KNOWLEDGE MANAGEMENT FOR DECISION MAKING IN HOLISTIC BUILDING RENOVATION DESIGN

Andrieux Franck, franck.andrieux@cstb.fr
Maïssa Sandrine, sandrine.maissa@cstb.fr
Thorel Mathieu, mathieu.thorel@cstb.fr
Centre Scientifique et Technique du Bâtiment, Sophia Antipolis, FRANCE

ABSTRACT

Undoubtedly the rehabilitation of housing offers the largest potential in energy saving and reduction of GHG emission to hit the ambitious goals of the French "Grenelle de l'Environnement" (and Kyoto agreements).

If the rehabilitation process is not following a holistic approach, performance gains might be lower than expected and thus ROI might be longer, with the risk of degradation of building's intrinsic qualities in terms of comfort, safety, health...

However, in spite of the energy cost increase, energy renovation is not today the first motivation of householders focusing more on the increase of space and comfort and the embellishment of the building.

Expert knowledge, at design stage, might contribute to convince householders to be engaged in energy renovation actions and support professionals in decision making process by:

- Alerting of energy renovation opportunities linked to specific type of maintenance work;
- Identifying possible impacts of specific retrofitting solutions on the building.

This paper aims to describe the work engaged in the frame of an internal CSTB research project dedicated to decision making tools for rehabilitation.

Keywords: Energy renovation, decision making, knowledge management, design process, ICT

1. INTRODUCTION

In France, the energy rehabilitation concerns more than 30 million houses, with 20 million built before the first national thermal regulation in 1974. These buildings are mainly very inefficient in terms of energy consumption and greenhouse gas emissions. Thus the rehabilitation of existing buildings, and especially housing, represents undoubtedly the largest potential in energy saving and greenhouse gas emission reduction according to the ambitious goals of the French "Grenelle de l'Environnement", the Energy Performance of Buildings Directive, and more generally to respect Kyoto agreements.

In case this process of rehabilitation is not properly driven (i.e. based on a holistic approach), performance gains might be lower compared to expectations, but moreover, this can degrade the building's intrinsic qualities related to comfort (thermal, acoustic), safety, health...

Compared to the construction of a new building, a renovation process have to manage knowledge uncertainties and imperfections all along its process: lack of information about building technologies (materials, hidden parts,…) or systems characteristics (no more available information), deterioration of material or systems performances with aging (e.g. insulation panel settling). In many situations, intrusive probing techniques are not possible.

In this context, a professional in charge of a renovation process should be compared to a veterinary rather than a doctor:

- He have to manage a large variety of buildings, as the veterinary manage many races of animals
- Existing buildings and animals can't speak (or are not clearly understandable)
- As the veterinary must sometimes decide to kill an animal, the decision can be to deconstruct a building instead of renovate it.

Furthermore, professionals can't be expert on all the domains useful in building rehabilitation (energy, acoustic, security, health, costs, social impacts…). All along the renovation process, professionals need to be helped to perform the more accurate diagnosis and to make the good decision, to select the more reliable and appropriate renovation solutions.

Decision making tools, information and expert knowledge are probably the keys of a holistic renovation process.

This paper aims to present a decision support methodology, based on dynamic simulations and knowledge management, dedicated to facilitate dialogue between building professionals and decision-makers on rehabilitation issues. The design stage of rehabilitation process is targeted. In any cases, our approach cannot replace detailed studies, but help professionals making the right decisions. The method will be implemented as online software. Therefore, a low CPU computational time, a reasonable number of input parameters, easily findable, are mandatory.

Our study focus on residential buildings (individual dwelling) built in France between 1945 and 1974 (i.e. between the end of Second World War and the first French thermal regulation). This target represents a high potential for energy savings.

2. DECISION MAKING IN HOLISTIC BUILDING RENOVATION DESIGN

2.1 Bases of proposed methodology

The state-of-the-art has enabled us to define a 4 steps process for the rehabilitation design with a holistic approach. The decision making tool we want to develop will rely on this 4 steps process: definition of issues related to the rehabilitation project, initial diagnosis, automatic and manual selection of renovation solutions.

- The definition of issues related to the rehabilitation project is the start point of the renovation process. Here the end-user (or the person who represents end-users) must define why or how he intends to refurbish his housing (i.e. solve pathology, increase comfort, reduce energy bill…) and must select the assessment criteria which matter to him: Financial investment, ROI, Comfort, Health... These criteria have got an impact on the questions we should ask to the end-users for the diagnosis part and on rehabilitation strategies, to select the best renovation solutions.
- The initial diagnosis is required to estimate the potential energy saving of a rehabilitation project and lead to the decision to deconstruct or refurbish the building, but also to assess the state of degradation of the building, and to identify the sources of eventual pathologies. This diagnosis is required to collect necessary information to feed energy calculation model, opportunity possibilities and experts rules (to identify compatible rehabilitation solutions). It will be performed through a set of interactive forms where most probable solutions might be suggested, based on a knowledge base on representative of housing from 1945-1974 period.
- An automatic selection of the most appropriate renovation solutions. The selection of renovation solutions is driven by two processes: (1) the "opportunity matrix" which links rehabilitation solutions with synergy effects (e.g. External thermal insulation of walls with facelift), (2) and expert rules base to identify and reject incompatible rehabilitation solutions with the project context and initial configuration. Rehabilitation solutions are automatically ranked in function of assessment criteria of holistic approach selected by decision-makers during the first step.
- A manual, but assisted, selection of the final renovation solutions. When the presented propositions don't totally fulfill the end-user requirements, the professional can make his own

selection of solutions. An intelligent assistant help him with expert system to generate warning or recommendation alerts when specific choices are realized.

To carry out such a methodology and the associated tool, we lead 3 different work packages as following:

1. Typological analysis and simulations
2. Information and knowledge management
3. Decision making process

2.2 Typological analysis and simulations

During last decades, several typological studies have been carried out on French residential buildings, from the period 1945-1974 (*1*, *2*). These relate to the identification of different construction techniques (bricks, stone, steel, and concrete) and energy equipments (boilers, ventilation systems…) that are the most representative of this period. This contributes to fill a database of construction techniques and systems used in existing building. That database will help the professional:

- To describe buildings during diagnosis phase by providing contextual average values for unknown parameters (linked to period of construction or localization) when intrusive probing techniques are not possible during initial diagnosis (however this approach leads to increase uncertainty).
- To the definition of a set of generic buildings.

From these typological studies and generic buildings we are able to define all the necessary input parameters useful to run energy simulations and perform sensitivity analyses. These analyses allow identifying influent input parameters on thermal behavior of a building typology with specific model calculation. At last, sensitivity analysis used in this context, should allow to:

- Make shorter data entry, simplify thermal calculation models and thus perform faster simulations ;
- Assess knowledge uncertainty on input data collected during diagnosis step.

Two levels of sensitivity analysis are used: screening (*3*) in order to identify influent input parameters among the vector of parameters required to run the energy calculation model, and global sensitivity analysis (*4*) to quantify uncertainty knowledge on these influent input parameters on the outputs of our model.

The objective here is to gather typological studies already conducted on residential buildings in France for the period 1945-1974 (part 2.1.1). Information collected from building structure and energy equipments can help the professional to describe buildings during diagnosis phase. Also, representative houses from typological family (generic buildings) can be used too.

2.3 Information and knowledge management

As we explain before, information and knowledge is a key factor to perform a successful holistic renovation process at the four steps described above. We organize this knowledge into distinct sources such as:

- A database of energy retrofitting opportunities linked to specific kind of renovation work ;
- A database of most common solutions used in existing buildings and in a renovation process ;
- A database of most frequent solutions used in existing buildings, linked to the context ;
- A knowledge base of expert rules including impacts, incompatibilities, recommendations or alerts linked to each renovation solutions.

All these sources should be designed and completed as the project progress.

2.3.1 Database of energy retrofitting opportunities

Depending of the type of refurbishment envisaged by the owner in step 1, it can be possible to envisage energy renovations at a lower cost. For example it may be possible to take advantage of a facelift (façade

renovation) to setup an external thermal insulation of walls. Here, costs (labor and scaffolding rental cost) are shared for both operations. In addition, present situation is also perfect to treat windows thermal bridges.
All the possible opportunities should be gathered into a database in order to select and rank the renovation solutions and of course to take the higher benefice from the existing building.

2.3.2 Database of most common solutions used in existing buildings and in a renovation process

In order to provide an assessment of the initial and final performance and quality of the building to be renovated, we should build a database of construction techniques (bricks, stone, steel, and concrete) and energy equipments (boilers, ventilation systems…) that are used in existing buildings or to renovate these buildings. For each solution we should gather all the technical characteristics and intrinsic qualities (as thermal or acoustic properties, investment cost, grey energy…) that allow us to define the criteria and indicators that will be used in the decision making steps. We should also include a description of the solution and an optional picture in order to simply identify the solution or understand how it works.

All this information is obtained from experts and typological studies (Figure 1). A first set of envisaged solutions for rehabilitation is listed in table 1.

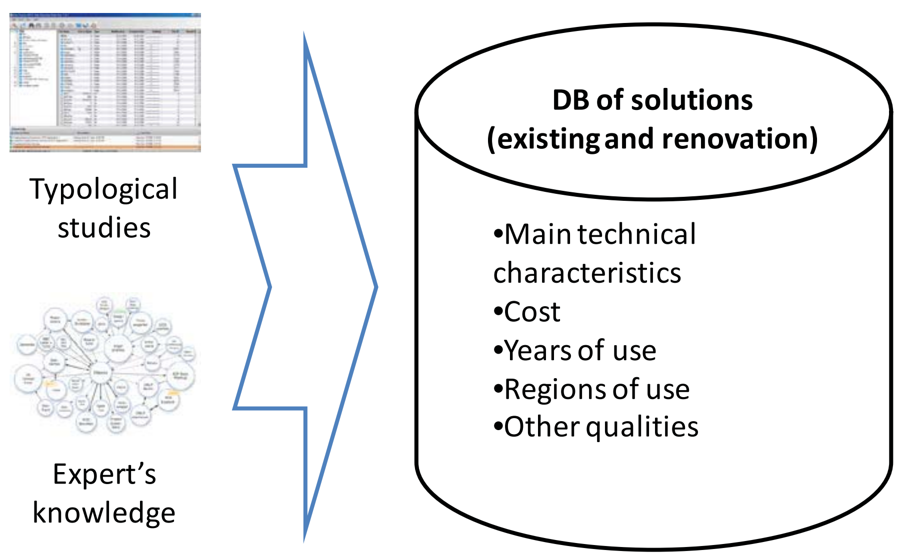

Figure 1: Database of solutions

Table 1: List of selected renovation solutions

N°	Name	N°	Name
1	Thermal insulation of external walls	10	Thermodynamic water heaters installation
2	Thermal insulation of floors	11	Heat pump installation (air-air, air-water, ground-water)
3	Thermal insulation of ceilings	12	Thermal insulation of hot water pipes
4	Windows replacement	13	Installation of solar heating panels
5	Air inlets and rolling shutter casings replacement	14	Heaters replacement (low temperature, radiant panels)
6	Loggias closing	15	Installation of thermostatic valves on existing heaters
7	Reducing parasitic air leakages	16	Installation of photovoltaic solar panels
8	Ventilation systems replacement		
9	Boilers replacement (gas, fuel oil, …)		

Some solutions can interfere with each other and should be associated in a package in relation with expert's recommendations.

2.3.3 Database of most probable solutions used in existing buildings, linked to the context

In a renovation process it frequently happens that pieces of information are missing. In addition to the previous database, this database contains the most probable construction techniques (bricks, stone, steel, and concrete) and energy equipments (boilers, ventilation systems…) in relation with the context of the building to be renovated (for example year of construction, localization of the building,…) that are used in an existing building. All this information comes from the typological studies and is supposed to help the professional during the diagnostic phase in case he doesn't know some information about the building and when there is no way to get it without deconstructing.

This database should mainly contain the range of years and the regions where each solution have been used. A probability of use will be very precious to suggest the best choice to end-users, but also to evaluate the impact of a wrong information, as it will be explained in §2.1.

2.3.4 Knowledge base of expert rules

After initial diagnosis and needs identification, next step is the selection of renovation solutions in order to build an adapted rehabilitation set. The proposed renovation solutions – described in table 3 – require specific configuration of existing building to be implemented without side effects. These "rules" determine the potential impacts of a solution on the building tested, on the needs expressed in diagnosis part, and on the interaction with other selected renovation solutions.

The use of an expert system should help to model and handle expert's knowledge on rehabilitation process. This knowledge is modeled in three process: a knowledge base (expert judgments on solution combinations and their potential impacts on assessment criteria), a fact base (information extracted from diagnosis), and an inference engine (algorithmic process in order to call expert rules).

In our study, knowledge base should help the professional to identify incompatible solutions through alert messages in order to explain risks (pedagogic approach). The second interest is to identify opportune solutions through recommendation alerts, or solution selection propositions (in adequacy with decision maker needs). The last interest is to use knowledge base to automatically ask additional questions to the professional, to reduce specific risk associated with the implementation of a solution in particular context (e.g. noise perception from inside or outside sources) by reducing uncertainties.

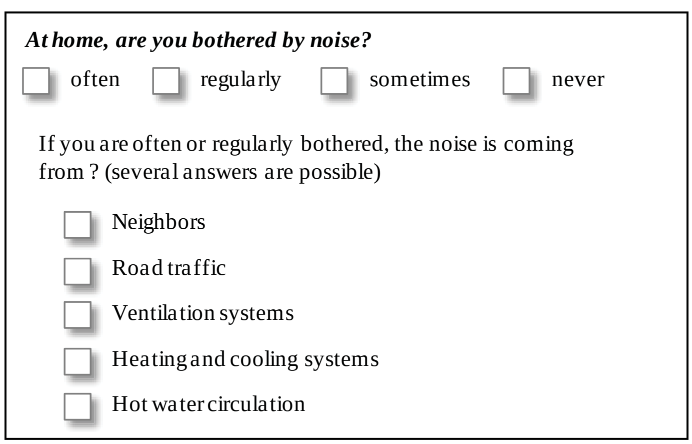

Figure 2: Example of acoustic comfort assessment (5)

The rules base should collect expert knowledge gathered from interviews with buildings' experts in different areas (environment, acoustic, thermal, humidity transfers…) and should be expressed in natural language. The added value of expert system is to use independent and short rules. This process allows adding, modifying, or deleting rules easily from a computational system. Rules are ranked from the more restrictive to the less restrictive to be able to deduce knowledge and process new rules. In order to emphasize the interest of expert rules, two examples are presented below in natural language (they can be controversial, but the aim here is to provide an illustration of the possible content for the rules base).

First example – pathology risk: for a building not with little thermal insulation, and equipped with natural ventilation (i.e. without any mechanical ventilation system), undertake thermal insulation and replacement of old windows without adding an active ventilation system may lead to humidity pathologies (appearance of mold, fungus, bad odor).

Second example – opportunity situation: If the current heating system is totally electric without any heat emitters connected to a boilers with hot water network, dry solutions as electric radiant panels or as air/air heat pumps, should be preferred in order to reduce the cost and difficulties associated to the installation of hot water pipes and pumps through the building. In the opposite situation, electric heating systems should not be preferred due to a high GHG content of electric kilowatt for environmental issues.

Both examples show simple rules which allow helping professionals to lead an efficient renovation process.

The elaboration of combination of renovation solutions (e.g. replacement windows or walls thermal insulation) requires expert knowledge to formalize what is a good combination, and what is not. Decision trees and experts systems allow obtaining selections of solutions from initial diagnosis, users requirements and experts knowledge (*1*).

2.4 Decision making process

As explain above, the rehabilitation design process relies on these 4 steps:

1. definition of issues related to the rehabilitation project,
2. initial diagnosis,
3. automatic selection of renovation solutions,
4. manual selection of renovation solutions.

The decision making process rely on the first two steps and concerns the last two steps.
We target to assist the professional, who is not necessary an expert of all the technical domains, during the design of the rehabilitation process. To reach this aim, all the information and knowledge bases described above should help the end-user to understand complex interactions between various solutions and the building to renovate. Alerts and recommendations should be automatically displayed when a risk or an opportunity is presented.

Also, only combinations of solutions that match initial requirements should be presented to support the professional in decision making. Finally, the decision support should help user to compare and select the bunch of renovation solutions which provides the best answers to the defined objectives.

2.4.1 Multicriteria decision making support

Decision making requires two essential parts: scenarios of selected solutions (called alternatives) and assessment criteria at buildings scale.

Alternatives are proposed from knowledge base and its rules base. Assessment criteria are built from a characteristic or a combination of several characteristics of each alternative, aggregated by expert judgments (logical functions or weighting methods).

Once alternatives and their assessment criteria are defined, multicriteria decision making methods help user to analyze which alternative fits the best to the requirements.

Roy describes three type of multicriteria decision making techniques in function of user requirements (*6, 7*): (Pα) choice problem, in order to find the best alternative; (Pβ) classification problem, in order to classify alternatives in type boxes (e.g. good, medium, bad) ; (Pγ) ranking problem, in order to rank alternatives from the best to the worst.

Table 2: Decision problem classification by Roy

Symbol	Problem type	Methods
P_α	Choice problem	ELETRE I
P_β	Classification problem	ELECTRE TRI
P_γ	Ranking problem	ELECTRE II, ELETRE III

In renovation process, when several strategies are available (i.e. compatible with user requirements), decision approach correspond to ranking problem (Pγ). The ELECTRE III method, described by Roy (*6*) allows resolving this type of problem by comparing solutions by couple (over-ranking methods) and by taking in consideration threshold values (e.g. uncertainties range).

Many multicriteria decision making methods are based on weighting criteria. The mathematic laws defining weightings are sensitive to threshold values; therefore a robustness analysis is required to assess their reliability.

2.4.2 Quantitative and qualitative assessment of renovation solutions

Performance assessment of renovation solutions relies on quantitative characteristics (objective results from measurements or calculation models), when it is possible, and qualitative characteristics (often subjective and defined by expert or user judgments), when models are too complex or not relevant. Both types are used to assess a rehabilitation process (solutions characterization and buildings diagnosis).

A common approach in a decision making process consists of aggregate qualitative and quantitative data derived from different sources: calculation models, survey questionnaires dedicated to building users, literature.

2.4.3 Criteria and assessment of renovation solutions

The assessment of rehabilitation strategies should rely on a holistic approach based on various criteria related to health, comfort, environmental impact, security, use, and applicability. As described in table 3 some criteria are relevant at product (P), system scale (S) or building scale (B). The definition of these criteria is essentially coming from the French standard NF P01-010 (*8*) and expert works.

Table 3: List of assessment criteria

N°	Criteria	Scale
1	Fresh air ratio	B
2	Grey energy	P
3	Climatic impact	B
4	Durability	P
5	Maintenance constraints indicator	S
6	Technical maturity (in France)	S
7	Workings disturbances	S
8	Weighted sound reduction index R_w (C ; C_{tr})	P
9	Airborne sound insulation index	B
10	Summer overheating indicator	B
11	Annual final energy consumption	B
12	Payback time	B
13	Global cost	B

B: building, S: system, P: product

Annual final energy consumption and summer overheating indicator are directly computed from selected thermal calculation method *Th-C-E ex (9)*. From this one, climatic impact and annual energy consumption costs coming from energy consumption are calculated.

Global cost calculation relies on the international standard ISO 15686-5. In this methodology, we should limit global cost by investment costs (material costs, labor costs), subsidies, loans, energy consumption costs, and maintenance costs. Because of high variations in investment costs, this value should be expressed by price range for each type of operation. Payback period correspond to a function of the investment plus the maintenance cost, over the difference of annual energy consumptions between the initial situation and the final situation (i.e. with renovation solutions implemented).

The fresh air ratio and airborne sound insulation index should be determined by expert knowledge regarding initial building configuration (from logic functions of initial diagnosis, user survey questionnaires, and selected renovation solutions). These criteria are not yet well defined; discussions with experts will help to assess their relevance.

Finally, energy diagnosis step, required to assess energy performance of initial building, helps to define characteristics linked with surface areas (square meter of insulation, and consequently material costs and grey energy).

3. CONCLUSION AND FUTURE WORK

This paper tries to show the importance of information and knowledge in the design phase of a holistic rehabilitation process. It presents the works that have been carried out by CSTB teams in the frame of an internal research project dedicated to rehabilitation (Réhascope) and in a PHD that is just starting. The principal objective is to give tools to the professionals in order to lead a rehabilitation process with a holistic approach. No results are expected before the end of 2012. The paper aims to make a brief presentation of completed and future works, to present the approach described, and make the scientific community react about the relevance of our approach.

REFERENCES

1. CSTB, POUGET Consultants, Guide ABC : Amélioration thermique des Bâtiments Collectifs construits de 1850 à 1974. (Paris, ed. EDIPA, 2011).
2. P. Graulière, Typologie des bâtiments d'habitation existants en France. Synthèse des caractéristiques des bâtiments d'habitation existants permettant l'évaluation du potentiel d'amélioration énergétique. (METL, 2005).
3. M. D. Morris, Reliability Engineering & System Safety **91**, 1252 (2006).
4. J. Jacques, Université de Lille (2011).
5. D. Caccavelli, J.-L. Genre, Energy and Buildings **31**, 159 (2000).
6. B. Roy, Méthodologie Multicritère d'Aide à la Décision. ECONOMICA, Ed., (1985).
7. S. Ben Mena, Biotechnol. Agron. Soc. Environ **2**, 83 (2000).
8. CSTB, Mieux comprendre la partie environnementale des déclarations environnementales et sanitaires des produits de constructions selon la norme NF P 01 010. INIES, Ed. (2005).
9. French thermal regulation for exisiting buildings, Méthode de calcul TH-C-E ex, Annexe à l'arrêté portant approbation de la méthode de calcul, Journal Officiel de la République Française, (2008).