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Using of Artificial Neural Networks in Support System of Forensic Building-Technical Expertise

Petro Kulikov, Roman Pasko, Svitlana Terenchuk, Vitalii Ploskyi, Bohdan Yeremenko

***Abstract:** The article contains an analysis of the order of forensic building-technical expertise and expert research to determine the reasons for the deterioration of the technical condition of the structural elements of buildings. The conditions for forming expert conclusions about the possible correlation between the appearance of negative changes in the technical condition of the structural elements that have become the subject of forensic building-technical expertise and the various factors of influence of the environment are investigated. In doing so, the focus is on the impact factors associated with carrying out renovation work in adjacent premises. In addition, issues related to the fuzzy uncertainty of the different nature of the expert researches are highlighted. Some of these problems are proposed to be solved by the using of artificial neural networks in the fuzzy subsystem of the system of support of forensic building-technical expertise. It is shown that a considerable part of the materials of forensic building-technical expertise and expert research is represented by photographs of injuries. Fixation of damaged structures is reflected in the plans of premises and schemes of placement of structures in the buildings. The graphic information of the research materials is accompanied by textual information, the processing of which requires the use of models and methods of fuzzy mathematics. The fragment of the knowledge base is provided, which contains information on the geometric parameters of damage to building structures and an example of a fuzzy rule that reflects an expert conclusion. The expediency of using fuzzy neural networks of adaptive resonance theory of the Cascade ARTMAP category is substantiated. Cascade ARTMAP memory card schematic is shown.*

***Keywords:** building construction, expert conclusion, fuzzy uncertainty, fuzzy rule, geometric damage parameters.*

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***** Correspondence Author

Petro Kulikov, Rector of Kyiv National University of Construction and Architecture, Kyiv, Ukraine. E-mail: terenchuksa@ukr.net

Roman Pasko, Laboratory of Engineering and Technical Research, Kyiv Scientific Research Institute of Forensic Expertise of the Ministry of Justice of Ukraine, Kiev, Ukraine. E-mail: ghiaccio@i.ua

Svitlana Terenchuk, Department of Information Technology Design and Applied Mathematics, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. E-mail: terenchuksa@ukr.net

Vitalii Ploskyi, department of Architectural Structures, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. E-mail: ploskyivo@ukr.net

Yeremenko Bohdan*, Department of Information Technology Design and Applied Mathematics, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. E-mail: erembm@ukr.net

I. INTRODUCTION

Forensic building-technical expertise and expert researches to determine the causes of the deterioration of the premise's TC, which were carried out by the RBW, enable the courts to determine whose fault brought to certain damages or defects of the existing structures of the building. Further, the conclusion of the FBTE is the basis for establishing the person responsible for the damage and determining the amount of compensation for material damage to the injured party.

Visual inspection and visual assessment of the building are conducted in order to provide expert conclusion in the process of FBTE and ER implementation [1, 2]. The first initial information about the TC of the objects that have become the subject of the FBTE is formed.

According to current methods [3], surveys and evaluations are carried out:

- the premises where the RBW was carried out;
- adjacent premises where defects and damage were found;
- premises which have not been affected by the RBW and have not been the subject of the FBTE.

At the same time, the located premises are inspected and evaluated:

- on the same floor as the premises where the FBTE were held;
- on the lower and upper floors;
- in other sections of the building.

Inspection of buildings, structures and BC also provides for the control of the existing technical condition, quality control of the manufacture and assembling of BC elements using the necessary devices [4].

Such control:

- reflects the current TC of the house, its structural elements and materials these elements are made, power supply and engineering networks;
- allows experts to match object parameters to project values;
- allows to estimate the degree of physical wear of structural elements.

The comparison of the survey data and the materials submitted to the analysis with the requirements of the current regulatory documents in the field of construction is an expert conclusion about the possible relation between the occurrences of damage to:

- conducting RBW in adjacent premises;
- negative changes in the process of exploitation;
- factors of influence of natural or man-made character.

In addition, a survey of the foundation of a building or structure is usually envisaged, since the very foundation of the foundation is often the cause of defects in the supporting structures of the building [3].

One of the main problems faced by the experts in carrying out the FSBE and ER for determining the reasons for the deterioration of the premise's TC, which were subject to the RBD, is the fuzzy uncertainty [5]:

Specialists are able to establish cause and effect relationships between the deterioration of the object's technical condition and the factors of impact that caused it, even in cases of different force and non-force factors. However, a significant increase in the volume of RBW in the conditions of compacted urban development, lead to the fact that ER to determine the causes of deterioration of the premise's TC, become mass. This is the reason for delaying the completion of the FBTE.

That is why the computerization of expert decision support systems for assessing the impact of RBW on the object's TC within the area of impact of these works is an urgent and timely task. But solving this problem requires the development of software capable of operating under uncertainty.

II. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

A. Abbreviations and Acronyms

- ARTMAP – Adaptive Resonance Theory Mapping.
- BC – Building Constructions.
- CAD – Computer-Aided Design.
- EC – Expert Conclusion.
- ER – Expert Research.
- FR – Fuzzy Rule.
- FU – Fuzzy Uncertainty.
- TC – Technical Condition.
- RBW – Repair-Building Works.
- ISSFBTE – Intelligent Support System for Forensic Building-Technical Expertise.
- FBTE – Forensic Building-Technical Expertise.
- NN –Neural Networks.

B. Some common concepts

Concept 1. TC is the set of qualitative and quantitative indicators that characterize the exploitation suitability of an object or its parts, compared to their maximum permissible values [6].

Concept 2. An object is a structural element of residential and public buildings and their furnishings.

Concept 3. FU is the uncertainty that characterizes the tasks of peer review as a whole. But in different tasks, FU can be caused by different fuzzy factors [4, 5].

FU appear in determining the causes of the deterioration of the premise's TC near which the RBW was carried out is related to the existence of such fuzzy factors as:

- incomplete knowledge of the expert about the objects;
- lack of confidence in the correctness of assessments;
- conflicting data provided by different parties to the conflict;
- unclear presentation of information;
- insufficiently defined role of subjective factors.

The main reason for the appearance of FU during the FBTE includes [4]:

- incompleteness or failure to provide all necessary source data;
- failure to provide access to all premises of the building, its structures and utilities during inspection;
- uncertainty associated with estimates of contingent event probabilities that led to structural damage in each case of dynamic effects on the superposition of natural and man-made factors;
- uncertainty related to the processing of textual and graphic information.

The main purpose of this paper is the implementation of artificial neural networks in ISSFBTE, which will allow the processing of fuzzy text and graphic information in the changing contradictory conditions of lawsuits.

Concept 4. A fuzzy implication is a binary logic operation that results in FU [7]:

$$\text{«if } x \in A, \text{ then } y \in B\text{»,} \qquad (1)$$

where:

- x – input variable specified in the FR definition area – X;
- y – output variable specified in the output definition area – Y;
- A and B – statements defined on X and Y with the measures of membership of $\mu_{A(x)}$ and $\mu_{B(y)}$ as $X \rightarrow [0, 1]$ and $Y \rightarrow [0, 1]$, respectively.

Plural of FRs (1) are used in expert TC evaluation systems for various building objects [6].

C. Basic information about Fuzzy Inference System

System of the fuzzy inference is the ISSFBTE subsystem discussed in this paper. System of the fuzzy inference is designed to draw fuzzy conclusions based on fuzzy initial data and uses basic operations of fuzzy logic [6].

According to [7], the fuzzy inference system contains:

- system inputs and outputs;
- rules over fuzzy variables;
- a set of fuzzy linguistic variables that describe the state of BC.

The input parameters are given as a vector, the coordinates of which can be defect and damage parameters. Each term is a fuzzy set [6, 8]. The output of the rule is also a linguistic variable that is characterized by plural of terms [6 – 8]

The plural of rules is a generalized knowledge of experts, which is represented as a fuzzy implication (1) given on the Cartesian product of input and output data carriers.

The truth of fuzzy implication can take the value determined by the formulas given in [7] or by the expert method.

Examples of fuzzy inference, based on expert assessments of TC of different BC's, using on the models of Mamdani and Sugeno, published in [6].

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There is also an example of expert evaluation of TC designs based on Mamdani and Sugeno models. Examples of expert support for fuzzy inference using the Fuzzy Logic Toolbox Matlab environment are explored in [9].

The formation of the fuzzy inference system is described in detail in [6]. The fuzzy inference algorithm used in [7, 9] allows the construct of fuzzy implications based on rules given by fuzzy geometric degradation parameters (Table 1).

There are other papers that are aimed at developing intelligent systems for evaluating building construction's TC with fuzzy logic. In these systems, FRs (1) are used to evaluate TCs of different BCs under different operating conditions.

Table-1: Formalization's Example of Fuzzy Geometric Parameters of Structural Damage

Defects and damages	Parameters and terms for linguistic assessment [8 – 10]	Possible reasons
▪ X_1 – crack; i=1.	▪ Type (X_{11}): longitudinal (lt); transverse (tv); slanted (sl); ▪ Opening width (X_{12}): small (sm); developed (dv); large (lr); ▪ Length (X_{13}): short (sh); medium (m); long (l); ▪ Location (X_{14}): near supports (ns); along armature (aa); in the seams between slabs (sbs); in the shelves of slabs (shs).	▪ Y_1 – conducting RBW in adjacent premises (effect of vibrations, consequences of interference in engineering networks, consequences of interference in the power grid); ▪ Y_2 – negative changes during exploitation; ▪ Y_3 – natural influence; ▪ Y_4 – influence of anthropogenic character.
▪ X_2 – destruction of concrete; ▪ X_3 – traces of water saturation; ▪ X_4 – peeling off the facing layer of concrete; ▪ X_5 – destruction of the plaster layer of concrete; ▪ X_6 – bloom; ▪ X_7 – fungus; i=2,…7.	▪ Coverage area size (X_{i1}): zero (ze); insignificant (ins); essential (es); extensive (ex); ▪ Coverage area form (X_{i2}): triangular (t); trapezoidal (tr); spherical (sph); sector-like (s); ellipsoid (e); rectangular (r); ▪ Defect position in the object (X_{i3}): on the facade (f), in the seams along the armature (aa); in the shelves of plates (sp); on overlapping areas (oa); on sections of walls (w); on sections of the ceiling (directions); on the steps of the flight (sf); above window cuts (wc); under the window slots (ws).	

However, all of these works do not include modelling of cause and effect relationships between the deterioration of the TC structural elements of buildings and the conduct of RBW in adjacent premises (Table 1). As RBW are most often the subject of an FBTE, this research seeks to develop an intelligent system for supporting expert decisions to assess the impact of RBW on the TCs of nearby objects.

III. BASIC MATERIAL

D. ISSFBTE Model

ISSFBTE is designed to assess the impact of RBW on the TC of the facilities near which these works were performed.

The system model is shown in Fig. 1.

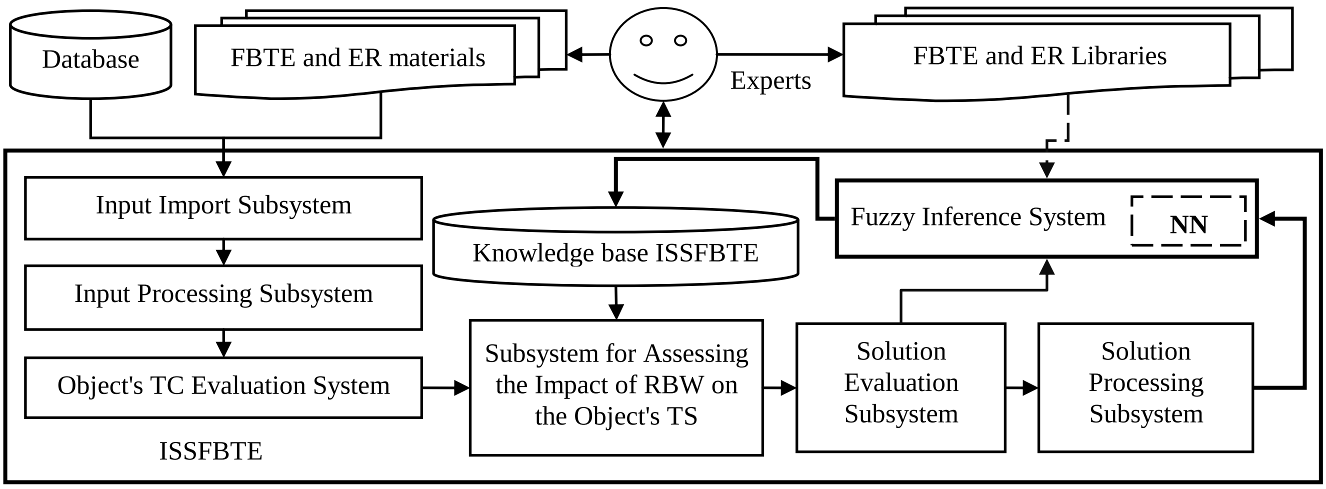

Fig. 1. Scheme of support for expert decisions on the assessment of the impact of RBW on objects's TC

The system interacts with external:

- database;
- FBTE and ER materials;
- FBTE and ER libraries.

In order to ensure the functioning of the ISSFBTE from the database through the subsystem of import of input data, the necessary legislative and regulatory technical data are loaded.

FBTE and ER materials are downloaded through the Subsystem of Input Import, which contains the inspection and evaluation data of the object's TC that have been the subject of the current ER. At the same time, experts can carry out computational experiments with the use of a CAD, in which the information model of the building is constructed and load calculations are performed on individual BC. Such calculations can, to varying degrees, resolve the uncertainty associated with the incompleteness of the raw data.

To overcome this type of uncertainty in the ER process, requests are made and examined [2, 3]:

- project documentation;
- documentation of housing and operating organizations (observation logs, operation logs, inspection acts, documents on completed works, etc.);
- documentation for the building and premises for technical inventory;
- conclusions, technical and expert reports, other documents drawn up by commissions of expert units of the respective institutions and organizations;
- reporting, executive and production documentation (general journal of the works, special journals for certain types of works, acts of the works performed, acts to close the hidden works, defective acts, etc.).

The study of the above documentation is carried out in order to answer the questions concerning [1, 4]:

- compliance of the RBW, individual elements and structures to the project documentation and requirements of regulatory documents in the field of construction;
- start and period of construction (reconstruction, repair);
- changes in technological processes or nature of exploitation of the facility;
- dates of accidents or violations of exploitation conditions that could lead to a deterioration of the premise's TC in which the RBW were conducted;
- accidents related to groundwater rise, flooding of foundations, etc.

However, such an order of ER leads to the fact that the a priori base of FR usually changes in the process of expert research and FBTE.

The consequence of these changes is the need to adjust the a priori knowledge base of ISSFBTE, namely:

- edit rules;
- add rules;
- delete rules;

Such manipulation of fuzzy data and FRs is accomplished by a system of fuzzy inference after evaluation and processing of expert decisions regarding the possibility of influence of certain RBDs in the adjacent premises on the object's TC. It is this feature of the subject area, which was first of all taken into account in the selection of the ANN for use in the fuzzy inference of the ISSFBTE.

The basis of ISSFBTE is a fuzzy knowledge base that contains a set of FRs that determine the relationship between the damage or defect data of an object under study and the impact of various factors on it [11, 12].

The ISPER Knowledge Base also stores [13]:

- the classification features of the object's TC categories with a list of relevant linguistic terms and the possible causes and effects of their destruction;
- atlas of defects and damage with description of conditions and causes of their occurrence.

The functioning of all ISSFBTE subsystems now requires expert support. But this model involves the use of NN in each of the subsystems.

This paper focuses on the study of NNs, the use of which in fuzzy inference, will automate the interaction of ISSFBTE with the FBTE and ER data libraries.

The FBTE and ER data libraries are formed by experts and contain the generalized experience of previous expertise. At the same time, the initial input data are characterized by a considerable amount of graphical information, which is used to justify expert conclusions (Figs. 2, 3).

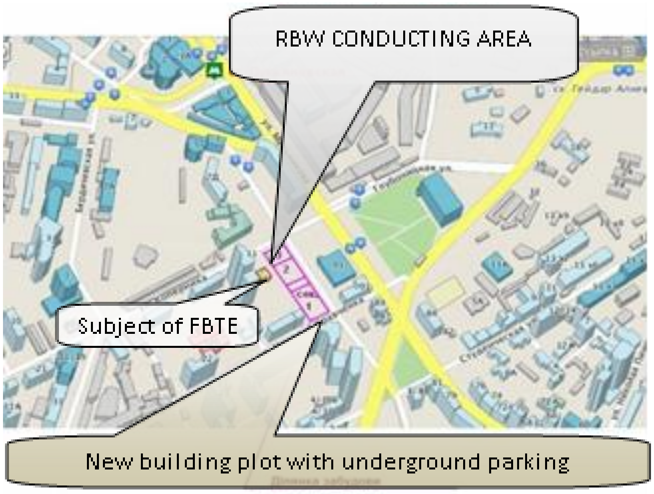

Fig. 2. The location of the study objects

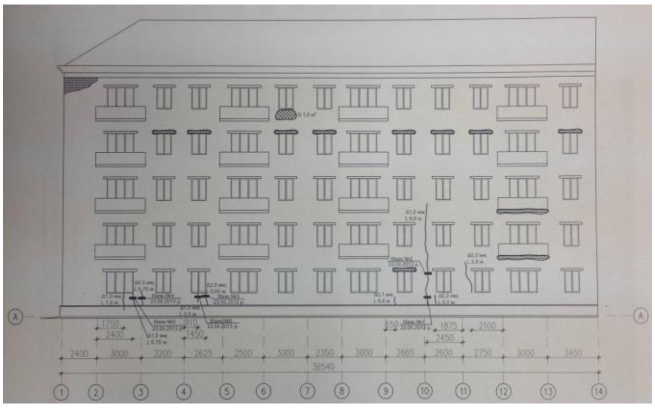

Fig. 3. Location's scheme of the BC damage in the FBTE and ER materials

Schematic representation of the damage to the BC and their location is accompanied by textual information.

Excerpt from EC:

"Between the Axes 10-11:

- vertical crack in the load-bearing wall with a width of opening up to 1.0 mm, 6.6 m long;

In axes 9-10:

- the destruction of the protective layer of concrete, exposed and corrosion of the working reinforcement of all reinforced concrete window linters of the first and fourth floors. "

The FBTE and ER materials also contain photographs of the damage (Fig. 4).

Fig. 4. Examples of photo-fixation of cracks (position on the scheme of the building)

The analysis of such geometric and graphic information by computer systems requires special processing and presentation. For this purpose, EC is first displayed as a FR system.

A typical FR has the form (2):

if (2)
"Defect type = crack
and
characteristic = longitudinal
and
position in the construction = vertical
and
direction of development = up »
and
location = in the load-bearing wall
and
opening width = large
and
length = critical
and
depth = through
then
<condition = emergency
and
probable cause = vibration,
what happened as a result of repair and construction work (type, time and duration of work) in the premises (address)
and
probable cause = probability estimate>
or
settling the foundations of the house
and
probable cause = change in stress-strain state of the soil base due to the construction of ditches of new construction (address, time and duration of work)
and
probable cause = probability estimate>.

So:

- FR displays the object's original TC information;
- conclusion FR contains a list of possible causes and an estimate of the likelihood of damage and defects in the design of buildings and their furnishings due to each of the reasons.

At this stage, the terms of the rules are formed in accordance with the results of the visual inspection and visual assessment of the object's TC that has become the subject of the FBTE. The probabilities of the cause of deterioration of the object's TC in each case are carried out by the expert method.

The next stage of research raises the question of the choice of NN, the use of which in ISSFBTE will provide an opportunity to automate the operation of the fuzzy output system.

E. Application of ANN to Fuzzy Inference System

The NN's analysis of different architecture, carried out in [14 – 16] revealed the properties of NNs of adaptive resonance theory, such as:

- capability to form associative pairs;
- evolutionary plasticity (adjusting knowledge in the learning process);
- evolutionary stability (knowledge retention).

It is these properties NN's of adaptive resonance theory category that give them a significant advantage in solving the classification problem in the dynamic context of providing different input to conflicting parties. The problem is complicated by the large number of damage standards used by experts and the complexity of assessing the likelihood of compatible events.

The fuzzy NN of the Cascade ARTMAP category is best suited for solving the fuzzy inference problem in the described conditions [15, 16]. Their ability to form associative pairs allows the rules of fuzzy expert conclusions to be displayed on the NN memory card. In this case, the property of evolutionary plasticity makes it possible to implement the procedure of optimization of the knowledge base by correcting the rules (Fig. 5).

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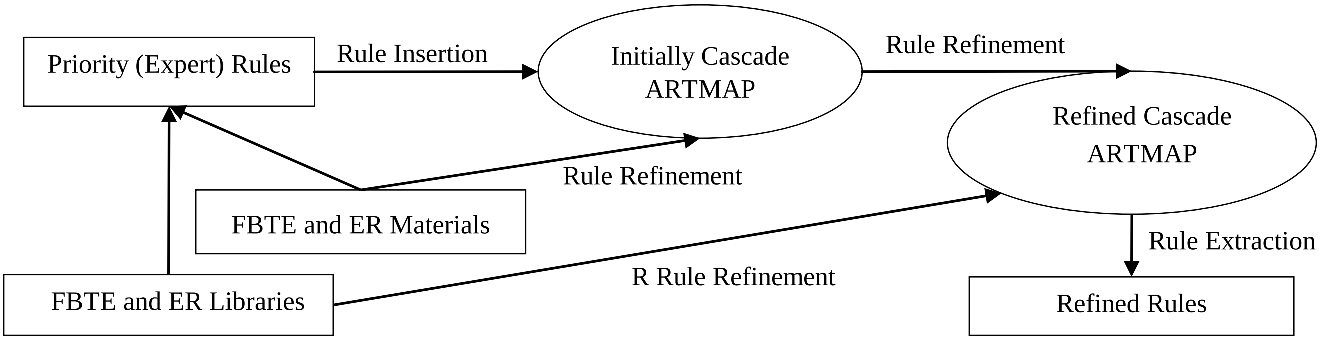

Рис. 5 Схема формування правил Cascade ARTMAP

The property of the network to learn in real-time at both the teacher and non-teacher stages makes it possible to modify the a priori policy framework and thus take into account input from expert research. In this case, the network is able to store the acquired knowledge [15].

In addition, the Cascade ARTMAP structure is compatible with the representation of knowledge in expert systems. This evolutionary property of the Cascade ARTMAP inheritance gives it a significant advantage in forming a fuzzy ISPER knowledge base,

because it is able to map FRs to the NN's topology even before training.

The Cascade ARTMAP architecture is described in detail in [15, 16]. However, this and other papers discuss the possibility of adapting Cascade ARTMAP to another task. In addition, some of the difficulties in implementing Cascade ARTMAP in ISPBC are related to the complexity of fixing expertise in the NN's structure.

IV. RESULT AND DISCUSSION

ISPSBTE provides for the implementation fuzzy NN of the Cascade ARTMAP category in systems of fuzzy inference.

At the present stage of research, a priori knowledge base is being formed, which is a generalized expert experience (Table 2).

Table-2: Fragment of a priori (Expert) knowledge base

BC (ID)	Defect/damage	Linguistic Assessment				Reason (EC)	
		X_{i1}	X_{i2}	X_{i3}	X_{i4}	Y_1	Y_3
Wall (ID)	X_1	lt	lr	l	shs	0,7	0,2
	X_2	ins	s	w	-		
	X_5	ins	s	f	-		

The Table 2 shows a fragment that includes fuzzy geometric parameters of objects damages.

Formalized Expert Rule has the form:

$$\textbf{\textit{if}} \quad (3)$$
$$X_1 = ID \textbf{ and } X_{11} = lt \textbf{ and } X_{12} = lr \textbf{ and } X_{13} = l \textbf{ and }$$
$$X_{21} = ins \textbf{ and } X_{22} = s \textbf{ and } X_{23} = w \textbf{ and } X_{51} = ins \textbf{ and }$$
$$X_{52} = s \textbf{ and } X_{53} = f$$
$$\textbf{\textit{then}}$$
$$Y_1 = 0{,}7 \textbf{ and } Y_2 = 0{,}2”.$$

It is precisely this task that will be devoted to further publications.

The next stages of ISSFBTE development suggest:

- mapping formalized expert rules (3) to Cascade ARTMAP;
- NN training using test cases FBTE and ER libraries.

V. CONCLUSION

The analysis of the FBTE's and ER's nature for determining the reasons for the deterioration of the premise's TC, along with which the RBW and the specifics of the input data were performed, showed the relevance of the development of automated systems for supporting expert decisions.

Further research will focus on:

- adaptation of the Cascade ARTMAP neural network to the task of identifying the causes of the deterioration of the premise's TC in which the RBW were conducted.
- using of different artificial NNs in the subsystems of the input data processing, evaluation of the object's TS and estimation of the effect of the RBW on the object's TS

The results of this work can improve the process of performing forensic technical-building expertise and expert researches of reasons of the deterioration of the technical condition of the premises, along with which the repair and construction works were performed, as well as the evidence and validity of the expert conclusion.

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AUTHORS PROFILE

Petro Kulikov Rector of Kiev National University of Construction and Architecture, Vice President of the Construction Chamber and the Academy of Civil Engineering. He is Doctor of Economics, Professor. He manages a research and production laboratory for testing building materials. He has more than 176 scientific and methodological publications. Research interests: creation of an internationally recognized compact and mobile educational and scientific centre of development of the architectural and construction industry of Ukraine at the Kyiv National University of Civil Engineering and Architecture on the basis of innovation and financial independence.

Roman Pasko Head of the Laboratory of Engineering and Technical Studies of the Kiev Research Institute of. He is a member of the editorial board of the interagency scientific and methodological collection “Forensics and Forensic Expertise”. He graduated from the Kyiv National University of Civil Engineering and Architecture with a degree in Urban Construction and Economics and obtained a qualification as a civil engineer. He has more than 10 research papers and publications. Scientific interests: "Research of real estate, building materials, structures and related documents", "Land allocation and definition of land use", "Determination of the estimated value of construction sites and structures" and "Valuation of land plots".

Svitlana Terenchuk works in department of information technology design and applied mathematics, Kiev National University of Construction and Architecture. PhD, Associate Professor. She graduated from Taras Shevchenko National University of Kyiv, Ukraine. She has more than 120 published scientific and educational works. Research interests: artificial neural networks in decision support systems, Neuro Fuzzy technology.

Vitalii Ploskyi Vice-rector for scientific activity of Kiev. He is Doctor of Technical Sciences, Professor. He is Member of ISGG – International Union of Geometers and Graphics. He initiated the creation of a relevant national association – the Ukrainian Association for Applied Geometry. He has more than 220 scientific and methodological works. Basically, these are works on energy-efficient design, spatial formation and geometric modeling in architecture. Research interests: Applied Geometry and Graphic Technologies and Technical Aesthetics began to develop the Energy Efficiency of Construction Objects.

Yeremenko Bohdan graduated from Kiev National University of Construction and Architecture, majoring in Information Technology of Design, qualification of Master of Computer Science. PhD. He works in department of information technology design and applied mathematics, Kiev National University of Construction and Architecture. He has more than 50 published scientific works. Research interests: data science, machine learning, artificial neural networks, integrated technologies of complex dynamic modeling, intelligent decision-support systems.