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Scientific and theoretical approaches to complex assessment of building life cycle from a low-carbon development perspective

Construction activity is carried out in close interaction with the environment, which has always focused the attention of researchers on ecological safety of construction objects, including low-carbon development and reducing resource intensity and energy consumption at all stages of the building life cycle. The global trends in construction are such areas as decarburization of not only existing but also newly constructed buildings, creating conditions for the implementation of investment and construction projects from a low-carbon development perspective, as well as assessing the carbon impact of implemented projects, including at the early stages of architectural and technological design. The World Green Building Council identifies the carbon impact at early stages as “upfront carbon”, which is becoming increasingly important in a complex life cycle assessment in buildings by low-carbon criterion. The article presents scientific and theoretical approaches to a comprehensive life cycle assessment in buildings from a low-carbon development perspective. The authors have identified the factors allowing to estimate the future building project from the position of low-carbon applied design solutions, suggested a multilayer factor space of the considered indicators (building resources) of carbon impact, proposed a minimization indicator of the building carbon impact, which enables to estimate comprehensively the influence of all factors and indirectly characterize the degree of carbon impact at the life cycle stages, preceding the building operation.

Keywords: *building life cycle, low-carbon construction, carbon footprint of buildings, whole building life cycle assessment from a low-carbon development perspective*

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INTRODUCTION

Adaptation to the effects of climate change and air pollution control is a priority for the Russian economy as a whole, including the construction industry. Intensive construction growth and increased attention to the global climate change makes the reduction of greenhouse gas emissions (GHG) from mass construction an urgent and promising area of research. GHG emissions occur at all stages of a building's life cycle [1]. Currently, according to the researches, about 70–80 % of the building carbon impact is associated with the operational phase, the rest, the so-called “embodied” indirect impact is associated primarily with the construction materials production, transportation to the construction site and construction operations [2]. The World Green Building Council identifies the carbon impact, reduced to GHG emissions, in the pre-operational stages as “upfront carbon” (preliminary GHG emissions), which is becoming increasingly important in a complex life cycle assessment in buildings by low-carbon development perspective.

The issue of the need in regulating GHG emissions against the background of climate change is considered at the state level in the Russian Federation in the framework of the “Environmental Safety Strategy of the Russian Federation until 2025”, approved by Presidential Decree No. 176 of April 19, 2017. Since December 30, 2021, the Federal Law of July 2, 2021 No. 296-FZ “On limiting greenhouse gas emissions” came into force, forming a system for managing greenhouse gas emissions. The law introduces the required conceptual framework (greenhouse gases, carbon footprint, climate projects, carbon units, regulated organizations, etc.) and forms the legal basis for the implementation of climate projects, including the construction industry, and the circulation of carbon units. The Russian Government Decree No. 3052-r of October 29, 2021 approved the Russian strategy of socio-economic development with low GHG emissions until 2050. The strategy aims to ensure Russia's transition to the trajectory of diversified economic development characterized by low greenhouse gas emissions and strengthening the national goal of reducing emissions, the launch of economic incentives for companies. In addition, the Government of the Russian Federation by its Order No. 3268-r dated October 31, 2022 approved the Development Strategy of the construction industry and housing services for the period up to 2030 and the forecast until 2035, where the climate agenda has a special place.

The analysis of the regulatory framework in order to improve the environmental safety of construction projects from the position of low-carbon development has shown that despite the global trend to reduce GHG emissions, the Russian regulatory framework and green building standards in the current edition do not sufficiently regulate the environmental condition of human habitat to reduce the carbon impact of buildings and the fight against global warming [3, 4]. The key practical drawback of the current situation is the underdevelopment of state policy at the federal and regional levels and used in practice science-based methods and algorithms for complex decarburization of construction and market incentives for low-carbon construction[1].

1 Prognosis of long-term socio-economic development until 2030. URL: http://www.consultant.ru/document/cons_doc_LAW_144190/

The MAIN PART

Based on a critical review of Russian and international theoretical and experimental researches and in order to minimize the indirect carbon impact of buildings, factors for assessing the future building design by low-carbon criterion are identified. To quantify the indirect carbon footprint of the building, analyze and systematize the various carbon footprint factors, a multi-layered factor space of considered indicators (building resources such as building materials, construction machinery, including vehicles) of indirect carbon footprint has been proposed.

The multi-layered factor space is shown in Fig. 1. On the top layer of the factor space is combined into clouds, grouping indicators of carbon impact by their purpose and the origin of indirect GHG emissions [5, 6]. The authors proposed to identify the l-th number of i-factors, among which production F_{1jk}, organizational F_{2jk}, logistical F_{3jk} have the most value.

The production factor includes energy consumption and, as a consequence, GHG emissions arising during the life cycle of construction materials (as a result of extraction and processing of raw materials, production of materials, etc.) [7]. The organizational factor includes energy inputs and, as a consequence, GHG emissions arising in the process of construction production from the operation of construction machinery and equipment [8]. The logistic factor includes energy inputs and, as a result, GHG emissions in the process of transportation of construction resources and their delivery to the on-site warehouse of the construction facility [9]. Factors F_{ijk}, formed on the central base layer from the groups of sources of indirect carbon impact of the building, consist of j-factor vectors that determine the list of building resources to assess their indirect carbon impact. Consequently, for the production factor F_{1jk} the number of analyzed construction resources depends on the building design solutions and may include the m-th number of j-factor vectors (F_{11k}...F_{1mk}). For the organizational factor F_{2jk} the number of analyzed vectors depends on the need for construction machinery and mechanisms, which are analyzed by type of fuel and their energy consumption. For the logistics factor F_{3jk} the number of analyzed indicators depends on the range of transportation of construction cargoes determined by cost-effective routes using information on the preferred modes of transport.

A subset of k-factor nodes by j-vectors determines the specific technological characteristics of the production of building materials, transportation, obtained from manufacturers or suppliers. The identified multi-layered factor space formed the basis of multi-criteria analysis of the indirect carbon impact of buildings [10].

The requirement for the building environmental safety on its carbon footprint is reduced to solve the optimization problem:

$$CI = \gamma_i \sum_{i=1}^{l} \gamma_j \sum_{j=1}^{m} \gamma_k \sum_{k=1}^{n} F_{ijk} \rightarrow \min, \qquad (1)$$

where CI — a comprehensive indicator of reducing the carbon footprint of construction projects;
γ_i — specific weight of the i-th factor;
γ_j — specific weight of the j-th vector;
γ_k — specific weight of the k-th node;
F_{ijk} — k-factor node j-vector i-cloud.

The specific weights of the factor space γ_i, γ_j, γ_k are the tools for focusing the low-carbon assessment of building on certain fragments of the created factor space.

$$\sum_{i=1}^{l} \gamma_i = 1, \ \sum_{j=1}^{m} \gamma_j = 1, \ \sum_{k=1}^{n} \gamma_k = 1. \qquad (2)$$

The presented complex assessment tool allows managing the scope and list of construction resources in accordance with the specifics of the region and stimulating local low-carbon industrial production [11]. Quantization (qualimetric ranking) of construction resources for complex life cycle assessment of buildings by

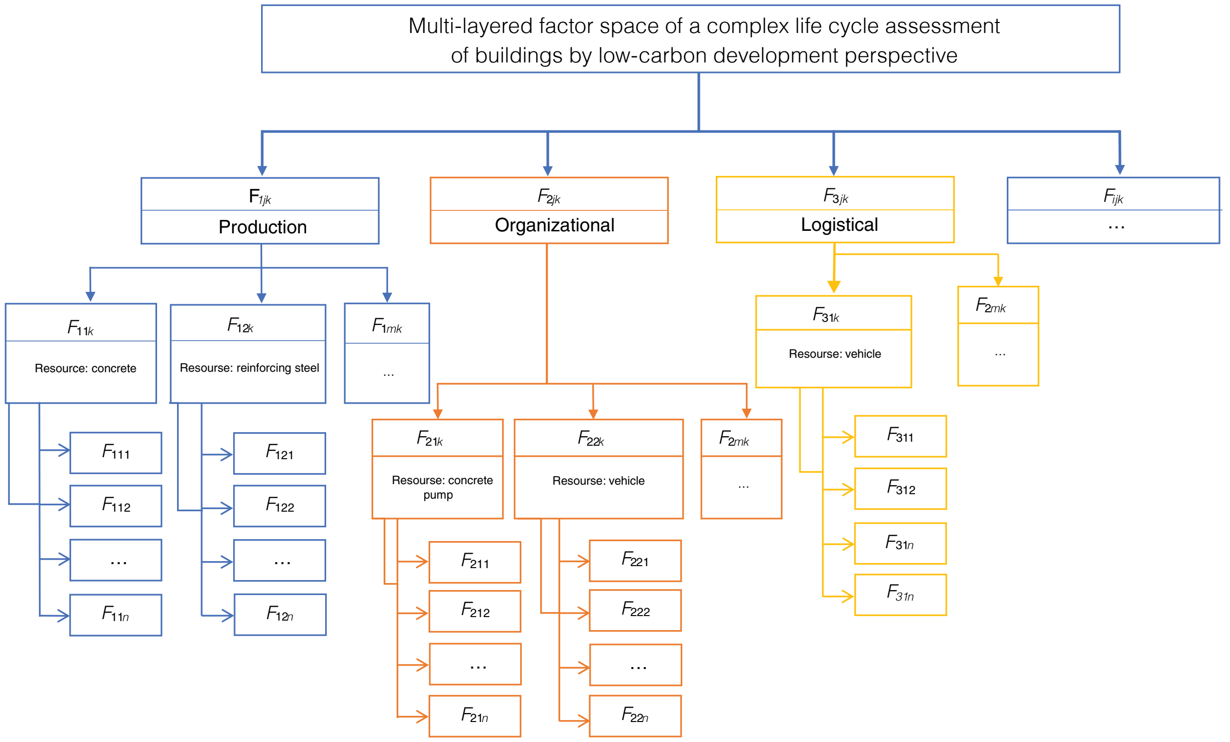

Fig. 1. System of factors to assess the building carbon footprint at the stage of design decisions

Quantization (qualimetric ranking) of construction materials for complex life cycle assessment of buildings by low-carbon development perspective

List of resources	Parameters of the carbon impact scale
Resources: materials (per 1 unit of material consumed)	Concrete, m³
	Reinforcing steel, tons
	Steel frame structures, tons
	…
Transportation	up to 20 km
	21–49 km
	More than 50 km
Construction operations	up 20 mash-hours
	21–49 mash-hours
	more than 50 mash-hours
Additional operations: organization of the construction site, provision of temporary construction infrastructure: power supply, roads, utility buildings	up 50 workers/20 machinery
	51–199 workers/21–49 machinery
	More than 200 workers/ 50 machinery

low-carbon development is presented in Table. In the first approximation, these values are equal for all construction resources and are determined by the method of expert evaluations [12]. An alternative option for assigning specific weights is the Fishburn weighting coefficient system.

All the features presented ought to be put in base of proposed Structural Carbon Analysis (SCAn) toolkit dealt with the quantitative carbon assessment embedded with the building, computated wholly and per building unit, as a monetized unit carbon footprint (UCF) in percent of construction's cost. Some buildings' UFC increasing cost of the construction resulted by authors are shown in Fig. 2. Building's UCF assessed by SCAn toolkit for comparative analyses of building carbon footprints seems to be practical criterion to pick the mostly carbon efficient building design within several possible ones at the stage of investments feasibility studies making building life cycle more efficient and carbon-friendly [13].

CONCLUSIONS

The proposed complex indicator of reducing the carbon footprint of construction projects (CI) allows comprehensively assessing the impact of all factors and indirectly characterizing the degree of carbon impact of the building at the early project stages, thereby creating an organizational and economic sustainable system of the regional construction cluster. The condition of improving the environmental safety of the building from the perspective of assessing its carbon footprint is reduced to the optimization problem solution [14].

Based on the created factor space of the carbon impact of the building created by the authors, it is possible to propose Structural Carbon Analysis toolkit, which evaluates the GHG emissions from the resource information presented in the design solutions. This tool unites carbon analysis and construction cost computation-providing assistance in the selection of environmentally friendly design and low-carbon technical solutions of buildings, taking into account the type and technological characteristics of construction resources and technologies of construction projects within monetized criteria on complex life cycle assessment.

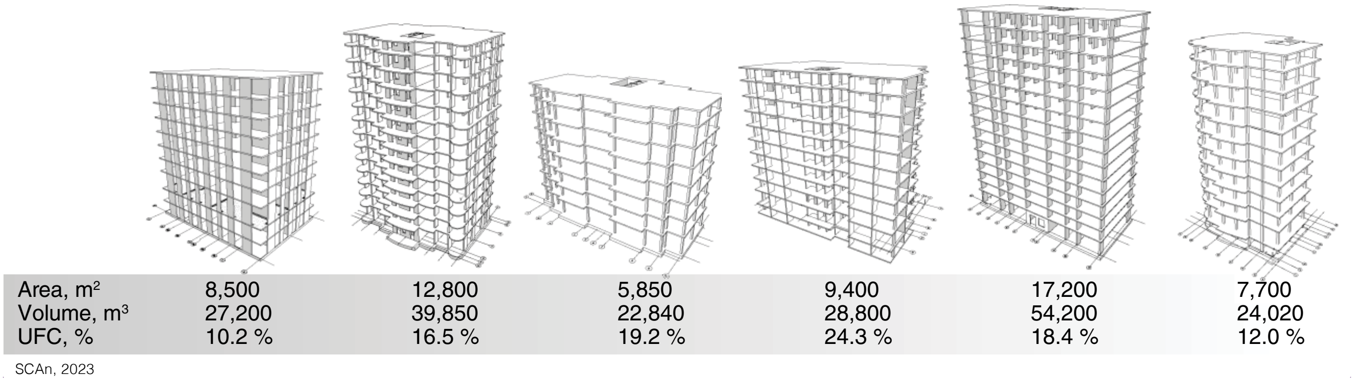

Fig. 2. Building carbon footprints assessment in SCAn toolkit

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Научно-теоретические подходы к комплексной оценке жизненного цикла здания с позиции низкоуглеродного развития

Строительная деятельность осуществляется в тесном взаимодействии с окружающей средой, что заостряет внимание исследователей на вопросах повышения экологической безопасности объектов строительства с позиции низкоуглеродного развития и снижения ресурсоемкости и энергопотребления на всех стадиях жизненного цикла здания. Мировыми трендами в строительстве являются такие направления, как декарбонизация не только существующих, но и вновь возводимых зданий, создание условий для реализации инвестиционно-строительных проектов с позиции низкоуглеродного развития, а также оценка углеродного воздействия реализуемых проектов, в том числе уже на ранних стадиях архитектурно-строительного и организационно-технологического проектирования. В соответствии со Стратегией долгосрочного развития России с низким уровнем выбросов парниковых газов до 2050 года, нормирование и снижение уровня углеродного воздействия и, как следствие, переход к низкоуглеродному развитию, в том числе и отрасли строительства, зависит, прежде всего, от научной проработки вопроса. Представлены научно-теоретические подходы к комплексной оценке жизненного цикла здания с позиции низкоуглеродного развития. Выявлены факторы, позволяющие оценить проект будущего здания с позиции низкоуглеродности применяемых проектных решений, предложено многослойное факторное пространство учитываемых показателей (строительных ресурсов) углеродного воздействия, предложен показатель минимизации углеродного воздействия здания, позволяющий комплексно оценить влияние всех факторов и опосредованно охарактеризовать степень углеродного воздействия на стадиях жизненного цикла, предшествующих эксплуатации здания.

Ключевые слова: *жизненный цикл здания, низкоуглеродное строительство, углеродное воздействие зданий, оценка жизненного здания с позиции низкоуглеродного развития*

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