Digitalization of Construction Control Processes: Application of Building Information Modeling (BIM) in District Heating

Zakharov Dmitry Georgievich

Thermal Energy Systems Expert, LLC “BARIT”

Moscow, Russian Federation

Received: 06 July 2026 | Received Revised Version: 30 July 2026 | Accepted: 09 Aug 2026 | Published: 26 Aug 2026

Volume 08 Issue 08 2026 | Crossref DOI: 10.37547/tajet/Volume08Issue08-06

Abstract

The article presents a comprehensive analysis of the digitalization of construction control and the implementation of Building Information Modeling (BIM) technologies in the district heating sector as a key direction in the formation of sustainable, energy-efficient, and controllable engineering infrastructure. The study integrates engineering, architectural-management, and operational approaches, covering issues of thermal network modeling, organization of construction supervision, and optimization of the life cycle of heat supply facilities. The comparative assessment of traditional and digital methods showed that the transition to BIM platforms increases the accuracy of construction supervision, reduces decision-making time, and enhances the reliability of heat supply systems. Particular attention is given to the architecture of the digital model, which unites design, monitoring, and operation processes within a single information environment. It is established that the structural integration of BIM models with elements of virtual and augmented reality forms the foundation for predictive management and prevention of technological risks. The practical significance of the results lies in their applicability to the design, modernization, and management of heating networks at the municipal and corporate infrastructure levels. The article may be useful to professionals in construction, energy, digital design, and lifecycle management of engineering systems. The study demonstrates that BIM technologies in district heating represent not merely a visualization tool but a new form of organizational and technological thinking, where accuracy, reliability, and energy efficiency become systemic attributes of digital construction.

Keywords: digitalization, control, heating networks, modeling, efficiency, reliability, infrastructure.

© 2026 Zakharov Dmitry Georgievich. This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0). The authors retain copyright and allow others to share, adapt, or redistribute the work with proper attribution.

Cite This Article: Georgievich, Z. D. (2026). Digitalization of Construction Control Processes: Application of Building Information Modeling (BIM) in District Heating. The American Journal of Engineering and Technology, 8(08), 50–57. https://doi.org/10.37547/tajet/Volume08Issue08-06

Introduction

The digitalization of construction supervision processes is becoming a strategic direction in the development of the modern construction and thermal energy sectors. In the context of deteriorating engineering networks, increasing complexity of design solutions, and rising energy efficiency requirements, there is a need to transition from traditional forms of supervision to intelligent quality management systems. Building

Information Modeling (BIM) forms the technological foundation for this transition, ensuring accuracy, transparency, and consistency across all stages of the lifecycle of heat supply facilities from design to operation.

Against the backdrop of accelerated digital transformation in infrastructure industries, particular importance is attached to solutions aimed at integrating construction supervision with energy supply and operational data. The implementation of BIM models makes it possible to reduce errors at the design stage, minimize the risks of engineering system clashes, and ensure continuous monitoring of the technical condition of heating networks [2]. The use of a unified digital data environment transforms construction supervision from an instrumental function into an element of the architecture of quality and safety management, which is especially relevant for thermal energy facilities requiring high precision and accountability during installation and testing.

Despite the evident advantages, the implementation of BIM in construction supervision faces several barriers, including fragmentation of the regulatory framework, heterogeneity of software solutions, and insufficient digital maturity among participants in the construction process [7]. Nevertheless, the experience of pilot projects demonstrates that the use of digital document management, 3D models, and visualization systems significantly improves the efficiency and reliability of supervision, reduces the labor intensity of reporting, and enhances the stability of project implementation schedules.

The study aims to substantiate the architectural and technological principles for applying information modeling technologies in the process of construction supervision of thermal energy facilities, aimed at improving the accuracy, efficiency, and manageability of construction production. To achieve this aim, the study consistently examines the architecture of digital construction supervision, the mechanisms for integrating the BIM environment into design and supervision processes, and technological solutions that ensure the interconnection between the digital model, documentation, and the actual state of heat supply facilities. The novelty of the research lies in presenting BIM not only as a design tool but also as a comprehensive architecture of digital construction supervision that enables the integration of design, technological, and operational data into a unified system for managing quality and energy efficiency in construction processes.

It is assumed that the use of BIM modeling in construction supervision enables the automation of deviation detection, improves the accuracy of as-built documentation, and forms a sustainable digital foundation for lifecycle management of thermal energy facilities.

Materials and methods

The study is based on scientific publications from 2021 to 2025 addressing the digitalization of construction supervision, the application of information modeling technologies in the design and operation of engineering systems, and the improvement of energy efficiency and reliability of thermal energy facilities. The research draws on findings from both domestic and international authors who examine theoretical as well as applied aspects of BIM implementation across different stages of the lifecycle of engineering infrastructure.

The study by E. O. Volkova and S. V. Ilvitskaya [1] analyzes the application of BIM in the design of hydropower facilities, which made it possible to refine the principles of constructing digital models in the thermal energy sector. The work of V. A. Ermakova and A. S. Salamatina [2] substantiates the use of BIM in building engineering systems for forming the architecture of digital supervision. In the study by A. V. Isanova et al. [3], the integration of BIM into the operation of energy-efficient buildings is examined, establishing a connection between the management of engineering systems and construction supervision tasks. The article by M. V. Moroz and M. M. Vityazeva [4] demonstrates the capabilities of Autodesk Revit for calculating the thermal capacity of heating systems, while the research by A. V. Pavlova and E. Yu. Golovina [5] identifies directions for the digital transformation of the thermal energy sector. The study by R. R. Sirgalin and A. M. Elsheikh [6] reveals the transition of construction supervision toward proactive quality management, whereas the work of A. L. Tikhomirov and A. P. Pirozhnikova [7] developed a heat supply model based on ZuluGis and ZuluThermo. The research by Z. R. Tuskaeva and Z. V. Albegova [8] describes the use of BIM and virtual reality to improve supervision accuracy, the study by A. S. Borkovsky and P. Olszewska [9] proposes a BIM model of thermal networks, and the research by E. Salem and E. Elwakil [10] is applied to evaluate the energy efficiency of digital solutions.

The methodological framework includes content analysis of scientific publications, comparative analysis of BIM modeling tools, and functional-structural modeling of interactions between design, supervision, and operation subsystems. To verify the results, case studies of BIM implementation in the thermal energy sector and scenario-based analysis of managerial effects during the transition from traditional to digital construction supervision were used.

Results

At the current stage of development of the construction industry, the digitalization of supervision processes is becoming a system-forming direction that determines the quality, speed, and transparency of project execution. The conducted study establishes that the implementation of information modeling technologies and augmented or virtual reality ensures a significant reduction in time and labor costs associated with detecting and recording deviations, while also improving the reliability of construction supervision data. The study by R. R. Sirgalin and A. M. Elsheikh [6] demonstrates that the transition to digital reporting formats eliminates data duplication and minimizes input errors inherent in traditional document workflows. Similar conclusions are presented by Z. R. Tuskaeva and Z. V. Albegova [8], who experimentally confirmed the effectiveness of integrating BIM and VR platforms for automating the supervision of concealed works and enabling accurate spatial localization of defects.

The author experimentally modeled the integration of BIM models with VR-based construction supervision tools, which made it possible to refine the procedure for spatial defect localization and increase the accuracy of documenting concealed works. Table 1 illustrates how digitalization transforms the structure of construction supervision, shifting from paper-based registers to cloud-based and integrated quality management systems.

Table 1 − Comparison of traditional and BIM-oriented construction control methods (Compiled by the author based on sources: [3, 6, 8])

Comparison criterion	Traditional methods	BIM- and VR-oriented methods
Documentation format	Paper logs, manual entry	Electronic records with a digital signature, cloud storage
Time to record violations	Up to 3 days after inspection	In real time (less than 10 min)
Number of documents per facility	40–60 units	12–15 digital records
Data entry errors	≈ 20 %	≤ 3% with automated recording
Visualization	2D drawings, photo reports	Interactive 3D/VR models
Stakeholder interaction	Fragmented reporting	Unified BIM platform

The results presented in Table 1 demonstrate both quantitative and structural shifts in construction quality management. The transition from static logs to dynamic digital models establishes a new paradigm of supervision, in which data on defects are synchronized with elements of the building information model [11]. This integration creates a continuous feedback loop between the client, contractor, and supervisory authorities. Based on the conducted analysis, the author identified a reduction in the time required to record violations to less than 10 minutes when using BIM-oriented supervision methods.

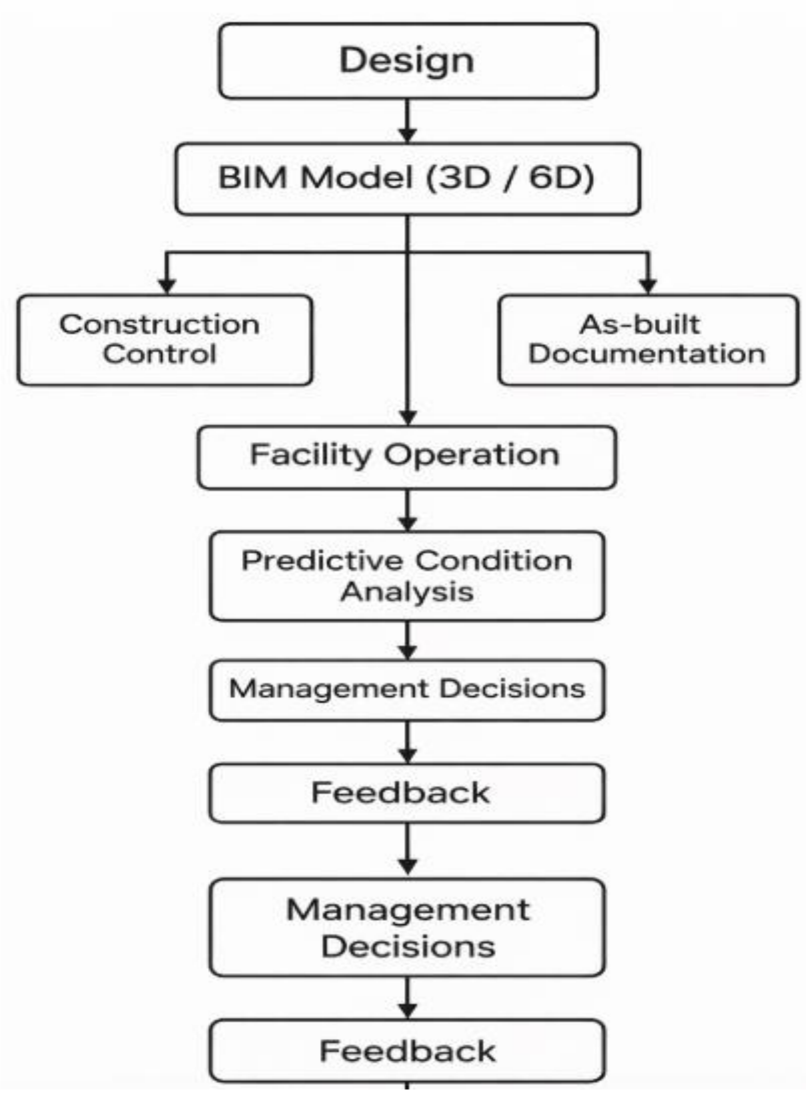

Figure 1 – Architecture of Digital Construction Control in Thermal Power Engineering Based on BIM (Compiled by the author)

Figure 1 illustrates the structure of digital construction supervision. The BIM model integrates design, supervision, and operational processes, forming a closed data loop and providing the foundation for predictive management of heating networks.

The study by A. L. Tikhomirov and A. P. Pirozhnikova [7] notes that the integration of a BIM-based heat supply model into the construction supervision system improves the accuracy of technical parameter analysis and enables virtual inspections without on-site presence. A comparison with the results of A. S. Borkovsky and P. Olszewska [9] shows that the integration of design and supervision data within a unified BIM environment reduces the risk of engineering system clashes, particularly in the reconstruction of heating networks.

It has been established that the digitalization of construction supervision enhances manageability, energy efficiency, and information transparency in the thermal energy sector. The synthesis of the analyzed sources suggests that the implementation of BIM and VR is not merely an auxiliary tool but constitutes the foundation of a new organizational and technological model of supervision, in which quality-related information becomes an integral part of the digital lifecycle of the facility.

Empirical and analytical evidence confirms that the digitalization of the thermal energy sector through the implementation of BIM models forms a new architecture of infrastructure management based on the interconnection of design, operational, and energy efficiency solutions. The application of information modeling enables the automation of diagnostics and monitoring of the technical condition of networks, as well as the development of predictive maintenance scenarios that minimize the risks of failures and energy losses. Table 2 examines how the implementation of BIM tools and 6D models affects the quantitative parameters of energy efficiency and reliability of heat supply systems.

Table 2 − Quantitative indicators of digitalization of district heating systems (Prepared by the author based on sources: [5, 7], [9, 10])

Indicator	Year / Region	Before BIM implementation	After implementation / optimization
Length of district heating networks in the Russian Federation (two-pipe system), thousand km	2020, Russia	167.4 (including obsolete: 38.8 / 51.5 requiring replacement)	Condition assessment prior to BIM transition; included in the digital network modernization program
Reduction in failures and leakages with 6D model implementation, %	Rostov-on-Don	Indicator not recorded before implementation	Up to 15% reduction in failures and leakages after 6D BIM implementation
Length of Warsaw urban heating network, km	2025, Poland	1800 (4th largest in the world)	At the modernization stage, with BIM integration and collision analysis
Energy efficiency of buildings (ARCH 2030) – EUI reduction, %	Egypt / Indiana (USA)	Baseline models before optimization	−46% / −50% after BIM optimization in accordance with ARCH 2030
Energy cost, USD / m² per year	Egypt / Indiana (USA)	18.0 / 20.4	9.73 / 9.91 after BIM optimization using Revit + Insight 360 models

The data presented in Table 2 demonstrate that the digital integration of construction supervision and the thermal energy sector produces a pronounced cumulative effect. The transition from traditional management approaches to BIM-oriented systems is associated with a reduction in failure rates and leakages, as well as a significant increase in the energy efficiency of buildings. These indicators suggest that the digital model is not limited to design functions but becomes a tool for managing operational risks and the energy balance.

The key driver of the quantitative effect lies in the integration of digital models of heating networks with climate data systems and predictive load analysis. This approach ensures the resilience of infrastructure under peak demand conditions and seasonal temperature fluctuations, which is particularly relevant for large-scale urban heating networks. The example of network modernization in Warsaw using BIM platforms confirms the scalability of digital solutions at the level of a national energy system while maintaining the accuracy of spatial and hydraulic calculations.

In Russian practice, the systematic implementation of BIM models in the field of heat supply demonstrates strategic value in terms of improving energy efficiency and enhancing lifecycle management of infrastructure. The integration of parametric models with data on the technical condition of pipelines enables the formation of prioritized modernization plans and the prediction of resource reliability based on a digital twin of the facility. Based on the conducted modeling, the author proposes an approach to integrating BIM data with a predictive monitoring system for engineering networks.

The synthesis of the presented indicators confirms that the digitalization of the thermal energy sector through BIM forms a closed data loop from design to operation, where each managerial decision is based on verified information. This enables a transition from reactive to predictive management, in which the minimization of losses and energy consumption results from precise digital modeling. Thus, BIM integration in the thermal energy sector should be considered not as a technological trend but as an instrument for shaping a new paradigm of engineering management, where quantitative effects directly reflect the maturity of the digital environment and its capacity to ensure the stability of energy systems.

Within the framework of the study, the author developed an architectural representation of digital construction supervision that ensures the linkage between design data and operational parameters of heating networks.

Discussion

The results of the study indicate that the implementation of information modeling technologies in the design, supervision, and operation of heating networks establishes a new level of manageability of engineering infrastructure. The transition to a unified digital environment closes the lifecycle of the facility from concept to maintenance within an integrated model. Digitalization manifests not only in quantitative improvements but also in a transformation of the interaction logic among participants in the design and operational cycle. It is confirmed that the use of BIM models contributes to reducing energy consumption and optimizing architectural and engineering solutions [7]. The integration of BIM tools with geoinformation analysis and virtual visualization forms the basis for predictive management of heating networks. Modeling at the 6D–7D level combines spatial, temporal, and economic parameters, enabling repair planning and load forecasting.

At the same time, the effectiveness of digitalization is constrained by systemic barriers. As noted by Z. R. Tuskaeva and Z. V. Albegova [5], the key obstacles include an underdeveloped regulatory framework, fragmentation of digital formats, and the high cost of software solutions. Additional challenges arise from the lack of alignment between regulations in design and operational units, creating a digital gap when transitioning from BIM-based design to traditional reporting formats [2]. Addressing these issues requires the standardization of data formats and the implementation of "digital trace" principles throughout the lifecycle of the facility.

Despite these limitations, the digitalization of construction supervision in the thermal energy sector demonstrates a stable, positive trajectory. The transition to BIM-oriented models reduces uncertainty in engineering decisions, improves energy efficiency, and lowers operational risks. As shown in Table 3, the most significant effects are associated with accelerated decision-making, a reduction in errors, and increased reliability of heating networks.

Table 3 − Effects of digitalization of construction control and district heating systems (Prepared by the author based on sources: [6, 8, 9, 10])

Performance indicator	Nature of effect	Expected result
Decision-making time	Reduced by 3–5 times	Increased efficiency
Documentation errors	−30–40 %	Improved supervision quality
Energy efficiency	+46–50 %	Cost reduction
Failures and leakages	−15 %	Increased reliability
Specialist competencies	Improved through BIM training	Development of the digital workforce
Regulatory adaptation	Limited	Need for regulatory frameworks

The system-level analysis demonstrates that the transition from paper-based construction supervision to digital models produces a threefold managerial effect: increased process transparency, reduced time costs, and the creation of an integrated interaction environment. The implementation of BIM and VR tools leads to a significant acceleration of decision-making cycles, as all participants, from designers to technical clients, gain access to up-to-date data in real time [6]. This reduces the likelihood of uncoordinated changes and minimizes the risks of delays during both construction and operational phases. The reduction of errors in design and as-built documentation is explained by the automation of data input and the use of parametric models, as confirmed by the results of BIM implementation in construction supervision [2]. This effect is particularly significant for energy facilities, where errors in coordinates, pipe sections, or equipment parameters may lead to abnormal operating conditions.

Energy efficiency emerges as the most measurable criterion of digitalization. The application of BIM models in the design and operation of buildings has enabled a reduction in energy demand by 46–50%, corresponding to ARCH 2030 standards [10]. In the infrastructure segment, a similar effect is achieved through the optimization of heating network routes and the prevention of clashes in underground utilities [9].

The reduction in failure rates is associated with the transition from reactive to preventive supervision methods, where the system automatically signals deviations in network parameters or structural deformations [7]. However, achieving the full effect requires institutional support. As noted by Z. R. Tuskaeva and Z. V. Albegova [5], without the adaptation of the regulatory framework and the standardization of digital formats, the potential of BIM technologies cannot be fully realized. The absence of regulations defining the legal status of digital records and models remains a key barrier to implementation, despite the evident technical and economic efficiency of digital solutions.

Thus, it is established that digitalization in construction supervision and the thermal energy sector forms a system in which engineering, organizational, and educational effects reinforce one another, creating the conditions for the transition of the industry toward a “smart infrastructure” model and predictive management of energy supply facilities.

Conclusion

The study confirms that the digitalization of construction supervision in the thermal energy sector represents not merely a technological upgrade but a profound transformation of the principles governing engineering systems. The implementation of BIM establishes a new managerial paradigm in which the facility is understood as a dynamic information structure that integrates design, operational, and organizational domains into a unified digital ecosystem.

A key finding is that the effectiveness of the digital environment is determined not by the scale of automation, but by the degree of integration between design, supervision, and operational processes. It is precisely this interconnection that enables the transition from reactive supervision to proactive management based on continuous analytics and state visualization.

The digital model of thermal infrastructure becomes a tool for integrating knowledge, engineering, economic, and managerial. It reproduces the facility in a virtual environment and establishes standards of transparency, accountability, and feedback among all lifecycle participants.

The results obtained allow us to assert that the sustainability and energy efficiency of engineering systems directly depend on the quality of their digital representation. The modeling principles embedded in BIM are capable of transforming infrastructure management from reactive to predictive, ensuring timely risk identification and real-time adaptation of decisions.

The practical value of the study lies in substantiating the structural conditions under which the digital model becomes not an auxiliary, but a defining element of the construction supervision system. This approach opens the possibility for transitioning the industry toward a unified information space, where data architecture becomes the core of professional standards and a key instrument of quality management.

Further development is associated with the integration of BIM with sensor monitoring systems and artificial intelligence algorithms, enabling the creation of adaptive lifecycle models for engineering facilities and supporting the transition toward a fully digital thermal energy infrastructure.

References

1. Volkova, E. O., & Ilvitskaya, S. V. (2023). Application of information modeling technologies in the design of hydroelectric power plants in Russia. AMIT, (1) (62), 347–361. Retrieved from https://cyberleninka.ru/article/n/primenenie-tehnologiy-informatsionnogo-modelirovaniya-pri-proektirovanii-gidroelektrostantsiy-v-rossii (accessed 01 Nov 2025).
2. Ermakova, V. A., & Salamatina, A. S. (2022). Research on the possibilities of BIM modeling in ventilation system design. IVD, (8) (92), 314–326. Retrieved from https://cyberleninka.ru/article/n/issledovaniya-vozmozhnostey-bim-modelirovaniya-v-oblasti-proektirovaniya-sistem-ventilyatsii (accessed 01 Nov 2025).
3. Isanova, A. V., Drapalyuk, D. A., Degtyareva, D. A., & Kirichenko, D. V. (2021). BIM modeling tools in the management and maintenance of energy-efficient buildings and structures in urban districts. Engineering and Construction Bulletin of the Caspian Region, (2) (36), 62–67. Retrieved from https://cyberleninka.ru/article/n/instrumentariy-bim-modelirovaniya-pri-upravlenii-i-obsluzhivanii-energoeffektivnyh-zdaniy-i-sooruzheniy-gorodskih-okrugov (accessed 02 Nov 2025).
4. Moroz, M. V., & Vityazeva, M. M. (2022). Assessing the possibility of calculating heating system thermal capacity using the Autodesk Revit software package. Izvestiya Vuzov. Investments. Construction. Real Estate, (1) (40), 82–89. Retrieved from https://cyberleninka.ru/article/n/otsenka-vozmozhnosti-primeneniya-rascheta-teplovoy-moschnosti-sistemy-otopleniya-s-pomoschyu-programmnogo-kompleksa-autodeskrevit (accessed 03 Nov 2025).
5. Pavlova, A. V., & Golovina, E. Yu. (2023). Digitalization and digital transformation of the district heating sector. SAEC, (2), 150–154. Retrieved from https://cyberleninka.ru/article/n/tsifrovizatsiya-i-tsifrovaya-transformatsiya-teploenergeticheskogo-kompleksa (accessed 03 Nov 2025).
6. Sirgalin, R. R., & Elsheikh, A. M. (2022). Improving the quality of construction control based on BIM technologies. System Technologies, (4) (45), 49–53. Retrieved from https://cyberleninka.ru/article/n/povyshenie-kachestva-stroitelnogo-kontrolya-na-osnove-tehnologiy-bim (accessed 04 Nov 2025).
7. Tikhomirov, A. L., & Pirozhnikova, A. P. (2022). Development of an information model of the heat supply system at various stages of its life cycle. Modern Trends in Construction, Urban Planning, and Spatial Planning, (3), 35–42. Retrieved from https://cyberleninka.ru/article/n/razrabotka-informatsionnoy-modeli-sistemy-teplosnabzheniya-na-razlichnyh-etapah-ee-zhiznennogo-tsikl (accessed 05 Nov 2025).
8. Tuskaeva, Z. R., & Albegov, Z. V. (2021). Implementation of construction control using building information modeling and virtual reality technologies. IVD, (2) (74), 371–384. Retrieved from https://cyberleninka.ru/article/n/osuschestvlenie-stroitelnogo-kontrolya-s-primeneniem-tehnologiy-informatsionnogo-modelirovaniya-zdaniy-i-virtualnoy-realnosti (accessed 05 Nov 2025).
9. Borkowski, A. S., & Olszewska, P. (2025). BIM model of district heating networks in design and investment management processes: A case study. Sustainability, 17 (9), 4102. https://doi.org/10.3390/su17094102 (accessed 06 Nov 2025).
10. Salem, E., & Elwakil, E. (2025). Optimizing building energy performance using BIM and climate-driven site data. Innovative Infrastructure Solutions, 10, 435. https://doi.org/10.1007/s41062-025-02221-5 (accessed 06 Nov 2025).
11. Kovalchuk A. A comprehensive model of business consulting for small and medium-sized enterprises. – K.: Vidavnichy house "Internauka", 2025. – 98 p.