UDC 69.057:004.9

Muradov A.N.

Approaches to Parametric Configuration Modeling and End–to–End Digital Identifier Generation in Industrial Modular Housing Systems

To meet the national target of commissioning 120 million square metres of housing annually, the Russian construction industry is transforming its technological approaches. Traditional construction methods, characterized by high labour intensity on-site and unpredictable processes, are giving way to industrial prefabrication. Large-scale modular housing construction represents one of the most promising technologies in construction, allowing up to 80 % of labour to be transferred to controlled factory conditions. However, the widespread adoption of this technology is hampered by issues associated with information gaps at different stages of the building lifecycle. This paper presents a scientific and methodological toolkit aimed at eliminating existing gaps through the use of parametric modelling of building configurations and an end-to-end digital object identification system. The study develops a mathematical model for generating architectural planning solutions based on constraint vectors that include geospatial, regulatory, production, and business requirements. The structure of a unique digital identifier designed for use as a key element of end-to-end management is presented. Research has shown that the transition to algorithmic design and digital certification of building system modules improves their organizational and technological reliability by reducing the risk of interface conflicts and optimizing production and logistics processes.

Keywords: *modular construction, parametric modelling, digital identifier, building life cycle, information modelling (BIM), organizational and technological reliability, prefabrication, industrial development*

Muradov Alesker Nazimovich,
Graduate student of Department of construction organization and real estate management; Moscow State University of Civil Engineering (National Research University) (MGSU); 26 Yaroslavskoe shosse, Moscow, 129337, Russian Federation; ID RSCI: 302470, Scopus AuthorID: 57194445053, WoS ResearcherID: AAE-9910-2022; aleskermuradov2@gmail.com

Currently, the investment and construction sector is facing a depletion of resources previously utilized in extensive management models [1, 2]. The current paradigm, which views construction as a sequence of loosely coupled stages, is ineffective for large-scale residential construction projects [3]. In light of the Russian Construction Development Strategy to 2030, which prioritizes industrialization and modular technologies to increase productivity, the relevance of this problem has increased significantly [4].

Large-scale modular construction (LSMC) is currently going beyond simple prefabricated building elements. It is a special type of industrialized construction in which the building is perceived as a product created using mechanical engineering principles. Modern factory production conditions allow for precision of up to 2 mm, significantly exceeding the capabilities of currently common monolithic technologies on construction sites. Despite the enormous technological potential, the implementation of modular construction projects is often hampered by issues arising from the interaction of rigid, immutable modules with imperfections in the foundation or adjacent structures. In this research paper, these issues will be referred to as “interface conflicts”.

These conflicts may arise due to the lack of a unified digital system and synchronization that could conceivably connect the design concept with the production pipeline and installation stages. Existing building information modelling (BIM) typically relies on the creation of 3D models, which can lose their accuracy and information completeness when transferred between different software environments used by various project participants. To overcome these obstacles, it is necessary to transform the static model into a dynamic parametric function. This function will be controlled by a comprehensive digital identifier system that will ensure continuous and flexible control over the object (Table 1) [5].

MATERIALS AND METHODS

A parametric modelling approach to modular building configurations

This study proposes a design system that utilizes mathematical modelling to find the optimal solution in a space with multiple constraints. a distinctive feature

Table 1. Comparative analysis of the life cycle of building systems

Life cycle stage	Monolithic construction technology	Modular construction technology
Design	Discrete creation of drawings and the possibility of modifications at later stages	Parametric modelling, fixing the module configuration at an early stage
Production	Delivery of building materials to the site	Manufacturing of high-readiness modules at the factory
Logistics	Flow of supplies of various building materials	Synchronized delivery of prefabricated large-sized modules
Installation	Long wet processes, weather dependent	High speed of module assembly (1 floor in 3–4 days)
Data management	Fragmented management, resulting in a predominance of paperwork	End-to-end digital identification, digital technical data sheets of module elements

of this methodology is its form, which is not limited to functional requirements but also takes into account the capabilities of the manufacturing process [6].

Mathematical model of constraint vectors

For the design system to function, a clear definition of four constraint vectors is necessary, which form a corridor of feasible solutions [7].

1. Geospatial and physical constraint vector (C_{env}).

Formalizes the context of the construction site:

$$C_{env} = \{G_{site}, S_{soil}, L_{gw}, A_{seis}, R_{clim}\}, \quad (1)$$

where G_{site} is the geometry of the site;

S_{soil} is the bearing capacity of the soil, which determines the maximum mass of the building;

L_{gw} is the estimated groundwater level;

A_{seis} is the seismicity, which dictates the requirements for the rigidity of the module frame;

R_{clim} are the climatic parameters that determine the thickness of the enclosing structures [8].

2. Vector of urban planning and regulatory restrictions (C_{reg}).

This vector allows us to ensure the legality of the project within the framework of current legislation:

$$C_{reg} = \{H_{\max}, K_{dens}, K_{ins}, F_{class}\}, \quad (2)$$

where $H_{\max}$ is the maximum permissible height of the object according to land use and development regulations;

K_{dens} is the coefficient of the maximum permissible development density of the site;

K_{ins} is the regulatory requirements for the duration of insolation of residential premises;

F_{class} is the functional fire hazard class of the building, dictating the requirements for materials and evacuation routes.

All requirements of the Land Use and Development Regulations (L&D) regarding the height and density of development are taken into account.

3. Vector of production and logistics constraints (C_{prod}).

The vector sets the boundaries of technological feasibility:

$$C_{prod} = \{Dim_{\max}, W_{mod}, T_{cycle}, Tr_{limit}\}, \quad (3)$$

where $Dim_{\max}$ is the maximum overall dimensions of one module (length, width, height) that the plant can produce;

W_{mod} is the maximum mass of the module, limited by the capacity of the crane equipment;

T_{cycle} is the cycle time of the production line (the time it takes to produce one finished product);

Tr_{limit} is the overall restrictions along the delivery route (the height of bridges, the turning radii of roads).

At this stage, the maximum dimensions of the module are determined, which are determined by the dimensions of the molds at the plant (for example, up to 15.5 × 7.5 m), as well as the weight, limited by the capacity of the crane equipment.

4. The vector is related to the economic part and reflects business requirements (R_{biz}).

The target performance function is formed for the developer:

$$R_{biz} = \{CAPEX_{target}, S_{sell}, Mix_{flat}, ROI_{\min}\}, \quad (4)$$

where $CAPEX_{target}$ is capital expenditure;

S_{sell} is the required useful (sellable) area of the building;

Mix_{flat} is the specified apartment layout structure;

$ROI_{\min}$ is the minimum acceptable level of return on investment.

At this stage, the desired apartment layout, budget and profitability of the project are determined [9].

Algorithm for optimized generative design and scenario-based alternative modelling

Specific optimization algorithms are used to synthesize a space-planning solution. The objective function is aimed at maximizing the saleable area while minimizing deviations from the target apartment matrix and complying with all constraints $F(X)$ [10]:

$$F(X) \to \max(w_1 \cdot S_{sell}(X) - w_2 \cdot \Delta Mix(X) - w_3 \cdot C(X)/CAPEX_{target}), \quad (5)$$

where w — project priority weighting factors.

This system can generate various layout options, depending on the initial conditions provided automatically:

- "investment" option: the goal is to quickly sell properties. The selection primarily includes studios and 1–2-bedroom apartments;
- "balanced" option: the selection includes a balanced and optimal combination of 1–2–3-bedroom apartments. This satisfies mass market demand;
- "family" option: in this case, the selection includes a large number of spacious 2–3-bedroom apartments.

It should be noted that a key step in this system is the configuration locking stage. This is a defined point of no return, after which the possibility of changing the geometry is blocked. This is necessary for a stable production flow.

End-to-end digital identification system for elements

To ensure an uninterrupted flow of information throughout the entire lifecycle of an object, a universal digital identifier system must be implemented. Under these conditions, the module becomes a unique element of the digital structure, containing a comprehensive data summary.

STRUCTURE AND SEMANTICS OF A DIGITAL IDENTIFIER

The digital identifier of a module is not just a serial number, but a semantically rich data structure integrated into the TIM model (Table 2) [11].

RESULTS

As a result of modelling the target state of the lifecycle management system using the developed methodology, the following predicted performance indicators were obtained:

1. Increased organizational and technological reliability (OTR). This is achieved by enhancing reliability at all stages of the lifecycle (design, production, installation, logistics). Design and production collisions are eliminated through parametric control and the implementation of digital identifiers.

2. Reduction of the investment cycle. Using an algorithm for recording the configuration of elements and end-to-end identification, the construction period for a 10,000 sq. m facility is reduced to 17 months [12, 13]. This acceleration occurs primarily at the design and installation stages of the aboveground portion due to the elimination of downtime and rework [14, 15].

3. Cost reduction. The synergistic effect of implementing the methodology ensures a reduction in project costs by approximately 10.35 % (Table 3).

Table 2. Proposed structure of five functional blocks

Data block	Composition of parametres	Function in the management system
Metadata	GUID, project code, module type (corner/row), production series	Clear link to the TIM model and the plant's ERP system
Spatial data	Global coordinates (*X*, *Y*, *Z*), floor, cardinal direction, installation zone index	Control of positioning accuracy, elimination of errors in installing the module in the design position
Technical parametres	Dimensions, weight, centre of gravity, design loads, fire resistance limit	Automatic selection of a transport trailer and calculation of the slinging scheme
Engineering saturation	Equipment specifications, network routing, article numbers of finishing materials	Control of plant assembly and support of operational processes
Dynamic status	Current phase (Project/Plant/Logistics/Installation), quality check log	Synchronization of flows, predictive monitoring of deadlines, activation of works

Table 3. Forecast of cost reduction

Cost item	Optimization factor	Forecast of reduction in expenditure item, %
Materials (supplied mainly to the plant)	Production of blocks using parametric cutting, taking into account precise specifications	1.35
Logistics	Improving the efficiency of transport loading and deliveries	1.50
Construction and installation works (carried out at the construction site)	Reduced lead times, no rework	3.00
Overheads	Reducing the site maintenance period	2.00
Finance (As part of the payment of interest on the loan)	Acceleration of the turnover period of funds	2.50
TOTAL	Complex effect	~10.35

CONCLUSIONS

As a result of the conducted scientific study, the following conclusions can be drawn:

1. The considered parametric design system, under constraint vectors, can enable high-level implementation of technical solutions with the ability to resolve conflicts during the assembly stage of modular units.

2. Digital identification of modular unit elements enables the creation of a sufficiently comprehensive information system from interconnected elements.

3. The considered algorithm allows for predicting the economic efficiency of the system.

4. The considered system of end-to-end identification and parametric design meets current requirements for the introduction of digital technical passports (DTP) starting March 1, 2026.

REFERENCES

1. On the national development goals of the Russian Federation for the period up to 2030 and for the period up to 2036 : Decree of the President of the Russian Federation. URL: https://normativ.kontur.ru/document?moduleId=1&documentId=470566 (rus.).
2. Strategy for the development of the construction industry and housing and public utilities of the Russian Federation for the period up to 2030 with a forecast up to 2035 : Order of the Government of the Russian Federation of October 31, 2022 No. 3268-r. URL: https://docs.cntd.ru/document/352185341 (rus.).
3. Grabovyy P.G., Bolotin S.A., Vlasov D.N., Egorychev O.O., Kirillova A.N., Kozhukhar V.M. et al. Reconstruction and renovation of existing urban development : textbook, 2nd edition. Ed. by P.G. Grabovyy, V.A. Kharitonov. Moscow, Prospect, 2013; 712. EDN ULTHYN. (rus.).
4. Grabovyy P.G., Solunsky I.A. Organization, planning and management of construction : textbook. Moscow, Prospect, 2012; 516. EDN QVBYMP. (rus.).
5. SP 501.1325800.2021. Buildings from Large Modules. Design and Construction Code. Basic Statements. URL: https://docs.cntd.ru/document/607168489 (rus.).
6. National Standard of the Russian Federation GOST R 71617–2024. Modular Buildings and Structures. Terms and Definitions. Classification. URL: https://docs.cntd.ru/document/1307419802 (rus.).
7. Ginzburg A.V., Baranova O.M., Blokhina N.S., Volkov A.A., Gariaev N.A., Ginzburg V.M. et al. Computer-aided design systems in construction : Study guide. Moscow, MISI – MGSU, 2014; 664. EDN TOCFDV. (rus.).
8. Sychev S.A. Regulatory and technological support for the installation process of prefabricated modular buildings. Regional architecture and construction. 2015; 3(24):49-54. EDN UXRSBZ. (rus.).
9. Mikhalevich V.S., Kuksa A.I. Methods of sequential optimization in discrete network problems of resource allocation. Moscow, Nauka. 1983; 208. (rus.).
10. Gusakov A.A. Organizational and technological reliability of construction production (in the context of automated design systems). Moscow, Stroyizdat, 1994; 252. (rus.).
11. Sborshchikov S.B., Shinkareva G.N., Maslova L.A., Sviridov I.A. On the issue of development of methods for managing housing construction programs. Estimate and contract work in construction. 2024; 1. URL: https://panor.ru/articles/k-voprosu-razvitiya-metodov-upravleniya-programmami-zhilishchnogo-stroitelstva/100199.html/ (rus.).
12. Bolotin S.A., Klimov S.E. Insurance of damage from untimely completion of construction based on statistical modeling. News of higher educational institutions. Construction. 2004; 11(551):52-56. EDN PIKRLD. (rus.).
13. Grabovyy P.G. Organization of construction and development of real estate. Part II: Real estate development. 4th ed., revised and enlarged. Moscow, Publishing house ASV, IIA "Prosvetitel", 2018; 608. (rus.).
14. Code of Practice SP 435.1325800.2018. Monolithic constructions of concrete and reinforced concrete. Rules of production and acceptance of work. URL: https://docs.cntd.ru/document/554818837 (rus.).
15. Rakhmetova A.Sh. Features of the construction of modular structures. Current scientific research in the modern world. 2021; 10-4(78):10-12. EDN DPOUGR. (rus.).

Подходы параметрического моделирования конфигурации и генерации сквозных цифровых идентификаторов в системе индустриального модульного домостроения

Для выполнения национальной задачи по ежегодному вводу 120 млн м^2 жилья строительная отрасль России проходит через процесс трансформации своих технологических подходов. Традиционные методы строительства, отличающиеся высокой трудоемкостью на площадке и непредсказуемостью процессов, уступают место индустриальной префабрикации. Крупногабаритное модульное домостроение представляет собой одну из самых перспективных технологий в строительстве, позволяя переместить до 80 % рабочих усилий в контролируемые заводские условия. Тем не менее широкое распространение этой технологии сдерживается проблемами, связанными с информационными разрывами на разных этапах жизненного цикла здания. В данной статье представлен научно-методический инструментарий, направленный на устранение существующих разрывов за счет применения подходов параметрического моделирования конфигурации здания и системы сквозной цифровой идентификации объектов. В исследовании разработана математическая модель для генерации архитектурно-планировочных решений, которая основывается на векторах ограничений, включающих геопространственные, нормативные, производственные и бизнес-требования. Представлена структура уникального цифрового идентификатора, предназначенного для использования в качестве ключевого элемента сквозного управления. Исследования показали, что переход к алгоритмическому проектированию и цифровой паспортизации модулей строительных систем повышает их организационно-технологическую надежность за счет снижения рисков конфликтов на интерфейсах и оптимизации производственно-логистических процессов.

Ключевые слова: *модульное строительство, параметрическое моделирование, цифровой идентификатор, жизненный цикл здания, информационное моделирование (ТИМ), организационно-технологическая надежность, префабрикация, промышленный девелопмент*

СПИСОК ИСТОЧНИКОВ

1. О национальных целях развития Российской Федерации на период до 2030 года и на перспективу до 2036 года : Указ Президента Российской Федерации. URL: https://normativ.kontur.ru/document?moduleId=1&documentId=470566
2. О стратегии развития строительной отрасли и жилищно-коммунального хозяйства Российской Федерации на период до 2030 года с прогнозом до 2035 : Распоряжение Правительства Российской Федерации от 31 октября 2022 г. № 3268-р. URL: https://docs.cntd.ru/document/352185341
3. Грабовый П.Г., Болотин С.А., Власов Д.Н., Егорычев О.О., Кириллова А.Н., Кожухар В.М. и др. Реконструкция и обновление сложившейся застройки города : учебник. 2-е изд. / под ред. П.Г. Грабового, В.А. Харитонова. М. : Проспект, 2013. 712 с. EDN ULTHYN.
4. Грабовый П.Г., Солунский И.А. Организация, планирование и управление строительством : учебник. М. : Проспект, 2012. 516 с. EDN QVBYMP.
5. СП 501.1325800.2021. Здания из крупногабаритных модулей. Правила проектирования и строительства. Основные положения. URL: https://docs.cntd.ru/document/607168489
6. Национальный стандарт российской федерации ГОСТ Р 71617–2024. Модульные здания и конструкции. Термины и определения. Классификация. URL: https://docs.cntd.ru/document/1307419802
7. Гинзбург А.В., Баранова О.М., Блохина Н.С., Волков А.А., Гаряев Н.А., Гинзбург В.М. и др. Системы автоматизации проектирования в строительстве : уч. пос. М. : МИСИ – МГСУ, 2014. 664 с. EDN TOCFDV.
8. Сычев С.А. Нормативно-технологическое обеспечение процесса монтажа быстровозводимых модульных зданий // Региональная архитектура и строительство. 2015. № 3 (24). С. 49–54. EDN UXRSBZ.
9. Михалевич В.С., Кукса А.И. Методы последовательной оптимизации в дискретных сетевых задачах распределения ресурсов. М. : Наука, 1983. 208 с.
10. Гусаков А.А. Организационно-технологическая надежность строительного производства (в условиях автоматизированных систем проектирования). М. : Стройиздат, 1994. 252 с.
11. Сборщиков С.Б., Шинкарева Г.Н., Маслова Л.А., Свиридов И.А. К вопросу развития методов управления программами жилищного строительства // Сметно-договорная работа в строительстве. 2024. № 1. URL: https://panor.ru/articles/k-voprosu-razvitiya-metodov-upravleniya-programmami-zhilishchnogo-stroitelstva/100199.html#
12. Болотин С.А., Климов С.Э. Страхование ущерба от несвоевременного выполнения строительства на основе статистического моделирования // Известия высших учебных заведений. Строительство. 2004. № 11 (551). С. 52–56. EDN PIKRLD.
13. Грабовый П.Г. Организация строительства и девелопмент недвижимости. Ч. II: Девелопмент недвижимости. 4-е изд., перераб. и доп. М. : Издательский дом АСВ, ИИА «Просветитель», 2018. 608 с.
14. Свод Правил СП 435.1325800.2018. Конструкции бетонные и железобетонные монолитные. Правила производства работ. URL: https://docs.cntd.ru/document/554818837
15. Рахметова А.Ш. Особенности строительства модульных сооружений // Актуальные научные исследования в современном мире. 2021. № 10–4 (78). С. 10–12. EDN DPOUGR.

Об авторе: **Мурадов Алескер Назимович** — аспирант кафедры ОСУН; **Национальный исследовательский Московский государственный строительный университет (НИУ МГСУ)**; 129337, г. Москва, Ярославское шоссе, д. 26; РИНЦ ID: 302470, Scopus AuthorID: 57194445053, WoS ResearcherID: AAE-9910-2022; aleskermuradov2@gmail.com.

For citation: Muradov A.N. Approaches to Parametric Configuration Modeling and End-to-End Digital Identifier Generation in Industrial Modular Housing Systems. *Real Estate: Economics, Management*. 2026; 2:53-56.

Для цитирования: *Мурадов А.Н.* Approaches to Parametric Configuration Modeling and End-to-End Digital Identifier Generation in Industrial Modular Housing Systems // Недвижимость: экономика, управление. 2026. № 2. С. 53–56.