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Digital Twin of Urban Areas as a Tool for Improving Development Project Business Planning

In the context of growing competition in the construction market, effective planning is a key tool for optimizing resources and minimizing risks, allowing construction companies not only to survive, but also to achieve sustainable profit growth through accurate forecasting and coordination of all stages of project implementation. One of the important documents in the implementation of a development project is a business plan. This document is developed based on an assessment of the urban development potential of the territory. The amount of project costs, the accuracy of the financial model, and, most importantly, the effectiveness of the project itself depend on how accurately and correctly this analysis is carried out and a business plan is drawn up. Digital technology tools are currently being actively used to improve the accuracy of forecasts and development scenarios, the reliability of set parameters, and the quality of information received. One of these tools is the creation of a digital twin of the territory.
Coordinated development of transport infrastructure and investment projects has also recently become an important factor. Based on the analysis of the transport network and the real estate market, demand is studied and the unmet demand of potential buyers are identified. Based on the data obtained, project concepts are being developed that reflect their uniqueness and attractiveness. Financial modelling, risk assessment, investment justification and forecast of results are carried out, and the developed business plans become the basis for making investment decisions.
Despite the active introduction of digital twins into urban planning practice, the issue of quantifying their impact on the synchronization of transport infrastructure and development projects has not been sufficiently studied in the scientific literature. The relevance of the research topic is due to the need to develop and formalize methods for assessing infrastructure lag and ways to minimize it.
The aim of this study is to develop an integrated model for quantifying the impact of the digital twin of an urban area on transport load parameters and the economic efficiency of development projects. The calculation of transport demand is based on aggregated normative indicators of urban mobility, and the assessment of the economic effect is based on a comparative analysis of investment attractiveness.
The theoretical basis of the research was scientific work in the field of construction organization, real estate development, urban planning and digitalization. Research methods: scenario modelling and comparative analysis.
Keywords: *digital twin, construction, transport infrastructure, residential real estate, infrastructure lag, development project efficiency, business planning*

The current stage of human development is characterized by accelerated rates of urbanization, which, on the one hand, stimulates economic growth, providing more comfortable and safe living conditions, and on the other hand, becomes a source of acute spatial contradictions, irreparable damage to the environment, and an increase in population concentration [1, 2]. According to the UN, by 2050, almost 70 % of the world's population will live in cities (Fig. 1) [3].

In the current context of urbanization, a persistent gap is emerging between the pace of housing construction and the development of transport infrastructure [4, 5]. This contradiction creates the phenomenon of "infrastructure lag", which justifies the need to create and utilize a unified digital environment designed to synchronize spatial planning and transport modelling [6]. Traditional territorial planning tools, based primarily on static documents and disparate information bases, do not provide a sufficient level of systemic management [7]. The lack of a digital tool capable of integrating fragmented data into a single database and modelling solutions is becoming a serious problem, resulting in congestion of the road network,

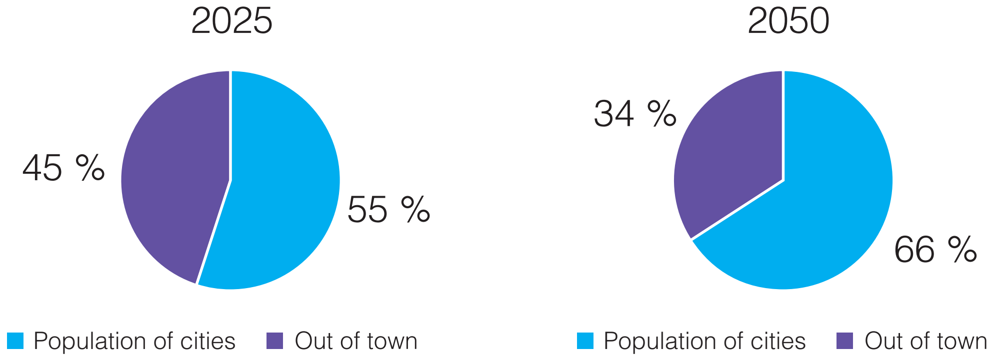

Fig. 1. Rate of urbanization

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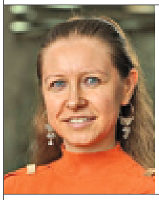

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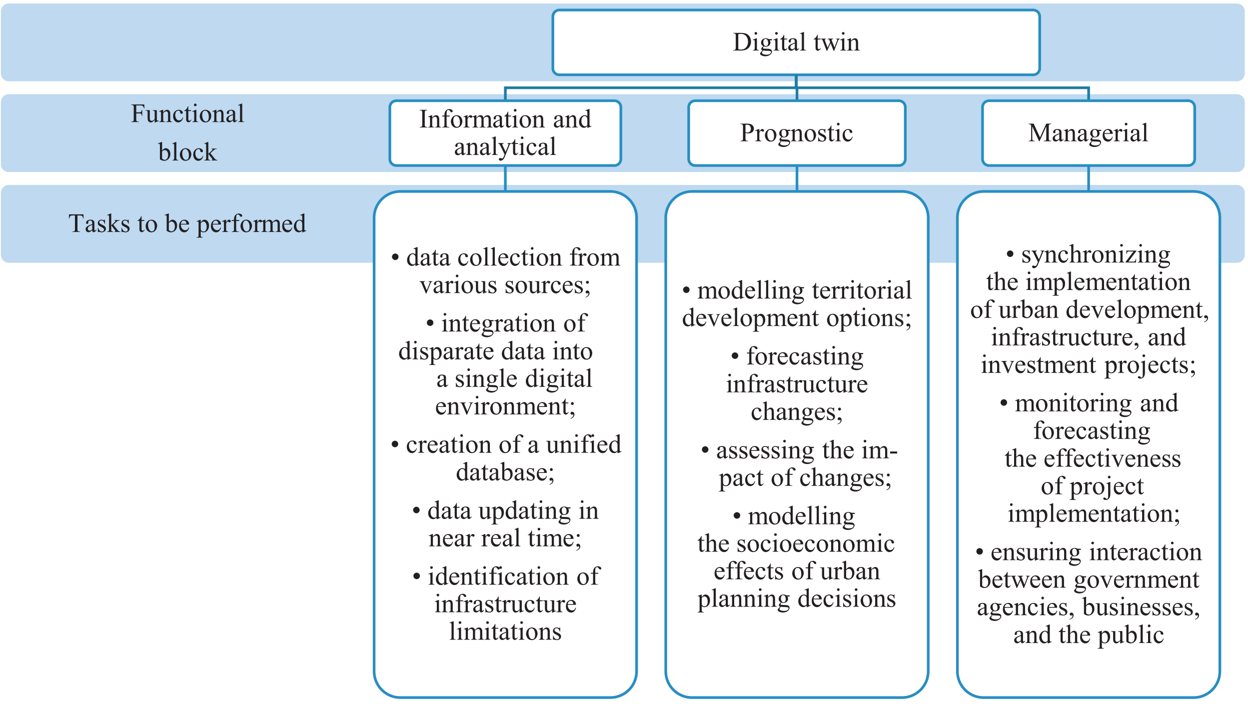

Fig. 2. Tasks of the digital twin of the territory

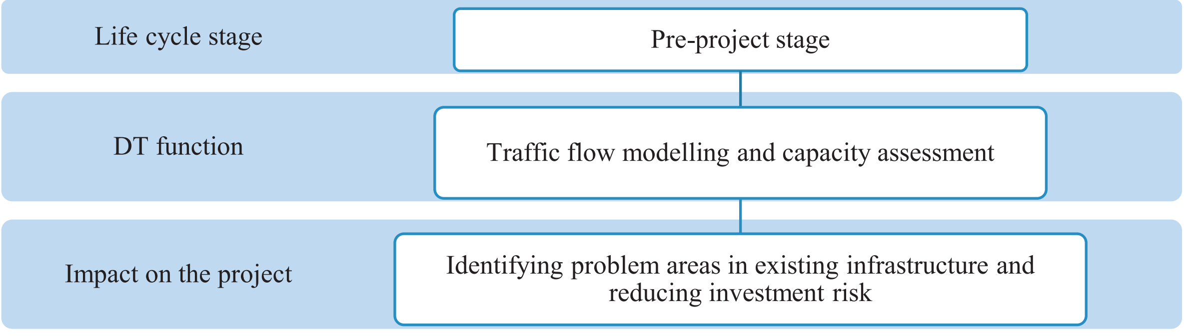

Fig. 3. Application of the DT at the pre-project stage

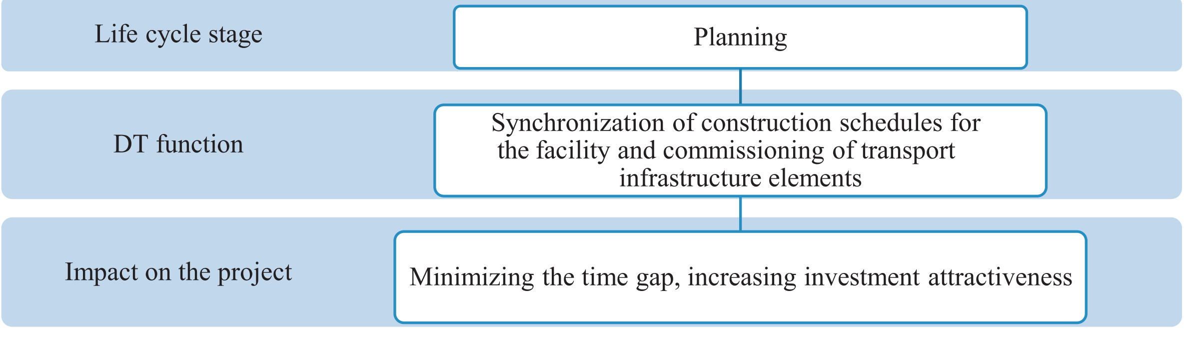

Fig. 4. Application of DT in the planning stage

increased social tension, and a decrease in investment attractiveness for both developers and property buyers [8, 9]. To address this problem, a digital twin of the territory can be used.

A digital twin of a territory (DT) is considered a visualized information and analytical system that integrates spatial, transport, engineering, social, and economic data [10, 11]. Unlike standard geographic information systems, which only store and display data, a DT is distinguished by the possibility of scenario modelling [12]. The tasks solved by a digital twin of a territory are formulated below (Fig. 2) [13].

This article introduces the concept of "infrastructure lag" — the time interval between the commissioning of a capital construction project and its provision with regulatory transport infrastructure [14]. The use of a digital twin of the territory allows the developer to

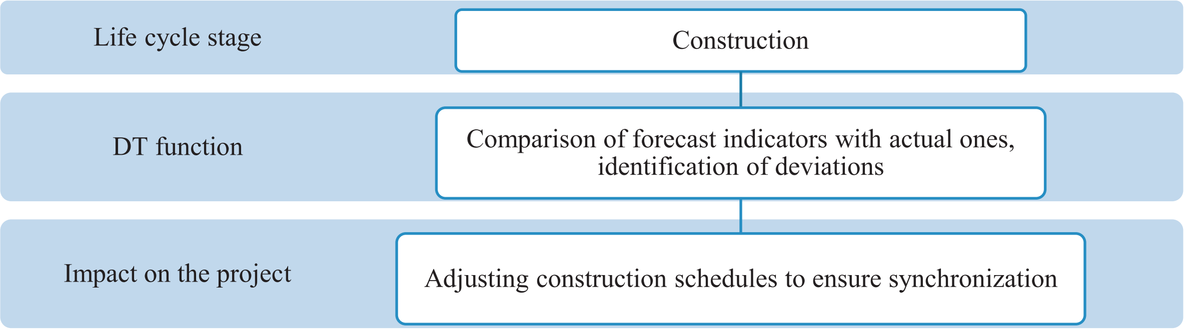

Fig. 5. Application of DT at the construction stage

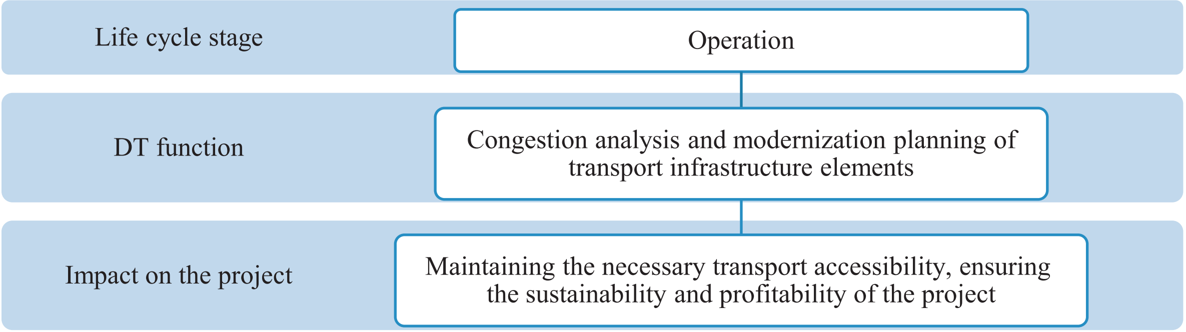

Fig. 6. Application of the DT at the operational stage

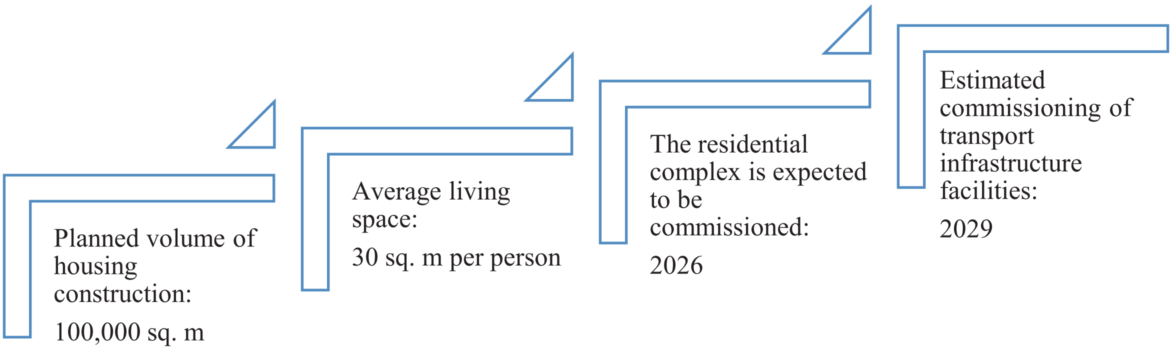

Fig. 7. Initial data of the residential complex development project

influence the size of this interval already at the early stages of the life cycle of the capital construction project (Fig. 3–6) [15, 16].

The conducted analysis of the functional application of the DT in the context of transport infrastructure at each stage of a building's life cycle allows us to conclude that this technology is not simply a tool for digitalizing the urban environment; it is being transformed into a systemic apparatus for managing the time and economic parameters of territorial management.

In calculating the infrastructure lag, we will use (1):

$$L = T_h - T_t, \qquad (1)$$

where T_h — date of commissioning of the facility;

T_t — launch date of transport infrastructure facilities.

If $L > 0$, a shortage of transport infrastructure begins. In today's reality, this indicator ranges from 1 to 3 years.

To quantify this indicator, we will consider two scenarios for implementing a residential development project: one with and one without the use of a DT. The initial data will be presented in the Fig. 7.

The calculation of the predicted number of residents P_p can be calculated using the indicator of the volume of residential development V_{rd} and the average housing provision A_{hp} according to (2):

$$P_p = \frac{V_{rd}}{A_{hp}} = \frac{100{,}000 \text{ m}^2}{30} = 3{,}333 \text{ people}. \qquad (2)$$

Next, we calculate the daily demand for transport infrastructure, D_{ti}. We take into account that, in the context of urban mobility, the average number of trips, Q, is two trips per person per day (3):

$$D_{ti} = P_p \cdot Q = 3{,}333 \text{ people} \cdot 2 \text{ trips/day} = 6{,}666 \text{ trips}. \qquad (3)$$

Note that pendulum migration M_p constitutes the dominant part of urban mobility, and for the calculation we will take the share of 75 % (4):

$$M_p = D_{ti} \cdot 75~\% = 6{,}666 \text{ trips} \cdot 75~\% = 5{,}000 \text{ trips/day}. \qquad (4)$$

Thus, the baseline scenario assumes a model in which residents will increasingly use personal transport (up to 60 % of all trips) over three years, generating additional vehicle traffic (Fig. 8).

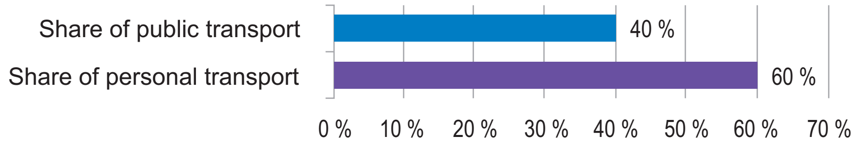

Fig. 8. Baseline scenario

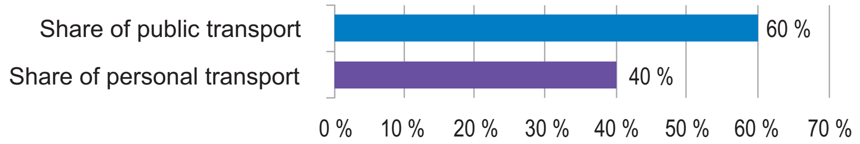

Fig. 9. Complex scenario

Table 1. Calculation results

Basic scenario (without synchronization)	Integrated scenario (using the DT)
Share of trips by car (k) — 60 %: $Q_{auto.b} = M_p \cdot k = 5{,}000 \cdot 60\ \% = 3{,}000$ trips per day. Infrastructure lag (1): $L = T_h - T_t = 2026 - 2029 = \|3\|$ year	Share of trips by car (k) — 40 %: $Q_{auto.k} = M_p \cdot k = 5{,}000 \cdot 40\ \% = 2{,}000$ trips per day. The infrastructure lag is reduced to 1 year by modelling the transport load at the design stage of the project and the phased commissioning of individual buildings
High load maintained for 3 years	Moderate load for 1 year

Meanwhile, the comprehensive scenario assumes a reduction in motorization by up to 40 % (Fig. 9).

Let's conduct a comparative analysis and display the data in Table 1.

Comparison of scenarios and calculation of relative load reduction will be calculated using (5):

$$L_r = \frac{Q_{auto.b} - Q_{auto.k}}{Q_{auto.b}} = \frac{3{,}000 - 2{,}000}{3{,}000} \cdot 100\,\% = 33\,\%. \qquad (5)$$

The economic consequences of reducing infrastructure lag are reflected in the increased investment attractiveness of the territory. Research in real estate economics demonstrates a correlation between the property value bonus and proximity to transportation infrastructure [17]. Reducing travel time to key transportation hubs increases the market value of a square meter of residential real estate by 5–10 % [18]. The calculation model assumes an average value of 7 % and a residential real estate selling price of 300,000 rubles per square meter. The calculation is presented in Table 2.

Table 2. Calculation of revenue in the baseline and complex scenarios

Basic scenario (without synchronization)	Integrated scenario (using the DT)
Revenue without the use of DT is:	Revenue using the DT is:
$R_b = V_{rd} \cdot P = 100{,}000$ m^2 $\cdot$ 300 thousand rubles/m^2 = 30 billion rubles	$R_k = R_b \cdot 7 = 30$ billion rubles $\times$ 7 % = 32.1 billion rubles

The study confirmed that the current misalignment between housing construction and urban transport infrastructure development creates a measurable infrastructure lag, which negatively impacts the performance of both. The proposed modelling allowed for a quantitative assessment of the results of possible development project scenarios and substantiated the positive impact of using a digital twin of the territory.

Thus, in the calculation model, the use of the centralized traffic control system for synchronizing residential and transport infrastructures creates the following effects:

- reducing the load on the road network by 33 %;
- reducing the infrastructure lag from 3 years to 1 year;
- redistributing transport demand in favor of public transport and reducing the share of trips by private car.

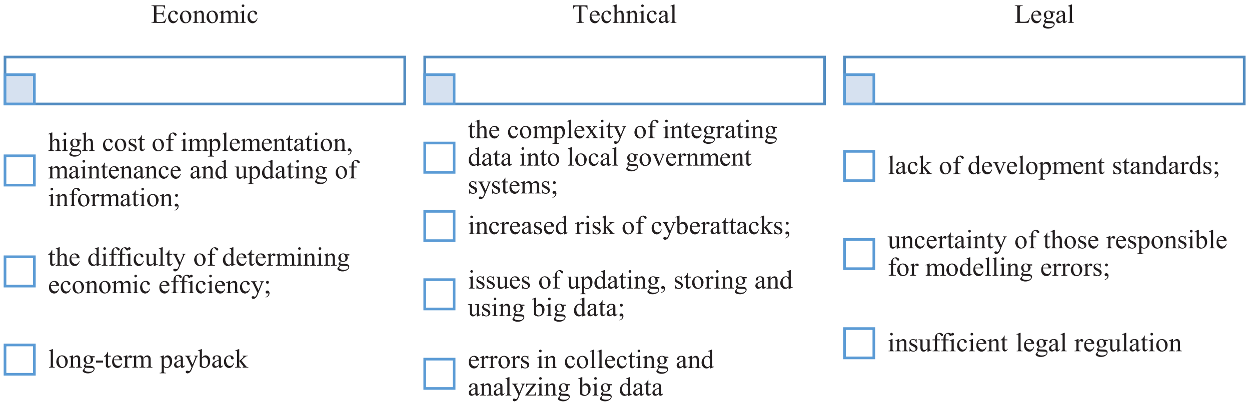

Fig. 10. Limitations on the use of DT

As a result, a more balanced functioning of the urban environment is achieved. Economic calculations show an increase in the project's investment value with improved transport connectivity: with the transport infrastructure development effects assumed in the model, the additional financial benefit amounts to 2.1 billion rubles, corresponding to a 7 % increase in revenue.

The synergy of the obtained modelling results allows us to consider the digital twin of a territory as a necessary tool for strategic management of territorial development, ensuring the coordination of spatial, transport and investment decisions in the life cycle system of capital construction projects.

However, it should be noted that the modelling conducted has a number of limitations related to its scenario-based nature:

- average indicators were used in the calculations;
- the costs of creating and/or accessing the digital twin were not taken into account.

And, despite the full potential of using a territory's digital twin, it has numerous limitations, as outlined in Fig. 10.

As a result, it can be concluded that a digital twin of a territory is an important tool for development projects, which allows for a quantitative assessment of transport load parameters, minimizing infrastructure lag, and increasing the economic efficiency of projects.

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Цифровой двойник территории как инструмент повышения эффективности бизнес-планирования девелоперских проектов

В условиях растущей конкуренции на строительном рынке эффективное планирование является ключевым инструментом оптимизации ресурсов и минимизации рисков, позволяющим строительным компаниям не только выживать, но и добиваться устойчивого роста прибыли за счет точного прогнозирования и координации всех этапов реализации проекта. Одним из важных документов при реализации девелоперского проекта является бизнес-план. Данный документ разрабатывается на основе оценки градостроительного потенциала территории. От того, насколько точно и правильно проведен данный анализ и составлен бизнес-план, зависит объем затрат в проект, точность финансовой модели и главное — эффективность самого проекта. Для повышения точности прогнозов и сценариев развития, достоверности закладываемых параметров и качества получаемой информации на сегодняшний день активно используются инструменты цифровых технологий. Одним из таких инструментов является создание цифрового двойника территории.

Также в последнее время важным фактором стало скоординированное развитие транспортной инфраструктуры и инвестиционных проектов. На основе анализа транспортной сети и рынка недвижимости изучается спрос и выявляются нереализованные потребности потенциальных покупателей. На основе полученных данных разрабатываются концепции проектов, отражающие их уникальность и привлекательность. Проводится финансовое моделирование, оценка рисков, обоснование инвестиций и прогноз результатов, а разработанные бизнес-планы становятся основой для принятия инвестиционных решений.

Несмотря на активное внедрение цифровых двойников в практику градостроительства, в научной литературе недостаточно изучен вопрос количественной оценки их влияния на синхронизацию транспортной инфраструктуры и девелоперских проектов. Актуальность темы исследования обусловлена необходимостью разработки и формализации методов оценки инфраструктурного лага и способов его минимизации.
Цель работы заключается в разработке укрупненной модели количественной оценки влияния цифрового двойника городской территории на параметры транспортной нагрузки и экономическую эффективность девелоперских проектов. Расчет транспортного спроса выполнен на основе укрупненных нормативных показателей городской мобильности, а оценка экономического эффекта на основе сопоставительного анализа инвестиционной привлекательности.
Теоретическую основу исследования составили научные труды в области организации строительства, девелопмента недвижимости, градостроительного планирования и цифровизации. Методы исследования: сценарное моделирование и сравнительный анализ.

Ключевые слова: *цифровой двойник, строительство, транспортная инфраструктура, жилая недвижимость, инфраструктурный лаг, эффективность девелоперских проектов, бизнес-планирование*

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