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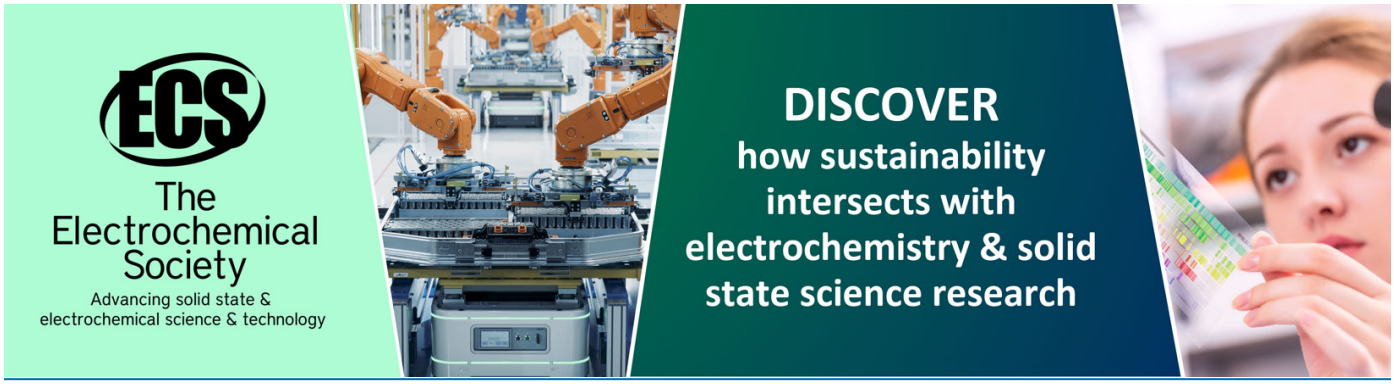

IOP Conf. Series: Materials Science and Engineering **497** (2019) 012016 doi:10.1088/1757-899X/497/1/012016

Digital technologies in construction monitoring and construction control

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Abstract. The article is addressing main methodological and normative-technical approaches to monitoring and control in construction as well as practical tools used in the context of digital economy. Monitoring and its purposes have been considered. Currently employed innovative construction control digitization methods which are envisaging monitoring of real property objects technical condition and enabling, by creating and functioning of visual models, design, construction companies and investors to perform detailed analysis of construction process and take efficient management solutions were disclosed herein. This paper presents investigation of commercially available digital technologies of monitoring of capital construction objects and describes their advantages and disadvantages. Finally, this paper reveals main problems arising during digital technologies integrating into construction monitoring and construction control with consideration of Russian construction companies intrinsic characteristics.

1. Introduction

Today's requirements put forward to the quality of capital construction objects demand application of modern methods and tools of monitoring and control by enterprises for the purpose of compliance with regulatory requirements and improving company competitiveness in the sphere of construction. Today's market is characterized by new construction materials, new methods of construction object costs estimation and new methods of construction-and-installation works execution. That is why it is extremely important to find practical tools allowing decreasing errors probability and guaranteeing reliability and safety of construction objects. Modern digital technologies used in construction monitoring and control enable the user to solve the aforesaid problem.

Today's Russian construction sphere has a number of problems which require implementation of new digital technologies. Actual lead time of large-scale investment-construction projects in actual practice exceed the planned deadlines by 20%, the budget – by 80% [1]. Today's investment-construction market is characterized by decrease of construction works productivity; economic efficiency of contracted works is mostly unstable and low.

Technological innovations implementation in construction sphere is slow and underactive and statistic data prove that. Innovative activeness (i.e. proportion of construction entities which were practicing innovations of any kind) of construction companies in 2017 reached 1.5%. Proportion of construction companies which were practicing technological innovations in 2017 reached 1.1% [2].

This problem is relevant for digital technologies as well. Scheduling of investment-construction projects is often left incompletely agreed upon and characterized as formalistic. Agreements with contracting companies often do not include motivation for innovation and risks section, productivity management is not efficient, organization of supply chains often fails to comply with project requirements throughout the entire period of project fulfillment.

Implementation of digital technologies in today's construction sphere is not systematic; it is characterized rather as fragmentary and demands considerable investments with long-lasting payback period. Expenses associated with research and development works in construction are considerably lower if compared with the same in other branches of industry: expenses for information technologies are less than 1% of incomes while in aero-space and automobile sectors they reach 3.5-4.5% [1, 2].

Intrinsic technical problems of construction sphere strongly affect digital innovations pace. Development and approval of design and permit documentation for construction objects which are located within different land plots is a complicated task. And, taking into account specificity of business maintained by representatives of medium and small construction companies who are frequently performing as subcontractors, full-pledged employment of advantages provided by modern digital technologies is often very problematic.

At the same time, investment-construction projects are becoming more widespread and complicated. A lot of construction business representatives are trying to concentrate their efforts on stage wise improvement of their activities. However, the fact that all projects are in their own way unique is forming an opinion that implementation of innovation technologies is irrational. Growth of demand for construction objects and raise of requirements to quality of works dictate that companies must considerably change their approaches to construction works organization.

Outflow of qualified personnel and managers aggravates the situation. Besides, it is necessary to mention a rather poor level of digital technologies employment by Russian companies, furthermore, implementation of digital technologies is procurable for large companies and holdings while for small construction companies these developments are economically inexpedient. All aforesaid once again stresses the need for digital technologies employment in construction monitoring and control.

2. Specific features characterizing monitoring and control in construction industry. Digitization practices

Research papers present various approaches used to define terminology for monitoring and control in construction. Construction monitoring means systematic and/or periodic observation and inspecting of strained and stress-strained condition of soils, foundations, basements, structures, whole buildings and its structures in the course of construction works execution performed in compliance with legibly developed program. Purpose of monitoring is to ensure safe operation of the construction object and to take necessary measures in case of fault so as to resume the design-required performance thereof. Construction monitoring is normally carried out either within the framework of construction scientific and technical support or as a specific job and on continuous basis when the object is in steady operation [3].

Construction control is a multilayer integrated system comprising mandatory activities and procedures intended for execution at any stage of construction, reconstruction and overhaul repair of the real property object. Construction Company can maintain construction control through monitoring of technical condition of individual structures, structural systems, surrounding housing and ecological environment [4]. Purpose of monitoring consists in long-term periodical control of loads, impacts, efforts, displacements, deformations and stresses occurring in various structures and in structures cross sections; another purpose is to identify compliance of actual structure stress-strain condition with nominal parameters and design requirements aiming to analyze object's technical condition and to avoid critical and pre-emergency situations.

Monitoring and control is carried out by specialized companies on contractual basis (agreements executed with construction companies) [5]. Contents and scope of monitoring and control works are presented in program and in regulatory documentation approved by the customer upon agreeing it with

the designer. Expenses associated with monitoring and control are included in object construction costs estimate; once the object has been put into operation – in object operation and technical maintenance costs estimate.

Thus, owing to efficient organization of construction monitoring and control, building owner or managing company responsible for building technical maintenance may be quite sure about safety of building and of personnel operating it. Monitoring and control of building structures quality allows to ensure safety of facility under construction, timely predict emergency situations and avoid occurrence thereof.

Nowadays, digital technologies are being actively implemented worldwide. Extent of BIM technologies implementation in foreign countries can be explained by potential advantages of using them at each stage of investment-construction project fulfillment. According to foreign analysts, implementation of information modeling may considerably decrease construction costs of budget-supported objects – by 25% subsequently decrease operation expenses – by more than 35% [6].

Due to essential advantages resulting from BIM technologies employment for state-financed construction, a number of foreign countries already defined the conditions of mandatory digital technologies use for design and construction of objects performed with participation of state budget. These requirements have been gradually followed by government customers in the USA since 2003, and from 2007 in some of Asian and European countries [7]. In 2011 Great Britain declared national construction industry strategy aiming to obtain maximum competitive advantages in the international market. A sophisticated sequential program targeting construction sphere transition to digital technologies was elaborated within the framework of the said strategy. This program is foreseeing the transition to mandatory employment of such technologies in design, monitoring and control activities beginning from April 2016 for all state budget-supported projects including new construction, reconstruction and overhaul repair. Solution taken on the state level duly ensured prompt BIM technologies promotion.

Figure 1 shows economic effect of visual modeling technologies implementation.

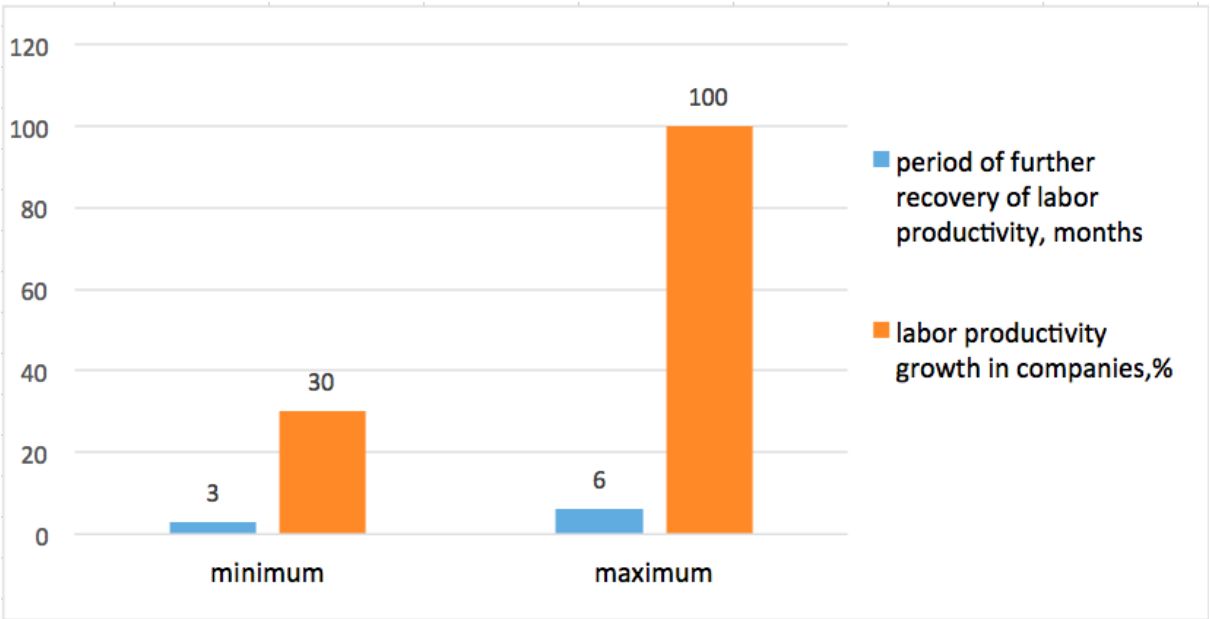

Figure 1. BIM technologies implementation effect [4, 8].

In 2012 over 70% of entire US construction companies declared information modeling technology employment for all construction-investment projects; in Great Britain – since 2016 – 54%. According

to Singapore state construction Agency, beginning from 2015 over 80% of all construction projects are being fulfilled with the use of BIM technologies. Today all design companies and over 70% construction contractors in Singapore are using BIM in their daily activities [9].

In January 2014 all-European Directive for state procurements was amended; according to this amendment, all EU countries, aiming to improve efficiency and enhance budget expenditures transparency, were recommended to make use of electronic forms for works which are including BIM technologies in construction works execution [6]. Currently, European Commission is running EU BIM Task Group – a special group comprising state customers representing various countries of the European Union. Main goal of this group is building-up of general all-European rules stipulating the process of scheduling and implementation of state orders for construction and engineering contracts [7].

Analysis of projects fulfilled by British companies with the use of BIM shows the following results. According to Sweett Group consulting company which put to analysis a number of projects fulfilled with the use of BIM and, on the other hand, some of the projects fulfilled using conventional methods, it may be concluded that digital technologies provide for [10]:

– saving about 20% of entire scope;
– reduction of works duration by 10–12% resulting in indirect costs lowering.

3. Digital technologies employment. Russian practices

Main regulatory act governing construction control in Russia is Urban Planning Code of the Russian Federation (article 53). Decree of RF Government dated June 21, 2010 No 468 “Concerning construction control execution during construction, reconstruction and overhaul repair of capital construction objects” is governing the below listed requirements and regulations:

– incoming inspection of developer's (customer's) design documentation;
– verification of geodesic control network of building under construction;
– incoming inspection of equipment, materials, items and structures used for construction;
– in-process inspection during execution and completion of construction-and-installation works;
– verification of executed works where construction control of subsequent works becomes inaccessible;
– verification of critical building structures and critical utility lines segments;
– testing of technical devices.

According to RF Government Decree dated February 16, 2008 No 87 “Concerning composition of design documentation sections and requirements to their contents”, summary cost estimate of construction project must comprise a section entitled “Construction control”. Requirement for construction control conduct is also set forth by the revised version of SNiP 12-01-2004 “Organization of construction” which is presented as set of rules SP 48.13330.2011 “Organization of construction” [3].

Construction monitoring and control must be maintained on continuous basis at any phase of construction, reconstruction and overhaul repair of capital construction objects [4, 5, 11]. Main goal of this procedure shall be identification of actually performed installation-and-construction works compliance with requirements set forth by design documentation, technical regulations, engineering survey results and land plot development plan. Development and implementation of construction monitoring and control system must take into account complicacy and specificity of capital construction objects erection [1, 4, 11].

Main elements of construction monitoring and control system include: incoming inspection of design documentation, geodetic and laboratory control, incoming operational control of quality of materials, items and structures used for construction, instrumentation control, production control, acceptance control, monitoring of technical condition of real property objects, individual structures and structural systems [12].

Today employment of innovative digital tools enabling execution of capital construction objects monitoring is underdeveloped in Russia. At that, mathematical model of object under monitoring is

developed individually within another program, does not depend upon designer's computational model of the object and is being detailed in the course of construction with reference to actual readings of monitoring system sensors [13, 14]. As a result, upon completion of construction works, mathematical model of object under monitoring (including all updates thereof) will by maximum correspond to actual object. The developed mathematical model is used during object construction and operation with a purpose to evaluate the results of monitoring and to predict defects occurrence [4]. In particular, judging from analysis of RF experience of construction sphere digitization, solutions based on SCADA system, StroyForm data bank, 4 D BIM, visual modeling etc. are deemed to be rather prospective. These technologies are already adopted to design management and Russian specificity and include design, monitoring of objects technical condition and automation [15, 16].

StroyForm software package: Construction control has StroyForm data bank which consists of process works packages by analogy with cost estimate packages. At that, in addition to cost estimate packages, StroyForm data bank has amended composition of process works which is giving more details of process operations and variations thereof (technological composition of works) [17]. As a result, it is possible (based on available composition of works) to automatically generate a calendar Plan of construction with consideration of works intended for execution. In regulatory base of StroyForm package each work is enclosed with intrinsic list of as-built documentation. When a record about work executed at the construction object is made it is also required to specify documents intended for construction control which should be selected from the list of as-built documentation intended for each work (technological composition of works). This enables the person-in charge to automatically develop and perform monitoring of as-built documentation avoiding mistakes which may occur at the stage of collection and compilation.

In construction it is also possible to employ digital system of building structures strain condition monitoring, the so-called “SODIS” – the system of collection, management and primary data processing enabling the user to govern, obtain, process and store measurement data, check operability and verify primary detectors and equipment on a centralized basis. “SODIS” is functioning on the basis of “SCADA” class standard information systems.

BIM concept which is also called 4D BIM (i.e. visual modeling) is a merge of 3D BIM and activity based network. “4” digit is referred to the fourth dimension i.e. time. 4D-models allow to track sequence of events within the framework of project [18].

Visual model of construction works sequence enables designers, contractors and investors to analyze, owing to real-time navigation, the process of construction and to take necessary managerial solutions. Modeling may get materialized either for entire project at once or partially – through development of visual model as of specific point in time. BIM technology is a modern and efficient construction monitoring tool [18].

Figure 2 shows specificity of employment of construction works sequence visualization with the use of modern digital technologies of construction monitoring and control.

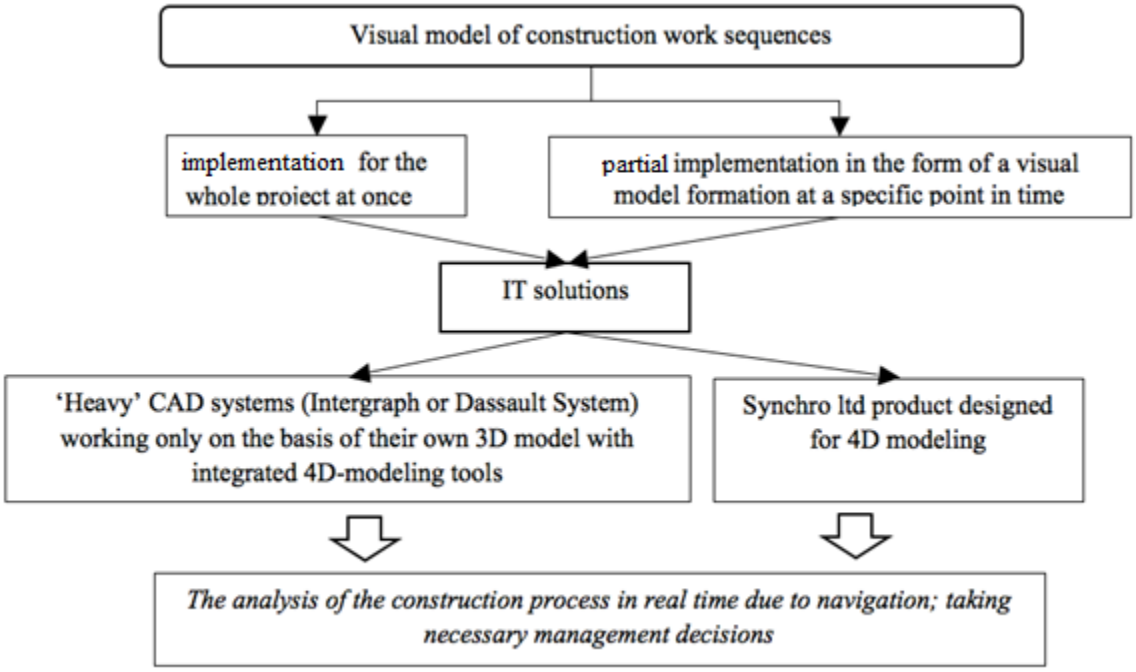

Figure 2. Specificity of visual digital models of construction works design and monitoring [10, 19].

From the point of view of IT solutions, 4D modeling tools are integrated into "heavy" CAD systems, "Intergraph" or "Dassault System", for example. Normally, such systems are functioning on the basis of intrinsic 3D model. Synchro Ltd company product developed for 4D modeling is exclusion. "Synchro" is binding the 3-dimensional model of input object (which may be imported from 3D design external systems) with activity progress chart from "Primavera" of "Microsoft Project". Synchro is implementing the models of work zones usage, cranes, on-site warehouses and traffic arrangement. As a result, a clearly arranged visualization of planned and actual status of works execution is being shaped. Synchro is a scheduling system which is integrating algorithms of schedule calculation using critical-path method, project calendars and cost estimates, and enabling the user to input actual data and analysis of project works progress using earned value technique [20, 21].

Figure 3 shows specific features of using construction works scheduling and monitoring with the use of Synchro scheduling system.

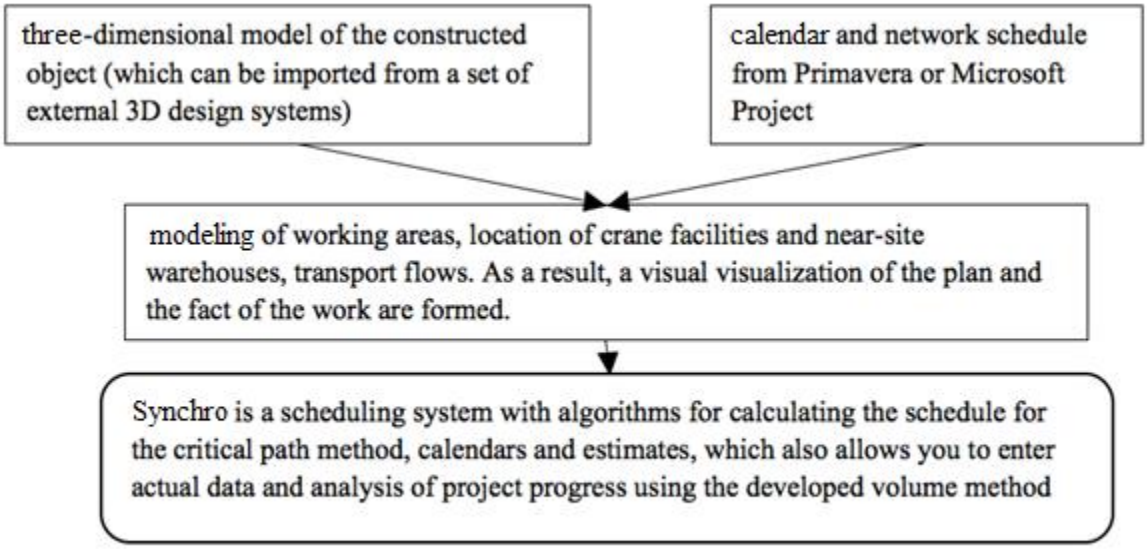

Figure 3. Synchro system of construction works scheduling and monitoring [4].

Synchro enables the user to undertake a multi-factor analysis and visual 4D modeling of the projects. Consolidation of activity based network data, design and cost estimate documentation results in a unified spatiotemporal plan of the project optimized in regard of resources and costs. This system allows to visualize, analyze and verify it, and, if required, to update it in case of errors. System performance results may be successfully used during compilation and approval of plans and in the course of implementation thereof, enabling the user to control progress of works directly at the site.

4. Discussion

Monitoring of construction and repair works quality allows considerably optimizing the production process at the site and thus having an effect on object commissioning deadlines and financial flows. Monitoring tools allow controlling the process of construction at any stage giving construction companies the possibility to timely update conditions and parameters of construction works execution where there are any deviations from design-required norms detected so as to avoid serious consequences.

At the stage of construction-and-installations works execution which is most important and time consuming, an important role is played by construction monitoring and control. Investments efficiency, observance of project deadlines, successfulness of project implementation and object commissioning strongly depend on quality and efficiency of construction monitoring and control execution.

Today's construction practice in Russia cannot offer ready-to-use technologies meeting the requirements put forward by forms and methods intended to verify capital construction object compliance with design documentation, technical regulations norms and rules. However, active attempts to fill this gap are taken.

Despite evident advantages offered by digital construction monitoring systems it is necessary to underline the following obstacles on the way to duly implement digital technologies for design companies who were initially using CAD technologies in design: obligation to procure new programs and organize personnel training, develop own templates and documents for the new programs, build-up the required library base, convert earlier created base into new format and take other measures in order to transfer to the new design system [18].

At that, it is expected that digital approach implementation will become effective provided that all employees change over for the new technology. Labor productivity of employees at initial stage will

fall since training, knowledge deepening and acquisition of skills needs time; after that it is expected to increase. According to expert evaluation of companies who changed over for digital technologies, period of further labor productivity recovery lasts during 3–6 months. Transition from CAD to digital visual modeling technologies gives labor productivity growth of about 30–50% (in some cases 100%) [4].

5. Conclusions

In summary it is necessary to underline that in the current context of activities conducted by construction companies efficient construction monitoring and control serves as an essential competitive advantage. Monitoring and control of construction process shall be carried out at initial stage beginning from pit excavation till object commissioning and further operation thereof and shall be aimed at emergency accidents prevention.

Monitoring and control in construction – additional tool necessary to verify: proper implementation of design and construction works, employment of high-quality construction materials, items and structures, efficient methods of construction control and acceptance and, accordingly, provision of safe and long-lasting life cycle of capital construction objects.

World experience proves efficiency of digital technologies implementation in the construction sphere. In particular, use of digital technologies in design and construction by Russian construction companies allows decreasing costs by 20%, reducing work deadlines by 10–12% and thus considerably lowering indirect costs [4].

Today in Russia there is a sufficient legal-regulatory, methodological and technical basis for digital technologies implementation for the purpose of construction monitoring and control. Most powerful capabilities are provided by visual 4D modeling enabling the user to develop a unified spatiotemporal plan of the project optimized in regard of resources and costs. However, currently applicable methods and means of construction monitoring and control are in most part instances are expensive for the majority of companies. Modern automated monitoring and control systems are used by rather small number of construction holdings and have certain limitations for smaller construction companies.

Acknowledgements

The article was prepared as part of the work on the grant of the President of the Russian Federation NSh-4028.2018.6

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