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Method for developing a corporate BIM classification system

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Abstract. The advancement of building information modeling (BIM) technologies is driving the implementation of construction information classification systems (CICS) to structure and standardize data across all phases of a project's lifecycle. This study aims to develop a formalized method for the formation of CICS, incorporate algorithms for selecting expert groups, develop the classification system, and assess its quality using the Delphi method. The proposed approach systematizes the classifier development process and ensures the incorporation of expert opinions, thereby enhancing the objectivity of evaluation and minimizing the risk of subjective distortions. The method consists of multiple iterative development cycles, each accompanied by testing and expert evaluation of the implemented improvements. To assess the effectiveness of the proposed approach, a comparative analysis was conducted, evaluating time and financial expenditures as well as the quality of the classification systems obtained using both the traditional and the newly proposed methods. The method was tested in a real-world production environment, where the CICS developed using the new method received 45 % higher expert ratings compared to traditional methods, while time and financial costs were reduced by 43 %. Thus, the application of the developed method optimizes the formation of CICS and enhances the quality of the final outcome, which is particularly relevant given the increasing complexity of construction projects and the accelerating digitalization of the construction industry.

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1. Introduction

In recent years, building information modeling (BIM) technologies have significantly transformed the processes of design, construction, and operation of buildings. Unlike traditional methods, where information is distributed among various participants, BIM creates a unified digital model that integrates data on geometry, materials, energy consumption, work schedules, costs, and other characteristics of the building. This model becomes the foundation for decision-making at all stages of the building's lifecycle – from initial design and detailed planning to its operation and subsequent maintenance. Thus, BIM contributes to the full digital transformation of construction processes, ensuring the relevance and availability of real-time information [1, 2]. This significantly enhances the accuracy of design decisions and reduces the number of errors occurring during data transfer between different project participants. As a result, collaboration among architects, engineers, builders, estimators, and other professionals becomes more coordinated and transparent, significantly reducing the time for project development and implementation, lowering costs and enhancing overall efficiency [3, 4].

An important feature of BIM is its ability to model not only the geometric and structural characteristics of buildings but also their operational attributes, such as energy efficiency and material durability, which enables the design of sustainable and energy-efficient buildings [5, 6]. Furthermore, the ability to create digital twins of buildings enables the simulation and testing of various operational scenarios, thereby significantly enhancing the predictability of building behavior over time, including potential emergency situations and repair needs [7, 8].

Against the backdrop of the global digitalization of construction processes, BIM technologies are being increasingly implemented in Russia. In particular, the Russian Federation Government Decree No. 331 dated March 5, 2021, mandates the compulsory use of BIM technologies for developers of multi-apartment buildings during the design phase, starting from July 1, 2024. Despite significant progress, according to data from DOM.RF as of January 14, 2025, only 30 % of Russian developers actively use or pilot BIM technologies, while 70 % of developers have yet to integrate these technologies into their processes [9].

One of the key stages in the implementation of BIM is the development and use of a construction information classification system (CICS), which ensures the structuring of data from information models. CICS is a tool that allows for the organization, systematization, and unification of information across all stages of the life cycle of a project. Unlike the traditional approach, where data tends to be fragmented and difficult to access, the classifier creates a structured and logically organized database, ensuring a unified data representation format. This simplifies access to information and makes it more comprehensible for all project participants, from designers to builders, reducing the likelihood of errors and misunderstandings related to the interpretation of information [10, 11].

Classification also allows for the prompt retrieval of necessary data, significantly speeding up the decision-making process. For example, when creating and managing projects, where each stage requires accurate and timely information, structured data prevents time-consuming searches and eliminates information duplication. In this context, the use of CICS not only increases work efficiency but also significantly improves communication among project participants, reducing the risks of errors and delays in construction and design processes [12]. This approach also fosters better interaction between various systems used for automating construction processes, such as project management systems, software solutions for cost estimation and schedule planning, as well as software for cost assessment and deadline control [13, 14].

Different construction and design processes require specific CICS, which determines their variety. For example, in 2020, a domestic CICS was developed by the Federal center of regulation, standardization and technical assessment of compliance in construction (FTSS FAU) for state expertise compliance. This classifier is responsible for the standardization of data to comply with regulatory requirements in construction. However, for other specialized tasks, such as the creation of work volume statements, the development of work schedules and cost estimation, corporate CICS are required, adapted to specific business processes and the employer's information requirements (EIR). It is important that such corporate classifiers may include not only standard data but also specialized categories unique to particular projects or companies, which allows for accounting for each construction object's distinct characteristics and operational requirements [15, 16].

For the effective implementation of corporate CICS, developers can select from several creation methods at the initial stages of BIM implementation, each characterized by distinct features and requirements. There are four primary strategies for developing corporate CICS: creating a classifier from scratch, modifying the existing CICS developed by FTSS FAU, adapting international classification systems, and using modified CICS from other Russian developers.

Each of these options has its advantages and limitations, and the choice depends on the specific conditions and needs of the developer. For example, creating a CICS from scratch requires significant effort and resources, as it not only involves the development of the classifier structure but also requires a comprehensive analysis of the company’s business processes and coordination with other participants in the construction process. In the case of modifying the CICS developed by FTSS FAU or adapting international classifiers, developers can save significant time since these classifiers already contain standardized data categories; however, they require further customization to fit specific conditions. Modifying CICS from other Russian developers is a less popular option since such classifiers are usually not published in the public domain, limiting the possibility of their use and further adaptation.

In this regard, an important aspect when choosing an approach for developing a corporate CICS is the evaluation of available international classification systems that have already proven their effectiveness on a global scale and can serve as a foundation for adaptation to the needs of the developer [17]. In the global construction practice, there are many well-known and proven classification systems, such as Uniformat, MasterFormat, OmniClass, Uniclass, CoClass, and others, each of which has its own specifics and area of application. At the international level, these systems have gained wide recognition due to their functional flexibility and ability to meet diverse requirements in construction management [10, 18].

As a result of a comparative analysis of 12 existing classification systems [19], it was found that the CoClass, the CICS developed by FTSS FAU, Uniclass, and OmniClass represent the most suitable solutions for use in the practice of developers. These systems are characterized by a multifaceted structure that uses a functional grouping approach and are open standards in compliance with international norms. Among the systems considered, special attention should be given to OmniClass and Uniclass, which are widely applied in international practice and cover various aspects of construction activities. OmniClass has additional advantages over Uniclass since it includes recognized classifications, such as MasterFormat and Uniformat, which significantly increase its functional flexibility and areas of application. Moreover, OmniClass is supported by one of the leading international organizations in building information modeling – buildingSMART, which confirms its high relevance and alignment with the latest global trends in the standardization of construction information [20].

The CICS, developed by FTSS FAU, is a system designed for structuring and classifying data in the construction sector. The main objective of CICS is the standardization and unification of construction information, which facilitates its processing, storage, and use at various stages of the building life cycle. CICS includes the classification of construction materials, structures, equipment, and processes, enabling the effective organization and integration of information during the design and operational stages [21].

CoClass is a facet-based classification system based on the Swedish system Byggandets Samordning AB (BSAB). Developed in 1972, it was modified and presented as CoClass at the end of the BSAB 2.0 project. The system includes seven primary and two additional tables, with elements encoded using alphanumeric combinations. CoClass supports open standards, object-orientation and complies with ISO 12006-2, making it suitable for international use in the construction industry [22].

Uniclass is an international classification system developed in the United Kingdom in 1997 to organize the stages of the building life cycle. Initially, it adhered to ISO TR 14177, and later it was adapted to ISO 12006-2 [23]. The system consists of 11 tables, allowing the classification of more than 6,500 elements, such as pipelines, that can be used in various systems. Uniclass is applied for asset and facility management, providing an accurate link between construction elements and their functional roles [24].

OmniClass is a classification system covering the entire building life cycle, from design to demolition. Developed in 2006, it includes 15 tables, each with a multi-level coding system for precise identification of elements [25]. OmniClass integrates data from various classifications, such as Uniformat and MasterFormat, and is used for managing construction information within BIM systems. It complies with ISO 12006-2 and serves as the basis for the National Building Information Standard (NBIMS) and Construction Operations Building Information Exchange (COBie) standards.

Despite the possibility of creating corporate CICS based on international systems, such as OmniClass, Uniclass, and others, each of the proposed approaches is inevitably associated with high costs. This is due to the need to adapt international standards to the specifics of national legislation, the requirements of specific enterprises and the peculiarities of their business processes. Moreover, the lack of standardized methodological materials for developing CICS requires significant labor and financial investments, including the involvement of highly qualified specialists and the conduct of comprehensive research and design work [26, 27]. In this regard, the development of a method for forming a corporate CICS represents a relevant scientific task aimed at optimizing and standardizing the process of creating and implementing classification systems in the construction industry.

The aim of this research is to develop a method for forming a corporate CICS. To achieve this aim, the following research objectives have been formulated:

1. Analysis of existing traditional approaches to the development of a CICS.
2. Development of a new method for forming a corporate construction information classifier.
3. Comparative evaluation of the proposed method and the traditional approach in terms of the quality of the resulting classifiers, as well as the time and financial costs associated with each approach.

2. Methods

Currently, there are no detailed methodological guidelines available in open access for the development of corporate classifiers of construction information. Traditional approaches to the formation of such systems are generally based on expert evaluation methods for assessing the quality of CICS, including interviews, brainstorming sessions, and discussions. However, these methods often lack sufficient systematization and may be subject to subjective distortions, which reduces their reliability and objectivity.

In order to address these limitations and improve the quality of CICS development, a more formalized approach is proposed, incorporating structured consensus-building among experts. Within the framework of the proposed method, experts are selected based on objective criteria, such as the competence coefficient, which ensures a highly qualified expert group and enhances the credibility of its conclusions.

In order to minimize the impact of opinion discrepancies and ensure a high degree of objectivity in the evaluation process, the Delphi method is employed. This method is an effective tool for achieving consensus within an expert group as it involves multiple rounds of surveys with feedback, facilitating the refinement and alignment of viewpoints while reducing the influence of personal biases and group pressure. The application of the Delphi method in this approach not only systematizes the expert evaluation process but also enhances the reliability and objectivity of decision-making, making a significant contribution to the improvement of methodological guidelines for developing corporate CICS. However, it should be noted that this method has potential limitations related to its dependence on the qualification and competence of the selected experts, as well as the challenges associated with adapting the method for small companies with limited resources and expert group size. These factors may affect the comprehensiveness and quality of expert assessments, necessitating additional attention when implementing the method across diverse organizational contexts.

The method for forming a corporate CICS is a set of methods, principles, materials, and tools aimed at developing CICS. The method consists of three stages:

1. Selection of the expert group.
2. Development of the corporate CICS.
3. Quality assessment of the developed CICS based on the Delphi method.

The algorithm for selecting an expert group (Fig. 1):

4. Formation of a candidate list for the expert group. Based on methodological guidelines regarding the composition of the expert group and the list of employees from the developer, a candidate list is compiled with a reserve of approximately 10 % of the final number of experts.
5. Surveying the candidates. Candidates provide statements regarding the inclusion of individuals in the expert group. Each candidate may choose to include or exclude themselves from the expert group.
6. Completion of the survey result matrix. A template matrix is filled out with the results of the candidate survey:

$$x_{ij} = \begin{cases} 1, & if \ \ the\, j-th \ expert \ named \ the \ i-th \ expert, \\ 0, & otherwise \end{cases} \tag{1}$$

7. Expansion of the candidate list. If individuals not included in the initial list appear in the survey result matrix, the candidate list is updated, and steps 2–3 are repeated.
8. Calculation of the competence coefficient of candidates. The competence coefficient for each candidate is determined based on the data from the survey results matrix:

$$k_i = \frac{\sum_{j=1}^{m} x_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{m} x_{ij}}, \left(i = \overline{1, m}\right), \tag{2}$$

where k_i is the competence coefficient of the i-th expert, m is the number of experts. The competence coefficients are normalized so that their sum equals one:

$$\sum_{i=1}^{m} k_i = 1 . \tag{3}$$

9. Interviewing the candidates. Candidates undergo interviews to assess their attitude toward expertise, constructive thinking, level of teamwork and creativity.
10. Selection and formation of the final expert group list. Based on the obtained individual characteristics of experts and the requirements for them, the final expert group list is compiled.

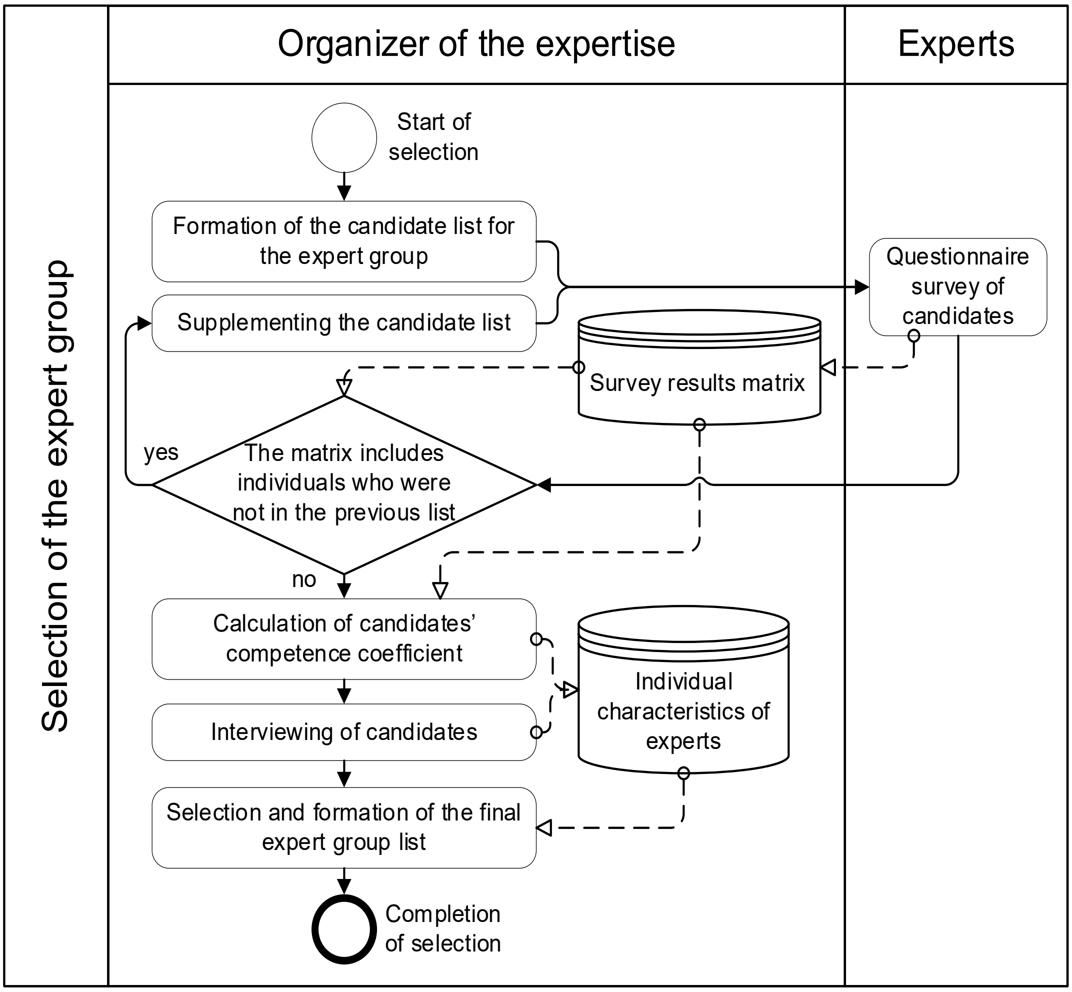

Figure 1. Algorithm for selecting the expert group.

The algorithm for developing a corporate CICS (Fig. 2):

1. Interviewing/brainstorming within the expert group. Interviews and brainstorming sessions are conducted with experts to determine the evaluation characteristics of the developed CICS.
2. Formation of the list of CICS characteristics. Based on methodological guidelines and the results of interviews and brainstorming sessions, a final list of characteristics for evaluating the developed CICS is compiled.
3. Analysis of CICS requirements. Requirements for the CICS are analyzed based on the terms of reference and the compiled list of CICS characteristics.
4. Development of the CICS. The CICS is created based on CICS templates and the CICS requirements.
5. Testing of the CICS. The system undergoes testing using tools for automatic classification of the information model according to the developed CICS.
6. Analysis and correction of CICS errors. If errors are detected during testing, an analysis is conducted, followed by error correction.
7. Expert evaluation of CICS characteristics using the Delphi method (described in detail later).
8. Definition of criteria for the final evaluation of CICS characteristics. After the first expert evaluation of the developed CICS (first iteration), criteria for the final assessment of CICS characteristics are determined.
9. Analysis of expert evaluations of CICS characteristics. If the evaluation of characteristics meets or exceeds the set criteria, the developed CICS is considered to satisfy all requirements, allowing the transition to the implementation phase. Otherwise, step 10 follows.
10. Refinement and modification of the CICS. Based on expert evaluations of CICS characteristics, modifications are made to the system, and the process returns to step 5.

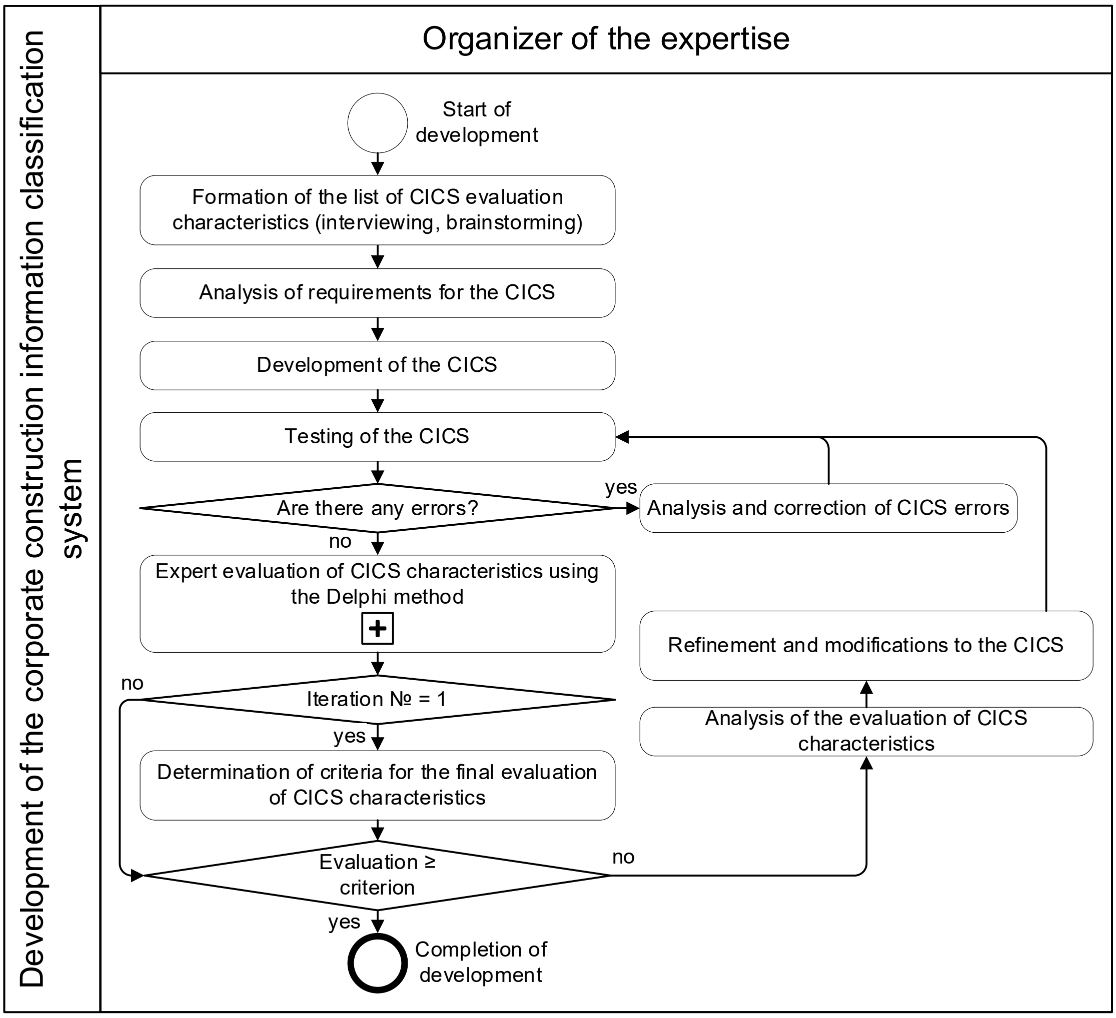

Figure 2. Algorithm for developing the corporate CICS.

Algorithm for evaluating the quality of the developed CICS based on the Delphi method (Fig. 3):

1. Development of a questionnaire for CICS evaluation. Based on questionnaire templates and the list of evaluation characteristics, a questionnaire is created to assess CICS using the Delphi method.
2. Expert survey. Experts are surveyed to obtain expert evaluations of CICS characteristics. The evaluation is conducted using a 10-point scale, where scores (ranks) may repeat. The survey results are compiled into a summary ranking matrix $\left\| r_{ij} \right\| \left(i = \overline{1, n}; j = \overline{1, m} \right)$, where r_{ij} is the rank assigned by the j-th expert to the i-th characteristic.
3. Rank restructuring. Since the summary ranking matrix contains tied ranks (identical ranking numbers), the ranks are recomputed to create a new matrix of recomputed ranks based on the following principles:
   - The expert evaluations of one expert are considered individually.
   - The smallest value is assigned rank 1, the next smallest is assigned rank 2 and so on.
   - The highest rank is assigned to the largest value.
   - If values are identical, they are assigned the same averaged rank (e.g., if two values share 4th and 5th places, both receive rank 4.5).
4. Statistical processing of survey results. The concordance coefficient of expert opinions and Pearson's chi-square statistic are calculated:
   - Concordance coefficient for tied (identical) ranks:

$$W = \frac{12 \cdot S}{m^2 \cdot \left(n^3 - n\right) - m \cdot \sum_{j=1}^{m} T_j}, \tag{4}$$

where S is the sum of squared deviations (calculated based on the recomputed ranks), T_j is the indicator of tied ranks in the j-th ranking (calculated based on initial ranks):

$$S = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} r_{ij} - \bar{r} \right)^2, \tag{5}$$

where $\bar{r}$ is the mean sum of ranks:

$$\bar{r} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} r_{ij}}{n}, \tag{6}$$

$$T_j = \sum_{k=1}^{H_j} \left(h_k^3 - h_k \right), \tag{7}$$

where H_j is the number of tied rank groups in the j-th ranking, h_k is the number of tied ranks in the k-th group of tied ranks in the j-th ranking.

- Evaluation of the concordance coefficient. The concordance coefficient W ranges from 0 to 1. A value of $W = 1$ indicates complete agreement among expert opinions, while $W = 0$ signifies the absence of agreement. If $W \geq 0.5$, the level of agreement among expert assessments can be considered satisfactory, whereas for $W \geq 0.7$, the agreement is deemed strong. If $W < 0.5$, expert assessments require refinement, and the process proceeds to step 5 [28].
- Computed value of Pearson's chi-square statistic χ^2_{calc} with $n-1$ degrees of freedom:

$$\chi^2_{calc} = m \cdot \left(n-1\right) \cdot W. \tag{8}$$

- Expert agreement is considered sufficient if $\chi^2_{calc} \geq \chi^2_{0.05}$, where $\chi^2_{0.05}$ is the critical value of Pearson's chi-square test at the 5 % significance level. If $\chi^2_{calc} < \chi^2_{0.05}$, it indicates a lack of agreement among experts, making the final ranking results unreliable. In this case, an additional expert review is necessary, involving a larger number of experts and broadening their specialization, proceeding to step 5. Otherwise, proceeding to step 7 [28].

5. Compilation of a report indicating the dispersion of opinions. Based on the results of statistical processing, a report is generated that includes the dispersion of expert assessments.
6. Surveying the experts. Experts are provided with a report on the results of the previous survey and are subjected to a repeated survey. Experts whose assessments significantly deviate from the majority are required to justify their opinion or revise their decision with an explanation. Then, the process returns to step 3.
7. Comparison of expert evaluations for each CICS characteristic over the last two iterations of CICS development using the Mann–Whitney criterion. To determine the impact of the implemented improvements on the quality of CICS, a null hypothesis is formulated for each characteristic: there are no statistically significant differences between the expert evaluations of a CICS characteristic after the last two iterations of CICS development. To test this hypothesis, two independent samples of expert evaluations for each CICS characteristic are compared using the Mann–Whitney criterion:
   - Two samples of expert assessments for a single characteristic after the final and penultimate iteration of CICS development are taken. These samples are conceptually combined into one group, and the ranks within this group are reassigned according to the principle outlined in step 3.
   - The sum of the reassigned ranks is calculated separately for each sample.

- The sample with the highest sum of ranks is identified.
- The empirical value of the Mann–Whitney U_{emp}-statistic is calculated using the formula:

$$U_{emp} = n_1 \cdot n_2 + \frac{n_x \cdot (n_x + 1)}{2} - T_x, \quad (9)$$

where n_1, n_2 are the numbers of expert assessments in the first and second sample, respectively; n_x is the number of expert assessments in the sample with the highest sum of ranks; T_x is the highest sum of ranks.

- The empirical value of the Mann–Whitney U_{emp}-statistic is compared with the critical value U_{crt}. If the empirical value U_{emp} is less than or equal to the critical value (U_{crt}), the existence of statistically significant differences between expert assessments of CICS characteristic in the compared samples is recognized (i.e., the alternative hypothesis H1 is accepted). If the empirical value is greater than the critical value, the null hypothesis of no statistically significant differences is accepted. The significance of the differences increases as the empirical value U_{emp} decreases.
- Thus, the null hypothesis is tested for each CICS characteristic. If the null hypothesis of no statistically significant differences is supported for a characteristic, the latest improvements in CICS have not affected its quality, and this factor should be taken into account in future improvements. If the alternative hypothesis indicating the presence of statistically significant differences is supported, the latest improvements in CICS have influenced its quality.

8. Determination of generalized assessments of characteristics. Based on the results of statistical processing, generalized assessments of the characteristics are determined.
9. Report generation. A report is compiled on the assessment of the developed CICS.

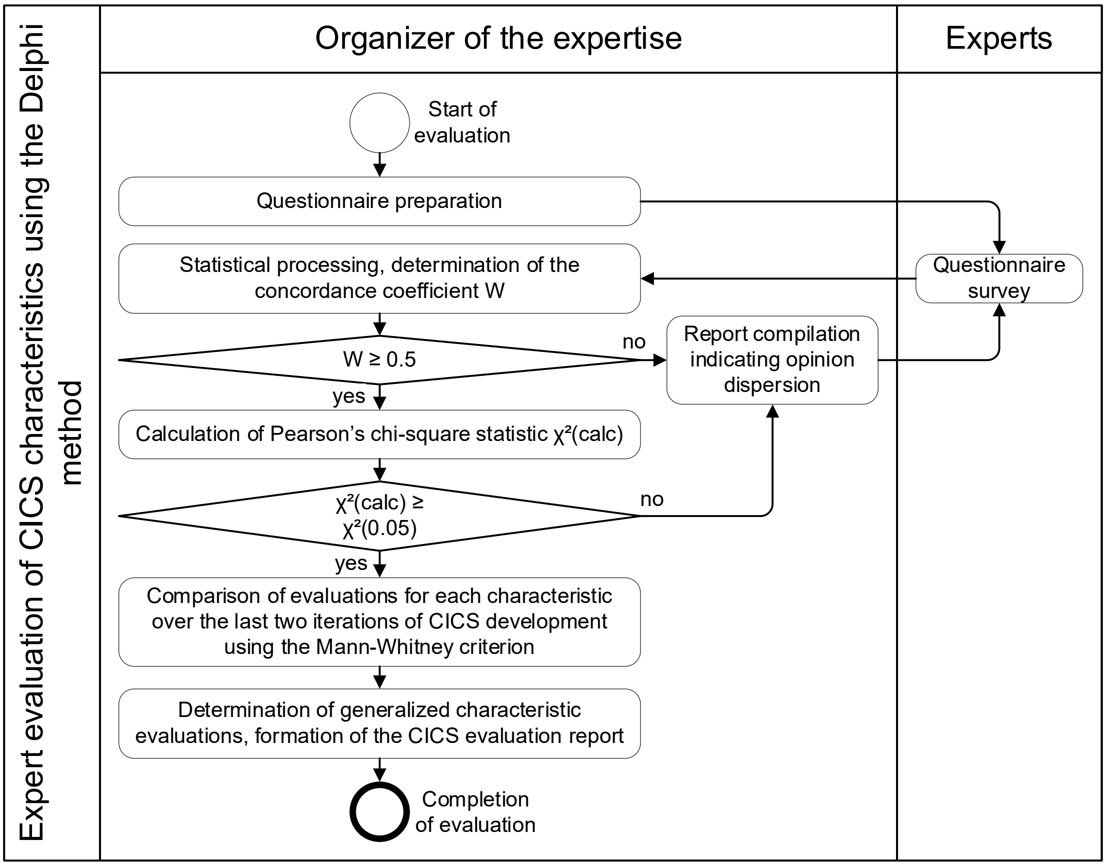

Figure 3. Algorithm for evaluating the quality of the developed CICS based on the Delphi method.

The validation of the developed method was conducted in a real-world production environment, specifically in the project department of the developer. As part of the comparative analysis, two versions of CICS were developed using different approaches: the traditional method and the proposed method, applied in two iterations.

To evaluate the effectiveness of the proposed approach and facilitate its further optimization, the following steps were implemented:

- Empirical determination of the time costs associated with classifier development using both the traditional and proposed methods.
- Calculation of financial costs for CICS development based on data on labor time expenditures, as well as information from Rosstat on the average monthly nominal accrued wages of employees working in information technology for the construction sector in Moscow for the period from January to October 2024.
- Evaluation of the quality of CICS developed using the traditional and proposed methods based on the Delphi method.
- Comparison of expert assessments of CICS characteristics formed using the traditional and proposed methods by applying the Mann–Whitney criterion. This made it possible to identify the impact of the developed method on the quality of the created CICS. During the analysis, a null hypothesis was initially formulated for each CICS characteristic, stating that there are no statistically significant differences between expert assessments of CICS characteristics obtained using the traditional and developed methods. The comparison was conducted following the principles outlined in step 7 of the “Algorithm for evaluating the quality of the developed CICS based on the Delphi method”, ensuring the objectivity and reproducibility of the obtained results.

3. Results and Discussion

As a result of the validation of the developed method, 15 candidates for the expert group were identified, and the competence coefficients of the candidates were determined (Table 1). Based on these coefficients, an expert group consisting of 12 members was formed, including design engineers, technical customer representatives, and BIM specialists (Table 2).

Table 1. Competence coefficients of candidates.

k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	k_{12}	k_{13}	k_{14}	k_{15}
0.07	0.08	0.04	0.07	0.07	0.08	0.07	0.07	0.05	0.06	0.08	0.07	0.07	0.07	0.05

Table 2. Composition of the expert group.

Expert position	Expert department	Quantity
BIM coordinator/manager	BIM department	4
Engineer of production and technical department	Development department (technical customer)	2
Design engineer for construction organization project	Design department	2
Architect	Design department	1
Design engineer for electrical systems and equipment	Design department	1
Estimating engineer	Design department	2
	Total	12

Based on the results of interviews and brainstorming sessions with the expert group, a final list of characteristics for evaluating the developed CICS was compiled (Table 3).

Table 3. List of characteristics for evaluating the developed CICS.

№	Name	Description
C1	Hierarchy	The structure of the classifier should be organized in a hierarchy, where categories and elements are logically distributed across levels
C2	Logic and ease of use	The classifier should be intuitive and user-friendly, with a clear and logical structure that is easily perceived by users
C3	Scalability and flexibility	The classifier should support the possibility of expansion by adding new categories or elements and be flexible for adaptation to new requirements
C4	Compatibility of facets (aspects)	The ability to use different facets or aspects of classification within the same context without creating data conflicts
C5	Independence of facets (aspects)	Separation of classification aspects so that they are independent of each other and can function autonomously
C6	Compliance of information presentation aspects with user needs	Classification aspects should be oriented towards the needs and requirements of end-users, providing maximum value and convenience
C7	Ability to divide according to required sections	The classifier should support the ability to divide elements into various required categories and sections for detailed work
C8	Consistency with regulations and standards	The classifier must comply with current regulatory requirements and standards, ensuring conformity with industry and legal norms
C9	Rationality of using categories for elements modeled through other categories	When categories other than the primary ones are used for modeling elements, this should be justified in terms of logic and functionality
C10	Appropriateness of linking the classification parameter to type/instance	Classification parameters should be linked to the type or instance depending on their significance and the features of the objects they are intended for
C11	Consistency of parameter usage by specialists from different departments	Classification parameters should be coordinated between departments to avoid conflicts and misunderstandings in data usage
C12	Sufficient detail for linking with cost estimate items	The classifier should provide sufficient detail for accurate linking with cost estimate items, without unnecessary complexity or loss of accuracy
C13	Minimization of redundant detail for linking with cost estimate items	Redundant detail should be minimized to keep the classifier efficient and avoid overloading it with unnecessary data
C14	Sufficient detail for linking with work schedule positions	The classifier should provide sufficient detail for accurate linking with work schedule positions, without unnecessary complexity or loss of accuracy
C15	Minimization of redundant detail for linking with work schedule positions	Redundant detail should be minimized to keep the classifier efficient and avoid overloading it with unnecessary data
C16	Sufficient detail for linking with technical customer requests	The classifier should provide sufficient detail for accurate linking with technical customer requests, without unnecessary complexity or loss of accuracy
C17	Minimization of redundant detail for linking with technical customer requests	Redundant detail should be minimized to keep the classifier efficient and avoid overloading it with unnecessary data
C18	Sufficient detail for linking with expert requirements	The classifier should provide sufficient detail for accurate linking with expert requirements, without unnecessary complexity or loss of accuracy
C19	Minimization of redundant detail for linking with expert requirements	Redundant detail should be minimized to keep the classifier efficient and avoid overloading it with unnecessary data

To evaluate the effectiveness of the developed method, two versions of CICS were created: one using the traditional approach and the other developed through two iterations of the proposed method. The results of the quality assessment of the created CICS, conducted using the Delphi method – comparing the traditional method, the proposed method after the first iteration, and the proposed method after the second iteration – are presented in Table 4 and illustrated by histograms in Fig. 4.

Table 4 shows that in all three cases, the concordance coefficients were greater than 0.5, and the calculated Pearson criteria ($\chi^2_{calc} \geq \chi^2_{0.05}$) indicated that the degree of consistency in expert evaluations in all three cases can be considered satisfactory and sufficient.

Table 4. Quality evaluations of the developed CICS based on the Delphi method.

№ of charac-teristic	Traditional method		Proposed method (1st iteration)		Proposed method (2nd iteration)	
	Weight of characteristic	Average rank	Weight of characteristic	Average rank	Weight of characteristic	Average rank
C1	0.083	6.92	0.086	7.42	0.089	9.50
C2	0.034	4.75	0.045	5.75	0.035	7.67
C3	0.049	5.25	0.056	6.17	0.075	8.92
C4	0.091	7.17	0.074	6.92	0.068	8.67
C5	0.065	6.00	0.070	6.67	0.077	9.00
C6	0.061	5.75	0.056	6.17	0.060	8.42
C7	0.043	5.08	0.026	4.92	0.030	7.50
C8	0.082	6.92	0.076	7.00	0.073	8.83
C9	0.040	4.92	0.029	5.08	0.061	8.42
C10	0.045	5.08	0.045	5.75	0.057	8.33
C11	0.045	5.17	0.061	6.33	0.034	7.67
C12	0.082	6.83	0.080	7.17	0.070	8.83
C13	0.011	3.25	0.011	3.92	0.025	7.33
C14	0.049	5.33	0.051	6.00	0.042	7.92
C15	0.022	4.08	0.015	4.33	0.011	6.67
C16	0.059	5.75	0.072	6.75	0.078	9.08
C17	0.026	4.33	0.029	4.92	0.046	8.00
C18	0.067	5.92	0.067	6.67	0.035	7.67
C19	0.046	5.17	0.050	5.92	0.036	7.67
	W	0.617	W	0.618	W	0.608
	χ^2_{calc}	133.191	χ^2_{calc}	133.381	χ^2_{calc}	131.237
	$\chi^2_{0.05}$	28.869	$\chi^2_{0.05}$	28.869	$\chi^2_{0.05}$	28.869
	Number of iterations of expert evaluations	3	Number of iterations of expert evaluations	3	Number of iterations of expert evaluations	2
	Weighted average rank	5.86	Weighted average rank	6.38	Weighted average rank	8.50

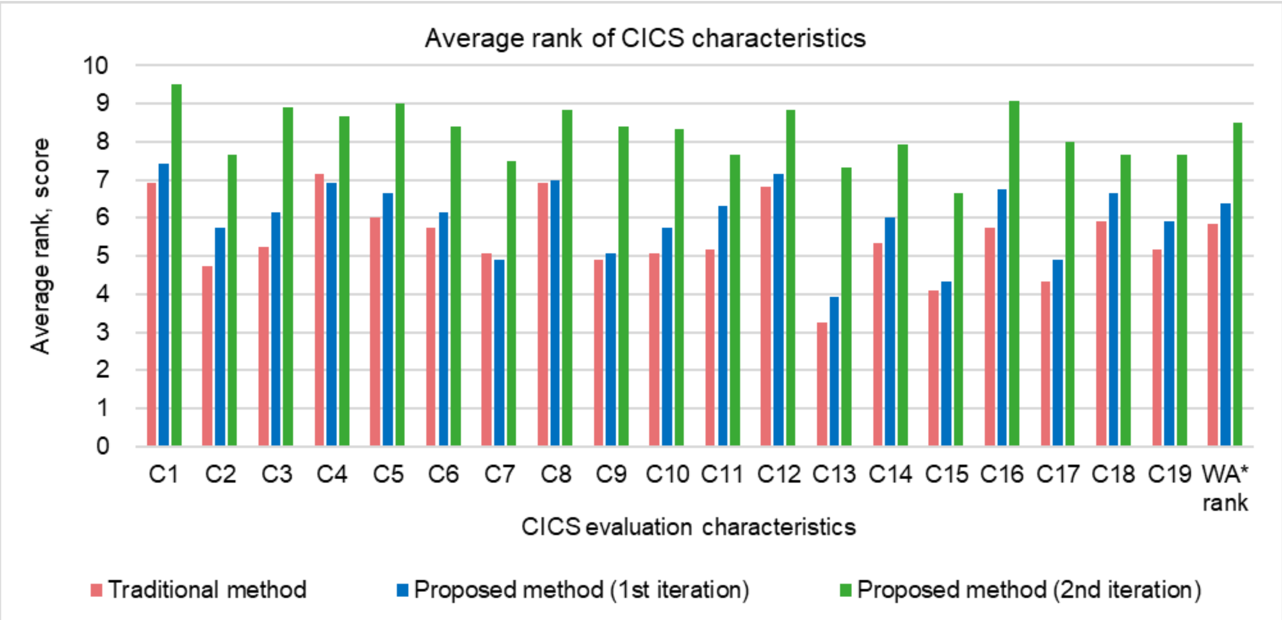

Figure 4. Average rank of CICS characteristics (*WA rank – weighted average rank).

Based on the histograms of the average ranks of CICS evaluation characteristics (Fig. 4), the following hypotheses were formulated:

1. When forming the CICS using the proposed method after the second iteration, the quality of the CICS improved across all characteristics.

2. When forming the CICS using the proposed method, a higher quality of the CICS was achieved across all characteristics compared to the traditional method.

To prove these hypotheses, the corresponding null hypotheses were formulated:

1. There are no statistically significant differences between the expert evaluations of CICS characteristics after the last two iterations of CICS development using the proposed method.
2. There are no statistically significant differences between the expert evaluations of CICS characteristics obtained using the traditional and proposed methods.

To test the hypotheses, we performed a comparison of two independent samples of expert evaluations for each CICS characteristic using the Mann–Whitney test (Table 5). From the table, it is evident that the obtained empirical value of the Mann–Whitney U_{emp}-statistic for each characteristic are lower than the critical value $U_{crt} = 42$, indicating the existence of statistically significant differences between the expert evaluations of CICS characteristics in the compared samples (i.e., the alternative hypotheses are accepted).

Table 5. Hypothesis testing using the Mann–Whitney test.

№ of charac-teristic	Hypothesis 1			Hypothesis 2		
	Sum of sample ranks		U_{emp}	Sum of sample ranks		U_{emp}
	Proposed method (1st iteration)	Proposed method (2nd iteration)		Proposed method (2nd iteration)	Traditional method	
C1	78.0	222.0	0	222	78	0
C2	80.0	220.0	2.0	222	78	0
C3	78.0	222.0	0	222	78	0
C4	84.0	216.0	6.0	216	84	6
C5	79.5	220.5	1.5	222	78	0
C6	81.5	218.5	3.5	222	78	0
C7	78.0	222.0	0	222	78	0
C8	86.0	214.0	8.0	214	86	8
C9	78.0	222.0	0	222	78	0
C10	78.0	222.0	0	222	78	0
C11	96.0	204.0	18.0	222	78	0
C12	90.5	209.5	12.5	212	88	10
C13	78.0	222.0	0	222	78	0
C14	90.5	209.5	12.5	222	78	0
C15	78.0	222.0	0	222	78	0
C16	81.0	219.0	3.0	222	78	0
C17	79.5	220.5	1.5	222	78	0
C18	98.0	202.0	20.0	218	82	4
C19	85.5	214.5	7.5	222	78	0
		U_{crt}	42		U_{crt}	42

Thus, the hypotheses we proposed are confirmed:

1. When creating the CICS using the proposed method, the improvements adopted after the first iteration contributed to the enhancement of the CICS quality across all characteristics.
2. When creating the CICS using the proposed method, a higher quality of the CICS was achieved across all characteristics compared to the traditional method.

As a result of testing the proposed method, the empirical time and financial costs for the development of the classifier using both the traditional and proposed methods were determined (Table 6). The cost reduction ratio of the proposed method amounted to:

$$d_{CRR} = \frac{T_{TM} - T_{PM}}{T_{TM}} \cdot 100\% = \frac{536 - 304}{536} \cdot 100\% = 43\%, \quad (10)$$

where T_{TM}, T_{PM} are the time or financial costs for the development of the CICS using the traditional method (TM) and the proposed method (PM), respectively.

Table 6. Time and financial costs for the development of CICS.

	Time costs, hours	Average daily salary, RUB	Financial costs, RUB
Traditional method	536	1,049	70,283
Proposed method	304	1,049	39,862

A theoretical study was also conducted to examine the relationship between the cost reduction ratio of the proposed method and the number of iterations in the development of the CICS (simulation of the processes of expansion and refinement of the CICS). From the graph (Fig. 5), it is evident that up to six iterations, the highest increase in the cost reduction ratio is observed, after which the growth slows down. The most cost-effective application of the proposed method occurs in processes with two iterations, with a reduction in costs of 50 %. This method is suitable for the development of a corporate CICS, typically involving between two and five iterations before commissioning.

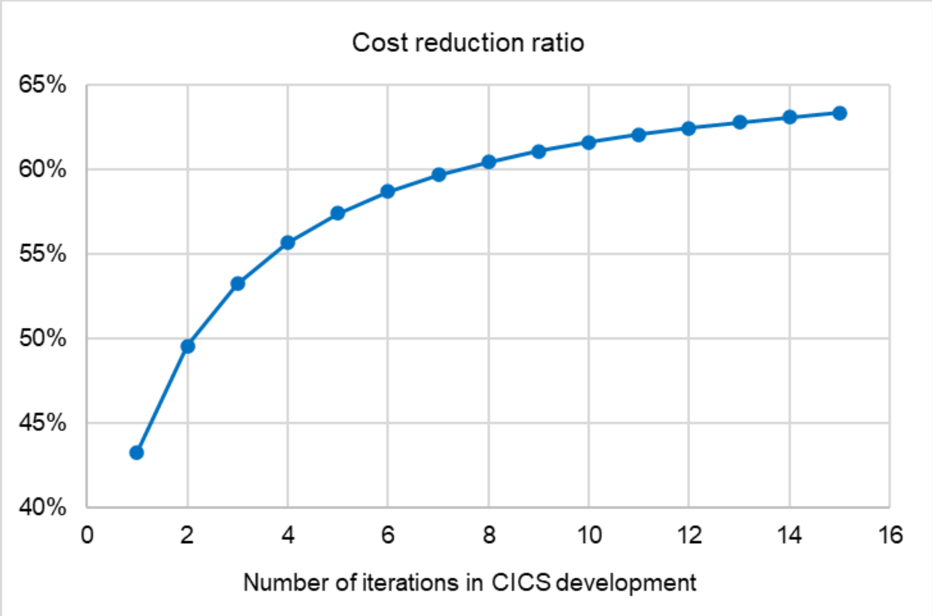

Figure 5. Dependence of the cost reduction ratio of the proposed method on the number of iterations in CICS development.

It is important to emphasize the originality of the present study. Despite a comprehensive literature review, no studies directly comparable to the presented results were identified at the time of this research. Consequently, a comparative analysis with findings from other authors could not be conducted.

4. Conclusions

The result of the conducted research is the developed method for forming a corporate CICS, which ensures improved quality, reduced time, and financial costs in the development and adaptation of the CICS compared to traditional approaches.

The main results obtained during the testing of the method are as follows:

- The weighted average expert evaluation of the CICS quality, formed using the developed method, was 8.50 points, which is 45 % higher than when using the traditional method (5.86 points), confirming the higher quality of the developed CICS.
- The time costs for creating the CICS using the proposed method amounted to 304 hours, while the traditional method required 536 hours. The reduction in costs using the new method was 43 %.
- The financial costs for the development of the CICS using the proposed method were 39,862 rubles, which is 43 % lower than the costs of the traditional method (70,283 rubles).

Additionally, a theoretical study was conducted to examine the relationship between the cost reduction ratio of the proposed method and the number of iterations in the development of the CICS. The analysis showed that the greatest increase in the cost reduction ratio occurs within the range of up to six iterations, after which the growth rate slows down. The optimal application of the proposed method is in processes involving between two and five iterations, where the cost reduction ratio of at least 50 % is achieved.

The application of the proposed method significantly reduces the costs associated with the development and maintenance of the CICS, while providing system flexibility in the context of the need for subsequent adjustments and expansions. The method is most effective when developing CICS with a larger number of iterations, which is particularly relevant for corporate systems that are in the stage of active development and adaptation to organizational needs.

In addition, the proposed method has the potential for implementation in various organizations and adaptation to diverse contexts, which expands its practical applicability across different sectors of the construction industry and allows for the consideration of specific requirements and features of corporate processes. It is particularly suitable for development companies and design bureaus that need to create and expand their own construction information classifiers for project and resource management. The method can also be effectively applied in companies that are at the initial stages of implementing BIM technologies, helping them to approach the formation and development of classification systems in a systematic manner with minimal time and financial expenditures.

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