4D modeling in high-rise construction

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Abstract. High-rise construction is a complex construction process, requiring the use of more perfected and sophisticated tools for design, planning and construction management. The use of BIM-technologies allows minimizing the risks associated with design errors and errors that occur during construction. This article discusses a visual planning method using the 4D model, which allows the project team to create an accurate and complete construction plan, which is much more difficult to achieve with the help of traditional planning methods. The use of the 4D model in the construction of a 70-story building allowed to detect spatial and temporal errors before the start of construction work. In addition to identifying design errors, 4D modeling has allowed to optimize the construction, as follows: to optimize the operation of cranes, the placement of building structures and materials at various stages of construction, to optimize the organization of work performance, as well as to monitor the activities related to the preparation of the construction site for compliance with labor protection and safety requirements, which resulted in saving money and time.

1 Introduction

With the complication of construction projects, there is a need to use more perfected and sophisticated tools for planning and construction management. Risk assessment at the design and construction stage is included in the main stages of the business plan development. The price of incorrect accounting of the risk component is the underfunding of the investment project. Therefore, when developing a business plan, the risk of underfunding, the likelihood of its occurrence, and the severity of its consequences are taken into account.

In order to be competitive and effective both in the construction market and in the design market, companies need to introduce new progressive methods of organizing work. Because of it, there is a need of systems that work more efficiently (save time and money, demand fewer resources and don't compromise quality), provide better coordination and

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communication between the participants of the project team, and also transfer all necessary information about the project to all Interested parties involved in the life cycle of the project.

At present time, BIM-technologies allow minimizing the risks associated with design errors and errors that occur during construction. Which means that BIM-technology can act not only as a tool for qualitative design, but also as a process of organizing this design itself. An important role is also played by the strategic management of the enterprise, which is engaged in designing. Today, experts talk about BIM-technologies, as an instrument that allows to reduce design time, to implement the project in a high-quality and fast manner, and also as an information base that allows reliably to operate the constructed objects.

Creation of the BIM-model is a process of collective creation of the model by all participants of the investment and construction process. Each specialist (engineer-designer) works in his field and forms a model of his section, i.e. all specialists work in a single information field, forming a 3D model of the project. There are many programs for project management, which are widely used in the construction industry (Primavera P3, Microsoft Project, etc.). However, such schedules force users to visualize and interpret the sequence of actions in their minds. Interpretation of the schedule may range depending on the level of knowledge and experience. 4D models are created to solve this problem [1].

2 Methods

2.1 4D planning

Software products like Bentley Systems Inc, Autodesk, SmartPlant 3D are useful for creating a BIM-model. They could also support BIM-technology. During the use of traditional design tools, buildings are usually found in the finished state [2]. At the same time, as a result, one of the main limitations of 3D models is their inability to display the exact state of the progress of construction [3]. In addition, traditional construction planning tools, such as schedules and diagrams, don't facilitate the visualization of the process and require the creation of a mental representation of the construction [4].

The addition of the time attribute to a 3D (x, y, z) environment results in what it is broadly known as 4D (x, y, z, t) environment. This extra feature provides the model with more dynamism in terms of representing the behaviour of the building elements along time, extending in this way its usage for other purposes. [5-6].
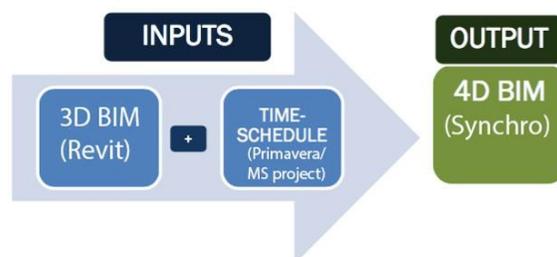

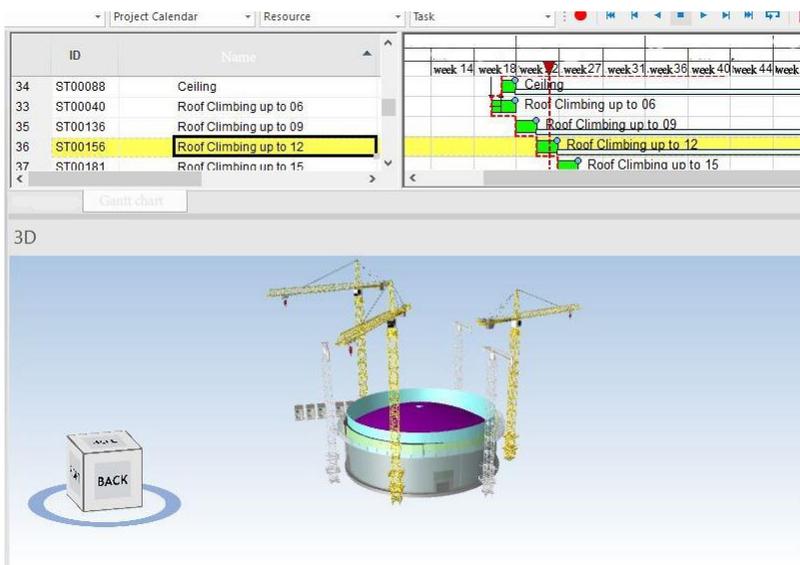**Fig. 1.** From conventional BIM model to 4D BIM model

Fig. 2. Illustration of 4D model

Regardless of the project phase, there is no doubt that these 4D models enhance project understanding, particularly in those large-scale projects with especially high complexity. This makes it easier to understand and detect errors before the construction starts, which leads to saving money and time. It is commonly known that the detection of problems during construction, which had to be solved at the planning stage, leads to time and financial resources.

It should be noted that the grouping of objects in the building model should be carried out in accordance with the stages of construction and is associated with the relevant activities in the construction schedule. For example, if a concrete slab needs to be built in three stages, then the slab model should be divided into three sections so that the sequence can be effectively planned and illustrated. In addition, temporary works, such as scaffolding and tower cranes, should also be included in the building model (Figure 2).

Knowledge of the contractor is very important when building a 4D model for the planning process. If the model is built during the design phase of the building, the contractor can give feedback on constructiveness, the approximate cost of construction and consistency. Modeling 4D for the planning process serves as a communication tool for identifying potential bottlenecks and as a method of improving cooperation between different project teams [7].

2.2 Study subject

Let us consider an example of using 4D modeling in the construction of a 70-storey building (Fig. 2-a).

To construct a constructive part of the building, in the program Primavera P3 was created a schedule of works, which includes 700 works (Figure 2-b). Accordingly, the number of working areas and the work included in them change.

At the first review of the schedule and 2D drawings it seems difficult to understand the construction logic, as well as to find any inconsistencies and errors.

To create the 4D model, the following actions were performed: a 3D model was created from 2D drawings, which was integrated with the construction schedule in the Synchro PRO program.

This model allowed to visualize the sequence of construction works, and also facilitated the verification of the calendar schedule. Re-examination of the sequence of construction works using the 4D model made it easier to understand the construction logic and determine the presence of inconsistencies and errors. 4D model was thoroughly checked in order to ensure the authenticity of the schedule and compliance with its construction process.
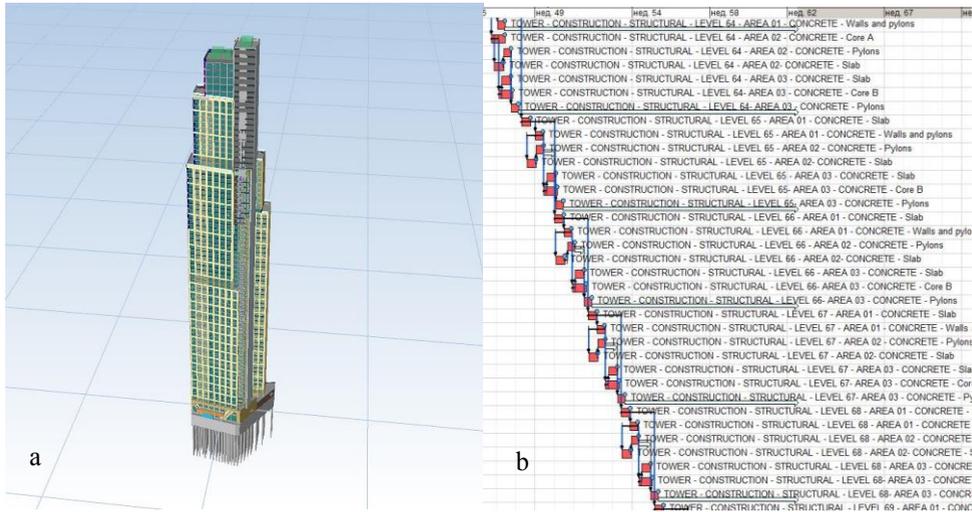

Fig. 3. a - 70 storey building, b – construction schedule

3 Results

During the analysis of the created model, several errors in the construction schedule were revealed (figure 3):
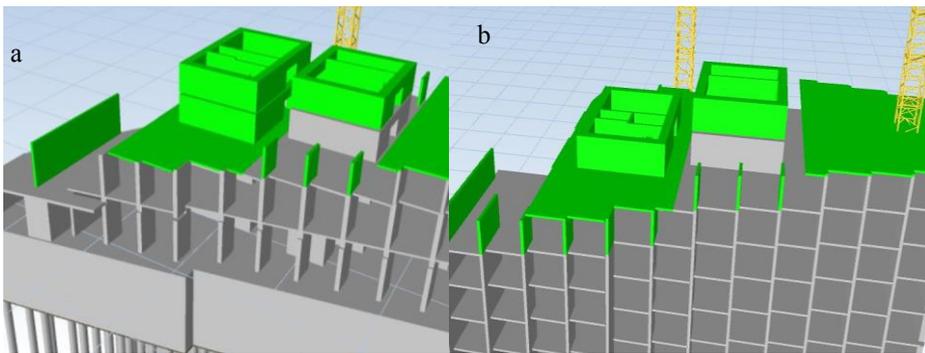

Fig. 4. Error detection

1.   On figure 4-a we can see that the stiffening core is erected on the 3rd floor, but the construction of the stiffening core on the 4th floor has begun. However, such a situation can't be realized.

2.   On figure 4-b shows that the walls are being erected, but install of the slab is started too, which does not correspond to the construction technology.

In addition to identifying design errors, 4D modeling has allowed to optimize the construction, as follow: to optimize the operation of cranes, the placement of building structures and materials at different stages of construction, to optimize the organization of

work, and to monitor the activities related to the preparation of the construction site for compliance labor protection and safety engineering [8].

4 Conclusions

In the process of analyzing the process of creating a BIM-model in comparison with a flat design, there were identified such advantages as: minimization of risks and mistakes between different sections of the project documentation, the ability to provide technical, aesthetic, economic, environmental, social and other requirements for the future facility, as well as space-planning solutions according to the specifics of the adopted norms, check the model on collisions and constructive errors.

With the help of visualization and communication, the planners, project team can achieve a better understanding of the project scope and objectives, which can improve the construction planning and execution process significantly leading to the project success. Implementing 4D modeling allows planners to detect the problems prior to construction phase which lead to reduction in the amount of rework and clashes. Therefore, a more reliable and detailed work plan can be obtained which assists the project to complete within prescribed time and budget.

Effective planning of construction of high-rise buildings plays an important role in the creation and maintenance of the project. One of the most significant advantages of 4D modeling is the provision of visualization of construction work, which can't be achieved with 2D drawings and schedule.

The 4D model is the best way to simulate the construction process before actually starting the construction of the project, as well as providing a basis for identifying potential problems in space and time that are difficult to take into account in the schedule.

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