Formation of a system for monitoring construction processes during the construction of buildings

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Abstract. The article considers approaches to the formation of a system for monitoring technological processes of building construction.
The effectiveness of geodetic scanning for the real display of the state of building structures and their compliance with design data was noted. The effectiveness of combined scanning methods for obtaining more extensive information about construction objects was noted. There are options for erecting prefabricated and monolithic building frames without using heavy crane equipment. It is proposed to form a system for monitoring technological processes based on combinational methods using photogrammetry and laser scanning. Based on the proposed assembly modules, a monitoring scheme for the erection of prefabricated and monolithic building frames has been developed. All this together makes it possible to develop a generalized approach to the creation of a system for monitoring construction processes, to determine the directions of development of such a system for filling the construction information model, obtaining data about the components of the construction object, including the state of structures, the pace of

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work, the behavior of machines and mechanisms on the site, the development of methods adjustment of technological flows, provisions of structures, etc.

Keywords. building constructions, geodetic scanning, construction technologies, methods of geodetic monitorings, craneless installation methods, information model, building mechanized equipment**.**

INTRODUCTION

The construction of frame buildings and long-span coatings in Ukraine is a complex engineering task that requires careful planning, the use of modern technologies, and consideration of specific conditions of work performance [1].

The basis of the implementation of such construction processes is the clear formation of the "structure - technology - construction equipment" system with the determination of the routes of influence of the components of the system among themselves. The formation of such a system is subject to the methods of functioning of complex production systems [18].

Works [2] are devoted to the study of the formation of technical systems. It is noted here that complex systems include subsystems that functionally interact with each other and combine to form new properties of the overall system.

The main factors limiting the processes of building constructions are climatic conditions, limited resources, and economic factors. These factors are investigated at the planning stage and have a significant impact on the construction process [1].

Buildings with a reinforced concrete frame have proven themselves as strong, durable and versatile structures that have high bearing capacity, resistance to atmospheric influences, have a significant service life, and can have large column-free spaces [1, 17-19].

THE PURPOSE OF THE WORK

The construction of buildings of construction objects is mainly realized by the crane method and by the crane-less method [1].

1 stage. Selection of construction technology

At this stage, a set of methods, techniques and means used for construction work is determined. The sequence of works, the choice of materials, constructive solutions and technological processes is also determined.

• Impact on mechanized equipment: Technology determines the type and amount of equipment needed.

• Impact on the monitoring system: The technology determines which parameters need to be monitored.

2 stage. Selection of mechanized equipment

Here, the choice of machines, mechanisms and tools used to perform construction works and their stages is substantiated, and the mechanization of labor-intensive processes is implemented.

• Impact on technology: Mechanized equipment determines possible technological solutions.

• Impact on the monitoring system: Mechanized equipment can be equipped with sensors that transmit data to the monitoring system. Today, such systems have been called the "Internet of Things" and have great prospects for development [19].

3 stage. Formation of the monitoring system

At this stage, the technical means and software designed for the collection, processing and analysis of data on the progress of construction are determined.

• Impact on technology: The data obtained as a result of monitoring allow to optimize technological processes.

• Impact on mechanized equipment: The monitoring system can control the operation of individual machines and mechanisms, adjust the position of their executive elements, and influence the position of building structures through the mechanisms.

Interrelationship between components

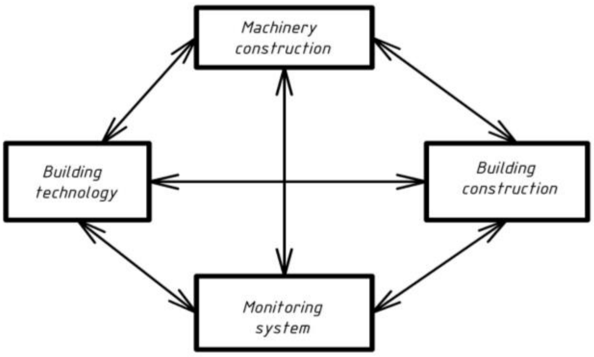


Figure 1. Diagram of the mutual influence of the components of the construction process

The relationship between technology, mechanized equipment and the monitoring system can be presented in the form of the following scheme (Fig. 1)

Figure 1 shows a diagram of the mutual influence of the components of the construction process. It is determined that the technology determines the methods of work performance, accordingly forms the construction process, determines the conditions for choosing the means of mechanization of the main and secondary processes, which in turn can change the technology itself. At the same time, the monitoring system is determined by the requirements of the work technology, the type of building, machines and mechanisms at the facility. Thus, the components of the construction system constantly interact with each other, changing and supplementing according to the real state:

- Technology determines mechanized equipment and monitoring system.
- Mechanized equipment affects the technology and provides data for the monitoring system.
- The monitoring system analyzes the data received from the mechanized equipment and makes corrections to the technology.

After the completion of construction, the monitoring system can be reoriented to obtain data about the building as a whole or its structural components [3-7].

Photogrammetry is a modern toolkit of the monitoring system, based on the formation of three-dimensional models of objects through a cloud of spatial points obtained from photographic images.

The photogrammetric scanning system consists of several main components:

- High-resolution cameras that provide detailed images of the object from different angles.
- Markers - special marks that are placed on the object to ensure accurate measurement of distances.
- Special software used to process photographic images and create a 3D model.

The scanning process includes the following stages:

1. Shooting: The object is shot from different points in order to obtain the maximum amount of information about its geometry.
2. Image processing: The resulting images are processed using special software that determines the coordinates of the markers and creates a 3D cloud of points.
3. Creating a 3D model: Based on a 3D point cloud, a detailed three-dimensional model of the object is created.

For more accurate measurements using a combination of photogrammetric scanning and LiDAR [14-15].

The synthesis of photogrammetric and laser scanning is implemented as follows.

1. Collection of LiDAR data. With the help of laser scanning, a dense cloud of points is obtained, which reflects the geometry of the object with high accuracy.
2. Photogrammetric surveying: It is used for a detailed description of the texture, color and other visual characteristics of the object.
3. Data fusion: The resulting cloud of LiDAR points and photographs are processed in special software. The program correlates the points of the cloud with the corresponding areas in the photos, creating a textured 3D model.

Separately, it should be mentioned about scanning by the method of structured light, the principle of operation of which is based on projecting a structured light pattern onto the object, followed by fixation of its deformations with the help of a camera. The implementation of this method has a low cost, but its application is limited to small distances and special lighting conditions.

Today, artificial intelligence tools are widely used in LiDAR and photogrammetry data processing, performing segmentation of scan data, object classification, reconstructing 3D models, optimizing scanning workflows, detecting changes in real time, etc.

In the table 1 shows the main comparative properties of monitoring methods using object scanning.

Table 1

Characteristics	LiDAR	Structured light	Photogrammetry
Accuracy	High	Average	Average
Speed	High	Medium	Low
Scanning range	Large	Medium	Low
Equipment cost	High	Medium	Low
Lighting effect	Low	Average	Large
Detail	High	High	Medium
Data processing	Complex	Medium	Medium

The most popular software products for scanning and data processing of point clouds are Pix4Dmapper, Agisoft Metashape, Bentley ContextCapture, CloudCompare, Tekla Structures, ReCap Photo [7-13]. This list is non-exhaustive and constantly changing, given the rapid development of the 3d scanning industry.

During the development of the monitoring system, it is necessary to determine the scheme of placement and movement of cameras during scanning.

There are the following basic camera movement schemes:

1. A circular scheme in which the camera moves in a circle around the object, shooting it from different angles [3-4]. This method is suitable for objects with approximately the same dimensions in all directions.

2. A linear scheme, when the camera moves along a straight line perpendicular to the plane of the object. This method is used for shooting long and narrow objects such as buildings or bridges.

3. Combined scheme, which combines elements of circular and linear schemes. This method allows you to get a more detailed model of objects of complex shape.

4. Chess scheme. The camera moves along a zigzag trajectory, creating a grid of images.

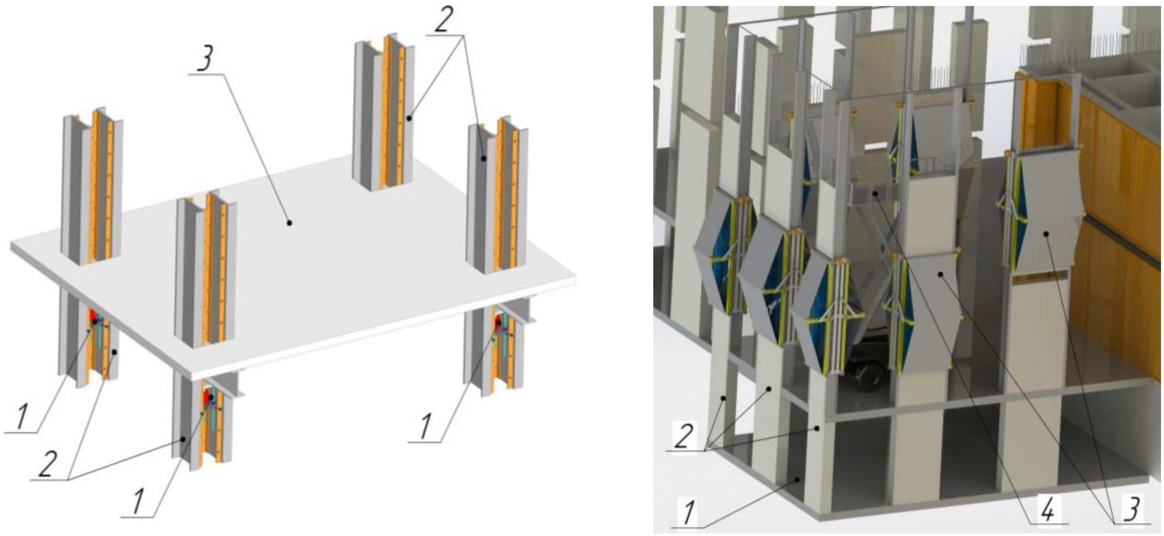
Taking into account that the erection processes in construction are variable in nature, it is obvious that the most appropriate application will be a combined scanning scheme. At the same time, the movement of the scanning camera can be applied by partially replacing the movement itself with an increase in the number of cameras.

Consider the construction of a building with a prefabricated frame (Fig. 2, a) and a monolithic frame (Fig. 2, b) using a craneless method [16, 17].

In fig. 2, a the scheme of lifting the long-span covering of the building without the use of heavy crane equipment [17, 18]. This decision proposes the use of lifting modules 1, which are connected in pairs to transverse beams 2, on which the covering 3 rests. The ascent to the design point in this case takes place on special columns 4, inside which the lifting module 1 rises.

In this case, the monitoring system is designed in such a way as to ensure the monitoring of the coverage dimensions, the horizontality of the coverage, its alignment with the corresponding coordinate axes is monitored accordingly; to monitor the verticality of the columns; monitor the position of each cargo-lifting module in the group; monitor the value of the power drive of the cargo-lifting modules.

In fig. 2, b shows the scheme of execution of monolithic works using the technological module for concreting pylons [16]. In this solution, the use of a mobile formwork module is proposed, which, after the monolithic formwork contour, is moved to the next technological level of concreting.



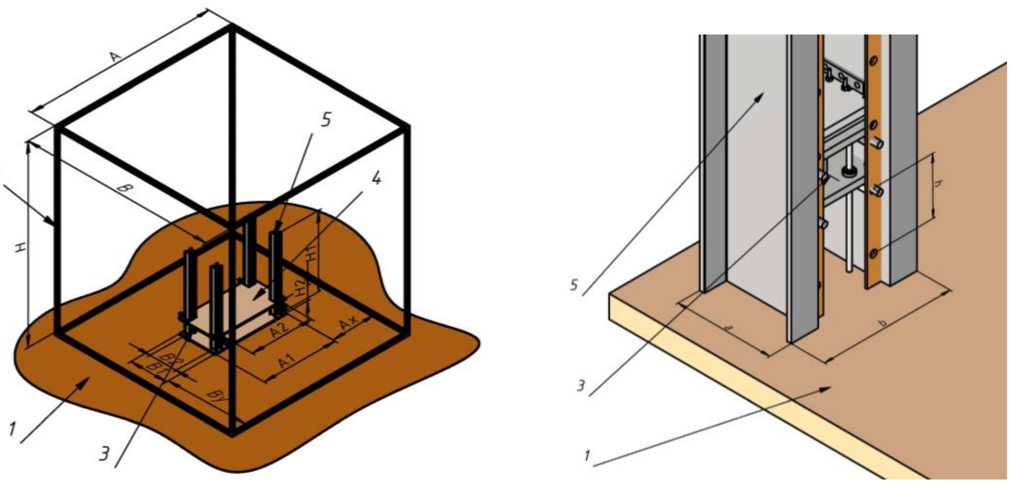
a b

Figure 2. the scheme for erecting structures by craneless methods: a – scheme of lifting the long-span covering of the building: 1 - lifting modules, 2 - columns, 3 – covering ; b – scheme of execution of monolithic works using the technological module for concreting pylons: 1 – base; 2 – pylons; 3 – technological module; 4 - service platform.

In this case, the monitoring system is designed in such a way as to ensure monitoring of the dimensions of the building, accordingly, compliance with the design provisions of the formed monolithic structures is monitored; to monitor the verticality of the building's pylons and their thicknesses; control the position of each module for concreting pylons separately; monitor the value of the power drive modules for concreting pylons.

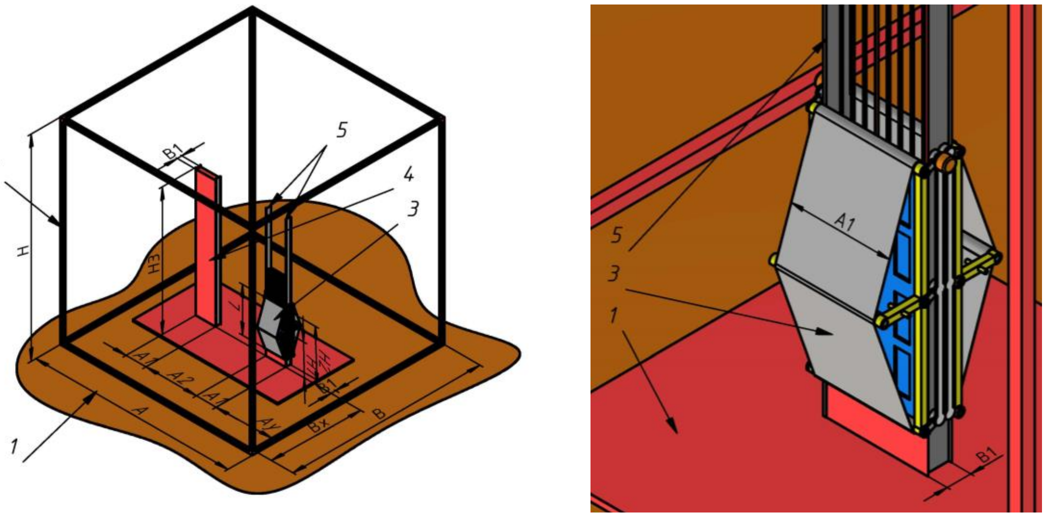
The algorithm for creating a monitoring system for monolithic works is somewhat similar to prefabricated processes, but must take into account the specifics of the mechanisms and the structural features of the building.

To simulate the basic system of monitoring the construction of a building with a prefabricated frame, the assembly process was



a b

Figure 4. The general view of the modeling scheme of the building construction process with a prefabricated frame: 1 – base; 2 – limiting frame; 3 – cargo lifting module; 4 – mounted building structure; 5 – forming columns of the building; a – main view; b – enlarged view.



a b

Figure 5. General view of the modeling scheme of the building construction process with a monolithic frame: 1 – base; 2 – limiting frame; 3 – mobile formwork module; 4 – formed monolithic structure; 5 – movement guides of the module; a – main view; b – enlarged view.

simulated using a lifting module (Fig. 3) in 1:25 scale.

To simulate the basic system of monitoring the construction of a building with a monolithic frame, the assembly process was simulated using a movable formwork module (Fig. 4) in 1:10 scale.

For the simulation of building construction processes with a prefabricated and monolithic frame, it is proposed to use the limiting frame 2, which conditionally plays the role of immovable objects, for example, buildings, masts, etc. Surveillance cameras will be placed on the fixed frame to form a photogrammetric scan. The location and number of stationary observation points is chosen for reasons of ensuring the maximum overlap of the obtained images of the research object. In addition, when taking pictures, use recommendations on camera settings [3, 4] to adapt to external conditions, eliminate unnecessary "noise", improve detail.

Stationary cameras are used as monitoring tools at the initial stage. The bounding frame can form rigid bases with free forms on which it is possible to place stationary cameras for scanning, movable gimbals [3] with cameras, jib equipment to reproduce circular or rectilinear movements of the camera relative to the objects to be scanned, etc.

The formed monitoring system allows modeling and researching the behavior of mechanized technological equipment during the construction of buildings. It allows you to monitor the condition of assembled and assembled structures, detect their manufacturing defects and fatigue damage, compare data obtained with a certain discretization in time, etc. [7, 17, 18].

It is expected that the formed monitoring system will allow filling the information model of construction processes, forming digital duplicates of construction structures, improving the construction processes of buildings with a prefabricated and monolithic frame by improving the automation of processes, will provide the possibility of virtual simulation of such processes for training and identifying problem situations.

CONCLUSIONS:

- monitoring of the process of building construction is important both at the initial stage, during the execution of works and after the completion of works, it allows to effectively obtain data on the state of building structures, compliance with construction terms, analyze the operation of machines and mechanisms;

- three-dimensional scanning is a modern means of determining the compliance of real construction objects with design data, as well as a promising means of monitoring the execution of construction processes and the state of structures;
- Scanning methods and means depend on the specifics of the technical task and the technical capabilities of the performer;
- Crane-less methods of erecting buildings with a prefabricated and monolithic frame are promising, reducing the specific share of the use of heavy crane equipment on construction sites.
- The system for monitoring construction construction processes is constantly changing and being supplemented, it can be used for both static and dynamic data acquisition of construction objects and their components. The results of obtaining a full information system can take place in many related fields.

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Формування системи моніторингу будівельних процесів під час зведення будівель

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Анотація. У статті розглянуто підходи до формування системи моніторингу технологічних процесів будівництва.

Відзначено ефективність геодезичного сканування для реального відображення стану будівельних конструкцій та їх відповідність проектним даним. Відзначено ефективність комбінованих методів сканування для отримання більшої інформації про об'єкти будівництва. Існують варіанти зведення збірних і монолітних каркасів будівель без використання важкої кранової техніки. Пропонується сформувати систему моніторингу технологічних процесів на основі комбінованих методів з використанням фотограмметрії та лазерного сканування. На основі запропонованих монтажних модулів розроблено схему моніторингу зведення каркасів збірних і монолітних будівель. Усе це разом дає змогу розробити узагальнений підхід до створення системи моніторингу будівельних процесів, визначити напрями розвитку такої системи для наповнення інформаційної моделі будівництва, отримання даних про складові об'єкта будівництва, в т.ч. стан конструкцій, темпи роботи, поведінка машин і механізмів на ділянці, розробка методів налагодження технологічних потоків, положення конструкцій тощо.

Ключові слова: будівельні конструкції, геодезичне сканування, технології будівництва, методи геодезичного моніторингу, безкранові способи монтажу, інформаційна модель, будівельна механізована техніка