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Evaluation of the technological structure of the work programme of construction companies

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ABSTRACT
The commercial performance of a construction company (CC) largely depends on the planned work programme. The annual CC work programme is a set of objects of a specific purpose and structure (a building system). The programme has the following characteristics: first, the number of objects; second, the construction technologies provided for in the projects (fully prefabricated, monolithic, brick, etc.); third, the variation of work scopes among objects; and fourth, the construction technology. These CC work programme features are interrelated, i.e., aligned with each other, forming the technological structure (TS) of the CC work programme. Once these attributes were formalised, four partial indicators were obtained: the first assesses the variation in construction objects' sizes; the second — their number; the third — the number of applied technologies; and the fourth — the technologies. The importance of these indicators was assessed to combine them into an indicator of the technological structure of the annual CC work programme. Its quantitative assessment has scientific and practical importance, providing an opportunity to analyse its impact on the results of commercial activities, to improve the organisational management structure of the company, etc.

KEY WORDS
construction technology, evaluation of the technological structure of the work programme of the construction company

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Introduction

Under market economy conditions, the formation of the annual work programme of a construction company (CC) is fundamentally different as it consists of projects won in competitions. CCs can only apply for projects within the scope of their construction license. The competent authority issues licences after the construction company submits documents proving its ability to build specific purpose objects, i.e., information about the available material and technical base, qualifications of employees, etc. More

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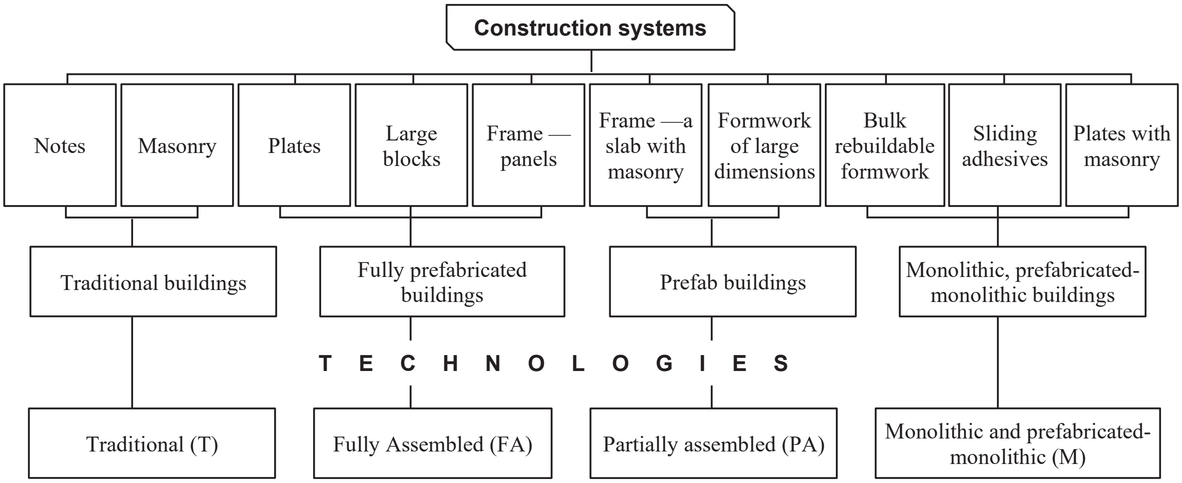

Fig. 1. Basic construction systems and technologies of public and industrial buildings
Source: elaborated by the author based on (Ginevičius, 1995).

diverse construction licenses allow for an easier formation of an annual work programme. On the other hand, a greater variety of objects has an ambiguous effect on the results of commercial activities. This is because different technologies are used to construct different purpose objects, which requires different mechanisms, employees with different qualifications and specialisations, different ways of organising work, etc.

Differences in construction technologies are evident from the definition: it is a set of processes for transforming materials and structures into construction products (Ginevičius, 1995). The definition suggests essential technology features. They differ in the structure of production processes, the performance consistency, and the performance methods.

The composition and consistency of the main construction processes are determined by the sequence of work necessary for the construction of objects, starting with construction preparation and earthworks, moving to construction installation, roof and finishing work.

The third characteristic of technology, the ways of performing production processes, can be different even for the same set of processes and the execution sequence so that it can be the most acceptable criterion for different technologies. The question arises as to what construction work methods depend on, given that a method is a deliberately applied order of actions to achieve a goal. In the context of the execution of construction works, they exclusively depend on the construction system (CS) of the building or structure, reflecting their basic structural solutions. In turn, the methods and means of performing the work depend on the project's construction solutions, i.e., the construction technologies that will be applied (Fig. 1).

Thus, the annual implementation of the CC work programme should be examined through the totality of the applied technologies. The analysis shows that regardless of their nature, this programme is characterised by the same features: first, it consists of a certain number of various purpose objects; second, certain technologies are used for their construction; third, the objects are of different sizes according to their contract price; and fourth, the applied technologies are different. All these signs are interrelated, and a growing number of objects included in the work programme increases the variety of their structural solutions, on which the number of applied technologies and their technological level depend.

Based on the theory of systems, the system's structure is a set of relatively constant connections among its elements; therefore, the features of the CC work programme constitute a system, and its structure can be called a technological structure.

Today, the quantification of the technological structure of the CC work programme is particularly important as the results of commercial activity largely depend on it. Such a possibility requires transforming the reflecting signs into indicators. In this case, it will be possible to apply multi-criteria methods to evaluate the CC's technological structure.

The purpose of the article is to propose and approve the methodology for the quantitative assessment of the technological structure of the annual CC work programme.

1. Literature review

In the market economy, the conditions for carrying out construction work have changed fundamentally. Not only their management and organisation have changed, but also the technologies for performing work and processes. The role of the institution that implements construction projects, the construction company (CC), has changed as well. Its work programme (WP) is formed completely differently. The content of the CC's role analysis in WP implementation follows from versatile functions it has to perform in this process, i.e., finance, personnel, purchases/sales, supply of construction facilities with transport, work contracts, quality and other management. Additionally, a CC also deals with other issues: accounting, subcontracting, estimates, provision of work tools, employee remuneration, material incentives, legislation, etc. (Barvidas, 2010; Belout, Gauvreau, 2004; Anderson, 1992). The costs of implementing all these functions largely depend on the kind of objects within the work programme, i.e., its technological structure (Belout, Gauvreau, 2004). The economic results of the CC's activities directly depend on these costs (Barvidas, 2010) (Fig. 2).

Fig. 2 shows that it is appropriate to examine literature sources analysing the conditions of WP implementation. Most attention is possibly paid to the management of construction projects based on BIM technology (Pezeshki & Ivari, 2018; Xie et al., 2022; Al-Ashmori et al., 2020; Koo et al., 2021; Sun & Kim, 2022) and examination of related information systems (Koo et al., 2019; Love & Irani, 2004). Supply is an important aspect of the analysis on which construction success largely depends (Cataldo et al., 2022; Suhi et al., 2019; Tiwari et al., 2014). The application of sustainability principles in construction is also analysed (Thies et al., 2019; Kamali & Hewage, 2017). A separate research direction is the evaluation of building technology (Lawson et al., 2012; Skibniewski & Chao, 1992; Chao & Skibniewski, 1998; Kim et al., 2011; Nanyam et al., 2015). Also considered are such construction aspects as noise and risk reduction (Love et al., 2020; Abad et al., 2019), waste disposal (Zhang et al., 2021; Naji et al., 2022) and energy issues of buildings (Ajayi et al., 2019), construction solutions for buildings (Lawson et al., 2012), working conditions (Trishch et al., 2021), quality improvement (Love et al., 2020), etc. Various mathematical methods are used for the analysis, mostly for evaluating technological solutions for house construction. Here, multi-criteria methods prevail (Skibniewski & Chao, 1992; Nanyam et al., 2015; Zavadskas et al., 2012; Zavadskas et al., 2013; Turskis et al., 2016). These methods are also applied in the assessment of working conditions (Trishch et al., 2021; Cherniak et al., 2020) and the quality of building materials and structures (Shahbazi et al., 2017). The Delphi method is widely used to assess construction project management (Kamali & Hewage, 2017; Kermanshachi et al., 2020), Fuzzy logic is used for risk assessment (Abad et al., 2019; Chao & Skibniewski, 1998; Liao & Plebankiewicz, 2021), and verbal analysis (Shevchenko et al., 2019) is also used.

The literature review shows that all the studies examine either the management of individual construction projects or the management conditions of the CC's construction functions, i.e., no studies analyse the management of a CC work programme in the context of its technological aspects as a whole. Meanwhile, the impact of its technological structure manifests primarily through changes in the organisational management structure, i.e., the role of services used

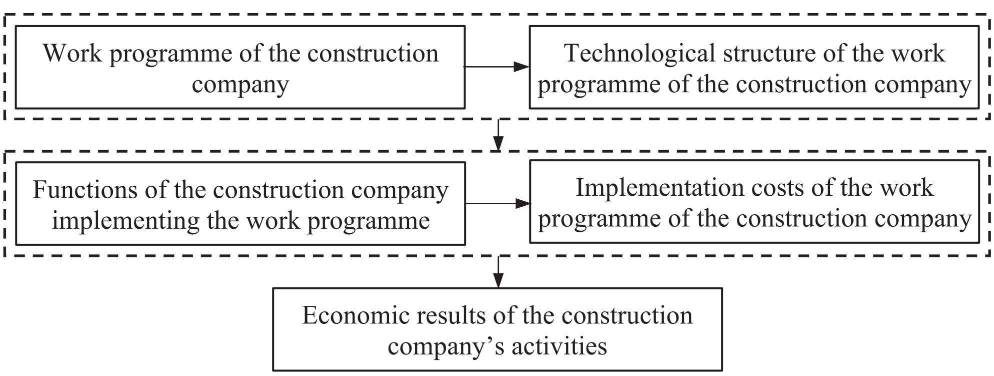

Fig. 2. Effect of the technological structure of the construction company's work programme on the economic results of operations

for construction objects with prevailing technology increases. All this presupposes the need, relevant in both scientific and practical sense, to quantitatively evaluate the technological structure of the CC work programme to determine its impact on the economic results of the activity.

2. Research methodology

The technological structure (TS) indicator of the annual CC work programme has to meet the following requirements:

- The annual CC work programme consists of different purpose objects (residential, public, industrial buildings, etc.) and, therefore, of different constructions. To evaluate it as a whole, the TS indicator must include both quantitative and qualitative aspects of the work programme.
- It is necessary to evaluate the quantitative side of the annual CC work programme because of the different technologies used for construction projects and the variety of objects to be constructed.
- It is necessary to assess the qualitative side of the annual CC work programme because of possibly different sizes of construction objects and different construction technologies used.

After evaluating the requirements for the TS indicator, its calculation scheme looks as provided in Fig. 3.

The changes in the value of the indicator for the technological structure of the annual CC work programme must correspond to Fig. 3. The effects of the specified TS elements.

The number of objects included in the annual CC work programme usually means the diversity and level of the applied technologies, and therefore, higher management and work organisation costs. Therefore, the growing number of work programme objects should decrease the value of the TS indicator.

The same applies to the number of technologies: more technologies applied simultaneously in various objects means a more complicated process for managing and organising the overall construction process. Therefore, as the number of technologies grows, the value of the TS indicator should decrease.

The commercial performance of the construction company also depends on the size of the objects in the work programme. Growing differences make the overall process of construction management and organisation and execution of works less efficient; therefore, the decrease in the uniformity of the work programme must also reduce the value of the TS indicator.

The more diverse technologies are used in the construction of objects, the greater are their technology differences. Meanwhile, the cost of the work and the duration and price of the construction largely depend on it. Therefore, the value of the TS indicator must increase as the technological level of the applied technologies grows. Fig. 4 provides the summarised effect made by the elements of the technological structure indicator on the results of the CC's commercial activity.

Based on Fig. 4, it is possible to proceed with compiling the indicator of the technological structure of the annual CC work programme.

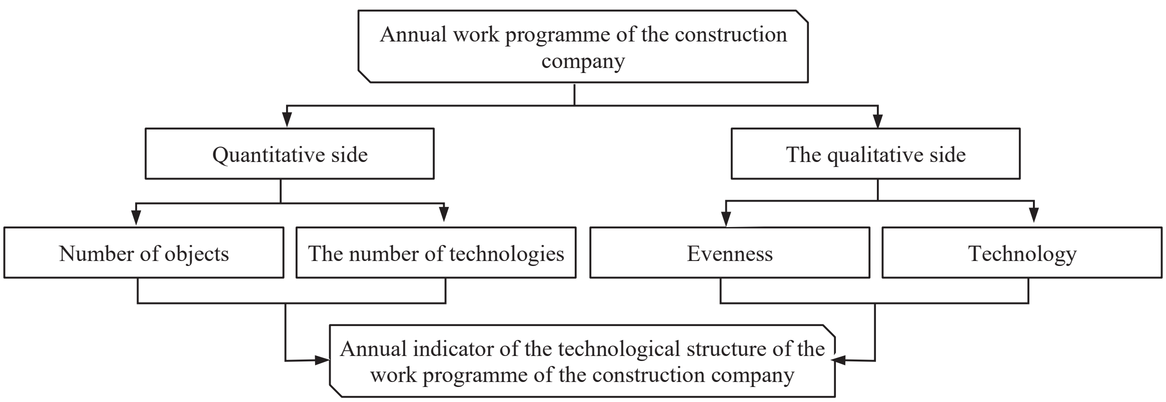

Fig. 3. Calculation scheme of the technological structure of the annual work programme of the construction company

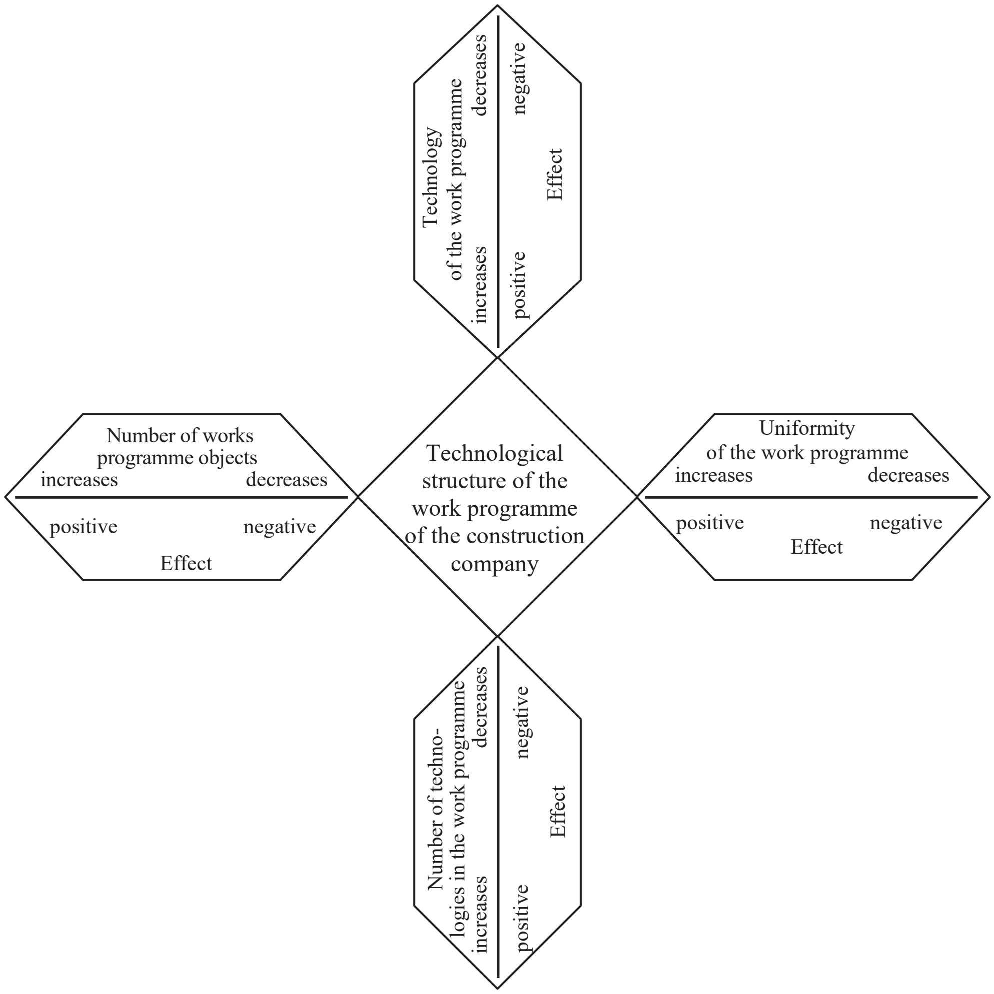

Fig. 4. Effect of the elements of the work programme of the construction company on the technological structure

The variation of the scope of work among the sizes of construction objects included in the annual CC work programme can be determined as follows:

$$K_{TV} = \frac{n-1}{\sum_{i=1}^{n} \frac{Q_{\max}}{Q_i}}, \quad (1)$$

here, K_V is the annual work programme uniformity indicator; $Q_{\max}$ — the size of the largest construction object according to the contractual price in the percentage of the total work scope; Q_i — the size of the i-th object in the percentage of the total work scope; n — the number of objects of the construction work programme ($i = \overline{1,n}$).

Based on formula (1), the maximum value equal to 1.0 K_V is reached when there is no variation, i.e., when $Q_i = Q_{i+1}$. As the variation increases, K_V value approaches 0.

The indicator reflecting the number of objects included in the CC work programme must vary within the same limits as K_T. It can be set as follows:

$$K_{TN} = \frac{1}{n}, \quad (2)$$

here, K_{TN} is the indicator of the number of objects in the annual work programme.

Based on formula (2), the indicator K_N takes on the highest value when the production programme consists of only one object.

The indicator of the annual CC work programme reflecting the number of applied technologies can be determined as follows:

$$K_{TT} = \frac{1}{T}, \quad (3)$$

here, K_{TT} is the indicator of the number of technologies applied in the annual work programme; T — the number of technologies at the level of the CC.

Based on formula (3), the indicator K_{TT} takes on the greatest value when the same technology is used for the construction of all objects of the annual work programme.

First, to determine the technological indicator of the objects of the annual CC work programme, it is necessary to evaluate the technology and predict its rank in construction projects. Based on these ranks, the level of technologies applied for the construction of objects within the annual CC work programme can be determined as follows:

$$K_T = \frac{\sum_{n-1}^{n} S_j \tilde{r}_i}{\sum_{i=1}^{n} \tilde{r}_{\max}}, \quad (4)$$

K_T — technological efficiency indicator of the technologies applied for the construction of objects within the annual CC work programme; S_j– S_j — the volume of the j-th CS in unit parts; $r_{\max}$ — the highest possible CS technologically transformed rank; r_i — the same, j-th CS.

Technology ranks are transformed to be comparable to S:

$$\tilde{r} = \frac{r}{10}. \quad (5)$$

Indicators of the technological structure of the annual CC work programme have different importance. For example, CS technology depends on the purpose of the objects included in the work programme and, thus, on their constructive solutions regarding the number of technologies to be applied in the implementation of the annual work programme, etc. Only experts can determine this importance.

After determining the values and importance of the indicators K_{TV}, K_{TN}, K_{TT} and K_r, they can be combined into one summarising quantity reflecting the technological structure of the annual CC work programme (Fig. 4). This can be done based on multi-criteria methods since the TS indicator is represented by four partial indicators. Today, they are widely used to determine the state of the most diverse technical-technological and socio-economic systems at a desired moment in time (Grybaitė, 2023; Išoraitė et al., 2022; Vysochan et al., 2022; Yücel & Görener, 2016; Choi & Choi, 2022). Some of them are simpler; others are more complicated in their application. The idea of these methods is reflected by the most popular and widely used SAW method:

$$K_{SAW} = \sum_{i=1}^{n} \omega_i \tilde{q}_i, \quad (6)$$

here, K_{SAW} — the significance of the multi-criteria assessment of the state of the considered phenomenon by the SAW method; ω_i — the importance of the i-th indicator; $\tilde{q}_i$ — the normalised value of the i-th indicator.

Multi-criteria evaluation methods, as provided by formula (5), can be applied only when the indicators are expressed in two quantities, i.e., importance and meaning. To combine these transformed values into one summarising quantity, they need to be made comparable, i.e., they must be dimensionless and vary in the same range and in the same direction. When using the multi-criteria SAW method, the normalisation of indicator values is performed as follows (Hwang & Yoon, 1981; Podvezko, 2008):

$$\tilde{q}_{ij} = \frac{q_{ij}}{\sum_{j=1}^{n} q_{ij}}, \quad (7)$$

here, $\tilde{q}_{ij}$ — the normalised value of the i-th indicator; q_{ij} — the initial value of the i-th indicator; n — the number of indicators ($i = \overline{1,n}$); m — the number of variants ($j = \overline{1,m}$).

The equalisation of the direction of change of indicators is carried out as follows:

a) the values of the indicators minimise:

$$q_{ij} = \frac{\min_j q_{ij}}{q_{ij}}, \quad (8)$$

b) values of indicators maximising:

$$q_{ij} = \frac{q_{ij}}{\max_j q_{ij}}, \quad (9)$$

here, $\min_j q_{ij}$ — the smallest value of the i-th indicator among all alternatives; $\max_j q_{ij}$ — the same, the largest.

All indicators of the technological structure of the annual CC work programme are dimensionless and vary in the same range, i.e., from 0 to 1, and also vary in the same direction, i.e., the situation improves as their values increase. Therefore, all of them can be combined without additional calculations into one summarising value, an indicator of the technological structure of the annual work programme of a State Enterprise.

3. Empirical study

The proposed methodology for the quantitative assessment of the technological structure is illustrated using specific examples. The annual work programme of the first construction company consists of ten objects, and the second has seven (Table 1).

Based on the data presented in Table 1, it is difficult to decide which construction company's technological structure of the annual work programme has greater significance since it is better for some TS indicators in one company and for others in another.

An expert survey was organised to determine the technology indicator. Employees selected as experts were responsible for the construction of objects (work managers), technologists, heads of CC departments, etc. A total of 12 experts were chosen. Based on the results of the survey, a summary table of expert evaluation was compiled (Table 2).

When evaluating the number of technologies, the concordance of expert opinions was determined based on Kendall's concordance coefficient W (Kendall, 1975). Its value was found to be equal to 0.72. Hence, the experts' opinions were consistent. The following results were obtained (Table 3).

After calculating the indicators of the technological structure of the work programme based on formulas (1)-(4), the following results were obtained (Table 4).

To determine a general indicator of the technological structure of the CC work programme, a survey of experts was conducted again. The survey involved the same experts who evaluated the technological properties of the objects. The value of Kendall's concordance coefficient W significantly exceeded the required minimum (W = 0.83). According to their opinion, the importance of technological structure indicators was determined: the number of technologies — 0.4, the level of technologies — 0.3, the uniformity of the work programme — 0.2, and the number of construction objects — 0.1.

Tab. 1. Annual work programme of the consideration construction companies (percentage)

Objects of the annual work programme of construction companies		1	2	3	4	5	6	7	8	9	10
The comparative weight of the contract prices of construction objects in the total work scope	first company	10	12	10	12	10	8	12	10	8	8
	second company	5	35	25	10	6	10	9	–	–	–
Object construction technology	first company	M	M	M	PA	FA	PA	FA	M	M	M
	second company	FA	PA	PA	T	M	FA	M	–	–	–

Source: data provided by companies X and Y.

Tab. 2. Expert assessment of the technology of objects in the CC work programme

Technology	Traditional	Fully assembled	Partially assembled	Monolithic and prefabricated-monolithic
Assessment of technology	3	1	2	4

Tab. 3. Technological ranks of construction technologies

Name of the technology	Traditional	Fully assembled	Partially assembled	Monolithic and prefabricated-monolithic
Place of the technology	4	1	2	3
Technology rank	1	4	3	2

Tab. 4. Calculation results of the indicator values of the technological structure of the annual CC work programmes

Construction company	Technological structure indicators			
First	0.672	0.100	0.333	0.652
Second	0.239	0.143	0.250	0.280

Based on formula (6), the value of the technological structure indicator of the first annual CC work programme was 0.47 and 0.24 for the second. These results do not contradict the logic of the proposed methodology. Experts gave the greatest importance to the technological structure of the number of technologies in the annual CC work programme. It is equal to three for the first company and four for the second. Based on formula (2), the first company is in a better position. In second place of importance is the technological nature of the applied technologies. In the first company, the comparative weight of such technologies is higher than in the second. The work programme of the first company also does not include the least advanced technologies. In addition, the value of the technological indicator of the first company is more than 2.3 times higher than that of the second.

The obtained results suggest new scientific research opportunities, as it will be possible to analyse the influence of the technological structure of the CC work programme on various performance results, including economic.

Conclusions

Under the conditions of the market economy, the formation of the annual work programme plays an important role in the activities of construction companies. The analysis shows that regardless of their nature, they all have the same characteristics: first, they consist of a certain number of various purpose objects; second, specific technologies are used for their construction; third, the objects differ in sizes; fourth, the applied technologies differ in their nature. All these features are interrelated and complement each other, so their entirety can be viewed as a system. In the theory of systems, their structure plays a special role, which can be viewed as a generalised characteristic of the system (Ginevičius, 2009). The features of the construction company's work programme, such as elements of the structure, follow from its comprising structural solutions of the buildings or structures. In turn, this depends on the construction technology, so the totality of these features can be evaluated as the technological structure of the CC work programme. The results of the construction company's commercial activity largely depend on it, so its quantitative assessment acquires both scientific and practical significance. For that purpose, the features of the work programme reflecting the technological structure need to be formalised, i.e., transformed into indicators. On the other hand, just knowing the values of the indicators does not yet convey the overall picture of the technological structure. To obtain it, the values of the indicators need to be integrated into a unified index of the technological structure. The importance of the indicators is not the same, so it should be determined based on expert judgments. Having the values and importance of the indicators, it is possible to calculate the technological structure index using multi-criteria methods.

Calculations of the technological structure index for two construction companies with significantly different work programmes confirmed the suitability of the proposed methodology.

Further research may be limited by the possibility of obtaining information about the structure of the annual work programme of construction companies. The strength of the obtained results can be attributed to the novelty of the study, allowing for the quantitative assessment of the technological structure of the annual CC work programme. This enables a more efficient, prompt and accurate management. The conducted research could be extended by highlighting and focusing more on evaluating the impact made by the technological structure on the organisational management structure of a construction company.

Quantitative assessment of the technological structure of the construction company's work programme opens up wide opportunities for relevant research: it will be possible to determine to what extent it affects the commercial activity results of the construction company, optimise the work programme to achieve greater economic efficiency of its implementation, etc.

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