added elements.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.
Window type	The shape (% glazing) and position (wall, ceiling, orientation) of all windows in the space.
Windows with architectural features	Architectural features (such as reflecting glazing, light shelves, sun shields made of stone or wood) added to the earlier chosen windows.

Figure D.8: EIKS diagram A2.1.3.



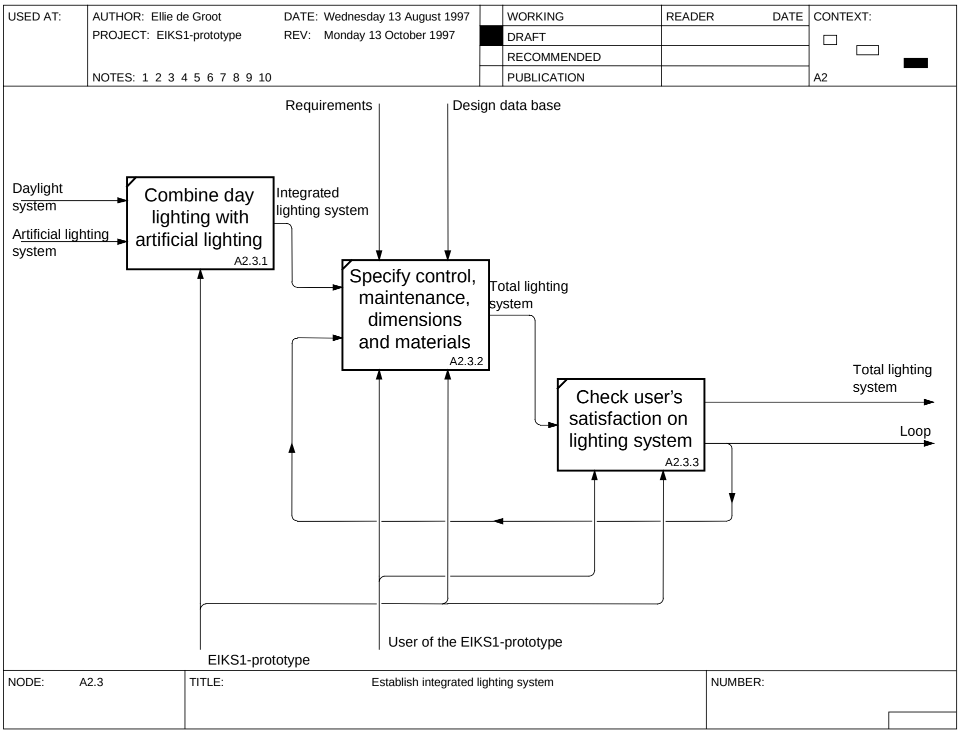
Activity or Arrow name	Definition
A2.2.1: Select total or aspects of artificial lighting system	The user has to indicate whether he or she wants to select a total artificial lighting system or the various parts one by one.
A2.2.2: Select total artificial lighting system	The user has to pick the most appealing total artificial lighting system from the examples meeting the requirements provided by the tool.
A2.2.3: Select all aspects of artificial lighting system	Subdivided further, figure B.10.
A2.2.4: Check user's satisfaction on artificial lighting system	The user has to indicate whether he or she wants to continue or make some changes on the artificial lighting system.
Artificial lighting system	Combination of a distribution of lighting, lighting sources and luminaires for artificial lighting.
Choice 1	First consult concept: selection of total day or artificial lighting system from example case base.
Choice 2	Second consult concept: selection of various parts of day or artificial lighting system from example case base.
Daylight system	Combination of an opening in a façade or ceiling, architectural adjustments and additional elements for daylight.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
Loop	A redirection in the program.
Requirements	All requirements for visual comfort and energy efficiency and lighting requirements. These provide the boundaries to the solution.
Total artificial lighting system	An artificial lighting system chosen from the example case base or built from distribution, lighting source and luminaires.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.

Figure D.9: EIKS diagram A2.2.



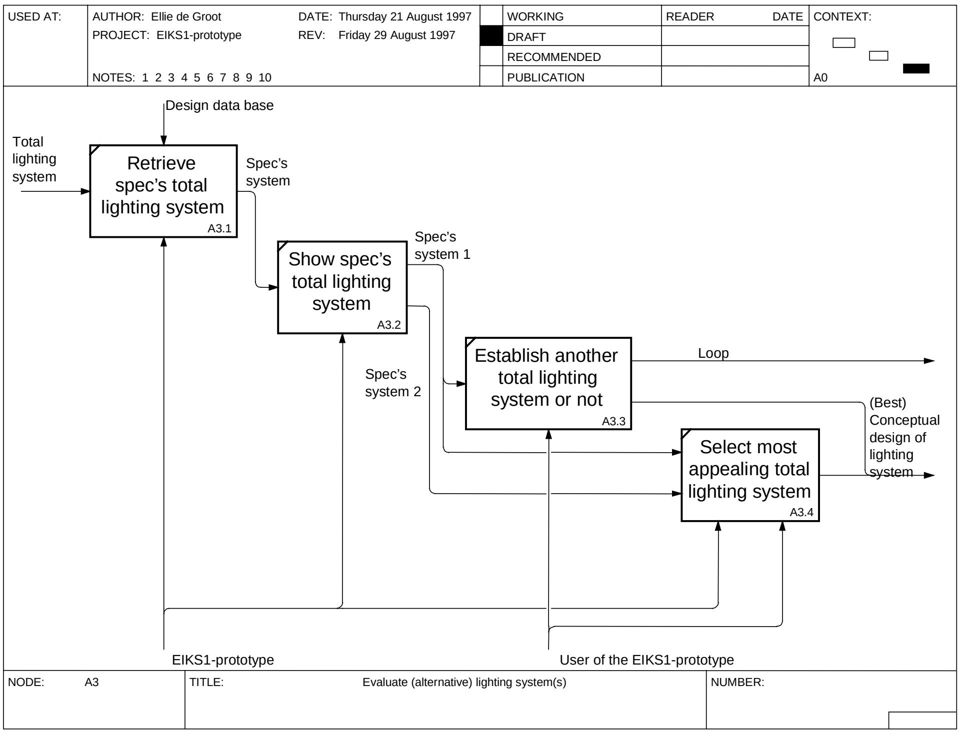
Activity or Arrow name	Definition
A2.2.3.1: Select artificial lighting distribution	The user has to pick the most appealing artificial lighting distribution from the examples meeting the requirements provided by the tool.
A2.2.3.2: Select artificial lighting source	The user has to pick the most appealing artificial lighting source from the examples meeting the requirements provided by the tool.
A2.2.3.3: Select luminaires	The user has to pick the most appealing luminaires from the examples meeting the requirements provided by the tool.
Artificial lighting distribution	The distribution of artificial lighting into the space: uniform, separation between work area and walk area, or task lighting.
Artificial lighting distribution & light sources	Types of light sources added to earlier chosen distribution.
Choice 2	Second consult concept: selection of various parts of day or artificial lighting system from example case base.
EIKS1-prototype	The demo computer system itself.
Example case base	A case base with examples of (aspects of) daylight and artificial lighting systems.
Requirements	All requirements for visual comfort and energy efficiency and lighting requirements. These provide the boundaries to the solution.
Total artificial lighting system	An artificial lighting system chosen from the example case base or built from distribution, lighting source and luminaires.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.

Figure D.10: EIKS diagram A2.2.3.



Activity or Arrow name	**Definition**
A2.3.1: Combine daylight with artificial lighting	The chosen daylight system and artificial lighting system are combined to an integrated lighting system.
A2.3.2: Specify control, maintenance, dimensions and materials	The user has to specify control, maintenance, dimensions and materials for the particular project.
A2.3.3: Check user's satisfaction on lighting system	The user has to indicate whether he or she wants to continue or make some changes on the daylight system, the artificial lighting system or the integration.
Artificial lighting system	Combination of a distribution of lighting, lighting sources and luminaires for artificial lighting.
Daylight system	Combination of an opening in a façade or ceiling, architectural adjustments and additional elements for daylight.
Design data base	Several data bases with data on products, theory, etc.
EIKS1-prototype	The demo computer system itself.
Integrated lighting system	A combination of daylight and artificial lighting.
Loop	A redirection in the program.
Requirements	All requirements for visual comfort and energy efficiency and lighting requirements. These provide the boundaries to the solution.
Total lighting system	A combination of daylight and artificial light of which control, materials and dimensions are adapted to make the performance of it meet the requirements.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.

Figure D.11: EIKS diagram A2.3.



Activity or Arrow name	Definition
A3.1: Retrieve spec's total lighting system	Retrieve the specifications of the found total lighting system.
A3.2: Show spec's total lighting system	Show the specific performances of the total lighting system.
A3.3: Establish another total lighting system or not	Determine whether the user wants to establish another total lighting system to compare the first one with or not.
A3.4: Select most appealing total lighting system	Select the most appealing total lighting system.
(Best) Conceptual design of lighting system	An integrated daylight/ artificial lighting system of which control, maintenance, dimensions and materials are adjusted to fit the project's requirements with the performances.
Design data base	Several data bases with data on products, theory, etc.
EIKS1-prototype	The demo computer system itself.
Loop	A redirection in the program.
Spec's system	Specific performances of the total integrated lighting system on visual comfort and energy use.
Spec's system 1	Specific performances of the first total integrated lighting system on visual comfort and energy use.
Spec's system 2	Specific performances of the second total integrated lighting system on visual comfort and energy use.
Total lighting system	A combination of daylight and artificial light of which control, materials and dimensions are adapted to make the performance of it meet the requirements.
User of the EIKS1-prototype	The user of the tool has to make some choices or decisions.

Figure D.12: EIKS diagram A3.

Appendix E

Final Workshop Results

Table E.1: Results validation Window size.

60%	**choice options**							Total	Mean	Mode	High	Low	STD	n	VCC
Secondary List	-3(-3)	-2(-2)	-1(-1)	0(0)	1(1)	2(2)	3(3)								
Flexibility			3	6	3			0	0.00	0	1	-1	0.74	12	0.75
initial costs			3	4	2			-1	-0.11	0	1	-1	0.78	9	0.74
visual comfort		1	6	4	2			-6	-0.46	-1	1	-2	0.88	13	0.71
energy efficiency		2	3	5	1			-6	-0.55	0	1	-2	0.93	11	0.69
operating costs		1	6	1	2			-6	-0.60	-1	1	-2	0.97	10	0.68

STD is ‘Standard Deviation’ and indicates the way in which the result is centred around its mean.

n is the number of attendees that voted.

VCC is ‘Ventana Coefficient of Concordance’ and reflects to which extent the group agrees on the results. Total agreement is reached if this value is 1.00, an no agreement is reached if this value is 0.00.

Continuation table E.1: Results validation Window size.

40%	**choice options**							Total	Mean	Mode	High	Low	STD	n	VCC
Secondary List	-3(-3)	-2(-2)	-1(-1)	0(0)	1(1)	2(2)	3(3)								
energy efficiency			1	6	4			3	0.27	0	1	-1	0.65	11	0.78
operating costs			3	3	4			1	0.10	1	1	-1	0.88	10	0.71
initial costs			3	3	3			0	0.00	??	1	-1	0.87	9	0.71
Flexibility			3	7	2			-1	-0.08	0	1	-1	0.67	12	0.78
visual comfort		1	5	2	5			-2	-0.15	??	1	-2	1.07	13	0.64
30%	**choice options**							Total	Mean	Mode	High	Low	STD	n	VCC
Secondary List	-3(-3)	-2(-2)	-1(-1)	0(0)	1(1)	2(2)	3(3)								
operating costs		2	1	1	4	2		3	0.30	1	2	-2	1.49	10	0.50
energy efficiency		1	2	4	3	2		3	0.25	0	2	-2	1.22	12	0.59
initial costs		1	3	2	2	1		-1	-0.11	-1	2	-2	1.27	9	0.58
Flexibility	1	3	2	4		2		-7	-0.58	0	2	-3	1.56	12	0.48
visual comfort	1	6	1		2	3		-8	-0.62	-2	2	-3	1.89	13	0.37

Table E.2: Results validation Window orientation.

Vertical oriented	**choice options**							Total	Mean	Mode	High	Low	STD	n	VCC
Secondary List	-3(-3)	-2(-2)	-1(-1)	0(0)	1(1)	2(2)	3(3)								
energy efficiency			4	3	4			0	0.00	??	1	-1	0.89	11	0.70
visual comfort	1	1	4	1	3	2		-2	-0.17	-1	2	-3	1.59	12	0.47
operating costs			4	5	1			-3	-0.30	0	1	-1	0.67	10	0.78
flexibility		3	3	2	3	1		-4	-0.33	??	2	-2	1.37	12	0.54
initial costs		3	2	3	2	1		-4	-0.36	??	2	-2	1.36	11	0.55
Combination horizontal and vertical	**choice options**							Total	Mean	Mode	High	Low	STD	n	VCC
Secondary List	-3(-3)	-2(-2)	-1(-1)	0(0)	1(1)	2(2)	3(3)								
visual comfort			5	3	3	2		2	0.15	-1	2	-1	1.14	13	0.62
energy efficiency			3	3	4			1	0.10	1	1	-1	0.88	10	0.71
operating costs	1		3	5	1			-5	-0.50	0	1	-3	1.08	10	0.64
flexibility	1	2	4	3	1	1		-8	-0.67	-1	2	-3	1.37	12	0.54
initial costs	2	2	3	4				-13	-1.18	0	0	-3	1.17	11	0.61

Table E.3: Results validation Target illuminance.

400 lux	**choice options**							Total	Mean	Mode	High	Low	STD	n	VCC
Secondary List	-3(-3)	-2(-2)	-1(-1)	0(0)	1(1)	2(2)	3(3)								
operating costs			2	1	10			8	0.62	1	1	-1	0.77	13	0.74
energy efficiency			2	2	9			7	0.54	1	1	-1	0.78	13	0.74
initial costs			2	6	4	1		4	0.31	0	2	-1	0.85	13	0.72
flexibility	1	1	4	7				-9	-0.69	0	0	-3	0.95	13	0.68
visual comfort	1	1	8	2	1			-12	-0.92	-1	1	-3	0.95	13	0.68
800 lux	**choice options**							Total	Mean	Mode	High	Low	STD	n	VCC
Secondary List	-3(-3)	-2(-2)	-1(-1)	0(0)	1(1)	2(2)	3(3)								
flexibility				1	6	5	1	19	1.46	1	3	0	0.78	13	0.74
visual comfort		1	1	1	2	6	2	17	1.31	2	3	-2	1.49	13	0.50
initial costs		4	6		1	2		-9	-0.69	-1	2	-2	1.44	13	0.52
energy efficiency	1	4	5	1	1	1		-13	-1.00	-1	2	-3	1.35	13	0.55
operating costs		6	5		1	1		-14	-1.08	-2	2	-2	1.26	13	0.58

Table E.4: Cases.

Variables	Reference	Case 1	Case 2
Daylight			
Façade type	Cavity wall, double glazing	Cavity wall, double glazing	Cavity wall, double glazing
Window area	50%	40%	60%
Window orientation	Horizontal oriented	Horizontal oriented	Horizontal/Vertical
Glazing type	Transparent	Transparent	Transparent
Features outside	None	None	None
Features façade	None	None	None
Features inside	None	None	None
Elements outside	None	None	None
Elements inside	Venetian blinds	Venetian blinds	Venetian blinds
Artificial lighting			
Target illuminance	500 Lux	500 Lux	500 Lux
Light distribution in room	Uniformity max.	Uniformity max.	Uniformity max.
Light direction	Direct	Indirect/Direct	Direct
Luminaire position	Ceiling	Pendent	Pendent
Luminaire type	Louver	High reflecting	High reflecting
Light source	Fluorescent tubes	Fluorescent tubes	Fluorescent tubes
Control			
Daylight control	Per room manual	Per room manual	Per room manual
Artificial lighting control	Per room	Per zone	Per zone
Control option	Switch on/off	Daylight sensor	Dimmer

Table E.5: Results validation Case 1.

	Much worse	Worse	Equal	Better	Much better	Total	Standard deviation	Mean	n
Visual comfort	0	1	1	7	4	14	1.72	1.08	13
Initial costs	0	13	0	0	0	-13	0.00	-1.00	13
Operating costs	0	4	2	7	0	3	1.85	0.23	13
Energy efficiency	0	2	2	8	1	8	1.74	0.62	13
Flexibility	0	5	5	3	0	-2	1.60	-0.15	13

Table E.6: Results validation Case 2.

	Much worse	Worse	Equal	Better	Much better	Total	Standard deviation	Mean	n
Visual comfort	1	5	3	3	1	-2	2.29	-0.15	13
Initial costs	0	13	0	0	0	-13	0.00	-1.00	13
Operating costs	0	0	7	6	0	6	1.04	0.46	13
Energy efficiency	0	1	4	8	0	7	1.32	0.53	13
Flexibility	3	4	4	2	0	-8	2.09	-0.62	13

Dankwoord

Destijds heb ik lang getwijfeld of promoveren wel iets voor mij zou zijn. Uiteindelijk ben ik gezwicht voor een compromis van vier dagen in de week promoveren op proefontwerp aan de TUE en een dag in de week werken voor het Centrum Bouwonderzoek [CBO-TNO-TUE]. Ik bedank Paul Rutten voor de mogelijkheden die hij voor mij geschapen heeft om via het Stan Ackermans Instituut bij de sectie FAGO te promoveren en alles wat hij verder voor mij gedaan heeft. Ik bedank ook Renz van Luxemburg voor het creëren van de mogelijkheid om tijdens het promoveren enige praktijkervaring op te doen. Om verschillende redenen heb ik geen spijt gekregen van mijn beslissing:

Ten eerste heb ik de drie jaren van het promoveren meestal als leerzaam en plezierig ervaren. Met name het eerste jaar waarbij de taken van het CBO en de TUE samenvielen doordat beiden betrokken waren bij het Europese EIKS-project. Dit was een hectisch jaar omdat veel van de Nederlandse taken op mijn bordje kwamen te liggen. Aan de andere kant bracht het echter ook veel leuke contacten en reismogelijkheden met zich mee. Voor één van de taken, het programmeren van de code voor de EIKS-demo, ben ik dank verschuldigd aan Joran Jessurun. Ook bij de totstandkoming van het ILSA-prototype bracht hij vaak uitkomst. Veel meer mensen hebben bijgedragen aan de totstandkoming van het uiteindelijke proefontwerp (o.a. alle mensen die betrokken waren bij de workshops en de interviews) die ik hier niet allemaal zal noemen, maar bij deze graag wil bedanken. Voor vier van hen maak ik een uitzondering omdat zij een grote rol hebben gespeeld en een positieve invloed hebben gehad op de kwaliteit van het werk: Rob van Zutphen, die vooral heeft geholpen bij de ontwikkeling van de tool, Laurens Zonneveldt, die als mijn belangrijkste kennisbron veel heeft bijgedragen aan het uiteindelijke resultaat, Henk Trum, die met name de laatste fase van het schrijven heeft ondersteunend, en Harry Timmermans die in zijn rol als tweede promotor veel aan het project heeft bijgedragen.

Ten tweede heb ik de ene dag per week voor het CBO altijd ervaren als een aangename onderbreking van mijn promotiewerk. Daarom wil ik Renz, Laurens, Cor, Theo en Susanne bedanken voor hun fijne collegialiteit; ik hoorde er voor 100% bij ook al was ik officieel maar 20% collega. Dezelfde collegialiteit heerste onder de AIO's tijdens de wekelijkse koffieronde en de AIO-uitstapjes.

Ten derde heb ik heel veel internationale contacten op kunnen doen. Niet alleen tijdens het EIKS project, mijn stage bij Lawrence Berkeley National Laboratory in California, en de conferentiebezoeken in Spa, Maastricht en Vancouver, maar ook dagelijks op mijn kamer op de TUE. Ik wil Shauna en Suresh bedanken voor de stimulerende werking die uitging van hun aanwezigheid en de leerzame gesprekken over allerlei onderwerpen (van de spelregels voor cricket tot de overlevingsstrategieën in Canadese winters bij 40°C onder nul). Shauna was naast kamergenoot ook een fijne collega, waarmee ik de afgelopen jaren veel van gedachten heb kunnen wisselen met betrekking tot onze projecten.

Ten vierde heb ik tijdens mijn promotie een aantal van de eigenschappen die ik van thuis uit heb meegekregen goed in de praktijk kunnen brengen. Hierbij dacht ik vaak aan de volgende uitspraken van mijn vader: “als je maar wilt, dan kan je het” en “als je iets doet, moet je het goed doen”. Ik bedank mijn ouders en zussen voor de goede basis die thuis gelegd werd en voor de onvoorwaardelijke steun bij alle beslissingen die ik nam.

Tenslotte is Marcel het meest geweldige dat ik aan mijn promotie heb overgehouden. Dat ik ooit een leven leidde zonder hem is nu ondenkbaar, en dat onze liefde eeuwig is staat buiten kijf !

Ellie de Groot
Eindhoven, september 1999.

Samenvatting

'Wicked' problemen - Het doel van het ontwerpproject beschreven in deze dissertatie is het *ontwerpen* van een gereedschap waarmee het *ontwerpen* van gebouwen ondersteund kan worden. Het ontwikkelen van een ontwerp wordt beschouwd als een *wicked* probleem, omdat het redelijke of voorspelbare grenzen overstijgt. Hieruit volgt dat we ons in dit ontwerpproject hebben gericht op twee 'wicked' problemen tegelijkertijd: een *dubbel wicked probleem*.

Het eerste 'wicked' probleem betreft het ontwerp van een Ontwerpbeslissingen Ondersteunend Systeem. Aanvankelijk werd een interactief computersysteem beschouwd dat het ontwerp van energie efficiënte gebouwen zou ondersteunen. Later is het gereedschap verder ontwikkeld om ontwerpers van gebouwen te ondersteunen bij de toepassing van energie efficiënte dag- en kunstlichtsystemen voor kantoorgebouwen.

Het tweede 'wicked' probleem betreft het conceptuele ontwerp van kantoorverlichting. Tijdens de conceptuele ontwerpfase wordt het functionele programma van eisen omgezet in een schetsontwerp. De beslissingen die tijdens deze ontwerpfase genomen worden hebben betrekking op zaken die vaak richtinggevend en tegelijkertijd beperkend en onomkeerbaar zijn. Deze beslissingen worden genomen op basis van de beschikbare informatie, die incorrect, onvolledig (bijvoorbeeld potentiële onderhoudskosten), of zeer complex (bijvoorbeeld wettelijke voorschriften) kunnen zijn.

Methode om 'wicked' problemen aan te pakken - Om grip te krijgen op het eerste 'wicked' probleem zijn twee workshops georganiseerd om mogelijke toekomstige gebruikers te ontmoeten en om met hen een gemeenschappelijke basis te creëren voor het te ontwikkelen gereedschap. Tijdens de eerste workshop werden door 29 bouwexperts in drie categorieën barrières geïdentificeerd, die het ontwerp van energie efficiënte gebouwen in de weg staan: het Ontwerpproces, de Huidige bouwtechnologie, en de Nederlandse regelgeving. Hierna werd de deelnemers gevraagd om aan te geven of een KennisgeBaseerd Systeem [KBS] in hun werkomgeving zou kunnen bijdragen aan het verlagen van de geïdentificeerde barrières. Door deze discussie te analyseren konden specificaties voor zo'n KBS worden afgeleid. Hiermee werd een demonstratie-computersysteem ontwikkeld dat zich richtte op het ontwerp van energie-efficiënte verlichting. Tijdens de tweede workshop is dit systeem getoond aan 14 bouwexperts die ook bij de eerste workshop aanwezig waren.

Om meer grip te krijgen op het tweede 'wicked' probleem zijn vervolgens een model voor kantoorverlichting en een prestatie-evaluatiemethode ontwikkeld. Het

verlichtingsmodel is gevalideerd en aangepast door vijf verlichtingsdeskundigen en een architect. De evaluatiemethode is gebaseerd op een psychofysische aanpak waarbij verlichtingsexperts werd gevraagd om de invloed van de verschillende variabelen in het verlichtingsmodel op de prestatie van een lichtsysteem te beoordelen. Het aangepaste verlichtingsmodel en de evaluatiemethode zijn geïmplementeerd in een nieuw prototype computersysteem: Integrated Lighting System Assistant [ILSA]. Het model en de methode zijn gevalideerd tijdens een derde, en laatste, workshop.

Resultaten van de drie workshops – Tijdens de eerste workshop waren de deelnemers het eens over het feit dat slechte communicatie tussen de verschillende leden van een bouwteam een van de belangrijkste problemen vormt. Verder gaven de deelnemers onder andere aan dat de bouwindustrie niet bereid is innovatieve oplossingen toe te passen vanwege de hoge risico’s die daaraan verbonden zijn. Een andere kwestie, betrof het feit dat het bouwteam zich richt op lage initiële kosten, en niet op lage operationele en life-cycle kosten. Ook kwam ter sprake dat regelgeving het gebouwontwerp minder creatief zou maken. Alle deelnemers waren het eens over het feit dat een KBS zou kunnen helpen bij het verlagen van de meeste geïdentificeerde barrières. De specificaties voor het KBS die tijdens de workshop opgetekend zijn, hadden echter een hoog abstractieniveau.

Tijdens de tweede workshop kon uit de enthousiaste reacties van de deelnemers geconcludeerd worden dat het demonstratiesysteem een goede basis vormt voor verdere ontwikkelingen. Het was echter duidelijk dat nog veel inspanning nodig zal zijn voor de realisatie van een operationeel systeem: een informatie en beslissingsondersteunend systeem voor energie efficiënte gebouwen. Verder werden er twee mogelijke toekomstige gebruikers van het systeem geïdentificeerd: de architect, die het gereedschap gebruikt voor routinematige ontwerpen, en de adviseur, die een deel van een complex ontwerp wil realiseren. In eerste instantie is besloten de aandacht te richten op de architect.

Tijdens de derde workshop bleek bij de validatie van het verlichtingsmodel dat de achttien gedefinieerde variabelen van het in ILSA geïmplementeerde model goed overeenkwamen met de dagelijkse ontwerppraktijk. Dit model was van te voren aangepast naar aanleiding van interviews met zes experts. De validatie van de evaluatiemethode liet echter zien dat de deelnemers het niet eens waren over de voorgestelde prestatiewaarden voor de afzonderlijke lichtvariabelen. Er was meer overeenstemming onder de deelnemers tijdens het workshoponderdeel waarbij de evaluatiemethode werd gevalideerd voor twee complete verlichtingsoplossingen.

Conclusies – De workshops blijken een goede bron van feedback en een essentiële link met de dagelijkse ontwerppraktijk te zijn. Hoewel het laatste ILSA-prototype niet is toegepast in echte projecten, zijn we ervan overtuigd dat een DDSS waarin het ontwikkelde verlichtingsmodel en de prestatie evaluatiemethode zijn geïmplementeerd kan functioneren als een hulpmiddel voor architecten dat het beslissingsproces in de vroege ontwerpfase zal ondersteunen op het gebied van het integreren van kunstlicht en daglicht.

Het ILSA prototype laat zien dat het mogelijk is het verlichtingsmodel en de evaluatiemethode te implementeren in een werkend prototype. Het gebied waarin ILSA kan worden toegepast is op dit moment echter nog erg beperkt. Alleen kantooromgevingen die voldoen aan een bepaald programma van eisen kunnen geëvalueerd worden, waarbij de uitkomst gerelateerd is aan een bepaalde referentieoplossing. Bovendien is het aantal geïmplementeerde verlichtingsconcepten beperkt. Het is echter mogelijk het aantal verlichtingsconcepten uit te breiden en om, door aanpassing van de geïmplementeerde prestatiewaarden, andere referentieconcepten te selecteren.

In de toekomst is het noodzakelijk het prototype te testen in echte verlichtingsontwerp-projecten. Verder zullen er meer DDSS-en ontwikkeld moeten worden opdat het gehele gebouw geëvalueerd kan worden. Daardoor kunnen dan ook andere dan de in dit project beschouwde architectonische niveaus, gebouwsystemen, en prestatieindicatoren aan bod komen.

Curriculum vitae

Ellie de Groot werd geboren op 3 oktober 1970 in het kleine Asperen aan de Linge. Zij heeft daar gewoond tot ze vlak voor haar vijfde jaar met haar ouders en twee zusjes verhuisde naar het dorpje Herwijnen, zeven kilometer zuidelijker aan de Waal. Daar heeft ze het grootste deel van haar jeugd doorgebracht en daarvandaan fietste zij van 1983 tot 1989 naar de RSG Wijdschild te Gorinchem, tegenwoordig het Merewade College genaamd. Hier behaalde zij in 1989 haar VWO diploma. Nog in datzelfde jaar werd een aanvang genomen met de studie Technische Natuurkunde aan de Technische Universiteit Eindhoven (TUE). Binnen deze studie studeerde zij af op een multidisciplinair project waarbij transportfysica, kernfysica en bouwfysica samenkwamen en behaalde in 1994 haar ingenieursdiploma. Meteen hierna nam Ellie deel aan een post initiële ontwerpersopleiding bij het Stan Ackermans Instituut te Eindhoven. Deze twee jarige opleiding werd afgesloten met een project bij de sectie FAGO van de faculteit Bouwkunde aan de TUE. In september 1996 werd het diploma voor Technologisch ontwerper verkregen en enkele maanden later werd een aanvang genomen met het promotiewerk dat in deze dissertatie is beschreven. Tegelijkertijd werd gedurende een dag per week projectwerk verricht bij de afdeling Centrum Bouwonderzoek van TNO Bouw.

Propositions

- Integrated Lighting System Assistant -

Ellie de Groot

1. A person who is commissioned to *design* a tool to support the building *design* process is confronted with a *double wicked* problem (see chapter 1 of this thesis).
2. Simulation programs that are developed for the detailed design phase cannot just be applied during the conceptual design phase (see chapter 1 of this thesis).
3. The ability to use Information and Communication Technology is vastly enhanced by the application of fourth-generation languages (see chapter 2 of this thesis).
4. The psychophysical method to determine performance values for lighting concepts is applicable in the conceptual design phase (see chapter 5 of this thesis).
5. As long as the performance of visual comfort cannot be expressed in financial terms, it will be inferior to currency-based performance indices.
6. “Light is the key to wellbeing” (after C.-E.J. Le Corbusier (1887-1965) quoted in: C. Christi, *Le Corbusier* (1970)).
7. “An expert is somebody who has made all the mistakes, which can be made in a very narrow field” (after N. Bohr (1885-1962) quoted in: A. Mackay, *The Harvest of a Quiet Eye* (1977)).
8. An alternative for an addiction to nicotine that causes much less harm to society is an addiction to chocolate.
9. “For those who believe in eternal love, no explanation is necessary; for those who do not, no explanation is possible” (MOVIEWEB’s review on the Polygram Film: *What dreams may come,* http://movieweb.com/).
10. “Qualche volta è meglio magiare come un re che esserlo” (Italian saying: Sometimes it is better to eat like a king than to be one).

Stellingen

- Assistent voor Integratie van Licht Systemen -

Ellie de Groot

1. Een persoon die opdracht heeft gekregen een gereedschap te *ontwerpen* waarmee het *ontwerp*proces van gebouwen ondersteund kan worden wordt geconfronteerd met een *dubbel 'wicked'* probleem (zie hoofdstuk 1 van deze dissertatie).
2. Simulatiesoftware die is ontwikkeld voor de detailontwerpfase kan niet zondermeer worden toegepast in de conceptuele ontwerpfase (zie hoofdstuk 1 van deze dissertatie).
3. Het gebruik van Informatie en Communicatie Technologie is enorm toegenomen door de toepassing van vierde generatie programmeertalen (zie hoofdstuk 2 van deze dissertatie).
4. De psychofysische methode om prestatiewaarden te bepalen voor verlichtingsconcepten is toepasbaar in de conceptuele ontwerpfase (zie hoofdstuk 5 van deze dissertatie).
5. Zolang de prestatie van visueel comfort niet kan worden uitgedrukt in een geldeenheid, zal het inferieur blijven aan prestaties waarbij dat wel mogelijk is.
6. "Licht is de sleutel tot welbevinden" (gebaseerd op C.-E.J. Le Corbusier (1887-1965) geciteerd in: C. Christi, *Le Corbusier* (1970)).
7. "Een expert is iemand die alle fouten gemaakt heeft die in een erg smal vakgebied gemaakt kunnen worden" (gebaseerd op N. Bohr (1885-1962) geciteerd in: Alan Mackay, *The Harvest of a Quiet Eye* (1977)).
8. Een alternatief voor nicotineverslaving waarvan de maatschappij veel minder schade ondervindt is chocoladeverslaving.
9. "Voor hen die in eeuwige liefde geloven, is geen verklaring nodig; voor hen die dat niet doen, is geen verklaring mogelijk" (commentaar van MOVIEWEB op de film van Polygram: *What dreams may come,* http://movieweb.com/).
10. "Qualche volta è meglio magiare come un re che esserlo" (Italiaanse zegswijze: Soms is het beter als een koning te eten, dan er een te zijn).