KNOWLEDGE MODEL FOR KNOWLEDGE MANAGEMENT IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

A knowledge model is developed for structuring construction information for use in the construction industry. Construction information is complex due to the involvement of various disciplines spanning engineering data from exact sciences and qualitative data from architectural considerations. Complexity is not only due to the size of the information but also due to context dependency. The context dependency is dealt with the method known as *analytical hierarchy process* (AHP). For structuring the entire information a special feed-forward neural net tree structure is developed, which is based on an underlying matrix referred to as *knowledge matrix*. Taking a particular example from the construction industry, the development of the knowledge matrix and the corresponding neural tree as a knowledge model is presented, and its use for the management of the knowledge is demonstrated.

Keywords Analytical Hierarchy Process, Knowledge Model, Knowledge Management, Neural Tree, Ontology

1. INTRODUCTION

Construction industry deals with various kind of diverse information. Information spans engineering data from exact sciences and linguistic or qualitative data from soft sciences. Generally, knowledge is obtained from information in a suitable form for use. Since, knowledge is context dependent, from the same information different kind of knowledge models can be derived where each model has its own merits. The type of knowledge considered in this research is the relations of aspects of concern in a construction process. As to this issue, existing works are rather limited and the approaches are more or less the same. Namely, the taxonomy of information items are prepared in a user friendly software environment and this is considered to be a knowledge model where the management of this weak knowledge becomes rather trivial in the sense that it is subjective, and haphazard in the sense that its consistency cannot be verified. Taxonomy should essentially be considered as information although only in some special cases it can be considered knowledge, as there is no sharp borderline between information and knowledge. In this respect, taxonomy essentially plays the role of information representation. However, this representation has to be structured in such a way that some knowledge is induced out of it. This means the structured information is a source of knowledge from which further knowledge can also be induced. Consequently, information representation can be seen as a help to review the information at hand more conveniently and it may inspire some hints about the way that information should be handled toward knowledge acquisition. In this work, a building constructional taxonomy is considered as structured information which may serve as a knowledge model in a minimal sense. However, the substantial knowledge can be developed by quantifying the relations in this structure, as a *first step*, and developing this structure enhancing its merits in practicality as to construction industry, in the *second step*. In a complex construction environment the knowledge of attribute relations can be used to identify the significance of any component in the consideration of the remaining components under consideration. After the attribute relations are duly determined and a relational data base is desirably established, it is important to know the implications of a modification of any relation in this scheme of knowledge as to the rest of the scheme. In this way the existing knowledge is put in a manageable form since all the pieces of knowledge in the model are presented in perspective quantifying their significance as to the rest. The management is effectively exercised during decision-making process, as much as the construction process needs. The first step mentioned above, is tackled in previous works (Ciftcioglu and Sariyildiz, 2005a, 2005b), applying a general mathematical approach. The method is known as Analytical Hierarchy Process (AHP) which determines the hierarchical priorities of the taxonomic components. The subject matter of the present research is the second step mentioned above, namely enhancing the effectiveness of the AHP method as to construction by a knowledge model. For this aim, a knowledge model is adopted which is used in relation to transformable building structures (Durmisevic, 2006) where the underlying scheme is referred to as *feed-forward knowledge model* since its structure is similar to an artificial feed-forward multilayer neural network structure merely in a feed-forward sense. In the present work, a similar form is adopted where the precise structural form is known as *neural tree* which is additionally combined with the AHP that it serves for knowledge management. The structure of the paper is as follows. Section two briefly explains the AHP for the hierarchical priority assignments to items subject to pair-wise comparison. Section three presents the implementation of the method of AHP in the form of a neural tree which becomes eventually ontology. It serves for the management of the knowledge of construction. Section four exemplifies the use of the knowledge model and this is followed by conclusions.

2. TAXONOMIC RELATIONS IN BUILDING AND CONSTRUCTION

Analytical hierarchy process in brief

The AHP method is a technique developed by Saaty (1980) to compute the priority vector, ranking the relative importance of factors being compared. The only inputs to be supplied by the expert in these procedures are the pair-wise comparisons of relative importance of factors, taken two at a time. This means, in an environment of complex relationships among the variables, one follows the principle of "divide and rule". If we denote the expert input comparing the *i*-th variable with respect to the *j*-th variable by $a_{ij} = w_i/w_j$, then the relative importance of the *j*-th variable with respect to the *i*-th variable is represented as $1/a_{ij} = w_j/w_i$. One notes that, in an environment with high number of complex relations to make a judicious relational assertion is not easy. However, to make a simple comparison between any two attributes and to make a judgment is much easier for an expert. The $[n \times n]$ matrix obtained by arranging these pair-wise comparison ratios is termed the reciprocal judgment matrix and designated as A. where n is the number of factors subjected to pair-wise comparison. The diagonal elements of A matrix are all unity. Since we take the reciprocals, we have to fill the upper diagonal elements which are altogether $n(n-1)/2$. The details of this technique are given by Saaty (1980). A comparison and highlighting its strengths can be found in Saaty and Vargas (1984).

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots\cdots\cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots\cdots\cdots & \frac{w_2}{w_n} \\ \cdots\cdots\cdots & & & \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots\cdots\cdots & \frac{w_n}{w_n} \end{bmatrix} = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots\cdots\cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots\cdots\cdots & \frac{w_2}{w_n} \\ \cdots\cdots\cdots & & & \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots\cdots\cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots\cdots\cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots\cdots\cdots & a_{2n} \\ \cdots\cdots\cdots & & & \\ \cdots\cdots\cdots & & & \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots\cdots\cdots & 1 \end{bmatrix} \tag{1}$$

The principal eigenvector W of ***A*** is computed by solving the eigenvalue problem, which is $AW=\lambda_{max}\ w$ where λ_{max} is the principal or largest real eigenvalue of ***A***. The normalized eigenvector corresponding to λ_{max} is the priority vector P. The beauty of the AHP operation can be appreciated by considering the tolerance of the method allowed during making the expert judgment. That is, some deviations in the expert judgments do not critically affect the final outcome. AHP is applied in many fields up to now, such as the economic analysis, urban or regional planning and forecasting etc, (Vargas, 1990), as well as knowledge model validation (Ciftcioglu, 2003).

Attribute relations in perspective

A number of attributes are involved in a construction process. It is essential to estimate the effect of each attribute to the result to keep the project under control to avoid probable uncertainties on the quality of the outcome. However, this simple statement is not an easy task to accomplish, due to the complexity involved. The complexity mentioned is twofold. Firstly, the number of attributes is generally high so that the number of attribute relations can be explosively high. Secondly, the relations themselves can be complex due to indirect relations, which appear to be seemingly direct. This situation occurs due to the attributes, which are never considered and therefore they are referred to as hidden attributes. The above mentioned complexity issues and associated attribute relations determinations are subject to determination. When these relations are established, they can be used for making a knowledge model, which can be used by an expert for a general use concerning the same categorical design. A firm clue addressing how to tackle this is still an issue due to the very soft nature of the problem. Terminologically, such issues are termed ill-defined problems, which require special treatment for solution. Such soft problems can effectively be treated by the special methods of the exact sciences. The method of interest in this research is the AHP, which primarily provides priorities among the elements by means of their pair-wise comparisons. This method is extended and it is applied for hierarchical attribute relations, the application area being architecture and construction.

Illustrative Example

Consider figure 1, which illustrates the interdependence of building constructional aspects in a construction process. To exemplify the utilization of AHP for the relational attribute determination relations among the structural aspects are considered. In the first step, let us make expert judgment for the structural aspects. The structural aspects are *Loads* (w_1); *Materials* (w_2); *Form and space geometry* (w_3); *Structural design approach* (w_4); *Structural behaviour* (w_5).

Only for illustrative purposes, we might do expert judgments about ratio with general building design considerations as follows:

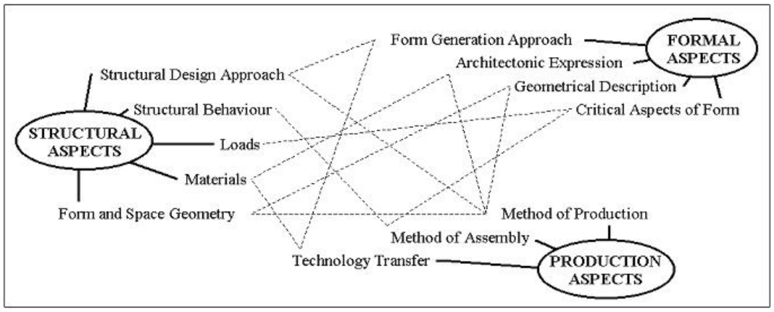


Figure 1: Illustrative description of interdependent relations among the design aspects in a construction process (Ciftcioglu and Sariyildiz, 2006)

$w_2/w_1=0.9$; $w_3/w_1=0.7$; $w_4/w_1=0.5$; $w_5/w_1=0.7$;
$w_3/w_2=0.8$; $w_4/w_2=0.5$; $w_5/w_2=1.0$;
$w_4/w_3=0.9$; $w_5/w_3=1.2$;
$w_5/w_4=1.5$;

The rationale about these ratios is due to expert judgment. Based on the expert ratio judgments given above, the reciprocal judgments altogether are shown in Table 1.

Table 1. Reciprocal ratios of expert judgments for the attribute relations among *Structural Aspects* attributes.

	Loads	*Material*	*FSG*	*SDA*	*SB*
Loads	1	1/.8	1/.8	1/.5	1/.7
Material	.8	1	1/.8	1/.5	1
Form and space geometry(FSG)	.8	.8	1	1/.9	1/.9
Structural design approach(SDA)	.5	.5	.9	1	1/1.5
Structural behavior(SB)	.7	1	.9	1.5	1

The reciprocal ratio judgment matrix, then, is given by

$$A = \begin{bmatrix} 1 & 1/.8 & 1/.8 & 1/.5 & 1/.7 \\ .8 & 1 & 1/.8 & 1/.5 & 1 \\ .8 & .8 & 1 & 1/.9 & .9 \\ .5 & .5 & .9 & 1 & 1/1.5 \\ .7 & 1 & .9 & 1.5 & 1 \end{bmatrix} \tag{2}$$

The largest eigenvalue $\lambda_{max}=5.03$ and the corresponding priority vector is

$$\begin{array}{lccccc} & \textit{Loads} & \textit{Material} & \textit{FSG} & \textit{SDA} & \textit{SB} \\ p^T = & [0.262 & 0.224 & 0.187 & 0.134 & 0.193] \end{array} \tag{3}$$

Another essential property of AHP method is the inbred consistency check in the method. Namely, for fully consistent expert judgment λ_{max} the same as the number of variables is being considered. In the above illustrative example the number of variables is $n=5$, and the largest eigenvalue is $\lambda_{max}=5.03$, which indicates the almost ideal consistency of the judgments, though this is a mere illustrative example

From Taxonomy to Ontology

For this study, we consider *loads, material,* and *form* as **structural aspects** and *form generation*, *architecture*, and *geometry* as **formal aspects**. This is illustrated in figure 2.

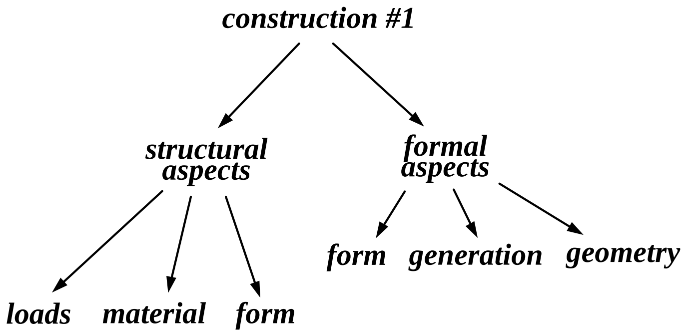


Figure 2. Indirectly related structural aspects and formal aspects attributes; the weights to be attached to the arrows are subject to determination by AHP.

The expert judgment ratios for structural aspects are asserted as

$w_2/w_1=0.5;\ w_3/w_1=0.6; w_3/w_2=1.2$

giving the expert judgement ratio matrix as

$$A=\begin{bmatrix} 1 & 1/.5 & 1/.6 \\ .5 & 1 & 1/.2 \\ .6 & 1.2 & 1 \end{bmatrix}$$

and the same ratios for formal aspects are asserted to be

$w_2/w_1=1;\ w_3/w_1=1.4; w_3/w_2=1.75;$

giving the expert judgement ratio matrix as

$$A=\begin{bmatrix} 1 & 1 & 1/1.4 \\ 1 & 1 & 1/1.75 \\ 1.4 & 1.75 & 1 \end{bmatrix}$$

so that ,the corresponding priority vectors are computed as

$$p^T_{structural} = [.327\ .167\ \ .231\ \ \ .275]$$
$$p^T_{formal} = [.291\ .270\ .439]$$

The relational matrix $R_{structural \to formal}$ as to from safety to comfort is computed from

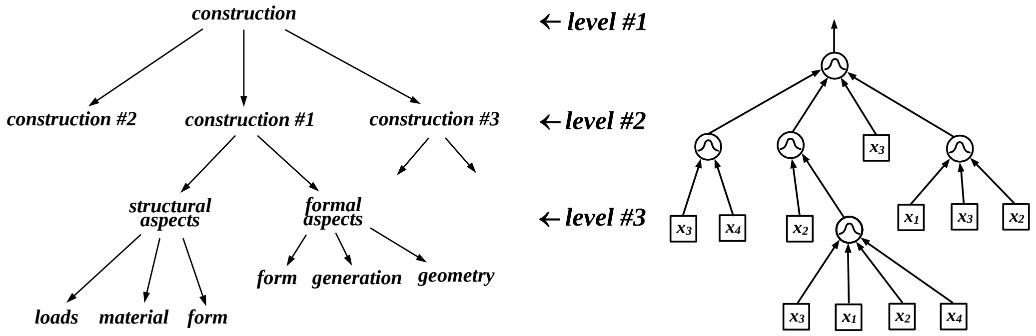
$$R_{structural \to formal} = p_{structural} \times p^T_{formal} =$$

$$\begin{bmatrix} .327 \\ .167 \\ .231 \end{bmatrix} \begin{bmatrix} .291 & .270 & .439 \end{bmatrix} = \begin{bmatrix} 0.0952 & 0.0883 & 0.1436 \\ 0.0486 & 0.0451 & 0.0733 \\ 0.0672 & 0.0624 & 0.1014 \end{bmatrix}$$

In the same way, the relational matrix $R_{formal \to structura}$ from formal to structural aspects is computed from

$$R_{formal \rightarrow structural} = p_{formal} \times p^{T}_{structural} = \begin{bmatrix} .291 \\ .270 \\ .439 \end{bmatrix} \begin{bmatrix} .327 & .167 & .231 \end{bmatrix} = \begin{bmatrix} 0.0952 & 0.0486 & 0.0672 \\ 0.0883 & 0.0451 & 0.0624 \\ 0.1436 & 0.0733 & 0.1014 \end{bmatrix}$$

In the above example the bi-directional relations between the components of safety and comfort aspects are established. From construction technological viewpoint these relations are of high importance. It is clear that the computations can be extended to any complexity. Such an extension is illustrated in figure 3a.



(a) (b)

Figure 3. Structural aspects and formal aspects attributes as part of a taxonomy of a construction process (left); The structure of a neural tree (right); the weights to be attached to the arrows are subject to determination, for instance, by AHP.

3. NEURAL TREE AS KNOWLEDGE MODEL

A 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 $T=\{x_1,x_2,...,x_n\}$.where x_i is the *i-th* component of the external input vector ***x.*** The input ***x*** is connected to a node via a radial basis function provide an output for this node which is given by

$$f(x) = w_j \, \phi(\| x - c_j \|) \qquad (4)$$

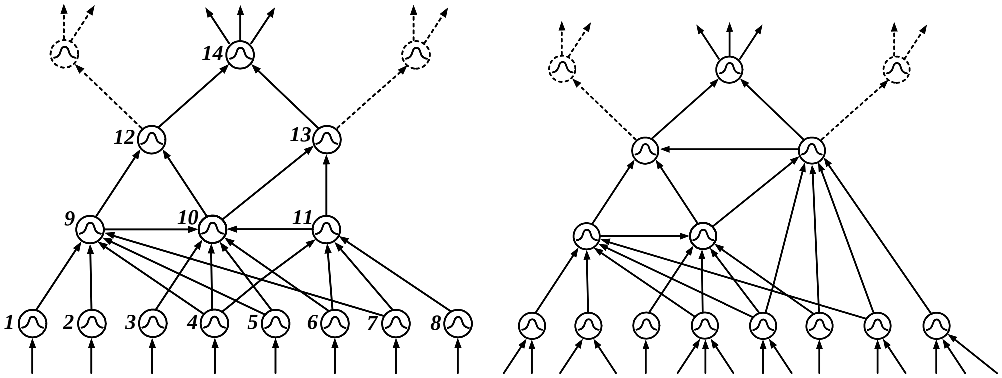
where $\phi(.)$ is the basis function, c_j is the centre of the basis function; w_j is the weight connecting the output of the basis function to the a terminal node in the form of an external input. c_j determined as a component of a priority vector and equal to w_j. Among several radial-basis functions,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

$$\phi(r) = \exp(-\frac{r^2}{2\sigma^2}) \qquad (5)$$

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***. An instance of the neural tree is shown in figure 4b. 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.

Two different configuration of the neural tree involved in this research are shown in figure 4a and 4b. Taking figure 4a as a particular example subject to analysis, we number the nodes to fix and trace the relations. The lowest level has 8 nodes. The immediate upper level has 3 nodes, which is followed by a layer with two nodes. The lowest level is a particular level since al the nodes have only a single input in this isolated configuration. We assume that they are stemming from fictive a layer that we can call it as zero-th level. If some inputs from the zero-th level are related through a priority vector, the inputs are equal to the components of this vector. Otherwise the inputs are equal to one. Considering the connections in figure 4, we can establish the matrix as shown in Table 2. This matrix is called *knowledge matrix*. One can easily note that, the knowledge matrix contains all the information exhibited by structure in figure 4a. The weights in figure 4 are the same weights to be determined by the AHP as indicated in figure 2. In this form, all the relations determined by AHP are represented in the neural tree form. In table 2, the relations are designated as the information flow from the horizontally enumerated nodes to vertically enumerated ones. Therefore the first column of weights contains eight values in a general case. Some of them may have a value as 1 if these inputs are not correlated with any others. Each weight is indexed with a number next to it. The index indicates the node to which an input is applied via the weight. In the example in figure 4a, there are 14 weights. The positioning of the weights in this figure forms the knowledge matrix given in table 2.



(a) (b)

Figure 4. Some possible structures of a neural tree with general connection schemes: starting from very first nodes (a) and a general scheme with cascade connections (b); the weights to be attached to the arrows are subject to determination, for instance, by AHP.

Table 2. Knowledge matrix.

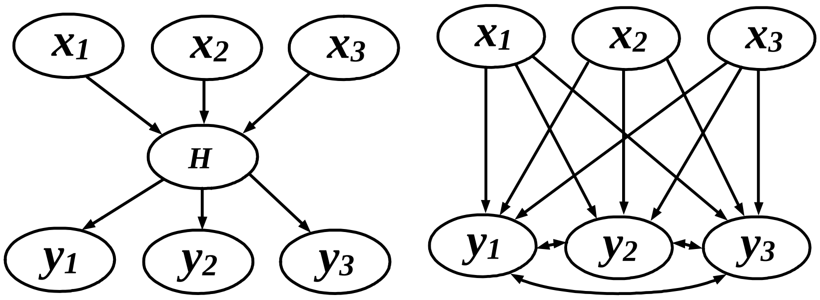
node	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	w1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	w2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	w3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	w4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	w5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	w6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	w7	0	0	0	0	0	0	0	0	0	0	0	0	0	0

8	w8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	w1	w2	0	w4	w5	0	w7	0	0	0	0	0	0	0
10	0	0	0	w3	w4	w5	w6	0	w9	0	w11	0	0	0	0
11	0	0	0	0	w4	0	w6	w7	w8	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	w9	w10	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	w10	w11	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	w12	w13	0

In table 2, the nodes are numbered in a hierarchical order in a feed-forward structure and each row in the table corresponds to the inputs attached to this node. In the case of any change of relations via the change of any weight in the neural tree, the inputs towards to the upper nodes change also. Before the weight change, these inputs are simply the associated weights. After a weight change, the upper weights relative to this node inputs in the tree structure are modified as the product of the weight and the associated basis function output which is originally 1, as mentioned earlier. In this way the implications of a weight change throughout the total net is established and the new relations can be computed as described in preceding section. One can note that, the weight values are always smaller than or equal to one that they comply with the requirements of being smaller than one as to the normalized priority vector elements.

One interesting feature of the knowledge model is the attribute relations as they can be interpreted in terms of fuzzy logic (Zadeh 1965, 1973), where the Gaussian membership functions play the role of membership functions. The important implication of fuzzy logical aspect of the computation is that the uncertainties and/or imprecision in the attribute relations are well taken care of with the elicitation of more precise outcomes.

Another interesting feature is the explicit consideration of the hidden variables, in the model. This is illustrated in figure 5, which is a knowledge model, where the dependent variables are y_1, y_2 and y_3 and the independent ones are x_1, x_2 and x_3. If the dependency is via a hidden variable shown as H in the figure, the model is represented by 6 relations in figure 5a. If the hidden variable is not considered, then the model has to be represented by 12 relations in figure 5b considering all possible relations although the relations among the dependent variables supposedly do not exist. This means, it implies some futile complexity in the model of this illustrative example case. In the knowledge model presented in this work and illustrated in figure 4, such situations are also circumvented.



(a) (b)

Figure 5. Illustration of modelling attribute relations with a hidden variable (fig. a) and without a hidden variable (fig. b)

4. IMPLEMENTATION OF THE MODEL

A knowledge model is developed for knowledge management and implemented for the analysis of a construction process. The particular aspect subjected to analysis in the present framework is referred to as *transformation capacity* (Durmisevic, 2006). In basic terms, it is defined as the potentiality of a building for transformation. This is directly related to the sustainability of the building with extended life cycle. The important feature of this concept is the possibility of effective decision-making in a construction process while decision-making on a complex building technological issue is boiled down a single parameter expressed in fuzzy logic terms. In the model, the total knowledge about the sustainability of a given construction is represented. After the knowledge model formation, the effect of changing the construction-related information is investigated by means of several test cases as to the transformation of the construction. In this way the effect of particular construction information on the construction itself is identified while the other constructional information items are inherently taken into account in this identification process.

Another application of the knowledge model is exercised using the available data (Durmisevic, 2002) on a metro station as to the effectiveness of this utility from the users' viewpoint. In this case the knowledge model contains the relevance of various design items and reveals the significance of any design variable change with respect to the other variables and ultimately the functionality of the station. The latter research is briefly reported before (Ciftcioglu and Sariyildiz, 2005b) as an application of information processing in a framework of decision-making process where AHP was central to that research. In the present research, the same application is considered in a framework of knowledge management, i.e. positioning the significance of each design variable in a taxonomic structure. In this form the present research presents ontology of a construction process particularly meeting the demand of knowledge management in the relevant project execution.

To illustrate the implementation of the model, we consider the interdependent structure shown in figure 1. We are aiming for to establish a relational knowledge model where the formal aspects are one side and both structural aspects and production aspects are at the other side. Among the formal aspects, we are interested in the *form generation approach* aspect and wish to model how both structure and production affect the formal aspects altogether via the aspect of *form generation approach*. The scheme is illustrated in figure 6. The structural aspects are represented by w_1, w_2, w_3, w_4, and w_5 which are given by (3) as $0.26, 0.22, 0.19, 0.13$ *and* 0.20. In the same way we assume that production aspects which are represented by w_6, w_7, w_8, are computed by means of the reciprocal ratio judgment matrix and found to be $0.30, 0.50$ and 0.20, respectively. With the same procedure, we assume that, w_9 and w_{10} are given by 0.4 and 0.6; w_{11}, w_{12}, w_{13} *and* w_{14} are found to be $0.2, 0.1, 0.3$ *and* 0.4 respectively. Referring to (4), for this scheme we write $w_1=c_1, w_2=c_2; w_3=c_3, w_4=c_4$ and $w_5=c_5$. In the same way $w_6=c_6, w_7=c_7$ and $w_8=c_8$. The centres c_9 and c_{10} are given by $c_9=m_1w_9$ and $c_{10}=m_2w_{10}$ where

$$m_1 = \frac{o_1}{o_1 + o_2} \quad , \quad m_2 = \frac{o_2}{o_1 + o_2}$$

Initially, $o_1=o_2=1$, so that $m_1=m_2= 0.5$ and consequently

$c_9=0.5w_9=0.2$ *and* $c_{10}=0.5w_{10}=0.3.$ (6)

Now, we assume that among the structural aspects, the material aspect for some reason has changed from $w_2=0.22$ to $w_2'=0.15$ while the other structural aspects remained the same. In the same way we assume that one of the production aspects changed from $w_7=0.5$ to $w_7'=0.3$, while the other structural aspects remained the same.

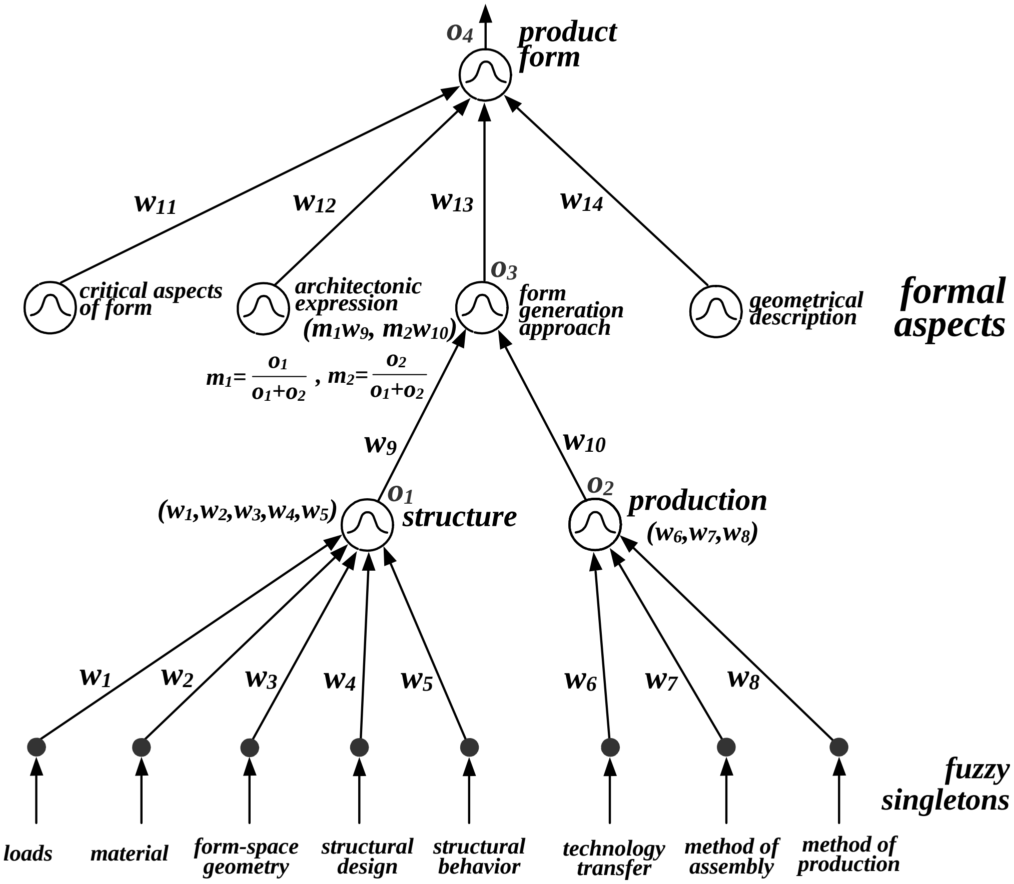


Figure 6. Illustrative example for computing the relational attributes of *product form* in connection with *structure* and *production* aspects

We can compute the effect of these changes on the formal aspects as follows: Using

$x_1=c_1=0.26;\ x_2=0.15,\ c_2=0.22;\ x_3=c_3=0.19;\ x_4=c_4=0.13;\ x_5=c_5=0.20$
and taking the width parameter as σ**=0.2**, from (4) we obtain

$f(x)=o_1=0.95,$

and using $x_6=c_8=0.3;\ x_7=0.3,\ c_7=0.5;\ x_8=c_8=0.2$ in (4), we obtain

$f(x)=o_2=0.74$

Correspondingly

$$m_1 = \frac{o_1}{o_1 + o_2} = \frac{0.95}{1.69} = 0.56 \quad , \quad m_2 = \frac{o_2}{o_1 + o_2} = \frac{0.74}{1.69} = 0.44$$

$$m_1 w_9 = 0.56 \times 0.4 = 0.22$$

$$m_2 w_{10} = 0.44 \times 0.6 = 0.26$$

Considering that $c_9=0.5w_9=0.2$ and $c_{10}=0.5w_{10}=0.3$ as given above, and using $c_9=0.2$, $c_{10}=0.3$, as given by (6) and $x_9=0.22$ and $x_{10}=0.26$ as computed above, from (4), we obtain $f(x)=o_3=0.51$.

$$o_3 w_{13} = 0.3 \times 0.51 = 0.153$$

so that the formal aspects which are originally given by $w_{11}=0.2$, $w_{12}=0.1$, $w_{13}=0.3$, $w_{14}=0.4$ take the new values as

$w_{11}'=0.23$, $w_{12}'=0.12$, $w_{13}'=0.18$, $w_{14}'=0.47$ due to the changes on w_2 from 0.22 to 0.15 and w_7 from 0.5 to 0.3, as described above. Above, for example w_{11}' is computed from

$$w_{11}^{'} = \frac{w_{11}}{0.2 + 0.1 + 0.153 + 0.4} = \frac{0.2}{0.853} = 0.23$$

and in the same way we obtain,
$w_{12}'=0.1/0.853=0.117$, $w_{13}'=0.153/0.853=0.178$, $w_{14}'=0.4/0.853=0.469$.

The computational results are indicated in figure 7.

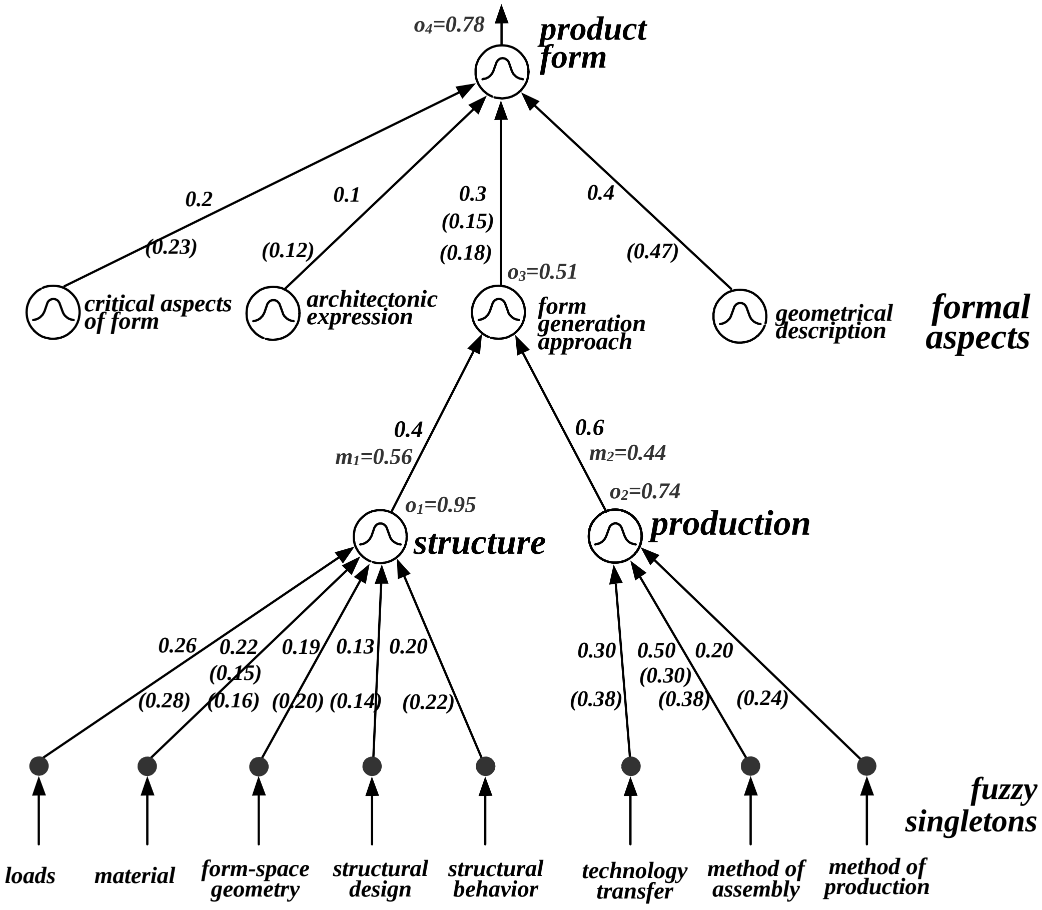


Figure 7. Illustrative example for computing the relational attribute alterations due to change of *material aspect* in the *structure* and *method of assembly* aspect of *production*; the numbers in the brackets at the lowest rows are the final modified weights

The illustrative example above indicates how certain decisions in structural aspects and production aspects affect the formal aspects, which are obtained by computation and not by human assessment. The computations are carried out in a straightforward way for any complexity of the scheme, while such objective assessments of the implications in such a complex scheme are beyond comprehension for a human expert or actors dealing with the process. In the case of determining the transformation capacity of a building one should calculate also o_4 in figure 6. With the present numbers $o_4=0.78$ as indicated in the figure. However, figure 6 six is not meant for transformation capacity calculation, and therefore the output o_4 is out of interest in the present relational attribute determination.

5. DISCUSSION AND CONCLUSIONS

Considering the rich information environment in the construction technological areas, to deal with this information is an essential task. The AHP provides a systematic approach especially converting this information to partial construction knowledge in the form of attribute relations. AHP has deep implications in the construction technology and the counterpart industry. This includes also the way of integration of intelligent technologies into the construction technologies. In this work, AHP is especially implemented for modelling hierarchical attribute relations as novel implementation in construction. The model is developed in the form of neural tree, where the nodes in this structure are represented by artificial neurons. This is essentially a taxonomic structure having detailed description. The mathematical representation of the knowledge model, that is, the weights among the nodes are contained in a matrix, which is referred to as knowledge matrix. The knowledge matrix having been determined by AHP, the final form of the knowledge model is established via the basis function centres of the nodes. For the detailed description process, the method determining the bilateral relations among the aspects and their sub-components is presented above with illustrative examples. By means of this, the taxonomic structure is converted to ontology for the purpose of knowledge management. The main goal of knowledge management is to assess the relations among the various construction process components and to assess the significance of each component during the presence of others. For instance, if the presence of one component is found to be insignificant, this component can be omitted for the sake of any convenience; say, convenience of cost, for instance. This simple example clearly hints the nature of the knowledge management activity in a construction process; namely, the knowledge management is about decision-making and successful management can be exercised by means of proficient ontology developed for this purpose. The taxonomic structures without ontological elaborations cannot serve for essential issues of construction since these issues are complex enough beyond taxonomic comprehension. It is noteworthy to mention that, the method of ontology presented in this work works with fuzzy logic concepts to absorb the uncertainties and imprecision of the construction information thereby enhancing the integrity of the decision-making. This is accomplished by using Gaussian radial basis functions at the neural tree nodes where the representative centres are defined by the key knowledge at hand as to the construction in question. The paper presents the development of this knowledge model leading to a knowledge management tool in the form of ontology to cope with the heavy demands which do occur in a construction environment.

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