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FUZZY SIGNATURE BASED MODEL FOR QUALIFICATION AND RANKING OF RESIDENTIAL BUILDINGS

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ABSTRACT

At the end of the 19th and at the beginning of the 20th centuries Budapest the capital of the Hungarian kingdom underwent a significant development. During this period the number of inhabitants of the city multiplied, as a consequence several new city districts were constructed. The functional and structural arrangement of these new residential buildings was very similar in respect of the materials used and the technologies applied. A considerable part of these buildings still constitutes the determining element of the townscape. It is one of the most burning issues of the present day Budapest that a part of these buildings are in very bad condition. Due to the limited financial resources it is an essential task to set up priority ranking of the renovation, upgrading and renewal of buildings with similar arrangement. In our case the traditional (two-valued) logic is unsuitable for modelling or handling the given phenomenon. When describing the status of a load-bearing building structure the terminology of "appropriate condition" cannot be handled by Boolean logic, since it cannot be strictly determined where the borderline is between appropriate or inappropriate condition. In the case of the majority of the linguistic characteristics of this type there is a well noticeable joint element, which expresses a kind of inaccuracy or uncertainty. For such tasks the application of fuzzy signatures is considered to be one of the possible solutions. The fuzzy type inaccuracy somehow links with human

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thinking. Fuzzy logic is an extension of the two-valued logic, which makes it possible to define transitions, too. By applying the fuzzy singleton signatures a status-determining and ranking model was created, which is suitable for the qualification and ranking of buildings of similar age and structural arrangement. This model was used for the first time on a database, which is based on expert opinions, relating to a given stock of residential building. The modelling of the load-bearing structural condition of the residential buildings is a complicated task, the components whereof are well-structured and a hierarchical structure can be built therefrom. Based on the foregoing a tree-structure, necessary for the examination of the load-bearing structures of buildings, has been proposed. In this framework primary and secondary structures were distinguished during the examination, which would be linked with qualification values based on their arrangement, materials and conditions (in accordance with fuzzy logic). The significance of the load-bearing structure of various building elements was taken into account by using relevance weights. For the aggregation of the fuzzy singleton signature the Weighted Relevance Aggregation Operation (WRAO) was used. The aggregate status descriptors, characteristic of the status of a building, provided the basis for the ranking of buildings in case of a certain stock of buildings. Discrepancies of the results achieved by method using membership functions of approximate and fine set of values, conclusions were drawn as to when and which method should be used in practise. The results of this study may make it easier to realize rehabilitation ideas of similar residential areas, and also can be efficiently used during utilization and renewal of certain buildings in bad condition.

Key words: Building Diagnostics, Structural Deteriorations. Fuzzy Signatures.

Introduction

From 1867 through the outbreak of the First World War (1914) was far the most dynamic period of development in the history of Budapest. In many respects the development of the city of Budapest was different from other metropolises of the world, since the town developed into a metropolis over a period of some decades only. During this short period of time the number of inhabitants increased from 280000 to 733000 by 650,000, and simultaneously 153000 flats were built. Over the course of some decades lots of new residential districts were erected, of course with the application of the structural and technological methods, which were known at that time. Most of the residential buildings, built at the end of the 19th and the beginning of the 20th centuries still exist, and are determining elements of the current townscape. The structure, material, age and the conditions of a considerable part of these buildings are similar.

It is one of the most burning issues of Budapest that a certain part of the buildings, built in this age, is in very bad condition. Static, functional and social deterioration can be observed in a considerable part of more than 100 years old buildings. Renewal and modernization of the similar buildings, which are in rather bad condition, and

their ranking from the aspect of the urgency of their renewal, are an important task due to the narrow financial circumstances. To be able to decide on the necessity of the intervention, standard parameters of the buildings (structural arrangement, materials) must be taken into account. At a given point of time the variable parameters (various impairments) can be identified by diagnostics using visual checking. Each residential building can be linked with a set of data, the data elements whereof can be organized into a hierarchical structure. Having collected all the constants and variables, necessary for drawing the conclusions, it becomes possible to assess and rank the quality of a stock of buildings. For this purpose one of the possible solutions is to apply the fuzzy singleton signature. Using the fuzzy singleton signature a model was created to determine and rank the condition, which is suitable for qualifying and ranking a stock of buildings of similar age and arrangement. The application of the method has been demonstrated through the examination of a given stock buildings. The database has been created by processing a reliable and independent set of data, based on several hundreds of official expert opinions. The reviewed residential buildings are located in the 13th district of Budapest (FIG 2).
A considerable part of the current stock of residential buildings in Budapest (FIG 1) was built simultaneously with these buildings, their age, structural arrangement and condition are similar, therefore the examination and diagnosis of the structures and failures of these buildings can be used for drawing conclusions about similar buildings, which are in other parts of the capital. With the elaborated method a stock of buildings can be examined. The examinations provide help to implement an optimal division of the economic resources, which can be used for the renewals. The ranking method based on the fuzzy singleton signature uses such a modern sub-technology, by which more significant results can be achieved, as compared to the traditional statistical methods. The elaborated model is suitable for determining the overall status of the structures of the residential buildings, as well as for ranking the stocks of buildings on the basis of the qualification of the condition of structures.

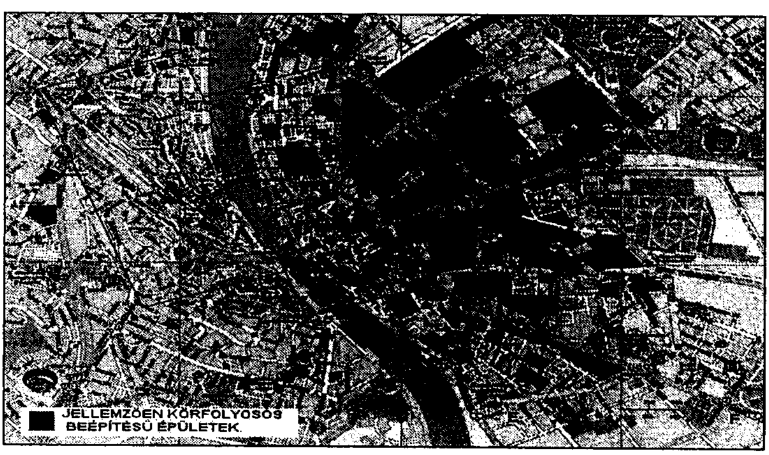

FIG 1. Areas in Budapest including buildings, similar to those under review

FIG 2. Location of the stock of buildings under review

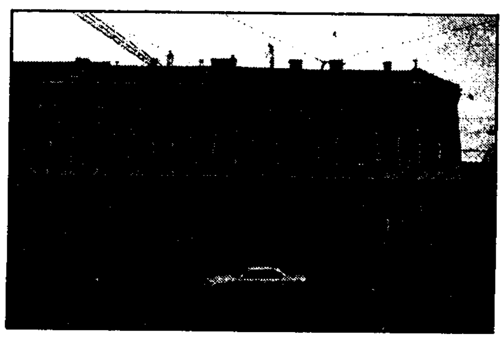

FIG 3. Some of the examined buildings

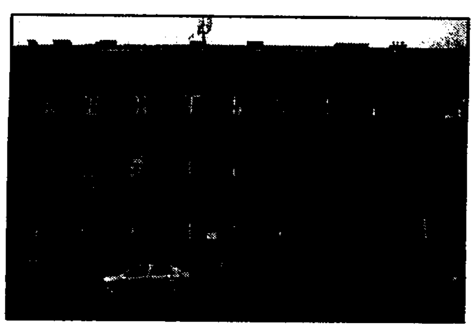

FIG 4. Some of the examined buildings

Set-up of the basic structure of fuzzy signature

A model, based on fuzzy singleton signatures was used to determine the condition of buildings. Fuzzy logic, as the extension of the two-valued logic, is suitable for characterizing certain structures of a building, and the conditions thereof. For modelling purposes, initially the basic structure of fuzzy singleton signature, featuring the problem was set up on the basis of the data available from the prepared data base.
Fuzzy member values, which can be used in the system, were determined for the individual data elements. It is a requirement towards the fuzzy singletons, situated on the leaves of the structure, to have their values within the interval of [0,1].
When using the qualifying and ranking method, based on the fuzzy singleton signature, the examined main load bearing structures are collectively named as „primary" structures. These are as follows: foundation structures, wall structures, floor structures, side corridor structures, step structures, roof structures. „Secondary" structures are those other (not main load-bearing) structures, which play an important role in the protection of the main load bearing structures. These are as follows: roof covering, surface formation, tin structures, insulation against soil moisture and ground water. The applicability of the elaborated method is demonstrated by using the created database, which contains multi-storey residential buildings (FIG 3 and 4).
Since the database was prepared on the basis of the examination of numerous residential buildings, characteristic of Budapest, the results achieved, well reflect the actual conditions – in case certain boundary conditions are satisfied. As the basic structure a four-level fuzzy signature was applied, since in the course of the examination of the stock of buildings this depth was considered necessary to achieve appropriate accuracy in defining the condition. The information available about the condition of the structure of the buildings in Budapest, providing the basis for the database, was divided into two main groups. These traits provide the first level of the basic structure of fuzzy signature. (□11, □12 in FIG 5)
Further levels of the basic structure and the whole set-up of the fuzzy singleton signature in the format of tree-structure are demonstrated in Figure 5, and in vector format in FIG 6. Vector format images illustrate the structure as vectors embedded in one another, while in case of tree-structure format each embedded vector is described by a sub-tree of the tree structure (FIG 5).

$$S^T = [[\mu_{1111}\ \mu_{1112}\ [[\mu_{11211}\ \mu_{11212}\ \mu_{11213}]\ \mu_{1122}\ \mu_{1123}]\ \mu_{113}]\ [\mu_{121}\ [\mu_{1221}\ \mu_{1222}]\ \mu_{123}\ \mu_{124}]] \quad (1)$$

When computing, a partial group of variables together defines a trait at a higher level. Thereby additional information can be stored with the help of the structure. Taking into account the structure a more effective comparison of the data, structured in this manner, can be performed based on various viewpoints.

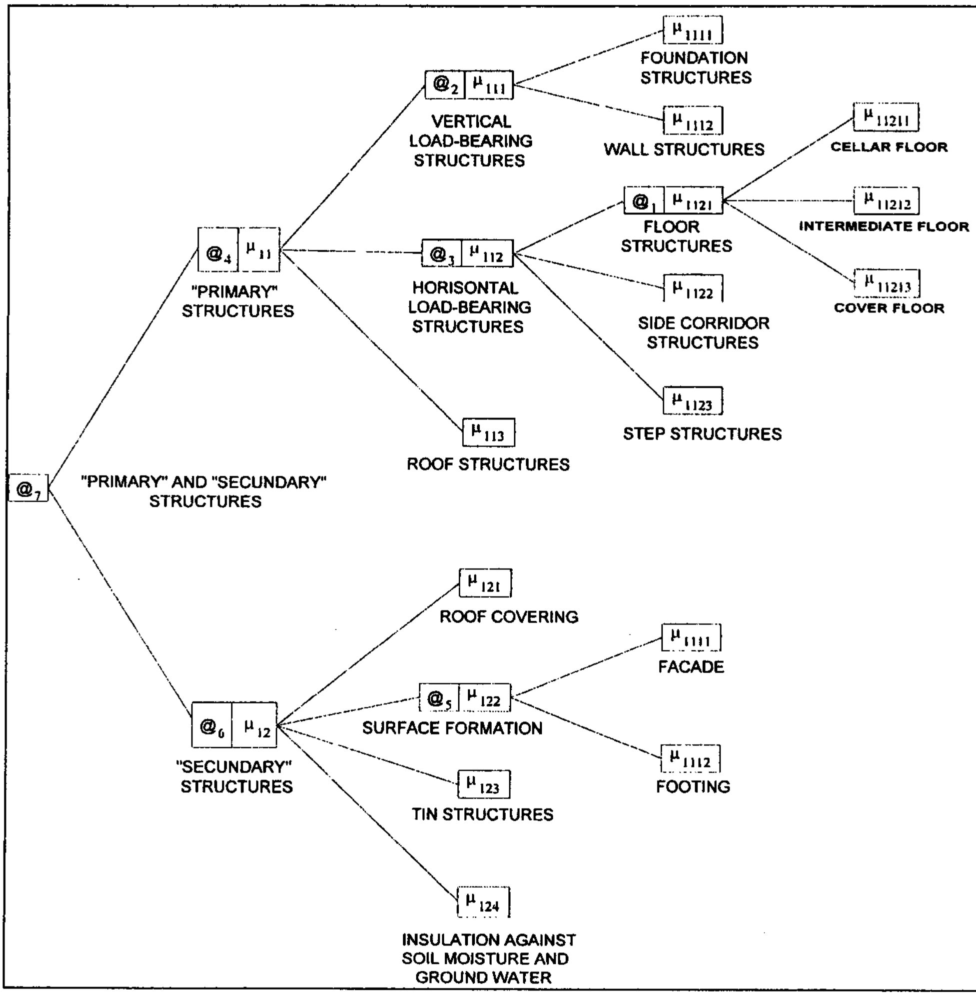

FIG 5. Set up of fuzzy singleton signature structure in the format of tree structure

Definition of relevance weights and aggregation operators

In the application of fuzzy singleton signatures the sub-groups of variables together determine a component on a higher level. Therefore the components within the sub-trees of the structure may relate to the roots of the sub-trees in a way unlike the components of other sub-trees relate to their respective roots. Hence dissimilar aggregation operators should be assigned to each peak of the fuzzy singleton signature structure. The aggregation operators play an important role in the comparison of two signatures, since it might be necessary to modify the structures, and the values appearing on the leaves of the modified structure largely depend on this operator.

When reducing the sub-trees, the loss of information will inevitably occur, since the aggregate status descriptors may be equal to one another even if the sub-tree has different arrangement and information contents. Weighted aggregation makes possible to take into account further expert knowledge in the model. The relevance weight, connected to each peak of the signature, shows the relevance of the peak, related to the root of the sub-tree.

The relevance weights and the aggregation operators were defined based on professional and observation experience, and on the basis of the relevance of the structure related to the whole building. The sensitivity of the structure, the impact thereof exerted on the other load-bearing structures, possible consequences of the deterioration, as well as the costs and complicacy of the elimination of the deterioration thereof were taken into account, too. In the course of further research it may become possible to change the sensitivity of the relevance weights and the aggregation operators. Thereby such studies can be performed, where special attention is paid to certain structural elements or the deteriorations.

For the aggregation The Weighted Relevance Aggregation Operator (WRAO) was used of the fuzzy singleton signature (Mendis 2006).

$$@(\mu_1, \mu_2, \ldots, \mu_n; \varphi_1, \varphi_2, \ldots, \varphi_n) = \left(\frac{1}{n} \sum_{l=1}^{n} (\varphi_l \cdot \mu_l)^p \right)^{\frac{1}{p}}, \tag{2}$$

Notations used in the formula: @: WRAO function, : value of successor l, φ: relevance weight of successor l, n: number of successors of the junction to be aggregated, p: aggregation factor (p Є R, p ≠ 0) Value of the aggregation factor (p) is φ1 within the applied WRAO function. Relevance weights were selected after the assessment of the related specialised literature and the studied expert opinions. The value of the relevance weights can be changed in accordance with the traits of the given test group. Using the aggregation operators it is possible to modify the structure of the fuzzy signatures. In such a case a sub-tree of the variables is reduced to the root of the sub-tree. One of the recursive processes of the model can be seen on FIG 7. To reduce the sub-tree with root φ1 first of all the sub-tree, marked φ12 must be reduced. Using the value, obtained in this way, the root, marked by φ1, can be reduced, too.

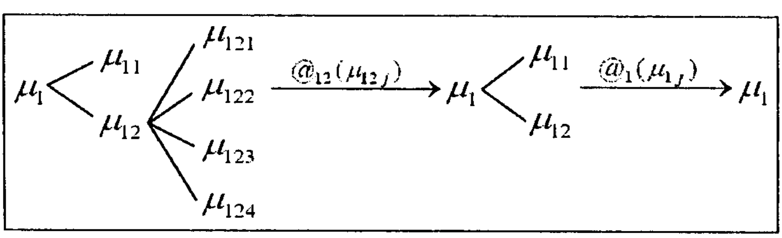

FIG 7. Recursive process

The aggregation operators to be used were defined by using the relevance weights and the values on the root of the structure. For example the aggregation operator, related to the floor structure, is given for the following value where m is the extent of the cellar built, n is the number of the storeys of the building.

$$@_1 = \frac{0{,}35 \cdot m \cdot \mu_{11211} + 0{,}45 \cdot (n-1) \cdot \mu_{11212} + 0{,}20 \cdot \mu_{11213}}{0{,}2 + 0{,}45 \cdot (n-1) + 0{,}35 \cdot m}, \tag{3}$$

Software

The software, prepared on the basis of the fuzzy singleton signature, serves the aim of defining the condition of multi-storey buildings of similar condition and age, and the ranking thereof. The input data related to the building are constant on the one part (formation of the building, applied structures, applied materials), on the other part they alter in terms of time (condition of the structure, appearance and extent of cracks, extent of the corrosion) With the help of the software the building and the set of buildings were examined in two ways, using the normal tuning and the fine tuning method. Input data are less detailed with the normal tuning method, than in the case of the fine-tuning method, and the output results give only approximate gradation.
The aim of ranking is to define the current status of the buildings, as well as to define their future and the utilisation thereof (suggested for demolition, suggested for renewal, renewal is necessary, but not immediately). For each member of the examined stock of buildings a value can be computed which refer to the quality of the residential building. Values fall in the interval of [0,1]. Based on this ranking a more mature decision can be made as to what can be done on the building.

Application of the model in the database under review

The database was studied with the fuzzy singleton signature based software. With its help useful information can be obtained on the condition of various structures and their relationship to one another. The values of the aggregate status descriptor μ1, related to the condition of the buildings, were computed with the help of the software. The results, achieved with the computation completed in the case of the normal tuning method, are demonstrated on FIG 8.
Studying the diagram the following findings can be made:
If the method is used the value of φ1 summarized aggregate state descriptor does not achieve the value of 0.3 in 17.65 % of the tested cases, which means that the status of the tested structures of the building is qualified inappropriate. In 80.88 % of the cases value φ1 is between 0.3 and 0.7, in this particular case the condition of the tested structures are qualified as appropriate. It occurs only in 1.47 % of the cases that the condition of the structures is qualified good. In this case the value of φ1 summarized aggregate state descriptor is greater than 0.7. From the proportions obtained it can be

established that a considerable part of the examined stock of buildings is in need of renewal, partly due to the omission of former conservation and the renewal works.
The stock of buildings was tested with normal and fine tuning methods, too. Examining the results it was determined that the value, relating to the quality of the condition of buildings was different to a minimum extent in the case of the two methods.

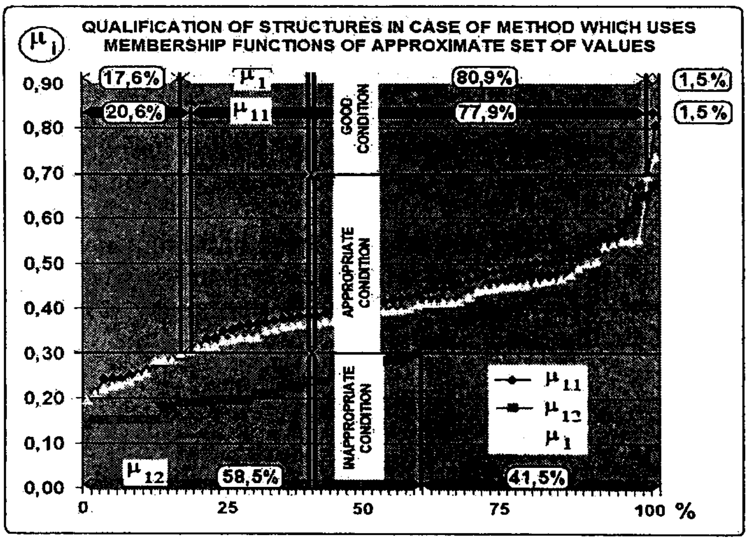

FIG 8. Qualification of structures in case of normal tuning method

From the foregoing it can be concluded that in the tests it is characteristically enough to use the normal tuning method and it is necessary to use the fine-tuning method only in special cases. Using the fuzzy singleton signature-based model it is possible to make a proposal for urgent interventions in order to avoid rapid deterioration of the condition. It is practical to start the renewal works without delay if the condition of the main load-bearing structures can be considered relatively good, at the same time the condition of the secundary structures, protecting the same is strongly deteriorated.
In such cases the „secondary" structures are unable to protect the „primary" structures from deleterious effects. Primarily those specialised industrial structures must be renewed which protect the load-bearing structures. Our further aim is to compile an urgency ranking (suggested ranking of interventions) on the basis of the database, too.
First of all it must be determined in which case of the summarised aggregate status describing values, related to $\varphi 11$ primary structures it is reasonable to check the summarised condition of the "secondary" structures. Following the study of the database it is suggested that in the case of the $\varphi 11 \geq 0{,}4$ summarised aggregate status describing value to check if it is necessary to perform rapid intervention.

In such a case the condition of the main load-bearing structures is good enough for an intervention, taking into account economical viewpoints and in order to avoid (prevent) any eventual accidents at a later time. It was necessary to define that range of φ12 summarised aggregate status describing value where it is practical to perform intervention. Rapid renewal of the "secondary" structures of a building is reasonable when $\varphi 11 \geq 0{,}4$ and $\varphi 12 \leq 0{,}3$ or $\varphi 12 - \varphi 11 \leq -0{,}2$.

Conclusion

The fuzzy singleton signature based model is suitable for evaluating and ranking of traditional residential buildings of Budapest, so that the tested buildings are qualified on the basis of their respective condition, and are ranked based on the qualification values. Important conclusions can be drawn with regard to the condition of a given stock of buildings.

Experiences gained through the examination of these buildings may be very helpful in the preparation of rehabilitation works of similar buildings, which can be found in other areas of Budapest. The results of this study may make it easier to realize the rehabilitation ideas of similar residential areas.

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