A Fuzzy-Neural Tree Knowledge Model for the Assessment of Building's Transformation

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ABSTRACT: One building is more flexible in terms of use than the other and to determine how much a building 'X' is more flexible than a building 'Y' is a rather complex task. This research focuses on houses for the elderly in terms of future use, since the requirements have changed and many of the existing buildings do not meet new requirements. To asses a transformation of a building one needs to take many aspects into account such as: spatial transformation, technical transformation and their various sub-aspects. There are also different future use scenarios, defined by Netherlands Board for Healthcare Institutions, and one scenario is more suitable for a building than another. Firstly, in order to deal with this complex topic there is a need for a systematic approach where all relevant aspects determining a transformation value of a building will be defined. Thereafter, fuzzy-neural tree structure is used as a suitable method for knowledge representation and knowledge modeling.

1 INTRODUCTION

Currently there is a rising problem of demographic aging in the Netherlands. The demographic ageing is a consequence of aging of the post-war generation. These are the so-called baby-boomers that were born between 1945 and 1955. At this moment 1 million people are 75 years and older. In 2050, according to the expectations, this number will increase up to 2.2 million (CBS, 2003). This demographic ageing has, among other things, a significant impact on a healthcare system. Since people are in general becoming older there is a higher chance that the elderly illnesses will increase as well. In the coming years there is a rapidly increasing demand for houses for the elderly and nursing homes (Bouwcollege, 2003). Next to such increasing demand there is at the same time a concern regarding environmental impact. There are many ways in which a construction industry can reduce the impact of buildings on the environment. One of the possible ways is to reduce the amount of building waste by demolishing less buildings. Even when a building has reached the end of a functional lifetime it does not mean that a building cannot be efficiently upgraded to meet new requirements or change a function and therefore adapt for another use. In the Netherlands such issues play an important role and this paper deals with finding the most suitable scenario for a building in terms of future use so that an optimum can be achieved between demand and environmental impacts.

2 RESEARCH BACKGROUND

In 2005 the Netherlands Board for Healthcare Institutions, further in the text will be reffered to as Bouwcollege, conducted a monitoring research. This study provided the most recent overview of the technical and functional quality of the existing buildings in the sector 'Houses for the elderly and Nursing homes' (Bouwcollege, 2005).

The main goal of the monitoring study was to establish untill which extend the existing buildings met user requirements in terms of functionality and use and at the same time to determine what the technical quality of the existing buildings was. The results were classified into three colors wherein each color represented an advice and indicated a possible future action. These colors were:

- green (a building satisfied the requirements or only minor improvements were needed)
- orange (a building needed to be upgraded and more improvements were necessary)
- red (a building did not satisfy the requirements and a question was whether these buildings had any future).

Figure 1 gives an example of the monitoring scores for three buildings, where two buildings obtained a red score and one had a green score. Later in the paper these results are combined with the results obtained by a knowledge model (for reference see *figure 5*).

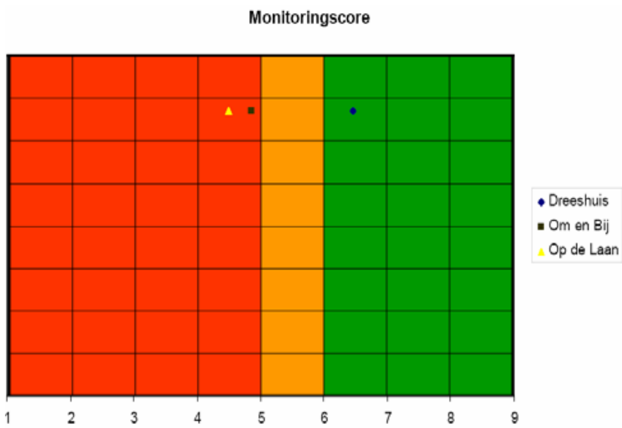

Figure 1: Representation of the monitoring results for three buildings (Nauta, 2007)

One of the conclusions from the monitoring study was that a majority of buildings (63%, meaning 652 buildings) had one or more lacks which should be taken care of within the coming years. These buildings had a green score. In total 36% of the institutions (349 buildings) had an orange and red score. Especially these buildings were problematic, since it seamed that for some of them the demolition was the only possible solution. Such decision would result in a large scale capital demolition, decrease of available places for the elderly and would as well have a high negative impact on the environment. Therefore it was necessary to research other possibilities such as changing functions but still remaining within the healthcare domain in order to meet the growing demand for places in nursing homes or houses for the elderly. So the next step was to investigate whether the buildings that had a red score could be upgraded to another (healthcare)function. In that respect it was necessary do define possible future use scenario's. Since most locations of the existing houses for the elderly had mostly a central location most of these healthcare institutions wanted to keep these locations in the future as well. Having all these issues in mind, Bouwcollege proposed four possible future scenarios where the existing houses for the elderly would be converted to:

1. nursing home (group of 6 to maximum 10 persons in a group, min. 15m^2 per bedroom)
2. nursing home (individual units, minimum 18m^2);
3. new apartments for elderly, according to new requirements (45 m^2)
4. apartments-for-all (separating living and care, apartments minimum 60m^2).

In order to make an end to an endless discussion about how flexible a particular building is in terms of future use, it was necessary to develop a tool that would provide an answer regarding the transformation capacity of the existing houses for the elderly. For this purpose, a systematization of all aspects determining transformation value of the buildings was necessary and thereafter suitable techniques are required for knowledge representation and modeling. Further in the texts, research methodology will be explained followed by knowledge modeling, with the main focus on knowledge modeling part.

3 RESEARCH METHODOLOGY

In the monitoring study Bouwcollege already obtained a lot of information regarding the buildings such as their typology, construction method/materials used, dimensions etc. What was still missing was the systematization of aspects that determine a transformation potential of buildings. Based on a PhD thesis of E. Durmisevic (2006a), graduation thesis of Schunselaar (2006), and in constant feedback from the Bouwcollege, E. Durmisevic systematized aspects related to the transformation capacity (*table 2*). These aspects were first of all divided into two main groups and thereafter further subdivided in other categories. A list of all nineteen aspects determining the transformation value is given in *table 1*:

Table 1: Aspects determining transformation capacity of a building

<table>
<tr><th colspan="4">TRANSFORMATION VALUE (TV)</th></tr>
<tr><th colspan="2">SPATIAL TRANSFORMATION (ST)</th><th colspan="2">TECHNICAL TRANSFORMATION (TT)</th></tr>
<tr><th>POSITIONING (PO)</th><th>DIMENSIONING (DI)</th><th>DISASSEMBLY (DIS)</th><th>CAPACITY (CA)</th></tr>
<tr><td>Minimal dimensions on a building level</td><td>Hallway width/position of load bearing construction</td><td>Main installation network</td><td>Capacity of the installation ducts</td></tr>
<tr><td>Load bearing construction: floor-to-ceiling height/floor thickness</td><td>Hallway width/position of installations</td><td>Distribution network</td><td>Capacity of the load bearing construction in relation to new (wall) openings</td></tr>
<tr><td>Load bearing construction: depth/grid system</td><td>Positioning of the vertical installations</td><td>Separation of separation walls</td><td>Capacity of the load bearing construction in relation to hallway width</td></tr>
<tr><td>Load bearing construction: dimensioning/ventilation system</td><td>Direction of the vertical installation ducts</td><td></td><td>Future expansion of the building</td></tr>
<tr><td>Hallway width</td><td>Clustering of vertical elements</td><td></td><td>Capacity of the elevators/stairways</td></tr>
<tr><td>Façade openings: dimension/room depth</td><td></td><td></td><td></td></tr>
</table>

In first instance to be able to generalize to certain extend, the buildings were subdivided into four major types, being:

- single corridor
- double corridor
- core/central corridor
- gallery

For each of these typologies and each scenario a minimum spatial requirements were determined both on a building level as well as on a unit level. Thereafter, based on extensive spatial analysis, having in mind four different future scenarios and related requirements, various spatial and technical solutions were graded on a scale between 0 and 1. An example of a grading is shown on the example of sanitary area (*figure 2*).

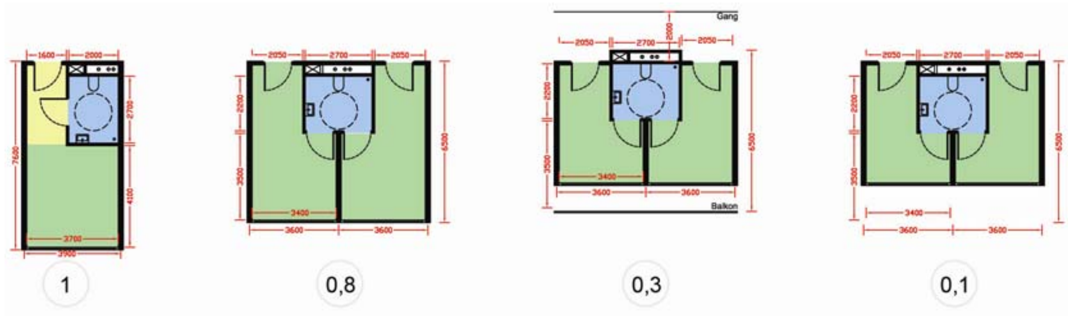

Figure 2: A grading of spatial solutions in terms of functionality

After grading is finalized for all aspects, the next step was to prioritize the relative importance of these aspects per scenario which was a starting point for knowledge modeling.

4 KNOWLEDGE MODELING

The systematization and the grading scheme are only a starting point for knowledge modeling. At this stage only information is provided, which cannot be used in a meaningful way, since at the level of systematization and grading there are no rules to apply that information. In other words, the interrelationship between the aspects is not yet modeled, which makes the information at hand difficult to interpret and apply in a knowledge form. Main purpose of this work was to model the knowledge which would be able to represent and capture expert's knowledge on the subject of transformation value. With such a model it would be possible for Bouwcollege to reuse the knowledge and apply it for evaluation of all houses for the elderly (more than 1000 buildings).

In general, knowledge can be characterized either as explicit or tacit. Explicit knowledge can be easily represented and applied due to its precise an unambiguous nature. It is mostly represented in building standards, regulations and guidelines. On the other hand, tacit knowledge, first introduced by Polanyi (1958), is much more difficult to represent, capture and reuse since it is generally fuzzy, ambiguous and imprecise. It is therefore rather difficult to express tacit knowledge since it is embedded in personal experience which involves subtle aspects such as personal beliefs, views and value system. It is a knowledge of experts regarding specific domain. Modeling tacit knowledge is a time consuming activity and knowledge models can be either *data* or *expert* driven. In first case, data driven knowledge models rely on large amount of data where some data mining techniques are applied for knowledge discovery and elicitation. Expert driven knowledge relies on one person's/group of experts knowledge on a particular subject (Durmisevic and Durmisevic, 2006). This paper deals with the later one, expert driven knowledge modeling, including both explicit and tacit knowledge.

Having systematized all aspects that are related to transformation capacity it was necessary to establish the relevant importance of all aspects. This was done using Analytical Hierarchy Process (Saaty and Alexander, 1981; Saaty and Vargas, 1982). The AHP method is a technique to compute the priority vector, ranking the relative importance of factors being compared. In the AHP computations expert knowledge plays the essential role. With AHP the model weights are determined. Based on these weights the structure of the knowledge model is established in a form of fuzzy-neural tree structure.

A fuzzy-neural tree is composed of terminal nodes, and weights of connection links between two nodes. Each terminal node is labelled with an element from the terminal set $T=\{x_1,x_2,\ldots,x_n\}$ where x_i is the *i-th* component of the external input vector $\boldsymbol{x}$. The input $\boldsymbol{x}$ is connected to a node via a radial basis function and provide an output for this node which is given by

$$f(x) = w_j \phi(\| x - c_j \|)$$

where φ *(.)* is the basis function, c_j is the centre of the basis function; w_j is the weight connecting the output of the basis function to the a terminal node in the form of an external input. c_j determined as a component of a priority vector and equal to w_j. Among several radial-basis functions, the Gaussian function

$$\phi(r) = \exp(-\frac{r^2}{2\sigma^2})$$

is of particular interest and used in this research due to its relevance to fuzzy-logic. Above, σ is the width of the basis function and it is used to measure the uncertainty associated with the node inputs designated as external input vector ***x***. For the model there can be as many basis functions as needed. The centres of the basis functions are the same as the terminal node inputs. Therefore for these input the radial basis function output is 1 and this is multiplied by the associated weight.

Neural networks can represent a broad class of feed-forward networks with or without layered structure. The tree structure involved in this work is a layered one and it allows for easy exchange of substructures by standard sub-tree variation operators without affecting the building blocks. Input from any sublevel to any upper level is possible. Connection between the nodes at the same level is also allowed. However, feedback from any upper level to sublevel is not allowed. By means of this basic configuration, the levels are clearly defined in a structure of any complexity (Ciftcioglu and Sariyildiz, 2006). *Figure 3* shows a configuration of the fuzzy-neural tree involved in this research.

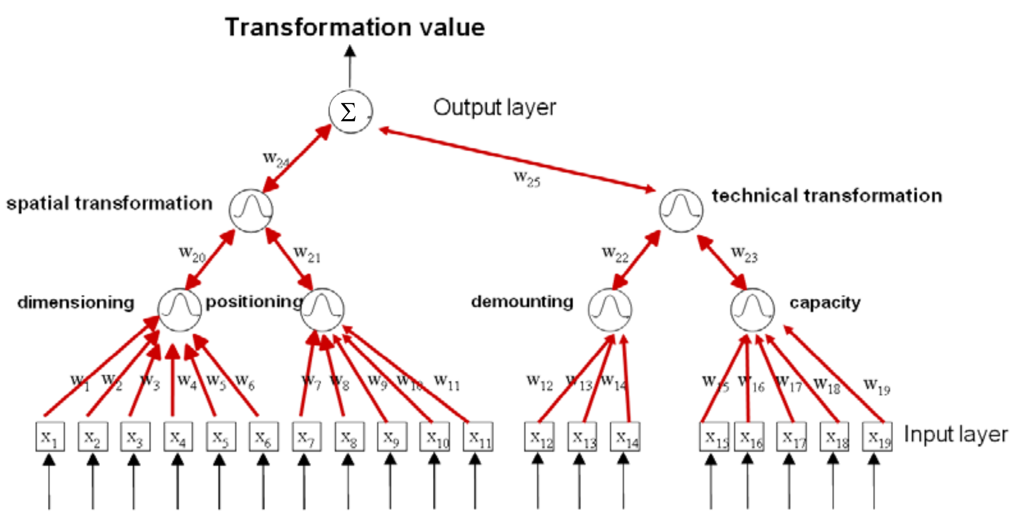

Figure 3: A schematic representation of a fuzzy-neural tree knowledge model

The lowest level has 19 nodes. The immediate upper level has 4 nodes, which is followed by a layer with two nodes. Finally, at the highest level there is one node which provides a final transformation value. The lowest level is a particular level since all the nodes have only a single input in this isolated configuration. The aspects listed in *table 1* are the inputs of the knowledge model, in *figure 3* represented as X_1 to X_n. The weights W_1 to W_n represent the factors of relative importance that were earlier established by the Analytical Hierarchy Process.

5 RESULTS

Since weights per scenario differ, this results into four knowledge models where each model corresponds to one of the scenario’s. In other words, the inputs for a particular building remain the same for each scenario but the weights changed which resulted in four knowledge models. The interpretation of the results is in the following form (*table 2*):

Table 2: The output values obtained by knowledge models and the related interpretations

output values	**interpretation**
0.1-0.3	transformation potential is very low; the transformation of the building is not realistic due to a deficit of spatial and technical capacity;
0.3-0.5	transformation of a building is moderate with a high level of difficulty;
0.5-0.7	a building has a transformation potential with a small level of difficulty;
0.7-0.9	a building has a very high transformation potential (very few adaptations are necessary/ none or very low difficulty level);

The knowledge model software has been tested successfully on several case studies and is currently used by Bouwcollege to evaluate the remaining buildings. The main advantage of having such knowledge models is time efficiency in comparison with comprehensive studies and months of elaboration needed only for one building to come to a conclusion regarding transformation potential. *Figure 4* show the results obtained by knowledge models for Om en Bij, indicating that a first scenario (transforming into a nursing home, 6-10 persons per group) would be the best fitting option for this building.

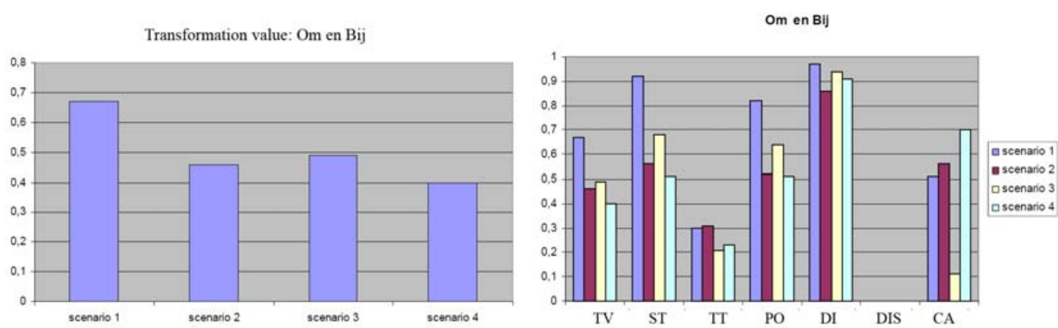

Figure 4: Transformation value for four scenarios (left) and more specific results (right - for explanation of abbreviations see *table 1*)

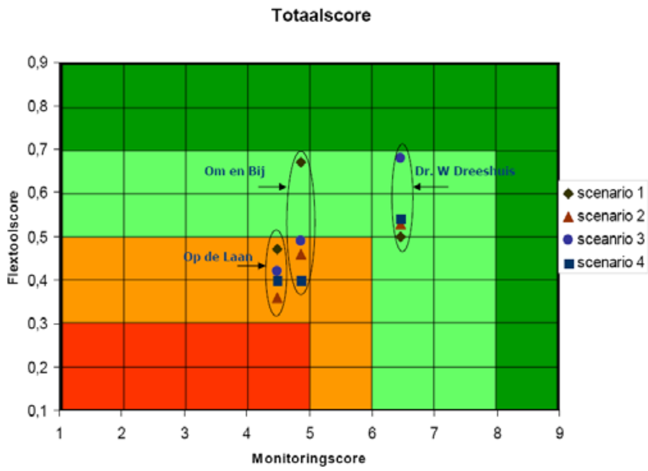

Figure 5: The monitoring results combined with the results from knowledge models (Nauta, 2007)

Comparing the results of the monitoring study and knowledge model (figure 5) indicates that a building Om en Bij, which had a low score in the monitoring, due to its technical and spatial organization could be transformed into a nursing home according to new use requirements. The results obtained by knowledge models show that a building has a transformation potential with a small level of difficulty.

6 CONCLUSIONS

The fuzzy-neural tree structures is especially suitable for tacit knowledge modeling. Firstly, considering the linguistic nature of the architectural data, fuzzy logic techniques are invoked. Secondly, knowledge is represented in a form of neural tree where the processing nodes are crucial for model functioning. In contrast to data driven knowledge models this is an expert driven knowledge model, which mainly captures the tacit expert's knowledge on this particular subject. Such a model is supposed to be generic and robust enough for buildings evaluations in the domain of concern. The methodology explained in this paper shows a way to tacit knowledge modeling.

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