Substitution of the labor market in the construction industry by technical and automated systems

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Abstract. Construction is one of the oldest branches of the national economy. With the development of mankind, construction technologies, instruments of labor, machinery and mechanisms were developing as well. A large number of technological processes and operations performed in the design and construction of real estate, were carried out manually. Modern pace of economic development increase requirements on the speed of construction, its quality, as well as on reduction of the works labor intensity. The aim of the research was to determine the areas of construction in which it is advisable to replace manual labor, and also to develop recommendations for construction companies on the implementation of mechanization and automation in their production. During the research it was found that the area of design, calculation and logistics was automated almost 100%. At the same time, specifically when erecting buildings on Russian construction sites, up to 70% of the total labor volume is manual. Even in excavation and installation works, the level of manual operations of the machinists and accompanying workers is quite large. In the course of the analysis of the existing market of technologies and software products in the field of construction, there were determined the ways to reduce labor intensity and to increase the profitability of production.

1 Introduction

In the last few years, virtual reality technologies have significantly expanded the boundaries of their applications. 3D modeling has become available not only for entertainment, but is also widely used for buildings design, facilities, transport routes, and etc. [1, 2]

Various technologies are used to create three-dimensional objects, and as a rule, they are based on photogrammetric processing of space and aerial photographic. The accuracy of the created models depends on the purpose, the requirements of the customer, etc. For the visualization of the microdistrict creation or for the assessment of a projected building installation, high detailization is not required, at the same time, to assess the quality of performed work or for uploading it into executive mechanisms, the accuracy must comply with the requirements of normative documents. [3, 4, 5]

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At the moment, one of the most common areas of three-dimensional models application is the high-altitude analysis of the construction site and surrounding buildings. Basing on this data, the works on planning, works on water disposal systems on the construction site, as well as landscaping, are carried.

The second area of application of 3D modeling in construction is the visualization of projected and existing facilities. Compared to two-dimensional classical drawings, 3D images are incomparably more visual and allow unprepared users to navigate more easily in space and to make the right decisions. Moreover, modern software allows to create high-quality realistic 3D models of construction projects.

The third direction of buildings and constructions digital models realization is the objects prototyping. This allows models of buildings and structures printed on a 3D printer to be tested for wind, seismic and other loads. The specific features of 3D models make them an ideal tool for planning the actions in emergency situations. [6]

In addition, with the help of virtual 3D models or prototypes, it becomes possible to identify the likelihood of the negative impact of the erected building on the environment.

2 Materials and methods

Modern building production process is a large interconnected complex of various units, from the coordinated work of which, the efficiency of construction depends in general. In accordance with the existing requirements of the Russian Federation to the project documentation, it undergoes a multistep inspection, refinement and after approval, a working draft is developed on its basis. At the same time, the customer of the project can often change the requirements to a project. And this requires secondary expert evaluation and contribution of modification. Traditionally, this stage of building design begins with engineering research, the result of which is the modeled terrain. As a rule, at this stage, a digital model of the geological features and relief, a model of the situational plan, a model of engineering communications, etc., are usually developed. Unmanned aerial vehicles and images from space are widely used for these purposes. With the use of such software products like Autodesk 3D's MAX, AutoCAD, and also "ArcGIS", the process of 3D modeling of topographical surface is substantially simplified. Also, BIM-technologies (Building Information Modeling or Building Information Model) have been widely introduced recently. [7, 8, 9]

The main advantages of BIM design include:

- reduction in the time for preparation of project documentation;
- the possibility of 2D design error detection;
- reduction of construction costs;
- control over expenses;
- reduction in the time of project implementation.

The study analyzed the impact of the introduction of modern methods on the duration of construction and the economic effect.

The study was carried out on the duration of the construction and the economic effect.

The second stage of construction is the direct implementation of the project, ie the erection of a building or structure. Many processes on the construction site are performed manually, and this does not meet modern requirements of the building production level and the projects pace of implementation. If possible, it is necessary to substitute traditional manual work by automated processes.

An integral part of the object construction is monitoring compliance with project decisions. In the construction there are three types of oversight: author's, technical and state. All of them are maintained during the investment period of the real estate objects life cycle, which means during the construction and installation works, and installation of equipment.

Traditionally, it is further subdivided into input, current and acceptance. In addition, a large number of documents associated with the construction: production work log, certificates for inside works, execution schemes, etc., are drawn up on the construction site. All these processes take a large amount of time on processing, coordination and transmission from one participant to another. It is necessary to optimize this process. [10, 11]

Commercial and user models of drones today can easily fly around the construction area and quickly demonstrate the progress of construction on maps with high resolution and 3D models, which is a very effective solution in comparison with traditional methods. In particular, Brasfield & Gorrie, one of the largest private construction companies, uses the 3D model obtained with the help of drones, in order to compare the actual implementation of earthworks on the construction site with planned indicators. With help of drones, they were able to assess the results of excavation much faster than if it would be done with help of traditional methods, without losing the accuracy. [12]

The final stage of the construction is the preparation for the commissioning and acceptance in operation of the erected real property. At this stage, there are also quite a lot of processes that can be automated, in order to improve the quality and to reduce the time of their implementation. [13]

The research methodology was built on the analysis of the most labor-intensive processes in the implementation of design solutions for the construction of building objects and the identification of ways of their automatization.

In the course of the study, an analysis was carried out using the example of the 16-storey residential building project, made of reinforced concrete. To evaluate the effectiveness of decisions taken, the Project Expert program was used. Project implementation period is 1.5 years. The main steps are given in Table 1

Table 1. The main steps of construction

Name of works	Investment costs, million rubles	Duration, months	Payback period of the project, month	Useful area, m2
Project works	32	8,5	10	13940
Preparatory work	5	3		
Excavations works	35	2,5		
General construction work	285	12		
Concreting work	198	12		
Landscaping	25	2		
Installation of equipment	70	5		
Finishing works	180	6		
Completion of the project	12	2		
Total	1067	-	-	-
Of these, costs for mechanization	128,345	-	-	-

The effectiveness of the decisions taken was estimated using the ratio of the average price of supply in the market (P_{av}) to the internal price of the enterprise (P_{out}) formula (1):

$$k = \frac{P_{av}}{P_{out}}$$

(1)

The price that an organization can offer on the market depends on many indicators, but in particular on its own total cost of the project [14].

The total costs can be determined by the formula:

$$Z_{ud} = S * (1 + \frac{F}{V} * \frac{r}{100}) + \sum_{i=1}^n \frac{S_i}{T_i}, \text{ rub}$$

(2)

S - the cost of works, rub; F - average annual cost of capital stock and working capital; V - annual turnover of the construction organization; r - internal rate of capital return; S_i - annual costs for the maintenance and operation of the i-th machine; T_{si} - estimated remaining useful life of the i-th machine; n - is the number of machines of this type. Determination of energy costs for the execution of works by a set of construction equipment is carried out according to the formula:

$$S_i = \sum_{i=1}^n E_i * K_{pi} * S_{ex} , \text{ rub} \quad (3)$$

where E_i - is the rate of energy consumption; K_{pi} - coefficient of loading of power equipment; S_{ex} - weighted average cost of energy. On the basis of a comparison of total spending for different variants of machine parks and methods of production, it is possible to complement and promptly manage the construction organization. The effect of the reduction of construction duration is determined by the formula

$$D = \varepsilon_n \cdot (k_n \cdot t_n - k_p \cdot t_p) , \text{ rub} \quad (4)$$

where ε_n - is the normative efficiency coefficient of investments, k_n and k_p - are the average size of capital investments in the construction of the facility, according to the norms and under the project, for the period of construction, which are determined by the formula:

$$k = \frac{k_1 + k_2 + \dots + 0.5 \cdot k_n}{n} \quad (5)$$

where $k_1, k_2, \dots, k_n$ - are the amounts of capital investments for the construction period, cumulatively by the end of each quarter (1, 2, ..., n), thousand rubles; t_n и t_p - the duration of construction, up to the norms and the project, years. The additional amount of profit for the period of early commissioning is determined by the formula:

$$D_s = \frac{r_s}{100} \cdot F \cdot (t_n - t_p), \text{ rub} \quad (6)$$

where r_s - is the average profitability of funds in the industry; f - cost of capital stock put into operation, thousand rubles. For the works where automation systems are used, the use of working time is improving, the losses of time reduces, and eventually, labor productivity grows. The growth of labor productivity with a decrease in intra-shift losses of working time can be determined by formula:

$$W = \left(\frac{100 - q_{n2}}{100 - q_{n1}} - 1 \right) \cdot 100 \quad (7)$$

where W - growth in labor productivity, %; q_{n1} и q_{n2} - losses of working time before and after the implementation of activities, %. The reduction in labor costs, due to the growth of labor productivity, is defined as,

$$D_w = q_s \cdot \frac{W}{100 + W} , \text{ person-hours} \quad (8)$$

where q_s - labour inputs for the erection of the object according to the estimated norms, are taken at the local estimate in person-hours.

3 Results

According to the requirements of the MRR-3.1.10.02-04 "Norms of the duration of the construction objects design in the city of Moscow", the duration of the design work for a similar object is:

$$T = T_1 + T_2 = 7.5 + 1 = 8.5 \text{ ,months}$$

(9)

where T_1 is the duration of the documentation development, months (p. 3.2), T_2 is the duration of the approval of design and estimate documentation, months (p1.3).

As a result of the modern BIM-software products usage, preparation of documentation for stage "P" (project documentation) and "W"(working documentation) required about 30% more labor input, than the usage of the traditional design methods. This was connected with the departure from the traditional principles of work organization and required the establishment of a clear linkages between the project departments. However, as it was not necessary to repeatedly clarify the related issues with subcontractors and the customer, the total duration of the design work was 8 months. Meanwhile, a full-fledged 3D model was received, and was used further for the construction process.

The suppliers of ventilation equipment changed during the production process, and it was necessary to amend the project. The changes were made more quickly, as a result of using the finished digital model of the building, since BIM is capable to calculate and modify the elements of the systems by itself, according to the required parameters. [14]

For the excavation work, bulldozers and excavators equipped with Topcon's SiteLink3D system were brought on a rental basis. The use of this technique increased the estimated cost of excavation by 15%, but as there was no need in additional works (layout, marking out the foundation, stripping of soil layer, etc.), the excavations cycle was completed 2 weeks before the planned time.[15]

The application of BIM 360 Team and BIM 360 Plan by AUTODESK® company, allowed to reduce the duration of works by 1 month.

The general results of the duration calculations are shown in Fig. 1.2.

Fig. 1. Comparison of the duration of operations

Fig. 2. Comparison of the given costs for operations

4 Discussion

As a result of modern software products of BIM-design implementation, the execution of project documentation requires more time and higher skill level of the perpetrators. In addition, we have to face the reluctance of experienced designers to master new methods and systems. The graduates who have recently graduated from university, but already have certain experience, are the best for this. Though, the initial time costs for building a full 3D model are compensated by a reduction in the duration of coordination, approval and adjustment of project documentation between contractors and other interested structures.

The use of modern automation systems for the production of works, earthworks in particular, allows to reduce the number of technological operations, which leads to the increase of productivity, reduces machine operating time, and therefore increases the service life before repair and maintenance. The transition from 1D-positioning systems to 2D and 3D positioning systems allows to implement the digital (design) model of the created surface at the construction site with a high accuracy at the construction. Such solutions allow not only to improve the quality of work performed, but also to carry out complex management of construction work on the site - to monitor the work of personnel, input of data, the operation of devices and machines - regardless of where they are. One such system allows to effectively manage construction projects and use available resources. However, the machinery parks of construction organizations must be equipped with modern machinery, which leads to higher construction costs.

With the development of unmanned aerial vehicles, technologies have emerged. During the preparatory stage and the stage of the project development, it is possible to obtain data of a higher quality with the help of drones, than with traditional methods.

During the construction phase, unmanned aerial vehicles are perfect for rapid on-site surveys, in order to collect accurate data for reports of project’s progress, and also to monitor the production process and to make the necessary revisions to the construction organization process.

Information from unmanned aerial vehicles is automatically processed, and investors can quickly obtain the complex data, which is necessary to respond in a prompt way, and to analyze the results effectively.

Apart from using drones to monitor the construction of open spaces, automated systems can also be used inside buildings. The Doxel company has represented a robot equipped with a lidar to control the construction. The robot can compare the pace of construction and check the correctness of the structure's installation with the project.

To ensure that the robot can move freely on the construction site without the help of people, it was equipped with a two-segment caterpillar drive. It is assumed that the robot will be used at night, when there are no people at the construction site. It will move around the building and scan it, and after will send a report concerning the works done to the cloud server.

5 Conclusion

In the process of analyzing the results of calculations, it can be concluded that in comparison with traditional methods, the works labour-intensity increases. This is connected with the need of staff training and with the complication of design, but as a result of the visibility of the 3D model and integrated calculation software packages, the time for harmonization and re-confirmation of project documentation is reduced. Also, the use of an integrated approach from design stage up to the completion of the project on a turnkey basis allows to:

- Improve communication between the participants of the project
- Carry out a careful approach and identify errors, both at the design stage and during the construction phase
- Perform integrated control by the customer
- Accelerate the exchange of information on work performed and track the work schedule
- Decrease the number of requests for changes by 10% comparing to traditional design projects, due to more accurate study and visualization of project documentation.

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