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TECHNICAL ASSESSMENT OF OLD BUILDINGS BY PROBABILISTIC APPROACH

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The paper contains synthetic and analytical test results and model solutions for technical maintenance and wear problems of apartment houses traditionally structured. The crucial methodological aspect of the research is striving to minimize the subjectivity of expert assessment while technical investigation of old buildings. The cause and effect between the occurrence of damage to the elements of the rental houses, treated as an expression of the conditions for their maintenance, and the size of the technical process of wear of these elements was determined on a representative, purpose-appropriate, sample of 102 residential buildings erected in the second half of the 19th and early 20th centuries in downtown Wrocław (Poland) district. Rational maintenance of existing buildings is nowadays significant issue for their proprieties. Therefore, there is constant need to find a research method that may lead to well thought out building maintenance management. The goal of undergone research was to search influence of apartment houses maintenance on the grade and intensity of their deterioration. As to fulfil the research objective the group of engineers identified symptoms of the technical wear growth, which means performed identification of causes and effects responsible for the defects appearance. The range of the work demanded elaboration of a new qualitative model of detected defects and its transfer into a quantitative model. Therefore, such approach enabled to establish the reason - effect connection 'defect - technical wear' related to the crucial structural parts of investigated apartment houses.

Keywords: building assessment, maintenance, defect, deterioration, technical wear, probability

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1. INTRODUCTION

While executing expert inspection of steel, concrete or timber structures, engineers meet issues of assessing the qualitative (immeasurable) more often than quantitative (measurable) ones. The decision making strategy leads to classical breakdown of options explicated in 3 dimensions laid down by *Kacprzyk* [1]:

- Level of certainties;
- Level of engineers;
- Level of decision stages.

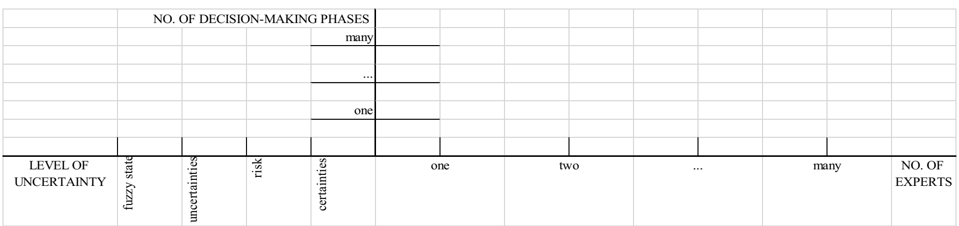

Figure 1. Breakdown of decision making strategy in cases of uncertainty

In the horizontal gridline different states from certainties to fuzziness were identified – figure 1:

- certainties: the whole data relevant to any decision making process is deterministic;
- risk: any information related to the decision making process is probabilistic;
- uncertainties: the decision making process means that the worst possible cases may appear;
- fuzziness: uncertainties stands for existence or non-existence any event appearance which means that the event may or may not appear at all.

The research findings are related to the probabilistic model practically applied for the quantitative / measurable influence of buildings' maintenance on their deterioration. Though the entire model is based on the well known probabilistic analysis presented below it enabled to describe a challenge that is quite complicated but commonly encountered in the buildings' technical conditions investigation practice: 'uncertainties – many engineers – one phase of decision making process' [1]. Determining the technical degree of wear of residential buildings is preceded by a decision on the purpose and scope of the renovation. Such a decision may concern individual cases, but may also relate to the targeting of activities for whole groups of facilities. In the latter case, methods are needed to allow for a smooth yet reliable estimation of the technical wear of the components of the structure under operation. Methods allowing for the theoretical determination of the technical wear of apartment houses or their components are known [2, 3, 4, 5, 6, 7]. However, due to the time of their creation and the changing conditions of maintenance of construction works since then, it is worth reviewing these methods. An attempt to verify such verification is the subject of the paper.

2. RESEARCH SAMPLE

Research work covered a group of 160 apartment houses located in the downtown district of Wroclaw (Poland). A characteristic feature of the test sample is that due to technical, social and economic deterioration and outdated functional solutions, buildings were designed in the 1970's to the so-called "technical death". For this reason, all renovations of the facilities were limited to repairs enabling the accommodation. At the beginning of the 1980s, previously made decision was amended by commissioning a complex examination and technical evaluation of those buildings. The aim of the research was a comprehensive technical assessment of this group in a way that allowed the decision to continue to use, carry out renovations or the need to disassemble individual facilities.

The level of technical wear of apartment houses may be assessed by simple mathematical equations. There are four figured out and easy to use formulas [8, 9, 10], which have been defined by *Ross* [8], *Unger* [8], *Romsterfen* [8] and *Eytelwein* [8]. All of them describe the level of technical wear z of buildings as a function of durability T and a period of their to date use t. Particular courses of the curves representing the formulas are dependent on states of building maintenance WU [11].

Direct use of formulas may result in misleading conclusions. It is difficult to attribute to the buildings considered only one means of maintenance described by the formulas. Due to this non-compliance, it was decided to compare the technical wear calculated in accordance with the theoretical formulas with the observed degree of technical wear of residential houses and their structural elements. The actual degree of technical wear was assessed on the basis of technical inspections of the building. Technical wear of 23 structural elements selected from the technologically and structurally homogeneous group of 102 (out of 160) apartment houses [12, 13, 14] (table 1) was established.

The procedure enabled to compare the technical wear Zt calculated by the theoretical formulas to the observed ones Ze, based on technical inspections and testing.

Table 1. Number of analysed apartment houses and their elements relevant to appropriate maintenance conditions

CLASS OF TECHNICAL WEAR	STATE OF BUILDING ELEMENTS' CONDITIONS MAINTENANCE	OBSERVED TECHNICAL WEAR OF BUILDING ELEMENTS [%]	foundations Z2	walls of basement Z3	solid floor over basement Z4	main walls Z7	inter-storey wooden floors Z8	stairs Z9	roof (rafter framing) Z10	window joinery Z13	inner plasters Z15	facades Z20	apartment house as a whole Z
1	2	3	4	5	6	7	8	9	10	11	12	13	14
I	**very well cared**	**0 -15**	0	0	**1**	0	0	0	**1**	**2**	**2**	**5**	0
II	**above than average**	**16 -30**	**7**	**12**	**23**	**16**	**3**	**17**	**12**	**17**	**10**	**17**	**2**
III	**average**	**31 -50**	**83**	**57**	**45**	**61**	**54**	**49**	**42**	**52**	**59**	**22**	**60**
IV	**poor**	**51 -70**	**11**	**24**	**23**	**25**	**37**	**32**	**43**	**27**	**22**	**27**	**37**
V	**poor**	**71 - 100**	**1**	**2**	**3**	0	**8**	**4**	**4**	**4**	**9**	**28**	**3**
TOTAL NUMBER OF ANALYZED APARTMENT HOUSES			**102**	**95**	**95**	**102**	**102**	**102**	**102**	**102**	**102**	**99**	**102**

3. PROBABILISTIC RESEARCH PROCEDURE

3.1. *Definition of technical wear of building elements – theoretical aspect*

3.1.1. Problem description

The theoretical model of technical wear of apartment houses' elements is a function of time t and their assumed expected life T [12, 13, 15]. Comparative analysis of the observed and theoretical technical wear pointed, however, to a conclusion that it is practically impossible to determine a precise relationship between an element's wear and its age [12, 16, 17, 18, 19]. This difficulty is due to the influence of numerous factors whose character is unique to individual buildings and which can only be described by a complicated mathematical model. In the circumstances where the investigator's goal is to establish a phenomenon trend, one should select uncomplicated models assuming their compliance with empirical observations as a selection criterion. Therefore the investigations were narrowed to the search for trend functions among relationships of a linear, power (multiplicatory), exponential and hyperbolic character [20, 21, 22, 23].

3.1.2. Theoretical research model solving with the use of the non-linear regression method

Parameter values for the models have been selected with the use of the non-linear regression method [20, 22, 23]. The random (dependent) variable, representing the level of technical wear of a building element, has been marked as Z, with values z_1, z_2, ... ,z_n, while the element age has been marked as t, with values t_1, t_2, ..., t_n. Then following the principles of the non-linear regression, a null hypothesis H_0 was assumed, according to which the model created cannot explain the systematic variation of the variable Z in relation to t (independent variable), described with a regression coefficient γ and increased by a constant remainder addend ξ:

$$Z = \xi + f(t, \gamma) = \xi + \gamma t \tag{1}$$

In the equation (1) the random component ξ plays an important role. It was included in the model because of four general reasons:

- the relationship under investigation is of a random character,
- it was impossible to include in the model of all factors that influence the dependent variable,
- after conducting the comparative analysis, there were doubts whether the assumed analytical form of the function f(t) entirely reflects the real form of the relationship under investigation,
- data from the macroscopic technical assessment that formed the basis for the further modelling were burdened with measurement errors.

The major obstacle to the correct creation of the model with the use of the non-linear regression was the absence of a precise definition of the value of part of ξ_1, ξ_2, ... ξ_k, that were basic components of the constant random ξ, and which should include factors of a twofold strength of influence:

- big – maintenance conditions of apartment houses and the subjectivity of evaluation of these conditions by each of experts who stated their opinion,
- small – the type of measurement equipment used and the type of measurement errors, the technical assessment method and its precision, incomplete knowledge on the technical condition and the age of an element investigated, etc.

In order to continue the analysis of the existing situation it was necessary to divide the whole model described with the equation into a part explained by the model searched for (dependent on the regression) and a part not explained by the model, described as a remainder addend (residuum) ξ, which included all the above mentioned factors not taken into consideration in the process of the apartment houses technical assessment.

The search for numerical values of parameters γ and ξ was carried out with the application of the least squares method [20, 21] in order to determine estimators corresponding to the constant A (=ξ) and the regression coefficient B (=γ). Next, for the directional coefficient γ of the regression function, the Student T statistics value and the number of degrees of freedom was determined, which for a k-element is k=1, and for the residues is: n-k. For the Student T distribution with n-k degrees of freedom the observed significance (probability) level was determined as the indicator of the null hypothesis H_0 in the FISHER t test, selected for its verification. When the observed significance level p(A, B) was lower than the assumed significance level α=0.05, the conclusion was drawn that the null hypothesis that contained the assumption of no influence of the independent variable t (=X) on the dependent variable Z (=Y) is not to be believed. As a result, an alternative hypothesis was assumed with the opposite meaning, but apparently opposite only in relation to the actual regression function described with the estimators determined.

It was assumed that the preliminary physical model of a physical phenomenon, whose independent variable is time, should be as simple as possible. Therefore, the research with the use of the non-linear regression concentrated on (apart from widely used parabolic relationships) four types of mathematical functions, i.e.:

- linear model: Y = A + BX;
- power model: Y = AXB;
- exponential model: Y = exp (A + BX);
- hyperbolic model: 1/Y = A + BX.

Results of modelling with the use of the non-linear regression were presented in table 2 for an example element, i.e. stairs.

3.1.3. *Variance analysis in the non-linear regression method*

The variance analysis explains variation of a function assumed according to one of the models proposed above, while maintaining the division into the part explained by the model and the remainder addend [20, 21, 22, 23]. By means of adjustment of the proposed relationship to the observation (empirical) data, the total sum of squares of the dependent variable deviations from the average was divided by the sum of squares of deviations explained by the linear regression in relation to the independent variable and the sum of squares that was not explained by this regression. An average square of deviations not explained by the regression represents a residuum variance $[d(\xi)]^2$. A positive root from this value is a standard deviation of residuums $d(\xi)$.

The standard deviation of residuums rendered information on the average deviations of the observed dependent values Ze from the theoretical values Zt. Thus, in its form, it indicated the level of adjustment of the model to the empirical data. As a proper measure of adjustment, one accepted, however, a determination coefficient R^2, calculated as a quotient of a sum of squares of deviations explained by regression and a total sum of squares of deviations. The value of the determination coefficient R^2, expressed in per cent, brings the following information: what rate of the variation of the element's wear observed in the sample was explained by its regression in relation to the building age.

Results of the variance analysis in the non-linear method were presented in the table 2.

Table 2. Result of probabilistic research - modelling of new functions Zt = f(t) and durability "T" revision

SEEKING OF ALTERNATIVE FUNCTIONS Zt = f(t) BY NON-LINEAR REGRESSION METHOD										RESIDUUM ANAL.
Z9 - STAIRS	NON-LINEAR REGRESSION				VARIANCE ANALYSIS					durability T, for which
	estimators		probability level		model		residuum		determination coef.	average deviation = 0
mathematical formulas	constant A	regression c. B	p(A)	p(B)	df	square sum	df	variance	R*R [%]	and remainder var. = min, for:
LINEAR MODEL: Y = A + BX	34,4926	0,1509	0,0000	0,0126	1	1269,919	100	196,666	6,07	804
POWER MODEL: Y = AX^B	3,1387	0,1552	0,0000	0,0004	1	1,206	100	0,090	4,78	6894494
EXPONENTIAL MODEL: Y = exp (A + BX)	3,4810	0,0038	0,0000	0,0038	1	0,083	100	0,094	8,06	519
HYPERBOLIC MODEL: 1/Y = A + BX	0,0323	-0,0001	0,0000	0,0021	1	0,001	100	0,000	9,04	301
RESEARCH OF RELATION SIGNIFICANCE BETWEEN Ze and t BY RANKS OF SPEARMAN'S C.										Ross & Unger formulas
observed significance level	p(S) = 0,0264 < 0,05 - CORRELATION Ze/t SIGNIFICANT									(III class of maintenance)
ASSESSMENT OF SIGNIFICANCE DIFFERENCE BETWEEN Ze and Zt DISTRIBUTIONS										Y=X(X+T**)/2T**T**
non-parametrical tests	WU I - V	WU II	WU III	WU IV	EXPLAINATION:					T = 160 lat
"WILCOXON'S TEST"	R	R	R	R	R - distributions are significantly different					literature durability
"SIGN TEST"	R	I	R	R	I - distributions are identical					for stairs Z9: T = 120 years

3.1.4. *Investigation of the significance of relationship between the technical wear of the building elements and their age, with the use of the SPEARMAN rank coefficient*

The SPEARMAN rank correlation coefficient was used to compare ranks of two variables in the model, i.e.: the dependent variable Z and the independent variable t [21, 22, 23]. Its determination made it possible to answer a question whether the higher ranks of one variable were related to the higher (or lower) ranks of another variable. When ranks of the variables were heading in the same direction, then the SPEARMAN rank correlation coefficient had a positive value. In the opposite situation, when ranks were heading in opposite directions, it was equal to the negative value; in all cases it was within the interval [-1,1]. The closer the coefficient value was to one, the stronger the relationship between the variables ranks was.

For all samples with the size from 95 to 102 elements (>30) the testing of significance was performed with the Student T statistics, with the number of degrees of freedom df = n-2. If the significance level observed p(S) was below the assumed α=0.05, the null hypothesis H_0 was rejected and the alternative hypothesis H_1 was accepted according to which the correlation technical wear – element's age may be regarded as significant.

A standard statistical package SPSS was used to estimate the SPEARMAN rank correlation coefficient. The significance levels p(S) were presented in the table 2.

3.1.5. *Assessment of significance of differences between the theoretical and observed values of distributions of technical wear of building elements with the use of WILCOXON test and the Sign Test*

In the assessment of significance of differences between theoretical and observed values of distribution of technical wear of apartment houses elements, there were used two non-parametric tests for two groups of independent data with ordered measurement scale of variables – the WILCOXON test and the Sign Test [22, 23]. The tests also consist in the adequate ordering of ranks, by dividing their sums by half. The result was also an exact calculation of the probability of a case when the statistics obtained from the sample supports the null hypothesis H_0 on the identical variables distributions. If the observed significance level (this exact probability) was below the assumed significance level $\alpha=0.05$, then the null hypothesis was rejected in favour of the alternative hypothesis H_1 that revealed a significant difference between the distributions.

The sign test is similar to the WILCOXON test [22, 23]. It checks whether the amounts of positive and negative differences between two variables are identical. Testing of the null hypothesis H_0 was carried out in the same manner as in the WILCOXON test. The WILCOXON test is regarded as a stronger one, but despite of this fact a decision was taken to include results of testing with the Sign Test that in several cases pointed to a considerable similarity of the distributions under research.

In the assessment of significance of differences between the theoretical and observed distribution values of the apartment houses' elements technical wear with the WILCOXON test and the Sign Test, a standard statistical software package STATGRAPHICS was applied. The significance levels indicating that distributions in whole samples and in their subgroups (WU II, WUIII, WUIV) are different (or identical), were presented in the paper for an example element, i.e. stairs (table 2).

3.2. *Analysis of the residuum of the model with regard to the expected life of apartment houses*

The estimation of the trend model consists, apart from the search for evaluations of structural parameters, also in the estimation of certain basic parameters of the stochastic structure [20, 21, 22, 23]. The knowledge of these parameters, in turn, makes it possible to calculate certain measures of the accordance level between the empirical data and the data appearing from the trend function. On this basis, one may draw a conclusion on the level of precision to be used for the future conclusion drawing on the basis of the estimated trend function.

The basic parameter of the stochastic structure of the most properly selected trend model was a random component variance $[d(\xi)]^2$. As the random component variance in the general population was not known, it was estimated on the basis of a sample population with n-k (k=1) degrees of freedom for the parabolic model. Thus, it was assumed that the unbiased estimator of the random component is a remainder addend variance expressed with the following formula:

$$[d(\xi)]^2 = \frac{\sum_{i=1}^{n}(Ze_i - \overline{Zt})^2}{n-1} \tag{2}$$

The remainder addend variance is a measure of the magnitude of random deviations of accidental variables Ze_i from the trend function.

An additional parameter to support the remainder addend variance was an average deviation of residuums $c(\xi)$ between the measured and the modelled technical wear of elements of buildings analysed:

$$c(\xi) = \frac{\sum_{i=1}^{n}(Ze_i - \overline{Zt})}{n} \tag{3}$$

Such a pair of measures to control the correctness of the trend function selection is crucially important for the analysis of the expected life of building elements. Assuming the expected time of an apartment house exploitation to be an independent variable T, a course of relationship of the remainder addends and their deviations average was tested as a function of the expected life: $[d(\xi)]^2=f(T)$ and $c(\xi)=f(T)$. The deviation of these functions for an example element, i.e. stairs, was shown in Figures 2.1 and 2.2. In a correctly constructed model, the variance $[d(\xi)]^2$ should reach the minimum for values of the expected life (T*=120 years) quoted in literature (e.g. [9, 10]), and the average deviation should be close to zero $c(\xi)$. However, depending on the stairs maintenance conditions, both the $c(\xi)$ assumes zero values, and the $[d(\xi)]^2$ reaches the minimum for the real/observed expected life T** that amounted to 178 (WUII), 160 (WUIII) and 157 (WUIV) years, respectively: figures 2.1 and 2.2.

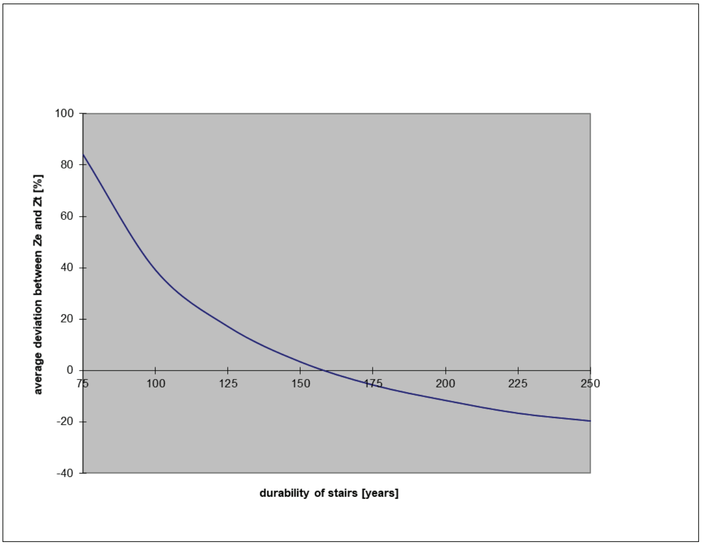

Figure 2.1. Deviation of observed technical wear and estimated theoretical wear representative to stairs' durability.

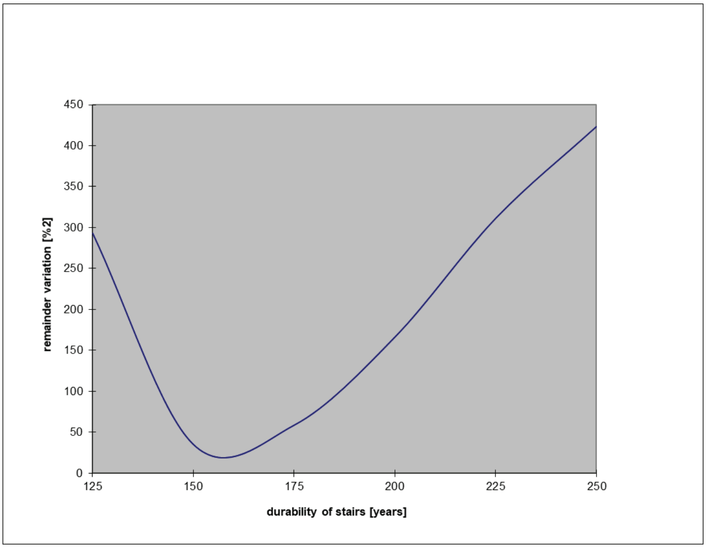

Figure 2.2. Remainder deviation as function of stairs' expected life at their average maintenance.

The expected life of 10 selected apartment houses elements was thus analysed for a twofold trend function, i.e.: for popular parabolic models and for one of models searched for with a considerable measure of matching (significant determination coefficient R^2). The analysis results are presented in Table 2.

3.3. *Results of the search for new mathematical models*

A multi-criterion analysis of the mathematical models proposed, that described observed states of technical wear of 10 elements of apartment houses was performed with the use of the most up-to-date statistical measures. Their intentional selection, due to the practical, transparent side of the statistical analysis developed with their help, made it possible to draw the following conclusions (table 2):

a) As regards alternative mathematical modelling with the use of the non-linear regression, the investigations of significance of the influence of the buildings' elements age on their technical wear with the SPEARMAN rank coefficients and the testing of significance of distributions differences of theoretical technical wear and the observed wear with the WILCOXON test and the sign test:
   - From among the four new mathematical models, analysed with the non-linear regression method, that describe the observed states of technical wear of apartment houses, none of the power models ($Y=AX^B$) represented the character of the determined trend of the wear process course with time (very low determination coefficient R^2 and unnatural (not realistic) value of the expected life represented by parameters T**);
   - Analysis of the theoretical wear function Zt = f(T**) points to a considerably better representation of the trend being modelled by exponential (Y=exp(A+BX)) and hyperbolic (1/Y=A+BX) relationships and slightly worse representation by linear functions (Y=A+BX);
   - Should an assumption be made that the measure of adjustment of mathematical models to the observed states is the determination coefficient R^2, then only in the case of three elements, i.e. the roof (rafter framing) (Z10), the window joinery (Z13) and the facade (Z20) – the magnitude of the variation of these elements wear observed in the sample was explained with their partial regression (to 30%) in relation to the age of the buildings under investigation; this observation was confirmed by the most correct age data regarding these elements;
   - The results of testing of significance of relationships between the technical wear of the building elements and their age, carried out with the use of the SPEARMAN rank coefficient pointed to the significance of this correlation between Zt and t at the assumed

significance level α=0.05 for 8 out of 10 elements (an exception being the solid floor over basement Z4 and the inter-storey wooden floors Z8, for which p(S)>0.05); one should however remember that a ‘considerably sensitive’ measure p(S) has been selected that indicates correlations even at low values of the determination coefficient R^2;

- The assessment of significance of differences between theoretical and observed distribution values of the technical wear of the buildings elements with the WILCOXON test and the sign test supported in most cases the conclusions drawn from the comparative analysis and revealed significance of differences between the distributions Zt and Ze, however the sign test implied that they were identical in the case of whole distributions (WUI-V) for the foundations Z2, the walls of basement Z3 and the main walls Z7, while the both tests - the WILCOXON test and the sign test confirmed that distributions in the individual groups were identical: WUIV for the foundations Z2, the walls of basement Z3, the solid floor over basement Z4, the main walls Z7, WUIII also for the main walls Z7 and WUII for the inter-storey wooden floors Z8;

b) With regard to the analysis of the remainder addend for widely accepted parabolic models, the following results have been obtained as to the assumed expected life T of the apartment houses elements :

- The expected life T**, defined as a parameter of the remainder addends variance $[d(\xi)]^2$, that has its minimum at the point of the T** looked for, takes on much higher values than the expected life values T*quoted in literature [24];
- the regularity of results is surprising, because the variation interval of T** is narrow, i.e. from 153 years (for the roof (rafter framing) Z10) to 177 years (for the solid floor over basement Z4); the respective values are presented in literature sources as T*=75 years (Z10) and T*=150 years (Z4);
- likelihood of the expected life T** results obtained from the analysis of the remainder addend was confirmed by results of testing of the exponential and hyperbolic models, in which the expected life T**, understood as a period of exhaustion of the usable value function of an element (Z=100%), takes on values similar to those obtained in the remainder addends analysis (this relationship holds only for elements with a significant coefficient of determination R^2).

3.4. *Association the defects occurrence with technical wear of apartment houses’ elements*

3.4.1. *A point bi-serial correlation coefficient*

A stage of the visual assessment of the defects extent in the apartment houses stood for distinguishing of two types of variables [12, 13]:

- Non-measurable – qualitative variables, i.e. individual defects present u_{ij};
- Measurable – quantitative variables, i.e. a degree of the technical wear of individual elements z_i.

Descriptive and conceptual analysis of the resulting damage to the elements of apartment houses in terms of systemic analysis of the "conventional" sets does not entitle them at this stage of work to be measurable variables. The biggest drawback of the method used by experts to assess the technical condition of the apartment houses was that it did not quantify the size (force) of the damage. It was not possible, even with the most faithful reproduction of the technical documentation and supported by verification tests, to distinguish between measurable values e.g. "significant corrosion" of the steel beams of the stairs from the "strong corrosion" of this element and e.g. "strong exploitation" of the electrical system from the "strong exploitation" of another element. With such a significant degree of unspecified amount of elementary damage, it was decided to determine the occurrence (or not) of damage in the binary system, that is, to assume that damage to the building element - identified at the basic level - as dichotomic variable.

After defining the types of variables z_i and u_{ij} an attempt was made to express the numerical relationship between them. The method for determining the two-series point correlation coefficient (usually marked as r(Z)) was used to calculate the strength of this relationship for the measurable z_i property and the dychotomic properties u_{ij}. This is one of the few cases in statistics where properties of different types are correlated [12, 23]. The correlation value factor is between [-1.1]. In the set of defects U for each elemental defect $u_{ij}=u_i$ (when j=1,2, ... ,m) and technical wear Z, the following elements have been established:

- u_i – dichotomous variable that takes on values 0 (ui0) or 1 (u_i1); i = 1,2, ..., n;
- u0 – number of observations of the variable ui marked as 0;
- u1 – number of observations of the variable u_i marked as 1;

apparently $u = u_0 + u_1$ (if by u, one shall understand the number of all observations u_i), and:

- z_i – measurable variable; values of this variable were divided into two groups distinguished on this basis: whether u_j takes values 0 or 1; i = 1,2, ..., n;
- zi0 – value of the property z_i for these units „i”, for which the property u_{i0} occurs;
- zi1 - value of the property z_i for these units „i”, for which them property u_{i1} occurs.

Next, arithmetic averages were calculated in the both groups:

$$\overline{z_0} = \frac{1}{u_0}\sum_{i=1}^{u_0} z_{i0} \tag{4}$$

$$\overline{z_1} = \frac{1}{u_1}\sum_{i=1}^{u_1} z_{i1} \tag{5}$$

the standard deviation (specified for correlation r(Z) with a relationship determined in a different way):

$$d(Z) = \sqrt{\frac{u\sum_{i=1}^{u} z_i^{\,2} - (\sum_{i=1}^{u} z_i)^2}{u(u-1)}} \tag{6}$$

and consequently, on the basis of (4-6), the coefficient of point bi-serial correlation r(Z):

$$r(Z) = \frac{\overline{z_1} - \overline{z_0}}{d(Z)}\sqrt{\frac{u_1 u_0}{u(u-1)}} \tag{7}$$

The above method of associating defects in building elements with their technical wear, which allows to determine the direction and strength of this relationship, has been used to investigate the impact of defects present on the deterioration process on the following stages of technical investigation: observed and theoretical condition.

***3.4.2.** Point biserial correlation coefficient test of significance*

Analysis of causal - effect "damage - technical wear", combined simultaneously for 10 selected building elements, indicates a significant extent of the force span of these compounds within the same type of elementary damage u_1 - u_{30} (Table 3). In order to compare the extent of the change in the correlation of damage and technical consumption with the direction of change in the sub-probabilities ranges p(u)II, p(u)III, p(u)IV they are recorded in one table 3, marking the association values of those damage which correlate with the technical wear most strongly, i.e. r(Z)>0.5.

Due to such a wide dispersion of the relationship between the measurable variable z_i and the dichotomous variable u_i it was decided to check the importance of this correlation in a sample of 95 to 102 measurements for 10 selected elements of apartment houses. The test of significance of the correlation coefficient r(Z) was carried out, as in the case of the PEARSON and the SPEARMAN tests [12, 123] with the use of the Student's t statistics, defined as follows:

$$t = r(Z)\sqrt{\frac{u-2}{1-[r(Z)]^2}} \tag{8}$$

with the number of degrees of freedom df=u-2. As a result, the exact probability of receiving such a t-statistics value as obtained from a representative sample was calculated, provided that there is a zero hypothesis H_0 (r(Z)=0) against the alternative hypothesis H_1 (r(Z)≠0) and the determination of a bilateral criterion area. The probability of p(s) corresponds to the observed level of significance. In fact, in the case of associating characteristics of different kinds, it would not be a mistake to accept a level of relevance at 10%. However, in order to strongly distinguish those types of damage that most strongly determine the degree of technical wear of building elements, it was assumed that if $p(r)<0.05$ then the correlation tested is indeed significant, and if $0.05 \leq p(r) < 0.10$ it can be considered that there is a tendency to the relationship sought. Table 3 shows the point values, the two-series association coefficients r(Z), highlighting those that correlate most strongly (at a materiality level of 5%) and those which tend to have a correlation between the damage occurring and the amount of technical wear of the buildings elements analysed.

3.5 *Impact of defects on technical wear*

The results of the causal-effect "damage - technical consumption" in a representative sample of inner-city residential buildings built by traditional methods authorize the following conclusions - table 3:

a. the direction of the relationship, as could be expected, is right-hand (positive) for all 10 building elements tested, but the correlation between the damage occurring and their technical wear shows a significant span (0,00 to 0,84);

b. whereas the rule is that the greatest impact on the volume of technical wear of the elements of the tenement houses analysed is damage caused by water penetration and moisture penetration (Group II) - an average of 0,54, which is always an important correlation;

c. the technical condition of each of the test components shall also show the effect of damage characteristic of its structural and material solutions;

d. no less significant damage to wooden parts of the elements (beams of ceilings, stair step, roof bond, window joinery), attacked by biological pests (group IV) - r(Z) = 0.42;

e. mechanical damage to the structure and texture (Group I), the significance of which applies only to those components in which these damage may cause a deepening of the impact of subsequent (cumulative) damage, e.g. construction walls of the underground and overground and interior and external plasters (but no longer foundations or massive basement ceilings);

f. damage resulting in loss of the original shape of wooden elements (group III) may be considered insignificant; except is the dislocation of the window joinery with a correlation of 0,42, for which this damage determines a significant decrease in the value of its function of use.

Table 3. Result of probabilistic relations "defect - technical wear" for 10 selected buildings elements

POINT BISERIAL CORRELATION COEFFICIENT r(Z)i BETWEEN MEASURABLE VARIABLE (zi) AND DYCHOTOMICAL VARIABLE (ui) FOR SAMPLE SIZE OF 95 < U < 102		foundations	walls of basement	solid floor over basement	main walls	inter - storey wooden floors	stairs	roof (rafter framing)	window joinery	inner plasters	facades
def. no.	*type of defect*	r(Z)2	r(Z)3	r(Z)4	r(Z)7	r(Z)8	r(Z)9	r(Z)10	r(Z)13	r(Z)15	r(Z)20
u1	MECHANICAL DEFECTS						0,05		**0,29**	0,09	**0,28**
u2	LEAKS								**0,26**		
u3	MECHANICAL DECREMENTS OF BRICKS	0,13	**0,23**	0,08	**0,19**		0,03				
u4	MECHANICAL DECREMENTS OF MORTAR		**0,28**		**0,30**						
u5	DECREMENTS CAUSED BY ROTTEN BRICKS	0,14	0,07	0,00	**0,17**						
u6	DECREMENTS CAUSED BY ROTTEN MORTAR		0,05		0,09					**0,47**	**0,48**
u7	PAINT COATING'S PEELING OFF									0,15	**0,55**
u8	PAINT COATING'S FALLING OFF									**0,25**	**0,57**
u9	CRAKS OF BRICKS	0,05	0,01	0,05	0,11						
u10	CRAKS OF PLASTER		0,03		0,03					**0,30**	**0,63**
u11	SCRATCHING OF WALLS				**0,21**						
u12	SCRATCHING OF PLASTER				0,12	0,05				**0,18**	**0,63**
u13	LOOSENING OF PLASTER					0,09				**0,67**	**0,81**
u14	PLASTER'S FALLING OFF									**0,57**	**0,50**
u15	SIGNS OF PERMANENT DAMP	**0,70**	**0,74**	**0,58**	**0,56**	0,07		**0,43**	**0,83**	**0,70**	**0,84**
u16	WEEPING	**0,64**	**0,52**	**0,67**	**0,46**	**0,27**	**0,59**	**0,50**	**0,74**	**0,61**	**0,79**
u17	BIOLOGICAL CORROSION OF BRICKS	**0,36**	**0,31**		**0,67**						
u18	HOUSE FUNGUS					**0,45**				**0,38**	**0,60**
u19	MOULD & DECAY	**0,49**	**0,43**		**0,34**				**0,49**	**0,41**	**0,56**
u20	LOCALIZED CORROSION OF STEEL BEAMS			**0,42**			**0,54**				
u21	SURFACE CORROSION OF STEEL BEAMS			**0,29**			**0,61**				
u22	PITTING CORROSION OF STEEL BEAMS			**0,55**			**0,53**				
u23	FLOODING OF FOUNDATION			**0,45**							
u24	WOODEN BEAMS OF FLOOR SENSITIVENESS TO DYNAMIC ACTIVITY OF HUMAN'S WEIGHT					0,00					
u25	DEFORMATION OF WOODEN BEAMS					0,12					
u26	SKEWING OF JOINERY								**0,42**		
u27	WARP OF JOINERY								0,04		
u28	STRATIFICATION OF WOODEN ELEMENTS							0,07			
u29	PARTIAL DETERIORATION OF WOODEN ELEMENTS PEST ATTACKED						**0,38**	**0,28**	**0,45**		
u30	TOTAL DETERIORATION OF WOODEN ELEMENTS PEST ATTACKED					**0,43**		**0,57**	**0,42**		
	number of cases:	100	93	93	100	100	100	100	100	97	100

The strength of relations has been highlighted the following way:

- r(Z)i stands for lack of correlation between "u" and "z"
- **r(Z)i** stands for tendency to correlation between "u" and "z"
- **r(Z)i** stands for strong correlation between "u" and "z"

4. CONCLUSIONS

The correctness of the test results for a representative group of old downtown apartment houses with traditional structure, erected in Wrocław (Poland) at the turn of the 19th and 20th centuries, can be summed up by the following conclusions:

a. Age of elements of old apartment houses with a traditional structure:
   - is of secondary importance in the process of the intensity of loss of its useful values;
   - is not the essential size determining the course of their technical wear and tear;

b. The technical extent of wear and tear of the components of an old residential building is determined by the conditions for its maintenance and use;

c. The previous theoretical methods for measuring the technical wear and tear of the building and its components do not sufficiently describe the actual states, which is called into question:
   - how these methods are assigned to the maintenance conditions of the building;
   - not precise selection of too general forms of mathematical functions;

d. Quantitative damage analysis carried out by experiential methods of assessing the technical condition of the building shall indicate the nature and magnitude of the damage to its components which are characteristic of the relevant maintenance conditions;

e. A study analysis of the processes of operation of residential objects and the basic dependencies of reliability theory made in it indicates that for the useful life of an object in which the working time to damage has an exponential distribution (this is in principle the life expectancy corresponding to the length of service of the dwellings concerned), the average remaining time of unsafe operation is constant at all times. Theoretically, therefore, residential objects, after some time of trouble-free operation, perform their functions as new. The age of the elements of an old residential building is then of secondary importance in the process of the intensity of loss of its useful value;

f. If assumed that the measure of matching the nonlinear mathematical models tested in the nonlinear regression method, as a function of the technical consumption of building elements over time, is the determination factor, then no more than 30% of the destruction of the elements is explained by the passage of time. Age is therefore not a determinant of the technological consumption of the elements of the buildings analysed;

g. Previous theoretical methods for measuring the technical wear and tear of the building and its components do not reflect the actual course of the deterioration process over time. Two facts pay attention:
   - an assessment of the significance of the differences between the theoretical and observed technical consumption distribution values of building elements by WILCOXON test and the Sign Test in most cases confirmed the conclusions of their comparative analysis and showed the significance of the differences between the distributions of theoretical and observed wear, although the Sign Test indicated their identity in the case of foundation distributions, underground walls and structural walls in the all five conditions of maintenance, while both WILCOXON test and the Sign Test confirmed the identity of the distributions only in individual maintenance groups of the building;
   - adopting too general and not always appropriate forms of parabolic and linear functions to describe the theoretical side of the progress of the technical consumption of the building's elements with age; of the four nonlinear regression separable tested, new mathematical models, none of the power (parabolic) models represent the nature of the designated trend of the time-consuming process (very low determination factor and unnatural size of parameterized durability); analysis of variance in the nonlinear regression method also indicates a much better representation of the modelled trend by exposive and hyperbolic dependencies and slightly worse by linear functions;

h. The quantitative analysis of damage, carried out by empirical (visual) methods of assessing the technical condition of the buildings, indicates the type and determines the magnitude of these damage to its components which are characteristic of the appropriate conditions of maintenance. Studies of cause - effect "damage - technical wear" in observed states allow a numerical recognition of the impact of the building's maintenance conditions on the degree of technical wear of its components:
   - the direction of the relationship is right-hand (positive) for all test elements of the building, but the correlation force between the defect occurring and their technical wear shows a significant span (from 0.00 to 0.84) depending on the conditions of the buildings maintenance;
   - the rule is that correlations of at least moderate strength always show damage caused by water penetration and moisture penetration (on average 0,54); only in the case of internal plasters and façade, individual mechanical damage to their structure and texture can also be considered moderate and quite strong;

- for the accepted confidence level of 95%, the dependence of moderate force can be applied to 34-48% of the general population size, and the correlations quite strong - to 49-71%.

5. DISCUSSION AND SUMMING UP

The research – the methodological assumptions and the probabilistic method for the decision making process – should be treated as an exploratory work. However, to some extent, there have been already presented approach to improving systems of housing maintenance decisions, though limited to financial side of the problem, presented by *Schroeder* [25], *Bowles* [26] and *Walls* [27]. Also *Frangopol* [28] and *Plebankiewicz* [29, 30] presented the topic in terms of life-cycle cost design, erection and maintenance of deteriorating buildings. This is extremally crucial approach which should always be taken into account while assessing technical condition and wear of any housing. Similar approach and conceptual method of detecting and analysing construction defects in residential buildings has been presented by *Zima* and *Biel* [31]. Methodological assumptions and findings are in line with outcomes of the laid out paper.

Finally, attention should be paid to the individual nature of the results of the work, based on the research of a homogeneous, coherent group of inner-city rental houses. The transfer of the results of the technical assessment to another population of traditional dwellings should be of great care and the need for surveys. Undoubtedly, such studies should be preceded by careful, deliberate selection of a typological sample representative of the general population. Such an attempt may contain a much smaller number of objects, but it is extremely important that the decisive criterion for selecting for the primary technical assessment are the elements (or only parts thereof) relevant to the structure of the building. Such a division is particularly important for the examination of complex and complex elements. It can then be assumed that, from the point of view of the boundary states of the load capacity of the components, the degree of their technical wear, maintaining the safety and reliability conditions of the facility, is 75%.

The methodological aspects of the reliability of the quantitative results of the technical assessment should also aim at minimising the subjectivity of expert assessment in the process of technical testing of residential buildings, by specifying the type and determination of the variability of at least a few predicted random influences. It is also necessary to remember to supplement the issue of technical research of construction works, especially residential buildings, to fully identify forms of their intangible wear - social and economic. It is a sign of recent times that it is the psychological aspects of the perception of the process of declining the useful value of dwellings by their users themselves, supported by an analysis of the cost-effectiveness of recreating entire buildings, play an essential role in making decision on the future of urban housing development.

The work must therefore be regarded as an exploratory study, the main purpose of which was a model solution to the causal-effect relationship, indicating the type and magnitude of these damage, which express the impact of the conditions of old downtown apartment houses for the technical wear of their components. Like any exploratory solution, it should be considered as a multi-criteria diagnosis of the mechanism of formation and effects of phenomena encountered by adjudicating at each stage of the technical facility's technical assessment. This assessment, in its nature, however, contains a non-measurable aspect (in part subjective). The construction of a new model of technical testing of residential buildings, based on the premises and conclusions of work, will allow the weight of the results of the technical assessment to be shifted from qualitative to quantitative part. The intention of the author is that further work, related to the widely understood diagnosis of technical facilities, should be pursued precisely in this direction.

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LIST OF FIGURES AND TABLES

OCENA TECHNICZNA STARYCH BUDYNKÓW PODEJŚCIEM PROBABILISTYCZNYM

Słowa kluczowe: budynki, ocena techniczna, zużycie techniczne, uszkodzenie, probabilistyka

Badania – metody, modele i wnioski - przedstawione w artykule zawierają syntetyczne i analityczne rozwiązania modelowe dotyczące problemów technicznego utrzymania i zużycia budynków mieszkalnych o konstrukcji tradycyjnej. Związki przyczynowo - skutkowe pomiędzy występowaniem uszkodzeń elementów kamienic czynszowych, traktowanych jako wyraz warunków ich utrzymania, a wielkością procesu technicznego zużycia tych elementów określono na reprezentatywnej, dobranej w sposób celowy, próbie 102 budynków mieszkalnych wzniesionych w drugiej połowie XIX i na początku XX wieku we wrocławskiej dzielnicy „Śródmieście".

Analiza studialna procesów eksploatacji obiektów mieszkalnych i wykonane w niej przekształcenia podstawowych zależności teorii niezawodności wskazuje, że dla okresu użytkowania obiektu, w którym czas poprawnej pracy do uszkodzenia ma rozkład wykładniczy (jest to w zasadzie okres eksploatacji odpowiadający długości czasu użytkowania rozważanych budynków mieszkalnych), średni pozostały czas bezawaryjnej pracy jest w każdym momencie niezmienny. Teoretycznie więc obiekty mieszkalne po upływie pewnego czasu bezawaryjnej pracy spełniają swoje funkcje tak jak nowe. Wiek elementów starego budynku mieszkalnego ma wtedy drugorzędne znaczenie w procesie intensywności utraty jego wartości użytkowych. Jeżeli przyjąć, że miarą dopasowania testowanych w metodzie regresji nieliniowej modeli matematycznych, jako funkcji zużycia technicznego elementów budynków w czasie, jest współczynnik determinacji, to nie więcej niż 30% zniszczenia elementów jest wyjaśniona upływem czasu. Nie wiek zatem jest czynnikiem determinującym przebieg technicznego zużycia elementów analizowanych budynków.

O wielkości technicznego zużycia elementów starego budynku mieszkalnego decydują warunki jego utrzymania i użytkowania. Wyrazem stanu eksploatacji tego budynku, jako procesu odgrywającego największą rolę w jego przyśpieszonym niszczeniu, są następujące uszkodzenia elementów spowodowane penetracją wody i przenikaniem wilgoci, istotne zwłaszcza dla budynków utrzymanych w sposób mierny.

Dotychczasowe teoretyczne metody pomiaru technicznego zużycia budynku i jego elementów nie odzwierciedlają stanu rzeczywistego przebiegu procesu zużycia w czasie. Uwagę zwracają dwa fakty:

- sposób arbitralnego przypisania metod teoretycznych, uwzględniających jako jedyne parametry wiek i trwałość elementów, do warunków utrzymania budynku; ocena istotności różnic pomiędzy teoretycznymi i zaobserwowanymi wartościami rozkładów zużycia technicznego elementów budynków testami Wilcoxona i Znaków w większości przypadków potwierdziła wnioski płynące z ich analizy porównawczej i wykazała istotność różnic pomiędzy rozkładami zużycia teoretycznego a zaobserwowanego, chociaż test Znaków wskazał na ich identyczność w przypadku rozkładów fundamentów, ścian podziemia i ścian konstrukcyjnych we wszystkich pięciu warunkach utrzymania, natomiast oba testy Wilcoxona i Znaków potwierdziły identyczność rozkładów tylko w pojedynczych grupach utrzymania budynku;
- przyjęcie zbyt ogólnych i nie zawsze właściwych postaci funkcji parabolicznych i liniowych do opisu teoretycznej strony postępu zużycia technicznego elementów budynku wraz z wiekiem; spośród czterech, badanych metodą regresji nieliniowej, nowych modeli matematycznych, żadne z modeli potęgowych (parabolicznych) nie reprezentują charakteru wyznaczonego trendu przebiegu procesu zużycia w czasie (bardzo

mały współczynnik determinacji i nienaturalna wielkość sparametryzowanej trwałości); analiza wariancji w metodzie regresji nieliniowej wskazuje ponadto na znacznie lepsze reprezentowanie modelowanego trendu przez zależności ekspotencjalne i hiperboliczne, a nieco gorsze przez funkcje liniowe;

Ilościowa analiza uszkodzeń, przeprowadzona empirycznymi (wizualnymi) metodami oceny stanu technicznego budynku, wskazuje rodzaj i określa wielkość tych zniszczeń jego elementów, które są charakterystyczne dla odpowiednich warunków utrzymania. Badania zależności przyczynowo - skutkowych „uszkodzenie - zużycie techniczne" w stanach zaobserwowanych pozwalają na liczbowe ujęcie wpływu warunków utrzymania budynku na stopień technicznego zużycia jego elementów:

- kierunek związku jest prawostronny (dodatni) dla wszystkich badanych elementów budynku, ale siła korelacji pomiędzy występującymi uszkodzeniami a ich technicznym zużyciem wykazuje znaczną rozpiętość (od 0,00 do 0,84) w zależności od warunków utrzymania budynku;
- regułą jest, że korelację o sile co najmniej umiarkowanej wykazują zawsze uszkodzenia spowodowane penetracją wody i przenikaniem wilgoci (średnio 0,54); tylko w przypadku tynków wewnętrznych i elewacji za umiarkowane i dość silne można uznać także pojedyncze uszkodzenia mechaniczne ich struktury i faktury;
- dla przyjętego poziomu ufności 95%, zależności siły umiarkowanej można odnieść do 34-48% wielkości populacji generalnej, a korelacje dość silne - do 49-71%;

Warto zauważyć, że omawiane dane ilościowe mogą stanowić podstawę do programowania wielkości i struktury specjalistycznych firm budowlanych zajmujących się konserwacją i remontami budynków mieszkalnych. Składają na informację techniczną niezbędną do zarządzania budynkami i projektowania organizacji tych działań obsługi technicznej obiektów mieszkalnych, które stanowią o jakości szeroko rozumianych warunków utrzymania zasobów mieszkaniowych.

Trzeba zwrócić uwagę na indywidualny charakter wyników pracy, opartej na badaniach jednorodnej, spójnej grupy śródmiejskich kamienic czynszowych. Przeniesienie rezultatów oceny technicznej na inną populację budynków mieszkalnych o konstrukcji tradycyjnej powinno się cechować dużą ostrożnością i koniecznością wykonania badań sondażowych. Niewątpliwie takie badania powinny być poprzedzone starannym, celowym doborem typologicznej próby reprezentatywnej dla populacji generalnej. Próba taka może zawierać znacznie mniejszą liczbę obiektów, ale niezmiernie ważne jest, aby decydującym kryterium wyboru do pierwszoplanowej oceny technicznej były elementy (lub tylko ich części) istotne dla konstrukcji (ustroju nośnego) budynku. Taki podział ma szczególne znaczenie w przypadku badania elementów zespolonych i złożonych. Można wtedy przyjąć, że z punktu widzenia stanów granicznych nośności elementów, stopień ich technicznego zużycia, zachowujący warunki bezpieczeństwa i niezawodności obiektu, wynosi 75%.

Metodologiczne aspekty wiarygodności ilościowych wyników oceny technicznej powinny ponadto zmierzać w kierunku zminimalizowania subiektywności oceny ekspertów w procesie technicznych badań budynków mieszkalnych, poprzez wyszczególnienie rodzaju i określenie zmienności przynajmniej kilku przewidywanych wpływów losowych. Trzeba również pamiętać o uzupełnieniu zagadnienia technicznych badań obiektów budowlanych, a zwłaszcza budynków mieszkalnych, o pełne rozpoznanie form ich niematerialnego zużycia - społecznego i ekonomicznego. Jest znakiem ostatnich czasów, że właśnie psychologiczne aspekty postrzegania procesu spadku wartości użytkowej mieszkań przez samych ich użytkowników, poparte analizą opłacalności odtworzenia całych budynków, odgrywają zasadniczą rolę w podejmowaniu decyzji dotyczącej przyszłości śródmiejskiej zabudowy mieszkaniowej.

Badania powinno się traktować jako opracowanie eksploratorskie, którego głównym celem było modelowe rozwiązanie zależności przyczynowo - skutkowych, wskazujących na rodzaj i wielkość tych uszkodzeń, które wyrażają wpływ warunków utrzymania śródmiejskich budynków mieszkalnych na techniczne zużycie ich elementów. Jak każde rozwiązanie eksploratorskie, powinno być traktowane jako wielokryterialne rozpoznanie mechanizmu powstawania i skutków zjawisk, z którymi styka się orzekający na każdym etapie oceny technicznej obiektu technicznego. Ocena ta, w swojej naturze jednak, zawiera aspekt niemierzalny (w części subiektywny). Budowa nowego modelu badań technicznych budynków mieszkalnych, opartego na przesłankach i wnioskach wynikających z pracy, pozwoli na przesunięcie ciężaru rezultatów oceny technicznej z części jakościowej na ilościową. Intencją autora jest aby dalsze prace, związane z szeroko pojętym diagnozowaniem obiektów technicznych, zmierzały właśnie w tym kierunku.

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