INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

SIMULTANEOUS EVALUATION OF ECONOMICAL, SOCIAL AND ENVIRONMENTAL PERFORMANCES OF A WORKPLACE DESIGN DURING THE DESIGN AND SALES STAGES

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ABSTRACT
In this paper, we present a work within the office building design domain. In this context, we were asked to build a decision-making tool that is able to quickly evaluate, for designers, in a multicriteria way (i.e. considering economical, social and environmental performances) workplace solutions as soon as a workplace solution is sketched or redesign options are proposed. This tool must also be able to propose rough sketches of good workplace solutions maximizing strategic expectations of the client while optimizing its resource management (human, material and immaterial).
Our choice has been to develop a computer-based information system linking the rough description of a workplace design to an assessment of business results and sustainability performances (economical, social, and environmental) while supporting decision-making about planning scenarios. Such facilities can provide determining differentiating arguments to the workplace design company comparatively to its competitors. This decision-making tool is based upon a model of need (for a new workplace design project) and a model of solution (roughly describing a solution sketch). In this paper, we describe the ontology of the tool and illustrate with a case study about a decision making process within a limited perimeter of lighting system.

Keywords: sustainability performances, design for sustainability, workplace design, multicriteria decision making, design selection, AHP, satisfaction function

1 INTRODUCTION
In this digital/information age, work teams form and reform to meet organizational needs, technological innovations, and changing business relationships. Buildings and interior spaces need to be flexible enough to anticipate and support this changing nature of work. Within the past few years, designers have sought to create a new generation of "flexible" buildings and workplace environments within buildings that have infrastructures and structures that fully support change while sustaining new technologies, and creating value to the company [1]. The changing nature of work means greater mobility for workers, a multiplicity of workspaces inside and outside buildings, geographically dispersed groups, increased dependence on social networks. This creates a greater pressure to provide for all of these needs and behaviors an adequate work environment. The idea of designing a workplace to support organizational effectiveness is not a new idea. Many workplace experts have written on the topic [2-4].
Furthermore, the current workplace research tends to address a limited number of topic areas (such as ambient conditions) and a limited number of outcomes (particularly occupant comfort and perceptions). There is much less attention paid to sustainability (economical, environmental and social) performance and potential benefits on business results.
However, there is clear interest in fashioning a new agenda for workplace research to understand how workplace design can influence organizational success, environmental and social performance. This assumption is due to the way that a workplace encapsulates different categories of performances (economical, social and environmental) having direct and indirect influence on the performance of a company and employee's productivity.
As a result of the rise of sustainable development issues, some companies and workplace/building experts become convinced by the contribution of workplace to the achievement of sustainability objectives. Aspects like energy consumption and CO_2 emissions are currently studied due to the fact that building represents a big

part of the total energy use and CO2 emissions. Tertiary buildings represent 30 to 40 % of CO2 emissions in OCDE countries.
These findings about the workplace and tertiary building put the accent on the complexity of the decision making in design process, where designers are not comfortable with all the performance parameters. There is a clear need for decision support tools in the current design process to make the right decision regarding the client expectations and legal requirements.
In the paper, we present quickly the project of development of a performance evaluation tool to support design and sales processes. We propose a clear definition of the ontological concepts of the proposed models (need and solution models) and the main difficulties and approaches to adopt. Finally, we illustrate our approach through an example of a design selection issue on a lighting system for a workplace.

2 PROJECT SCOPE

2.1 The Tertiary Workplace Market

Office furniture suppliers and workplace solutions providers are commonly working together to propose the appropriate solutions to clients regarding their needs and organizational structures. These solutions can be the space planning, selection of office furniture, lighting design…ect. Moreover, we can found in the market a range of environmentally friendly products due to the commitment of manufacturers with ecodesign and environmental management strategies in the last years.
Today, this market is going toward an innovative orientation of managing sustainability performance of the overall workplace. This preoccupation is demonstrated by the consideration building certification systems as one of the main strategic objectives of buildings in some company . The goal of this type of certifications like LEED-CI [5] and the corresponding certification named HQE in France [6], is to encourage companies to take care to the environmental performance of buildings in order to generate economical and social benefits.
Today, actors in the market of tertiary workplace (Interior Office Building) wants to increase client awareness about the strategic importance of this kind of issues by developing a performance evaluation tool dealing with different technical parameters and enabling to provide a clear assessment of the sustainability performance of workplace solutions. This kind of tool must have two roles, the first is to support decision making in the design process and the second to help sales people to promote the proposed solutions with relevant arguments.

2.2 Stakeholders Expectations

Stakeholders mean the people that will benefit from the tool. In order to define the different requirements and the expected added-value of the tool, understanding stakeholder’s needs is quite important. We must respond to the different expectations to have a relevant tool.
In fact, there are two distinct needs, for salespeople/dealers and workplace designers. A lot of meetings, workshops and discussions were done with different persons and experts. The findings of these workshops are primordial to give persuasive results when the tool will be finalized.
In the one hand, *workplace designers/interior architects* expect a potential mean for the evaluation of concept performances during the design process. This kind of evaluation brings a constant decision-making aid to build a good solution. In the same manner, a multicriteria choice between radically different solutions should be made possible. This multicriteria assessment will also be used to choose good concept solutions in picking up potentially compatible *design elements* from a workplace library and fulfilling the given specifications.
In the other hand, sales people and dealers want to have a kind of multicriteria reporting tool for the suggestion of few viable concepts of workplace arrangement to customer. The customer will then be able to make a decision based on the level and contribution of company’s performances of each solution. The client could be able to make a compromise or choice in accordance with his strategy (for example: a higher initial investment but lower cost of exploitation/maintenance and better social and environmental performances).

3 THE TOOL MODELLING: A MULTI-LAYER STRUCTURING

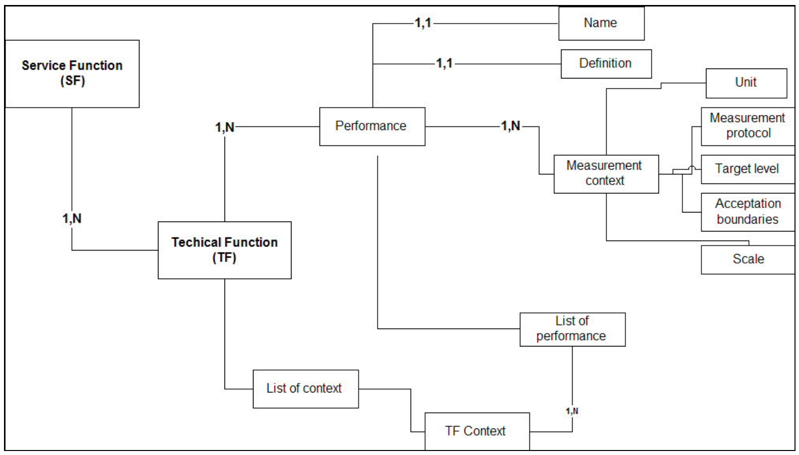
We want to define functions and targets with clients (need model) and propose design recommendations of preferred *design elements* (solution model) that best match the targets. The *Need Model* represents the definition of need in the form of service functions, performance criteria and corresponding targets (for the new workplace to design). The *Solution model* refers to the different technical domains (e.g. lighting, heating and ventilation...) in which design elements will be defined which characteristics impacting the aforementioned *performance criteria*.
However, a critical stage consists on linking the two models by defining an appropriate *semantic of correlation*. The semantic is under construction and we just present in this paper (section 4) the operating principle foreseen.

3.1 Structuring the Need model

We define the need model for a new workplace on three layers or hierarchical levels (See Figure 1):

- *Service functions (SF)* or High level objectives expressed in term of company requirements from the workplace dealing with sustainability issues and influencing company's business results (those business results could in turn be modelled in Business Score Cards)
- *Technical functions* are the sub-functions (which are means) contributing to service functions and for which we can measure the accomplishment regarding performance criteria.
- *Performance criteria:* under each technical function, we have a list of performance criteria specified by a measurement context. A measurement context is defined considering the type of scale (qualitative or quantitative scales) and the nature of target (fixed by codes, standards, legislation or client needs).

Figure 1: UML modeling of Need



First level of need definition: Service Function (SF)

Innovative companies want to show their strategic and organizational objectives through their workplace solutions. We used this assumption to translate company's requirements into expected contributions for workplace called *"Service Functions"*. These SFs address not only the investment on physical products and the financial impacts but also the social performances potentially improved by the work conditions, as well as the environmental benefits which potentially create economic savings in a medium or a long term (reduce energy consumption, recyclability of building elements or workplace products, promote renewable resources…). Examples of SF from the three sustainable development categories (namely, social, environmental and economical) can be (not exhaustively provided here for reason of confidentiality):

- "Improve occupant's satisfaction in physical work environment"
- "Reduce workplace energy consumption level"
- "Reduce operating costs of workplace"

Second level of need definition: Technical Function (TF)

Technical Functions are the mean to fulfil or support Service Functions. It's a practical mean to economically but efficiently measure a part of a functional performance. A given Technical Function may contribute (positively, negatively or at different degrees) to the achievement or satisfaction of different Service Functions. Moreover, we must define a set of TFs which are complementary and which cover the whole set of SFs. The choice of the Technical Functions to activate and their tuning must be made adequately so as to maximize the FS satisfactions. . E.g. Improving employee's satisfaction in physical work environment may be performed by promoting visual comfort for different tasks in workplace as well as ensuring a sufficient acoustic comfort, etc… (See figure 2).

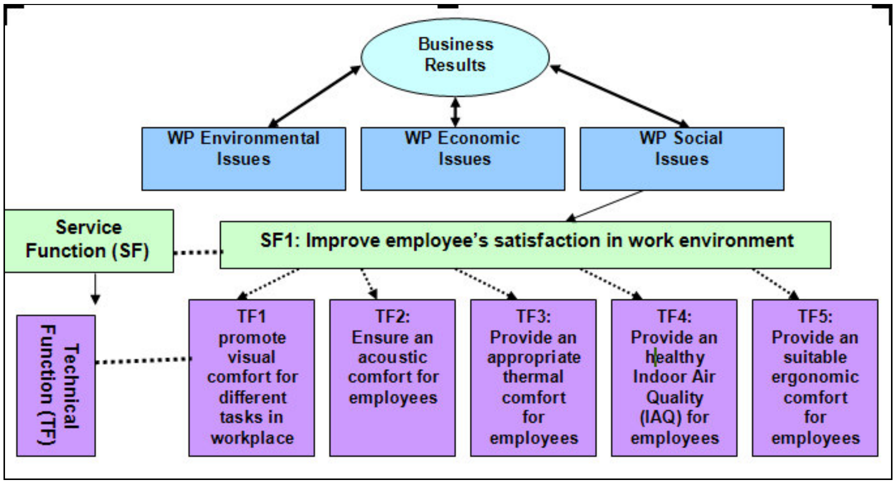


Figure 2: Representation of the linkage between business results and workplace functions

Third level of need definition: Performance Criteria & measurement protocols

Technical functions are defined through different (technical) performances sometimes with different measurement protocols. Protocols define the way of measuring a performance (unit, localisation, timeframe...). For example, the assessment of the performance of "visual comfort" in open plan space and in meeting room is different because the requirements are not the same.

When investigating the different performance criteria of Technical functions under a common Service Function, we identified a list of *quantitative and qualitative performance criteria*. These performances have existing indicators in the quantitative case (Table 1) with target values fixed by codes and standards [7]. The considered criteria were selected regarding the main standards, legislations and the specific sectors of building and workplace. For example, a part of these criteria was extracted from workplace lighting standards (Table 1), others from LEED-CI and HQE systems [5, 6]. There are several sources of data; our approach was to extract the criteria having a great importance in TF achievement.

				Target Min Ti Max accepted	
	Performances	Measures	Unit	Min	Max
Artificial lighting	Level of Illumination in task surfaces	Average Illuminance	lux	300	500
	Light Uniformity in workplace	Uniformity Rate I_{min}/I_{Av}	%	0,7	
	Space luminance	Reflectance of Wall	%	60	90
		Reflectance of ceiling	%	30	80
		Reflectance of floor	%	10	50
		Reflectance of work surfaces	%	20	60
	luminaire distribution of Luminance	UGR (Unified Glare rate) of luminaires		19	23
	Level of Color discrimination	Color rendering Index of lamps		80	100
	Visual ambiance	Color Temperature of lamps	°K	3000	5000
	Individual Controllability of lighting systems	% Occupant controlling lighting systems	%	80	100
Daylighting		Daylight Factor	%	2	100
		% of occupants exposition to daylight and outside view	%	75	100

Table 1: Quantitative performance criteria for visual comfort

In the case of qualitative performances, we need to define a general scale. We propose to develop a qualitative scale presenting different levels of performance, ranging between 1 and 5 characterized by a grid of levels. A *general pattern of a qualitative scale* is used for the different qualitative performances (see Table 2). We assume that the satisfaction of a current performance is acceptable from level 3 and more. The 5 levels are described as follows:

1. *Awareness*: No action exists for the moment however the person/service in charge of the workplace is conscious of the importance of this performance and is ready to launch actions.
2. *Measure*: the company is able to evaluate (qualify and quantify) at the moment its situation, and its results are compared to the objective target it has fixed. A gap analysis is then performed but no systematic action plan is yet neither defined nor applied.

3. *Implementation of actions*: the company uses on the one side the analysis gap and on the other side organizes a technological and standard watch to regularly update action plans to conduct a continuous change.
4. *Partial Innovation*: The entity has reached a maturity in the management of the performance by benchmarking the available best practices. The company is innovative on some aspects comparatively to other similar companies.
5. *Excellence/exemplarity*: the company puts in place innovative actions in this area, which places it on a level of excellence beyond the current practice and state of the art in the field.

For each qualitative performance, the general scale pattern is interpreted for generating meaningful scale levels (see for instance table 2 for the "individual control of artificial lighting systems").

Individual control of artificial lighting systems

1	2	3	4	5
- No possibility to adjust light to occupant's preferences and tasks needs	- Luminaire switching ON/OFF - Occupancy sensor in workstations	- Calling up lighting scenes - Manual call-up of defined lighting scenes (combination of several luminaires set to different dimming levels) - Individual always perfectly adapted of lighting scene at the press of a button	- Task lighting with individual control - Luminaire dimming	- high level of lighting system control for individual occupants, and specific groups in multioccupant spaces

Table 2: Example of a qualitative scale for a performance criterion

Difficulties & potential solutions

The encountered difficulties consist in transforming the different indicators or measures into the same measurement unit due to the fact that indicators are originally incommensurate or expressed in different units.

In every design process, the goal is to find a compromise solution which is not so bad for any of the performance criteria and which is globally satisfactory.

For that purpose, we propose to embed this compromise into an objective function expressing the overall *utility* of a conceptual solution. Then, we propose to transform the performances into *Utility Functions* $U_i(E_i; T_i)$ which are function of the current evaluation of the performance criteria (E_i) (current meaning for the conceptual solution under study) and the corresponding target value (T_i). We have decided to use a simplified form of Utility theory (see [8] for a general presentation of preference aggregation models). Here, the designer must choose a utility function of the trapezoidal (see Figure 3) or the triangular shapes (see Figure 4) and model the target for the corresponding performance criterion through constant values a_{ij}. The value of utility for a given performance criterion is then given from an assessment of the current criterion value; it is comprised between 0 representing the worst preference (dissatisfaction) and 1 the best (total satisfaction) (see also [9] for another example of this simplified version of preference aggregation).

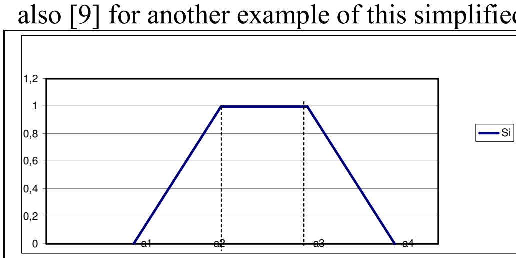


Figure 3: Curve Type 1: Trapezoidal function

$$U_i \begin{cases} 0 & \text{for } x < a_1 \\ \dfrac{x-a_1}{a_2-a_1} & \text{for } a_1 \le x \le a_2 \\ 1 & \text{for } a_2 \le x \le a_3 \\ \dfrac{a_4-x}{a_4-a_3} & \text{for } a_3 \le x \le a_4 \\ 0 & \text{for } x > a_4 \end{cases} \qquad (1)$$

Example: If we consider the performance criteria "Level of Illumination in task surfaces", the satisfaction equal 1 between 300 lux and 500 lux.

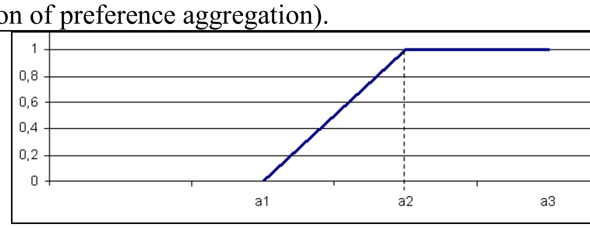


Figure 4: Curve Type 2 (Triangular Function)

$$U_i \begin{cases} 0 & \text{for } x < a_1 \\ \dfrac{x-a_1}{a_2-a_1} & \text{for } a_1 \le x \le a_2 \\ 1 & \text{for } x > a_2 \end{cases} \qquad (2)$$

Example: for the performance criteria "light uniformity", the satisfaction equal to 1 when uniformity factor= I_{av}/I_{min} is higher than 70%.

A clear need for weighting criteria

A last thing remains to be done: the aggregation between the contributions of elementary utilities. We propose here to hierarchically weight these contributions in following the functional decomposition in *Service Functions*, *Technical Functions* and *Performance Criteria*. We adopt here the linear and hierarchical aggregation model of the *Analytic Hierarchy Process* (AHP) methodology (see the paper from Saaty [10]). The construction of an AHP aggregation model is made upon successive applications of a *pairwise comparison* process between the elements at a same node-level. This process aims at resulting in a weighting vector after pairwise comparing the elements of a node-level, i.e. filling a comparison matrix. In that way, pairwise comparison methods notably simplify the rating problem by focusing the attention of decision makers on pairs of elements to be compared. The literature is rich of methods of pairwise comparison (PC). We have used a LSLR (Least Square Logarithmic Method) PC method for the case study we will further present in chapter 6.2; this method has been developed by some of the authors to be flexible and adapted to design assessments (see [11] for instance).

3.2 Structuring the solution model

Technical domains or Expertise Fields in workplace

We defined the solution model by modular ("lego") *design elements* roughly characterizing a solution sketch under an identified *technical domain*. When working with experts in building and workplace design, we identified 8 main technical domains (lighting systems, acoustics systems, HVAC systems, Power & data systems, Interior design elements, Safety & security systems, technological equipment and Space planning). We note that *space planning* is a transverse domain which takes into account the requirements and constraints of the seven other technical domains and fix the design choices that globally influence the functional performances (see [12] for an evocation of global performances for a workplace).

Each technical domain may, in turn, be decomposed into sub-domains, what we call *design element classes* (see figure 5). For instance, *wall systems*, *furniture systems*, *ceiling systems* and *flooring systems* are *design element classes* of *interior design elements* technical domain. Each *design element class* may be instantiated into an *elementary solution*, which represents a qualitative category of the *design element class* and a rough class of dimensioning. Finally, a conceptual solution of a workplace is a total or even partial instantiation of the design element classes affiliated to the technical domains.

We assume that the 8 technical domains are the contributor domains which permit to roughly define a given solution concept and then to fulfil service functions and corresponding technical functions.

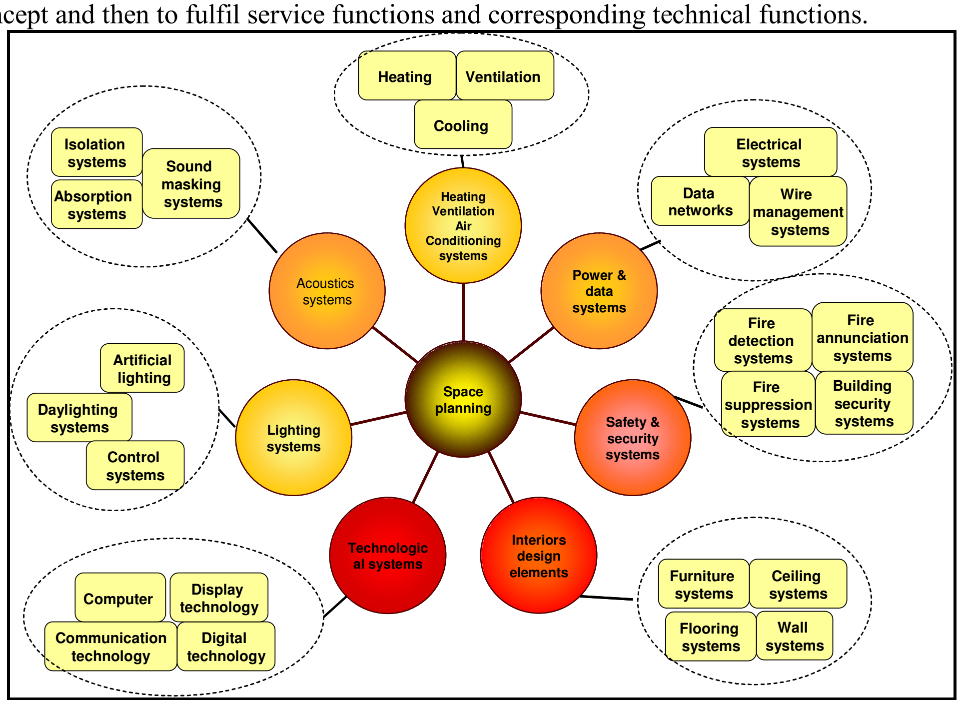


Figure 5: Design elements under technical domains

Design elements and corresponding attributes or properties

As we said above, a technical domain is decomposed into design element classes having proper attributes or characteristics specifying the intrinsic performances (*technical characteristics*). These attributes are defined with regards to performance criteria that they can influence positively or negatively.

For example *Artificial Lighting class* have attributes like *lamp type*, *wattage*, *luminosity*, *Color rendering index*, *ballast type*, *material content*, *maintenance factor*, *maintenance interval*, *maintenance cost*. The relationships between attributes of design element classes and performance criteria are casual influences which defines the correlation semantics (see Figure 6).

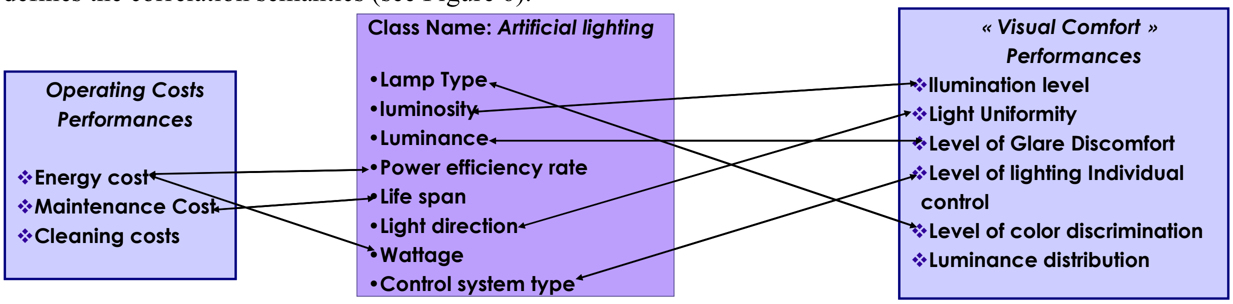


Figure 6: Causal influence Diagram logic between performance criteria and design element attributes

4 ASSUMPTIONS ABOUT THE CORRELATION MECHANISMS

The definition of the correlation mechanism is based on using expert's knowledge about *design elements and performance criteria*. This knowledge specifies the interactions of *elementary solutions* with the performances (of technical functions). Generally, some attributes can be quantitatively correlated with performance criteria (e.g. *illumination level & luminosity of lamps*) by making calculations. However, there are possibly non linear effects of solution elements on performances and some subjective performances such as those related to comfort and health are influenced by overall performance of specific solutions. This non-trivial trade-off may be conveniently modelled by a fuzzy rule-based approach. Fuzzy rule-based approach can be used here by defining verbally formulated rules. Fuzzy rules are linguistic *IF-THEN- constructions* that have the general form "IF A THEN B" where A and B are (collections of) propositions containing linguistic variables. A is called the premise and B is the consequence of the rule. In effect, the use of linguistic variables and fuzzy IF-THEN- rules exploits the tolerance for imprecision and uncertainty [13]. In our case, an example of fuzzy rules can be:

IF glazing system is GOOD AND workstation localisation is MEDIUM, THEN Daylight penetration is GOOD.

This approach will enable to translate expert's knowledge into quantitative functions. We are currently defining some rules and it seems appropriate for our case.

Finally, we can say that the contribution of fuzzy sets, that we want to apply, is the ability of fuzzy rules to conveniently express complex relationships among data. In addition to generalizing material implication and association rules to fuzzy predicates, fuzzy rules also model gradual and uncertain relationships [13].

5 USE SCENARIOS OF OUR DECISION-MAKING TOOL

After presenting the different concepts and the overall approach, the question is how this computer based information system will work in the use stage. In order to cover great part of user's needs and client's expectations, we define *3 use scenarios* enabling to provide different and complementary results:

- *Generation of General Recommendations (GGR)*: The first scenario doesn't require having any modelling of a potential conceptual workplace solution but it requires the modelling of the *ancient* (if any) workplace to replace (this is often the case) and the modelling of the need for a new workplace to design. It is a four-steps process consisting on:
    - Expressing the *Need* for new workplace by targeting a sub-list of performances (practically, we do not require to be exhaustive)
    - Positioning of the *ancient* workplace to be replaced (if existing) on the appropriate performance scales
    - Gap analysis (*ancient* and *target/need*) under each performance and top-down propagation to result in Best/Worst *design element classes* and *elementary solutions*
    - Providing explanations by showing mutual influences of given elementary solutions on performances
- *Solution Analysis (SA):* The process of the second using scenario is as follows:
    - Expressing Need for new workplace by targeting a sub-list of performances
    - Positioning of the ancient workplace on the performance scales
    - Defining the solution for the designer (by an appropriate combination of *elementary solutions*) by relevant technical attributes extracted from engineering data.
    - Bottom-Up propagation to generate the *current* solution performance vector
    - Gap Analysis (twice: between *current* and *target*, and *current* and *ancient*) and top-down propagation to result in bad/worst design elements and elementary solutions. The objective

being to prove that the *current* solution tends to ideal *targets* and is better than the *ancient* solution.

- *Solution Optimization (SO):* optimization of existing technical solutions regarding target need and expert's requirements. It starts with a Solution Analysis and continues with:
    - Setting up a redesign (Selection of a sub-list of bad elementary solutions to revisit)
    - Proposal of new optimal combinations of elementary solutions available in the library (by an optimization algorithm)

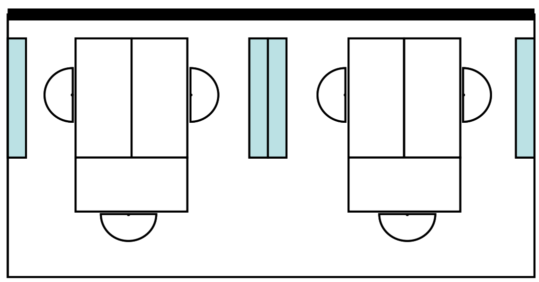
These different use scenarios were defined in this stage to clarify the way to develop the corresponding sub-models (Need and Solution models) and limit their input and output.

6 CASE STUDY

6.1 Problem definition

We test a part of our model with a problem of selection of a lighting system for a specific space used for individual tasks (Total area of 72 m^2). This decision problem demonstrates some parts of scenario (2) of solution analysis.

Figure 7: Space to light up



The client company expects three objectives for this space:

- Improve satisfaction of occupants by promoting visual comfort in task surfaces
- Lower the energy consumption and generated CO2 emissions by optimizing lighting energy use and increasing energy savings
- Optimize operating costs by lowering maintenance and energy costs.

The designers have two alternatives for artificial lighting systems provided by supplier Z. Both solutions have the same initial cost and operating hours/year (2000 h). Lighting designers judge that the existing daylighting system is satisfactory, so there no need to integrate it in the study.

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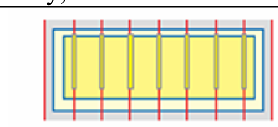
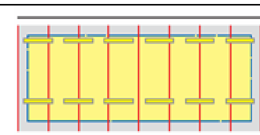
<tr><td>
Figure 8: Alternative (1)
6 luminaires Type fluorescent T16 with 5 bulbs (1/54 W + 2 x 2/24 W) with switching control systems.
Energy Use: 2100 kwh/year
Maintenance (luminaire and room Cleaning): 6 times along 15 years (1415 €/time)</td><td>
Figure 9: Alternative (2)
12 luminaires Type fluorescent with 2 bulbs T16 (35 W) with dimming control systems.
Energy Use: 1680 kwh/year
Maintenance (luminaire and room Cleaning): 6 times along 15 years (2510 €/time)</td></tr>
<tr><td colspan="2">Conversion factor 1kwh= 0,43 kg CO2</td></tr>
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We consider the following specification about the space luminance described by reflectance factor of surfaces (See Table 3)

Reflective surfaces	**Reflectance**
Partitions	50%
Floor	30%
Ceiling	70%
Work surface (Desks)	60%

Table 3: Surfaces luminance characteristics

6.2 Decomposition of the decision problem

In the first stage, the decision making criteria were chosen based on past experience. Hierarchical relationships were drawn between the criteria and are presented in figure 10. Those mentioned in the figure have been selected from a given list of criteria. The *first level* (upper level) corresponds to *four groups of criteria* where each one consists of a list of criteria (lower level).

1. *Artificial lighting performance*
2. *Daylighting performance*
3. *Energy & emissions*
4. *Operating costs*

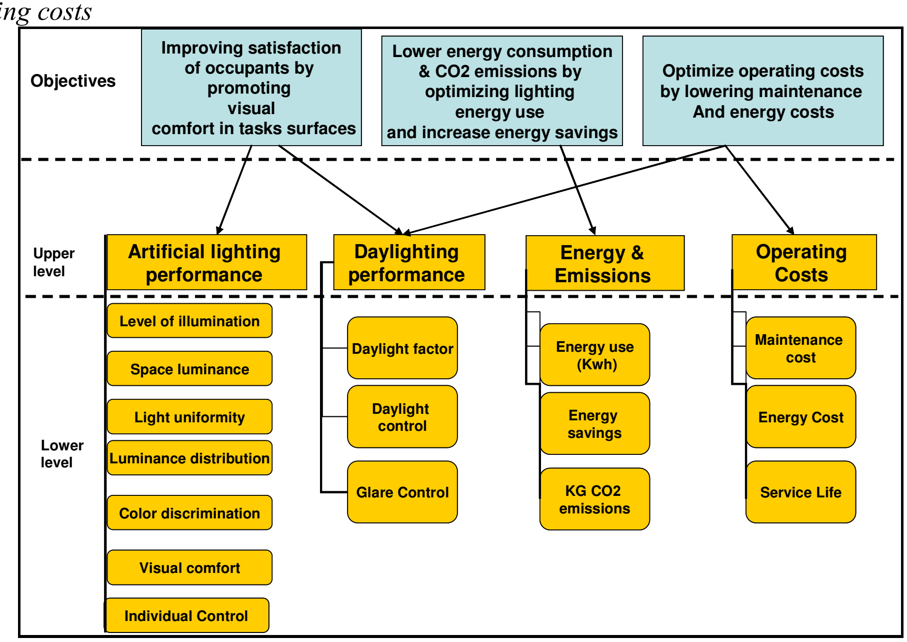

Figure 10: The hierarchy of the decision making process

Based in our need model presented in section 3.1, Table 4 represents the problem following the hierarchy of the model.

Table 4: Need model for the decision problem

Service Function (SF)	Improve satisfaction of occupants	Reduce the energy consumption and generated CO2 emissions	Optimize operating Costs
Technical Function (TF)	Promote visual comfort in task surfaces	Optimize lighting energy use and increase energy savings	Reduce maintenance and energy costs
Performance criteria (decomposed into groups)	***Artificial lighting performance**:* Level of Illumination Light Uniformity Space luminance Luminance distribution Color discrimination Individual Control ***Daylighting performance*** Daylight factor Daylight control Glare control	***Energy & emissions:*** Energy use Energy savings Kg CO2 equivalent	***Operating costs**:* Maintenance Cost Energy cost Service life

Table 5: Levels and groups of performance criteria

Upper level	Lower level
C1: Artificial Lighting performance	$C_{1.1}$. Level of Illumination in space
	$C_{1.2}$ .Light Uniformity
	$C_{1.3}$.Space luminance
	$C_{1.4}$. Luminaire distribution of Luminance
	$C_{1.5}$. Level of Color discrimination
	$C_{1.6}$. Visual ambiance
	$C_{1.7}$.Individual Control of lighting
C2: Energy & Emissions	$C_{2.1}$. Lighting energy use (kwh)
	$C_{2.2}$. Energy savings (%)
	$C_{2.3}$. Kg CO2 equivalent (kg CO2)
C3: Operating Costs	$C_{3.1}$. Maintenance Cost (€)
	$C_{3.2}$. Energy Cost (€)
	$C_{3.3}$. Service life (year)

6.3 Relative weighting of criteria

In the second stage, weighting matrices have been generated and filled with pairwise comparisons between criteria (qualitative comparisons). The comparison was done between criteria from same group and the same level (see Table 5). The comparison allowed the calculation of criteria *weighting vector*. The criteria are compared in pairs with respect to each element of the next level. The so-called comparison matrix represents all possible combinations of pairs. Each pairwise comparison has been qualitatively assessed by an expert group on a seven-level Likert scale: *Extremely less Preferred*, *Strongly less Preferred*, *Moderately less Preferred*, *Equally Preferred*, *Moderately Preferred*, *Strongly Preferred*, *and Extremely Preferred*. The graphical representation of these levels is given in Table 6. As it has been mentioned, we have used a LSLR procedure (with different sophistications that we do not evoke here) which is detailed in [11, 14]. In practice, this semantic scale is indexed onto a numerical scale (10%, 25%, 40%, 50%, 60%, 75%, 90%) corresponding to the estimation of the relative part of the score of criterion i over the sum of both scores of criteria.

For instance, at upper level (Figure 10) of our need model, we identified 3 categories of criteria "C1: Artificial Lighting performance", "C2: Energy & Emissions" and "C3: Operating Costs" decomposed respectively in list of 7, 3 and 3 sub-criterions (lower level). Calculation results that C3's weight (Operating Costs) is 71,87%, followed by C2's (Energy & Emissions) 16,61%, and then C1's (Artificial Lighting performance) is 11,52%.

When the comparisons are done for all matrices of lower level, the resulting weighting vectors must be multiplied by weights associated to the corresponding upper level criterion, so their total weight is equal to the weight of previous level criterion. We talk about *absolute weight vector*. For example, the total weight for C2: Energy & Emissions is 16,61%, then the total absolute weight for lower level sub-criteria Table 8 (lighting energy use, energy savings, Kg CO2 equivalent) is equal to 16,61% too.

Table 6: Qualitative comparison scale used

Value	Preference
<<	Extremely less Preferred
<	Strongly less Preferred
~<	Moderately less Preferred
□	Equally Preferred
~>	Moderately Preferred
>	Strongly Preferred
>>	Extremely Preferred

Table 7: The scores obtained by a PC computation at the upper level

	C1	C2	C3	Local Weight vector
C1		~<	<	11,52
C2			<<	16,61
C3				71,87
			SUM	100

Table 8: The scores obtained by a PC computation at the lower level (Energy & Emissions)

	$C_{2.1}$	$C_{2.2}$	$C_{2.3}$	Local Weight Vector (%)	Absolute Weight vector (%)
$C_{2.1}$		~<	>>	69,23	11,50
$C_{2.2}$			~>	23,08	3,83
$C_{2.3}$				7,69	1,28
			SUM	**100**	**16,61**

Table 9: The scores obtained by a PC computation at the lower level (Operating Costs)

	$C_{3.1}$	$C_{3.2}$	$C_{3.3}$	Local Weight Vector (%)	Absolute Weight Vector (%)
$C_{3.1}$		>	>>	69,23	49,76
$C_{3.2}$			<<	23,08	16,59
$C_{3.3}$				7,69	5,53
			SUM	**100**	**71,87**

Table 10: The scores obtained by a PC computation at the lower level (artificial lighting performance)

	$C_{1.1}$	$C_{1.2}$	$C_{1.3}$	$C_{1.4}$	$C_{1.5}$	$C_{1.6}$	$C_{1.7}$	Local Weight Vector (%)	Absolute Weight Vector (%)
$C_{1.1}$		>	>	>>	>>	>>	>	38,99	4,49
$C_{1.2}$			~>	⊔	~>	>>	>	17,07	1,97
$C_{1.3}$				~>	~>	>>	~>	14,59	1,68
$C_{1.4}$					~>	~>	<	8,12	0,94
$C_{1.5}$						~>	~<	8,96	1,03
$C_{1.6}$							~<	3,30	0,38
$C_{1.7}$								8,97	1,03
							SUM	**100**	**11,52**

6.4 Evaluation of alternative solutions

After calculating the *absolute weight vector* of criteria, the two alternative solutions (Figure 8-9) were rated resulting in a level of satisfaction or utility between 0 to 1, by linear combination of elementary utilities. The calculation is done by using the equations of utility functions (Equations (1) and (2) of Figures 3 and 4) based on the technical characteristics of luminaires and space. In addition, the utility with some criteria related to cost, energy and emissions are determined by the preference of decision maker. Thereafter, a multicriteria evaluation following the AHP process is adopted.

Let U_{ij} be the utility for criterion i and alternative j, the AHP theory requires that the utility or satisfaction values be normalized over the alternatives under each criterion [15], meaning that each criterion has 1 point to dispatch among its different corresponding scores. This is given by the formula:

$$\overline{U}_{ij} = \frac{U_{ij}}{\sum_{j=1}^{N} U_{ij}} \qquad (3)$$

Let W_i be the absolute weight of criterion i, N the number of criterion. The final evaluation of alternative j is given by:

$$U_{Solution} = \sum_{i=1}^{N} W_i \overline{U_{ij}} \qquad (4)$$

Using the calculated rates of the two alternatives, we are able to evaluate the potential alternative solution satisfying the overall criteria. We found that *Alternative (1)* totalizes an **overall rating of 60,0 %, which is much better than Alternative (2) with a poor 40,0%.**

Table 11: Utilities for criteria Vs design alternative and final ranking of lighting alternative solutions

	Absolute Weight Vector (%) W_i	**Utility values**				**Final evaluation (%)**	
		Alternative (1)		**Alternative (2)**		**Alternative (1)**	**Alternative (2)**
		U_{ij}	$\overline{U}_{ij}$	U_{ij}	$\overline{U}_{ij}$		
C1: Artificial lighting performance							
$C_{1.1}$. Level of Illumination in space	4,49	1	0,5	1	0,5	2,245	2,245
$C_{1.2}$ .Light Uniformity	1,97	0,8	0,444	1	0,556	0,876	1,094
$C_{1.3}$.Space luminance	1,68	1	0,5	1	0,5	0,840	0,840
$C_{1.4}$. Luminaire distribution of Luminance	0,94	0,5	0,333	1	0,667	0,313	0,627
$C_{1.5}$. Level of Color discrimination	1,03	1	0,5	1	0,5	0,515	0,515
$C_{1.6}$. Visual ambiance	0,38	1	0,5	1	0,5	0,190	0,190
$C_{1.7}$.Individual Control of lighting	1,03	0,2	0,2	0,8	0,8	0,206	0,824
C2: Energy & Emissions							
$C_{2.1}$. Lighting energy use	11,50	0,5	0,333	1	0,667	3,833	7,667
$C_{2.2}$. Energy savings	3,83	0,2	0,286	0,5	0,714	1,094	2,736
$C_{2.3}$. Kg CO2 equivalent	1,28	0,5	0,333	1	0,667	0,427	0,853
C3: Operating Costs							
$C_{3.1}$. Maintenance Cost	49,76	0,8	0,8	0,2	0,2	39,808	9,952
$C_{3.2}$. Energy Cost	16,59	0,5	0,417	0,7	0,583	6,913	9,678
$C_{3.3}$. Service life	5,53	1	0,5	1	0,5	2,765	2,765
						60,025	**39,985**

7 CONLUSION

The purpose of this paper is to present an approach for supporting decision making in workplace design process through an evaluation of predicted performances. The methodology proposed in this paper directly considers design "lego" elements and technical domains. We have presented in detail each step of the approach and illustrated with particular example of lighting system. The decision making problem in the case study has been solved with several conflicting criteria: increase social performance visual comfort, improve environmental performance (energy and emissions) and avoid extra costs. To evaluate lighting system efficiencies for a specific space, engineering data were extracted from solution technical data for the two proposed alternatives and a set of criteria was selected to describe performances of the design solutions. The presented methodology in the case study has provided a systematic approach to evaluate the overall efficiency of design. The system is effective in helping designers to see the differences of various design alternatives and to make design decisions on them.

The usefulness of weighting patterns and utility values for the 3 use scenarios consists on the way to aggregate performance criteria to provide rated value of the satisfaction with service functions. In addition, the refinement will concern the solution model by defining a framework to extract the required technical data to correlate with performance criteria and model the impact of solution on qualitative performances. The definition of correlation semantics is still under development to conveniently express complex relationships among data and model gradual and uncertain relationships using the Fuzzy rule-based approach. The soundness of the tool depends a lot on the completeness of correlation semantics.

ACKNOWLEDGEMENTS

This work has been granted by *ADEME* agency (www.ademe.fr): the French governmental Agency for Environment and Energy (Grant TEZ05-11). Thanks to the people from the industrial partner *Steelcase Inc*. (www.steelcase.com) who contributed to this work.

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