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THE INVESTIGATION OF THE FACTORS WHICH LEAD TO THE DESTRUCTION OF ORTHODOX CHURCH BUILDINGS AND THEIR PARTS

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Annotation. *Problem Statement.* The main characteristic of the buildings, including Orthodox churches, is a reliability index. It depends on the service condition and includes reliability, durability, effective age of a structure and suitability of buildings and their separate elements to repairs [4; 10]. Despite the fact that the greatest losses Ukrainian architectural heritage have suffered from the policy of the communist regime and utilitarian, equally important factor was the low cultural standard of living. A number of lost churches as a result of neglect and "unconscious vandalism" is equal to the losses that were caused by the First and Second World Wars [2; 9]. As a result of the increase, the intensity of the adverse factors impact on Orthodox churches building their reliability is reduced. Since the dominant number of scientific publications dealing with technical condition and methods of restoration only for particular buildings, it is still no common data on the primary cause of the destruction of Orthodox churches. The main unexplored issues include the following: 1) what kinds of structural destructions have a mass character; 2) what kinds of what factors have a critical role in reducing building reliability index; 3) what are the main causes of the loss of interior decoration of churches. Research in this area will help to prioritize the development of constructive and technological solutions for the restoration of Ukrainian sacral architectural heritage. *The purpose of the article.* To identify factors which have the most impact on the durability of supporting structures of stone Orthodox churches (including which were built before 1917) and preserve their interior decoration on the basis of the expert survey. *Conclusion.* According to the results of expert evaluation and calculations, found that: cupolas, vaults (domes) and vertical bearing structures suffered the most significant losses; the main destructive factors of Orthodox churches can be considered disturbance of building structural scheme of the building, disturbance of service condition, temperature and humidity condition; mistakes in the design and construction of churches caused minimal loss of Orthodox church (due to the fact that churches are considered those that have survived).

Keywords: *expert evaluation, the expert group, destroying factors, the durability of construction, stone Orthodox churches, decorative finishing*

ДОСЛІДЖЕННЯ ФАКТОРІВ, ЯКІ СПРИЧИНЮЮТЬ РУЙНУВАННЯ БУДІВЕЛЬ ПРАВОСЛАВНИХ ХРАМІВ І ОКРЕМИХ ЇХ ЧАСТИН

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Анотація. *Постановка проблеми.* Показник надійності − основна характеристика будівель, в тому числі й православних храмів, яка залежить від умов експлуатації. Він включає в себе безвідмовність, довговічність, ступінь збереження та придатності до ремонтів будівлі та окремих її елементів. Незважаючи на те, що найбільших втрат архітектурна спадщина України зазнала від політики комуністичного та утилітарного режиму, не менш важливим чинником виявився низький культурний рівень життя. Кількість втрачених церков у результаті недбалого ставлення та «несвідомого вандалізму» дорівнює втратам, які були спричинені Першою та Другою світовими війнами. Саме підвищена інтенсивність дії несприятливих факторів на будівлі православних храмів зумовила зниження їх надійності. Оскільки у науковій літературі питання дослідження технічного стану православних храмів і методів їх відновлення наводяться лише для конкретних об'єктів, досі лишається не відомим руйнування яких конструктивних елементів мають масовий характер, які фактори відіграють вирішальну роль у зниженні коефіцієнта надійності будівель та які основні причини втрати внутрішнього оздоблення храмів. Дослідження у цьому напрямку дозволять визначити пріоритетність розроблення конструктивних і технологічних рішень для збереження сакральної архітектурної спадщини України. *Мета статті* − на основі методу експертного оцінювання визначити фактори, які мають найбільший вплив на довговічність несних конструкцій кам'яних православних храмів (у тому числі зведених до 1917 року) і збереження їх оздоблення. *Висновки.* Встановлено, що найбільш значних втрат зазнали конструкції верхів і вертикальних несних конструкцій; основними руйнівними факторами православних церков можна вважати порушення конструктивної схеми будівлі, умов експлуатації та температурно-вологісного режиму; мінімальних втрат завдали православним храмам помилки у їх проектуванні та зведенні.

Ключові слова: *експертне оцінювання, експертна група, руйнівні фактори, довговічність конструкцій, кам'яні православні храми, оздоблення*

ИССЛЕДОВАНИЕ ФАКТОРОВ, КОТОРЫЕ ПРИВОДЯТ К РАЗРУШЕНИЮ ЗДАНИЙ ПРАВОСЛАВНЫХ ХРАМОВ И ОТДЕЛЬНЫХ ИХ ЧАСТЕЙ

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Аннотация. ***Постановка проблемы.*** Показатель надежности – основная характеристика зданий, в том числе и православных храмов, которая зависит от условий эксплуатации. Он включает в себя безотказность, долговечность, степень сохранности и пригодности для ремонтов здания и отдельных его элементов. Несмотря на то, что наибольшие потери архитектурное наследие Украины понесло из-за политики коммунистического и утилитарного режима, не менее важным фактором оказался низкий культурный уровень жизни. Количество утраченных храмов в результате халатного отношения и «бессознательного вандализма» равняется потерям, которые были вызваны Первой и Второй мировыми войнами. Именно повышение интенсивности влияния неблагоприятных факторов на здания православных храмов приводит к снижению коэффициента надежности. Поскольку в научной литературе вопрос исследования технического состояния православных церквей и методов их восстановления описывается только для конкретных объектов, до настоящего времени не установлено: разрушения каких конструктивных элементов имеют наиболее распространенный характер; какие факторы выполняют решающую роль в снижении коэффициента надежности здания; какие основные причины разрушения внутренней отделки храмов. Исследования в данном направлении позволят определить приоритетность разработки конструктивных и технологических решений для сохранения сакрального архитектурного наследия. ***Цель статьи*** − на основании метода экспертной оценки определить факторы, которые имеют наибольшее влияние на долговечность несущих каменных православных храмов (в том числе и возведенных до 1917 года) и сохранность их отделки. ***Выводы.*** Установлено, что наибольшая часть потерь приходится на верхушки и вертикальные несущие конструкции; к основным разрушающим факторам православных - храмов относятся нарушение конструктивной схемы здания, условий эксплуатации и температурно влажностного режима; ошибки проектирования и возведения причинили минимальный ущерб.

Ключевые слова: *экспертная оценка, экспертная группа, разрушающие факторы, долговечность конструкций, каменные православные храмы, отделка*

Problem Statement. The main characteristic of the buildings, including Orthodox churches, is a reliability index. It depends on the service condition and includes reliability, durability, effective age of a structure and suitability of buildings and their separate elements to repairs [4; 10].

Despite the fact that the greatest losses Ukrainian architectural heritage have suffered from the policy of the communist regime and utilitarian, equally important factor was the low cultural standard of living. A number of lost churches as a result of neglect and "unconscious vandalism" is equal to the losses that were caused by the First and Second World Wars [2; 9]. As a result of the increase, the intensity of the adverse factors impact on Orthodox churches building their reliability is reduced.

Since the dominant number of scientific publications dealing with technical condition and methods of restoration only for particular buildings, it is still no common data on the primary cause of the destruction of Orthodox churches. The main unexplored issues include the following: 1) what kinds of structural destructions have a mass character; 2) what kinds of what factors have a critical role in reducing building reliability index; 3) what are the main causes of the loss of interior decoration of churches.

Research in this area will help to prioritize the development of constructive and technological solutions for the restoration of Ukrainian sacral architectural heritage.

Analysis of publications. A considerable amount of research was carried out by domestic and foreign scientists to study the factors that affect the durability of sacred buildings [1; 8; 11; 12]. The cause and nature of the destruction of bearing structures of buildings, methods for their strengthening and renovation were interpreted in their works.

The purpose of the article. To identify factors which have the most impact on the durability of supporting structures of stone Orthodox churches (including which were built before 1917) and preserve their interior decoration on the basis of the expert survey.

The presentation material. To determine the main reasons for the loss and destruction of stone Orthodox churches, members of the architectural heritage, the study was conducted by an expert evaluation. It was made in two stages: the first stage is the identification of the most common factors that affect the durability of supporting structures and buildings in general; the second stage is to determine the cause of losses interior decoration of Orthodox churches [5; 6].

The study of the causes of the main supporting structures churches destruction was done in 2 levels. The aim of the first level is to establish constructive elements of Orthodox churches buildings have the greatest damage and defects discovered by the technical survey. The purpose of the second level is to define which factors have the greatest negative impact on the technical condition of the main load-bearing elements.

Rational organization of expert analysis of the problem of quantitative assessment and treatment results has allowed to find a solution to the research questions (Fig.1).

In this study, experts offered only those factors which influence can be avoided or reduced. It follows that the occasional emergency factors such as military actions, vandalism, natural disasters, fires, were not considered.

The main information source in the formation of expert evaluations is experts. Therefore, there are special requirements for the selection of the expert group, including determination of their level of professional competence. Lack of expert competence can lead to rough errors in expertise data, and consequently to the uncertainty of results [3; 7].

The candidate suitability to participate in the expert evaluation was carried out by self-assessment and by calculation of the candidate competence coefficient (K_i), which is determined by the formula:

$$K_i = \frac{\sum_{j=1}^{3} K_{ij}}{3}, \qquad (1)$$

where K_{i1} – information coefficient of the i-th candidate;

K_{i2} – personality measure of the i-th candidate;

K_{i3} – work stability coefficient of the i-th candidate.

Informativity of the candidate is determined by the experience of his work (the number of years devoted to Orthodox architecture and the number of finished projects) and the relevance of his knowledge in the study area (remoteness of publication of written evidence on the survey, the design and the restoration of Orthodox churches).

For the assessment of individual qualities, the initial data was taken from observations of the teamwork, speed and objectivity in decision-making, organization and punctuality. To determine this coefficient there is used scoring whose values are in the range of 0.1 to 1, where 1 is the best result, 0.1 is the worst result.

Experience in the building industry served as an indicator of the work stability of the candidate. It was estimated as follows: 1 – 2 years - 0.2, 3 - 4 years - 0.4, 5 - 6 years - 0.8, 7 – 8 years - 1.0.

Quantitative composition of expert groups for each stage is established by the formula:

$$m_{min} < m < m_{max}, \qquad (2)$$

where m_{min} – minimum number of experts:

$$m_{min} > n, \qquad (3)$$

where n – number of factors, which are investigated;

$m_{мах}$ – the maximum number of experts:

$$m_{max} = 0.5 * \left(\frac{3}{r} + 5\right), \qquad (4)$$

where r – allowable error in the results of the evaluation ($0 < r < 1$).

The expert survey was carried out by using questionnaire, which included objects of research. Experts have fulfilled ranking (ordering) of the objects of expertise, namely, have arranged them in order intensity characteristics of reduction (a factor which received the highest praise from the expert receives 1).

1. Preparatory stage

Define the goals and objectives of the expert judgement

Define the composition of the working group

Formation of the expert committee:
- make an initial list of candidates;
- formation of an extended list of candidates;
- determine the competence factor of candidates;
- quantitative determination of the expert committee;
- the final determination of the expert committee.

2. Information stage

Determination the methods for data collection

Determine the type of grading scale

Development of forms to obtain expert data

3. Collection expert assessments by questionnaire

4. Analysis of questionnaire

Assessment-rank conversion

Analysis of the significance of the investigated factors

Evaluation of middle degree of concordance of all expert opinions (W)

Yes — $W \geq 70\%$ — No

Evaluation of concordance coefficient (Pearson criterion χ^2)

Yes — $\chi^2_{prox} \geq \chi^2_{cr}$ — No

Construction of sum rangs bar plot to factors

Preparation of expert committee solution (determination of the weight coefficient)
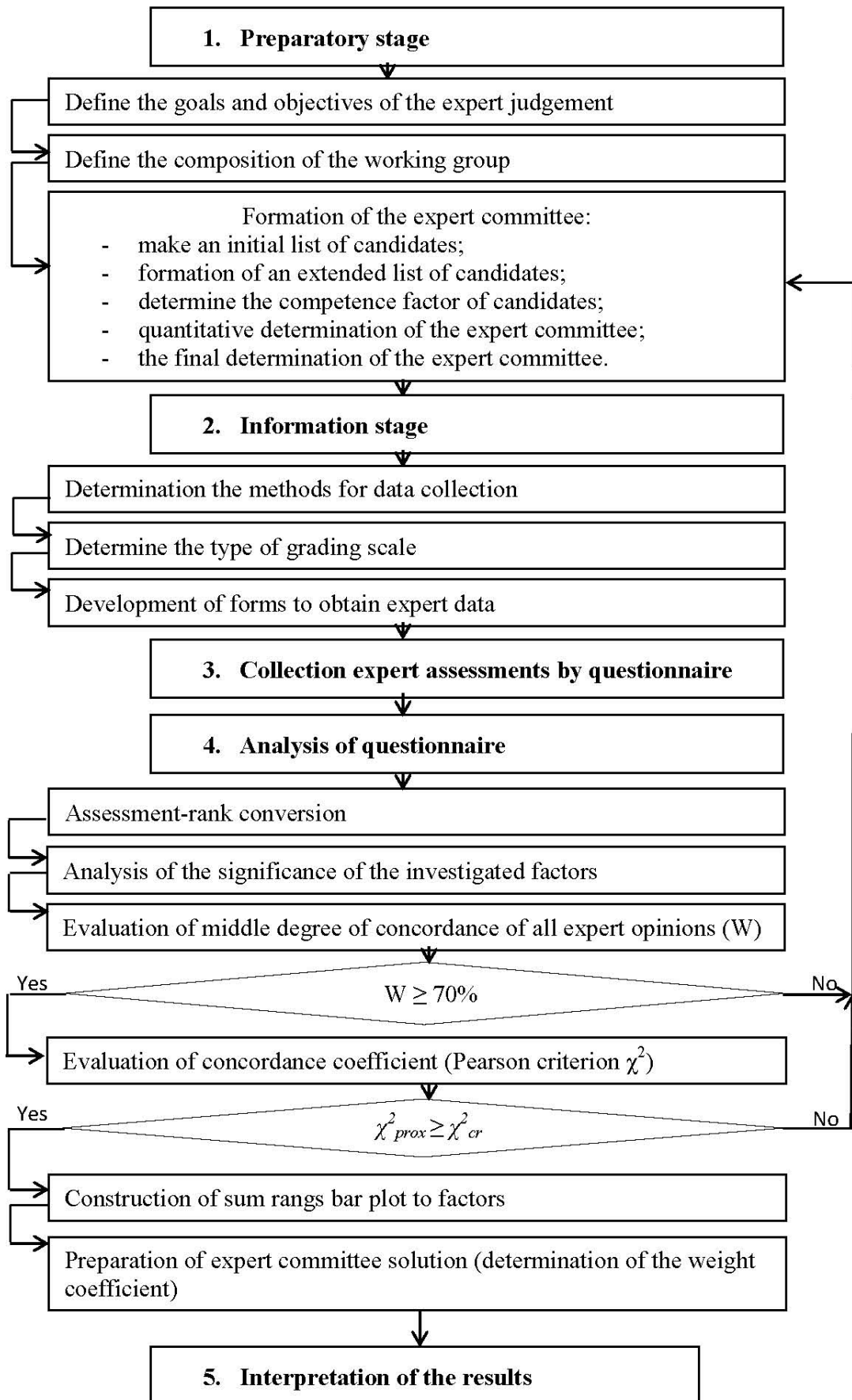
5. Interpretation of the results

Fig. 1 - Implementation of expert evaluation algorithm

To establish the degree of harmonization of experts opinions, the coefficient of concordance (*W*) for the case when the results of the evaluation are related ranks is determined:

$$W = \frac{S}{\frac{1}{12}m^2(n^3-n)-m\sum T_i},\qquad(5)$$

where *S* – total sample of variation:

$$S = \sum(\sum x_{ij} - \frac{\sum\sum x_{ij}}{n})^2,\qquad(6)$$

where *n* – number of experts who participated in the questionnaire;

m - total number of investigated factors;

T_i – number of links (types of repetitive elements) in the assessments of the i-th expert:

$$T_i = \frac{1}{12}\sum(t_k^3 - t_k),\qquad(7)$$

where t_k – the number of elements in the *k*-th link for the i-th expert (the number of repetitive elements).

Since the concordance coefficient is the random variable, as there was a need to assess its significance. To test the statistical hypothesis (H_0: Expert views coincided by chance, H_A: Expert views coincided not by chance) there was calculated Pearson criterion χ^2 with a number of freedom degrees (v = n-1), which is determined by the formula:

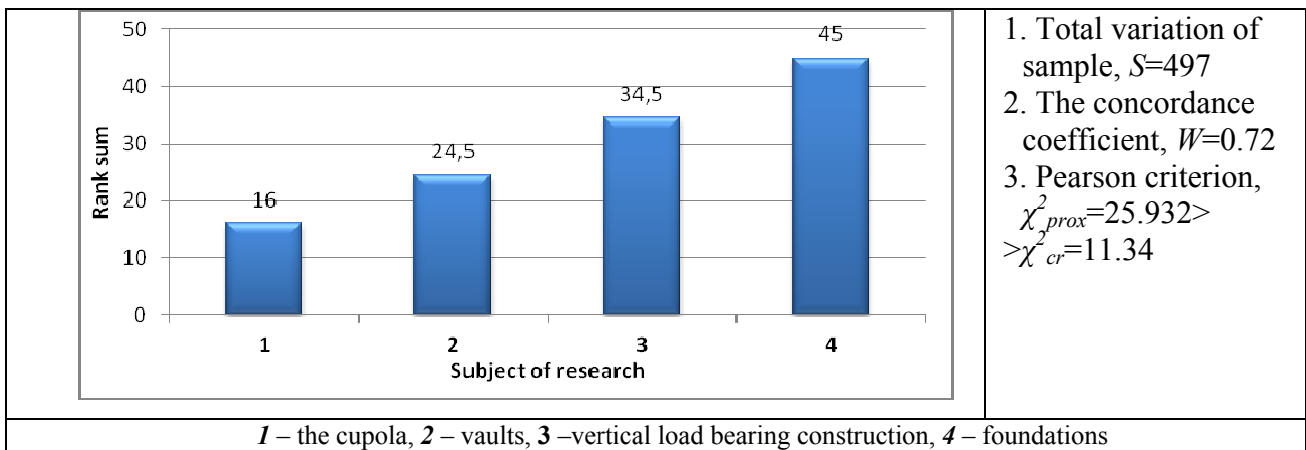$$\chi^2_{prox} = \frac{12S}{mn(n+1)-\frac{1}{n-1}\sum T_i}.\qquad(8)$$

	1. Total variation of sample, S=497
	2. The concordance coefficient, W=0.72
	3. Pearson criterion, χ^2_{prox}=25.932> >χ^2_{cr}=11.34

1 – the cupola, *2* – vaults, *3* –vertical load bearing construction, *4* – foundations

Fig. 2 – The rank sum bar plot of factors (destruction of the main structures of Orthodox churches)

	1. Total variation of sample, S=17272
	2. The concordance coefficient, W=0.70
	3. Pearson criterion, χ^2_{prox}=105.2> >χ^2_{cr}=23.2

d.1 − absence of the roof covering; *d.2* − disturbance of building structural scheme; *d.3* − lack or removal of the dome bracing; *d.4* – biological damage of vaults and structure of cupolas; *d.5* − disturbance of renovation technology; *d.6* – use of building materials which are not compatible and reversible for primary; *d.7* − disturbance of service condition, temperature and humidity condition; *d.8* − absorption of environmental pollution; *d.9* − physical aging of vaults building material; *d.10* − mistakes in the designing or detailing of the building; *d.11* − mistakes in the construction of the building.
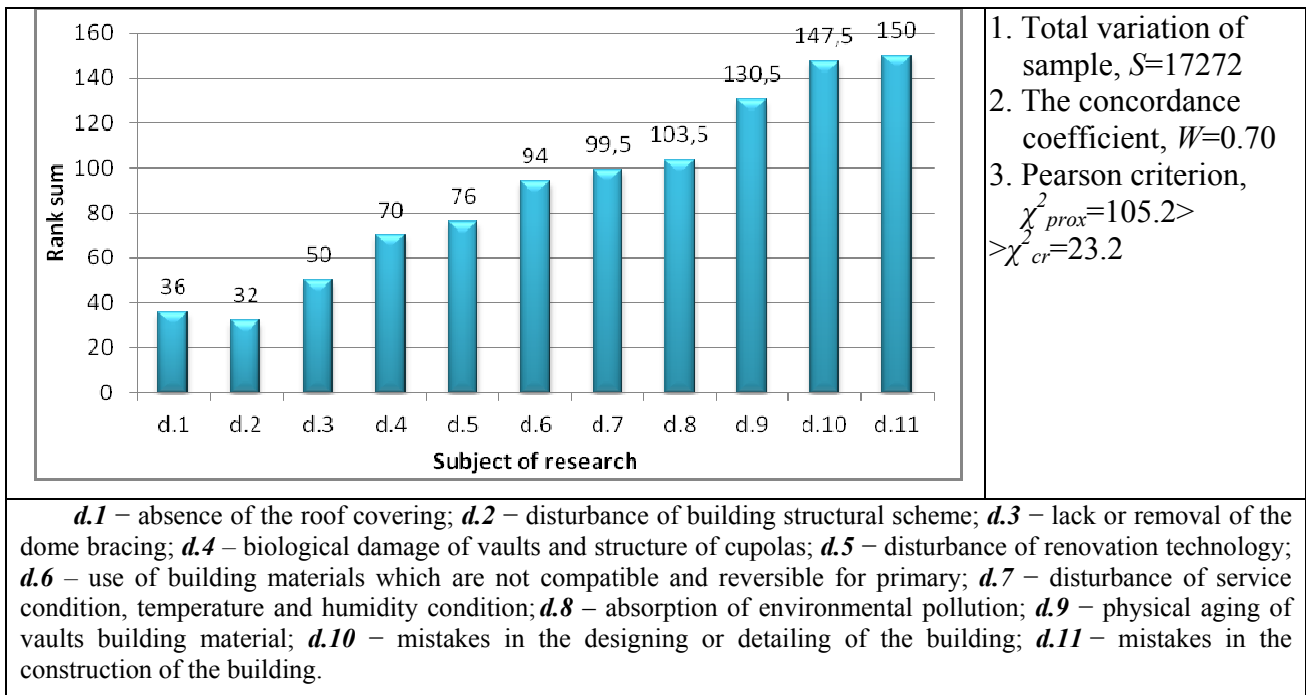
Fig. 3 – The rank sum bar plot of factors, which influence on domes technical condition of Orthodox churches

1. Total variation of sample, S=18319
2. The concordance coefficient, W=0.74
3. Pearson criterion, χ^2_{prox}=111.5> >χ^2_{cr}=23.2

v.1 – disturbance of building structural scheme; *v.2* – disturbance of service condition, temperature and humidity condition; *v.3* – softening or process of deterioration of the masonry surface layers due to frost and sulphate wearing; *v.4* – biological damage of structure; *v.5* – disintegration and softening of full-thickness masonry with fallback or without it, the strength characteristics of bricks and mortars were of the of masonry with a reduced; *v.6* – use of building materials which are not compatible and reversible for primary; *v.7* – absence of controlled water disposal; *v.8* – disturbance of renovation technology; *v.9* – physical aging of vaults building material; *v.10* – mistakes in the designing or detailing of the building; *v.11* – mistakes in the construction of the building.
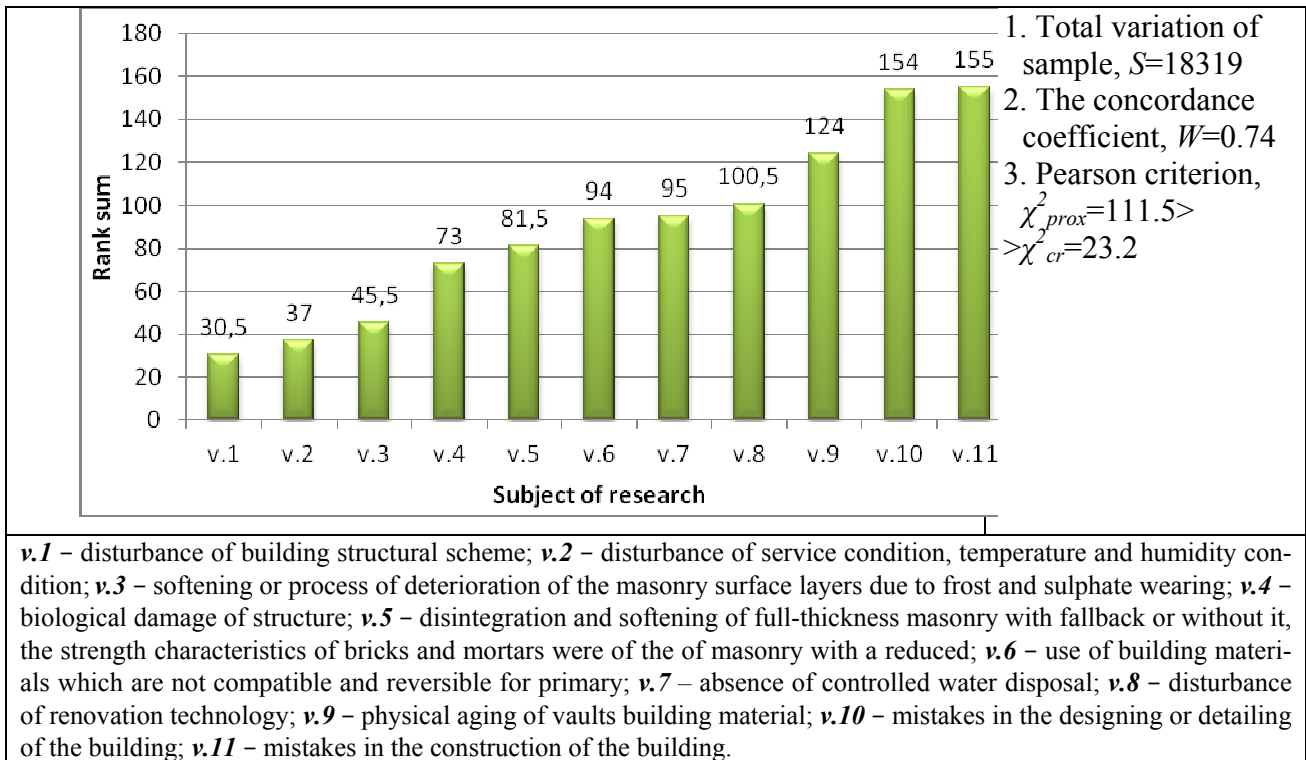
Fig. 4 – The rank sum bar plot of factors, which influence on technical condition of vertical load bearing constructions of Orthodox churches
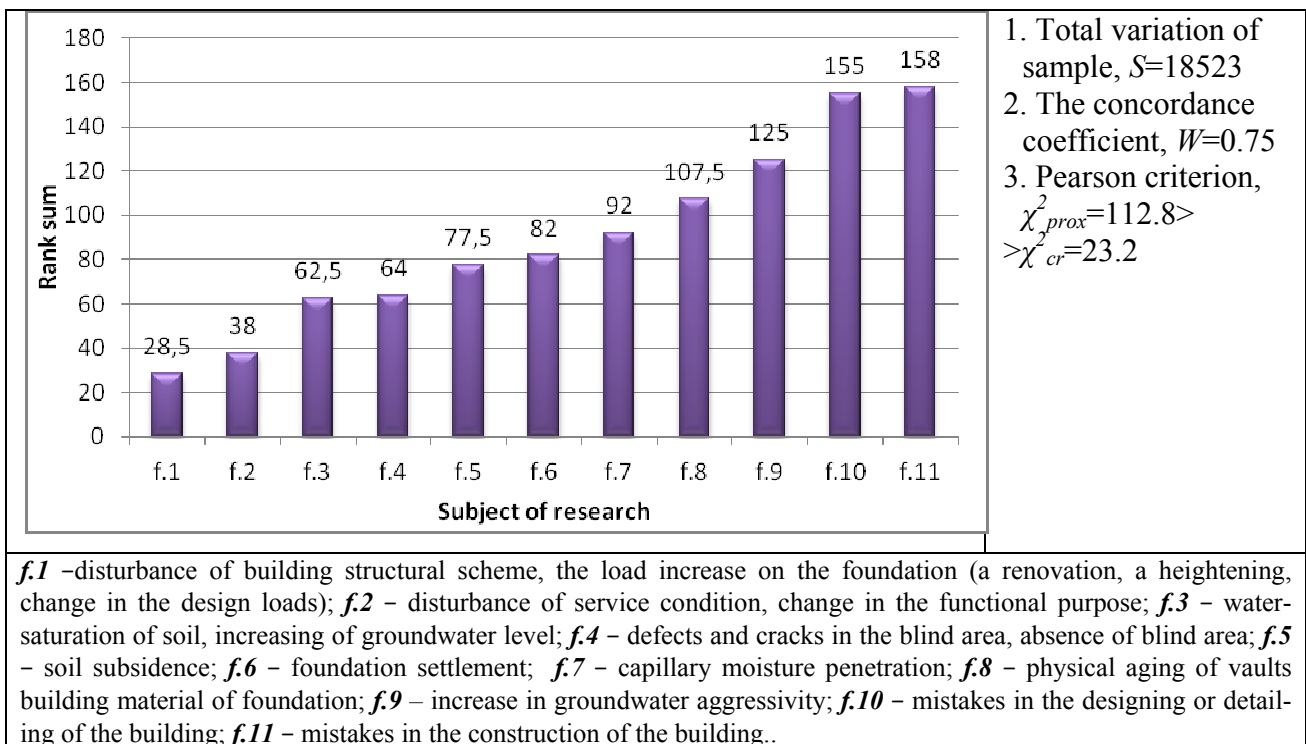

1. Total variation of sample, S=18523
2. The concordance coefficient, W=0.75
3. Pearson criterion, χ^2_{prox}=112.8> >χ^2_{cr}=23.2

f.1 –disturbance of building structural scheme, the load increase on the foundation (a renovation, a heightening, change in the design loads); *f.2* – disturbance of service condition, change in the functional purpose; *f.3* – water-saturation of soil, increasing of groundwater level; *f.4* – defects and cracks in the blind area, absence of blind area; *f.5* – soil subsidence; *f.6* – foundation settlement; *f.7* – capillary moisture penetration; *f.8* – physical aging of vaults building material of foundation; *f.9* – increase in groundwater aggressivity; *f.10* – mistakes in the designing or detailing of the building; *f.11* – mistakes in the construction of the building..

Fig. 5 – The rank sum bar plot of factors, which influence on foundation technical condition of Orthodox churches

The critical criterion (χ^2_{cr}) is determined using a table of Pearson distribution at a significance level of α = 0.01 and degrees of freedom ν = n − 1. If $\chi^2_{prox} \geq \chi^2_{cr}$, the null hypothesis is refuted, that is no reason to believe that the experts' opinions coincided by chance.

As a result of research obtained diagrams of total ranks (Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6), where the axis of abscissa was postponed objects of study, and the vertical axis

postponed the sum of ranks. Since more powerful factors received the lowest rank (numerically) in stage ranking, then their sum of ranks will be low and consequently, they have the lowest value.

Thus, according to the results of expert evaluation and calculations, found that:

➤ cupolas, vaults (domes) and vertical bearing structures (walls, columns, pylons) suffered the most significant losses;

➤ the main destructive factors of Orthodox churches can be considered disturbance of building structural scheme of the building, disturbance of service condition, temperature and humidity condition;

➤ mistakes in the design and construction of churches caused minimal loss of Orthodox church (due to the fact that churches are considered those that have survived).

1. Total variation of sample, S=497
2. The concordance coefficient, W=0.72
3. Pearson criterion, χ^2_{prox}=25.93> >χ^2_{cr}=11.34

i.1 − disturbance of temperature and humidity condition; *i.2* − disturbance of renovation technology; *i.3* − use of building materials which are not compatible and reversible for primary; *i.4* − paintings destruction due to pollution
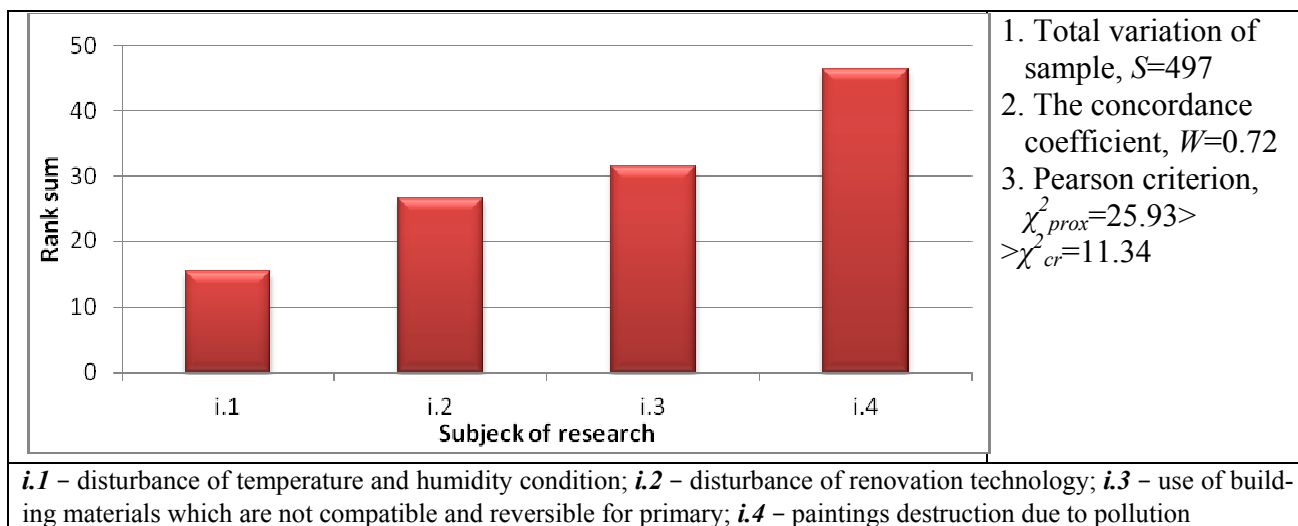
Fig. 6 – The rank sum bar plot of factors, which have the most negative impact on the interior decoration of Orthodox churches

Conclusion. Since the restoration works are the first to eliminate the negative impact of internal and external destructive factors, which sufficient attention should be paid to production technology works and the selection of building materials. Therefore, not there only will be able to improve the service conditions of the sacral monuments, but also reduce the influence of controllable destructive factors, such as disturbance of technological processes, using of incompatible or reversible materials, etc.

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