Scientific Journal of Astana IT University
ISSN (P): 2707-9031
ISSN (E): 2707-904X

DOI: 10.37943/AITU.2021.43.51.007

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MODELS, METHODS, AND MEANS OF REPRODUCTION OF EXPERT KNOWLEDGE IN INTELLIGENT SUPPORT SYSTEM BUILDING-TECHNICAL EXPERTISE

Abstract: The paper is devoted to solving such a scientific and practical problem as the creation of computerized infocommunication systems for support building-technical expertise to determine the causes of destruction and deformation of buildings and structures. The analysis of the current state of expert activity within the framework of building-technical expertise is carried out. Perspective directions of the introduction of intelligent infocommunication systems in the course of performance of building-technical expertise and expert researches are outlined. The architecture of Intelligent Support System Building-Technical Expertise and the communication scheme of experts with the system are shown. To mapping expert knowledge formalized in the form of fuzzy associative rules to the memory card of the Cascade ARTMAP category fuzzy artificial neural network, it is proposed to use a fuzzy Mamdani-type inference system. The main input data, on the basis of which a fuzzy conclusion is realized to establish the degree of influence of various environmental factors on the technical condition of buildings and structures, are systematized and presented in a form acceptable for processing by computerized systems. At the same time, the main focus is on the study of facilities that are built and operated on subsidence loess soils. The process of formalization of heuristics, which is based on the formation of associations related to information on the position of signs of deterioration of the technical condition of the objects of expertise and the position of the changed soil, is described. Examples of interpretation and fuzzification of input information on soil properties, characteristics of the soil base of the object of building-technical expertise, and the surrounding area are given. The described approach provides an opportunity to reduce the risks of making wrong decisions by using the system as an intelligent database. The use of an artificial fuzzy neural network of the Cascade ARTMAP category gives the system the ability to form an expert conclusion on the degree of influence of various environmental factors on the technical condition of objects in the fuzzy conditions of a partially observed environment.

Keywords: Associative rule, expert conclusion, fuzzy inference, subsidence loess soil.

Introduction

Analysis of the current state of expert activity in the framework of building-technical examinations (BTE) and expert research to establish the technical condition (TC) category of buildings and structures, as well as to establish the causes of deterioration of their TC showed that BTE materials usually contain a significant part of photographs and schemes [1-3].

Information on the geometric parameters of the observed signs of deterioration of the technical condition of the objects of the expertise can be fixated on photographs [4, 5].

Each damage photo fixation (**Figure 1**) is accompanied by textual information with fixation of its position in the structure.

Fig. 1. Photo fixation examples of observed damage to the BTE object:
a – traces of soaking, effusion and fungus on the walls of the basement in the axes 1-7 in lines "B" - "C";
b – cross-cutting inclined crack in the wall of the first floor in a line "A" in the axes 26-29;
c – displacement of floor slabs from the nodes of the basement wall in the axes 26-29 in line "A";
d – horizontal deformations of the wall of the first floor and the base in the corner of the house along the axes "A/29";
e – vertical crack in the wall of the basement in the axes 26-29 in a line "A"

From the schemes and plans of BTE objects and their parts, experts also obtain information on the position and purpose of the structure in the building (**Figure 2**) and information on significant environmental factors (**Figure 3**).

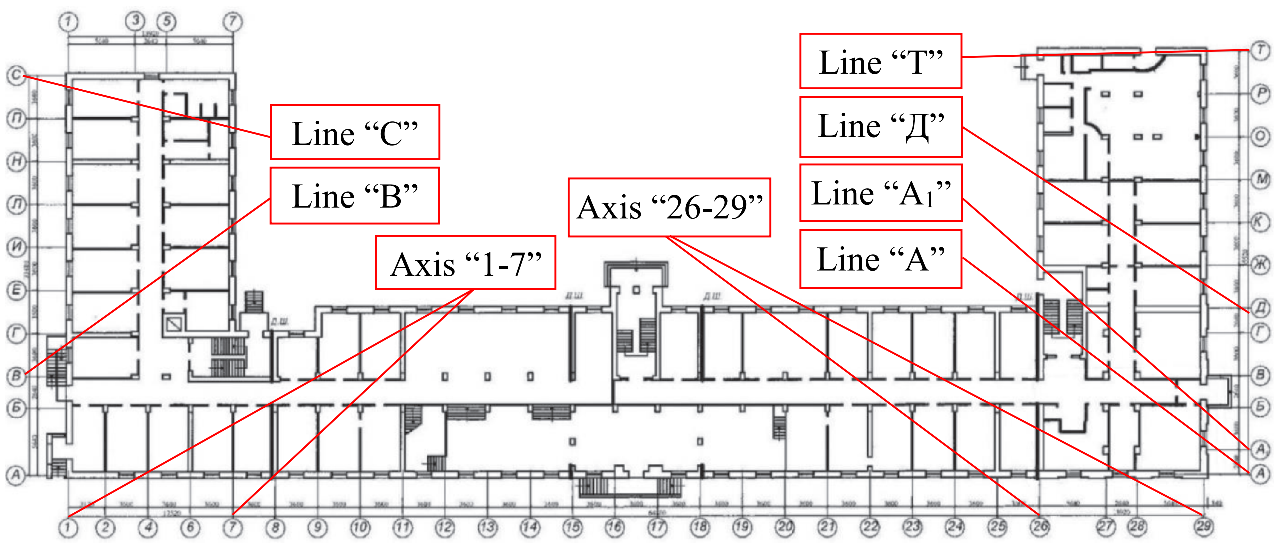

Fig. 2. Plan of the BTE object first floor

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ISSN (P): 2707-9031
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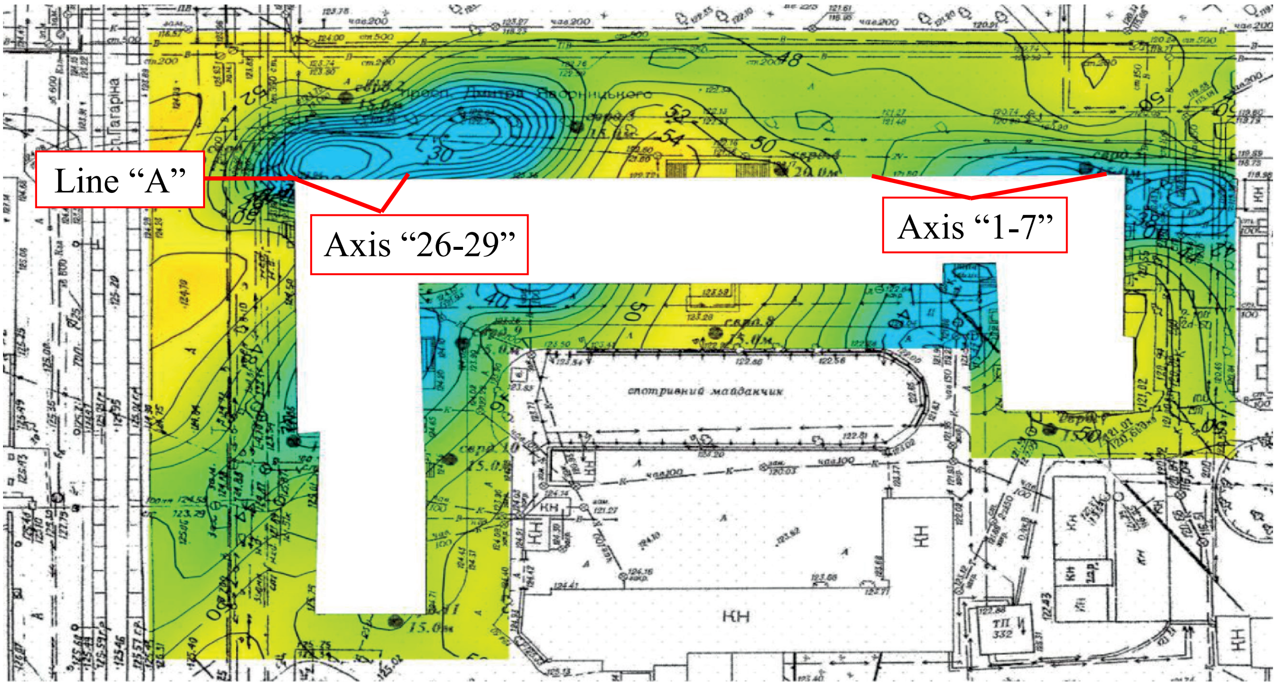

Fig. 3. Scheme of the density of the Earth natural pulsed electromagnetic field

Figure 3 shows an example of the results of special geophysical surveys that reflect the changes in soil properties around the BTE object due to changes in hydrogeological conditions [2, 6].

Changes in the mechanical and deformation properties of the soil base of the object, in turn, are one of the main hidden reasons for the transition to the state of emergency or destruction of buildings and structures built on subsidence loess soils. Execution of BTE in the described conditions is complicated by fuzzy uncertainty, and automation of activity of experts by the introduction in the course of carrying out BTE of the intelligent infocommunication systems capable to function in conditions of partially observed environment is extremely actual [7-9].

Main part

1. Trends of Information Systems Implementation into Process of Building-Technical Expertise

Figure 4 shows the scheme of the building-technical expertise support process automation.

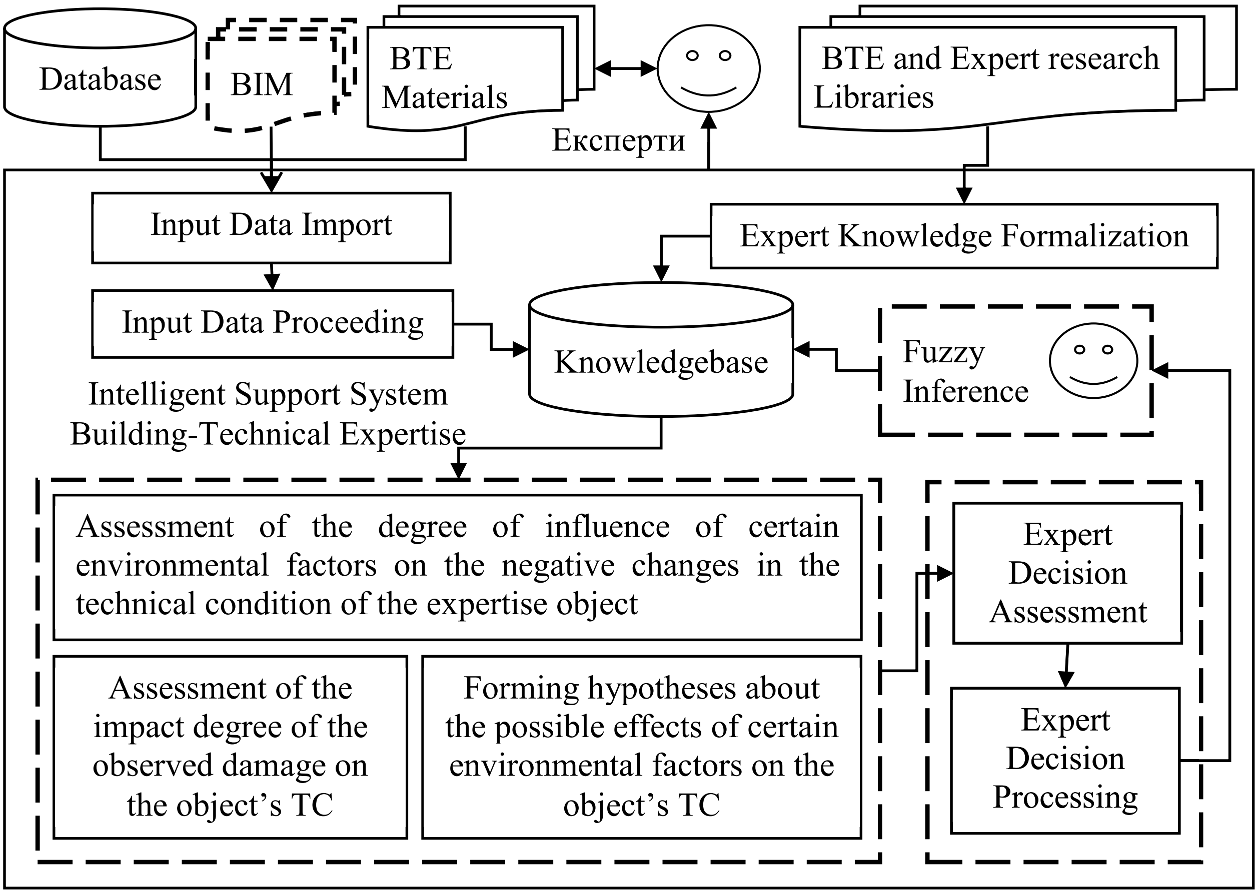

Fig. 4. Automation scheme of the BTE support process

Automation of the BTE process with determining of the technical condition category of the object provides the ability to download the information contained in the case files, and the interaction of the system with the database, BTE data libraries and expert research and software packages in which could be build an information model of the building (BIM). In this case, the data of legislative and regulatory-technical documentation required for the implementation of BTE can be uploaded from the database using the module for importing BIM parameters. Experts can also obtain information and perform computational experiments using any CAD system, in which the construction of BIM is performed, as well as to calculate the loads on individual structures [8, 10]. Calculations using BIM give experts the opportunity to solve the uncertainty problems associated with the incompleteness of the data in the study of various hypotheses about the possibility of the influence of hidden internal and external factors on the object's technical condition. However, the use of BIM for the construction and technical inspection of facilities created without BIM is usually not economically justified.

Another trend in automating the BTE execution process is the use of neuro-fuzzy inference systems. This approach makes it possible to use available expert information without collecting and processing statistics to train artificial neural networks [7, 11 and 12].

Scheme of communication of experts with the intelligent system, which is means of supporting building-technical expertise, shown in **Figure 5**.

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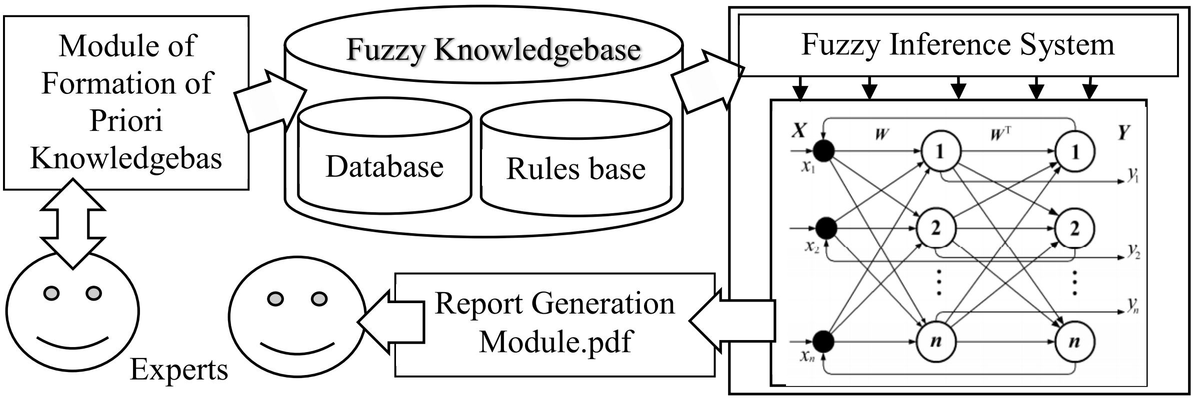

Fig. 5. Communication scheme of experts with Intelligent Support System Building-Technical Expertise

Communication of experts with the system involves:

- Formalization of special knowledge used by experts in forming Inference on the assessment of the degree of influence of certain environmental factors on the development of the changes in the technical condition of the expertise object
- Mapping the a priori knowledge base to the memory card of the Cascade ARTMAP category fuzzy artificial neural network;
- Formation of an expert inference using the Cascade ARTMAP category fuzzy artificial neural network [13, 14].

The possibility of using a neural network of this category in the Intelligent Support System Building-Technical Expertise is justified in [2]. To map the prior knowledge base into the memory card of the fuzzy artificial neural network of Cascade ARTMAP category, it is advisable to use the Mamdani type fuzzy inference system [15, 16].

The heuristics formalization process, which are based on the formation of associations related to information on the position of deterioration signs of the BTE objects technical condition and information on the position of the changed soil is shown in **Figure 6** and **Figure 7** [17].

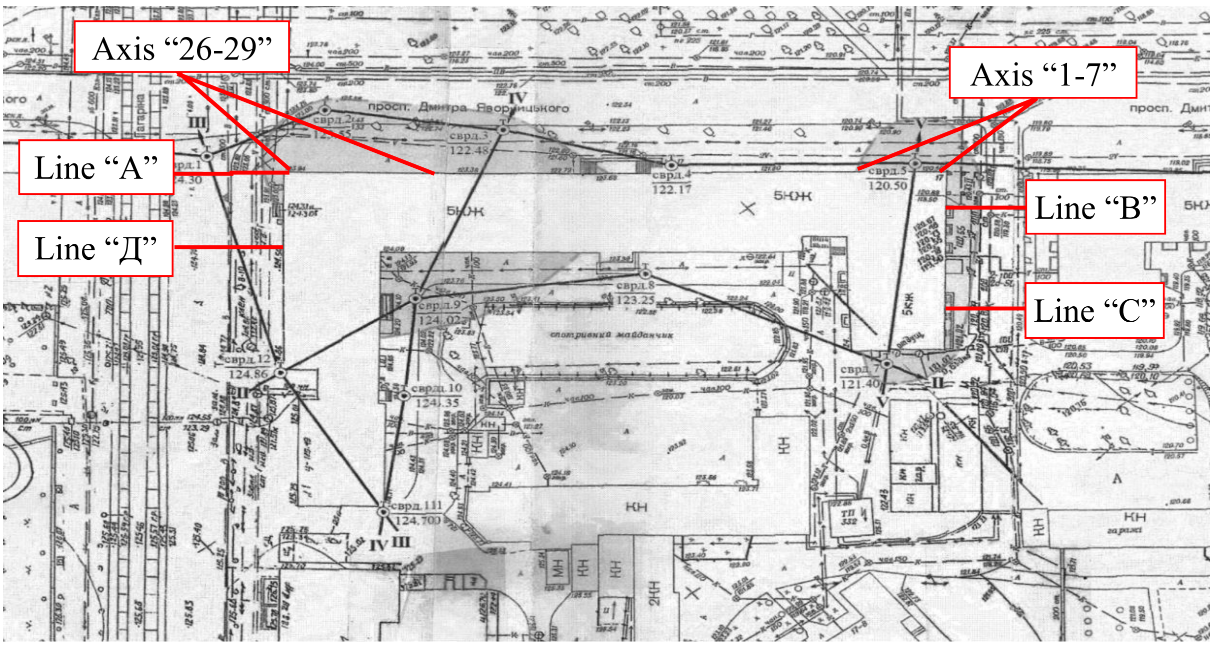

Fig. 6. The plan fragment of geological workings location with reflection of the expected zones spreading of the soaked soils

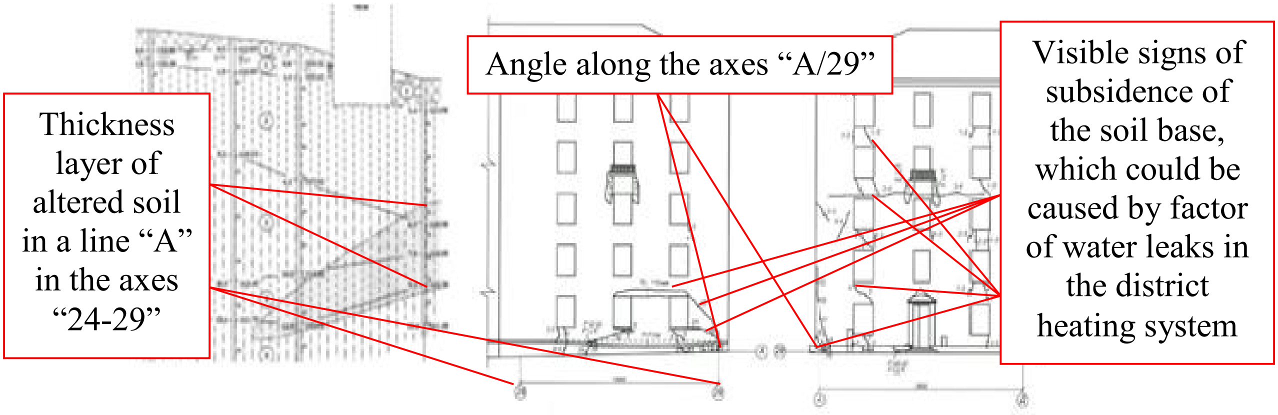

Fig. 7. Formation example of associations in the BTE execution process: the scheme fragment of engineering-geological section of the site location of the object and horizontal deformation of the wall and plinth in the corner along the axes "A/29"

Experts solve similar problems using heuristics based on special knowledge and experience. However, the heuristics use in computerized expert systems requires appropriate processing and presentation of expert knowledge. Fuzzy rules used in a fuzzy logical basis makes it possible to formalize the BTE process and build a system of fuzzy production models that reproduce expert fuzzy logical reasoning [5, 11]. In the future, these models are forming the rules base of the fuzzy knowledge base of the fuzzy inference system. It is taken into account that inference systems with fuzzy logic, formalized in the form of fuzzy implications, are convenient tools, the use of which provides an opportunity to understand the logic of the system according to its internal model [5]. This understanding was crucial when choosing models for formalizing the knowledge of experts in the form of fuzzy implications, as the expert is personally responsible for the conclusion of the BTE, which will determine the cause of destruction and / or deformation and determine the amount of compensation for damage to the injured party.

Thus, the development of an intelligent support system for building-technical expertise primarily requires addressing the formalization of the implementation process of BTE and expert research that is [5]:

Presentation of insufficiently structured expert expertise in the form of fuzzy rules;

Fuzzyfication and information interpretation reflecting the set of variables that form the input and output of fuzzy inference system.

2. Formalization of Building-Technical Expertise Process and Expert researches

The rules used in the fuzzy inference module of the Intelligent Support System Building-Technical Expertise can be presented in the form of fuzzy implications (1), (2), which are formed on the basis of BTE materials.

Excerpt 1 from the expertise 1:

Basement premises in axes 1-7 on line "B"–"C" (**Figure 1**):

Traces of soaking, efflorescence, fungus on the walls and ceiling of the basement (**Figure 1**a) with an area of 4m^2 due to the flow in the district heating system with an area of 4m^2 due to the flow in the district heating system are fixated in BTE materials.

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Rule $^{1}R_{11}$: if "damage type = traces of soaking; (1)
& characteristic = significant;
& place of damage in the structure (system) of the building = wall;
& the position of the structure in the house horizontally = left part;
& the position of the structure in the house vertically = basement;
& leaks in the district heating system = significant;
& the effect of humidity = significant;
& the vibration effect = not significant;
& temperature effect = significant;
then technical condition = unfit for normal exploitation".

Excerpt 2 from the expertise 1:

Facade along the axes "A/29" (**Figure 1** та **Figure 2**):

Horizontal deformations of the first floor wall and the plinth (**Figure 1d**) with an area of $4m^2$ due to the flow in the district heating system are fixated in BTE materials.

Rule $^{1}R_{21}$: if "damage type = deformation; (2)
& deformation type = subsidence;
& direction = horizontal;
& characteristic = critical;
& place of damage in the structure (system) of the house = plinth and wall;
& position of the structure in the house horizontally = right part;
& the position of the structure in the house vertically = the lower part;
then technical condition = emergency".

The process of formalizing the expert's inference on the category of technical condition of the object of in the form of fuzzy rules (1), (2) is described in detail in works [4, 5].

Processing of materials of standard building-technical expertise and expert researches on the basis of which the assessment of a technical condition category of building constructions and objects as a whole is carried out has shown that the output of fuzzy inference system (Y) of automated expert systems that had developed for their diagnostics, usually, is linguistic assessment, characterized by a set of such terms: "normal", "satisfactory", "unfit for normal exploitation" and "emergency" [5]. However, the output of the fuzzy inference system may be another vector, the choice of coordinates which depends on the purpose and problem statement. In this case, the rules formed on the basis of typical assessments, in addition to the observed signs of damage to the object technical condition, may contain information on the impact of certain environmental factors on its technical condition and information about the observed deterioration reasons of object technical condition ($^{1}R_{11}$). But, the use of rules of type (1) and (2) does not make it possible to directly assess the extent of the impact of certain environmental factors on the expertise object technical condition, as the observed damage may be the result of hidden causes. This means that solving the problem of automating the process of determining the degree of environmental impact on the nature of negative changes in the objects TC requires the development of other fuzzy rules, the conditions of which will contain information about possible causes of TC deterioration of the research object, and the conclusions reflectthe extent to which each of them affects the deterioration noted in the BTE materials.

The process and methods of forming such conclusions in the form of rule (3) on the basis of input data containing information on signs of deterioration of the expertise object technical condition and information on repair and construction works near the object is described in detail in [11].

Rule $^{3}R_{21}$: (**Figure 7**): if "damage type = traces of soaking; (3)
& characteristic = significant;
& place of damage in the structure (system) of the house = wall;
& position of the structure in the house horizontally = left side;
& the position of the structure in the house vertically = basement;
& leaks in the district heating system (factor 1) = significant;
& soaking of the grant during road construction
works (factor 2) = significant;
& position of the flow source in the structure (system)
house horizontally = left side;
& position of the flow source in the structure (system)
house vertically = basement;
& humidity effect = significant;
& temperature effect = significant;
then factor 1 = could be the cause of object expertise
technical condition deterioration with probability p_1
& then factor 2 = could be the cause of object expertise
technical condition deterioration with probability p_2».

Rule $^{3}R_{21}$ was formed on the basis of fragment 2 of expertise 1, taking into account information on the properties of the soil base of the object FBTE and information on physical-geographical and geological researches of the site on which the object is located [2, 3].

In [4, 11] the formalization process of experts production activity in establishing the connection between the deterioration signs of the expert research object technical condition and possible environmental factors that could cause this deterioration in the form of fuzzy associative rules is described in detail (4):

$$\mu_{R_1 \cdot R_2}(q,f) = \max_y \left[\min\left(\mu_{R_1}(q,z), \mu_{R_2}(z,f)\right)\right]. \quad (4)$$

Here:

- $X=Q\cup F$ – set of input data;
- $q\in Q$ – a sign of deterioration of the technical condition of the BTE object on the set of corresponding signs;
- $z\in Z$ – sign of significant changes in the soil basis of the BTE object on the set of corresponding signs;
- $f\in F$ – a sign of the environmental factor that could lead to landslides, subsidence or subsidence of the soil base of the BTE object;
- fuzzy relationship between Q and F, which is defined by the $R=R1\bullet R2$;
- $R1:(Q\times Z)\rightarrow[0,1]$;
- $R2:(Z\times F)\rightarrow[0,1]$;
- «•» – logical multiplication operation;
- μ_(R_1) (q,z) and μ_(R_2) (z,f) – measures of membership, which at this stage of the research are determined by experts based on information on the soil base properties of the object and the surrounding area, is shown in Tables 1, 2.

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Table 1. Fuzzyfication examples of the soil base characteristics of the object and the surrounding area

denotation	Assessment of Characteristic
$\vec{r}=(\overrightarrow{r_1; r_2})$	clear (on axis r_1=1,…,29 or between axes 1-29 1-29; along the line r_2=A,…,T or between line A-T) or fuzzy (left part, middle part, right part) topological information about position of the changed soil under the object;
$\vec{s}=(\overrightarrow{s_1; s_2})$	clear (distance to the object) or fuzzy (significantly, relatively significantly, not significantly) information on the position of the changed soil of the adjacent territory;
$\vec{V}=(\overrightarrow{v; \Delta v})$	generalized information about the depth of the altered soil under the object:
v	clear (top mark) or fuzzy information about the impact of the altered soil layer (significant, relatively significant, not significant);
Δv	thickness layer of altered soil (**Figure 7**);
$\vec{W}=(\overrightarrow{w; \Delta w; a})$ w	generalized information on hydrogeological conditions: clear (top mark) or indistinct (sufficiently or not deeply enough) information on the depth of occurrence of soil engineering-geological elements on the site;
Δw	clear (indicating the level) or fuzzy (significant, relatively significant, not significant) seasonal dynamics of groundwater;
$\vec{a}=(\overrightarrow{a_1; a_2})$	degree (high, medium, low) of groundwater aggressiveness to concrete and reinforced concrete foundations (a_1) and corrosion activity of groundwater in relation to materials used in the construction of utilities (a_2);
nd	clear (normative) or fuzzy (significant, relatively significant, not significant); information on the depth of seasonal freezing of engineering-geological elements

Table 2. Examples of input information interpretation on soil properties

Denotation	Soil property	Characteristic
s	subsidence type	s=1– the soil subsides from external loads; s=2 – the soil subsides under the load of its own weight, which acts on the soil base;
${}_{FO}^{s}G_j^i$	geological structure	j=1,…,J – engineering-geological element number; i=1,…,I – geological index; FO – fuzzy description of inclusions;
R_π	danger: landslide ($\pi = 1$); осідання ($\pi = 2$); просідання ($\pi = 3$)	major (ma); average (av); minor (mi)

The approach to the formalization of associative thinking of experts described in the paper is based on the application of models and methods of fuzzy mathematics, which provides an opportunity:

- To use available expert information to train the system without collecting and processing statistics;

- To take into account any quantitative and qualitative factors in drawing conclusions about the degree of influence of various environmental factors on the technical condition of buildings and structures, which are performed in unclear conditions of the partially observed environment.

Further research is planned to focus on:

- Creating of a fuzzy Mamdani-type inference system;
- Mapping the a priori knowledge base to the memory card of the artificial fuzzy neural network of the Cascade ARTMAP category, the use of which will allow to configure the fuzzy knowledge base Intelligent Support System Building-Technical Expertise during its exploitation.

Conclusion

1. The possibility of improving the process of construction and technical examinations and expert research by implementing in expert work Intelligent Support System Building-Technical Expertise is shown.

2. Modelling of the process of forming an expert conclusion on the assessment of the degree of environmental impact on the technical condition of the object of Building-Technical Expertise is made. The main attention is focused on the development of models and means of reproducing the associative thinking of experts.

3. To formalize the expert's conclusion on the assessment of the possible relationship between the deterioration of the technical condition of the object of examination and various environmental factors, it is proposed to use max-min composition.

References

1. Ukraine, Z. (1994). About forensic examination. *Information of the Verkhovna Rada of Ukraine (VVR),* (28), 4038-12. https://zakon.rada.gov.ua/laws/show/4038-12#Text.
2. DBN A.2.1-1-2014. Research, design and territorial activities. Engineering surveys for construction, Ministry of Regional Development of Ukraine, 2014.
3. Buratevich, O.I., Senik, N.V., Kharchenko, V.V. (2015). *Methodical recommendations for determining the physical demolition of non-residential buildings*. Report on research work IV.3.3-2014/2 (state registration number 0114U000706), 177.
4. Kulikov, P., Pasko, R., Terenchuk, S., Ploskyi, V., & Yeremenko, B. (2020). Using of Artificial Neural Networks in Support System of Forensic Building-Technical Expertise. *International Journal of Innovative Technology and Exploring Engineering*, 9(4), 3162-3168.
5. Terenchuk, S., Pashko, A., Yeremenko, B., Kartavykh, S., & Ershova, N. (2018). Modeling an intelligent system for the estimation of technical state of construction structures. *Eastern European Journal of Advanced Technology,* (3 (2)), 47-53.
6. Pasko, R., Terenchuk, S., Aghezzaf, A. (2020). Analysis of Deterioration Causes to the Technical Condition of Buildings Constructed on Subsidence Loess Soils. *Management of Development of Complex Systems*, 43, 116 – 122.
7. ISO, B. (2018). ISO 19650-2: 2018. *Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modeling (BIM)-Information Management using Building Information Modeling. Part, 2*. URL: https://www.iso.org/standard/68078.html.
8. Komandirov, O., Levchenko, O., & Kisil O. V. (2019). Prospects for the use of BIM-technology (BUILDING INFORMATION MODELING) in construction and technical expertise. *Forensics and Forensics*, 64, 633-638.
9. Domanetska, I., Honcharenko, T. Borodavka, Y., Dolya, E., & Fedusenko, O. (2020). Comprehensive Information Support of Urban Planning on BIM-based Design. *International Journal of Advanced Trends in Computer Science and Engineering*, 10, 9197-9203.

Scientific Journal of Astana IT University
ISSN (P): 2707-9031
ISSN (E): 2707-904X

10. Razov, I.O., Bereznev, A.V., & Korkishko, O.A. (2018). Problems and prospects for the introduction of BIM technologies in construction and design. In *BIM modeling in construction and architecture problems* (pp. 27-31).
11. Katasyov, A.S. (2019). Neurofuzzy model of formation of fuzzy rules for estimation of a condition of objects in the conditions of uncertainty. *Computer Research and Modeling*, 11 (3), 477-492.
12. Menshikov, P.V. (2021). Modeling methods in forensic engineering: Artificial modeling languages in forensics. *Technology and language, 2* (2), 77-85.
13. Pasko, R., & Terenchuk, S. (2020). The use of neuro-fuzzy models in expert support systems for forensic building-technical expertise. *ScienceRise*, (2), 10-18.
14. Fu, L.M., & Fu, L.C. (1990). Mapping rule-based systems into neural architecture. *Knowledge-Based Systems*, 3(1), 48-56.
15. Tan, A.H. (1997). Cascade ARTMAP: Integrating neural computation and symbolic knowledge processing. *IEEE Transactions on Neural Networks*, 8(2), 237-250.
16. Jang, J.S. (1993). ANFIS: adaptive-network-based fuzzy inference system. *IEEE transactions on systems, man, and cybernetics*, 23(3), 665-685.
17. Atanassov, K. T. (2017). Type-1 fuzzy sets and intuitionistic fuzzy sets. *Algorithms,* 10(3), 106. https://doi.org/10.3390/a10030106.
18. Pasko, R., Aznaurian, I., Terenchuk, S., (2020). Adaptation of fuzzy inference system to the task of assessment impact of repair-building works on the technical condition of the construction object. *Management of Development of Complex Systems,* 42, 113-118.

Главный редактор:
Белощицкий А.А.
Ответственный редактор:
Амиргалиев Б.Е.

Подписано в печать 28.06.2021 г.
Формат 60х84 1/8. Усл.п.л. 5,5.
Тираж 300 экз. Заказ № 742.
Отпечатано в ТОО «Шаңырақ-Медиа».
г. Нур-Султан, ул. Кокарал, 2/1, тел. 87077770066.
www.smedia.kz