BIM IN CONSTRUCTION PROJECT MANAGEMENT

Lecture notes

Kovrov A. V., Meneiliuk O. I., Nikiforov O. L., Russyi V. V., Marianko Y. G., Pushchina N. V., Bochevar K. I., Meneiliuk I. O.

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within the scope of the project

«The BRIDGE – Bridging the gap between university and industry: Master Curricular Supporting the Development of Green Jobs and Digital Skills in the Ukrainian Building Sector»

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The lecture notes review the results of scientific research and practical experience in the application of BIM technologies in construction project management. Particular attention is paid to digital tools for planning, coordinating, monitoring and implementing construction at all stages.

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CONTENT

INTRODUCTION

The lecture notes were developed as part of the international project ERASMUS-EDU-2023-CBHE-STRAND-2, Project ID 101127884; Acronym – The BRIDGE. Project title: “Bridging the gap between university and industry: an innovative master’s program supporting the development of green jobs and digital skills in the Ukrainian construction sector”.

The aim of the project is to create new master’s programs using BIM technologies in architecture, engineering and construction at Ukrainian universities, with a view to promoting EU best practices in the development and implementation of educational methodologies and specific knowledge and practical skills related to energy efficiency and sustainability of the life cycle of buildings and the urban environment, based on the requirements set out in the UN Agenda for the period up to 2030, with a particular focus on Sustainable Development Goals 7, 10 and 11, as well as the priorities of the EU’s Green Deal and an economy that works for people.

The BRIDGE international project coordinator: Ukrainian State University of Science and Technology, Dnipro, Ukraine.

The head of the project team from Odessa State Academy of Civil Engineering and Architecture is the rector, Ph.D., Prof. Kovrov A. V. The task manager of the team is the head of the international relations department, Ph.D., Associate Professor Pandas A. V.

As part of The BRIDGE project, Odessa State Academy of Civil Engineering and Architecture has developed an educational and scientific program called “BIM Engineering” for students pursuing a second (master’s) degree in the field of knowledge G Engineering, production and construction, specialty G19 Construction and Civil Engineering. The guarantor of the educational and scientific program is PhD, Associate Professor Shekhovtsov V. I.

The educational component “BIM in Construction Project Management” is taught by the Department of Construction Technology at Odessa State Academy of Civil Engineering and Architecture in accordance with the educational and scientific program “BIM Engineering”.

The lecture notes summarize the experience of authors, renowned scientists, specialists and builders. The lecture notes have been developed taking into account the experience of teaching the educational component “Innovations in the organization and management of construction” and the publication of 12 books in the *Modern Construction* series, which were developed by the authors.

The lecture notes consist of a table of contents, an introduction, eight chapters (each accompanied by review questions) and a list of sources used.

The essential content of the lecture notes is determined by the following elements: consideration of general information on the use of BIM in construction project management and analysis of the application of the provisions of State Standard of Ukraine (SSU) ISO 19650; consideration of traditional and innovative organizational forms of construction project management; information on the development of a general plan for the implementation of a construction project with different options for organizing the work of teams using BIM; analysis of the possibilities for creating a matrix of distribution of responsibilities for the project team; consideration of modern information and communication concepts for construction management; analysis of the use of shared data environments and open data formats; analysis of the use of modern software tools and special information technologies; consideration of methods for optimizing construction solutions using modern software tools.

The lecture notes will help you understand the variety of solutions used in managing construction projects using BIM. The information provided on the solutions with drawings will allow you to study their features.

Modern construction is rapidly changing under the influence of digital technologies that cover all stages of the life cycle of such projects – from conceptual design to operation and dismantling of the facility. One of the most effective technologies in this area is BIM (Building Information Modeling). It enables the creation of a BIM (Building Information Model). It also allows for its storage, integration, analysis, filling with information, correction, and much more throughout the entire life cycle of a construction project. At the same time, BIM is a platform for interaction between all stakeholders.

Amidst the urgent need for effective, safe, sustainable and resource-efficient restoration of Ukraine's infrastructure, the relevance of BIM is rapidly growing.

BIM not only improves the quality of construction project lifecycle implementation, but also significantly reduces costs and risks and improves the quality of construction process management. BIM helps to reduce construction project implementation costs by 20 – 40% [1]. Thanks to these advantages, BIM is actively used in the EU, the USA, China, and Japan. And recently, in Ukraine as well: in the development of the regulatory framework; in educational programs and in the practical implementation of construction projects. Especially those intended for multiple reproduction.

In Ukraine, more than 100,000 buildings and structures have been damaged or completely destroyed. The use of BIM in their restoration is critical to ensuring effective planning, coordination, and implementation of restoration projects. BIM makes it possible to adapt restoration to existing resource constraints and take into account current environmental, energy, and social challenges. Therefore, the use of BIM in construction project management is extremely relevant.

The lecture notes are based on the best European practices for implementing BIM in project management. They have been adapted to Ukrainian conditions and standards (in particular, SSU ISO 19650), taking into account the goals of sustainable development and the European Green Deal.

The main objective of this course is to provide higher education students with a systematic understanding of BIM as a tool for managing construction projects at the managerial level.

The implementation of BIM is not only a modern trend, but also a strategic necessity for Ukraine's post-war recovery and its integration into the European digital construction space. That is why studying the issues discussed in this lecture notes are an important step towards creating a competitive, efficient and sustainable construction industry.

The lecture notes are recommended for students of all forms of education and levels of higher education in the field of knowledge G "Engineering, Manufacturing and

Construction”, students of advanced training and retraining courses for specialists, postgraduates, teachers, scientists, specialists of design and construction companies.

KEY DEFINITIONS AND ABBREVIATIONS

1. **BIM** – Building Information Model or Building Information Modeling.
2. **PIR** – Project Information Requirements.
3. **EIR** – Employer`s Information Requirements.
4. **BEP** – BIM Execution Plan.
5. **CDE** – Common Data Environment.
6. **OpenBIM** – Open Building Information Modeling.
7. **TeamWork systems –** software tools that enable stakeholders in a construction project to work together as a team.
8. **AR, MR та VR** – Augmented Reality, Mixed Reality, Virtual Reality.
9. **IoT** – Internet of Things.
10. **PM –** Project Management**.**
11. **SP –** Software Package.

SECTION 1. GENERAL INFORMATION AND CONCEPTS RELATED TO PROJECT MANAGEMENT USING BIM

Building Information Modeling (BIM) is one of the most promising areas of development in the architectural, engineering and construction industries [2].

Due to BIM technology, an accurate virtual model of a building is created digitally. BIM takes into account many functions necessary for modeling the life cycle of a building, providing a basis for new opportunities and changes in roles and relationships within the construction project team.

The introduction of BIM allows for a significant reduction in resource consumption and optimization of solutions at all stages of a construction project's life cycle. For example, the UK Government's Level 2 BIM program supports the achievement of the following objectives set out in the Construction 2025 policy:

- 33% reduction in initial construction costs and total cost of constructed assets;
- 50% reduction in the total time from the start of operation to the completion of construction of new buildings and renovated facilities;
- 50% reduction in greenhouse gas emissions in the construction industry;
- 50% reduction in the trade gap in construction goods and materials [3].

Building information modeling is a digital technology for describing and representing information applicable to the planning, design, construction and operation of building projects. This approach to modeling is becoming increasingly widespread, covering all aspects of the built environment, including infrastructure, utilities and public spaces. This approach to information management combines various data sets used throughout the life cycle of a construction project into a unified information environment, reducing and sometimes eliminating the need for many types of traditionally used paper-based documentation [4].

This approach is commonly referred to as Building Information Modeling (BIM); the concept was first applied in the field of architecture, and the same abbreviation is also used to refer to the result of the process – the information model itself, or the Building Information Model (BIM) [4].

Although the above-mentioned construction processes focus primarily on the physical structure of the built environment, BIM technology can also contribute to processes related to the management of the usable space of buildings and, on a larger scale, urban neighborhoods and cities, as well as infrastructure facilities and building engineering networks [4].

A common understanding of the processes throughout the entire life cycle of a construction project in a built environment is required, in particular, the information needed to implement the process and obtain its results. This applies to any activity that leads to the exchange of information and may not be directly related to BIM, such as the process of drawing up a work plan or concluding a contract [4].

The basic terms and definitions for analyzing the main provisions of construction project management using BIM should be defined.

According to [4]:

- *BIM – Building Information Modeling* – the use of a common digital representation of a construction project (including buildings, bridges, roads, technological equipment, etc.) to facilitate the design, construction and operation processes, as well as to create a reliable basis for decision-making. The abbreviation BIM also means a digital representation for sharing the physical and functional characteristics of any construction objects;
- *BIM software application* is software used to create, modify, analyze, manage, publish, share, delete or perform other actions with BIM elements;
- *construction works* – anything that is built or is the result of construction work. The term can refer to a building, infrastructure (road, bridge, pipeline, etc.) or landscaping element, and can also be used in a broader sense to encompass the combination of these elements that make up an urban area, university campus or institutional facility;
- *construction process* is the process in which construction resources are used to achieve construction results.

According to [5]:

- *BIM execution plan* is a plan specifying how the executive team will implement the tasks related to information management. The plan for implementing BIM tasks at the pre-qualification stage should be based on the approach to information management proposed by the executive team, taking into account its competence and capacity for information management.

According to [6]:

- *life cycle of an object* is a set of periods of existence of a construction object that are sequential in terms of content and time, from the concept of its creation to decommissioning and liquidation;
- *Building Information Model, BIM* is a set of structured and unstructured information containers (data sets) within an integrated information system that contain the necessary geometric, physical, functional, and other characteristics of an object, which are the source for documentation accompanying the object's life cycle (project documentation, estimates, etc.). The content of the building information model is identical to the content of the project documentation, expanded with additional data;
- *BIM management* is a more specific concept based on the definition of information management. In the construction industry, it refers to the performance of certain tasks and procedures applied to the processes of inputting, processing, creating and transferring data to ensure the accuracy and integrity of information throughout the entire life cycle of an object. BIM management also involves managing the process of implementing BIM in an organization, ensuring that BIM-related goals are achieved, and supporting the development/provision of new services and the effective use of information modeling.

In general, the possibilities for applying BIM at different stages of the life cycle are most clearly reflected in [6] (Fig. 1.1).

From Figure 1.1. we can conclude that the construction industry, along with related industries, is shifting from the production of drawings to the generation and management of information as an intellectual and analytical asset, which significantly changes the approach to all processes and shifts the focus from their linear step-by-step progress to a more interactive and collaborative process [6].

BIM Life Cycle	Concept	Design	Parametric Modeling and Libraries	(Parallelism and Reliability of Design)	⇦ Integration of Field Laser Scanning Data
	Project		Structural Calculation and Clash Analysis		⇨ Data Repository for Project Optimization Analytics
	Analysis		Interdisciplinary Coordination		⇨ Reference Model for Simulations and Rapid Prototyping
	Estimate		Integrated Design of Construction Processes		⇔ Data Transfer/Integration for Performance Analysis
	Construction	Construction	Construction and Cost Planning	(Real-Time Data Exchange; Integration and Coordination)	⇔ Data Exchange via Project Management Tools
			Efficient, Information-Rich Tenders		⇨ Reference Model for Prefabrication of Manufacturing Elements
			Coordination of Contractors and Suppliers		⇨ Reference Model for Automated and Autonomous Equipment
	Transfer		Continuous System Integration Among Stakeholders		⇔ Data Exchange with Construction and Monitoring Tools
	Maintenance Repair	Operation	Storage, Maintenance, and Use of Building Information	(Refined BIM Operations and Maintenance)	⇔ Construction Support for Repair and Disposal
					⇨ Data Platform for Object Condition Monitoring and Maintenance Forecasting
					⇔ Data Repository for Facility and Asset Management System
					⇨ Data Platform for Virtual Model Handover and Commissioning

Fig. 1.1 BIM technologies within the construction project life cycle

Standard [5] contains requirements related to information management during the construction phase of a real estate property, which should be reviewed regularly until best practices are implemented. In general, when using BIM management, it is necessary to divide it into: organization; asset and project; information (Fig. 1.2) [5].

From Figure 1.2: *AIM – asset information model*; *PIM – project information model*; A – start of the construction phase: transfer of relevant information from AIM to PIM; B – gradual development of the model of project solutions into a virtual model of the construction object; C – end of the construction phase: transfer of relevant information from PIM to AIM [5].

In her work [7], Meshcheryakova O.M. states that the main specialist in effective BIM is the BIM manager or construction project manager. Their main areas of work are defining the main objectives of the project and coordinating all participants in the process and their decisions for the successful implementation of the construction project. In addition, the BIM manager's functions may include two other major areas: the development or adaptation of BIM standards and monitoring the progress of the facility's construction, which are described in detail in [7].

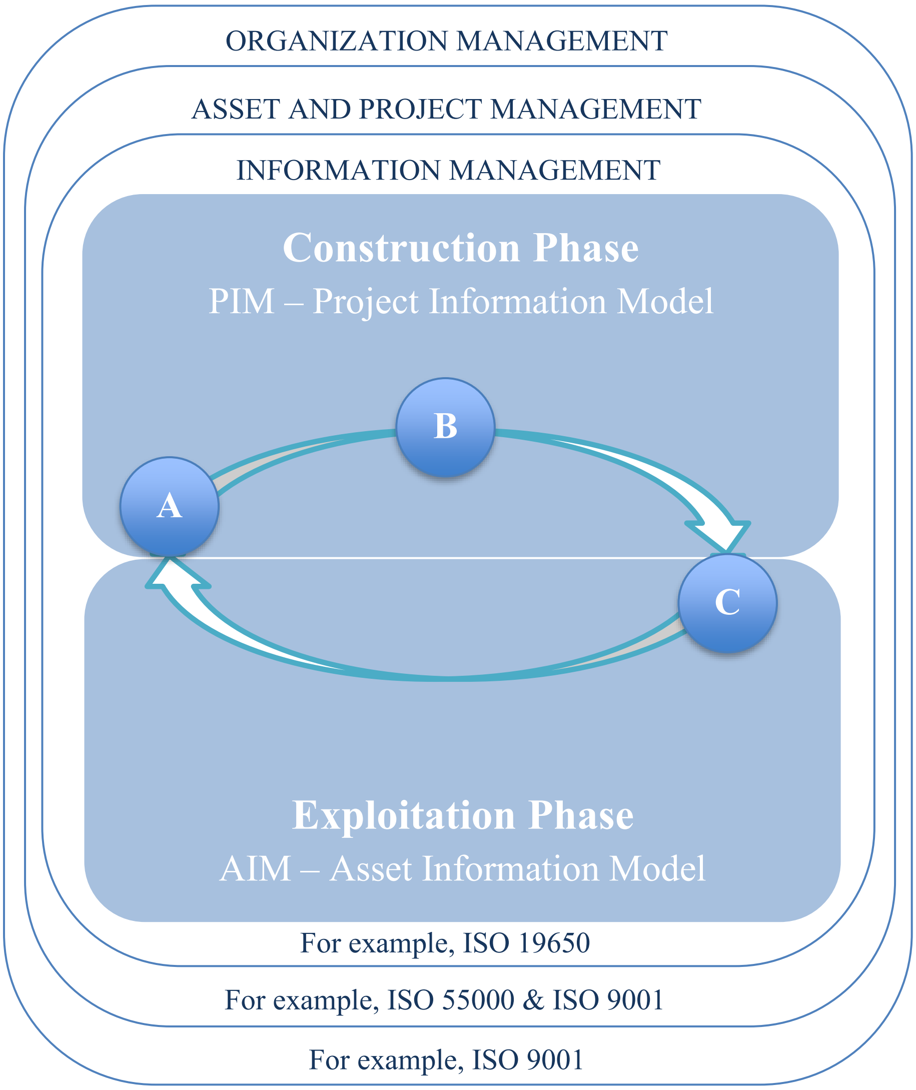


Fig. 1.2 Differentiation of the use of regulatory documents in management: organization; assets and projects; information

The BIM manager is responsible for coordinating the team and using the model. To do this, they must monitor progress, evaluate and compare it with the set goals. The BIM manager must have a high level of knowledge of the software used by the company, the logic of the BIM program and the essence of the technologies [7].

Some of the functions listed may fall within the remit of a separate *BIM coordinator*, who may perform the duties of a BIM manager assistant, while the coordinator retains strategic and organizational functions. Responsibilities may also include consulting and organizing training courses for employees; attending conferences, seminars, and workshops to acquire new knowledge and best practices in BIM design, software updates, and knowledge dissemination within the organization [7].

BIM modeler/technician. The main responsibilities of a BIM modeler are to create and filling in an information model, design graphic images based on it in accordance with the BIM standard, and coordinate and validate BIM [7].

One example of managing a BIM project by a BIM manager is shown in Figure 1.3. This option is proposed in [7].

From the above and Figure 1.3, it can be concluded that project management using BIM requires multidisciplinary training of the BIM manager.

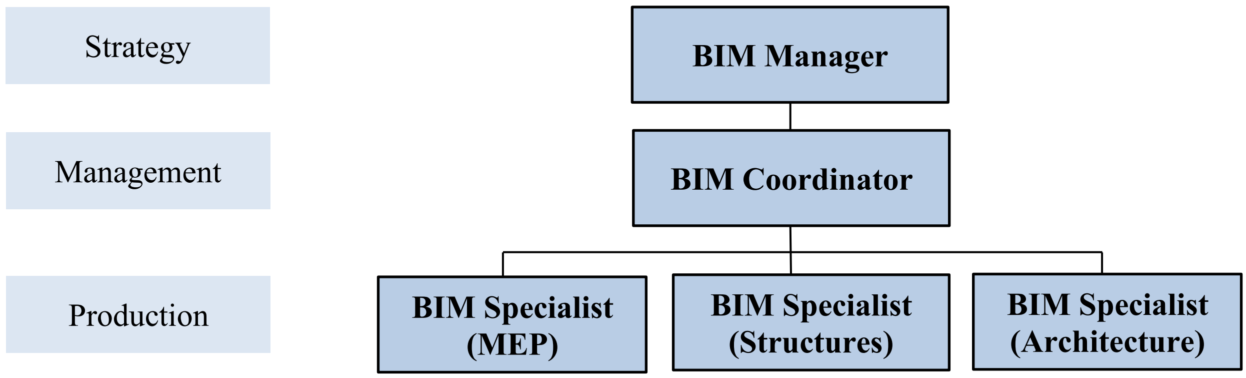


Fig. 1.3 Roles and functions of project participants: MER – communications specialists

Thus, the BIM manager performs their main function of managing the implementation of a construction project.

The term "*project*" is understood to mean a chain of tasks that must be completed within a set time frame and with the expenditure of certain resources in order to achieve a result. The second definition of a project is the process of solving a problem, from the conception or idea of a solution to the final implementation of the idea [8].

The project management is an activity aimed at solving problems and achieving the set project goals.

The project management refers to the application of knowledge, skills, tools and methods to execute a project in accordance with specified requirements [8].

Project resources – labor (engineering and technical personnel and workers), technical (equipment, machinery) and/or material (consumables) resources used to perform project tasks [8].

The use of BIM in the organization and management of construction allows specialists to be brought together: from project development and construction, control, operating organizations, etc. by creating a single information model of the object.

In construction management, the information model is used for planning, analyzing and controlling the execution of construction and installation works, accounting for the supply of materials and equipment, compliance with safety regulations, control and accounting of funds expenditure, etc.

Review questions for Section 1.

1. What is Building Information Modeling (BIM) and what are the main objectives of its implementation in the construction industry?
2. What are the advantages of using BIM compared to traditional design and paper-based document management?
3. What is the "construction project life cycle" in the context of BIM, and what are its main stages?
4. What are the main functions of a BIM manager and how do they differ from the responsibilities of a BIM coordinator and BIM modeler?
5. How does BIM promote the integration of construction project participants at different stages of project implementation?
6. What is the significance of using BIM in managing project resources (labor, technical, material)?

SECTION 2. FEATURES OF IMPLEMENTING THE PROVISIONS OF UKRAINIAN REGULATORY DOCUMENTS IN PROJECT MANAGEMENT USING BIM

An active impetus for the application of BIM in Ukraine was provided after the approval of the Concept for the implementation of building information modeling (BIM) technologies in Ukraine (by order of the Cabinet of Ministers of Ukraine No. 152-r of 17 February 2021). At the same time, the state-owned enterprise Ukrainian Scientific and Research Centre for Standardization, Certification and Quality (SE UkrNDNC) developed SSU ISO/TS 12911:2020 Structure of Building Information Modeling (BIM) (ISO/TS 12911:2012, IDT). In addition, SE “UkrNDNC” and other structures developed standards [4, 5, 9-11].

The SSU ISO 19650 series of standards [4, 5, 9-11] is a set of international standards that define the structure, principles and requirements for the collection, use and management of information in construction and civil engineering projects and facilities throughout their life cycle, and are primarily aimed at:

- entities involved in the design, construction and commissioning stages of built facilities, referred to in this document and in accordance with the ISO standard as the development stage;
- entities involved in asset management activities, including operation and maintenance, referred to in this document and in accordance with ISO as the operational phase [4, 5, 9-12].

According to SSU ISO 19650, the project life cycle is divided into two components: the project information model (PIM) during planning and construction, and the asset information model (AIM) during operations (Fig. 2.1) [4, 5, 12].

Project information (models, data, and documents) is created throughout the planning and construction phases. Most of this information can be used for installation work, although there is a significant amount of information that is only useful for design and construction and can then be discarded [4, 5, 12].

The Asset Information Model (AIM) provided during the implementation of a construction project is usually a condensed form of *the Project Information Model (PIM)*. However, the AIM must contain the information necessary for the digital description and operation of the asset. During operation, the AIM will be expanded with additional information as a result of future modifications and general data accumulation. From the owner's point of view, the AIM offers the greatest value, while the PIM is a means to an end [4, 5, 12].

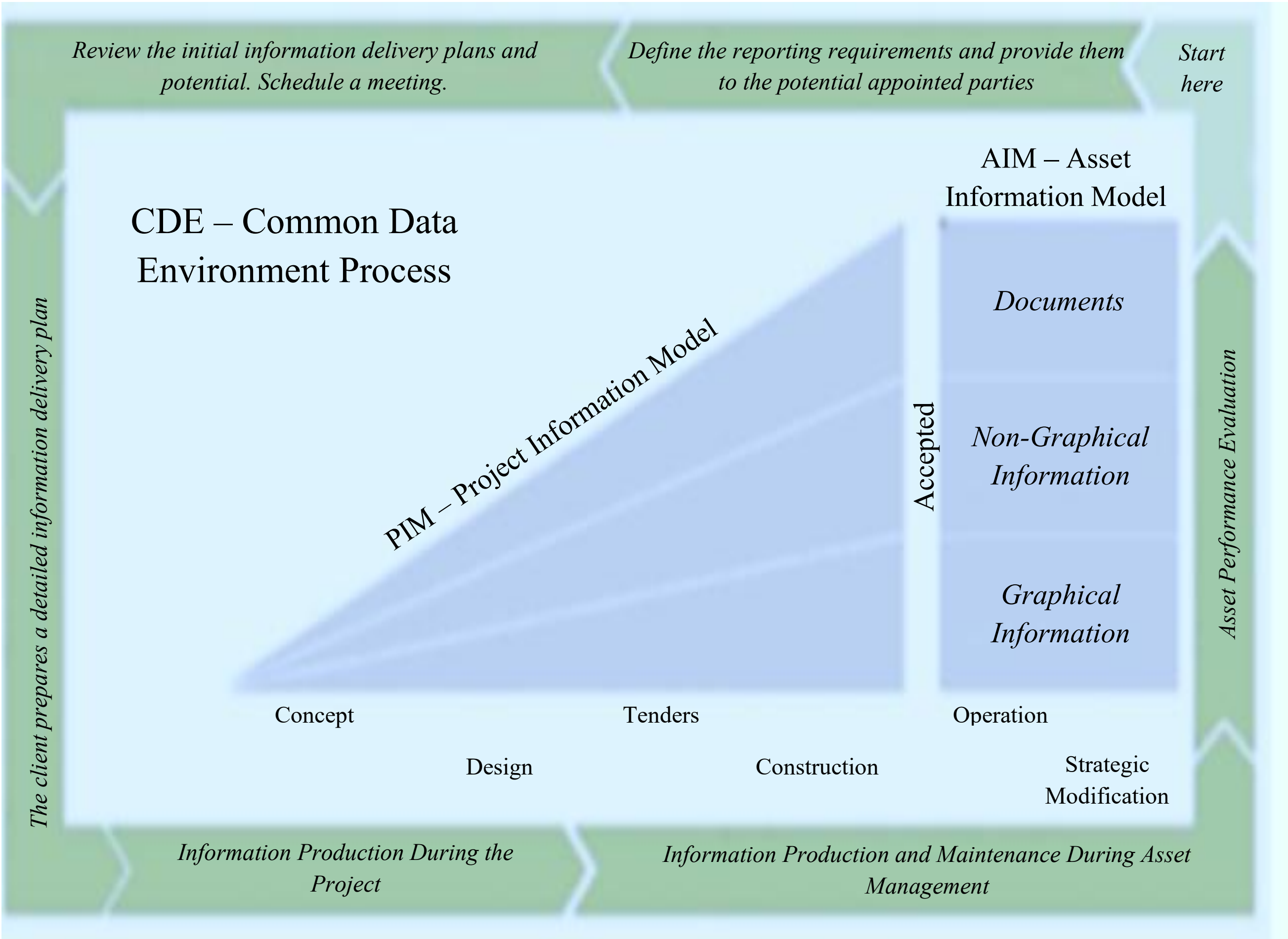


Fig. 2.1 Roles and functions of project participants

The ISO 19650 Information Life Cycle describes other activities related to the BIM process. In Figure 2.1, we see that regular exchange cycles occur throughout the project life cycle (marked with blue circles). In addition, there are periodic data delivery points (or "data drops") that are provided to the client at key decision-making moments (marked in green). In this example, there are three such points at the beginning of the project (at the end of the first three phases of the project), one during project handover, and one during the operation phase [4, 5, 12].

Although the detailed components of BIM project management (definition of BIM use, data exchange requirements, and protocols for collaboration and coordination) are not developed in ISO 19650, these standards are an excellent resource for establishing a general definition of the BIM life cycle and outlining the general processes associated with this process. It is recommended to use ISO 19650-1 and -2 as a reference system on which to develop BIM project specifications and implementation plans [12].

The introductory section of ISO 19650 explains key concepts and benefits for project management. BIM is presented not only as a 3D tool for managing digital information, but also as a new approach to project management, where the parties to the contract exchange digital information at all stages of a construction project, including design, procurement, putting into operation and construction [13].

The result of BIM is a *"digital twin"* of the asset to be built. This is a digital copy of the future physical system, and it is used for both development and design. This also provides a basis for developing new services or new ways of using the asset, as well as for further maintenance [13].

BIM provides the ability to better manage information exchange, use advanced tools for quality control, and increase confidence in the information being exchanged. It increases the productivity of designers and consulting engineers as they increasingly leverage its many capabilities in information management. BIM processes are also a way to build trust between the different parties involved in any project. By promoting genuine collaboration, the use of BIM processes helps to strengthen mutual understanding and trust [13].

Using BIM and both parts of ISO 19650, consulting engineers can demonstrate the relevance and compliance of a project in real time. The concept of *"common information"* refers to the ability to use digital information in BIM to model and reproduce a project at every stage of development. Sharing this structured information with all relevant parties also facilitates decision-making, including final approval. Using open standards to structure information simplifies its dissemination [13].

Today, the implementation of BIM as a methodology yields the best results, which are reflected in improved quality of information outcomes and structured enhancement of cooperation and integration into the project management process [13].

It is important that the project management process remains familiar, with all the necessary basic knowledge and experience. BIM introduces additional tools, metadata and concepts to the same fundamental traditional processes of design, planning, tendering, execution, communication and coordination. This leads to improvements in terms of reducing financial losses, saving time, improving quality and reducing risks [13].

The BIM approach advocates flexible and economical principles for better planning of both the initial data in the project and the final results. This improves communication and interaction between different stakeholders and different stages of a construction project and promotes a comprehensive approach to change and optimization [13].

The main regulatory documents for project management when using BIM are [4, 5]. Let is check out some of their features.

SSU ISO 19650-1 [4]. Key concepts of the document:

- *BIM Execution Plan (BEP)* is a plan that explains how the construction project implementation team will perform aspects of information management for the assignment. The BIM Execution Plan (BEP) defines how, why, when, and by whom aspects of the contract's information modeling will be performed. The use of BIM must be clearly agreed with the client and specified in the contract along with the "requirements" that correspond to the agreed contractual obligations. The BEP (BIM Execution Plan) should be considered as part of the quality architecture of the project in addition to the Project Management Plan or implemented in it. It should provide detailed information not only about the process of creating and delivering information, but also its objectives (defining the application of BIM) and subjects (assigning responsibility for it). Part 2 of ISO 19650, which focuses on the asset implementation phase, provides some supporting information on defining processes and entities. The objectives are usually part of the recommendations for the implementation of the BEP (BIM Execution Plan) as part of defining the use of the proposed BIM.

- *the level of information need* is the basis that determines the volume and detail of information. One of the goals of determining the level of information need is to prevent the provision of too much information;

- *an information container* is a permanent set of information obtained from a file, system, or applicable storage device. Example: including a subdirectory, an array of information (covering a model, document, table, graph), or a separate subset of an array of information, such as a section or part, layer, or label. This concept is important and should be linked to the level of information need. The process of delivering digital information should be linked to various sources of information, which should only be the geometry of signs [4, 13].

SSU ISO 19650-1 key concepts:

- *the life cycle* is the service life of an asset, starting from the definition of requirements for it and ending with the termination of its use, covering the stages of conceptual design, development, operation, maintenance and disposal;
- *the common data environment* is a source of information agreed upon by the parties for any specific project or asset, for the collection, management, and distribution of each information container through a controlled process. The concept of a common data environment (CDE) refers to three concepts: “work process” – work in progress (WIP) or approved work on the status of information; “life cycle” and “common and single source” of information. ISO 19650 presents CDE as a single source of information for any given project or asset, used to collect, manage and distribute all elements of the information model through a controlled process. This is a means of ensuring a common environment for sharing and coordinating work, as information can be transferred through information exchange and managed through the CDE. Strict workflows ensure a consistent approach by all organizations involved;
- *requirements management*. The purpose of creating information requirements is to specify the information that participants in the implementation or supply chain of an asset or project must deliver within the scope of their work. They will be stored in the asset information model or project information model, respectively. The

different types of information requirements are shown in Figure 2.2. Information Requirements Management is one of the key concepts of ISO 19650: BIM is a process for delivering information in accordance with management requirements based on a systems engineering approach developed for other industries. It covers:

- organizational information requirements (OIR) – information necessary to satisfy conditions or provide information regarding higher-level strategic objectives within the asset owner/operator organization relating to the constructed assets they own, operate, use or manage;
- asset information requirements (AIR) – detailed information that is necessary to meet organizational information requirements;
- project information requirements (PIR) – information necessary to satisfy conditions or inform about higher-level strategic objectives within the asset owner/operator organization or project client organization relating to a specific project for a constructed asset [4, 13].

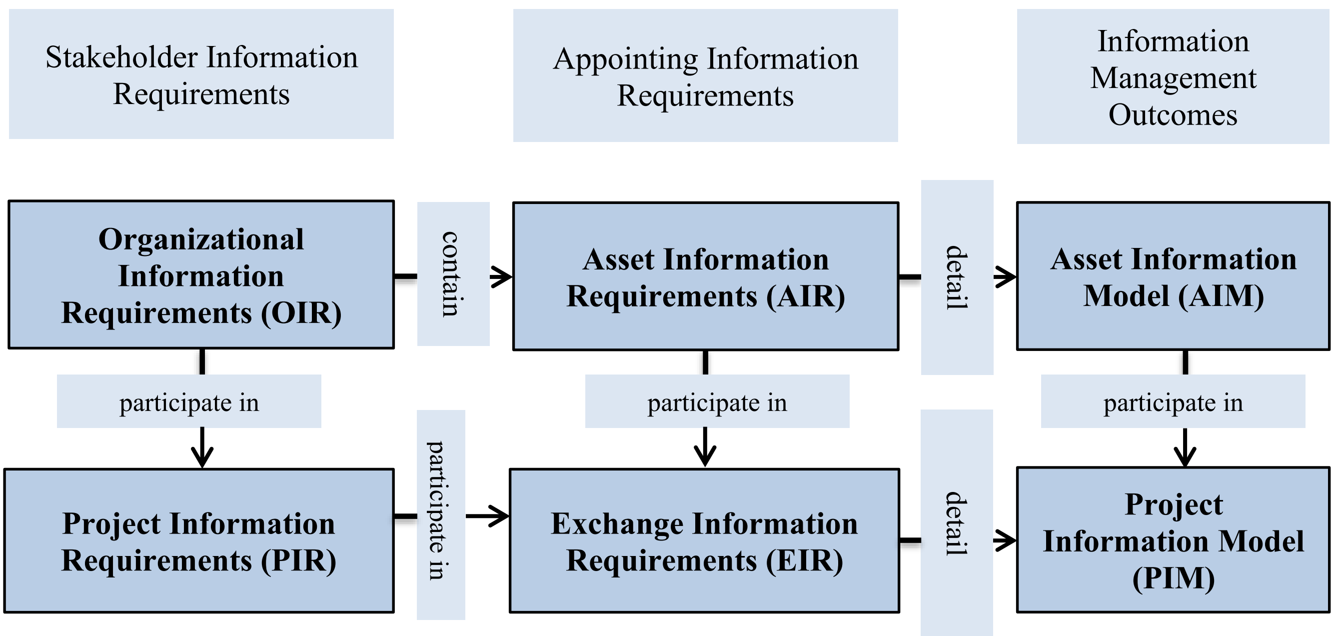


Fig. 2.2 Different types of information requirements and information models according to ISO 19650

SSU ISO 19650-2 defines the specifics of project management when using BIM, namely the following:

Part 2 of SSU ISO 19650 provides explanations regarding the set of processes for delivering information at the design, construction and handover stages, including processes related to tasks, roles and responsibilities, as well as the identification and appointment of responsible parties for each type of activity and task [5, 13].

Figure 2.3 outlines the main elements of information delivery process management. They include:

- the appointing party and the appointed party;
- the process of transmitting or exchanging information [13].

The figure shows the traditional project organization: the appointing party (client) and the appointed parties (consultant or contractor). Information flows from C to B, rather than from C to C, and then from B to A or B to B, depending on the type of contract [13].

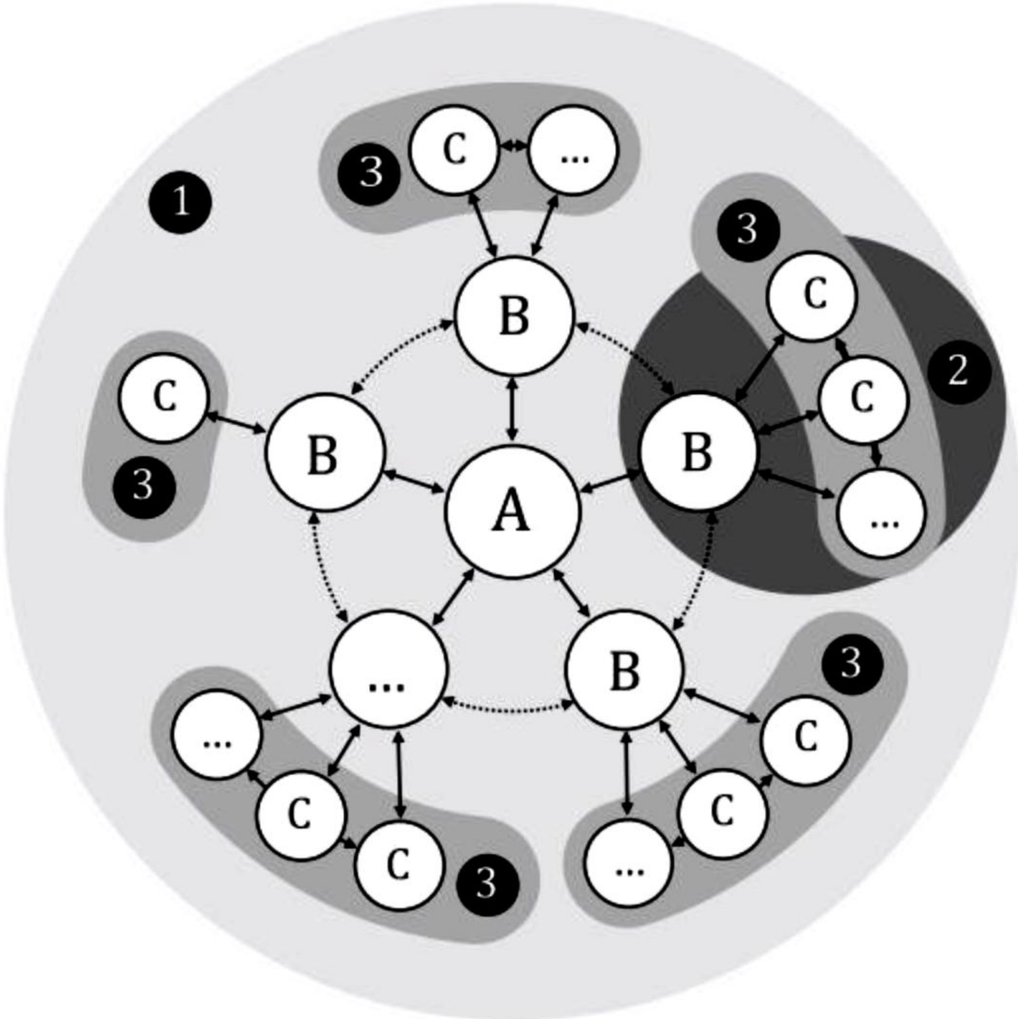


Fig. 2.3 Interaction between parties and groups for the purpose of information management (part 2 ISO 19650): A – appointing party; B – the party appointed by the manager; C – appointed party; … – variable value; 1 – project team; 2 – project team representation; 3 – working group (groups); ↔ requirements for information and information exchange; ↔ consistency of information.

It should be noted that the roles of BIM manager and coordinator are not covered in the final version of Part 2 of SSU ISO 19650. Role titles may vary depending on the project due to the specifics of the market sector, project size, and supply chain level, but important factors are being implemented, covering ownership, responsibility, and authority. In small companies, many of these roles may be performed by one person. The organization may vary depending on the project, but the implementation tasks remain [13].

The information management process is presented in detail in Figure 2.4 [5, 13].

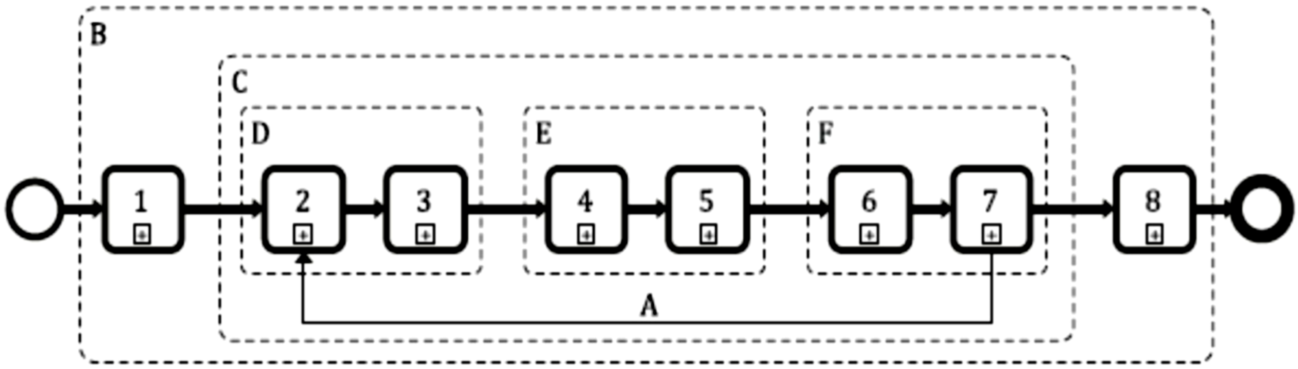


Fig. 2.4 Information delivery process by stages: 1–8 in accordance with Part 2 of ISO 19650: 1 – assessment and needs; 2 – invitation to participate in the tender; 3 – competitive bid; 4 – appointment; 5 – mobilization; 6 – joint information gathering; 7 – implementation of an information model; 8 – project completion (completion of the implementation phase); A – information model developed by the next group (groups) implementing the construction project for each appointment; B – measures implemented within each project; C – measures implemented for each appointment; D – activities carried out at the procurement stage (for each appointment); E – activities carried out at the information planning stage (for each appointment); F – activities carried out during the information preparation stage (for each appointment).

Two aspects are worth noting:

- the starting point is the specification of requirements. Stage 1. Assessment and needs;
- the final point is the completion of the project. Stage 8. Project completion [13].

The development of regulatory documentation governing the use of BIM in Ukraine did not stop at the standards developed above. Subsequently, SE UkrNDNC developed the following:

- SSU EN ISO 23386:2023 Building information modeling and other digital representation processes applicable in construction. Methodology for description, authorization, and technical support in related data dictionaries (EN ISO 23386:2020, IDT; ISO 23386:2020, IDT);
- SSU EN ISO 23387:2023 Building Information Modeling (BIM). Data templates for building objects applicable throughout the life cycle of building assets. Concepts and principles (EN ISO 23387:2020, IDT; ISO 23387:2020, IDT).

Review questions for Section 2.

1. What are the main components of the information lifecycle defined in SSU ISO 19650?
2. What is a project information model (PIM) and at what stage is it formed?
3. What is the purpose of the asset information model (AIM) in the facility operation process?
4. What is the role of the “common data environment” (CDE) in the project management process according to SSU ISO 19650?
5. What types of information requirements are defined by SSU ISO 19650?
6. How is interaction between parties during the implementation of a construction project organized in SSU ISO 19650-2?
7. What are the key stages in the information delivery process according to Part 2 of SSU ISO 19650?
8. How is the level of information need determined and what function does it perform?
9. How does the implementation of BIM contribute to increasing trust between project participants?

SECTION 3. THE ORGANIZATION OF CONSTRUCTION PROJECT IMPLEMENTATION USING BIM

3.1. Traditional and innovative organizational forms of construction project management

Before considering the features of using BIM in organizing the construction project implementation process, it is necessary to analyze the known organizational forms. The organizational forms of construction production management can be divided into traditional and innovative (Fig. 3.1).

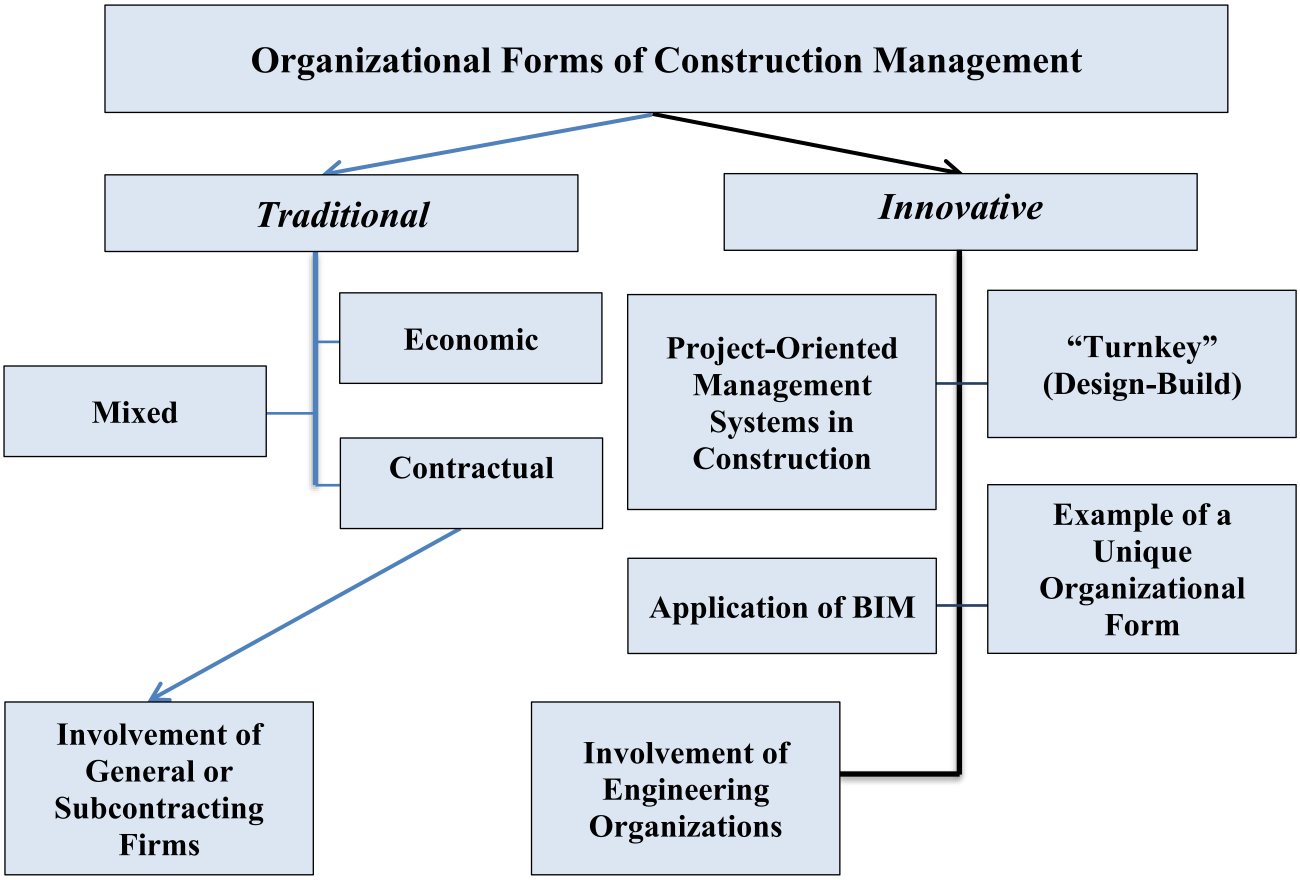


Fig. 3.1 The traditional and innovative organizational forms of construction production management (light red lines and arrows indicate traditional ones, and green ones indicate innovative ones)

Before considering the organizational forms, indicated in Fig 3.1, it is necessary to recall the main terms and definitions used in project management and to identify participants in construction and investment activities.

An investor is a legal or natural person (Ukrainian or foreign company, state, private individual) that makes financial investments in assets and projects to generate income [8, 14-17].

The concepts of "project", "project management", and "project resources" are discussed in section 1 of the lecture notes.

A general contractor is a legal entity that is directly involved in organizing construction and installation work at a facility and is responsible for the entire complex of construction complex works before the facility is out into operation before the investor or the customer.

A contractor is an individual or legal entity who undertakes to perform certain types of work for a specified fee and is responsible for the quality of their performance [8, 14-17].

In the economic method (Fig. 3.2), all the work (sometimes including design work) is performed by the forces and funds of existing enterprises or organizations.

This method is used by departments (departments) of capital construction/major repairs of state-owned enterprises or private investors [8, 14].

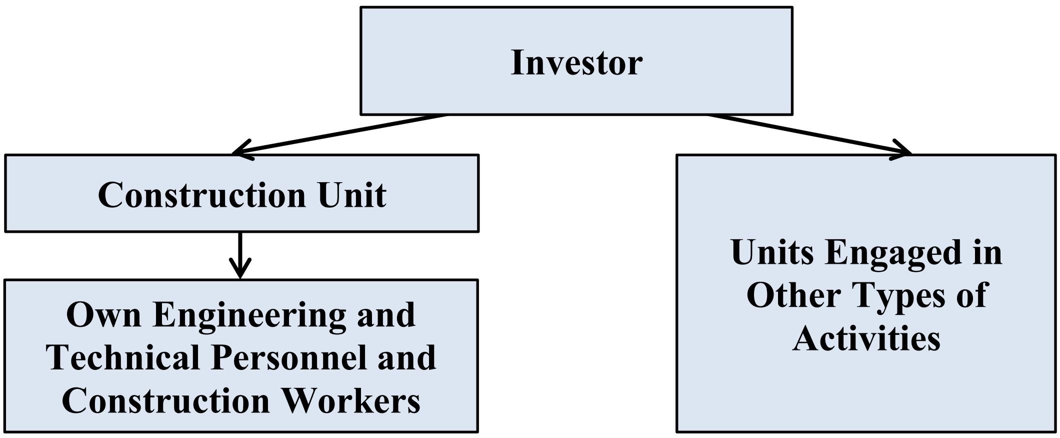


Fig 3.2 The organizational structure in the economic mode

Compared to the general contracting method, the advantages of the economic method are as follows:

1) No need to pay for the services of a general contractor – up to 12%.
2) Higher efficiency under control.

3) High efficiency under the construction of simple and small objects.
4) Simplified control over the use of funds.

Compared to the general contracting method, the disadvantages of the economic method are as follows:

1) the need for independent quality control of works and materials. The inability to compensate for costs if poor-quality works and materials are detected;
2) the need to have or create qualified engineering and technical workers, construction workers, and our own production base;
3) the need for reorganization, and in some cases, disbandment of the construction team and production base upon the completion of the construction of the facility;
4) the difficulty of creating conditions for improving technology and organizing work, since the construction is not the main activity of the enterprise.

The contractual method has several varieties (Fig. 3.3).

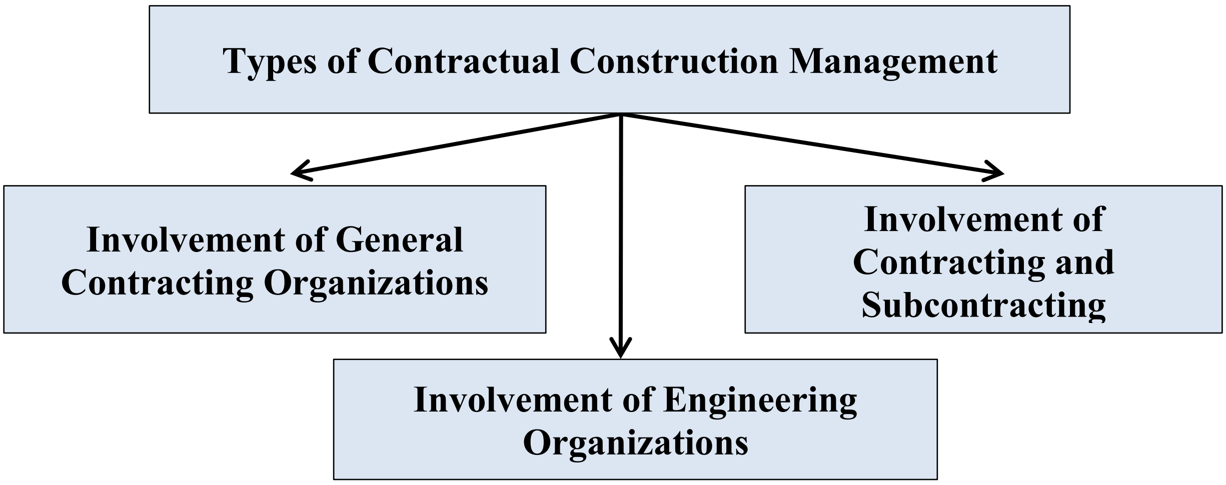


Fig. 3.3 The types of contracting methods for the organization of construction production management

The essence of the method when involving general *contracting organizations* (Fig. 3.4) is as follows. An investor contract is concluded with the general contractor. He is responsible for the terms of work and the quality of the materials used.

The service for the general contractor is paid for in the form of up to 12% of the estimated cost of the object.

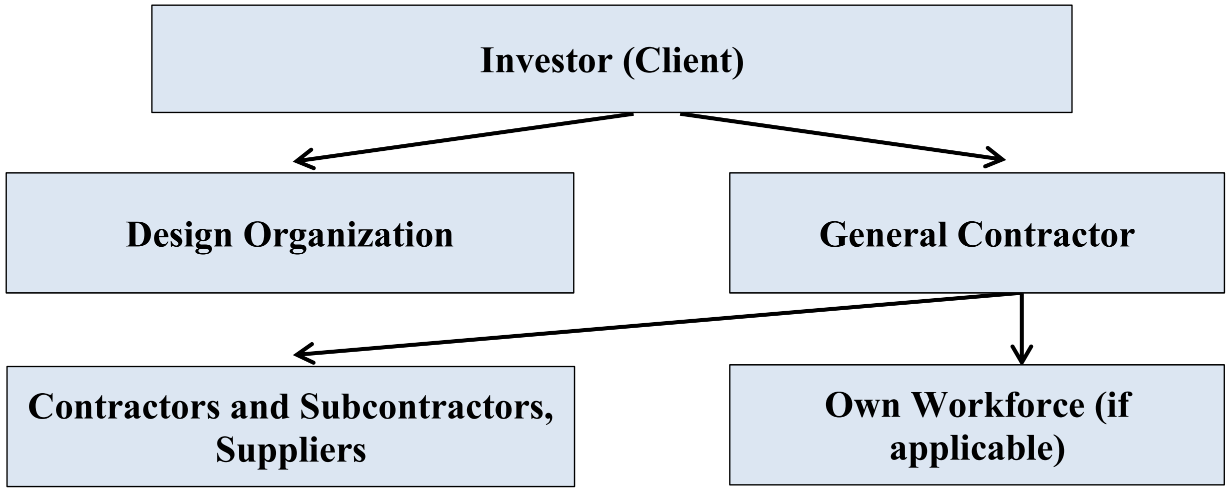


Fig. 3.4 The organizational structure of the method when involving general contracting organizations.

The general contractor may enter into contracts with subcontractors, as well as perform a part or all of the work itself. The subcontractors are responsible for the quality of the work and materials.

The essence of the method when involving *contracting and subcontracting organizations (directly)* (Fig. 3.5).

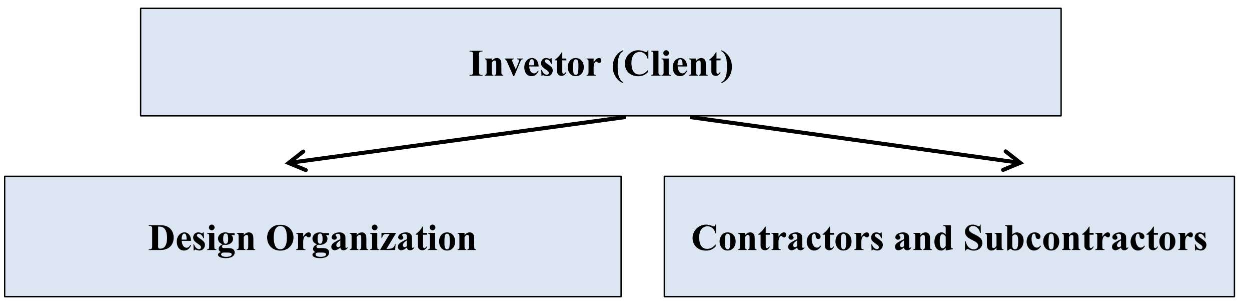


Fig. 3.5 The organizational structure of the method when involving contracting and subcontracting organizations.

In this case, the customer doesn't turn to general contracting organizations, but himself (or with the help of a manager), at his own risk, concludes contracts with contracting and subcontracting organizations for the performance of construction work. And here the mutual work of these organizations is linked by the customer's representative [8, 17].

The essence of the method of involving *engineering organizations (innovative organizational forms of construction production management according to Fig. 3.1)* (Fig. 3.6).

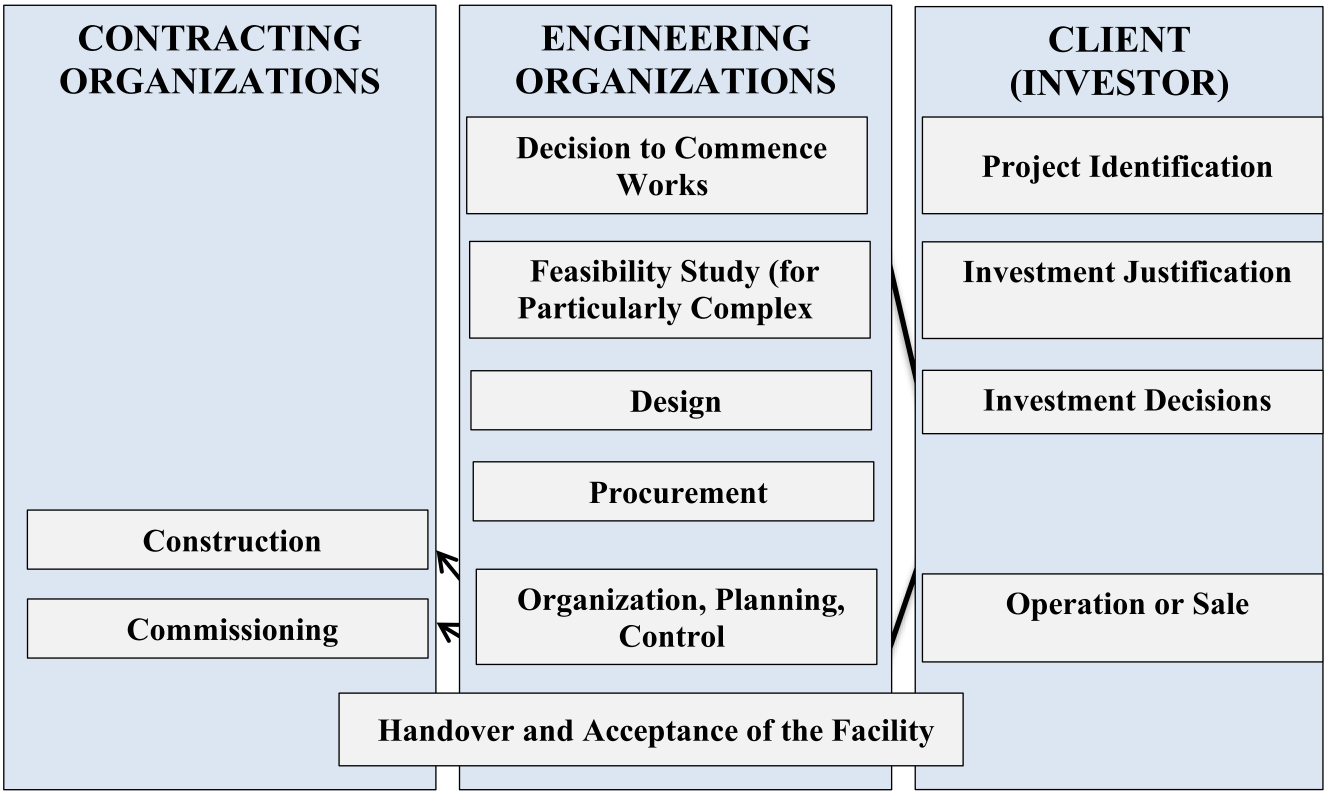


Fig. 3.6 The schematic diagram of construction management based on the engineering concept

Engineering is aimed primarily at increasing business efficiency: providing research, design, calculation, analytical, and production services, including preparing feasibility studies (FEO), developing recommendations on the field of production organization and management, and even product sales.

Engaging engineering firms allow the customer (investor) to take some of the issues (responsibilities) off their shoulders, such as: procurement, search and selection of contracting organizations, acceptance of work, technical supervision, and commissioning of the facility. In addition, an engineering company can perform the functions of a designer or some of the functions of a general contractor - organization, planning, construction control.

And here the customer (investor) can only deal with investment decisions, and even the acceptance, operation or sale of the facility [17].

The advantages of the considered types of contracting methods compared to the commercial methods or organizing construction production are as follows.

1) Ensuring high quality materials and work performance.
2) Reduction of construction time (with proper organization of work).
3) Reducing uncertainties and risks.
4) Minimal investment involvement in the implementation of the construction project (exception – involvement of contracting and subcontracting organizations under agreements directly with the investor).

The disadvantages of the considered types of contracting methods compared to the economic method of organizing construction production are as follows.

1) The increase in the estimated cost (up to 12%) when involving general contracting organizations.
2) The autonomy of the activities of designers and contractors (builders cannot start work until the design documentation is prepared).
3) The risk of making ineffective construction decisions due to the contractor not participating in the design.
4) Disunity and conflicts between designers and contractors (usually disappear with long-term cooperation).

In the mixed method *of organizing construction production management* (Fig. 3.7), a part of the work is performed by contracting organizations under contracts, and a part of the work is performed by the company itself [8].

The method of construction management "turnkey" (design-built method). Its types are shown in Figure 3.8. In the case of using this method, a holding company is usually created (controlling of the work of a group of companies) according to the principle: investment-management-construction. The unity of economic activity is ensured by the fact that the participants of all three processes are gathered under the management of the holding company [8].

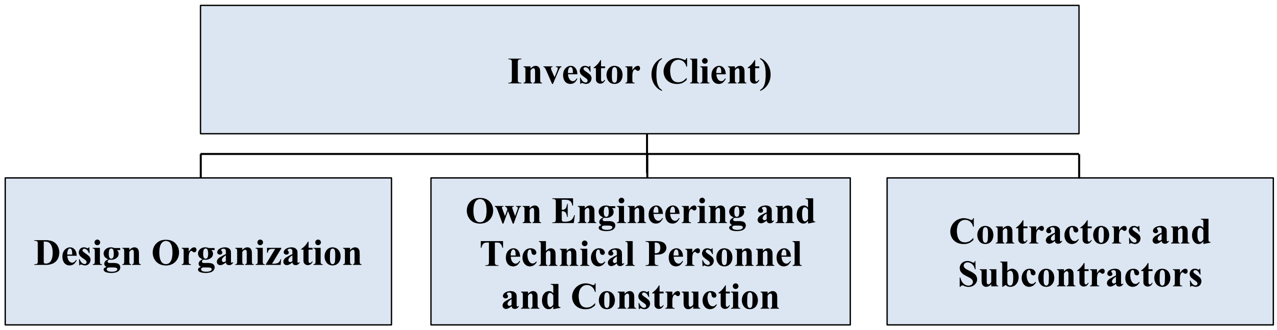


Fig. 3.7 The organizational structure of a mixed method of organizing construction production management

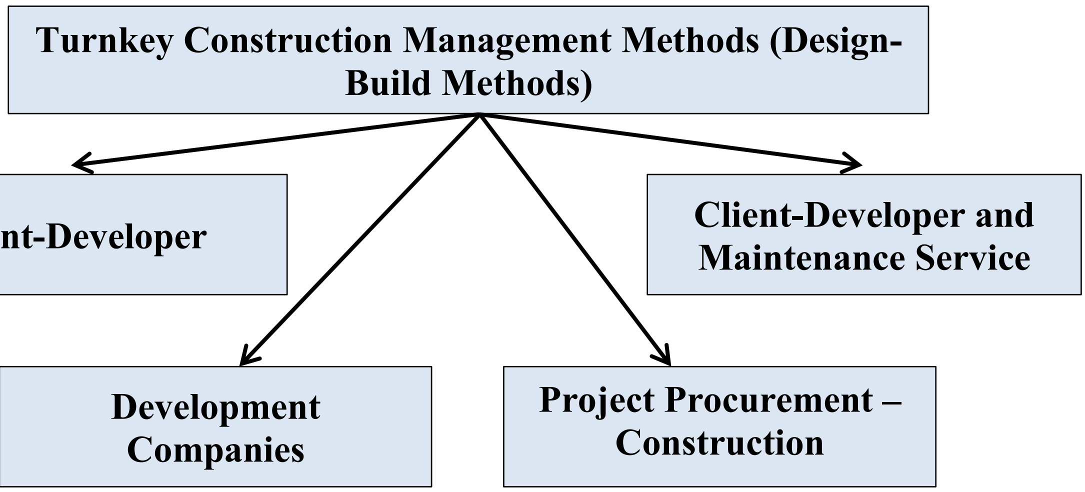


Fig. 3.8 The types of turnkey construction management methods

A holding company is a group of commercial firms legally related to each other.

The term “corporation” is a very capacious one. One of its meanings is the association of commercial organizations for the joint solution of business problems. Another meaning of the term "corporation" is any commercial firm in principle.

Concern is a financial and industrial group of companies. A group of companies united by the business interests of its participants, joint activities, capital, mutual contracts and obligations.

A relatively small amount of highly-specialized work for the holding can be performed by external contractors [17].

In addition, holdings for turnkey construction may include services or organizations responsible for marketing, the introduction of information technologies into design, the provision of telephony and internet services, technical and design supervision, training of qualified personnel, real estate promotion, engineering research, etc.

Enterprises can be united into concerns, and their number can reach hundreds and even thousands. In this case, there may be enterprises for the production and extraction of building materials, scientific and research organization, etc. Several levels of management can be maintained in this, for example: management of the concern/corporation – management of the association – directors of companies [17].

With the construction management method *"customer-developer"* (Fig. 3.9).

The holding company takes on the functions of design and construction, possibly also as the customer (investor).

To prepare an investment project with turnkey delivery of the facility, the holding company acts as a developer (customer-developer) and ensures the implementation of design work under contracts with external contractors on its own resources; plans development prospects.

An example of the organizational structure of the "customer-developer" construction management method is shown in Fig 3.10 [14, 17].

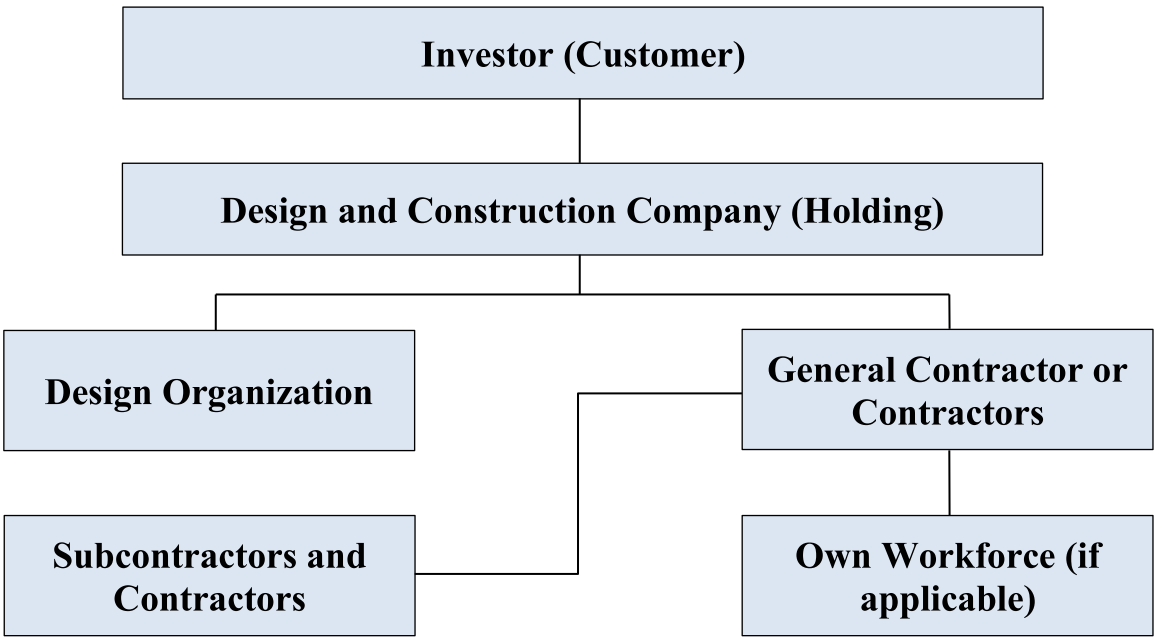


Fig. 3.9 The organizational structure of the construction management method "customer-developer"

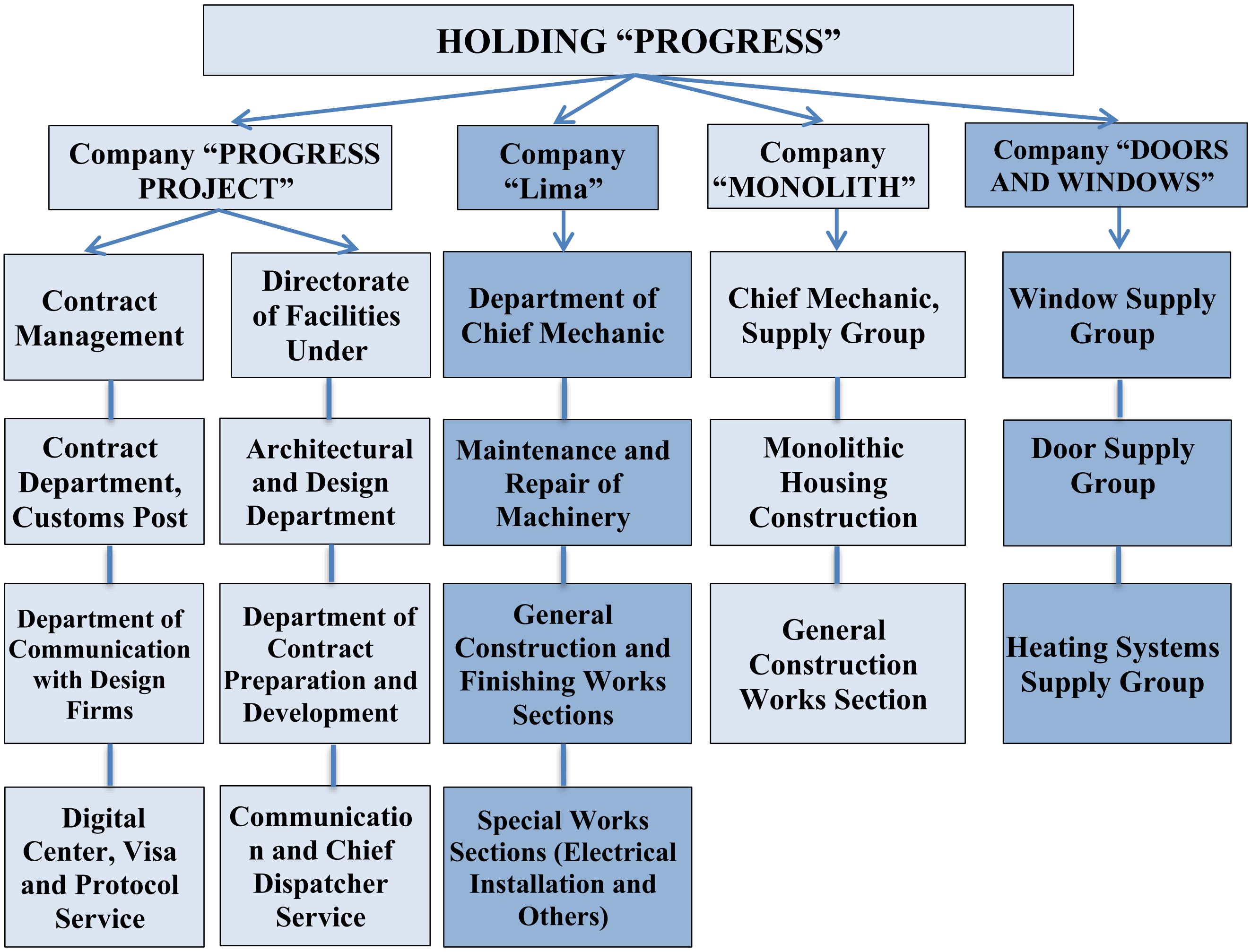


Fig. 3.10 The example of the organizational structure of a holding company using the “customer-developer” construction management method

The essence of the construction management method *“customer-developer and operation service”* (Fig. 3.11). Currently, organizations (holdings) are beginning to operate, which include most of the participants in the investment project.

In addition to the participants specified in the “customer-developer” structure, this method may include building operation and/or maintenance services, and they may be subordinated to both the investor (customer) directly and the holding company [8].

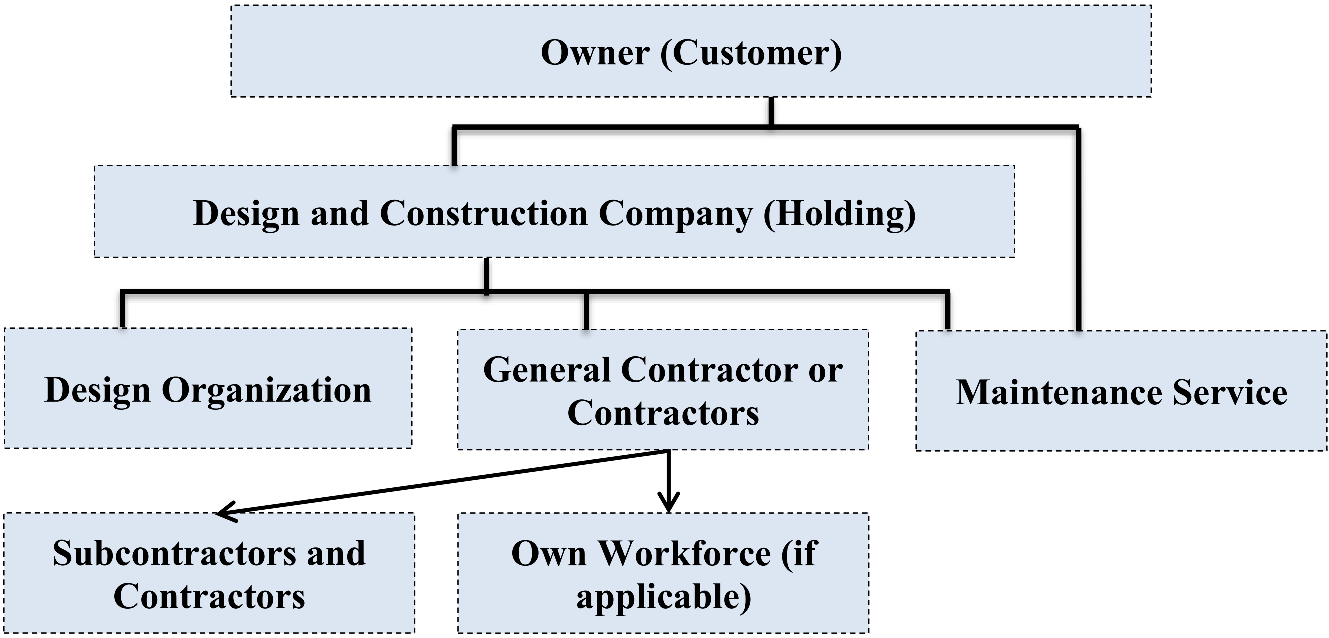


Fig. 3.11 The organizational structure of the construction management method “customer-developer and operation service”

It is possible to highlight the following advantages of the construction management method “customer-developer” and “customer-developer and operation service” compared to traditional organizational forms.

1) Joint work of designers and contracting organizations.
2) High level of development of project documentation.
3) Attracting highly-qualified personnel.
4) The owner (customer) contracts not with several, but with one organization.
5) Reducing construction times through easier and faster approval of project changes.

It is possible to highlight the following disadvantages of the construction management methods “customer-developer” and “customer-developer and operation service” compared to traditional organizational forms.

1) The owner’s ability to control the cost and other parameters during the construction project is limited.
2) The owner design and construction organizations when there is only a budget concept, and the real cost will be received upon completion of the design work (it is impossible to use a firm fixed price when concluding contracts).

3) Design and construction organizations may sacrifice some types of work and quality to meet the budget.

The essence of the method of construction management with the help of *development companies* (Fig. 3.12).

The goal of development companies is to make a profit or achieve a positive result (development of production, solving social problems, etc.) by transforming a territory, a plot of land, or a real estate object.

Development companies are an analogue of the previously considered holdings and associations, which have some distinctive features [8, 14, 17].

It is possible to highlight the following distinctive features of development companies.

A developer is, first and for most, an investor and owner of a real estate object (a plot of land), he can make investments in the entire project: marketing, design, construction, exploration, operation, enterprises producing building materials, etc.

Only the developer interacts with government agencies.

Development companies, unlike, others may include: real estate companies, marketing and consulting agencies, enterprises for the production and/or sale of building materials, etc.

The main managing development company can either invest in all stages of construction itself (with its own investment companies) or, in addition, attract external investment companies (which can act as a customer).

Development companies allow to implement all stages of the life cycle of a construction project (Fig. 3.13-3.15) [8, 14, 17].

An investment platform is an information system on the internet used to conclude investment contracts using remote technologies and technical means; access to the platform is provided by the investment platform operator through a personal account [8, 14].

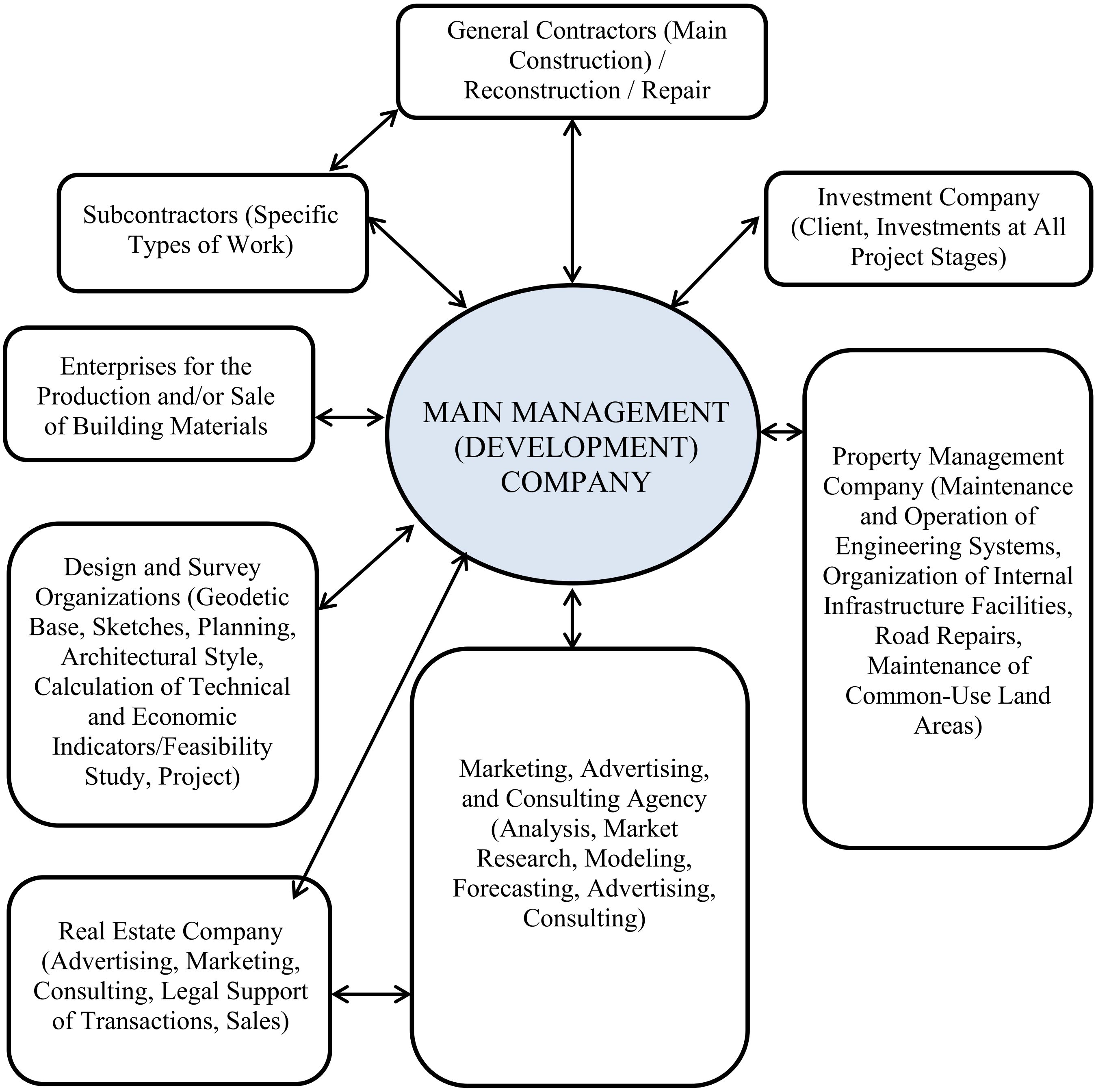


Fig. 3.12 The most complete version of the organizational structure of the management of a development company (a consulting agency is a company that has expert knowledge in certain areas of business and provides its clients with advice on these areas.

Marketing agency is a company specializing in market research and developing solutions that increase sales)

I PRE-INVESTMENT STAGE

• formulation of the development idea;
• search for the property;
• preliminary evaluation of the development project's efficiency;
• audit of the development property;
• audit of the land plot.

Result:
• marketing and investment analysis;
• feasibility study of the project.

Fig. 3.13 The first stage of the life cycle of a construction object

II PRE-INVESTMENT STAGE

2(2.1) Pre-Project Preparation:
• development of the project concept and business plan;
• purchase of the investment site/development property;
• obtaining the necessary permits and approvals;
• approval of the technical and economic indicators for the development of the investment site.

(2.2) Design and Construction Preparation:
• detailing of the project concept and its design;
• conducting engineering surveys;
• preparation, coordination, and expert review of design documentation.

(2.3) Construction Works:
• conclusion of contracts with the contractor;
• construction and installation works;
• coordination of the project participants' activities;
• monitoring the progress of project implementation;
• connection of the constructed facility to engineering and technical infrastructure networks.

(2.4) Commissioning of the Facility and State Registration of Rights:
• obtaining a certificate of compliance and technical passports;
• obtaining a permit for commissioning;
• state registration of property rights.

Result:
• architectural design;
• engineering design;
• refinement of the project's feasibility studies;
• package of documents with approvals and construction permits;
• commissioning of the facility

Fig. 3.14 The second stage of the life cycle of a construction object

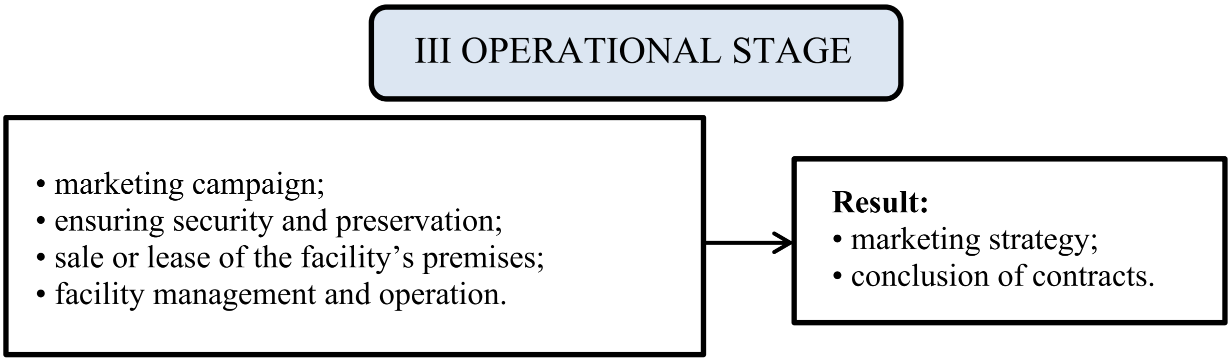


Fig. 3.15 The third stage of the life cycle of a construction object

The operational stage is carried out during the implementation of the entire development project.

Marketing campaign is a set of marketing activities carried out within the framework of a single strategy and aimed at promoting the brand and its products, attracting new potential buyers, and increasing sales [8].

The advantages of managing construction with the help of development companies are as follows.

1) A through market analysis and the right choice of a plot of land by the development team allows you to make an investment decision that differs from the "average market" by 20-50% for the better.
2) Preliminary justification of investments, as a rule, allows you to optimize the use of investment funds by another 10-15%.
3) Proper registration of property rights and resolution of other legal issues can increase the value of a plot of land by another 150-300%.
4) Reduction of the duration of development and implementation of a construction project by 7-15%.
5) Reduction of costs for the entire project by 5-15% (reduction in construction costs by 10-20%; reduction in labour intensity at the construction project implementation stage by 5-15%; reduction in operating costs by 15-25%).

Disadvantages that arise when managing construction with the help of development companies.

1) A large amount of initial capital may be required. Development projects usually require significant investments – tens of millions of dollars.
2) High requirements for the level of training of managers of the main management development company.
3) Long-term nature of projects and the need to monitor their implementation (the role of planning and forecasting is increasing; taking into account changes in the external environment - demand, supply, the environment of objects, etc.).
4) The complexity of the project and the high involvement of participants, the need for their coordination.
5) Increased public interest in development projects and the need for their public protection.
6) High level of state regulation (in particular urban planning conditions) and public control.

A possibility of modernizing (increasing the efficiency) of the considered methods of organizing construction production is a type of "turnkey" construction management – *"design-supply-construction"* (Fig. 3.16 and 3.17).

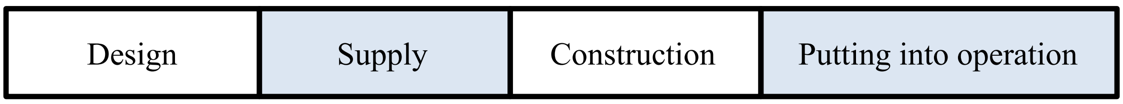


Fig. 3.16. The traditional construction management organization

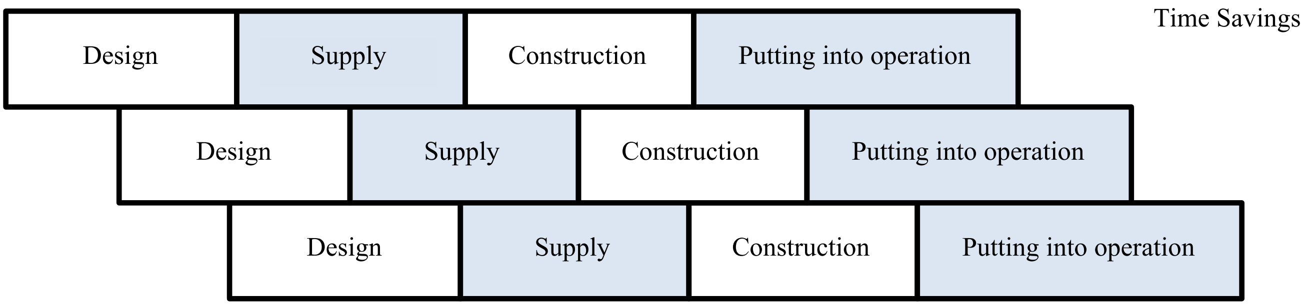


Fig. 3.17 The type of turnkey construction management – "design-supply-construction"

Compared to the traditional construction management organization (Fig. 3.16), the fast-track construction management organization ("design-provision-construction") involves combining the design, provision, and construction processes (Fig. 3.17).

Provisioning is concluding contracts with contractors, ensuring logistical construction processes.

The design of the second part of a construction project can begin while the design of the first part is still incomplete. A similar situation applies to procurement, construction and operation [8].

Project-oriented construction management systems (Fig. 3.18). In this method, the investor (customer) hires a firm that performs management (or project manager) functions [8, 14, 17].

The project manager performs only management functions in the interests of the investor (customer) who hired him, without interfering in the economic activities of enterprises [8, 14, 17].

Project-oriented management systems are effective for a large number of projects.

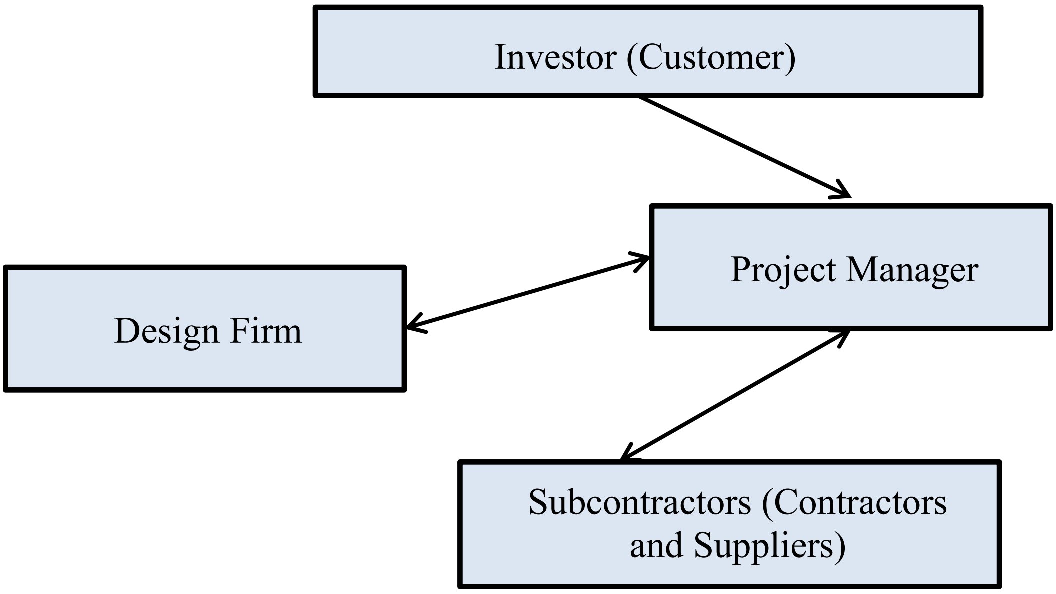


Fig. 3.18 The organizational structure of project-oriented management systems construction production

Project-oriented management systems in construction can be divided into construction project management and program management (Fig. 3.19). Their type depends on the tasks and competence of the management company.

In construction project management (Fig. 3.19), the following 3 options are possible.

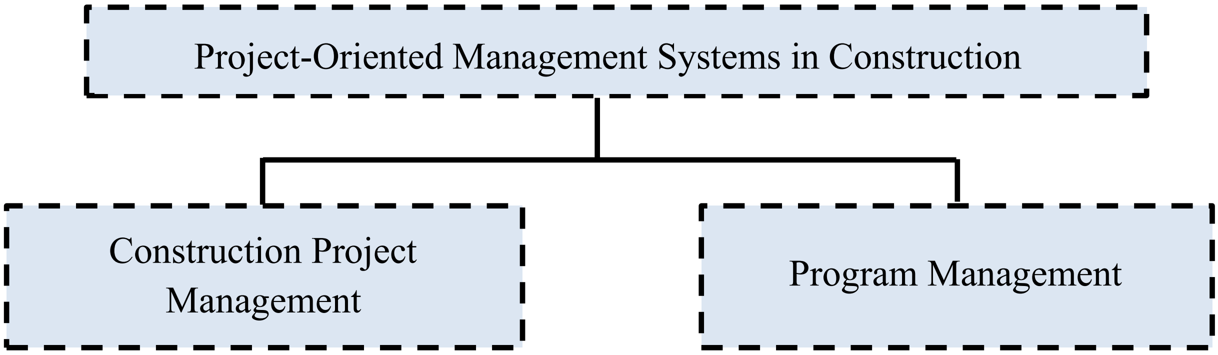


Fig. 3.19 The types of project-oriented construction management systems

1) The management company (a construction project manager) provides the investor (customer) with management services, without setting the project completion date and cost of the work, since the investor (customer) himself concludes contracts with contractors.
2) Construction project management provides management services, as well as contracting with contractors; establishes a minimum guaranteed price and completion date if the scope of work is defined.
3) The investor (customer) enters into a contract with a construction manager who develops the project and provides the investor with services for its implementation.

Payment systems for project management services. There are the following 2 options for the investor (customer) to pay for the services of the management company (a project manager) [14, 17].

1) Fixed cost of project management services (for a specific project or period of time).
2) Payment for project management services depends on the profitability of the project.

In the second case, the manager is interested in saving money and high project efficiency. His interest is expressed in at least two directions: remuneration in the form of a share of the profit and increasing his authority as a manager.

Program management is sometimes called *"program project management"* (Fig. 3.19, 3.20). It is intended to guide all managers of individual projects related by the single goal of program implementation (multi-billion dollar research, energy projects, the practice of large design and construction firms, etc.) [14, 17].

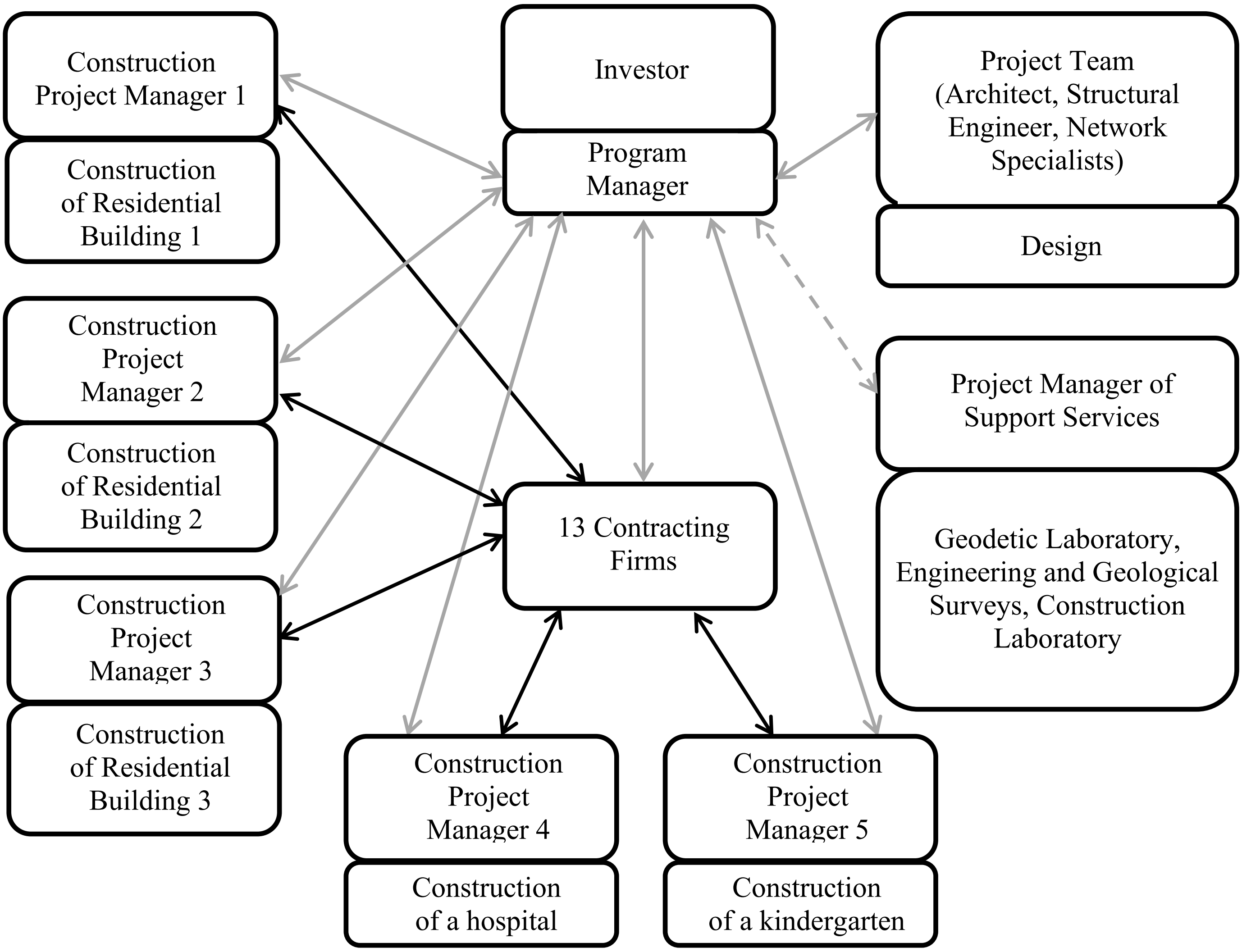


Fig. 3.20 The example of program management (the organization of construction of a residential complex worth $43 million)

In this form of organization, the relationships between team members are crucial. The involvement of the owner and the need for this competence across the entire spectrum of problems or the appointment of a project manager with appropriate qualification to manage the program as a whole are important.

An example of program management for the construction of a building complex is shown in Fig. 3.20 [14, 17].

An example of a unique organizational form: construction of two nuclear power plant units (Fig. 3.21). This is a modernized version of the contract construction method. For such facilities, the investor is usually a state organization. The customer (operating organization) shares functions with the investor, in addition, he is engaged in commissioning and operation of the facility.

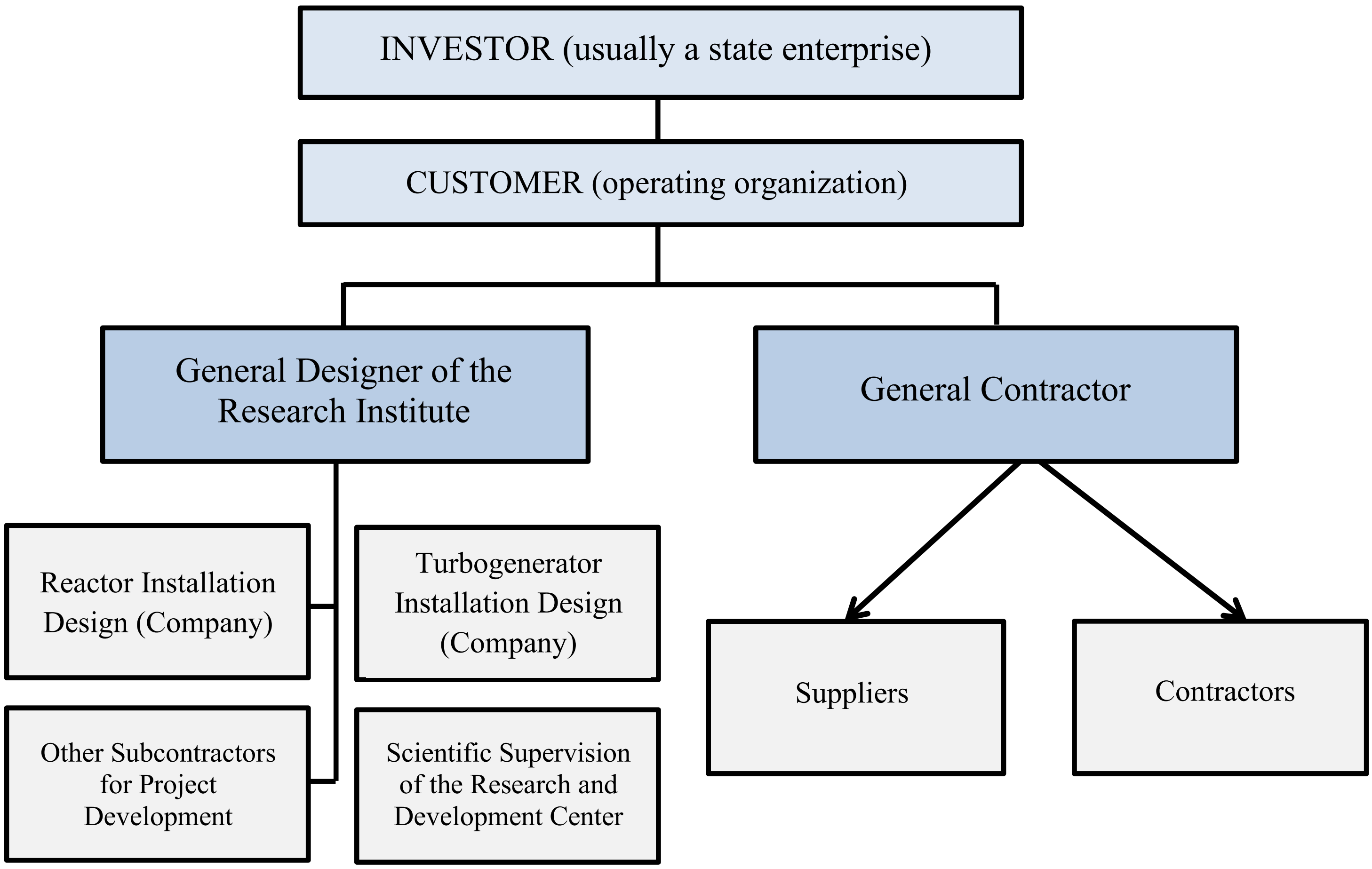


Fig. 3.21 The example of a unique organizational form – construction of NPP units

The general designer manages the work of the designers.

The general designer may independently manage the designers or include a project manager in the team to manage certain aspects of the design (in this example, scientific support, author's supervision, etc. are performed by the scientific research centre SRC). A similar situation applies to the general contractor.

3.2. The organization of interaction between project participants and in case of using BIM

BIM is used to coordinate input data, organize co-production and data storage, and use it at different stages of the project life-cycle.

BIM allows covering all stages of the project life cycle (architectural concept, the design of structures and engineering systems, the organizational and technological part of the project graphics or 4D models of the construction project implementation, etc.) (Fig. 3.22, 3.23) [2, 3, 6, 12].

An enterprise resource planning system (ERPS) (Fig. 3.23) is the software that can manage finances, supply chains, operations, trade, reporting, production, and personnel [12].

Information modeling is used at all stages of the project life-cycle, where the information model is created, supplemented or changed [12].

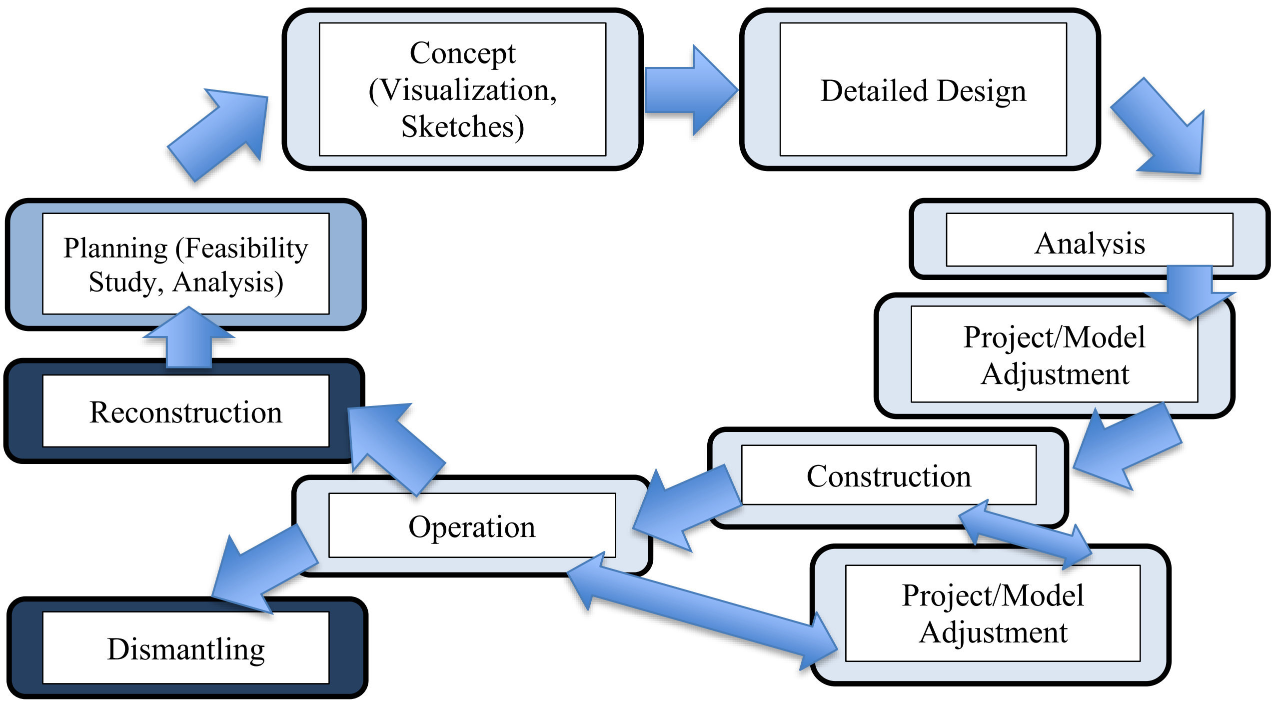


Fig. 3.22 The stages of the life-cycle of the information model of the construction project. The beginning of the life-cycle is highlighted in red, the end in gray-red. The detailed design stage includes the architectural design, structural calculation, modeling (in particular, 3D-6D models, which is discussed in section 6.2 of the lecture notes)

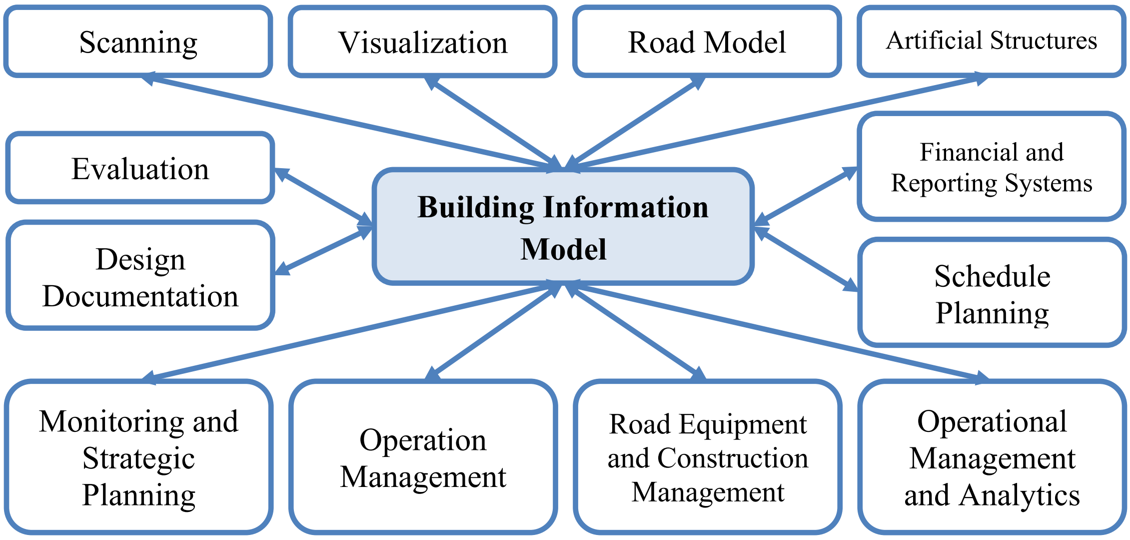


Fig. 3.23 The Building Information Modeling (BIM) capacities. A road model is a model of any object (the example of the road model)

In the construction organization, the information model is used to plan, analyze and control the performance of construction and installation works, record the supply of materials and equipment, observe safety regulations, control and record the expenditure of funds, etc.

In essence, the use of BIM allows any organizational form to improve the interaction of all participants in the implementation of a construction project. Based on the use of BIM, a new organizational form of construction project management can be created, which will consist in the communication and interaction of all stakeholders through a single information model.

The interaction of construction project participants can be simplified by using BIM and displayed in the form of a diagram (Fig. 3.24).

Compared to the previously considered forms and methods (section 3.1 of the lecture notes), it is possible to highlight the following advantages of using BIM in organizing construction production management:

- reducing the cost of a construction project (reducing costs for the reworking project documentation and the additional costs, associated with identifying shortcomings and mistakes at the design stage; the opportunity to adjust the model during construction and operation quickly);

- modeling of different options of a project and choosing the optimal one;
- providing participants of the construction process with up-to-date data;
- the opportunity to monitor and plan;
- the opportunity to change the project during its realization.

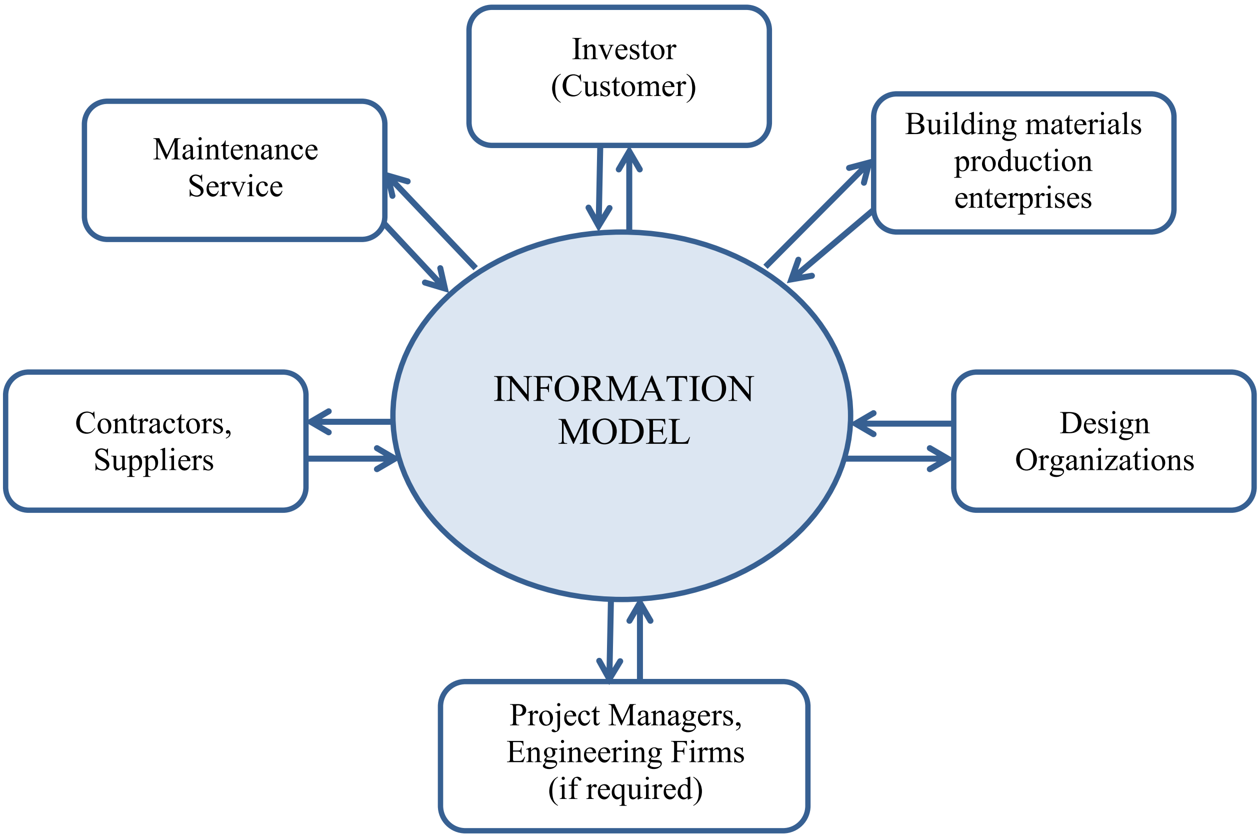


Fig. 3.24 The scheme of interaction between project participants when using BIM

Compared to the previously considered forms and methods (section 3.1 of the lecture notes), it is possible to highlight the following shortcomings of using BIM in organizing construction production management:

- the use of a large set of software (architectural, estimating, calculation programs, project management and visualization, programs for 4-D, 5-D, 6-D... modeling);
- the requirements for high qualification of software users;
- high prices for software.

3.3. Organizing construction project management teams using BIM

The roles and responsibilities of BIM within a company's structure will vary between different construction organizations depending on their size and internal structure. It is possible to think of BIM roles as a new level of competence added to the roles that already exist in your organization, rather than as new roles that complement or replace existing ones. Over time, these layers will evolve, but the core functions will continue to be performed [12].

Regardless of the size of the company, BIM must be implemented simultaneously from the top down and bottom up (at the strategic, tactical and operational levels). Such coordinated implementation requires open communication between all roles and levels [12].

Management commitment is essential to align processes with the company's goals and vision, provide strategic leadership, and allocate sufficient financial and human resources [12].

In addition, a tactical team (or individual, depending on the size of the company) is needed to assess the company's needs and challenges, develop a customized solution and implement it. This team will also provide regular reports, conduct reassessments and research and development to address current issues [6, 12].

At the same time, BIM must be integrated into everyday operations. These operational workflows must be tested, stretched, broken down into parts, and promoted in order to be strengthened. As a general guideline, the functions of BIM implementation in an organization can be structured into three levels: strategic, tactical, and operational (Fig. 3.25) [12].

The BIM manager (or *BIM administrator* in large companies, where there may be more than one BIM manager) is the main person responsible for BIM implementation in the company. This person manages the tactical direction of BIM within the parameters set by management, i.e., manages the development of company guidelines, general processes, project templates, and technical issues or problem solving [12].

In small companies where there is no IT administrator, the BIM administrator may also take responsibility for installing and maintaining software and hardware [12]. The BIM manager must be aware of innovations related to software, as well as national and international standards and recommendations [12].

The IT manager is responsible for the installation and operation of all software, hardware and IT systems. He or she may also be involved, together with the BIM manager, in research and development to identify and test new technologies [6, 12].

At the operational level, we have end users: architects, engineers, and construction managers who ultimately create and use the model data. The activities here are wide-ranging and diverse and can include anything from model creation, design analysis, scheduling, running simulations, to reporting on progress and tracking changes or defects on site [2, 3, 12].

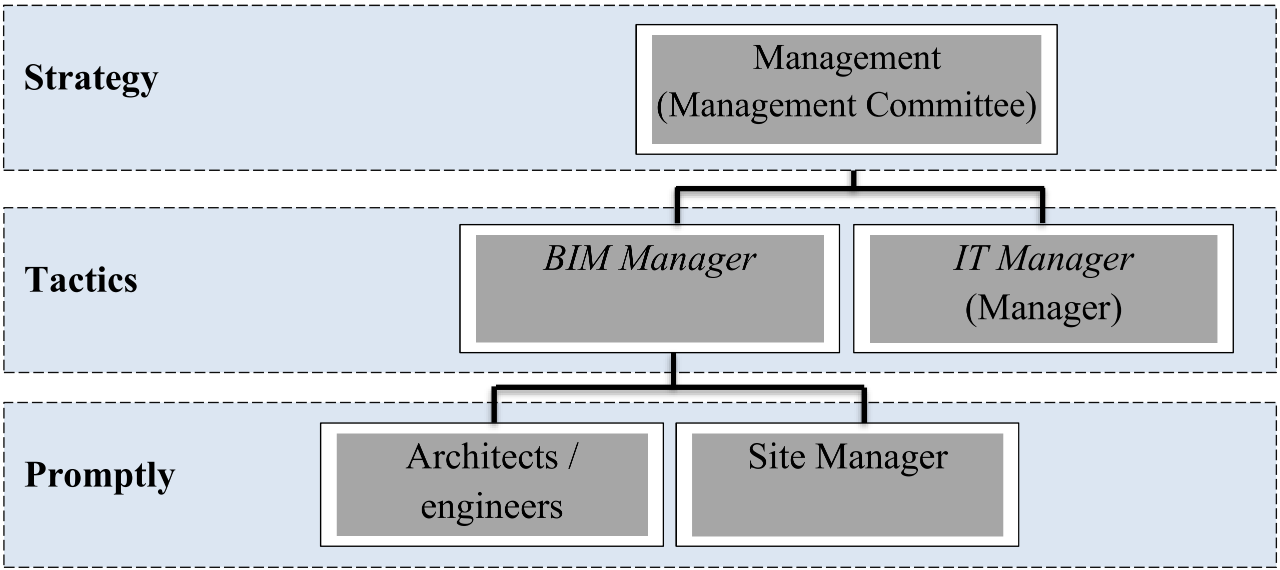


Fig. 3.25 BIM functions in an organisation

To be most successful, the team must be engaged and informed about high-level policies and procedures; this means that management needs to communicate how the strategic direction will affect the individual roles of end users [12].

Each of the traditional project functions can be supported by BIM functionality (Fig. 3.26). In the short term, a BIM expert can perform additional functions, but in the long term, projects should have the same number of "full-time" employees with BIM competencies. The only exception is a BIM consultant for the owner, who may remain an external function [12].

The BIM champion (Fig. 3.26) is the driving force behind BIM in the client's organisation and defines the BIM strategy and objectives from the owner's perspective.

This means promoting BIM activities and vision within the client's organisation, as well as external communication with partner companies.

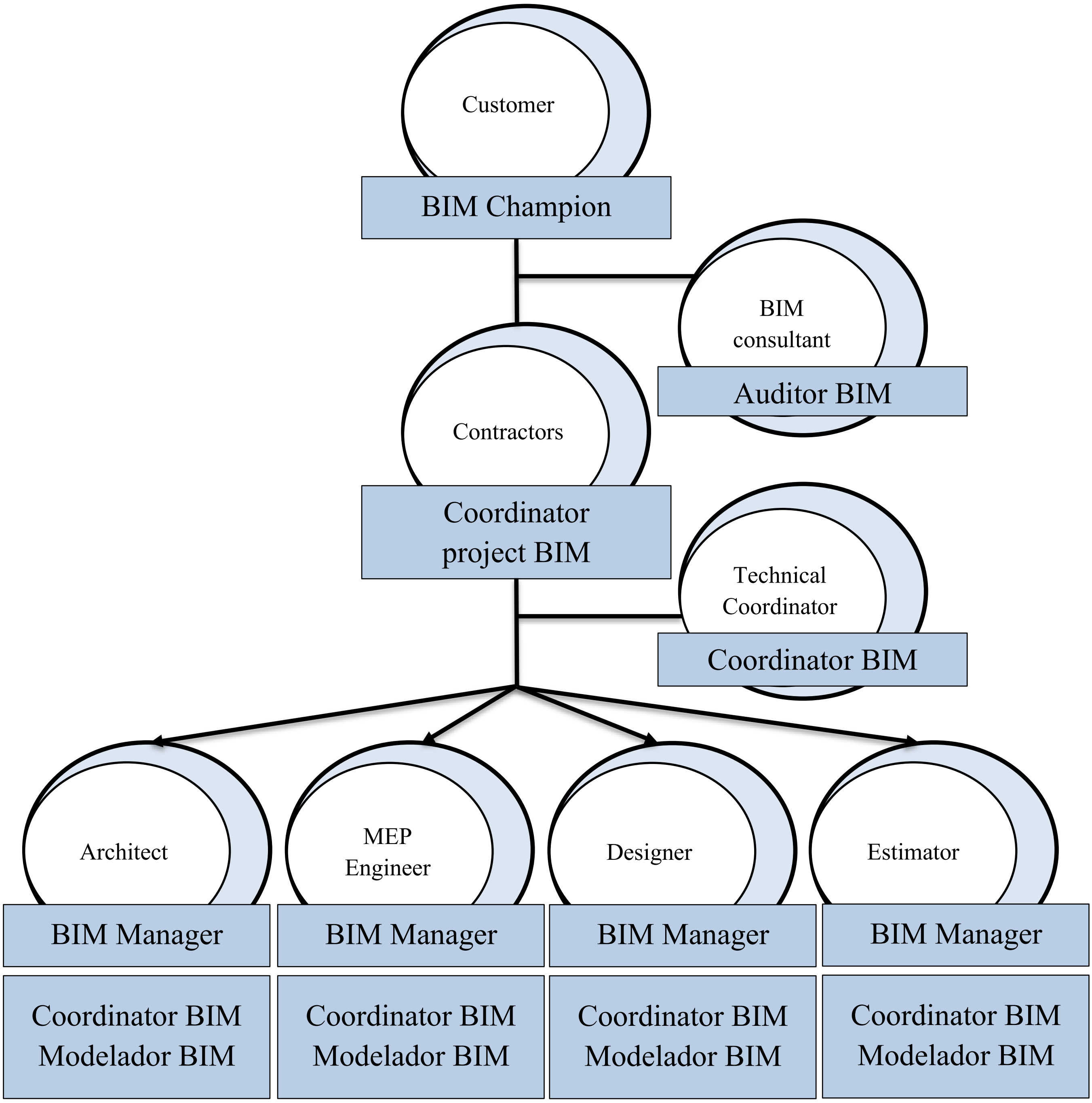


Fig. 3.26 Traditional Roles Assigned for BIM Competencies

The BIM champion's responsibilities include:

- internal coordination of BIM training;
- planning internal resources (staff, costs, planning);
- BIM project planning [12].

A BIM champion is a BIM driver at the strategic level within an organisation (usually used in relation to a client organisation) [2, 12].

A BIM auditor (or quality manager) is usually an external consultant to the building owner who helps to define and implement BIM requirements and protocols in a project [12].

The BIM project coordinator is the main contact person for the BIM project. Their role is usually to strategically coordinate and control projects [12]. The BIM coordinator performs a quality control function at the operational level.

The BIM auditor is primarily involved in planning and monitoring the project from the client's perspective. This is a quality management function that may include defining project protocols, monitoring the BIM process, and auditing project results. This person represents the owner's technical interests at coordination meetings and establishes requirements for the necessary technologies, standards, and guidelines to be applied during project implementation. Other responsibilities of the BIM auditor include:

- establishing communication protocols between BIM teams through the relevant BIM coordinators;
- quality assurance and control;
- data consistency support [12].

BIM project coordinator (main contractor). This is the main project support function for all teams working with BIM. The BIM project coordinator manages BIM project reviews and coordination meetings, acts as an information manager and issue coordinator, and provides communication between teams on site. This coordinator ensures productivity and communication between BIM, as well as data consistency among project participants. Other responsibilities of the BIM project coordinator include:

- quality assurance and control;

- on-site BIM support; support for the transfer of documentation on the actual status to FM [12]. FM (Facility Management) – This involves managing the operation and maintenance of buildings and structures after the construction phase is complete.

The BIM coordinator determines the spatial planning of construction services and ensures the technical coordination of work (including the opening of construction sites) [12].

Other responsibilities of the BIM coordinator include:

- model quality control (checking geometry and properties);
- ensuring the quality of trade coordination;
- regular reporting and monitoring of issues [12].

As part of the company's function, *the BIM manager* supervises the internal BIM team and CAD/BIM processes, and as part of the project function, the BIM manager ensures that the project results comply with the project requirements and the BIM project implementation plan. Other responsibilities of the BIM manager include:

- liaising with the project coordinator and other BIM managers;
- leading the project team;
- ensuring quality control [12].

BIM manager is the BIM operational manager within the organization. This is a technical role responsible for creating information models of buildings in accordance with project specifications, coordination and resolving minor issues. BIM authors must also identify and report issues for further consideration [12].

A BIM author is any person involved in the creation of model data [12].

Key functions of a BIM project (Fig. 3.27):

- (1-2): model creation, export and analysis are activities managed by individual consultants (authors and BIM managers);
- (3): model exchange management and quality control (with commercial coordination) is carried out by the BIM coordinator;

- (4): project coordination and collaboration (including managing project coordination meetings, reviewing issues, planning costs and schedules) is the responsibility of the BIM project coordinator;
- (5): Validation of data extractions is verified by an external BIM auditor [12].

Paper	*BIM Modeler BIM Manager / Coordinator*		*Technical Coordinator*	*Project Coordinator*	*Auditor*
Activity	Creation of BIM	Data Extraction and Analysis	Quality Control	Coordination	Quality Control
Working	Native Environment		Exchange Environment	Collaboration Environment	Exchange Environment

Fig. 3.27 Comparison of key BIM project activities with roles

In the project environment, the BIM manager (Fig. 3.28) acts as a liaison. He represents the interests of his organisation at BIM project coordination meetings and ensures that project requirements are met within the scope of his company's activities. The BIM manager is the main contact person for the BIM project coordinator in the relevant project teams. On the other hand, the BIM project coordinator primarily manages the BIM processes of the entire project. The BIM project coordinator may be hired by the owner or general contractor and is the main contact person for all project teams regarding the BIM requirements of the project [2, 6, 12].

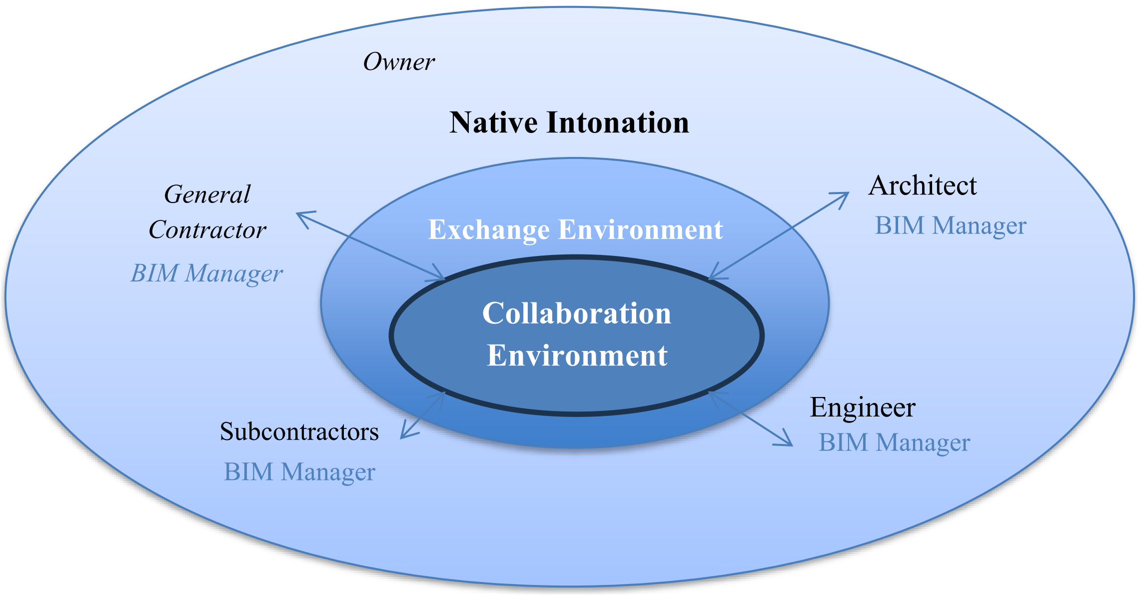


Fig. 3.28 BIM manager and BIM project coordinator

As an interface between the functions of the company and the functions of the entire project team, we can define another subgroup: "project functions" within the "company or discipline". The number of people involved in the project and, of course, their responsibilities will always depend on the project, discipline, and phase. In a small residential development, the lighting planner may only assign one specialist at an early stage, while in a large development, an architectural firm may easily have ten or twenty specialists to develop the construction documentation. Nevertheless, it is possible to define generalised roles and activities. The European research project BIM4VET defines three main roles in a project: BIM manager, BIM coordinator and BIM author (Fig. 3.29). The BIM author (both the modeller and the model user) is also divided into senior and junior roles. BIM4VET assigns specific activities to each role with corresponding levels of competence [2, 3, 12, 18].

BIM Manager	BIM Coordinator	Senior BIM Author	Junior BIM Author
1) Defines and maintains project standards. 2) Agrees on the software solutions to be implemented. 3) Determines project outcomes in accordance with client requirements. 4) Develops and maintains a coordination program for service delivery. 5) Ensures the implementation of the project information exchange system. 6) Manages BIM activities at the project level. 7) Evaluates the project team's ability to meet project standards.	1) Ensures compliance with project standards. 2) Ensures compliance with corporate standards. 3) Ensures compliance with national and international standards. 4) Coordinates the results of BIM modelers/technicians to ensure proper quality and compliance with BEP requirements. 5) Monitors reports on conflict detection and resolution. 6) Addresses urgent issues related to software and staff professional development. 7) Ensures the implementation of BIM software.	1) Refers to other shared models to ensure design coordination and avoid conflicts. 2) Develops and maintains graphical and non-graphical models in accordance with project standards. 3) Derives project outputs from graphical and non-graphical models. 4) Assists in maintaining project standards. 5) Resolves urgent software issues and supports staff training. 6) Ensures full compliance with best industry practices in the field of information production and exchange. 7) Assists in maintaining internal CAD standards and workflow by providing feedback to the BIM Coordinator.	1) Refers to the work performed by other members of the project team. 2) Develops and maintains graphical and non-graphical models in accordance with project standards. 3) Prepares templates to share with internal and external stakeholders. 4) Derives project outputs from graphical and non-graphical models. 5) Reviews outputs to incorporate conflict resolutions. 6) Refers to other shared models to ensure design coordination and avoid conflicts. 7) Checks outputs in accordance with the QA/QC protocol. QA (Quality Assurance) – quality assurance. QC (Quality Control) – quality control.

Fig. 3.29 BIM4VET BIM. Definition of roles and activities

The BIM process organisation scheme is shown in Figure 3.30. Here, you can see an option for organising the team and their joint work [18]. From Figure 3.30, it should be noted that there can be either an asset owner (e.g., a building) or a project owner (a chain of tasks). The main thing is that these persons are the customers for further actions [3, 18].

The project manager considers that, on the one hand, he has customers as clients, and on the other hand, he has customers as contractors. That is, there is no purely hierarchical relationship.

The main contractor and subcontractor are hired by the BIM manager.

The appointed design consultant coordinates the work of structural design, engineering design, architectural design, etc. [18].

The designated architect divides the processes for which the designers will be responsible (e.g., facades) and determines how to bring them together in the cloud [18].

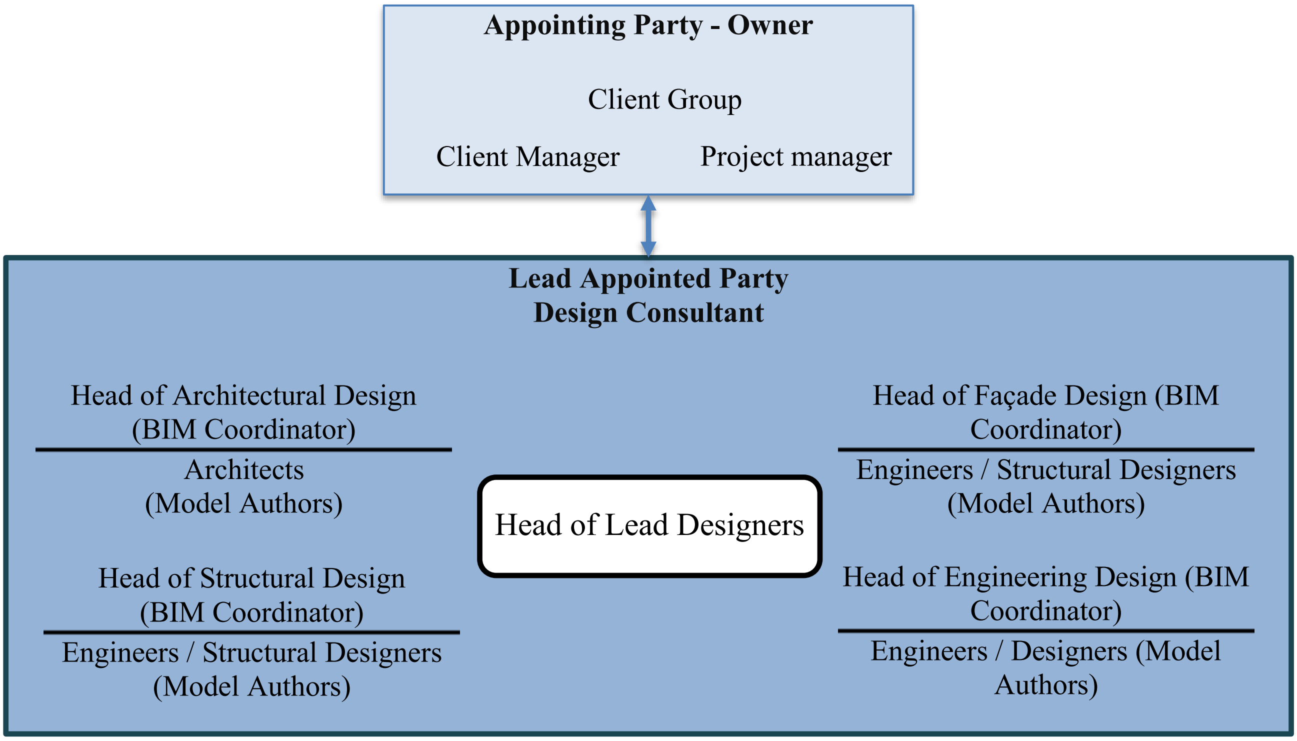


Fig. 3.30 Example of Team Organization in BIM

3.4. Matrix of distribution of responsibilities among participants in a construction project

The matrix of distribution of responsibilities reflects what is being done as part of the implementation of a construction project using BIM and who is doing it. The responsibility matrix is the basis of the BIM *Exclusion Plan*, which is a plan for the implementation of a BIM project developed by the general contractor to regulate interaction with subcontractors and agreed upon with the customer. This is where the information and details of this information are linked [18].

An example of a responsibility matrix is shown in Figure 3.31 [18].

Figure 3.31 shows that one link is solely responsible for the geometric description, while the other is responsible for the information. At the same time, the first link may have different levels of detail at different stages of the project life cycle. However, they must be placed within the general concept of detail. Conversely, the second link means that the more information is added to a particular element, the more structured this information will be at a higher level of description of this model [18].

When a certain piece of information is entered, it is already possible to distribute responsibilities at this stage. For example, it can be specified that less qualified specialists – construction industry managers – can enter general information about available building materials. Meanwhile, the engineer who performs the calculations has seen which materials to include in the project [18].

At the stage of compiling the responsibility matrix, it is possible to divide the information into two parts:

- information to be provided by suppliers (belongs to suppliers);
- information to be provided to suppliers (belongs to contractors).

In the BEP, this is prescribed for the organization of interaction by the general contractor [18].

Responsibility Matrix	RIBA Stage 2			RIBA Stage 3			RIBA Stage 4			RIBA Stage 5			RIBA Stage 6		
	Design			Design			Procurement			Delivery			Transition		
				Data drop 2a/b			Data drop 3			Data drop 4			Data drop 5		
	Originator	LOD	LOI	Originator	LOD	LOI	Originator	LOD	LOI	Originator	LOD	LOI	Originator	LOD	LOI
Surveys															
Topographical survey	Client	7	7	Ground	7	7							Contractor	7	7
Existing Utilirbes survey	Client	7	2	Ground	7	7									
Three survey				Enviro	7	7									
Asbestos demoition survey	Client	2	2	Enviro	7	7							Contractor	7	7
Ground investigation desktop study	Client	NA	2												
Intrusive ground investigation survey				Ground	7	7									
Acoustics survey	Client	NA	2	Enviro	NA	3									
Flood risk assessment				Flood	4	2									
Habitat survey	Client	NA	2	Enviro	NA	3									
Transport assessment	Client	NA	2												
Architectural															
Form and context															
Site Massing & ground layout				Arch	3	2	Arch	4	3	Contractor	4	3	Contractor	6	6
Boundary Treatment				Arch	3	2	Arch	4	3	Contractor	4	3	Contractor	6	6
Hard & soft landscaping				Arch	3	2	Arch	4	3	Contractor	4	3	Contractor	6	6
External form and appearance				Arch	3	2	Arch	4	3	Contractor	4	3	Contractor	6	6
Internal Layouts				Arch	3	2	Arch	4	3	Contractor	4	3	Contractor	6	6
Design Strategies and Performance															
Fire safety strategy				Fire	2	2	Fire	3	4						
Physical secunty				M&E	2	2	M&E	3	4						
Schedule of accommodation				M&E	2	2	M&E	3	4						
Disabled Access				M&E	2	2	M&E	3	4						
BREEAM				M&E	2	2	M&E	3	4						
Maintenance Access				M&E	2	2	M&E	3	4						
Acoustic Analysis				M&E	2	2	M&E	3	4				Contractor	7	7
Daylight design & analysis				M&E	2	2	M&E	3	4				Contractor	7	7
Thermal comfort & analysis				M&E	2	2	M&E	3	4				Contractor	7	7
Building components															
External walls				Structures	3	2	Structures	4	3	Contractor	4	3	Contractor	6	6
External doors and windows				Structures	3	2	Structures	4	3	Contractor	4	3	Contractor	6	6
External finishes				Structures	3	2	Structures	4	4	Contractor	4	4	Contractor	6	6
Floors				Structures	2	2	Structures	4	3	Contractor	4	3	Contractor	6	6
Roofs				Structures	2	2	Structures	4	3	Contractor	4	3	Contractor	6	6
Stairs				Structures	2	2	Structures	4	3	Contractor	4	3	Contractor	6	6
External walls				Structures	2	2	Structures	4	3	Contractor	4	3	Contractor	6	6
External doors sets				Structures	2	2	Structures	4	3	Contractor	4	3	Contractor	6	6
Cerings				Structures	2	2	Structures	4	3	Contractor	4	3	Contractor	6	6
External finishes				Arch	2	2	Arch	4	4	Contractor	4	4	Contractor	6	6
Floor plans				Arch	2	2	Arch	4	3	Contractor	4	3	Contractor	6	6
Furniture Fixture and Equipment				Arch	2	2	Arch	4	4	Contractor	4	4	Contractor	6	6
ICT				Arch	2	2	Arch	4	4	Contractor	4	4	Contractor	6	6

Fig. 3.31 Example of a responsibility matrix

3.5. General plan for the implementation of the construction project (PIR+EIR+BEP)

BIM Execution Plan. From English, BIM Execution Plan, BEP (less commonly BxP) is a document prepared by contractors to explain how certain aspects of information modeling of a construction project will be implemented. The BEP is agreed upon by all parties [6, 12, 18] (Fig. 3.32). Another definition of BEP is a BIM project implementation plan developed by the general contractor to regulate interaction with subcontractors and agreed upon with the customer [18]. The BEP clarifies the roles of project participants and their responsibilities, outlines the final results and deadlines for their achievement, as well as the standards to be applied and the procedures to be followed. Both pre- and post-contract implementation plans are developed within the framework of the BEP [6].

Another definition of BEP is as follows. The BEP (BIM Execution Plan) is a technical document that is usually developed by the general design and/or general contractor organization to regulate interaction with sub-project (subcontractor) organizations and is agreed with the customer. It reflects the customer’s information requirements, the tasks of information modeling, the necessary levels of processing, and the roles and functional responsibilities of the participants in the information modeling process [18].

The BEP is formed by the contractor. According to the BEP, a preliminary plan for the implementation of the BIM project is formed. The diagram and plan for the implementation of the BEP by the team are shown in Figure 3.33.

Project Information Requirements (PIR) is a document that describes the customer’s general requirements for information that must be created or provided during the project life cycle. PIR focuses on what information is needed, when it is needed, and who should provide it.

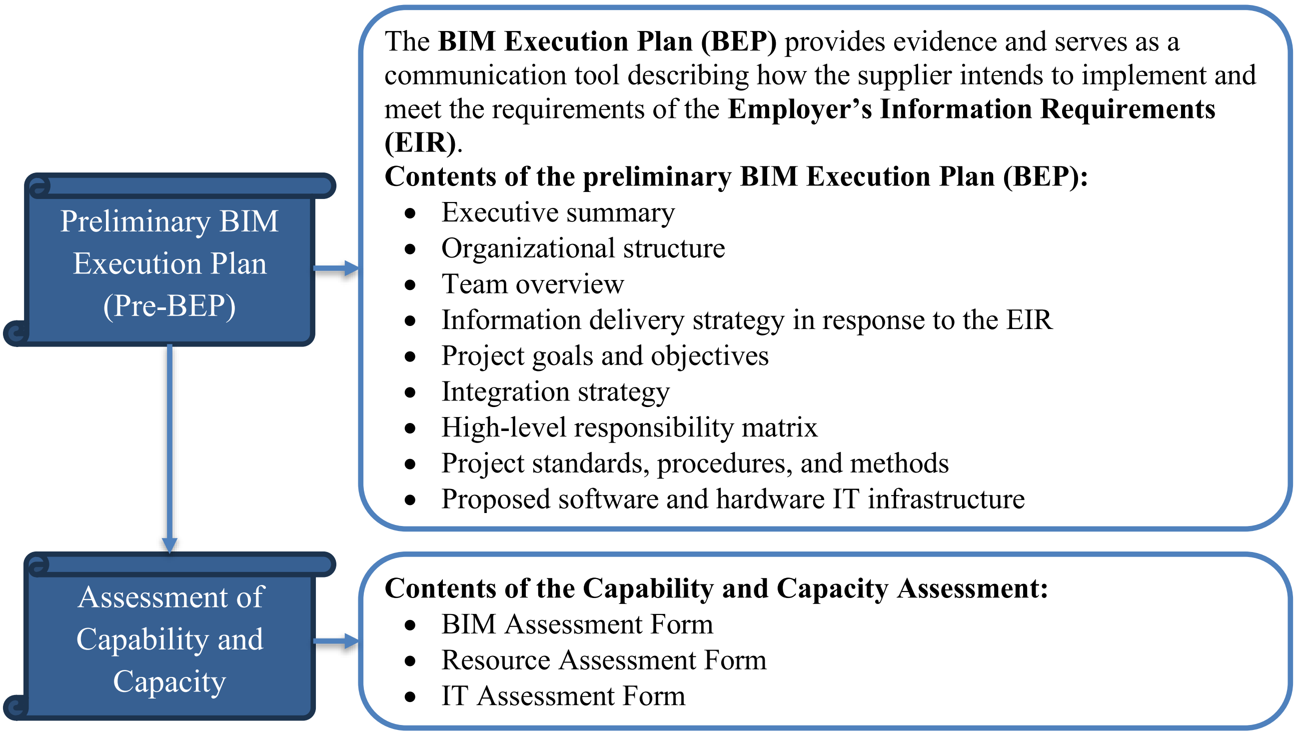


Fig. 3.32 Who compiles the BIM project

When creating information requirements for a project, many aspects are taken into account, including: project scope; project action plan; key milestones; delivery method; planned use of information; all explanations to ensure that they can make informed decisions [18].

Exchange Information Requirements (EIR) is a document that specifies the requirements for information exchange between project participants. It is based on PIR but goes deeper into technical and organisational aspects [18]. EIR defines exchange formats, frequency of information transfer, responsible persons, protocols and tools. This is the basis for developing BEP. The structure of EIR according to ISO 19650 is as follows [4, 5].

1. Technical requirements.

- file formats (IFC, PDF, RVT, etc.);
- level of detail/information (LOD/LOI/LOIN);
- requirements for CDE (common data environment).

2. Commercial requirements.

- stages of information delivery;
- participants' obligations regarding information;

- requirements for resources, qualifications, audits.

3. Management requirements.

- who is responsible for providing data (roles);
- TIDP / MIDP schedules;
- verification, approval, and control procedures.

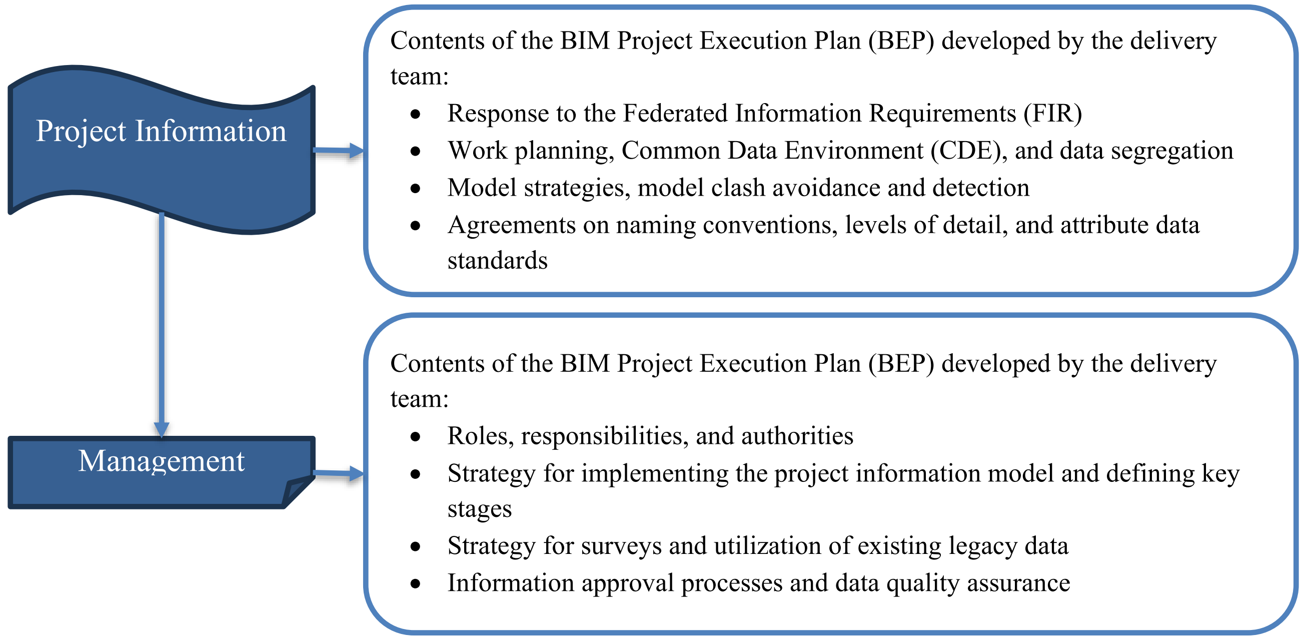


Fig. 3.33 Diagram and plan for implementation of the VER by the team

The Integrated Project Delivery (IPD) model is prepared by the task provider in accordance with the EIR. Another definition of the Information Production Delivery Plan (IPD) is also used – what reports we must submit to higher authorities [18].

The Master Information Production Delivery Plan (MIPD) tells us when certain equipment and materials must be on the construction site.

The workflow of the construction project implementation plan is shown in Figure 3.34.

Figure 3.34 shows that the responsibility matrix is divided into the Master Information Production Delivery Plan (MIDP) and the Task Information Delivery Plan (TIDP). These are separate documents, but there must be a connection between them [18].

Once the customer's information exchange requirements have been received, it is possible to determine whether it is technically feasible to upload the project to the cloud environment and include all the properties specified by the customer [18].

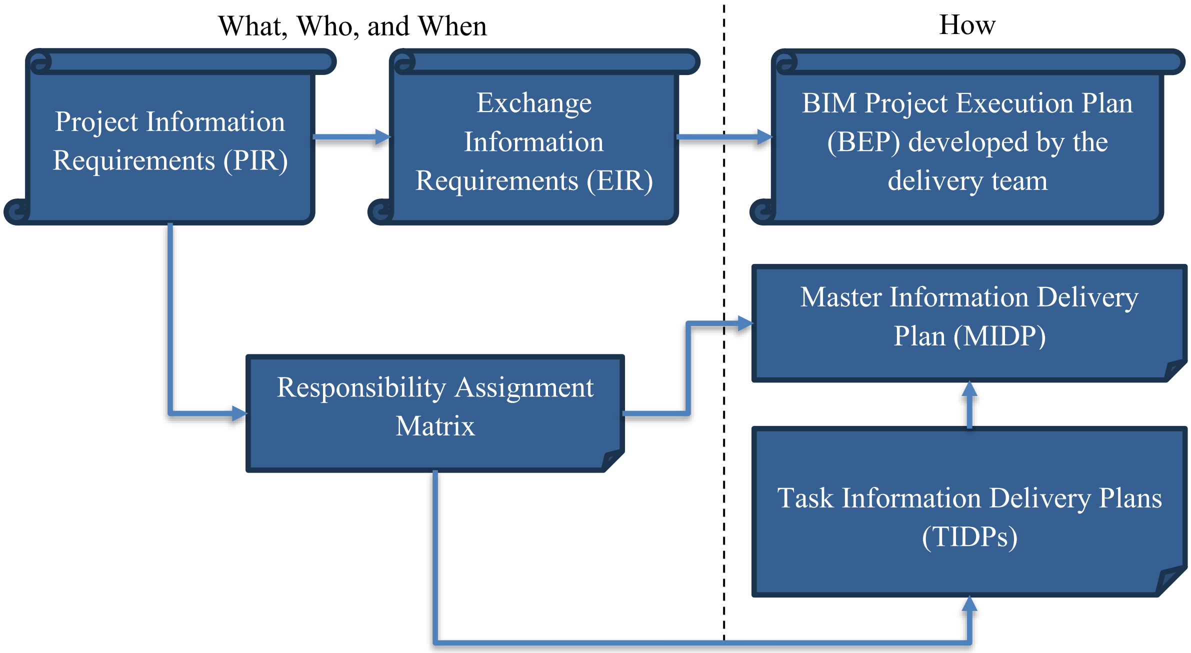


Fig. 3.34 Work process of a construction project implementation plan

An example of a BIM project implementation plan (BEP) is shown in the block diagram (Fig. 3.35). Engineering communications are already part of the building's "framework". They are not considered at the BEP stage, so they are not included in the block diagram. The following can be said from the diagram. Architects design the premises, can say what building materials are needed and what the facade will look like. The designer collects the loads, makes calculations and performs the design. Technologists organise the construction site, develop building construction technologies and determine what equipment is needed for this. In other words, separate models are created, which are then combined into a single model. However, in Figure 3.35, they are shown separately, which is not typical for BIM. These components constantly interact with each other and exchange information. This is reflected in the second example of BIM (Fig. 3.36) [18].

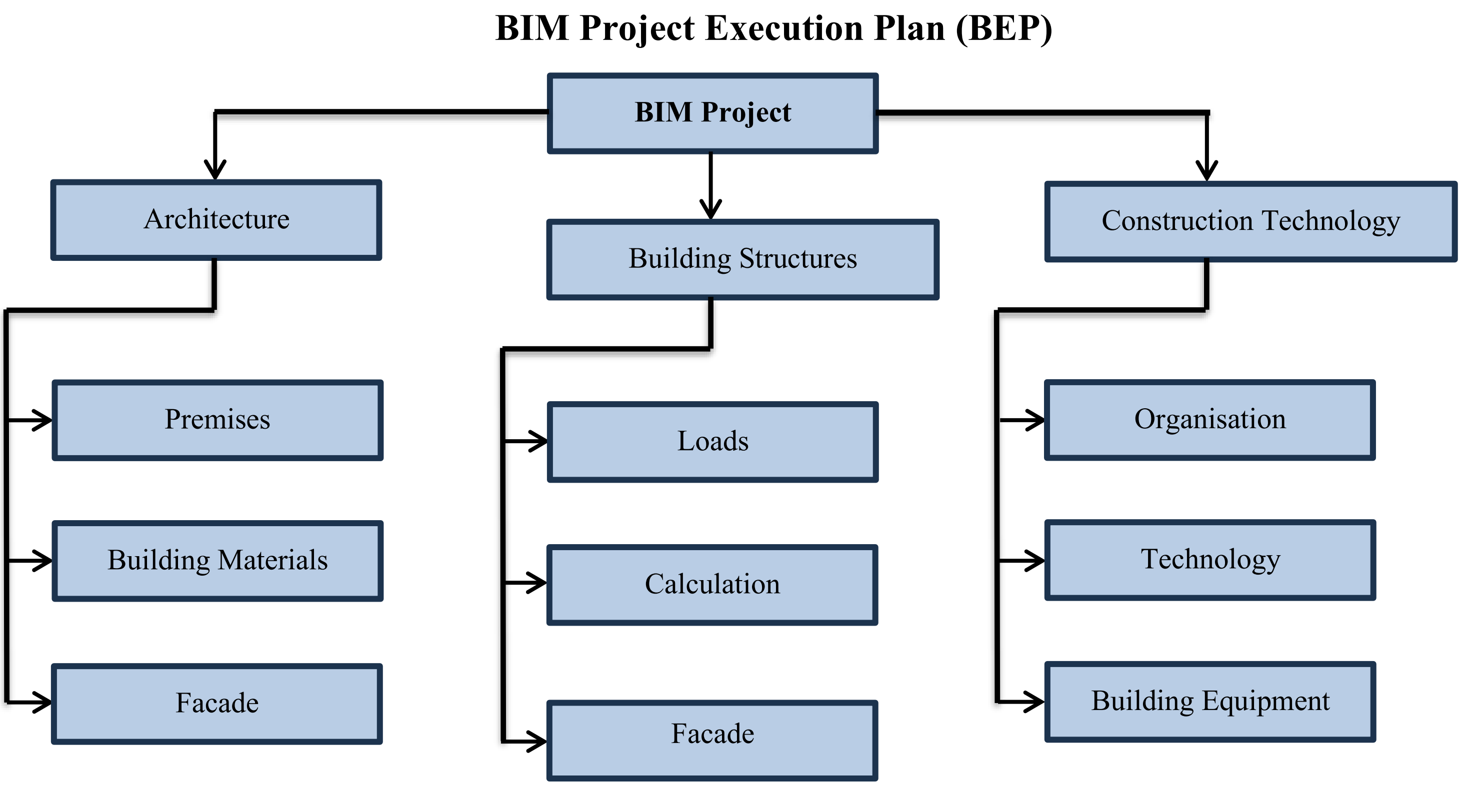


Fig. 3.35 Example of a BEP

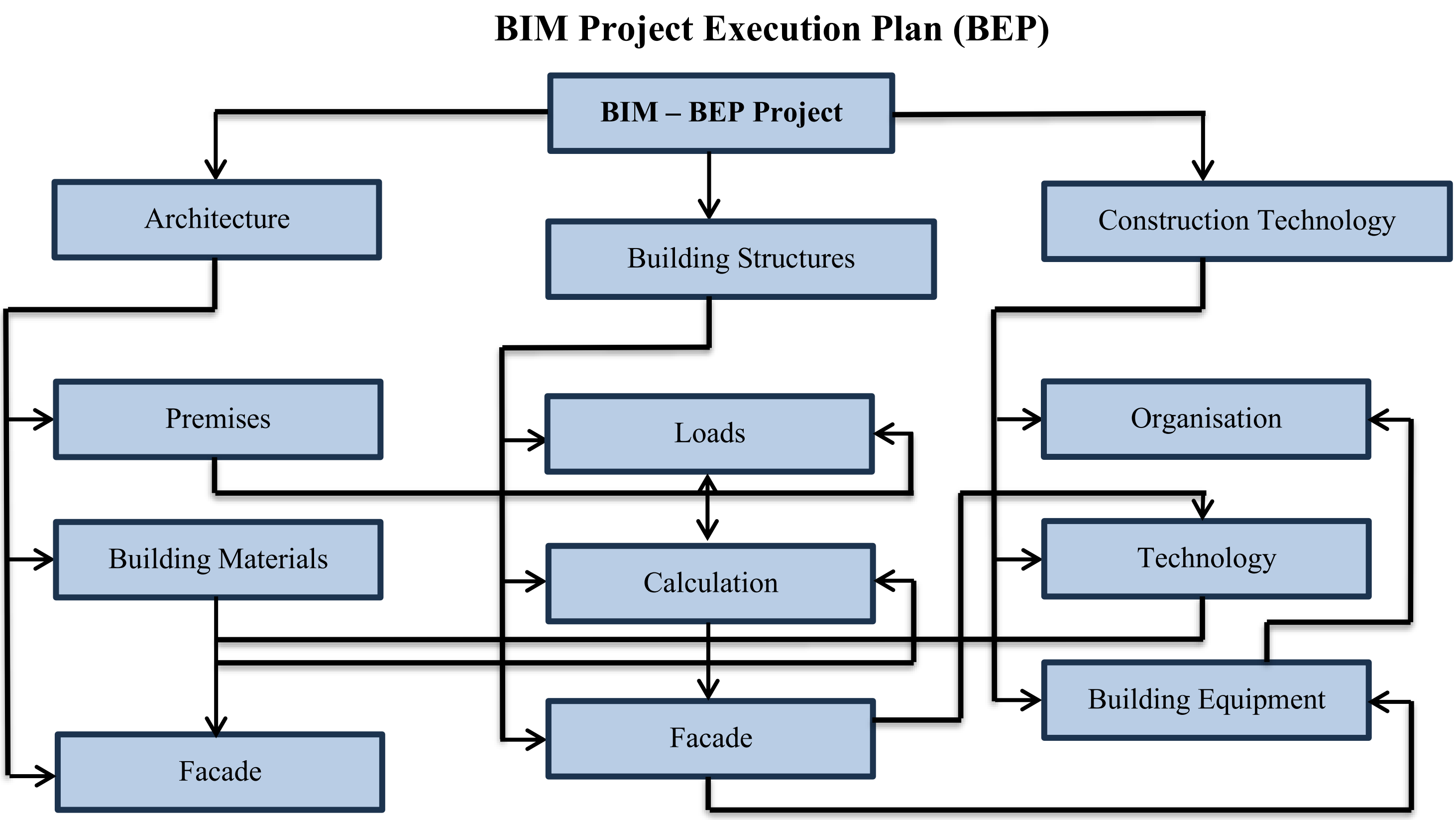


Fig. 3.36 Second Extended Example of a BEP

Figures 3.35 and 3.36 are not static. For example, at the design stage, checks for errors, collisions and duplications can be performed. In this case, the model will be returned to the architect or previous stages for correction. New connections will appear in the diagram. That is, the BEM can vary significantly when implementing different BIM projects [18].

Review questions for Section 3.

1. What are the traditional and innovative organisational forms of construction production?
2. What is the main difference between traditional and innovative forms of construction production organisation?
3. How does the interaction between construction project participants change when transitioning to innovative forms of organisation?
4. What are the advantages of using innovative BIM-based approaches compared to traditional forms of construction organisation?
5. Name the key roles in a BIM project and briefly describe the functional purpose of each.
6. What organisational levels of the team are distinguished in the process of implementing a BIM project? Briefly describe them.
7. What are the characteristics of interaction between BIM team members at different stages of the project life cycle?
8. What is the purpose of the responsibility assignment matrix in a BIM project?
9. What is BEP and what role does it play in the implementation of a BIM project?
10. What information is included in the EIR? Scope of use.
11. What information is included in the PIR? Scope of use.
12. What are MIDP and TIDP? Explain the relationship between them.

CHAPTER 4. MODERN INFORMATION AND COMMUNICATION CONCEPTS OF CONSTRUCTION MANAGEMENT

The traditional organisational (or information and communication) scheme of interaction in construction includes the following main participants: the customer, the designer and the contracting organisations. *The customer* is an investor or other legal (natural) person who, on behalf of the investor, issues orders for design and survey work and construction, concludes agreements (contracts), performs technical supervision, controls the progress of construction, accepts completed work (services), makes calculations and puts the facility into operation. *Designer* – a legal or natural person, regardless of the form of ownership (design institutes, workshops, etc.), who has a licence to develop project documentation or its individual sections and exercises author's supervision over construction. *General contractor (main contractor)* – a construction organisation that performs a complex of works on the construction of an object using its own resources and the resources of specialised organisations involved. All these parties are bound by civil law agreements (contracts) under which they perform the relevant work and defend their own interests. If these interests become a source of conflict between the parties, the flow of production information is disrupted and corresponding losses occur, which can lead to performance disruptions. That is why the latest systems aim to solve the problem of information and communication gaps and consolidate the most important functions within a single structure – the consulting engineer. *A consulting engineer* is a specialised engineering organisation or specialist that provides organisational and advisory support for the design and construction of facilities.

Figure 4.1 shows a diagram of the relationship between the organisational structure and the information environment of an enterprise when implementing information tools [19]. The assumption of such a relationship is based on the following:

- the information environment of an enterprise, namely, the set of software tools and the level of access to them, reflects the production structure and hierarchy of business roles within the enterprise;

- the architecture of the enterprise's information environment must be designed for each individual case, based not only on the specifics of the industry, but also on the specifics of the organizational structure of the enterprise. For example, the architecture of the information environment for project-oriented and functional organizational structures will be different;
- the implementation and effective use of information tools cannot be achieved without a sufficient level of business process organization and changes to the organizational structure [19].

Based on the above-mentioned relationship between the *organizational structure and the information environment* of an enterprise, it can be concluded that during a certain period of time, their implementation will be supplemented and dynamically changed over time. The current level of development of software tools suggests that it is possible to record the indicators of these changes [19]. Among these indicators, the following appear to be the most important:

- indicators of the compliance of the functions actually performed by users with those designed;
- indicators of the speed and quality of transmitted production information: financial and technical;
- indicators of user satisfaction with the functionality of information tools [19].

Thus, it is important to take these indicators into account when implementing information tools, while not forgetting the relationship between the organisational structure and the information environment of the enterprise.

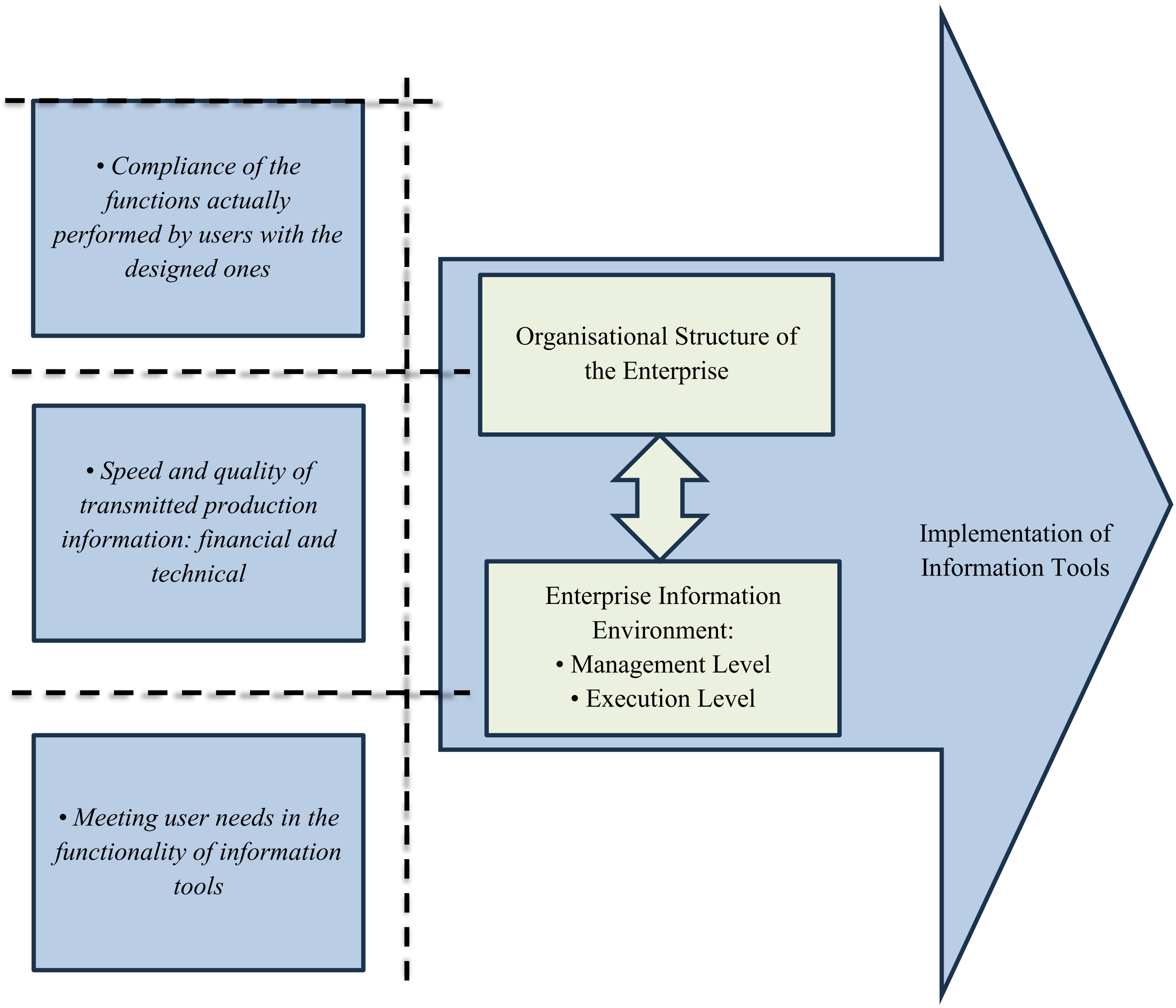


Fig. 4.1 Diagram "Organizational structure ↔ Information environment"
(the left side contains indicators, and the right side contains components of the process of implementing information tools in construction.)

Next, as an example, let us consider one of the modern information and communication concepts – the "construction management template".

Definition of the concept of "construction management template". A construction management template (CMT) *is an information and communication model in the form of a volumetric parametric part of a building or structure and the associated resource schedule of works, which is used to make and monitor planning, design, technological,* *organisational, operational and economic decisions throughout the entire construction project (Fig. 4.2) [19].*

From a business modeling perspective, the construction management template is a component of the business model of the investment and construction process. The following classification of relevant business processes for investment and construction projects can be proposed:

- approval and permitting procedures;
- architectural and structural design processes: preliminary design, permitting stage and working design;
- organizational and technological support (production and technical support; material and technical support; processes of the chief power engineer, mechanic, etc.);
- construction processes – construction management templates;
- sales processes – for example, in the form of a “sales funnel”;
- support and administrative processes (personnel service; security service; legal support; financial and accounting support, etc.).

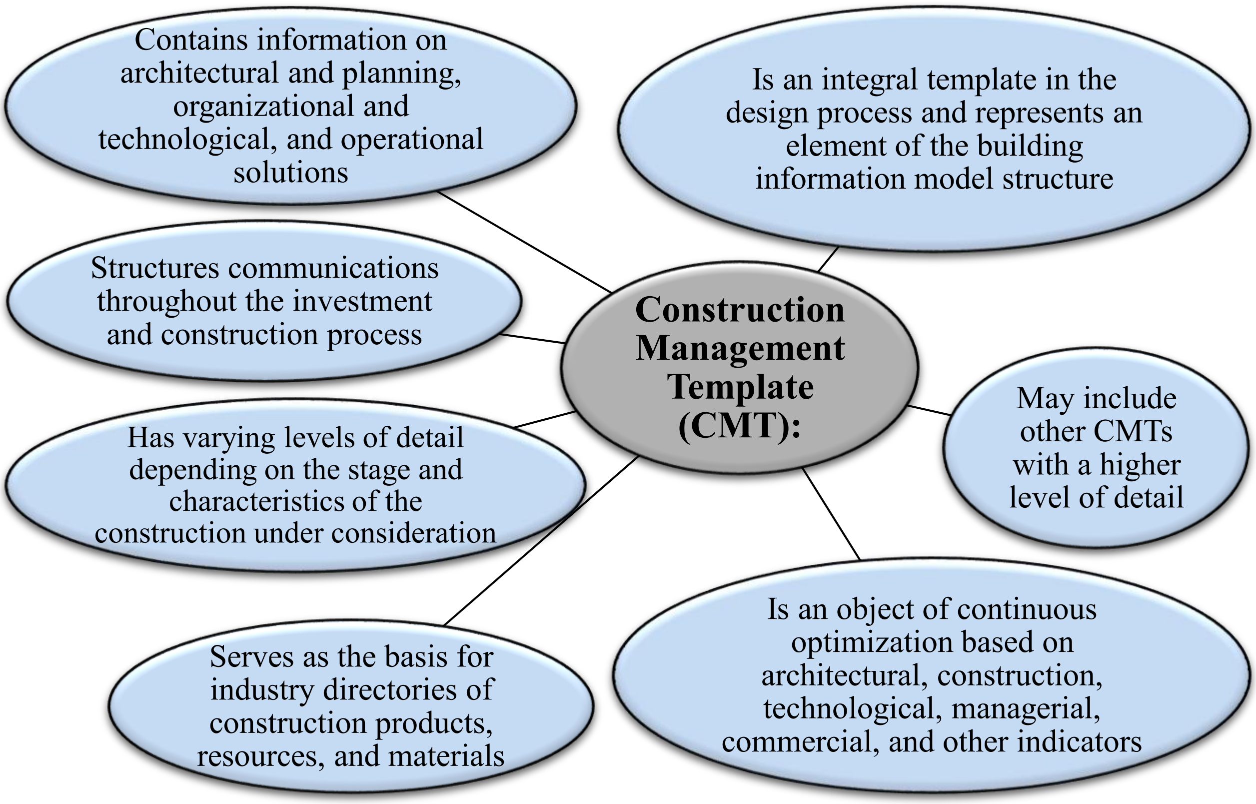


Fig. 4.2 Construction management template as an information and communication tool for management

It should be noted that the decisions included in the BCM are the result of design processes and a model of investment and construction activities. At the same time, the BCM is a task for the organisation and a method of construction control.

According to Figure 4.3, a number of areas of application for the concept of a "construction management template" can be identified: commercial, communication, management, architectural and structural, technological, and operational.

Commercial Application Direction:	CMT represents a model of construction products.
	The use of the CMT allows the assessment of a project's investment attractiveness at any stage of its implementation.
Communication Application Direction:	The CMT is a formalized block that organizes the process of issuing, processing, and receiving production information
	CMTs increase the speed of data logistics and the accuracy of their delivery, thereby reducing communication costs
Managerial Application Direction:	CMT is formed under the influence of the organizational structure of the construction process
	CMT is an element of the construction business model
	CMT is used for task assignment and production control
Architectural and Structural Application Direction:	CMTs reduce labor costs associated with changes and coordination of design solutions while increasing their clarity and visual comprehensibility
	CMTs make it possible to evaluate and enhance the technical, economic, and environmental efficiency of architectural and construction solutions
Technological Application Direction:	CMT formalizes: the method of production, the resources required to create the product, and the requirements for initiation, results, and production culture
	CMTs make it possible to evaluate and improve the technical, economic, and environmental efficiency of the technologies being used
Operational Application Direction:	CMTs display the key operational indicators of the product resulting from investment and construction activities
	CMTs serve as the foundation for the operational model of the facility
	CMTs make it possible to assess and improve the energy efficiency of construction

Fig. 4.3 Using the concept of a "construction management template"

The effectiveness of this concept consists of the following.

From a communications perspective, the preliminary preparation of CMT information blocks facilitates the creation of information and communication models. Unified information blocks reduce the likelihood of data distortion during transmission.

This, in turn, allows for more accurate and faster communications, as well as shifting the control point to the earliest possible time.

From a management perspective, CMT allows for the formalisation of the operational component of the business model. This formalisation reduces the need to focus on administration and production organisation. As a result, the quality of management improves and it becomes possible to pay more attention to leadership and strategy, as well as informal management factors. From an architectural and structural point of view, the use of BIM includes all the advantages of building information modeling, and from a technological point of view, it includes the use of the principles of scientific organisation of labour and management.

From an operational point of view, the combination of architectural, structural and technological components allows the efficiency of investment and construction activities to be calculated for the entire life cycle of a building on the basis of a comprehensive model – a set of BIMs.

More detailed information on modern information and communication technologies (in particular, BIM) can be found in [19].

Review questions for Section 4.

1. What are the advantages and disadvantages of the traditional concept of interaction in construction?
2. How does the relationship between the organisational structure of an enterprise and its information environment affect the implementation of information tools?
3. What indicators are important to record during dynamic changes in the organisational structure and information environment of an enterprise?
4. What is a construction management template (CMT) and what role does it play in business modeling of the investment and construction process?
5. What are the main areas of application of the CMT concept in construction and how does it contribute to improving project efficiency?

CHAPTER 5. USE OF COMMON DATA ENVIRONMENT (CDE) AND OPEN DATA FORMATS (OPENBIM)

Throughout the asset's life cycle, there is a continuous flow of information. *The Common Data Environment (CDE, Common Data Environment)* collects, controls, manages and shares this information (referred to as "metadata" in ISO 19650) everywhere [13].

The CDE is the agreed source of information for any specific project or asset, for collecting, managing and distributing each information container through a managed process [13].

The CDE is the agreed source of information for any project or asset for collecting, managing and distributing each information container (data) through a managed process. The term CDE can be considered both as a set of standards and protocols that regulate the organization, storage and naming of various information containers (data), describe the processes of their exchange and circulation, as well as certain software solutions that provide the technical implementation of such processes [6].

The CDE is a data and information management system. The CDE is not just a web- or cloud-based "database". It contains the necessary processes and rules to ensure that people are working with or using the current version of the file or model and are informed of the purpose for which they may be used. These processes were clearly defined and managed in the paper-based document submission system, but with the adoption of new electronic technologies and the massive increase in the amount of data generated during typical construction projects, the need for quality management has been overlooked and old systems have not been replaced [3].

The principles of CDE are well-defined and described. They are derived from a well-developed project management methodology and have also been adjusted to meet the specific needs of construction projects. Many data management systems have implemented a standard workflow mechanism that allows the process to be efficiently configured and administered [3].

Collaboration between construction project stakeholders and asset management is crucial for effective implementation and operation of facilities. Organisations are increasingly working in new environments to achieve higher quality standards and greater use of existing knowledge and experience. The main component of these environments is the ability to communicate effectively, reuse and exchange data without loss, conflict or misinterpretation. This approach does not require additional work, as this information is always required to be obtained. However, true collaborative work requires mutual understanding and trust within the team and a deeper level of standardised process than before; this information must be produced and made available consistently and in a timely manner. Information requirements must trickle "top-down" until the information becomes most efficient. When it rises upwards (the reverse direction), the information must be as comprehensive as possible. Currently, significant resources are spent on correcting non-standard data, training new personnel in approved data creation methodologies, coordinating subcontractor efforts, and resolving data recreation issues. This is considered waste and can be reduced if the concepts and principles of CDE are adopted at general meetings [3].

Information management throughout the life cycle through a common information environment is part 1 of DSTU 19650 [13].

The transition from file-based project delivery to model-based project delivery has led to changes in work methodology and interaction models between its participants. Models are 10-100 times larger than previous model files, and calculations are performed directly in the models. This has led to new requirements for storage capacity, general file access, and accounting capabilities. Infrastructure, hardware and software requirements are increasing significantly, and software vendors have changed their strategies to meet these new requirements. Cloud solutions increase storage capacity, distribute software and databases (weather and climate data, the Internet of Things, etc.) and interact with projects in multiple companies without the need to open them [13].

Cloud applications belong to software providers and are closely linked to their platform. As a result, the number of data storage locations increases along with the number of applications and their cloud solutions used in the project. Not every program is flexible in terms of formats that suppliers do not have the rights to use, and for many solutions it is impossible to use storage that they cannot fully control. An open format for CDE, the use of open standards and related information applications based on international open standards, through open available "platforms", can help prevent this problem, providing data security and protection, as well as protection against misuse of data [13].

Communication and process management with the main contractor, customer and subcontractors is carried out through the CDE. When managing the design, models are analyzed in comparison with the projects that will be implemented in the production process. The appropriate design solution is then selected. Information about models and drawings is distributed and approved in digital form. Quantitative information is extracted from BIM models for cost management. By following the project schedule through model integration with the work program, site logistics planning, building location and its surroundings, as well as related structures are added weekly and reported along with the developed BIM models. This enables short-term and long-term time and risk analysis. In addition, the customer is provided with information on the planning and progress of the construction project. This ensures effective access to project data and their availability for designers and construction participants [12].

The fact that it can be viewed creates additional value in terms of increasing situational awareness in the project flow, as well as reducing disruptions and risks. Project stakeholders use a hybrid cloud file management system to work with files, while the cloud CDE is used for information exchange and processes [12].

Communication and data exchange in the project is a complex and convoluted process, which means that it must be highly structured. Uncontrolled emails and file sharing between project participants can quickly become chaotic and untraceable. This is not just a matter of cleanliness. At the contract administration stage, the loss of an important message or a reference to an outdated plan can mean a loss of time, additional costs and, in the worst case, can lead to litigation [12].

In the early stages of the project, communication may take place between a small group of organizations: the owner, the project manager and the design or construction company. As the project progresses and specialist consultants join the team, the communication network becomes increasingly complex and cumbersome [12].

Even with a document management system in different offices, there is still a lot of duplication as documents are uploaded to local servers and worked on from there. In any case, email and model servers are parallel domains that are usually not connected to the central document management system [12].

The presence of a centralized virtual project room can solve many communication and data exchange problems. The so-called CDE is a common project domain that manages information exchange, and sometimes it is used to manage the organization [12].

"OpenBIM" is an approach to data exchange based on open standards and workflows. OpenBIM is an initiative of building Smart and several leading software vendors using the building Smart open data model. To date, there are several open formats being developed by building Smart (including IFC, BCF, COBie, etc.) [6].

The concept of *"OpenBIM"* is an approach that involves the use of open formats and protocols, the most suitable and widely used of which is the IFC format. This format has an open specification that is not controlled by any vendor (software developer), but in fact all 44 software systems have the ability to operate with this format - in other words, they support its structure and have the ability to export and import data in IFC format. On the other hand, due to the focus on universal use, there may be discrepancies in the interpretation of data in different software environments, difficulties in their transmission, and slower rates in supporting and implementing new technologies and standards [6].

The use of the OpenBIM approach in the project was a great advantage. Working with OpenBIM allowed using the strengths of different software solutions. Although BIM process management increased the time frame of the project compared to traditional methods, it significantly accelerated implementation on site when it came to the construction stage, minimized contradictions and allowed achieving significant cost savings [12].

Each OpenBIM project has its own working environments. Each design team works in their own software before making the data available in the collaborative environment. Design and construction teams often need to perform quantitative calculations in their native environment. This is generally a simpler, easier and more controlled process than the OpenBIM alternative [12].

In the world of BIM, the most recognized standard for open exchange is the *IFC (Industry Foundation Classes, open data exchange format for BIM, industry base data classes*) format. Although this is an oversimplification, one can say that IFC is the PDF file of BIM. IFC is a copy of the original model, with some limitations. The IFC schema contains the geometry and properties of objects, but it is not intended for editing. It is primarily intended for visualization, analysis and coordination. Instead of editing the model geometry in the IFC file, you need to request changes from the model author. As in the document management described above, the model author makes the requested change in the native model and re-exports the model as a new IFC (Fig. 5.1).

OpenBIM refers to collaborative processes (i.e. data exchange) using neutral and publicly available standards such as IFC (Industry Foundation Classes) and BCF (BIM Collaboration Format) [12].

The term "OpenBIM" exists to distinguish it from proprietary commercial solutions, that is, closed BIM. This distinction is important, but sometimes leads to misunderstandings. The fact is that it is impossible to work in a purely open environment. The model data is almost exclusively created using proprietary software, and then exchanged using an open standard [12].

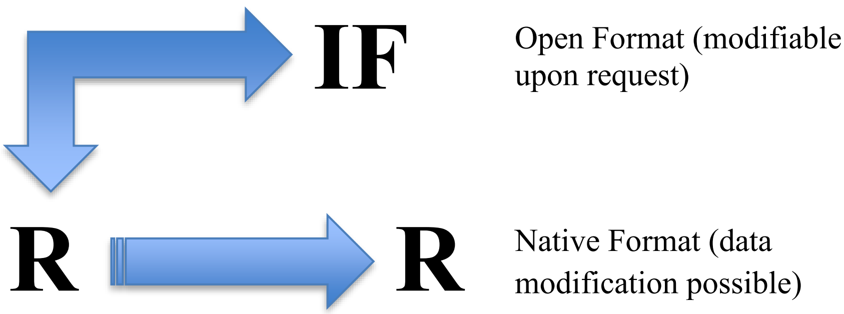


Fig. 5.1 BIM Workflow from Creation to Exchange Using OpenBIM

To speak of modeling as a closed BIM process mostly limits and misleads. At any stage of the project, IFC files can be exported and exchanged, thus initiating an open BIM process. It is more appropriate to call work in proprietary software a native BIM process. If there is an exchange of IFC (or other OpenBIM standards) (Fig. 5.2), then modeling is the very BIM activity in a broader OpenBIM workflow. Only in cases where OpenBIM standards are intentionally excluded, one should talk about a closed BIM workflow [12].

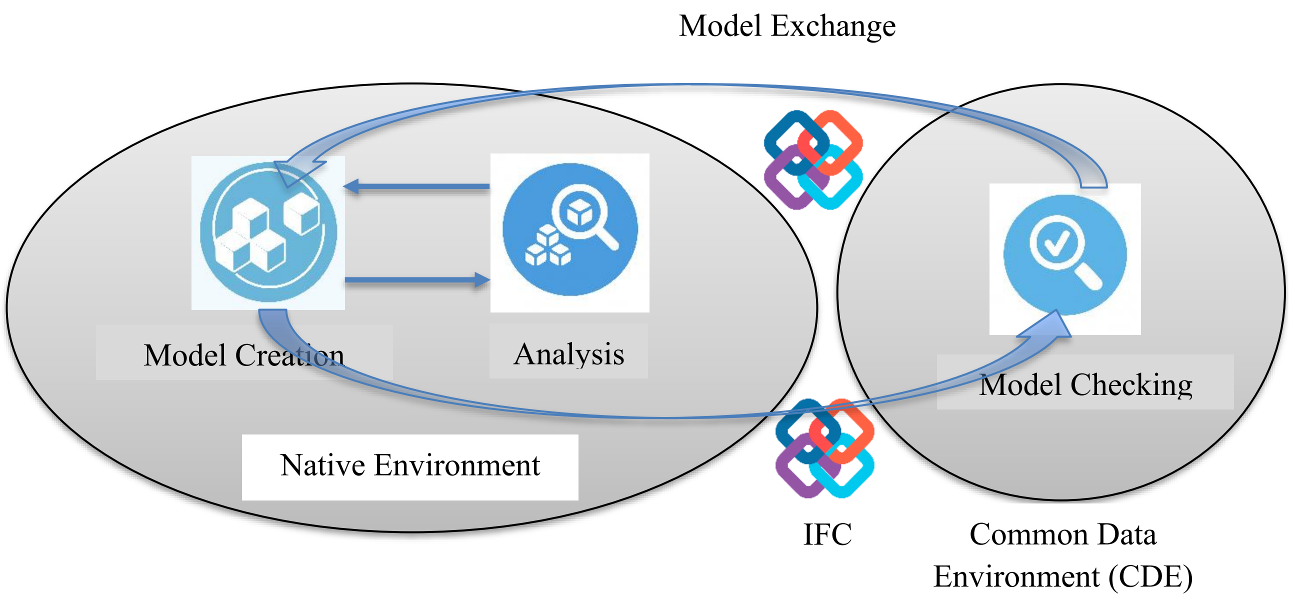


Fig. 5.2 BIM Workflows: Proprietary and Open

Review questions for Section 5.

1. What role does CDE play in ensuring data integrity and effective collaboration between construction project participants?
2. How does the application of OpenBIM standards facilitate data exchange between different software environments in BIM processes?
3. What are the key advantages of using cloud-based CDE platforms compared to traditional document management methods?
4. What are the main challenges encountered when implementing CDE in interdisciplinary teams and how can they be overcome?
5. How does the implementation of OpenBIM impact transparency, version control, and accountability in BIM projects?

SECTION 6. SOFTWARE TOOLS USED IN PROJECT MANAGEMENT USING BIM

The constantly evolving 3D and BIM software can perform tasks related to:

- document management, including revision control;
- workflow, logbooks, audit logs, progress monitoring, cost control;
- integration with corporate systems, e.g. financial data;
- project collaboration, e.g. information exchange via email, PDF files, etc.;
- BIM tools such as viewers, clash detection and code compliance checking, etc. (also supports communication between stakeholders);
- up-to-date information calculations;
- addition of individual graphic and non-graphic information;
- operation and asset management.

Examples of software tools used to implement some of the functions from the list above, specifically the functionality aimed at ensuring the implementation of project management using BIM, are discussed further.

6.1. Main functions and capabilities of project management software

Estimate software complexes can complement or partially implement the functions of construction production management. In particular, this includes:

- formation of tender documentation;
- interaction with project or enterprise management software complexes;
- scheduling and other functions.

The functionality of 7 main estimate software complexes (Table 6.1) [21-29] used in Ukraine has been considered.

Table 6.1

General characteristics of estimate software complexes in Ukraine

Name of the Software Package for Preparing Cost Estimates	Visualization of the Progress of Construction and Installation Works	Additional Features of Estimating Software
AVK-5	*via the IBD format*	***Estimating software that complements or partially implements construction management functions*** *(such as tender documentation preparation, interaction with project or enterprise management software, scheduling, etc.)*
AS-4	*directly in the software and via the IBD format*	
IVK	*via the IBD format*	
Estimate XXI	*via the IBD format*	
Construction Technologies: Estimate 8	*via the IBD format*	
TK-ISSII	*via the IBD format*	
Expert-Estimate	*via the IBD format*	

In the considered estimate and integrated programs, the calendar planning for construction management is implemented on the basis of a single format of estimate data adopted in Ukraine "IDB" (Information Data Block) [21-29].

This format allows exporting data from one estimate program to another, as well as to project management programs such as MS Project, Primavera P6, OpenProj.

Some estimate programs allow exchanging information with enterprise management systems, and performing calendar planning of construction and installation works.

The *AVK-5* software package based on the *"IDB"* data format allows the following [22-24]:

1) Generating estimate and contract documentation.

2) Exchanging information with other software packages that use the IDB data format.

3) Interact with accounting software packages (accounting for actual consumption of inventory and actual cost of work performed).

4) Based on integration with project management software packages (MS Project, Primavera P6 and others), construct schedules.

Identical functions are performed by the *Exspert-Cost estimate, IVK and TK ISSII* software packages [25, 29].

IVK has gained less popularity due to its complexity. Distinctive features of TK ISSII: the ability to draw up estimates not only according to DSTU, but also according to Euro-codes (European standards) [26, 29].

Project management software packages are digital platforms that can be used for project planning, execution and monitoring. With its proper application, it is possible to implement projects within the budget and time constraints.

Project management software packages help project managers and their teams meet investor and/or customer requirements and manage time, budget and scope constraints.

There are many project management software packages on the market. Some of them are discussed below. Traditional software packages, the main purpose of which is planning the implementation of construction projects, are presented in Table 6.2 [30-34].

Table 6.2

General characteristics of traditional project management software packages

Main Functionality	Name of the Software Package
Scheduling, Allocation, and Management of Project Resources	*Primavera P6*
	Microsoft Project
	Openproj
	Gantt Project

Microsoft Project (MS Project) – is one of the most popular and widespread project management programs [31].

Managers using MS Project can monitor the implementation of assigned tasks and properly allocate project resources [32].

The functionality of Microsoft Project allows the following:

1) Develop a plan for the implementation of a construction project (including the project schedule and calculation of the critical path, task linking, linking resource and financial needs, and their distribution over time).
2) Optimize the project plan and monitor its implementation (adjusting the composition of project resources and their optimal distribution, financing schemes, project reserves, task deadlines).
3) Identify problematic project tasks.
4) Create project templates.
5) Analyze the current state and prospects of the project development using reports.
6) The ability to synchronize with the Office 365 system, through which you can instantly distribute all information among the participants.
7) Model any possible solutions (replacement of mechanisms, changes in the supply scheme) and analyze their impact on the project. Which, in the future, allows for more informed decisions regarding the implementation of the project [31, 32].

The popularity of MS Project is explained by a number of undeniable following advantages:

1) Intuitive interface and ease of learning.
2) Flexibility in configuring the program for specific needs.
3) Simple and effective analysis and management of schedules.
4) An interactive step-by-step planning assistant that allows you to quickly master project management processes.
5) A rich set of built-in reference materials, designed for both beginners and project management professionals [31, 32].

PC Primavera P6 provides an environment for interaction among all project participants. Working in this environment, project participants receive information about the projects in which they are involved. Each participant can be sure that the contribution they make to the common cause of project management will not go unnoticed and the information will definitely be received by those to whom it is intended [33, 34].

Primavera P6 PC is a powerful and reliable tool for planning, execution and project management. The product allows managing construction projects of any size and complexity, and offers an unlimited number of resources without restrictions on the number of plans being developed [33].

Primavera P6 has a very wide range of functionality due to the presence of various types of software:

- planning, scheduling and control of large-scale programs and individual projects;
- the ability to connect multiple users to access the system;
- the ability to collaborate project managers to coordinate costs;
- simultaneous opening and scheduling of multiple projects;
- the ability to automatically link information on contracts and resource supply with schedules;
- automation of document management between organizations (approval of documents, obtaining permits, requests, correspondence, etc.), as well as operational reporting from contractors from the sites on the site status, weather conditions, etc.;
- the ability to implement optimal resource allocation and track the current project implementation;
- the ability to integrate with cost management and human resource management systems;
- the presence of project portfolio management: the ability to simultaneously manage multiple projects in the portfolio;
- the ability to manage risks: identification, tracking and elimination of risks before they become problems;
- the ability to generate reports (resource consumption, schedule execution, participant status, etc.) in real time [33, 34].

Advantages and disadvantages of Primavera P6.

Advantages:

- participants can share information and adjust the project from smartphones and tablets;
- the ability to collaborate project managers to coordinate costs;
- the ability to organize projects containing up to 100,000 tasks;
- generation of real-time reports that can be provided on request or schedule.

Disadvantages:

- one of the main disadvantages and low prevalence of Primavera P6 software in the domestic market - high costs for its use (3-12 thousand UAH per year), labor intensity and complexity of mastering the program interface (requires involvement of qualified specialists);
- the bulkiness of the program for small and simple projects [33, 34].

OpenProj ma Gantt Project is an open-free replacement for a commercial product. These PCs are very simple and include only “basic” functions of PM software: Gantt chart construction, resource allocation and some reports.

Disadvantages of most paid PM software:

1) Unjustifiably high labor intensity for use in small projects.
2) Significant financial costs for acquisition or temporary use.
3) Some functions, such as compatibility, interconnection of work must be set manually.

Disadvantages of free PM software:

1) Limited functionality.
2) Limitation of solved tasks.
3) Difficulties or inability to use large projects.
4) Some functions, such as compatibility, interconnection of work must be set manually.

6.2. Main functions and capabilities of software systems used to create new BIM levels. Use of cloud environments

Building Information Modeling (BIM) – is a paradigm of construction activity, in which all stages of the construction process are carried out using a single information model of the object, which includes all types of necessary information (design and estimate documentation, work schedule, supply management, accounting, etc.) [2, 6, 12].

BIM involves creating and using an information model of a construction project. When using BIM, changes made in most PCs are automatically synchronized.

The effectiveness of BIM application, including in the organization of construction, may lie in the possibility of:

- finding the most rational management, design solution at the planning or implementation stage of the construction project;
- minimizing risks, project deadlines and costs by timely detection and elimination of management, technological and financial errors;
- effective (operational) copyright and technical supervision;
- increasing the level and quality of communication with the investor through vivid and visual representation of the progress of the construction project using 4D modeling;
- efficiently operate these structures after construction or reconstruction by setting up automated management systems, technical monitoring tools.

At the moment, BIM software allows implementing the following types of models (Fig. 6.1):

- *3D building model* that allows project documentation control;
- *4D (construction process management) building model* – is a 3D model of the object, considered not only in space, but also in time (the schedule is tied to the elements of the 3D model). It is even possible to view the animated process of step-by-step construction or a video;

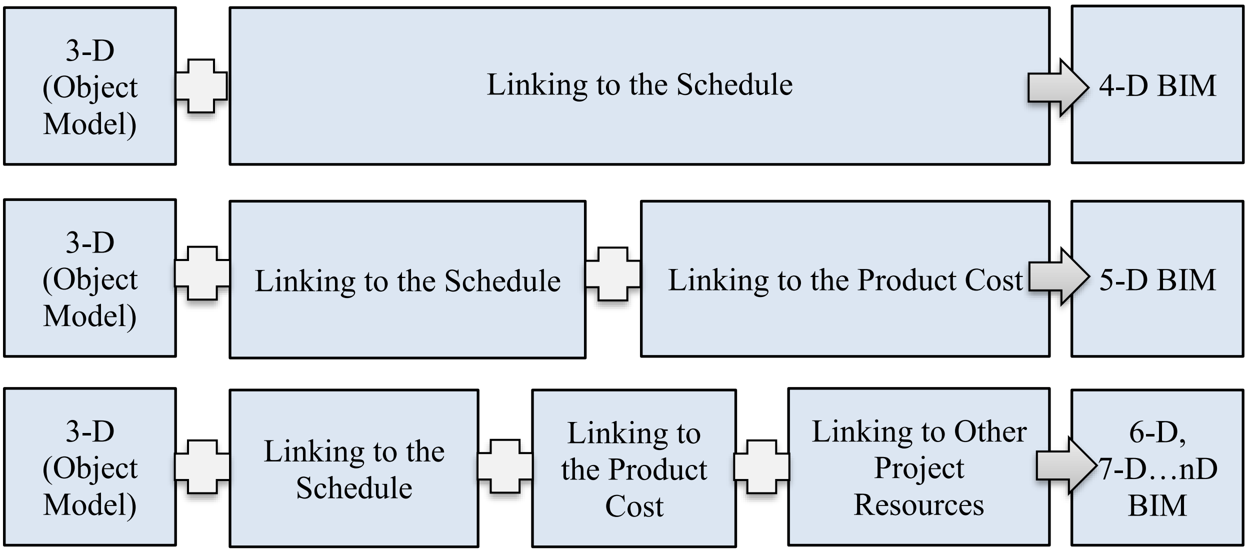


Fig. 6.1 Concept of Creating “New Dimensions” of Building Information Models

- *5D (cost management)* building model is similar to the 4D model: supplemented with the cost of the object’s elements, resources and/or work (product cost);
- *6D, 7D... (building operation model)* – in addition to the construction model, it is filled with data for the process of maintenance and operation of the building according to the "smart building" principle (monitoring and maintenance of communications, calculation of building maintenance costs, etc.). Or this is a link to other aspects of project management (supply schedules, production of building materials, etc.).

4D, 5D, 6D... models help to improve the process of organization and management of construction and operation of the building.

The analysis of some programs (Table 6.3) used to create new BIM dimensions and stakeholder interaction in BIM (BIM clouds) [35-39] is presented below. Among other things, they have project management functionality.

Table 6.3

BIM General characteristics of software complexes used to create new BIM dimensions

Program Name	Development of Architectural and Structural Models	Project Management	Cost Estimates	Integration with Other Software Packages	Capability for Enterprise/Production Management	Additional (or Unique) Features
Allplan	+	+	+	Estimating Systems; SCAD and LIRA	Partially	-
BIM Software Suite by Autodesk	+	+	-	The software suite interacts with its components	-	Environmental Analysis of the Object. Development of 4D Models
Software Suite by Bentley Systems	+	+	-	MS Project, Primavera P3/P6, Revit, AutoCAD, CATIA, ProEngineer, etc.; interaction with each other	-	Project Progress Reports. Development and Monitoring of 5D – 6D Models
Graphisoft ArchiCAD	-	+	-	ArchiCAD	Partially	The BIM model will be stored on the Graphisoft server; TeamWork technology; Building energy calculations

Modul Allplan BIMplus is a centralized open BIM platform for a construction project. The Allplan Bimplus collaboration platform allows comprehensive and efficient coordination of project teams, contractors, and provides full oversight of the BIM model. Thanks to Bimplus, project inaccuracies can be quickly identified, and tasks can then be promptly distributed among the employees and partners involved in the project [36].

Bimplus provides the ability to store, share and visualize the construction information developed within the organization. Bimplus is a cloud service for every specialist included in the project team, including the design, construction, or facility management process. It consolidates all information about a specific object, providing tools for visualization, sharing, and interacting with 3D object models and 2D drawings from anywhere in the world, at any time of day, using a tablet, laptop, or computer [36].

Bimplus improves and accelerates interaction with owners, managers, or contractors, ensuring consistency of information for all participants in the process.

Navisworks PC – coordination, integration, and consistency checking of all parts of the project created in different programs [37]. In addition, it is possible to visualize the construction process in the form of a 4D model.

When working on a project, information can be quickly transferred from one program to another (e.g., from Revit to Navisworks). Thus, universal specialists receive a good set of tools for independent work with its complex sections. Navisworks also solves the tasks of organizing the construction production of the object [37].

The main task of Navisworks is the integration and joint analysis of different (performed in different programs, for example, using the Revit PC) parts of the project. At this (unifying) stage, errors and misalignments are detected, project data exchange between the participants of the work, as well as some joint actions on the project as a whole (for example, visualization) [37].

The Navisworks program creates 4D models (Figure 6.2) (monitoring in space with observance of the time mode) of the building construction process and logistics, which clearly reflect the progress of the project and help avoid overlaps and downtime, allowing to assess the practical implementation of the construction, restoration or demolition of a building or its individual parts [37].

It should be noted that the 4D model in Navisworks is not interactive (dynamic). Its editing directly in Navisworks is limited. Any significant editing of the schedule (linked to the 3D model in Navisworks) is performed in an external PC (e.g., in MS Project). After that, the edited schedule for the construction project is re-imported into Navisworks and re-linked to the 3D model.

The program consists of three modules.

1) Navisworks Manage – calculation, modeling and coordination of project data, checking for intersections and collisions.
2) Navisworks Simulate – comprehensive 4D simulation, animation and obtaining photorealistic images of the assembled project, real-time navigation combined with model verification tools.
3) Navisworks Freedom – a free viewer application that allows sharing data with all project participants [37].

Synchro Pro from Bentley Systems allows creating and modifying multi-dimensional BIM [38].

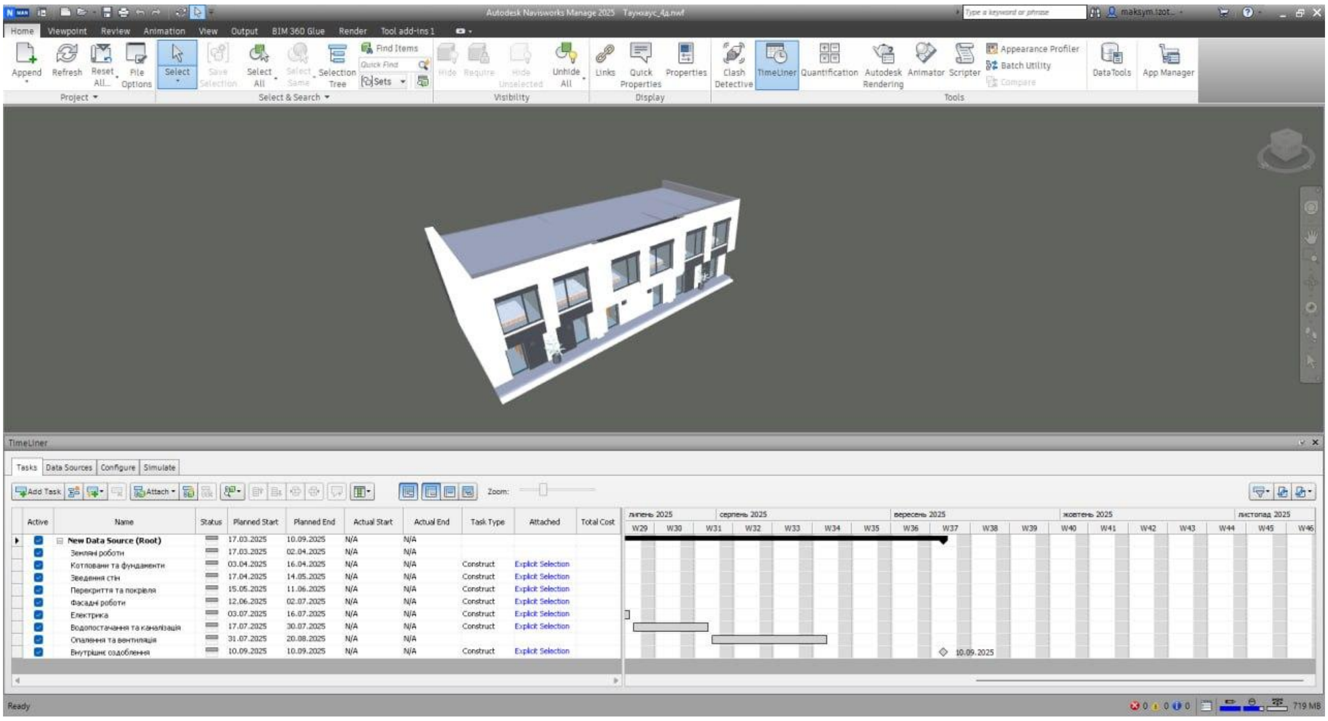


Fig. 6.2 Example of a 4D Model Construction Animation Fragment Displayed in Navisworks Software

The advantages of the Bentley Systems software suite compared to traditional project management software are as follows:

1) Associativity between architectural elements for rapid changes in the project.

2) Review and manage collisions in multi-file documents using Bentley Interference Manager.
3) Generate project progress reports using Bentley Navigator and project management applications such as Microsoft Project or Primavera P3.

The limitations of the software suite from Bentley Systems are as follows:

1) The need to purchase a number of programs for integrated projects (usually undertaken by large architectural and construction companies).
2) The high cost of the software.

Synchro Pro is an environment that combines project resource (including time) alignment solutions and 3-D object models [38].

The main tasks solved using Synchro Pro are as follows:

1) Visual comparison of various organizational and technological solutions, and even comparison with the actual plan.
2) Visualization of stream design.
3) Checking for spatial and temporal conflicts [38].

During the construction stage, Synchro Pro allows quickly navigating the project, understanding the project status, and comparing it to the current situation.

4D model is created by linking 3D model elements to the schedule. It is much easier for the project manager to analyze the 4D model than the calendar-network schedule [35, 38], as a 4D model is an animation of the construction process from the fence to commissioning.

Unlike Navisworks, the 4D model in Synchro Pro is interactive (dynamic). The 4D model in Synchro Pro can be actively changed and optimized. That is, the 4D model in Synchro Pro is a live planning tool. The key feature of Synchro Pro is the ability to fully edit the schedule directly in the 4D model environment, without the need to export/import changes each time.

In addition to the 4D model, Synchro Pro can create 5D and/or 6D models. This allows making changes, monitoring, and aligning the 4D model with costs and material supply schedules [35, 38].

The advantages of Synchro Pro are as follows:

1) The ability to optimize the project planning process by visually showing the construction process.

2) Works with a variety of 3D model formats and scheduling programs.

3) The ability to change and optimize the 4D model during the implementation of the construction project.

The disadvantages of Synchro Pro are as follows:

1) The program has some shortcomings due to lack of user testing.

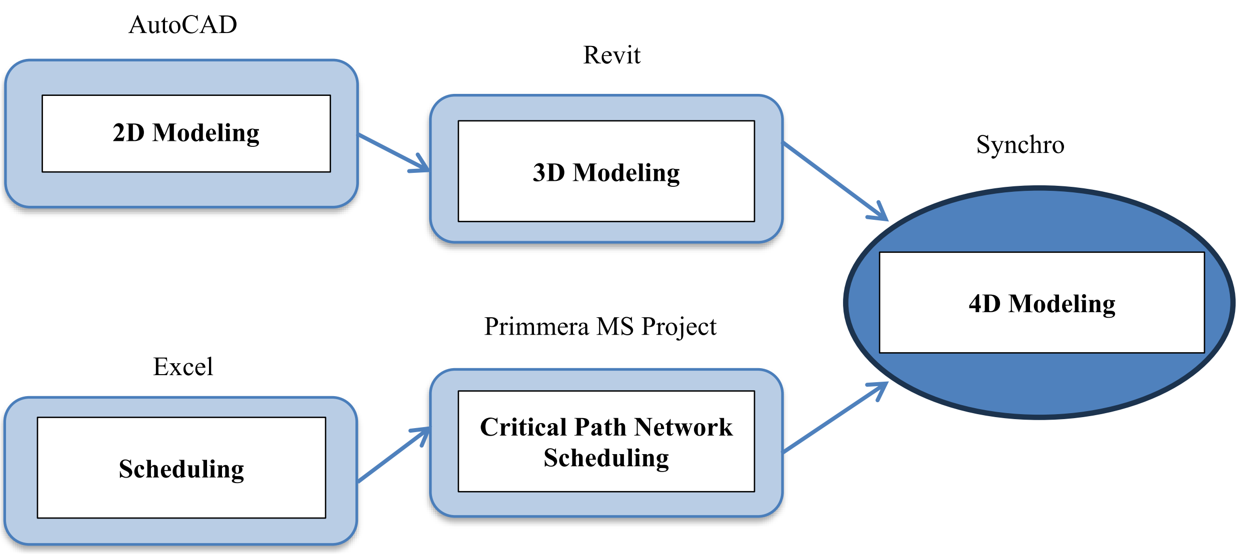


Fig. 6.3 Concept of Synchro Pro Operation

2) The program has some shortcomings due to lack of user testing.

3) High price (around $4,500/year).

4) High system requirements.

The concept of the Synchro Pro operation is shown in Figure 6.3.

By adding cost estimation and other programs (accounting for product costs), you can also create a 5D model, but this will incur additional costs. The figure shows the need to acquire a number of programs [38].

Example of a 4D model animation fragment performed in Synchro Pro is shown in Figure 6.4.

The latest example is a PC that can be used in project management with the use of BIM. Specifically, the *BIM cloud from Graphisoft ArchiCAD* [39] has been considered.

The BIM cloud is a collaborative design tool in ArchiCAD. The BIM cloud places a strong emphasis on the collaborative work of architects on a common project. In this approach, the overall model is stored on a dedicated server, called the BIM server. To synchronize the work, only the changes are sent to the server, not the entire project.

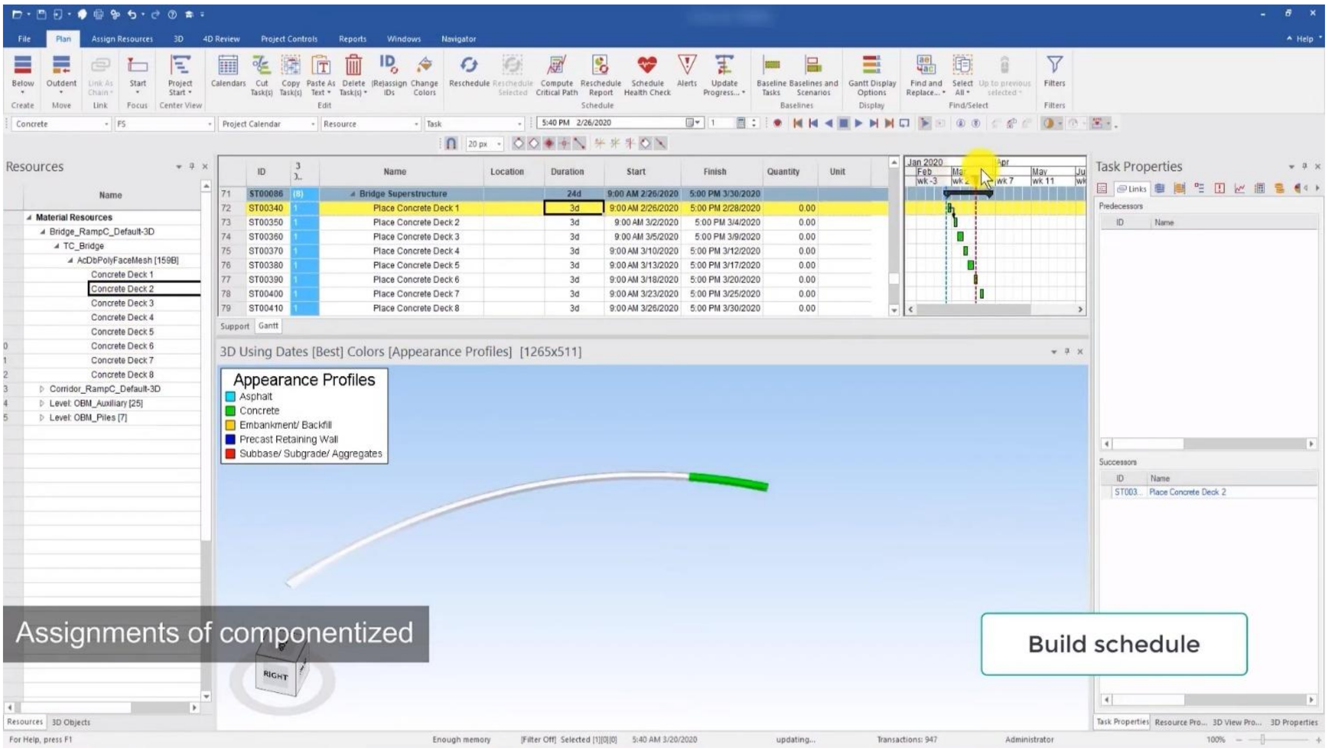


Fig. 6.4 Example of a 4D Animation Model Fragment in Synchro Pro (the sequential change of the building's 3D model from the fence installation to the commissioning stage is linked to the work schedule)

This minimizes the load on the network and allows synchronizing the data on the developing object both within the office and over the Internet in real-time [39].

ArchiCAD is used to transfer data in the IFC format, which enables collaborative design. The collaborative work of the contractor team is ensured using the Integrated Project Delivery (IPD) technology [39].

Industry Foundation Classes (IFC) is an open specification data format that is not controlled by any company or group of companies. The file format was developed by the international building Smart organization to facilitate interaction in the construction industry. It is used as a format for the Building Information Model (BIM) [2, 3, 12].

Figure 6.5 clearly shows the principle of interaction between different team members when working on a single object using the software package under consideration [39].

Figure 6.6 clearly shows the principle of interaction between different team members when working on a single object using the software package under consideration [39].

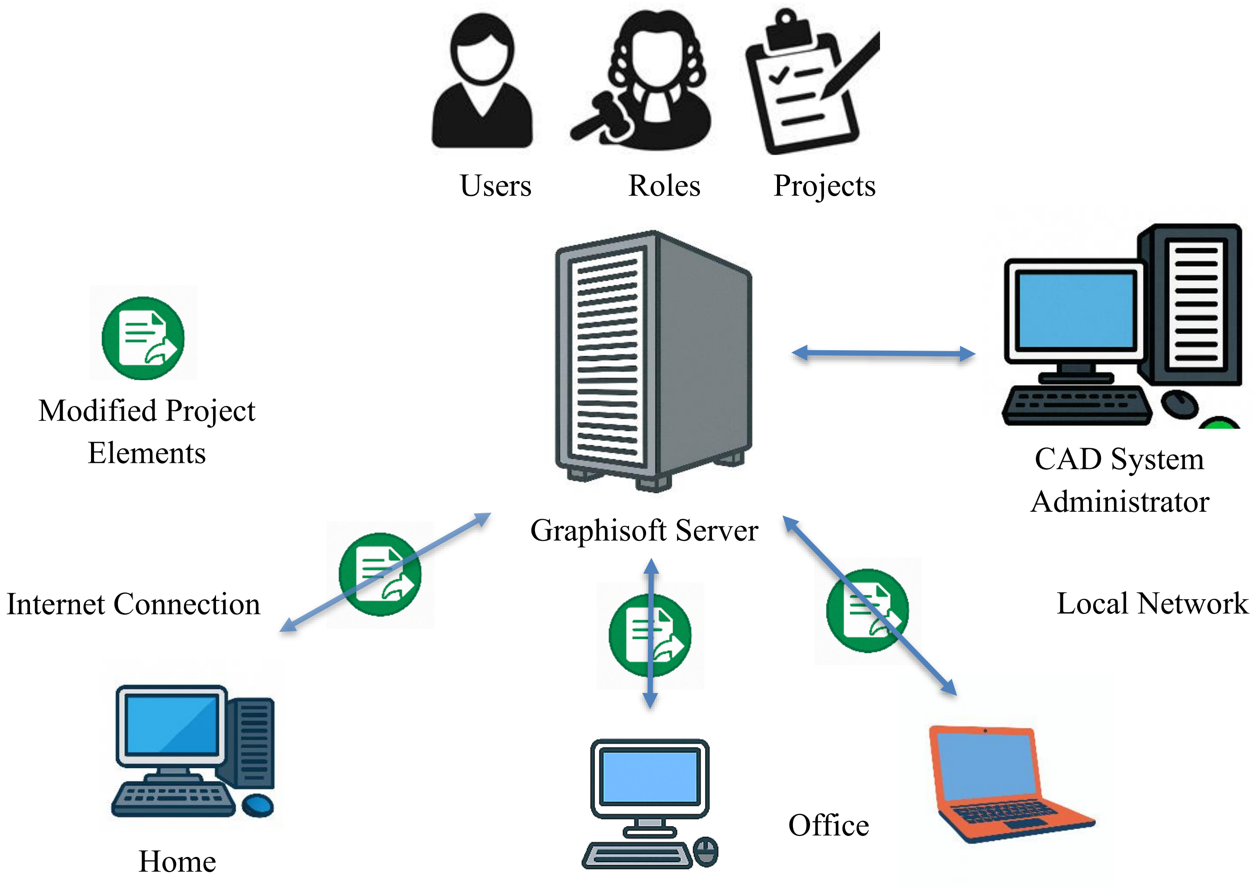


Fig. 6.5 Interaction of Participants via Graphisoft ArchiCAD: BIMcloud

BIMx for Archicad – this is an innovative interactive tool for architects who need modern methods of interaction and presentation of their projects. Any person – a customer, consultant, or builder – can now literally “immerse” themselves in the architectural project: a user-friendly three-dimensional environment [39].

BIMx is based on technology that provides simultaneous navigation through 2D documentation and 3D building models. This unique technology allows access from mobile devices even to very complex BIM models containing large volumes of 2D documentation [39].

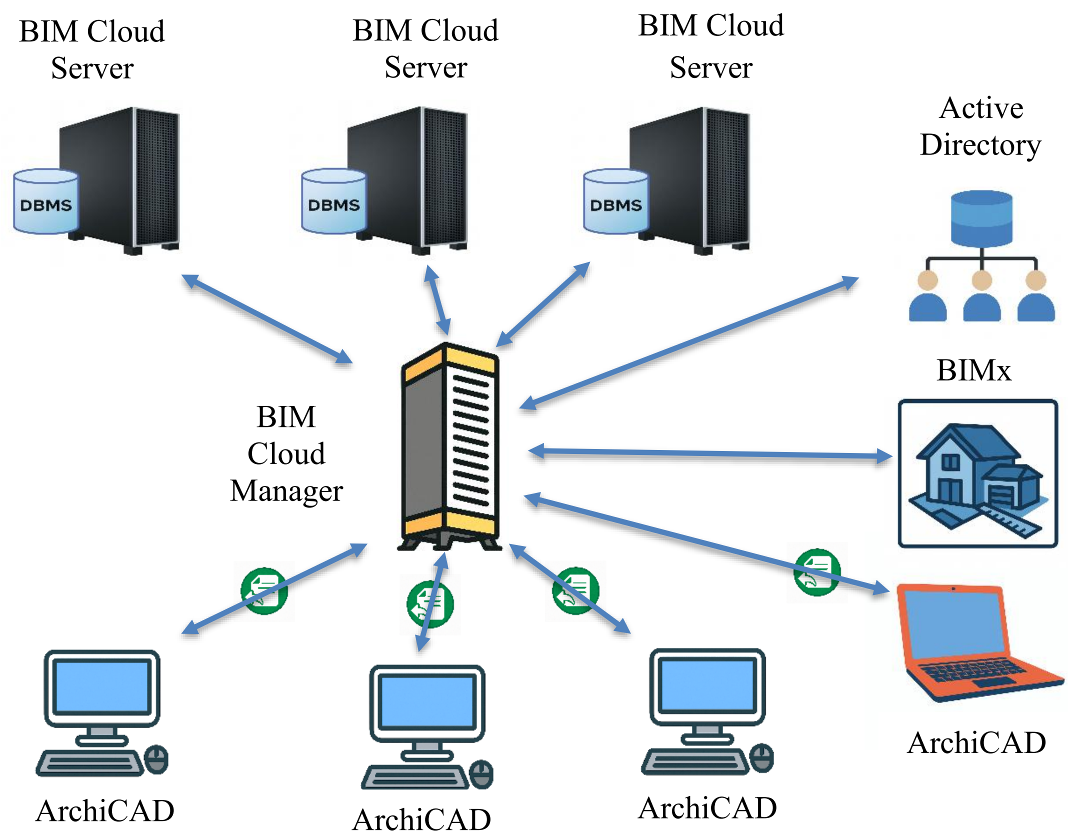


Fig. 6.6 Interaction of Participants via Graphisoft ArchiCAD: BIMcloud

6.3. TeamWork systems. Management systems for construction companies and construction project portfolios

TeamWork systems are systems for teamwork using BIM.

- TeamWork systems are systems for team collaboration using BIM.
- The cloud environments discussed in section 6.2 of the lecture notes partially implement the functions of TeamWork systems. In particular, these are ALLPLAN BIMPlus and Graphisoft ArchiCAD: BIM cloud. The basis for interaction between project participants in the cloud is the constantly evolving TeamWork technology. It allows a group of designers to work simultaneously with a single model [36, 39].
- However, for less complex projects, it is important to be able to use specialized online tools that enable teamwork. They are collectively referred to as

"TeamWork systems." One example of such a system is the Basecamp software [40].

- Basecamp is an online tool (service) for project management, collaboration, and task assignment within projects, featuring a simplified interface. It is essentially a task manager [40].
- Basecamp provides users with the following capabilities:
- view general information about clients and projects on a single screen;
- using the chat room to discuss the project;
- use a message board for announcements and notices;
- assigning and tracking tasks;
- using forums to discuss tasks and projects;
- maintaining the schedule and managing key project milestones;
- tracking time spent;
- adding messages and comments [40].

Basecamp is compatible with many applications, widgets (a widget is a compact application that performs a single function (e.g. clock, calendar, message exchange, or player), and other programs. Despite its widespread popularity, Basecamp is considered insufficiently adapted for managing complex and long-term projects, as well as for use in large companies [40].

For analyzing indicators and managing project portfolios, it is possible to use [8, 12, 41]. A "project portfolio" is understood as a set of several projects. For example, a project portfolio may include the construction of a residential complex that consists of:

- project for the construction of a residential building;
- infrastructure construction project;
- school construction project and other projects.

Such software products as *HP Project Portfolio Management (HP PPM)* allow management to determine the importance of a particular project based on objective data, assess the prospects for their implementation, and, considering resource requirements, select the most priority projects.

HP PPM helps manage dependencies, allocate time and resources for the development of shared components for different projects, and create a “roadmap” of new developments for the next one and a half years.

HP PPM is a platform for automating key processes for managing project portfolios and individual projects in large organizations under strict time, resource, and financial constraints. The main feature of the HP PPM solution is the ability to flexibly configure system objects to fully meet the tasks in hand [41].

HP PPM software enables you to:

- identify the organization’s most important projects, track project progress, and monitor the implementation of the portfolio as a whole in real time (including change management, risk management, task management, etc.), make timely adjustments, etc.;
- visually analyze and prioritize strategic and operational requirements and requests, form projects and tasks based on them, allocating resources;
- quickly adapt to changes and ensure that the company’s business processes and projects align with the established strategic and operational goals;
- efficiently distribute the workload among the organization’s employees, which in turn allows maximum attention to be given to the highest-priority tasks, as well as provides a clear understanding of current resource utilization and enables planning for future needs;
- automate the organization’s portfolio management processes (project initiatives, business goals, business case approval, etc.);
- automate the processes of managing the enterprise’s project activities (portfolio and project formation, resource management, etc.) [41].

Figure 6.7 shows the concept of project portfolio management using HP Project Portfolio Management [41].

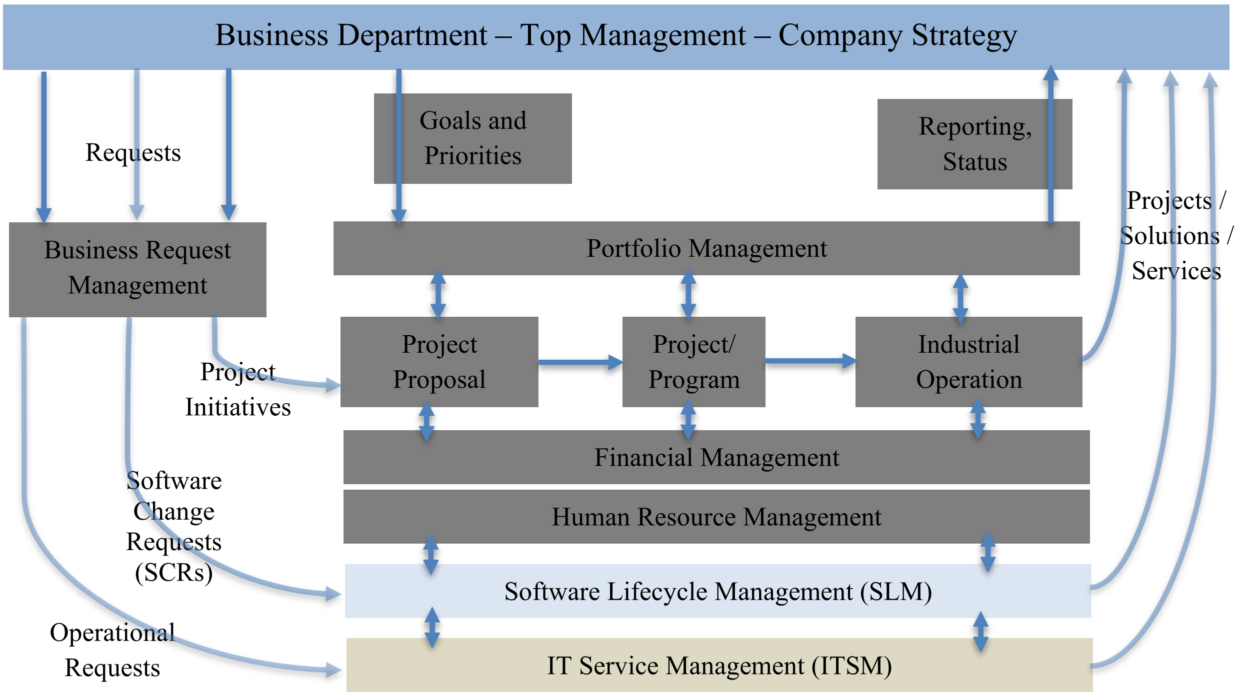


Fig. 6.7 Concept of Project Portfolio Management Using HP Project Portfolio Management

Figure 6.7 shows the automation of the project portfolio management process – several projects. The portfolio management system is designed to solve the following tasks:

- automation of the organization's portfolio management process: collection of project initiatives, their ranking, linking to the organization's business goals, coordination of business cases, "alignment" of the portfolio with the available budget and resources, taking into account current project and operational activities;
- automation of the organization's project management processes: formation of portfolios, programs, and projects; management of project resources; monitoring of key performance indicators (KPIs) during the implementation of construction projects/programs; generation and delivery of management reports on the organization's project activities in real time;
- automation of resource management processes: creation and maintenance of resource pools; management of resource qualification directories; individual resource calendars; support for the process of allocating resources to projects;

subsystem for recording the working day (both project and operational activities) [41].

The HP PPM system is modular and supports the implementation of portfolio management processes in an organization both “top-down” and “bottom-up.” It also supports the execution of individual functions–such as program/project management, resource management, and project proposals–with the possibility of further expanding functionality and covering related functions and processes [41].

The main feature of the HP PPM solution is the ability to flexibly configure system objects to fully meet the specified tasks. Each HP PPM object has its own attributes, workflow, and lifecycle. These capabilities ensure a well-organized work process and effective interaction among all participants, as well as the implementation and monitoring of any performance or efficiency parameters within this process [41].

HP PPM allows you to visually analyze the relationship between current risks and portfolio value; minimum and total resource and financial costs of the project portfolio; and much more. In other words, it is basically information about the project portfolio and how the projects interact with each other, which can be used for management and planning purposes [41].

However, it is very important *to be able to manage* not only a construction project, but also a *construction organization*. There is a range of specialized software for this purpose. Let is consider the example of Building Manager [42].

The Building Manager feature allows you to:

- exchange data with architectural design software, construction cost estimation programs compliant with State Building Norms, accounting programmes, enterprise management systems, and office applications (Construction Technologies – Cost Estimate, MS Project, Primavera P3);
- to generate a list of works directly from a 3D model (from CAD systems InteAr4.x, ArchiCad, Arto);
- to calculate estimate documentation and to develop scheduling plans (including consolidated projects for more than 200 sites), financing schedules, material (equipment) supply schedules, and workforce movement schedules;

- to visualize the construction schedule for each day in a 4D model;
- to prepare both commercial estimates and works integrated with cost estimation software in accordance with State Standards of Ukraine / State Building Norms standards;
- to carry out operational accounting of work progress with automatic visualization of schedules; financing and expenditure of funds; delivery of materials and equipment, with the generation of work completion certificates and material write-off forms – integrated with accounting software;
- allows the manager, including in real time, to monitor the work of various company departments using the “BmMonitor” module [42].

Review questions for Section 6.

1. What are the main functions performed by cost estimation software packages in the field of construction management?
2. What capabilities does the Microsoft Project software package provide for planning and controlling construction projects?
3. What are the advantages and disadvantages of the Primavera P6 software package for managing construction projects?
4. What are the main functions and advantages of BIM models with new dimensions (4D, 5D, 6D, etc.) in construction?
5. Which software packages are used to create new dimensions of BIM, and what do they provide in the project management process?
6. What are the features and advantages of the Allplan BIMplus platform for coordinating the actions of participants in a construction project?
7. How does BIM cloud technology in Graphisoft ArchiCAD improve collaborative work on a construction project?
8. What are TeamWork systems, and what is their main function in collaborative project work?
9. What capabilities does the online tool Basecamp provide?

10. Why is Basecamp considered insufficiently suitable for managing complex and long-term projects?
11. What is a project portfolio?
12. What are the main functions performed by the HP Project Portfolio Management (HP PPM) software?
13. What advantages does the use of the Building Manager software package provide?

7. SPECIAL INFORMATION TECHNOLOGIES USED IN PROJECT MANAGEMENT WITH BIM APPLICATION

7.1. Augmented, mixed and virtual reality technologies (AR, MR and VR) integrated with BIM software complexes

Augmented reality (Fig. 7.1, a) – is a technology that supplements the image of the real world with virtual objects [43-45].

Using augmented reality (AR), we look at the world not directly, but through a certain "filter" that embeds virtual objects into the real world as if they were really there [43-45].

Most often, a smartphone or tablet is used as a "filter" for AR. A less common method is AR on large screens: it is usually used in shopping malls, at bus stops as part of advertising campaigns, etc. [46].

The screen becomes either a "window" in which, in addition to the back side, additional objects are shown, or a "television" showing the audience and virtual objects nearby [43].

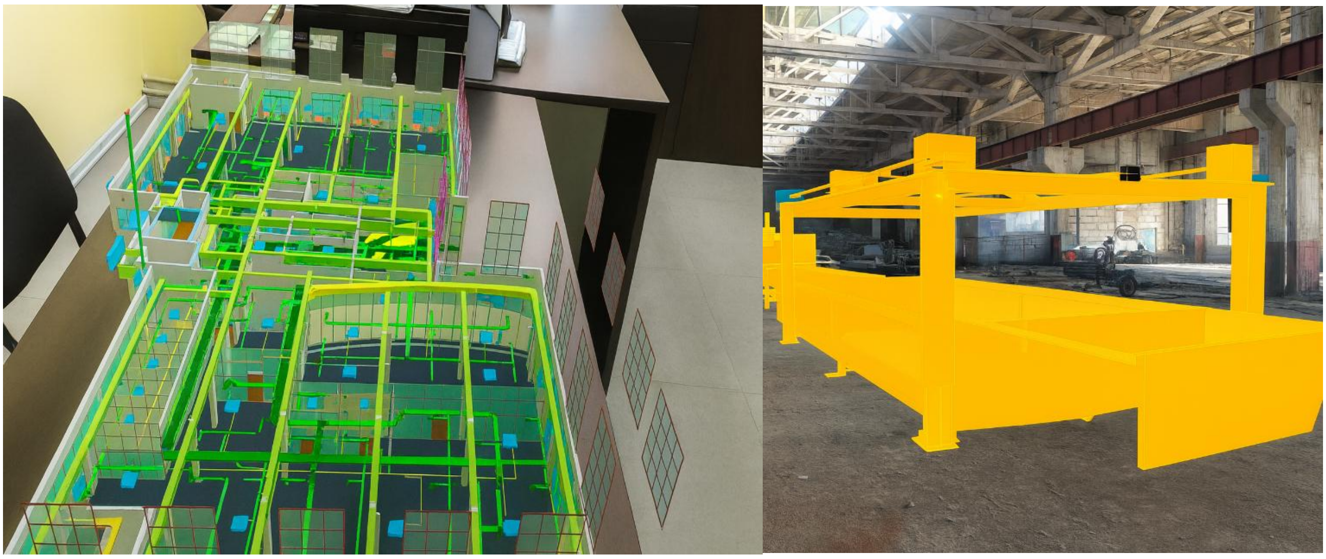
A rarer "filter" – augmented reality glasses [43].

Mixed reality (Fig. 7.1, b), sometimes referred to as hybrid reality, is the result of combining the real and virtual worlds to create new environments and visualizations, where physical and digital objects coexist and interact in real time [43, 44, 47].

The main difference between MR and AR is that these technologies allow you to interact with digital objects in augmented reality (AR) [43, 44, 47].

A huge advantage of mixed reality (MR) technologies is the ability to project images invisible to the human eye, for example, illuminating a structure behind an iron panel [44, 47].

Using the *Unity Reflect* program, it is possible to create special augmented (AR) and mixed (MR) reality programs, the interface of which can include information about construction stages, construction deadlines, information and links to working documentation, the possibilities are generally unlimited and allow you to cover a wide range of necessary information using programming. The only aspect is that there will be changes in the staff, where programmers will play a significant role in organizing the company's work [46, 47].



a) b)

Fig. 7.1 Examples of using augmented and mixed realities: a) – augmented reality using a tablet; b) – mixed reality using a smartphone (when clicking on the elements of an object, it is possible to interact with it – take notes, change properties)

Mixed reality (MR) and augmented reality (AR) technology has a big future in construction. It is not just about the benefits such as increased efficiency, shorter construction project timelines and lower costs. As the global workforce becomes less skilled and projects become more complex, MR and AR could eventually form a more sophisticated interaction model where workers are shown exactly where to place elements – without the need to consult documentation [44, 46, 47].

Currently, there are already objects that have been constructed using these technologies. In the future, this technology will be improved and will allow most large companies to use it to its full potential.

Virtual reality (VR) is simulations created using virtual reality headsets [44-47].

Virtual reality (VR) involves complete immersion of a person in an artificially created environment, unlike augmented reality (AR), which provides virtual elements in the form of overlays or 3D objects of the real world [47].

Virtual reality (VR) in construction is the next level in 3D modeling. But unlike 3D modeling, it places the user directly in the virtual environment, and the user experiences complete immersion in the virtual space [46-47].

The possibilities that virtual reality (VR) opens up are as follows: [46-47].

1) VR meetings. Virtual reality is a convenient tool for discussing any important issues related to the model, regardless of where the team members are while jointly reviewing the model.
2) Presentations in VR. This can be a VR tour for potential apartment buyers, which allows them to see the layout, design, view from the windows of the future apartment, compare finishing options, or, for example, a concept presentation for clients of construction companies.
3) Real-time VR construction site tours. By combining VR technology with a 3D camera that records 360-degree video in real time, any participant can be given access to remotely walk through a construction site to observe the construction process.
4) VR simulators (Fig. 7.2). VR simulators allow you to transfer a person to a space that copies the real situation and circumstances, for training in regular, non-regular, emergency situations. VR simulators with full immersion are an excellent tool that allows you to develop and form skills.

An example of a PC for virtual reality is *Iris* VR. This program provides direct integration with Navisworks, Revit, Rhino, SketchUp [46-47].

After synchronizing a project in Iris, VR, it becomes possible to add other participants for a joint review of the project, which is one of the main purposes of this platform - making decisions in virtual reality mode regardless of the location of the participants [46-47].

Insite VR provides direct integration with Navisworks, Revit, BIM360, SketchUp. The platform can be used both through the program on your computer and through a web browser [46-47].

Fig. 7.2 An example of the use of VR for training. The American CM Labs presented a virtual simulator for crane operators. It gives young workers the opportunity to get acquainted with the machines before trying their hand at real conditions. The simulator has received approval from the New York Department of Buildings

Currently, the program provides most of the features when opening a model in VR with BIM360 which is a cloud data storage [46-47].

In addition to the 2 programs considered for using virtual reality technology, there are a number of similar programs, such as RevizTo (viewing model data in VR and solving project tasks), Autodesk Live (visualization in VR of a project created in Revit PC), The Wild (Virtual meetings, education, project discussion with Revit in VR, etc.), Enscape (virtual walks around the object) and others [44-47].

7.2. Internet of Things (IoT), drones, robotics and artificial intelligence

Robots can replace humans in routine construction tasks, and can also be used to monitor progress and safety regulations. Their use increases work productivity and worker safety. [43].

Figure 7.3 shows a test run of a *robot dog* from the engineering company Boston Dynamics on a construction site. The robot is integrated with a control PC and scanners and can be controlled using a controller. It can walk in difficult conditions (ladders, outdoors, etc.). Various cameras and scanners can be installed on this robot. The robot can be left overnight, and in the morning it can automatically make a detour to the object and scan it. When personnel arrive at the site, snapshots of its condition are ready for project management [48-52].

Fig. 7.3 Testing a construction site robot dog from the engineering company Boston Dynamics

Drones (Fig. 7.4) monitor sites using cameras from above. In addition, multicopter delivery vehicles are used to reduce the load on the site by vehicles. Finally, special drones have been developed for the demolition of building elements after the project is completed [50].

The use of drones has proven its effectiveness in the field of construction, architecture and urban infrastructure. Unmanned aerial vehicles (drones) are successfully used for topographical surveying of areas for future development, monitoring the construction process and tracking the stages of work, creating 3D models of buildings when planning restoration work, identifying dangerous areas and other needs. Using a PC, drone images can be visualized in 3-D [50].

Fig. 7.4 Using drones on a construction site

Internet of Things (IoT) technologies (Fig. 7.5) allow monitoring of construction site activities through sensors. They collect data and can then be processed using AI* (artificial intelligence). This allows monitoring of large-scale projects, reducing time and costs. [48, 49, 51, 52].

In addition, IoT helps reduce risks and prevent traumatic events. For example, if construction workers wear sensors on their clothes, they can track their movement through dangerous zones, as well as the content of harmful substances in the air. Sensors on materials can detect violations of storage rules, emergency conditions, etc. For example, the “smart” soles of the American company SolePower Work Boot track the user’s movements, record falls or tension in the legs, and also provide lighting when moving in dark places [48, 49, 51, 52].

Fig. 7.5 “Smart” soles from SolePowerWork Boot, USA

The possibilities of the Internet of Things (IoT) technology are as follows: [48, 49, 51, 52].

1) Increased productivity. Companies often operate multiple projects in different locations, and it is important to monitor the lifecycles of each and meet deadlines. Sensors collect data on the construction site, then this data is processed using special programs and gives the contractor a picture of the working situation. Technology helps control large-scale projects, reducing the time and cost of solving tasks.

2) Safety/security. The problem of injuries and deaths in modern construction is still relevant. IoT can significantly reduce risks and prevent traumatic incidents. Sensors on construction workers’ clothing, sensors on the site, sensors in building materials track the movement of people through zones, harmful substances in the air, violations of storage rules, emergency conditions, etc. Sensors on building materials can also prevent theft.

3) Resource management. IoT can optimize the costs of maintaining a facility and supplying resources. Smart sensors can help track electricity, water or fuel consumption and optimize this expense item. Data is collected automatically and an unbiased result is given: when it is necessary to replenish stocks or carry out preventive maintenance,

replacement or repair. Allows you to identify problems with excessive water, electricity consumption, etc.

A study by the MCKinseyGlobal Institute, which assessed the impact of the Internet of Things on the construction and mining industries, found that business owners could save more than $160 billion by implementing IoT. [43, 48, 49].

The potential of the "Internet of Things" will only be revealed in construction in the coming years, as we await the global digitalization of the construction industry.

Artificial Intelligence (AI) is a technology that imitates human cognitive functions: solving tasks and problems, recognizing images, objects, and learning. There is also a special area of AI - Machine Learning, it is built on the collection of statistical data, on the basis of which conclusions and inferences are drawn. [48-53].

New construction technologies will not do without machine learning and AI. In fact, it is an invisible assistant that analyzes terabytes of data, finding problems. This can be both a routine filtering of unnecessary information, and vice versa, searching for specific data [53].

The functions provided by the use of AI are as follows: [48, 49, 53].

1) Predictive Analytics:
- forecasting safety threats based on historical data;
- recognizing critical attributes and elements on the construction site;
- monitoring site area, number of workers, and use of personal protective equipment (PPE).

2) Project Planning and Design:
- budget control using collected or simulated data;
- tracking and mitigating risks, identifying priorities.

3) Robotic Mechanisms and Process Automation:
- performing routine, simple, but labor-intensive construction tasks, replacing manual labor;
- optimizing operations requiring high productivity.

The combined use of Internet of Things (IoT) technology and artificial intelligence (AI): sensor inspectors [52].

Construction companies hire safety experts to prevent accidents. However, there is a shortage of such specialists on the market, and their services are not cheap. The American company Smartvid.io has revolutionised the solution of safety issues at construction sites with the help of machine vision. Thanks to its self-learning AI (artificial intelligence), it uses cameras to monitor safety compliance round-the-clock and alerts when it detects violations – from workers without helmets to scaffolding or stairs without guardrails [52, 53].

7.3. Working with data array (BigData). Digital twins

Big Data refers to various facts, data, and information not only from people, but also from various sensors, systems, and programmes – and together with AI (artificial intelligence) and IoT (Internet of Things), this data becomes a powerful management tool [53-56].

For example, the use of Big Data allows you to identify patterns of change in weather or climatic conditions at the planned construction site to calculate the best time to start construction. Big data analysis also provides forecasts on the feasibility of certain jobs, costs, etc. An example of BigData is the BIM 360ProjectIQ cloud service, which contains a knowledge base of 20 million questions and answers related to construction tasks. Only AI can analyse such a large amount of data as quickly as possible [56].

Technologies developed by companies such as Smartvid.io will enable competent management of big data and more informed decisions in construction management based on competent analytics. In 2017, Boston-based technology start-up Smartvid.io raised $7 million in its first round of investment. It set itself the ambitious goal of developing a platform for intelligent analysis of photos and videos from construction sites. Smartvid.io has implemented machine learning technologies for analytics into its platform, as it would take a person much longer to process such a volume of data. By recognising the images it receives, the system can indicate whether protective equipment has been worn and whether scaffolding and safety systems have been installed correctly. The technology highlights areas in the photo where something is wrong and needs to be corrected to improve work safety. You can upload photos and videos to the Smartvid.io platform, any number of images from any device – drones, GoPro cameras, mobile phones and tablets. Data processing takes place in the cloud, and the results can be viewed on a smartphone. Such analytics help prevent risks and reduce the possibility of incidents on construction sites [53, 56].

Digital twins are digital representations of real objects or systems. To explain it more simply, this is the connection between a real-world object and its digital representation using data from sensors. A more detailed definition could be as follows: a digital twin is a software analogue of a physical device that simulates the internal processes, technical characteristics and behaviour of a real object under the influence of interference and the environment [54, 55].

An important feature of a digital twin is that information from sensors on a real device operating in parallel is used to apply input influences on it. BIM (except for 4-6D models) is static, while a digital twin is in a state of gradual dynamics – it changes over time [54].

Digital twins make it possible to test various scenarios and threats – the impact of natural disasters, various emergencies – fires or the collapse of an element – using simulation. Based on BIM, a digital twin can “test” the embedded information by integrating various blocks of information [54].

The digital twin’s prediction function is one of its main features. Potential problems or, conversely, a precise understanding that the object will be able to withstand the predicted loads allows builders to avoid unnecessary expenses and optimise processes and make adjustments at an early stage. If an air conditioning system needs repair, a technician can use a digital twin not only to locate the fault on a smartphone or tablet, but also to fix the problem more effectively using the data obtained from the twin. Building owners can send digital twins to contractors, who can create their own models based on this data [54].

If we add information about the current state of the object to BIM, we can obtain the following types of digital twins:

- at the construction stage – the actual process of erection the object and decisions that were not included in the initial project;
- at the operational stage – data for the current state and changes in structures after the commissioning of a facility, for the installed equipment and its condition, for the status of sensors and smart devices [54, 55].

An example of a digital twin in action is the SODISBuilding system (Fig. 7.6). It analyses and stores data in real time, with access from anywhere in the world via the internet. The SODISBuilding platform combines controlled elements (building structures, security systems, engineering systems), configurable sensors and monitoring parameters, large amounts of data and algorithms for processing them, visualisation technologies and BIM building. This approach minimises the involvement of technical specialists in the monitoring process. SODISBuilding supports data collection from sensors manufactured by leading global manufacturers of measuring equipment. It provides continuous monitoring [54, 55].

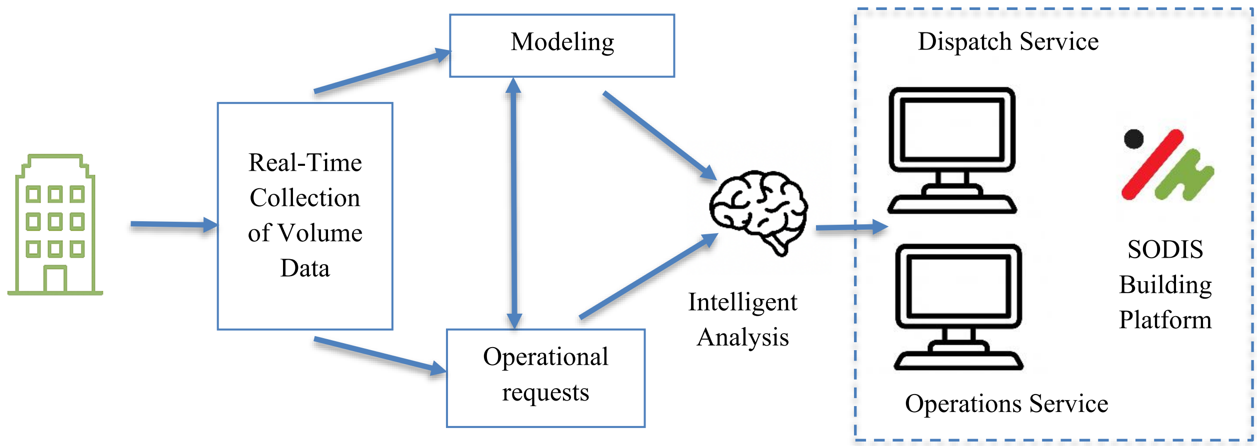


Fig. 7.6 General diagram of the operation of a digital twin of a building or structure using the SODISBuilding platform

Sometimes, “digital twins” are seen as a new stage in the development of BIM modeling, which can be used for the most complex and large-scale projects. However, in the future, it will be possible to remotely or even autonomously control objects, the physical analogues of twins. All thanks to the Internet of Things (IoT) and AI: a digital twin of a building will be able to collect data and use it to respond to incidents without human intervention – and such a scenario is becoming a reality, not fiction. However, there is an important difference between BIM technologies and “digital twins”: the latter help not during the construction phase, but during the operation of the facility [53, 54].

According to estimates by Markets and Markets, the global market for digital twins was worth $3.8 billion last year, and by 2025 it could reach $35.8 billion. However, in our country, the emphasis is currently on information modeling, and it is not yet known when its technological “successor” (digital twin) will become widespread. [53, 54, 55].

Review questions for Section 7.

1. What are the main differences between augmented reality (AR) and mixed reality (MR) technologies in the context of their application in BIM project management?
2. How does virtual reality (VR) technology help improve teamwork and decision-making in construction projects?
3. What opportunities does Unity Reflect offer for integrating AR and MR technologies into construction projects?
4. How VR simulators can be used to train employees in the construction industry, and what advantages they offer over traditional methods?
5. What functions do drones and robots perform on construction sites?
6. How does Internet of Things (IoT) technology help reduce actual costs, increase productivity and improve safety in construction projects?
7. What are the main functions of artificial intelligence (AI) in construction, particularly in combination with IoT, and how do they help in risk prediction?
8. How do Big Data and artificial intelligence (AI) technologies contribute to the optimisation of construction project management, particularly through the analysis of large data sets?
9. What is a digital twin, and how does its use differ from a static BIM model during the construction and operation phases?
10. What opportunities does the SODISBuilding platform offer for working with digital twins, and how does it minimise the involvement of technical specialists in monitoring?

SECTION 8. OPTIMISATION OF CONSTRUCTION SOLUTIONS USING MODERN SOFTWARE TOOLS

8.1. Methodology and software tools for multi-criteria analysis for selecting effective construction solutions

The methodology for multi-criteria analysis of construction solutions [57-59] was developed at the Odessa State Academy of Civil Engineering and Architecture. It allows for the analysis of the effectiveness of construction solutions. In particular, structural and technological, organisational, managerial, financial and others.

After realization a multi-criteria analysis, construction solutions are usually optimised. Maximum efficiency is achieved in this way.

The general provisions of multi-criteria analysis are as follows [57-59].

1) First of all, it is necessary to identify which of the many known solutions are subject to comparison.
2) The next step is to select the most effective solutions using the multi-criteria analysis method.
3) To make a choice, it is necessary to compare the most common traditional solutions and known innovations. The term "innovations" refers to both completely new and non-traditional solutions that are rarely used.

The algorithm of the multi-criteria analysis method is shown in Figure 8.1. [57-59].

At the beginning of a multi-criteria analysis, a search and/or development of solutions for comparison is performed. To accomplish this task, information sources are analysed. Next, the decisions to be compared are identified, described, and their advantages and disadvantages are noted; evaluation criteria are selected and their quantitative and qualitative assessments are obtained. After determining the qualitative and quantitative assessments of the decisions and converting them into a single point scale, the data obtained are included in "summary tables" in the MS Excel software package. Next, using the MS Excel "PivotChart" function, charts are constructed and analysed from the data array of the “summary tables”. This determines the levels of effectiveness of each of the compared solutions. The charts are analysed by grouping, sorting and ranking the solutions according to various criteria. The next and final step of the methodology is to implement and unambiguously select the most effective solution with a step-by-step justification. The exclusion of solutions must be consistent and internally consistent [59].

More details on the multi-criteria analysis methodology, which is performed using modern PCs, can be found in [57-59].

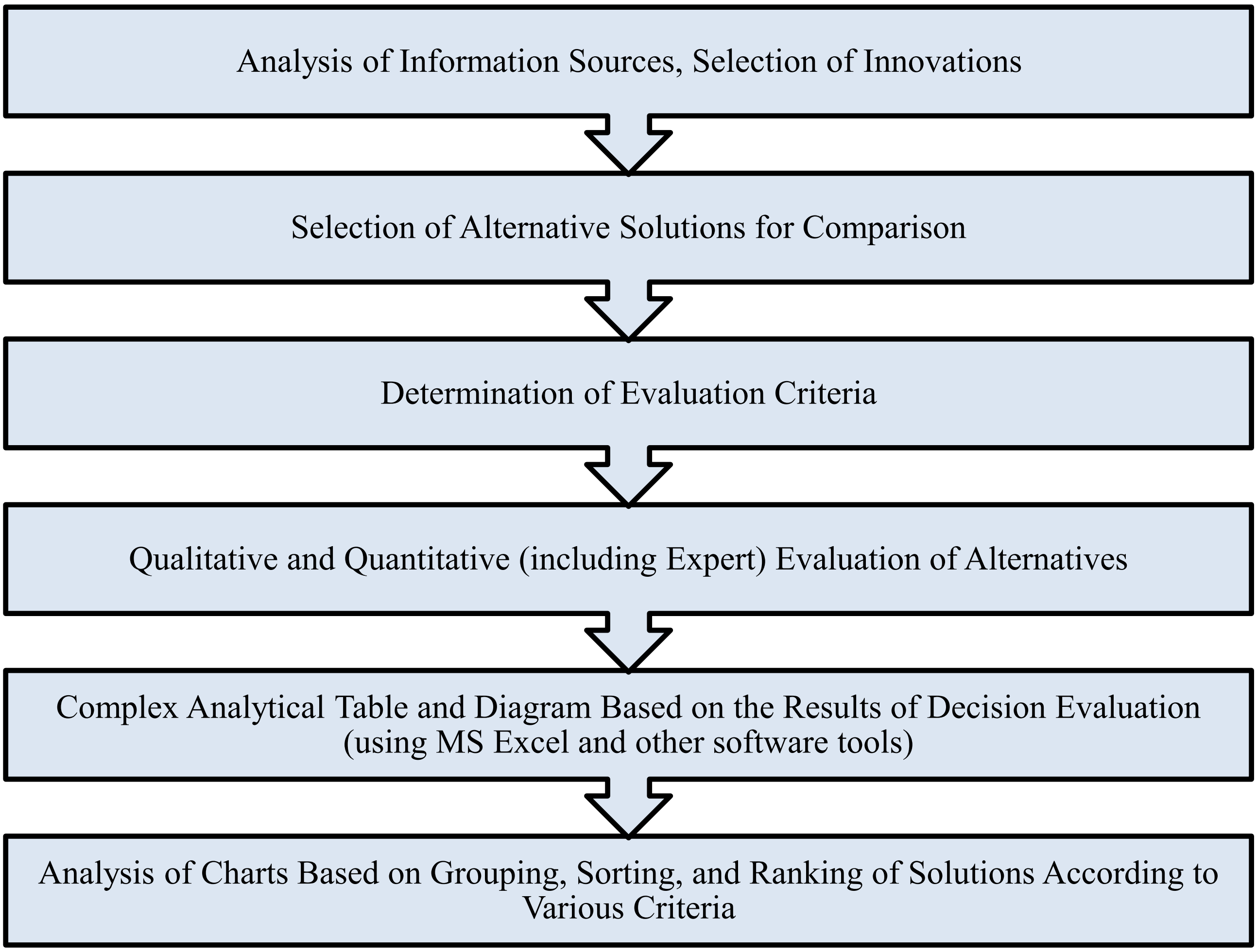


Fig. 8.1 Algorithm of the multi-criteria analysis method

8.2. Methodology for optimising management decisions in construction, considering existing constraints

Experimental statistical modeling (ESM) methods are used for optimisation. [59-62].

It is implemented in the CompEx2009.01, MATLAB, Design–Expert software package or other similar PC software [59-62].

The following software packages are most commonly used to optimise organisational, technological and management decisions:

- MS Project (calendar planning, project management);
- AVC 5 (cost estimate documentation);
- Autodesk AutoCAD (drawings);
- MS Office software packages.

When optimising (modeling) other construction solutions, other specialised software packages may be used.

A characteristic feature of construction process management is the multiplicity of solutions. The choice of an effective solution is complicated by the rapid development of construction technologies and methods of construction organisation. The problem of taking into account the multiplicity of solutions is solved by constructing various models. A model is an abstract representation of the most influential properties, processes, and relationships of real systems. A model is an imagined vision of an object, constructed to simplify its study [59].

It is possible to determine the optimal values of performance indicators by constructing a certain number of models (for example, cost estimates and organisational and technological models). Models are created using specialised software packages (for example, AVC 5, MS Project) in accordance with the selected experimental plan. Information models are divided into descriptive, tabular, and hierarchical. Tabular and graphical models are the most useful for determining optimal construction solutions. The main graphical models are linear graphs, cyclograms, and network graphs [59].

The choice of software for modeling is made taking into account the specifics of the research and the possibilities of its use on a given object to solve the tasks in hand. For example, the following specialised software packages are used to create graphical models: MS Project, Primavera P6, etc. [59].

To optimise (Fig. 8.2) organisational and technological performance indicators, the required number of models is constructed in one of the project management programmes (e.g., MS Project) according to the selected experimental plans. These models reflect many aspects of mathematical statistics and experimental design theory.

It is possible to determine the analytical and graphical dependencies of the obtained efficiency indicators on the varied factors using the experimental and statistical modeling technique, for example, in the CompEx 2009.01 software package. Using the theory of experimental design, the constructed cost estimates and graphical models are implemented and studied, i.e., a computational experiment is performed. Such an experiment is performed using experimental statistical modeling. It allows the following tasks to be solved:

- minimising the expenditure of intellectual, time and material resources in the search for the desired engineering result;
- increasing the reliability and informativeness of experimental research;
- improving product quality and competitiveness, searching for ways to save resources while ensuring the required quality indicators [59-62].

The following can be considered as existing constraints: maximum funding amounts and/or construction project implementation deadlines; maximum and minimum number of workers and/or mechanisms (equipment); financing methods and intensity, etc.

As a result of analysing the dependencies obtained, it is possible to find the optimal values of recovery indicators and the corresponding combinations of factors. The process of searching for optimal values of performance indicators may include imposing existing restrictions on the dependencies obtained in order to take into account the characteristics of the processes being modelled [59].

***1.** Development and analysis of design and estimate documentation or an investment project, and determination of initial data for optimization research*

***2.** Selection of the most significant indicators and the factors influencing them*

***3.** Development of construction solution models in accordance with the designed experimental plan using one of the project management software tools (MS Project, Primavera P6, or others)*

***4.** Development of experimental–statistical models showing the dependence of indicators on the studied factors using specialized software (CompEx2009.01, MATLAB, Design-Expert, or others)*

***5.** Graphical interpretation and quantitative analysis of the obtained results*

***6.** Introduction of Active Constraints. Optimization of Solutions Considering These Constraints*

***7.** Managerial decision-making and its formalization in a form suitable for practical implementation (for example, through the development of a 4D–6D model)*

Fig. 8.2 Algorithm for optimisation using BIM

More details on the methodology for optimising construction solutions using modern PCs can be found in [59-62].

Review questions for Section 8.

1. What are the main stages of the multi-criteria analysis methodology for selecting effective construction solutions?
2. How are traditional and innovative solutions compared in the multi-criteria analysis process, and why is it important to consider non-traditional solutions?
3. How is consistency and non-contradiction ensured when excluding less effective solutions during multi-criteria analysis?
4. What are the main types of information models used to optimise construction solutions?

5. What tasks does experimental statistical modeling solve in the context of optimising construction processes?
6. How does experimental statistical modeling (ESM) help to find optimal solutions?

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