Building a Case-Based Design Assistant for Workplace Environment Design

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Abstract. This paper reports on the early stages of development of a case-based design tool. The purpose of this tool, called the Workplace Environment Design Advisor (WEDA), is to support architects in the conceptual design of workplace environments. The objective of this system is to provide electronic storage, retrieval and the exploration of post-occupancy performance knowledge of workplace environments. The paper provides a description of the reasoning behind choosing a case-based approach and the steps used to develop a prototype case-based system. This includes recent efforts to collect and structure real case data. This experience led to observations about issues such as case content (the availability and format of post-occupancy data) and retrieval strategies. The data collected for use in the system is based on a building-in-use study of the Centre of Building Research's office rooms located at the University of Eindhoven, the Netherlands.

1.0 BACKGROUND

This research originates from a desire to improve the quality of indoor environments. Commercial clients invest a large amount of their organisation's assets in facilities and the people who work in them. Yet Post Occupancy Evaluations [POE] of buildings in-use reveal serious problems in the areas of spatial comfort, acoustics, thermal quality, air quality, visual comfort and building integrity. These problems in turn impact on worker productivity and safety.

Preliminary research into this problem reveals that it relates, in part, to a lack of technical knowledge and feedback in the early stages of design. During briefing and conceptual design key design requirements are established and preliminary selections are made towards a solution. Even though decisions made at these stages of design can have a large impact on later decisions, briefing and conceptual design remains a relatively informal and poorly supported process.

In 1996 the *Strategic Building Performance Planning & Evaluation* [SBPPE] research program was set up by the Department of Building Physics at the Eindhoven University of Technology in the Netherlands. The aim of this research program is to investigate the use of Knowledge-Based Systems [KBS] for supporting decision-making during the early stages of workplace indoor environment design. Within the program's framework two main strategies for enhancing technical knowledge are currently being investigated: (1) professional development and (2) practice-based learning. These strategies are the topics of two separate doctoral research studies.

1.1. Professional Development

One way of enhancing technical fluency is through professional development. This implies a continuous upgrading of skills and knowledge to keep up to date with constant changes in the building industry. To do this designers have to commit themselves to life long learning. This should not be limited to their particular field. To avoid an imbalance in the analysis of the problem, or in the synthesis of a design solution, a designer must be able to maintain at least a fundamental understanding of the connections between building-related domains (engineering, management, construction...etc.). Depending on the depth and complexity of the field being studied, this can be a time-consuming endeavour. The best approach for any individual practitioner is to learn enough to allow them to work effectively in a team of other consultants.

Over the past years researchers have been striving to make sharing technical information between project team members easier using computers. Much of this effort has been in developing exchangeable formats that enable designers to describe the building design in such a way that engineering computer tools can expertly evaluate technical performance. However, the incompleteness of conceptual design descriptions prohibits the straightforward use of detailed simulation (Augenbroe and de Wit, 1997). Obviously it is much more desirable to be able to have technical feedback well before a design reaches a finished (detailed) stage.

The strategy being pursued to help address this problem in our research program is to create a KBS design assistant to provide advice to designers about the consequences of their early design choices. The basis of this KBS system is the heuristic reasoning (rules of thumb) and factual knowledge of a domain expert captured in the form of *rules*.[i]

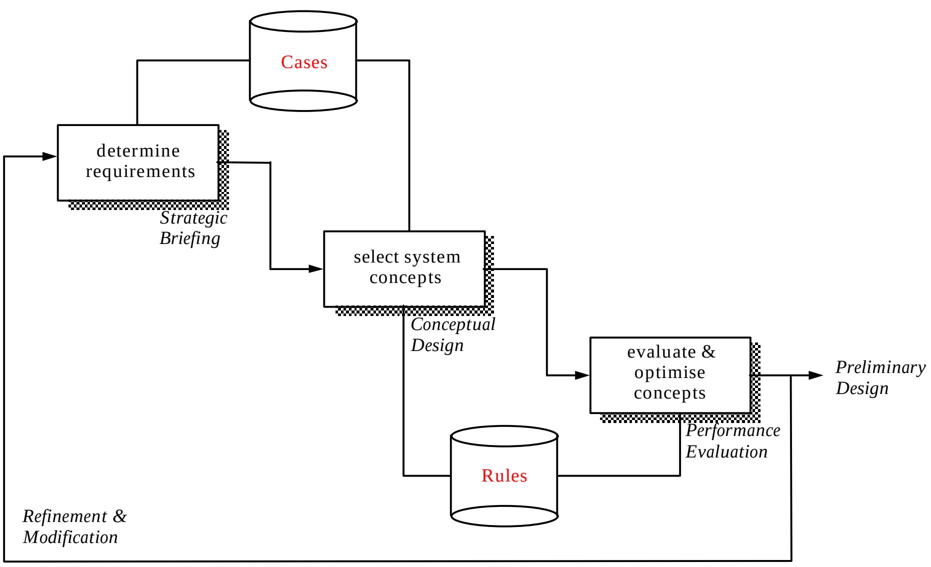

Figure 1. Hybrid of KBS Support for Conceptual Design

1.2. Practice-based learning

A second way to gain technical fluency is from practice. The experience of designing a workplace and, in particular, the completed product itself is rich sources of technical knowledge. However, because office buildings are designed collaboratively with multiple agents, knowledge tends to be unavailable, distributed over many sources or difficult to acquire. Collection of knowledge requires a long time period, especially if it is to include the time in which the building is in-use (a time when most problems relating workplace comfort arise). In most design contracts, no provision is made by anyone to provide for the collection or analysis of post occupancy evaluation data once the construction of a project has been completed. As a result, the design team may be unaware of problems and go on to repeat them again.

The strategy proposed to help address this problem is to create a KBS design assistant that provides a means of easily accessing and capturing a wide range of previous workplace design experiences. The basis of this KBS is the descriptions and evaluations of previous workplace designs by various agents in the design process captured as *cases*. This paper reports on the progress to date in developing this case-based strategy.

2. PROJECT GOAL AND STATUS

The ultimate goal of this project is to develop a prototype design support tool. The development of this tool is divided into six development stages (figure 2). The planned outcomes from the various stages in the process are shown on the right hand side of the figure. At the present time the preliminary stages of development have been completed: problem assessment and knowledge acquisition. The outcomes from these two stages form the basis of discussion in this paper.

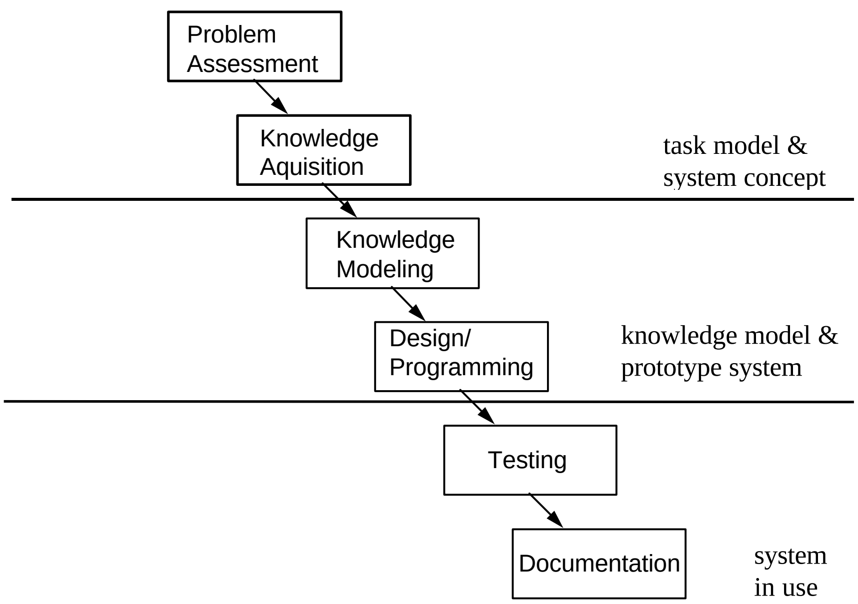

Figure 2. Project Development Stages

3. PROBLEM ASSSESSMENT

The goal of problem assessment is to provide a more comprehensive definition of the task that the proposed case-based KBS is intended to support. This is achieved by undertaking an analysis of system user (design agent), the activity (conceptual design) and the types of support for doing that activity (design environment). By understanding the designer and establishing a basic task and support model first, is it then possible to propose a suitable concept for computer-based support.

Defining the problem involved an extensive literature search and discussions with experts in the field of environmental engineering design of office buildings. A details of this definition study are presented in (Hill, 1997). An overview of the results from the definition study is provided below.

3.1 The designer

It is suggested that by using a case-based strategy in this research we are only doing electronically what architects already do manually. Theorists of Case Based Reasoning [CBR] propose that the basis of expertise is contained in experience. Indeed, one can observe design practitioners making significant use of previous cases, particularly as they work through the early stages of new design problems. At the start of a new design project there are no clear rules and a multitude of potential solutions. As a result architects tend to seek guidance through examples of what has been done before.

This practice can be attributed to architectural education. Lacking experience of their own, student architects are taught to learn by studying the success and failures of others. Cases are often used to re-call and communicate ideas about design. Design theory and detailing are frequently taught by using cases or examples of existing "landmark' architecture. This develops a facility for extracting generalizations and potentially useful information from new examples encountered that continues into practice (B. Dave et al. 1994). Through careful observation of the world architects collect a rich body of "virtual experience" that forms a pool of information drawn upon during the many associative processes that occur during designing (Mendivil 1995). Two of the most common ways designers re-use cases are by adaptation or by combination of parts of several cases.

In most architectural education emphasis is placed on finding and adapting precedents of spatial, functional or aesthetic importance, while exposure to technically innovative cases involving building physics (the domain of the "building engineer") are overlooked. Integration between professional domains is sadly lacking. Architectural magazines and journals for example, rarely contain analysis about the performance of an indoor climate system. It is not hard to imagine that architects miss out on learning from many examples of unassuming buildings that are successful because occupants are comfortable or conversely, "architecturally-celebrated" buildings that are failures because of overheating or being impossibly noisy to work in.

To improve the quality of workplace designs it is desirable that we encourage the recognition of such technical issues. By exposing architects to a rich source of relevant technical precedents it may be possible to take advantage of the existing propensity of architects to acquire and apply knowledge from cases. Computers provide an obvious vehicle for providing this access effectively.

3.2 The Task

This research focuses on conceptual design. Generally speaking, the objective of conceptual design is to generate the best concept. This objective is achieved through generating, adjusting, and evaluating different concepts (Netten, 1997). In this research it is important to focus on an approach to conceptual design that would support an integrated approach (non-domain specific) in addressing building technology and user satisfaction.

Strategic Building Performance Planning & Evaluation [SBPPE] is a theoretical approach for briefing and conceptual design for office building projects (Hill, 1997). It is based on a desire to define a better approach for the early design of office buildings. It combines user requirement analysis techniques from *strategic facilities planning* (Brand 1994) with performance-based conceptual representation and evaluation known as the *Total Building Performance Concept* of building (Ware, 1972; Wright, 1972; Davis and Venture, 1990). Both methodologies have close ties to TQM and ISO 9000 techniques.

Strategic planning is principally concerned with treating the building design as a strategy for accommodating multiple scenarios of use (supporting organizational flexibility). The Total Building Performance Concept is an integrated *systems-based approach* to design. Both user requirements and buildings are defined in terms of performance or functional terms only. This includes tests (if known) to judge performance as well as a clear statement of (sub)system interfacing.

Performance-based approaches require the representation and evaluation of a wide range of systems and performance criteria that tend to cross traditional design discipline boundaries. By centering the design process on satisfying user requirements attention is placed on achieving *outcomes* rather than particular *solutions* (see figure 3).

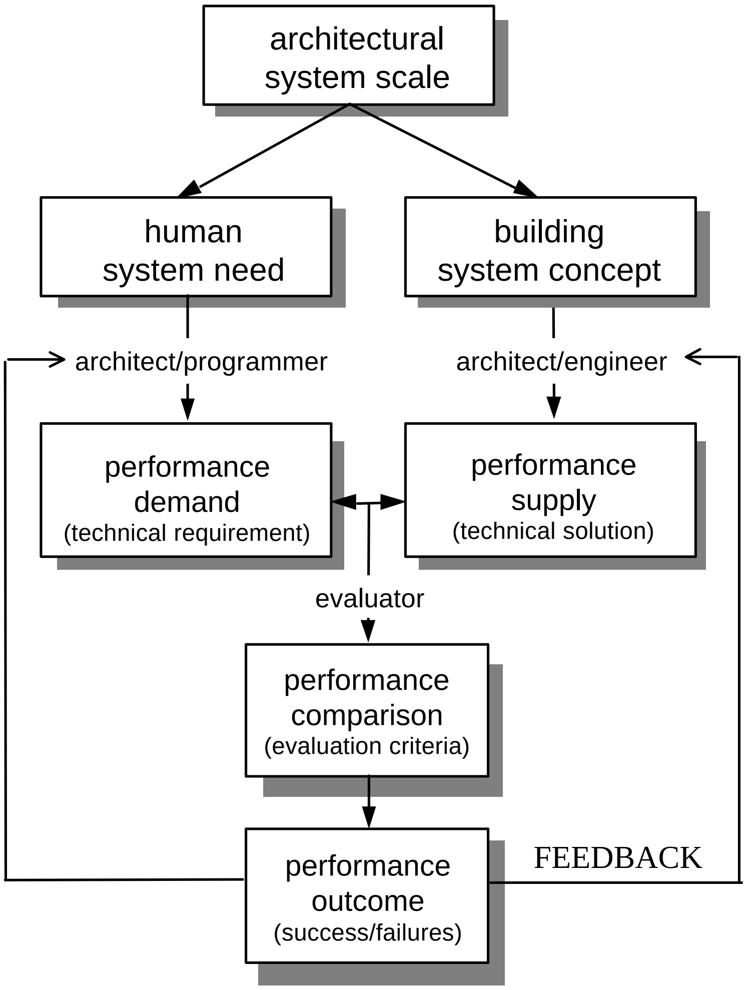

Figure 3. Performance Evaluation

As the adopted model for conceptual design, the characteristics of Strategic Building Performance Planning and Evaluation establishes the underlying tasks and design representations that need to be supported. One of the key characteristics of this approach is the integrated analysis and evaluation of a range of building performance issues. To do this effectively requires a great deal of technical knowledge.

3.3 Design environment

Before proposing new support tools it is helpful to explore the design environment to see what types of support are currently provided for conceptual design. In particular, to see what sources are available to provide the architect with technical performance feedback.

In the design of office buildings there are two types of design environments. The personal design environment and the multidisciplinary design environment of the project team.

Within their personal working environment designers use a number of sources for technical feedback. Probably one of the most commonly observed practice is the designer's use of sketching to aid in the recall and application of their own experience. Practitioners also search for feedback by reviewing architectural magazines and journals, sifting through the firm's archived project materials, or making visits to similar buildings. Accessing these sources is time-consuming and usually ineffective at providing good technical feedback. Although computers have become as standard as drafting tables and pencils in most firms, the inability of CAD to adequately support sketching has continued its relegation to later design stages as a production tool. Architects rarely employ specialized engineering evaluation programs such as RADIANCE, ESP-r, or TranSys. Such tools are hard to use without training. Conceptual designs also lack the level of detail required for accurate results from simulation.

Within a multi-disciplinary design environment design concept selection and evaluation can be seen as establishing (within the team) a clear view of what the design is supposed achieve (performance) and the options for doing so. In multidisciplinary contexts this process can be likened to brainstorming with people who do not speak the same language. However, the various performance perspectives of design team members needs to be considered in order to create balanced conceptual design decisions. One method that is used to communicate between team members is through sketches, glyphs, or pictures. Technical feedback in such situations often is given informally as *story-telling* about previous solutions. New computer tools such as group ware, electronic whiteboards, and video-conferencing are now available to support team communication but have not yet been widely adopted into design practice.

From this general analysis it is observed that the use of precedents to access technical knowledge is common to both personal and multidisciplinary design environments. This creates a need for referencing (search and record) and remembrance (story-telling and graphic representations) of the performance of previous examples. However, design environments currently lack any particular methods or support tools that make it possible to easily and quickly access relevant precedents

4.0 OBJECTIVES FOR CASE-BASED SYSTEM SUPPORT

Three fundamental issues characterize CBR systems: case representation, case retrieval and case adaptation. Conventional CBR systems solve problems by retrieving and automatically adapting prior solutions to suit the specifications of the current problem (figure 4).

One might then conclude from this that a main objective for the system might be to generate design solutions. However, performance based conceptual design is an iterative process in which a great deal of complexity exists in evaluating and refining design alternatives. The application of CBR techniques to automatically resolve design problems is ultimately limited by the availability of appropriate cases and lack of

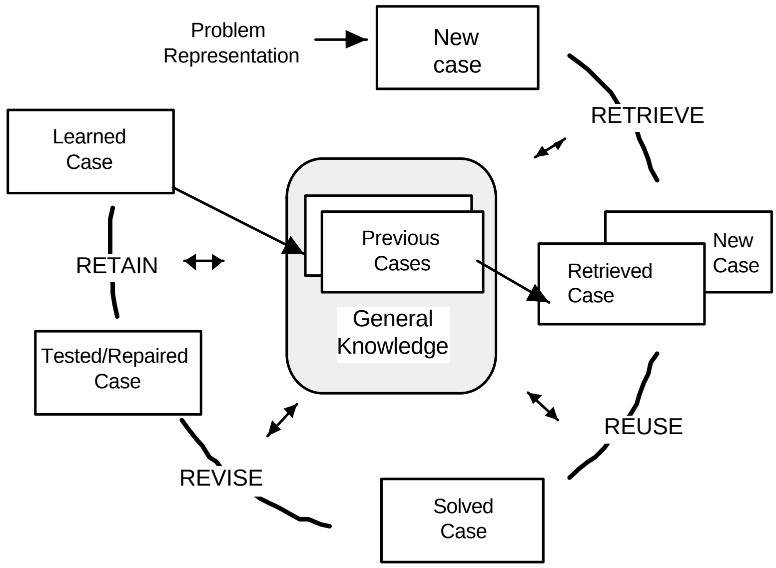

Figure 4. Case-Based System Reasoning Cycle
(Aamodt and Plaza, 1997)

standardizable (creative) adaptation routines. Whereas the system may be capable of performing an advisory role, such as suggesting initial solutions, or identifying key performances, the designer needs to remain the final judge in whether or not a particular evolving solution is satisfactory.

The *Workplace Environment Design Assistant* [WEDA] is intended to assist in the case-based design of workplace environments. The initial goal for WEDA is to provide access to existing technically innovative workplace cases. These cases will contain evaluations according to total building performance and systems integration principles for individual comfort.

WEDA is intended to be a 'stimulative' CBR system as described in (Dutta, et. al, 1997). Although less is known about this type, stimulative CBR systems are used in a more interactive manner. Such CBR systems promote creative decision-making (story-telling) and enhance learning (advising) about the decision situation in a

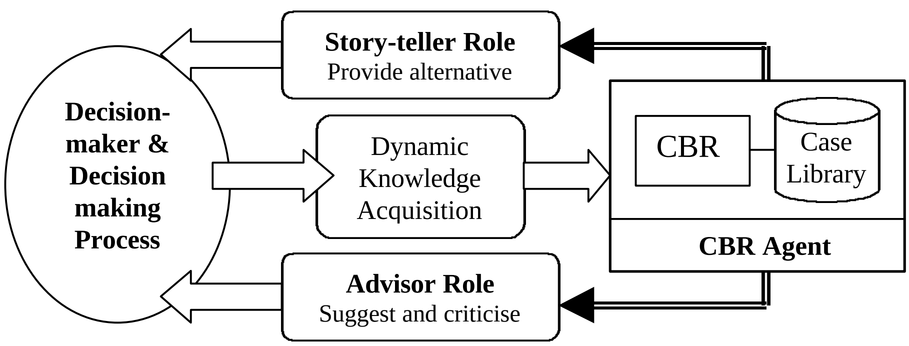

Figure 5 Stimulative CBR (Dutta, 1997)

designer as they work (see Figure 5). Thus the designer can be responsible for their own adaptation.

By selecting a stimulative-type approach, case representation will necessarily need to include more knowledge about the process used to obtain the workplace solutions and reflect the appropriate level of detail for a particular stage of design decision-making (from preliminary idea selection to refinement of a candidate concept). The system needs to be tied to the design decision-making environment so that retrieval strategies are triggered by events in the process indicating support is needed.

5.0 Related Research

The current research efforts to develop electronic design assistants are preceded much earlier by a computer briefing tool designed to translate occupant needs into indoor climate performance criteria. The Bouw Fysisch Informatie Model [BFIM] (Van Luxemburg, et al. 1994) has been under development for over ten years at the Center for Building Research [CBO].[ii]. This prototype decision-support system defines indoor environment requirements for residences. The system collects descriptions of the occupant and what tasks they perform in a given space and then calculates performance target values for acoustics (dBA), lighting (Lux), heating (degrees Celcius and PMV), and ventilation systems (litres/second). If one alters the characteristics of the occupant or their activities, such as increasing the age of the occupants or the intensity of work from reading to heavy lifting, the performance targets are then re-calculated accordingly (e.g. increasing light levels, reduced temperature). Originally designed as a Hypercard™ program, BFIM has undergone numerous revisions and is now being developed as a Window's -based application using DELPHI.

BFIM is not a true KBS. Knowledge in the system (in the form of calculations) is embedded in the software code itself, which makes it difficult for domain experts to maintain and keep the knowledge up-to-date themselves. A lack of transparency means that the system is not capable of explaining how it determines the climate requirements it says are necessary. Furthermore, the system does not offer any assistance to the designer in selecting design concepts that can satisfy the indoor requirements it determines. Despite these limitations, BFIM demonstrates an approach for establishing the initial performance criteria that can, in turn be used by future case-based systems to recall relevant examples.

There are a number of examples of computer systems that have been developed elsewhere have applied case-based reasoning to providing design support. HI-RISE is an example of an early case-based system used to provide assistance in structural design based on prototypical solutions (Maher and Fenves, 1985).

SEED is a system currently being developed at Carnegie Mellon University which supports the early stages of building design through a case-base of different design versions, alternatives and past designs created within its own generative and three dimensional configuration environment (Flemming et al, 1998).

Building Design Advisor [BDA] is a program being developed at Lawrence Berkley National Laboratory (Papamichael et al, 1997). BDA is a software environment that supports the integrated use of multiple analysis and visualization tools throughout the design process. It is linked to a multimedia Web-based Case Studies Database (CSD) which contains information about existing buildings to "provide a realistic context for the specification of performance goals as well as for the evaluation of performance of design alternatives through comparison to real world data." (ibid., p. 351)

ARCHIE (Domeshak, Kolodner and Zimring, 1994) is an extended research program that has produced a number of systems, all of which have been developed around the concept of creating Case-Based Design Aids [CBDA]. ARCHIE provides evaluative feedback from a variety of stakeholder perspectives about its cases. That way one can know if a particular case ended up being a good solution or not before it is used again.

All of the systems use different approaches for using cases to support design. Of these examples, most place emphasis of design task by the computer. BDA and SEED both include special adaptation environments that largely dictate how a form can be generated. Depending on the designer this may or may not be too constraining and add unnecessary detail too early into the design. Outside of any particular design environment, ARCHIE emphasizes lessons to be learned. This is consistent with our performance-based method, where the most important aspect of a case is not its physical solution, but its technical outcome.

These various examples provide a good foundation for future work. Rather than concentrating on adaptation assembling new design concepts from existing case pieces, we plan to concentrate on developing a stimulative/learning approach that equips the designer with the knowledge required to make their own adaptations to the design.

6.0 KNOWLEDGE ACQUISITION

The goal of knowledge acquisition is to gain an understanding of the knowledge to be used in the system. To achieve this goal the technical knowledge (case data) to be made available in WEDA is considered and modelled. This stage is sub-divided into three parts:

1) <u>Knowledge Modelling</u>; establish a basic theoretical framework (objects and relationships)
2) <u>Classification of Case Data</u>; identify and organize workplace performance data into the model.
3) <u>Collection of Real Case Data</u>; collect and represent real case knowledge

The scope of the knowledge contained within the system relates to one "cube" within the entire *building performance evaluation domain* matrix (Hill, 1997) (Figure 6). The information within this cube relates to the design performance of environmental control systems in providing individual comfort (*basic well-being*) at the workplace

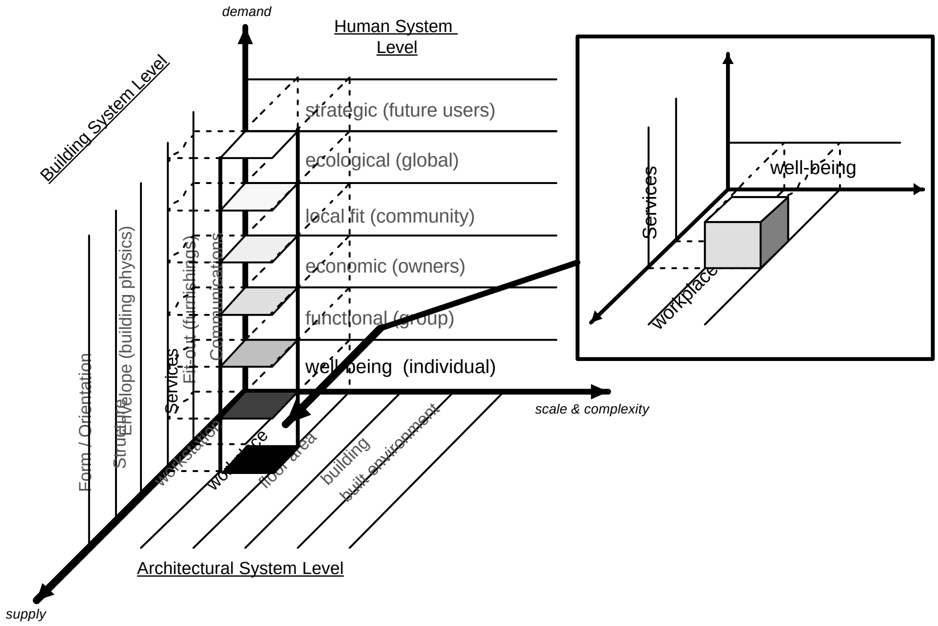

Figure 6. Performance Evaluation at the Workplace Level.

level. The ability to extend the contents of the case-base beyond this level is something we believe can be achieved after proving the approach by resolving a single cube.

6.1 Knowledge Model

A performance based approach provides us with a particular view of design.
The ability to judge and give feedback about the performance of any given system is dependent on being able to link what the client asks for to building concepts using measurable criteria. To decide between potential concepts experts use values of performance criteria (temperature, light levels, etc.). This divides the knowledge about the design into three categories:

1) User Requirements (demands)
2) Building Systems Concepts (supply)
3) Criteria (outcomes)

6.2 Classification of Knowledge

The next step is to explore the content and relationships between these various types of knowledge. This means breaking down the various types of user requirements and building systems into their component parts and relating them to key performance criteria used by domain experts (Choukry, 1994).

This involved an extensive identification and classification of various types of workplace environment performance requirements and measures. Diagrams are used to show what elements of building systems influence performance criteria values. Figure 7 provides a simple example of the relationship established between the requirement "visual comfort"(measured in "lux") and the elements of a lighting systems concept. Performance criteria provide a "bridge" between requirements and performances perspectives.

One of the interesting issues that arose from creating these knowledge frameworks was seeing that building system selection have influences (sometimes non-obvious) on different levels of performance. A typical example is the use of large areas of glazing to introduce more light into an office building. Although the introduction of natural light have can have a positive effect by reducing the need for artificial lighting it can also have a negative effect by introducing thermal gain and the need for mechanical air-conditioning. Understanding that a glazing concept impacts on both lighting and thermal performance is knowledge that an expert uses to avoid selecting an inappropriate solution.

6.3 Collecting Real Case Data

The collection of data from real precedents serves two purposes (1) to provide initial data to "seed" the prototype system with and, (2) to consider how more data may be easily added to the system in the future (particularly if the user has to do it themselves).

The starting point for collecting initial case data was an energy and comfort design analysis of two different innovative workplace lighting systems. The evaluation of the lighting systems was undertaken at the Center for Building Research [CBO] under the direction of one its lighting experts, L. Zonneveldt.

CBO undertook the research when an architect of a new office building in the Netherlands approached them with the problem of choosing between two new innovative energy efficient daylighting system designs. The initial computer simulation of the two lighting system designs in RADIANCE revealed that the systems had more or less the same physical performance. This was despite the fact that the systems were quite different in design (one system used totally indirect lighting and the other system included both indirect and direct lighting). It was decided to build a full-scale "mock-ups" of both office lighting designs.

The mock-ups were created in existing cell-type offices[iii] that, with the exception of the lighting system design, were more or less identical. Each office room contains only one occupant. Over a period of several months both the physical performance of the lighting system (light level, energy use) and the perceived performance (occupant survey) was recorded. The collected data was used by the expert to determine the energy performance of the lighting system as well as user acceptance and comfort.

Even though both systems were measured to have acceptable physical performance and were capable of saving energy, the indirect system was totally rejected by its user. He described his room as "dark" and "dingy" and asked that the experiment be taken down as it was negatively affecting his productivity.

The collected case data falls into the following categories:

(1) the problem (required behaviour),
(2) physical solution (system description)
(3) predicted outcome (simulated behaviour)
(4) physical outcome (measured behaviour)
(5) perceived outcome (user behaviour)

The format of the case data was fairly typical of the type of data one might find from a post-occupancy study. This includes CAD drawings, digital images, room simulations, monitoring data, system manufacturer specifications, and a user survey. The 'lessons' had to be extracted from this material by the domain expert.

7.0 ISSUES ARISING FROM CASE COLLECTION

The cases in WEDA are intended to provide designers with general technical guidance in which to avoid previously-experienced mistakes and to make it easier to quickly determine a satisfactory design solution. The energy efficient lighting cases provide both interesting solutions and lessons. Considering how WEDA might use the information collected from the lighting system study raises some interesting issues, some of which are included below.

The first issue to quickly become evident is the importance of the performance evaluation description (outcome). If the system retrieves the lighting solutions without their evaluated performances then the decision-maker would not know how energy efficient the systems were, or that one of the system was totally rejected by its occupant. *How* the lighting systems were evaluated is important too. Simulating the lighting designs provided a good indication of the physical performance but it did not predict that the room occupant would reject one system. It is also helpful to know *why* the indirect lighting system was rejected. Is it something that can be fixed? From this we can conclude that cases need to include not only solutions but also good outcome descriptions. It was also helpful to compare two outcomes against each other. One of the roles CBR system can play is to help with evaluation by showing factors to be considered and clustering cases to make comparison easy (Kolodner, 1993)

A second issue that arose is in relation to what data was collected. Many other performance aspects of the office rooms were not measured and compared (e.g. thermal, acoustics, air quality). It simply was not practical (nor interesting) to measure everything. This can be generally said of all of the workplace performance data from domain literature or consultant work that was reviewed. Case content will naturally be limited to those areas deemed by the evaluator to be important enough to record. Cases contained in the system therefore are likely to provide insight on only a part of the overall workplace environment problem.

A third issue is that there are other features of these cases that may make them relevant to other workplace design problems such as: location, similar climate, appearance, office-type or work task. Several different aspects about a case may need to be recorded to allow for cross referencing from different perspectives.

8.0 FUTURE WORK

At the present time we are working towards developing a working prototype system. Our emphasis for the system is on information (case) exploration that is driven from occupant performance requirements. Part of this work includes careful consideration of interface issues that correctly ties the tool (and the knowledge it contains) to the design process it is intended to support. Another aspect involves the size and content of the case-base we create.

The knowledge in CBR system is the case-base. Cases are generally easier to acquire and maintain than explicit relations such as rules and constraints (Netton, 1997). However, as we try to obtain suitable cases of workplace environments (i.e. integrated post occupancy evaluations) to put into the system we have found that there is a general lack of readily available information and expertise. Of course, the scarcity of technical knowledge was the underlying reason for creating the system in the first place. Nonetheless, it is an important consideration, particularly when we think about how to facilitate the long-term maintenance of the system.

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[i] The ongoing development of the rule-based system is described in more detail in (de Groot, 1998) and (de Groot and Pernot, 1998).

[ii] CBO is a collaborative program between the Building Physics Department of the Eindhoven University of Technology and the Netherlands Organization for Applied Scientific Research (TNO).

[iii] It is estimated that 70% of the Dutch office population are employed in similar cell-type offices.