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Advantages of building information modeling (bim) during the operational life

Переваги інформаційного моделювання побудови (імп) протягом терміну експлуатації

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Abstract

Building Information Modeling (BIM) technology is rapidly gaining traction in facility management and operations. This software aids in the effective management and exchange of building data, offering valuable benefits throughout construction stages, from planning to maintenance. This study delves into the factors affecting the operational performance of a BIM model and its paramount benefits during the digital design phase. Emphasis is placed on the merits of BIM during the operational phase, primarily using Autodesk Revit software. The research includes an analysis of engineering systems, particularly digital modeling of HVAC, water supply, and electrical systems. Drawing from BIM implementation experiences in Ukraine, the study reviewed significant contributions to digital model designs, examining BIM models across various infrastructure projects. A unique aspect of this research is the development of a digital BIM model using Autodesk Revit 2016, which uses advanced tools to spotlight the benefits of modeling throughout the design process.

Анотація

Технологія Моделювання Інформації для Будівництва (BIM) швидко набирає обертів у управлінні та експлуатації об'єктів. Це програмне забезпечення сприяє ефективному управлінню та обміну даними будівництва, пропонуючи цінні переваги на всіх етапах будівництва, від планування до обслуговування. Це дослідження вивчає фактори, які впливають на операційний результат моделі BIM та її основні переваги під час цифрової дизайнерської фази. Основний акцент робиться на перевагах BIM під час операційної фази, переважно використовуючи програмне забезпечення Autodesk Revit. Дослідження включає аналіз інженерних систем, зокрема цифрове моделювання систем HVAC, водопостачання та електричних систем. Виходячи з досвіду впровадження BIM в Україні, в дослідженні розглядалися важливі внески в дизайн цифрових моделей, аналізуючи моделі BIM в різних проектах інфраструктури. Унікальною особливістю цього дослідження є розробка цифрової моделі BIM за допомогою

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Keywords: digitalization, BIM, software, Autodesk Revit, digital model.

Autodesk Revit 2016, яка використовує передові інструменти для виявлення переваг моделювання на всіх етапах процесу дизайну.

Ключові слова: цифровізація, BIM, програмне забезпечення, Autodesk Revit, цифрова модель.

Introduction

In the modern world, numerous operations and processes are facilitated by computer technologies, which encompass a range of information transformations in various forms, such as textual, graphical, and auditory, into a digital format known as digitization. Digitization combines advanced technologies and systems from architecture, engineering, and construction, transitioning from traditional design methods to contemporary approaches using Building Information Modeling (BIM) (Tan et al., 2021).

Although initial attempts to apply computer technologies in building projects date back to the early 1980s and 1990s, the most significant utilization of such technologies occurred in the early 2000s when computer technologies entered the era of modernization and optimization in building design. The concept of the "Building Information Model" emerged in the early 1990s but gained prominence in the early 2000s when software provider Autodesk published an article titled "Building Information Modeling" (BIM), followed by other software companies joining the field (Panteli & Fokaides, 2020).

The digitization of building information modeling (BIM) involves complex processes for developing an intelligent model that integrates professionals from architecture, engineering, and construction to ensure efficiency in building design, construction, and operational phases. The primary advantage of BIM technology lies in developing and utilizing computer-generated n-dimensional (n-D) models to simulate the facility's planning, design, construction, and operation. It enables architects, engineers, and builders to visualize what will be constructed within the modeled environment while also identifying potential design, construction, or operational issues (Ibem et al., 2018).

Modern BIM capabilities can solve many problems and shortcomings that indicate a lack of consistency in the development and exchange of digital information, such as resource intensity and minimal efficiency in managing the processes of design, construction, operation and lack of effective life cycle management of facilities, as well as the inadequacy of regulatory support for modern construction technologies, etc. To solve these problems, many countries and Ukraine propose the introduction of BIM technologies, which consist in the development and sharing of a digital model that can contain all the necessary characteristics on the basis of which design and estimate documentation is developed (Šimenić, 2021).

The digital model, created by designers using specialized software, allows for integrating information related to physical and functional characteristics. However, the key advantage of BIM technology over traditional design methods lies in its ability to unite architecture, engineering, and construction professionals through a shared database of digital models. This enables efficient data exchange throughout the entire project lifecycle. During the development and operation of a building, the model data allows for valuable information about the construction elements and the interconnections between model components. Determining the necessary resources (materials) and minimizing project implementation time on the construction site is crucial. Moreover, any changes made to model elements enable quick and accurate updates across all associated sections of digital drawings (Krasovskaya et al., 2021).

One of the advantages of BIM is its adaptability, as the model can be accepted at any stage of construction and infrastructure, both during the design and operational and post-construction phases. The design phase encompasses implementing architectural design aspects, structural analysis, mechanical, electrical, and plumbing evaluations, and environmental and energy assessments for analysis purposes. Implementing BIM during construction involves monitoring progress and addressing safety and security issues. In contrast, the post-construction phase is associated with monitoring the building's operation, typically from the digital twins' perspective and machine learning technologies' application. It is worth noting that BIM can be used for assessing building operations after completion and reflects the actual energy performance (Panteli & Fokaides, 2020).

However, BIM technologies are only used in the design of individual buildings and structures. BIM technologies have not yet been fully implemented in the practice of design, construction and operation, which certainly makes a large number of studies particularly relevant today (Jian, 2020).

The task of architects, engineers, and builders during the design phase is to employ efficient methods to reduce project costs, enhance productivity and quality, and shorten project implementation timelines. BIM, which contains a digital potential, serves as a means to achieve these goals and objectives (Eastman, 2011).

Over the past decade, BIM has been widely utilized in prefabricated construction in the building industry. Recent scientific and industrial research has shown that the application of BIM with software influences the reduction of life cycle costs, waste reduction, increased productivity, and improved quality in construction (Zhang et al., 2021).

Literature review

Implementing and developing building information modeling (BIM) technology has brought numerous advantages to the industrial and construction industries. The use of BIM is associated with benefits such as eliminating unforeseen budget variations, improving cost estimation accuracy, and reducing time for compiling cost estimates and project timelines (Sepasgozar et al., 2022). El Mounla et al., (2023) suggest that the development of information technology enables cost and time savings in project and construction activities and facilitates effective integration of inputs from contractors and suppliers during the design phase, enhancing the construction performance of projects. The studies by Darko et al., (2020) and Bello et al., (2021) identified key advantages of BIM, which include:

- instant detection of conflicts between different building systems;
- reducing fragmentation in the construction industry;
- enabling seamless integration of various industry segments;
- enhancing efficiency in the sector;
- reducing costs associated with information exchange and utilization among project stakeholders;
- providing an alternative solution for design coordination as projects can be reviewed in a digital model.

Rodrigues et al., (2020) described how, for an entire project, design conflicts alone among designers could amount to tens of thousands of observations, making such an approach unsatisfactory in the long term.

Ding et al., (2019) analyzed that BIM contributes to rapid visualization and accurate change updates during the conceptual stage of building project development, improving communication among project design teams and enhancing collaboration between architects and engineers in the development team. The authors presumed that improving the quality of architectural and engineering design regarding error-free drawings leads to a continuous increase in work productivity.

Compliance with safety rules during the operation and maintenance of buildings is equally important when designing a digital BIM model. Wang et al., (2021) proposed an evaluation method that, combined with BIM technology, allows for quick and reliable assessment of the fire hazard of the target building model and realizes an organic unity of science, efficiency, and economy. Additionally, the authors developed a risk calculation model for the operational and maintenance periods to enhance the fire safety capacity of buildings.

The operational phase of a building's life cycle can consume a significant amount of energy, leading to a considerable negative impact on the environment. While energy modeling can be applied as a tool to assess the energy performance of an operational building, the emergence of BIM technology facilitates the evaluation process through defined and enriched building information. However, this approach has a drawback concerning the compatibility issue between BIM software tools and energy modeling tools, and the modeling results are rarely verified due to the lack of corresponding experimental data.

In the United States, the construction sector and building operations account for nearly 43% of the total energy consumption in the country. Furthermore, during the operational phase, buildings consume 87% and 84% of the total energy in Europe and the United States, respectively. Therefore, in the struggle with a deleterious influence, the operational phase of a building's life cycle gains practical significance, wherein energy modeling can play a crucial role in predicting energy efficiency, optimizing design, and building operation (Li & Mills, 2020).

Construction regulation of streets and roads is determined according to a previously formed urban planning plan (Samko, 2023).

Aims

This study **aims** to determine the key advantages of building information modeling during the operational phase based on global research using Autodesk Revit software. An analysis of engineering systems during the operational phase was conducted as part of the research. It included the digital modeling of HVAC systems (heating, ventilation, and air conditioning), water supply, and electrical systems.

The following tasks should be accomplished to achieve the set **goal**:

– review and analysis of literature on global research regarding the use of building information modeling.
– identification of the most suitable software for design and model development.
– analysis of patterns in building information modeling to determine key advantages and disadvantages during the operational phase.
– analysis and comparison of two software programs, Autodesk Revit and AutoCAD, regarding their digitalization capabilities.

The **scientific novelty** lies in developing a digital BIM model using Autodesk Revit 2016 software, utilizing comprehensive professional tools to identify the key advantages of modeling at each stage of the design process.

The **practical significance** of the results obtained is that the authors have studied and analysed the developed BIM model at the stage of building design with the characteristics of operational properties, which made it possible to determine the main advantages of using BIM technology in the design of a digital model of any object.

Methods and Materials

Autodesk Revit 2016

The Autodesk Revit series software, developed by the leading global provider of digital design software, Autodesk, is a parametric 3D design and architectural design software platform. The software consists of three main professional tools for design: Autodesk Revit Architecture (architectural version), Revit Structure (structural version), and Revit MEP (Mechanical Electrical and Plumbing - equipment, electrical, water supply, and drainage version), as shown in Figure 1 (Sun, Fan & Sharma, 2021).

Autodesk Revit 2016 version comprises three software components with powerful data exchange capabilities to create a collaborative design platform and facilitate multi-disciplinary 3D design. The software has a robust data management function and can store all the necessary information about component parameters in the model database.

The first step in determining whether or not to use Autodesk Revit software is to analyze the advantages and disadvantages of this product. So let us explore and consider the three software tools of Autodesk Revit 2016 more closely.

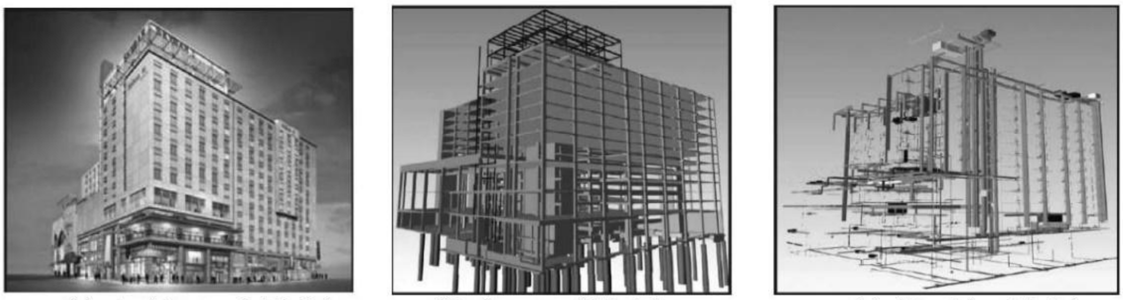


Figure 1. The main professional tools of Autodesk Revit
Source: (Azhar, 2011).

a) **autodesk Revit Architecture.** Software for 3D simulation designed for modeling plumbing, electrical, heating, and other related equipment, suitable for architectural design specialization. The program features powerful parametric modeling capabilities and enables quick project creation. The software is visually depicted in Figure 1 (a) - Architectural Model.

b) **autodesk Revit Structure.** A program for three-dimensional design specifically developed for structural designers. The software provides a wide range of structural components to meet the design requirements of construction professionals. The software is visually depicted in Figure 1 (b) - Structural Model.

Advantages of Autodesk Revit Architecture and Revit Structure:

- increased accuracy: Allows construction engineers to create precise and validated projects, facilitating easy design modifications and visualizing how changes impact the entire building model.
- improved collaboration and communication: Enables construction engineers to collaborate with other team members in real time, reducing errors and discrepancies during the design process.
- efficient project management: Helps construction engineers effectively manage their projects, allowing easy tracking of project progress, task planning, and resource management).

c) **autodesk Revit MEP.** A program for constructing a BIM model with all plumbing systems: water supply, drainage, electrical system, heating, ventilation, and air conditioning systems for construction firms and owners. The BIM model contains all the information about the parameters of the plumbing system, and the software can be used for all plumbing systems. The software is visually depicted in Figure 1 (c) - Plumbing Model.

Advantages of Autodesk Revit MEP:

- improved coordination: Enables building engineers to coordinate their projects with other disciplines, helping reduce clashes and errors during construction.
- increased efficiency: Allows MEP engineers to create accurate and detailed designs, making it easy to make changes and see how they impact the entire building model.
- accurate cost estimation: Assists MEP engineers in accurately estimating the cost of building systems, making it easy to calculate the quantities of materials and equipment needed for the project.

The software has detailed settings, such as pipe layout parameters and material properties. After creating a BIM model of the piping system, the software can intelligently lay out the pipes, establishing spatial connections between the piping system and building models, and Autodesk Revit MEP includes clash detection functionality. Designers can optimize the layout of the piping system. The software can also be used with Navisworks for comprehensive clash detection between specialized pipes and auxiliary equipment.

The disadvantages of using Autodesk Revit software include the following:

- large file sizes.
- incompatibility with the Mac OS operating system (it operates only on Windows).
- the requirement for a more powerful processor.

Analysis of Autodesk AutoCAD software

AutoCAD is a computer-aided design (CAD) program developed by Autodesk in 1982, which has been continuously improved and developed to create a multitude of additional components that leverage the capabilities of AutoCAD. The software is commonly used for the 3D design of machine parts, but its lack of parametric objects makes it only a good tool for designing heating, ventilation, and air conditioning (HVAC) systems. HVAC design is performed using AutoCAD or the more widely used MagiCAD software for AutoCAD.

Each design zone is modeled separately in its file, typically one file per floor or level. Thus, it limits the ability for concurrent editing by multiple users, even though designers from different specialties often work simultaneously. Consequently, simultaneous collaboration is not possible. Depending on the project's scope, a large number of files are created, and each file requires a manual layout to satisfy the specific design requirements.

Building information modeling based on AutoCAD typically involves using two programs simultaneously. AutoCAD is used for design, while another program like Navisworks is used for integrating all models and performing BIM checks. As a result, real-time visualization of changes to existing models is impossible. (Kalpio, 2018).

Results

BIM model development at the building design stage

Using BIM technology to create a digital prototype of the hospital model enables viewing each individual component of the designed plan through a software library. The small area model covers 100m^2 and includes several sections: separate corridors for medical staff, patient service rooms, and personal hygiene rooms (bathrooms).

The digital building model is presented in Figure 2, which includes the following architectural and structural elements from the library: a base consisting of corrugated sheeting, steel column fastenings, a roof with interior ceiling finishes, 60 mm sandwich panels, doors and windows, and staircases with fastenings. The MEP systems include sanitary facilities with water supply and drainage, electrical system layout, and ventilation system. Equally important are the heating and conditioning systems, which engineers collectively consider during the design phase. The MEP systems will be addressed in the following subsection with the operational characteristics of the model.

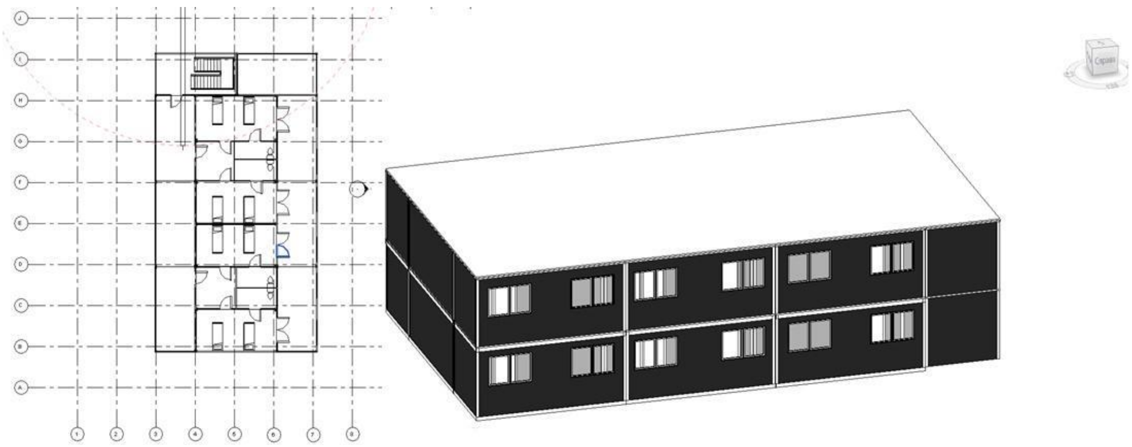


Figure 2. Digital prototype of the hospital model with a schematic plan and 3D version.

The initial modeling stage consists of designing and erecting the framework on a grid, followed by assembling the structure using a library - each container block has dimensions of 3x6x2.8 meters. They are connected to each other using fastening elements - clamping bolts. The material for the structural fastening consists of galvanized steel, and the basic structure of steel columns is made of 4mm galvanized steel with four columns. The doors, measuring 900x2040, are made of steel and aluminum frame with an integrated handle, and the window size is 800x1100, consisting of plastic and aluminum frame with embedded glass, with a thickness of 5x9 mm. The model consists of two floors, with each floor containing 14 assembly structure containers, providing access to the second floor through stairs. The visual assembly realization of the first and second-floor structures is shown in Figure 3.

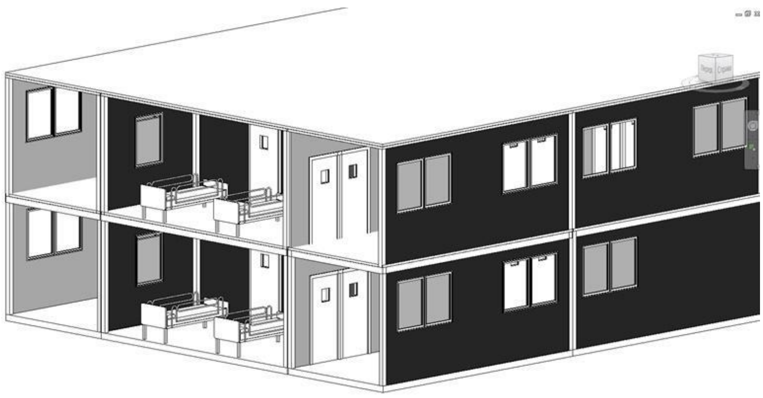
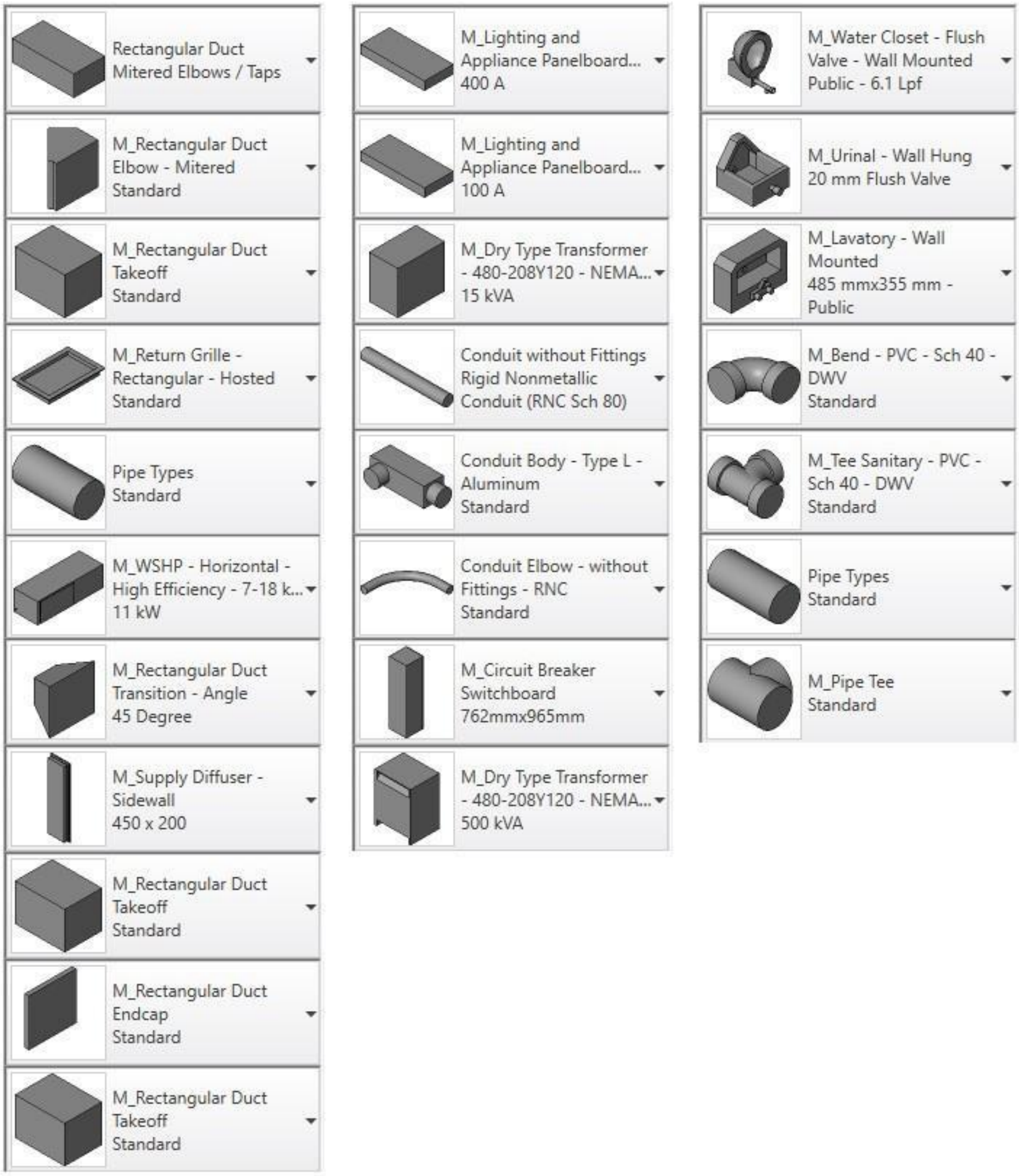


Figure 3. Digital 3D model of the construction of two floors structure.

Before proceeding to the installation phase of sandwich panels, windows, and doors, it is necessary, first and foremost, to assemble and securely attach the framework of the fastening elements of the structure – steel beam-columns with dimensions of 115x115 mm.

Operational characteristics of the BIM model

During the development of a BIM model in the building design phase, it is necessary to determine which engineering systems and structures can be used to meet human needs and provide services during the operational period throughout the facility's entire life cycle. These engineering systems include heating, ventilation, air conditioning, water, and power supply. Figure 4 illustrates the main Autodesk Revit 2016 software library elements for constructing engineering systems.



а) б) в)

Figure 4. The use of elements from the library to build systems for the operation of a) heating, ventilation & air conditioning; b) water supply; c) power supply.

1) heating, ventilation, and air conditioning systems

The design of the HAVC system consists of elements from the Autodesk Revit library and is designed as follows: a central rectangular air tube is connected to the other tube lines by the M_Rectangular Duct Elbow, M_Rectangular Duct Takeoff, and M_Rectangular Duct Endcap. Then the piping system is connected to a water source heat pump (M_WSHP) with a high efficiency of 7-18 kW, with left reverse and the right discharge of 11 kW, at the outlet of which, on the other side, the piping is laid along with the outlet of air diffusers with side walls (M_Supply Diffuser - Sidewall) using connecting elements. The types of air ducts and connecting elements are standard in size.

The floor plan of a typical room with a water source heat pump (WSHP) is shown in Figure 5 a) together with its section and its b) plan.

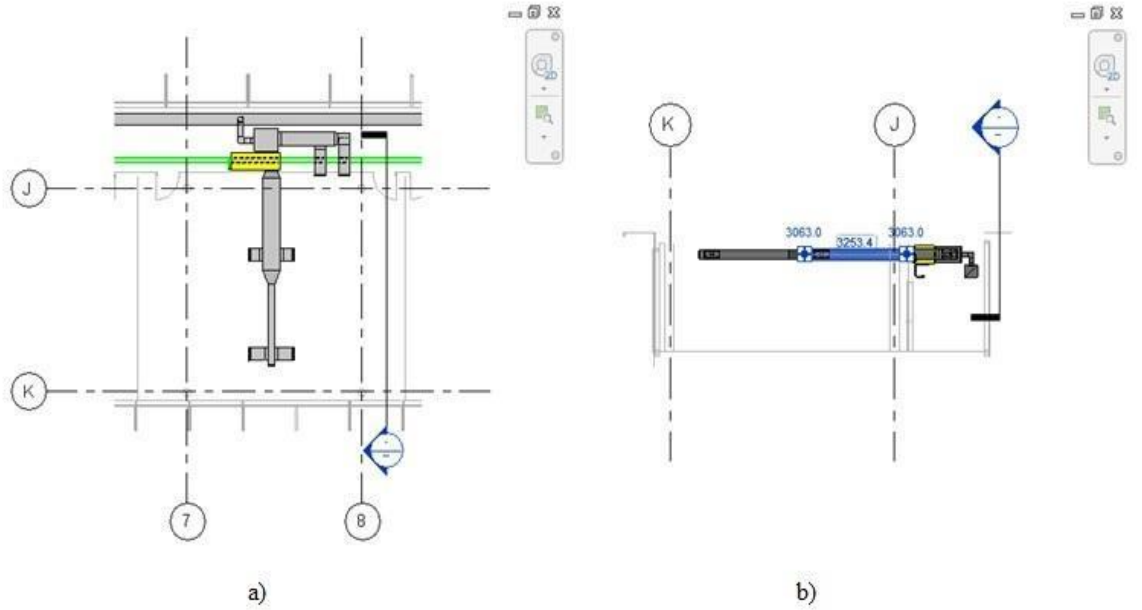


Figure 5. The floor plan of a room with a water source heat pump (a) and a cross-sectional plan (b).

After constructing the floor plan in the software environment, it can be visualized in a 3D format, displaying all elements within the inter-room space, as shown in Figure 6.

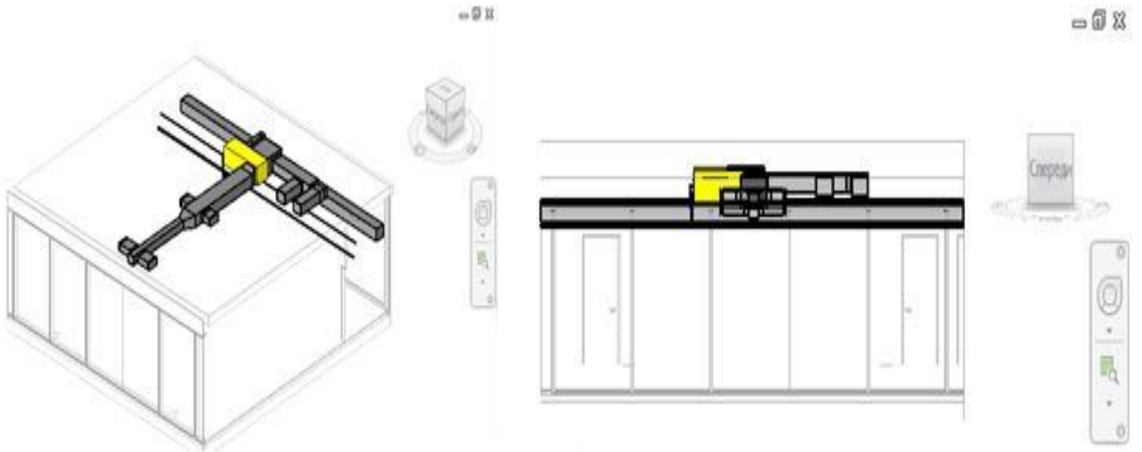


Figure 6. 3D model of the completed HVAC system.

2) water supply

Figure. 7 illustrates a schematic floor plan of a sanitary unit using elements of the MEP library.

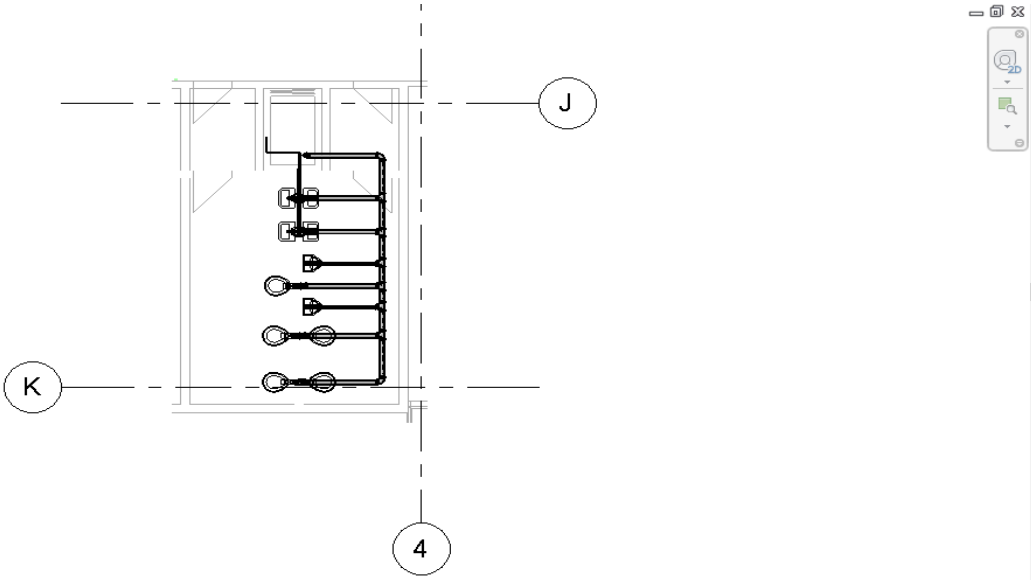


Figure 7. Schematic floor plan of the sanitary unit.

The design of the water supply system consists of a standard type of pipeline (M_Pipe Standard) and a common type of pipe elbow (M_Pipe Elbow Standard), with a drainage system (M_Bend - PVC - Sch 40 - DWV) and a sanitary tee (M_Tee Sanitary - PVC - Sch 40 - DWV). The sanitary fixtures include a wall-hung urinal with a 20mm flush valve (M_Urinal Wall Hung 20 mm Flush Valve), a wall-mounted public toilet measuring 485mm x 355mm (M_Lavatory - Wall Mounted 485mm x 355mm - Public), and a wall-mounted public water closet with a flush valve (M_Water Closet - Flush Valve - Wall Mounted Public).

A 3D rendering of the designed water supply system is shown in Figure 8, illustrating the main elements of sanitary fixture mounting with the pipeline components and drainage system.

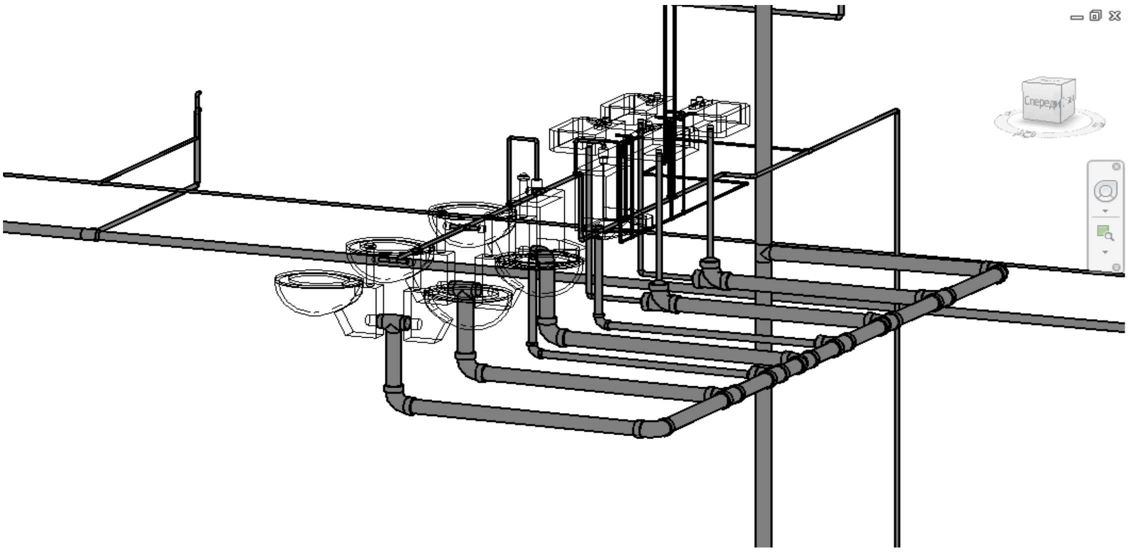
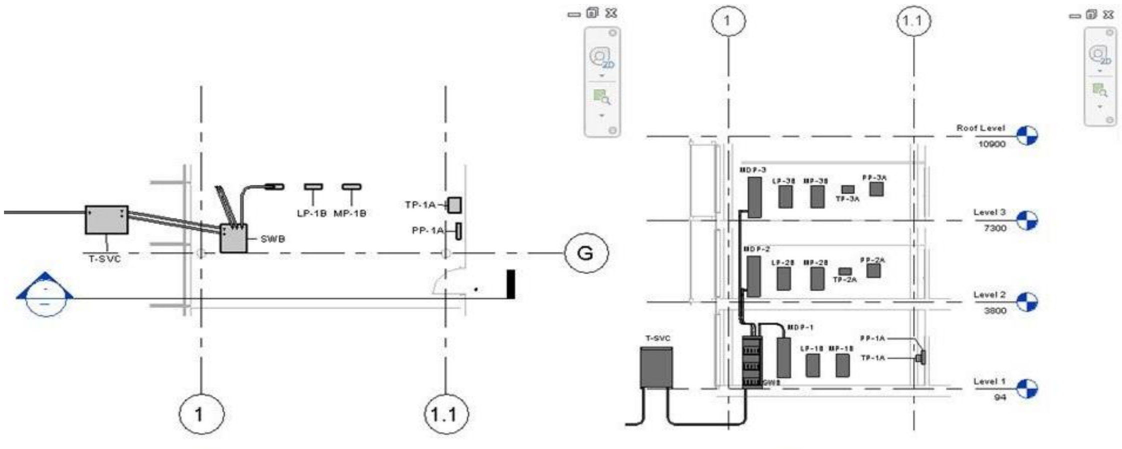


Figure 8. 3D model of the water supply system.

3) power supply

An electrical system schematic plan design consists of electrical equipment elements, a transformer, boxes, and box connectors. Figure 9 shows a floor plan and a sectional view. The model of the designed power system comprises electrical equipment for lighting panels and devices with a voltage of 480 V.



a) b)

Figure 9. Floor plan and section view of the power system.

Let us take a closer look at the power system construction scheme. Starting from the 480V Dry Type Transformer (Dry Type Transformer - 480 - 208Y120 - NEMA Type 2: T-SVC), it is connected to the Switchboard with Circuit Breaker (Circuit Breaker Switchboard: SWB) using a junction box and its associated components. From there, the wiring is distributed to the first, second, and third levels, respectively, using connecting elements.

As shown in Figure 10, there is electrical equipment and a 480V Dry Type Transformer labeled TP-1A, TP-2A, and TP-3A on each level. Each level is equipped with a Lighting and Appliance Panelboard 480V enclosure (MDP-1-MDP-3), Lighting and Appliance Panelboard 480V with surfaces MP-1B- MP-3B, LP-1B-LP-3B, and PP-1A-PP-3A, which operate at 208V.

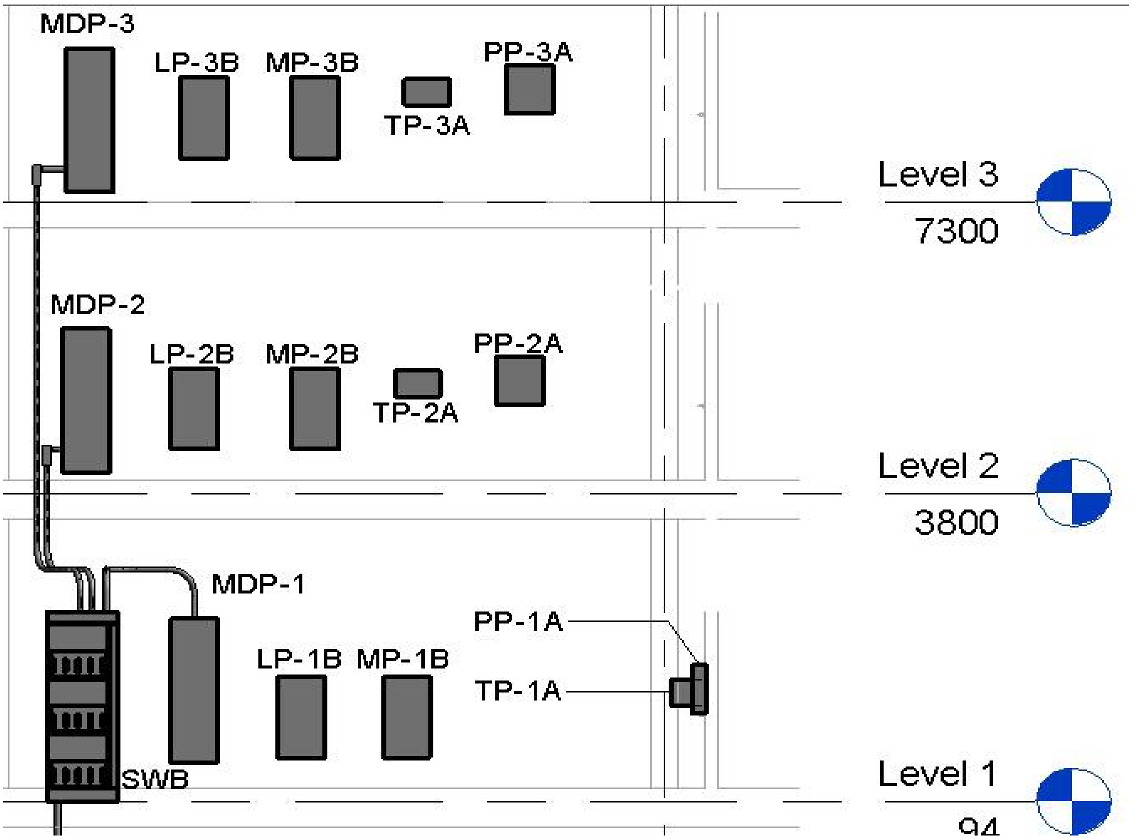


Figure 10. Compliance with the installed power equipment according to the levels.

The fully designed model, which includes HVAC, plumbing, and power systems, is shown in Figure 11 as a 3D model, showing the elements from the library for monitoring during the entire life cycle of its operation.

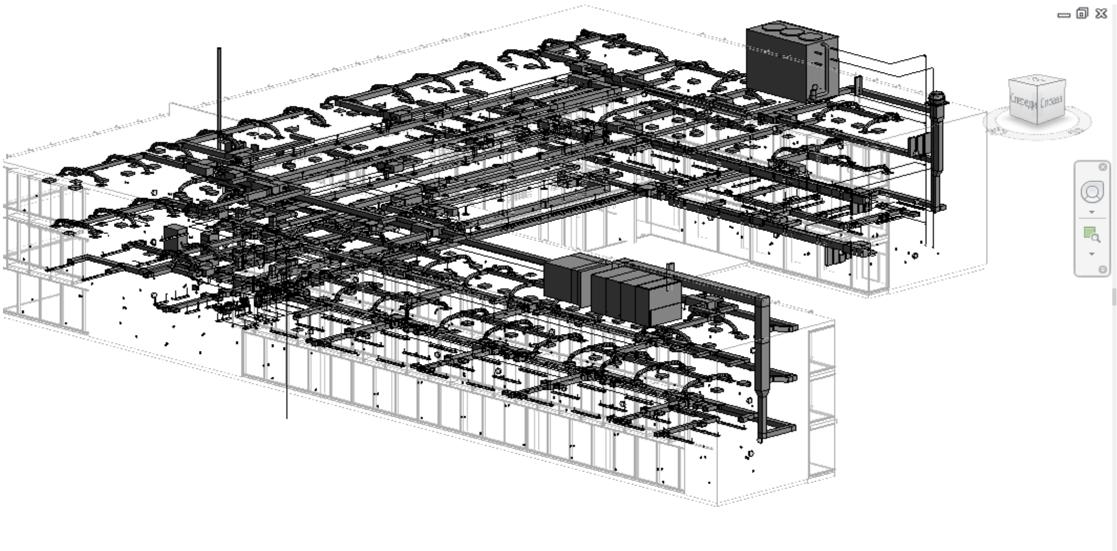


Figure 11. 3D model of the MEP software environment showing HVAC, water supply, and power systems.

Advantages of using BIM technology in digital model design

Table 1.
BIM technology benefits at the model design stage

Pre-construction stage	*Construction stage*	*Post-construction stage*
Visualization - allows (1 visualization and showing a detailed part of the plan as a 3D model, with the ability to display a digital model of the entire project to ensure sustainable design and analysis.	***Construction Planning:*** BIM (1 requires linking the construction plan to 3D objects in the project to evaluate the progress of construction and demonstrate how the site and building should appear at each stage of construction	***A 3D model for facility and operations management*** (1 that allows viewing specific aspects of management and provides up-to-date information about the building, as all changes will be automatically updated in the BIM system. It also has advantages in managing operations and maintenance of the building. A BIM component can display maintenance-related information, such as maintenance schedules, spare parts ordering information, etc**.**
An accurate and coordinated (2 ***drawing*** obtained for a specific type or detail of the project reduces time and the number of errors in the plan. The BIM system provides for the automatic change of information on one of the drawing plans based on automatic generation when changes are made to the project.	***2) Clash Detection during BIM Design:*** Virtual 3D clash detection eliminates design errors caused by inconsistent 2D drawings. In the BIM system, projects from all disciplines can be compared within a unified design system, making it easy to systematically and visually verify multi-system coordination	***2) Information monitoring and communicability.*** During the operational phase of the facility, there is always access to its technical condition, allowing the identification of deficiencies related to the replacement of structures, constructions, equipment, and more. It enables designers to monitor the technical condition of the building on a communicative level and improve systems
Cost estimation at the design (3 ***stage*** allows for an accurate summary estimate. With BIM, it is possible to calculate the costs of a specific project even before a detailed design estimate is made, which is necessary for construction.	***Waste Management:*** BIM (3 ensures accurate model design and material resources required for each work segment, improving contractor and subcontractor planning and schedules. It enables the timely arrival of equipment and materials, reducing costs associated with construction waste.	

The Building Information Modeling (BIM) system is utilized from the design stage to the construction stage, demonstrating various advantages at each stage. Based on the analysis of building information modeling, the key benefits can be characterized when designing the model at each stage, as shown in Table 1.

Development and implementation of BIM technologies in Ukraine. Examples of BIM

models of urban development and road infrastructure.

In Ukraine, the Cabinet of Ministers of Ukraine (CMU) Resolution No. 152-p /2021 approved the concept of introducing BIM technologies. The document (Šimenić, 2021) points out the lack of consistency in the development and exchange of digital information, resource intensity and inefficiency of managing the processes of design, construction, operation, lack of approaches to effective management of the life cycle of facilities (survey, design, construction, liquidation), inconsistency of regulatory support with modern construction technologies, facility accidents, etc.

BIM is an effective tool for ensuring the principles of sustainable development throughout the entire life cycle of buildings and structures and road infrastructure. After long-term operation of the facilities, the use of a building information model provides opportunities for quick and resource-saving planning of capital repairs and reconstruction.

The BIM technology is based on the development of three-dimensional graphic elements (virtual prototype of building structures) and information related to them, which characterises the physical, mechanical and functional parameters of a building in a structured and interconnected manner.

A BIM model is a digital three-dimensional representation of an object and information about it obtained in the course of surveys and design (modelling), which can be used as an information resource in the construction, management, reconstruction, and operation of an infrastructure facility. Infrastructure objects include roads, artificial and underground road transport facilities, engineering networks, etc. For the development and analysis of BIM models, appropriate computer programs are used, as shown in Figure 12.

BIM elements (models) are imported from the default BIM authorization tools. Most tools available on the market allow the input of data from numerous sources so that the data exchange can use the original file formats (e.g., DWG, DGN, RTV, SKP format). There are also various add-ons that make it easier to transfer data between authorization programs and validation programs. For infrastructure projects, data from Civil 3D is often exported to Navisworks via NWC exports. The use of the IFC format, generally the most used format for exchanging data between BIM applications in architecture, has so far been less widespread in infrastructure projects for the reasons stated in the chapter on data interoperability (Šimenić, 2021).

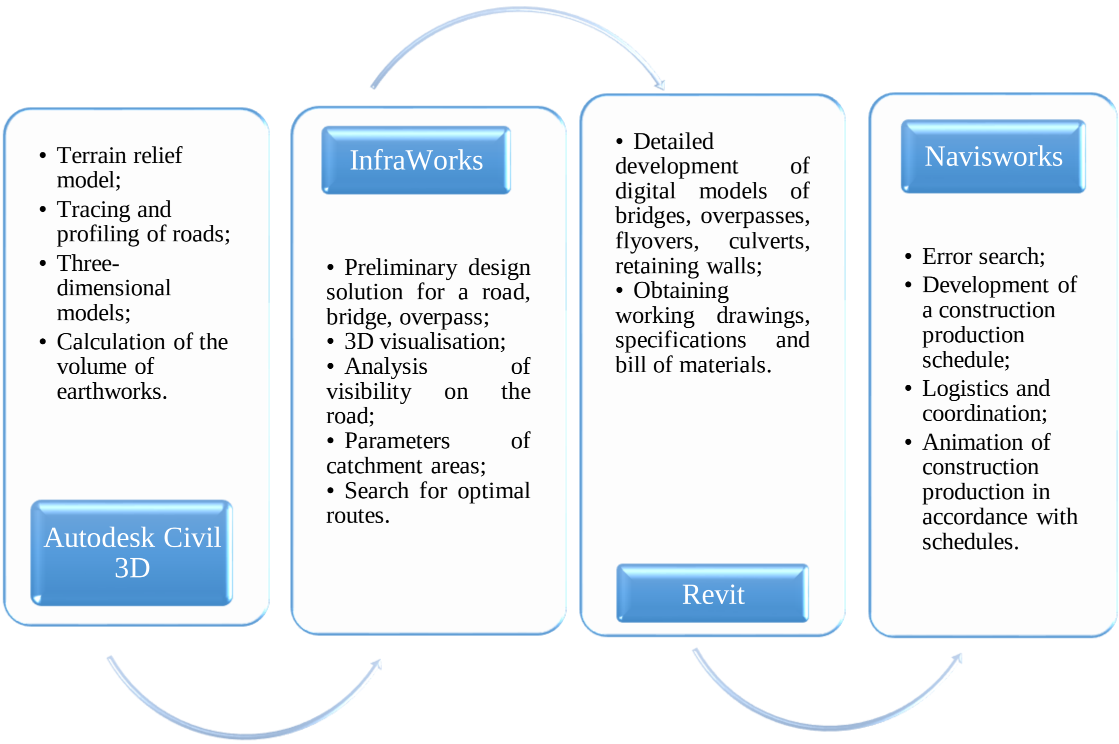


Figure 12. Structural and logical sequence of developing a BIM model of road infrastructure.

Figs. 13-17 show examples of building information models of urban development and road infrastructure. Let's take a look at the main BIM models of a traffic junction, an overpass, an urban development, a motorway and a bridge.

Figure 13. BIM-model of the transport interchange at the construction site of the Northern Bypass in Dnipro city.

Figure 13 shows a BIM model of the Northern Bypass road junction, which was developed using Autodesk Civil 3D software. In the common authoring tools (Autodesk Civil 3D), the modelling process begins by selecting the cross-sectional elements of the road – predefined shapes that can be modified by parameters (Figures 14 and 15).

Figure 14. BIM model of the construction of the Northern bypass overpass in Dnipro city.

There are many additional useful features – for example, tools developed for the generation of intelligent intersection objects. Autodesk Civil 3D has tools for creating standard intersections and roundabouts as shown in the Figure 15 and Figure 16.

a)

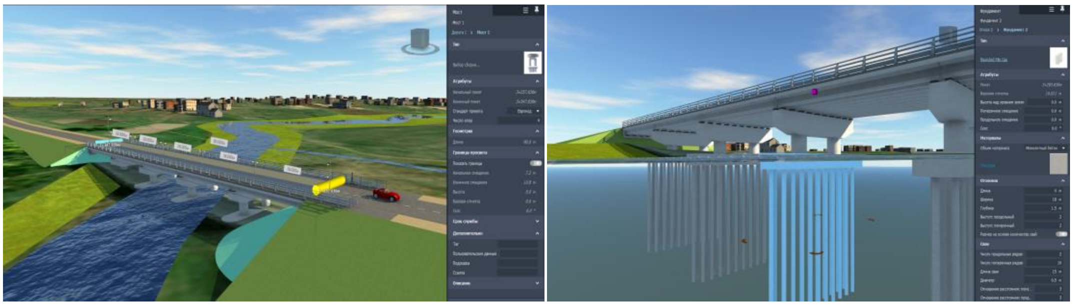
b)

Figure 15. a) BIM model for the reconstruction of urban development and street and road network in Dnipro city; b) BIM model of urban development and road network roundabout in Dnipro city.

When using these features, consideration should be given to the possibilities of editing and adapting them to real projects in terms of compliance with applicable standards and elements of road safety (Figure 16). For example, the design of roundabouts varies considerably between countries. Therefore, when using predefined elements, besides satisfying the technological form in terms of BIM, attention should also be paid to the appropriate standards.

Figure 16. BIM model of existing urban development.

The development of the bridge BIM model shown in Figure 17 consists of the following parameters (a): type (assembly selection); attributes (initial 3+257.636 m and final 3.347.636 m pickets), project standard (Eurocode), number of supports 4; geometry (length 90 m); clearance boundaries (initial 7.2 m and final 10.8 m offset), height 5.0 m, base mark, slope; service life, etc. The parameters of the monolithic block foundation are shown in Figure 17 (b) and consist of the following: length 4 m, width 18 m, depth 1.5 m, longitudinal and transverse projections 2 m.



a) b)

Figure 17. An example of parameters of a bridge BIM model: a) parameters of a digital BIM model object; b) parameters of the structure foundations.

Discussion

BIM technology, used for the design and construction of buildings, plays a significant role during the operational phase. Numerous studies have been dedicated to the trends of the building lifecycle using information technologies. However, one of the current issues is the adoption and implementation of BIM-based building operations. In the work of Aengenvoort & Krämer (2018), the main six stages of building operation are described as follows:

1. Requirements management.
2. Preparing for operation.
3. Commissioning.
4. Ongoing operation.
5. Change of ownership or operator.Data collection for existing buildings.

Due to their structure and sequential algorithm, these stages facilitate updating data related to building operations. They also simplify various use cases that arise during the operational phase, such as operation, inspection, and equipment maintenance. Data related to the operational stage can be obtained either by transferring design and construction data or by collecting data for existing buildings, including those where BIM methods were not used before operation.

One of the most significant barriers to utilizing BIM methods during the operational phase of buildings arises from the limited availability of digital data models (which can only be used with BIM methods) for existing buildings. Furthermore, for these digital building data models to be helpful during the operational phase, they must also reflect the actual state of the facility, including information on "as-built" conditions.

Since BIM technology is considered a technological breakthrough that contributes to the modernization of the construction industry and enhances its productivity, it is necessary to pay attention to the peculiarities of facility management during the operational and maintenance period. In the study by Hoang et al., (2020), the authors investigate the implementation status of BIM for facility management during the operating and maintenance stages of buildings in Vietnam. They discuss the main problems, advantages, and disadvantages that need to be addressed by design professionals in the construction industry to fully leverage the potential of BIM during the operational and maintenance phase.

For opinion Tregub O., Demura A., BIM technology can serve as a virtual design based on innovative methods, which makes it possible to improve the predictability of building efficiency and operation (Tregub & Demura, 2022).

The benefits and key characteristics of using BIM technology can improve and transform operations and maintenance to provide facilities with digital information to their supervisors to extract analysis and process information about the condition of the building in a three-dimensional digital environment. However, Gao & Pishdad-Bozorgi (2019) suggested that due to the rapid development of BIM, researchers and professionals need a more contemporary overview of BIM implementation and research in facility management and maintenance. First and foremost, additional research is required to understand the fundamental principles of BIM implementation for facility management and maintenance, including data requirements, areas of inefficiency, process changes, and more. Secondly, research on the return on investment in innovative systems is necessary to justify the value of BIM applications in technical servicing and to enhance the life cycle cost analysis method, which plays a vital role.

Over the past decade, technologies for creating digital twins have found the most comprehensive application in various industrial sectors to enhance maintenance procedures. However, the operational and maintenance stage in a building's life cycle is the costliest.

Therefore, intelligent building technologies are combined with BIM technology to manage objects, and in some cases, machine learning methods are employed for prediction capabilities. In the study by Coupry et al., (2021), the authors combine these technologies to enhance technical servicing operations in "smart" buildings. According to research findings, BIM technology can be used in conjunction with XR technologies to improve technical servicing operations. Additionally, the authors highlight challenges related to proper implementation based on BIM in combination with XR devices and propose an example of using a scheme of possible interactions during maintenance operations.

The report on the requirements and recommendations of the UN Economic Commission for Europe (Šimenić, 2021) states that the introduction of BIM technology into the practice of design, construction and reconstruction has a number of advantages:

- development of a 3D model using computer-aided design systems, rapid correction of model information and reduction of the number of changes in the project in an automated mode, operational control, creation of error protocols;
- reduction in the number of inconsistencies and conflicts;
- accurate estimation and optimisation of construction, reconstruction, and operation costs;
- development of a virtual construction model, accurate scheduling of construction equipment;
- improvement of logistics processes in construction and reconstruction.

Having analysed the results and benefits of implementing BIM technology in the practice of design, construction and reconstruction, the authors have put practical value into the development of BIM technologies.

Conclusion

The key modeling aspects were considered and analyzed based on the developed BIM model to create a digital model using architectural and structural elements from the software library. Autodesk Revit 2016 software was used to analyze the main advantages of BIM modeling in the software environment, which made it possible to design many engineering features with operational characteristics based on a digital model. The operating characteristics of the BIM model during the engineering network design stage include the use of necessary engineering systems, structures, and equipment required throughout the object's lifecycle. The designed engineering systems include heating, ventilation, air conditioning, water supply and drainage, and power systems.

The designed systems, based on the library with elements and created templates, allowed us to fully visualize the MEP layout of the digital BIM model, which includes the design and calculation of internal engineering systems and the processing and production of relevant documentation. The distinctive feature of such a model is its ability to track the object at any stage of design and implementation, whether it has been commissioned or not. The BIM model contains all the information about the piping system parameters, and the software can be used for all piping systems.

Thus, the interdependence between the three design and construction stages was established during the digital BIM model's design and construction. Visualization, precise and sequential drawing with cost estimation during the design stage falls into the initial construction phase, allowing a detailed 3D model of the plan based on the BIM model, reducing time costs, and enabling cost estimation for the developed project.

Construction planning, clash detection during design, and waste management allow for changes to be made during the construction phase. Waste management ensures accurate design modeling and material resources for sequential work execution, improving the planning and scheduling of contractors and subcontractors. However, during the construction phase, BIM design can identify and rectify errors that may have occurred due to 2D drawings.

The structural and logical sequence of developing a BIM model of road infrastructure is based on the experience in Ukraine. Based on the experience of implementing BIM technologies in Ukraine, a significant contribution to the design of digital models was reviewed and investigated, where BIM models of a traffic junction, an overpass, urban development, a motorway and objects connecting motorways with structures were considered.

After the completion of construction, the 3D model of facility management allows revisiting and reviewing the necessary management aspect with up-to-date information about the object. BIM technology enables automatic updates of all system changes, contributing to operational management and maintenance advantages. Therefore, each component of the BIM model reflects information about the technical condition and servicing, enhancing efficiency and minimizing time costs.

Comparing the two software, Autodesk Revit and Autodesk AutoCAD, the second one is more commonly used for designing machine details and equipment. However, the absence of parametric objects is one of its main drawbacks, along with separate modeling of each zone within the software file. Each design zone is modeled separately for each floor or level, limiting file editing to a single user, whereas designers from various disciplines often work simultaneously, indicating the inability for simultaneous collaboration. As a result, real-time visualization of changes in existing models is impossible.

Bibliographic references

Aengenvoort, K., & Krämer, M. (2018). BIM in the Operation of Buildings. Building Information Modeling: Technology Foundations and Industry Practice, 477-491.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), 241-252.

Bello, S. A., Oyedele, L. O., Akinade, O. O., Bilal, M., Delgado, J. M. D., Akanbi, L. A., ... & Owolabi, H. A. (2021). Cloud computing in the construction industry: Use cases, benefits, and challenges. Automation in Construction, 122, 103441.

Coupry, C., Noblecourt, S., Richard, P., Baudry, D., & Bigaud, D. (2021). BIM-Based digital twin and XR devices to improve maintenance procedures in smart buildings: A literature review. Applied Sciences, 11(15), 6810.

Darko, A., Chan, A. P., Yang, Y., & Tetteh, M. O. (2020). Building information modeling (BIM)-based modular integrated construction risk management–Critical survey and future needs. Computers in Industry, 123, 103327.

Ding, Z., Liu, S., Liao, L., & Zhang, L. (2019). A digital construction framework integrating building information modeling and reverse engineering technologies for renovation projects. Automation in Construction, 102, 45-58.

El Mounla, K., Beladjine, D., Beddiar, K., & Mazari, B. (2023). Lean-BIM Approach for Improving the Performance of a Construction Project in the Design Phase. Buildings, 13(3), 654.

Eastman, C. M. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

Gao, X., & Pishdad-Bozorgi, P. (2019). BIM-enabled facilities operation and maintenance: A review. Advanced engineering informatics, 39, 227-247.

Hoang, G. V., Vu, D. K. T., Le, N. H., & Nguyen, T. P. (2020). Benefits and challenges of BIM implementation for facility management in operation and maintenance face of buildings in Vietnam. In IOP Conference Series: Materials Science and Engineering (Vol. 869, No. 2, p. 022032). IOP Publishing.

Ibem, E. O., Uwakonye, U. O., Akpoiroro, G. O., Somtochukwu, M., & Oke, C. A. (2018). Building information modeling (BIM) adoption in architectural firms in Lagos, Nigeria. Int. J. Civ. Eng. Technol, 9, 902-915.

Jian, S. (2020). The application of BIM technology in road and bridge construction management. In IOP Conference Series: Earth and Environmental Science, 587(1), 1-5.

Kalpio, R. (2018). Integration of 3D MEP System Design Software for Multidiscipline Design Projects. Degree Programme in Building Services, Oulu University of Applied Sciences, 1-52

Krasovskaya, O. A., Vyaznikov, V. E., & Mamaeva, A. I. (2021). Application of BIM technologies as it projects for digital transformation in the industry. In International Scientific and Practical Conference Digital and Information Technologies in Economics and Management (pp. 104-116). Cham: Springer International Publishing.

Li, H. X., Ma, Z., Liu, H., Wang, J., Al-Hussein, M., & Mills, A. (2020). Exploring and verifying BIM-based energy simulation for building operations. Engineering, Construction, and Architectural Management, 27(8), 1679-1702.

Panteli, C., Kylili, A., & Fokaides, P. A. (2020). Building information modeling applications in smart buildings: From design to commissioning and beyond A critical review. Journal of Cleaner Production, 265, 121766.

Rodrigues, F., Isayeva, A., Rodrigues, H., & Pinto, A. (2020). Energy efficiency assessment of a public building resourcing a BIM model. Innovative Infrastructure Solutions, 5, 1-12.

Samko, B. (2023). Construction information modelling of urban streets and roads (Master's thesis) Prydniprovska State Academy of Civil Engineering and Architecture.

Sepasgozar, S. M., Costin, A. M., Karimi, R., Shirowzhan, S., Abbasian, E., & Li, J. (2022). BIM and Digital Tools for State-of-the-Art Construction Cost Management. Buildings, 12(4), 396.

Šimenić, D. (2021). Building Information Modelling (BIM) For Road Infrastructure: TEM Requirements and Recommendations (No. ECE/TRANS/308). United Nations Economic Commission for Europe, 1-119. https://unece.org/sites/default/files/2021-05/2017495_E_pdf_web.pdf

Sun, H., Fan, M., & Sharma, A. (2021). Design and implementation of construction prediction and management platform based on building information modeling and three-dimensional simulation technology in Industry 4.0. IET collaborative intelligent manufacturing, 3(3), 224-232.

Tan, T., Mills, G., Papadonikolaki, E., & Liu, Z. (2021). Combining multi-criteria decision making (MCDM) methods with building information modeling (BIM): A review. Automation in Construction, 121, 103451.

Tregub, O. V., & Demura, A. V. (2022). Methodology for implementing the concept of building information modelling (BIM technologies) in the design of road infrastructure facilities. [File PDF]. http://srd.pgasa.dp.ua:8080/bitstream/123456789/9361/1/Trehub.pdf

Wang, L., Li, W., Feng, W., & Yang, R. (2021). Fire risk assessment for building operation and maintenance based on BIM technology. Building and Environment, 205, 108188.

Zhang, S., Zhongfu, L. I., Tianxin, L. I., & Mengqi, Y. U. A. N. (2021). A holistic literature review of building information modeling for prefabricated construction. Journal of Civil Engineering and Management, 27(7), 485-499.