Project management in large-scale construction: development of approaches in the conditions of digitalization

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Abstract. The economic situation of 2020 showed that the sustainability of the implementation of large-scale construction projects is determined by a substantiated project life cycle strategy and the effectiveness of technologies and project management methods. The article presents an analysis of the current domestic and foreign experience of project management. Practice shows that the organizational and technological features of large-scale projects in construction are so individual and complex that it is rather difficult to apply general management principles in the process of their implementation. Therefore, in large-scale construction, it is necessary to highlight separate management principles for local projects (with internal funding) and object projects implemented by several participants - general contractor and subcontractors under contracts concluded. The methods of management that are applicable within the framework of management processes at successive stages of the life cycle of a construction object are systematized. A number of specific IT methods and management models are considered, the most promising from the point of view of use in the organization and management of large-scale construction. The systematization of processes and methods of management by phases of the life cycle of a construction object is proposed. Systematization can be recommended to design and construction organizations, municipal and state customers, and other participants to effectively solve applied problems of large-scale construction management in the context of digitalization.

1. Introduction
The share of large-scale construction projects in the modern investment economy is constantly increasing. At the same time, the economic situation that developed in 2020 due to the pandemic clearly showed that the success of the implementation of projects of this level very much depends on a well-founded project lifecycle strategy and on the effectiveness of project management methods and approaches. In recent years, the concepts, methods and tools of project management, which constitute the theoretical and practical basis for the management of large construction projects and complexes, have been intensively developed. The project management methodology incorporates everything new and effective from the theory of management and the practice of the activities of design and construction organizations, municipal and state customers, developers, and other project participants [1-3]. Many new specific technologies and methods of project management have entered the management practice, which came to construction not from production, but from the software industry of the IT sector.
The current domestic and foreign experience of project management must be analyzed and summarized in order to understand which methods and mechanisms correspond to the specifics and features of large-scale projects in construction and can be used for more effective management of such projects in modern conditions and risks.

2. Materials and methods

In general, large-scale construction projects as management objects are based on general management principles [4-6]. The basic principles of project management include unity of project management, maintaining a balance of interests of project participants, voluntariness of participation in the project, determination of the most economically feasible project option, phased implementation of the project (idea and initiation, implementation, closure), and, in addition, a number of principles: openness, awareness, regulation, etc. [7].

At the same time, practice shows that in relation to large-scale projects in construction, the signs and organizational and technological features of projects of this level are much more individual and in the process of project implementation it is rather difficult to effectively apply the above principles in management [8-10]. This is primarily due to the organizational and technological features of construction as an object of management and with significant differences in construction projects with internal and external financing. Projects funded by the organization itself or internal projects include projects to introduce new technology, improve the structure of the organization, enter new market segments, and similar examples of projects. From this point of view, it is logical to classify almost all orders in construction, which are carried out under concluded contracts, to external projects. For a general contractor, this is the construction of buildings and structures, for subcontractors - the performance of specialized work.

Most of the general principles and management methods described in the scientific literature are applicable mainly to internal projects or such external projects, the participants of which are concentrated in one organization. Let's designate them as internal projects.

External projects implemented by several organizations and project participants, according to the logic of the budget terminology, will be called object projects. An object project can combine multiple internal projects. The internal project is managed by a team formed from the permanent employees of the organization, and not from outside representatives. The position of a project manager or project team leader is hardly discussed at all. In a project, an external or object manager can be with a government customer, a technical customer or a general contractor [11].

The principles and approaches to managing a large-scale project for technical customers, developers and EPC-contractors are significantly complicated, since here the system of concluded project contracts often covers several dozen different contractors [12]. Therefore, it should be determined: are the same principles of project management applicable for internal and object projects?

First of all, it should be noted that for the relationship of the customer, designer and contractor, the principle of a single management practically does not work - their relationship within the project is equal and is determined by the terms of the contractual relationship [11, 13]. In addition, the principle of a single project team is based on a single focus on the interests and goals of its participants [14]. In practice, in addition to the final goal of building a building by common efforts, the interests of the project participants are not only very different, but often multidirectional: the investor is trying to reduce the cost of construction, and the contractor is trying to increase the cost of work; the technical customer seeks to shift the tasks and work of coordinating the project to the design organization, but that requires additional payment and etc. [15].

Also, in large-scale external projects, the principle of choosing the most cost-effective option is practically not implemented [16]. If we consider this principle from the point of view of the state customer, then ensuring the fulfillment of the order is his official duty, for which he does not receive any money. The contractor would like to receive the most profitable construction order, but in the order market he faces stiff price and other types of competition, as a result of which he often receives only small municipal orders.
Consider a number of specific management methods and models that are most interesting from the point of view of use in the organization and management of large-scale construction [117÷21].

The so-called waterfall model is very close to reflecting the features of the organization of construction (Waterfall). The waterfall model was widely used by programmers during the 1980-2000 periods. Here management was structured into seven clearly defined phases: assignment — design — coding and testing of modules — integration — system testing — installation — maintenance. In a waterfall model, the phases follow one after another in sequence, and calendar schedules can be used. Another method widespread in the 2000s is called “PRINCE” (Projects in a Controlled Environment). In this method, management in the same way is represented as a sequence of six stages, close to dividing the project into phases: start — initiation — decision making — control by deviations — production management — management of stage boundaries — completion [22, 23].

In the creation of complex software, as well as in construction planning, the Critical Path Method (CPM) is often used, which forms the basis for mathematical modeling of the development of production processes in time. A method that takes into account the dependence of processes on consumed resources, as well as additional uncertainty and risks of work and project events, time reserves of work, is called the "critical chain method" [24]. To account for the uncertainty in control, the Monte Carlo method is also often used, which simulates random fluctuations of various factors influencing the project. In German-speaking countries, the Petri nets method has become widespread, which is used to manage repetitive production cycles, while it can also be applied to project management. Unfortunately, this method is little known in the Russian Federation [25].

Some of the problem-oriented and aspect-oriented methods are economic methods. For example, the Lean method, known as lean manufacturing, eliminates redundant functionality and long development cycles. Another method is “Benefit Realization Management”. Here, the target function is to search for the maximum economic efficiency for investors; accordingly, this method is optimization.

In the concept of process-oriented project management, PBPM (English — Process-Based Project Management), the basic setting is the constant analysis of the compliance of management processes with the company's strategic goals. Project implementation is structured as a cycle consisting of phases: planning — process analysis — design — implementation — handover to the customer — operation. The emphasis here is on project functions, which is close to configuration management methods, requirements, development quality, etc. [26].

Another method of project management is Six Sigma (σ is the standard deviation of the normal distribution). In project management using this method, they try to bring the number of design errors to a statistically insignificant value, since with deviations up to ± 3σ in each direction, the number of defects does not exceed 0.27%. The cyclical sequence of phases of a project in the Six Sigma method is built as follows: definition - measurement - research - development - control.

Some of the methods that came into control from the programming sphere are difficult to consider generally applicable. So, for example, in the Kanban method (Japanese 看板 — signboard) the following principle is implemented — the volume of work of the current stage is determined not by the capacity of the performers, but by the needs of the subsequent stage of work. To do this, unfinished products are transferred to the next stage to another team of performers based on the performance limit of each team of participants in all stages of production or a project. This approach is fairly close to the in-line construction management method. The difference is that a systematic transition to other captures is not considered. In industry, the method is interpreted as a production and technological chain with minimal storage of an intermediate product, and is part of a flexible production management technology.

In the early 2000s, Agile, based on iterative approaches to software development, was widely used. In this approach, the creation of a product or project is divided into subprojects, the development cycle is repeated, and the results of each cycle are presented to the customer. In terms of content, the method is somewhat reminiscent of the construction and assembly cycle, tied to the monthly delivery of the volume of work. In this case, the economic basis of the cycle is formed by monthly payroll and
financial reporting. The essential difference is that the construction process is not an iterative and repetitive process. Adaptive project management (Adaptive Project Framework – APF) is referred to as flexible methods of management based on initial conditions and requirements for the result. There is no clear division into stages, subprojects and phases. [27]. Also, the method of extreme project management belongs to the flexible methods of project management (Extreme Project Management, XPM). Here, the emphasis is made on the fact that the initial phase of the project is characterized to some extent by an unclear goal and uncertain conditions and that can be changed many times during the implementation of the project [28]. Another specific control method is a system called «Scrum» (scribe as well as Scribing United Methodology — Unified markup methodology). This method divides the execution of the project into short and intensively performed parts — jerks or sprints, implemented by a small team of professionals. The results of each short stage or sprint are agreed and approved by the customer. To achieve the goal of the project, the system has a set of software and hardware products for managing flexible workflow, for internal exchange of documentation and knowledge, for interaction between developers and tracking overloads. [29].

3. Results
All these practical patterns lead to the need in the construction industry to highlight separate management principles for internal and object projects. The analysis shows that for object projects, the purpose of which is the implementation of orders for the construction of buildings and structures, as the main ones it is necessary to focus on the following management principles:

- a competitive basis for the selection of participants in project contractual relations;
- comprehensive justification and careful observance of the terms of contracts;
- reasonable and proportional economic profitability of the project for all project participants as a target;
- mandatory creation of reserves required to cover project risks, pay for unforeseen work and insure the project in various ways;
- implementation of the function of coordination of project participants by the project manager;
- the formation of a construction headquarters or a project team from among representatives of organizations involved in the construction;
- organization of independent work control with the involvement of an expert, consulting or engineering firm;
- ensuring equal load of organizations implementing several projects as a function of the heads of these organizations;
- the place of the head of the object project should be in the main organization for this project - at the customer (state or technical), general contractor, investor or developer.

A common problem in the application of existing management methods and their classifications is also their inconsistency in many cases with the management phases. For example, among the methods, authoritarian and democratic methods of management are shared. The question arises, is it possible to apply this classification, for example, at the planning stage? Is there authoritarian or democratic planning?! Most likely not, while among the planning methods, network, calendar, structural, resource and other methods are logically distinguished.

For the cost management the earned value method is often used, which allows us to monitor the construction project progress. For internal project, the earned value is determined unambiguously as common cost. However, for an external project, the customer, General contractor, and subcontractors have different cost structures. Therefore, the authors recommend that the customer determine the earned value as contract price, the General contractor - as total cost, and subcontractors – as the amount of their own costs.

In addition, estimating the total cost of the project may produce erroneous results. For example, contractor performs the necessary amount of work, but not on those objects that are important for
construction in general, but on those where it is more convenient for him. As a result, the volume is completed, but the result is missing.

To prevent this, the authors recommend that only critical path work and subcritical work on schedule should be included in the earned value.

Effective solution of practical management problems requires substantiating and defining project management methods applicable at certain phases of the project. Let's analyze the initial differences between the processes and phases of management. In project management, as a rule, a sequence is determined corresponding to the four phases of the project life cycle: concept, development phase, implementation phase, completion phase.

In construction, several other, more specific industry terms are used: concept or pre-design phase, engineering, construction, commissioning of an object. Project management techniques applicable to sequential project phases and management processes are organized in a matrix (Figure 1).

![Figure 1. Construction Project Life Cycle and Management Cycle: Matrix of Applicable Management Practices.](image)

It should be emphasized that the phases of the life cycle of a project and a construction object generally do not completely coincide. The life cycle of a construction object includes not only commissioning, but also all operational phases, including current maintenance, and all types of repairs, stages of modernization and completion of operation [20]. At the same time, at all stages of the life cycle, it is possible to distinguish repetitive management cycles consisting of sequential management processes, such as planning — implementation — control — adjustment (in the Deming-Shewhart cycle: Plan — Do — Check — Act). The management cycle is formed as a consequence of the production cycle and is determined by its characteristics. Therefore, despite the fact that the management of a construction project is a non-cyclical activity, many cycles and even continuous processes are formed within it.

The duration of the control cycles and processes is different. For example, the control cycle for a construction equipment is measured in minutes required to complete a construction sequence. The team management cycle can last minutes or hours, usually within one shift. Within a building management or site, management cycles are measured in days and weeks and are reflected in weekly-daily charts. The management cycle at the management level of a construction organization can be linked to monthly operational and accounting reports. If we consider the strategic management of a
company, including positioning on the market, development and justification of development directions, updating the technical park of a construction organization, then the duration of such cycles can be calculated in years. Management cycles of different hierarchical levels are integrated and synchronized with each other, thereby forming an integral structure for managing modern production and large-scale construction.

As the analysis of construction management practice shows, different methods, approaches and concepts are used at different stages of management and in a variety of management processes. In particular, the following management methods are effective in almost all phases in relation to the planning process: normative, analog, expert, predictive. At the same time, there are a number of features in construction. If at the design phase (project development) the normative method is based on the use of estimated norms and aggregated indicators, then at the construction phase (project implementation) it is required to apply more accurate production standards for the consumption of material and labor resources. During the construction phase, balance and factor planning methods can be used, while in the phase of developing the idea and concept of the project, there is usually not enough data for these management methods. Similarly, for the management of work in the phases of concept, design (development) and construction (implementation), the method of structuring goals, the flow method of organizing work, and others can be effective. At the same time, the nodal, complete-block, combined and other methods are applicable only to the construction phase, although it is obvious that the prerequisites for their successful use are formed in the earlier phases of management.

Along with general methods in project management, specific management methods have been increasingly used recently. Unlike project management, specific methods of project management were formed not in production, but initially by software developers in IT sector companies, which influenced their methodological approaches and tools. First of all, these methods are mostly focused on internal or local projects, the executors of which work at the same enterprise. Because of this, development results, scope of work, composition of performers and project participants, including invited organizations and individuals (contractors, consultants, etc.) are not clearly indicated, the composition and timing of work can often change.

During a rather short history of the development of the IT sector, the methods of software development have changed several times. In parallel with the formation of high-level programming languages, procedures and functions appeared that became the basis of the procedural software architecture. The stages of development were highlighted, information and mathematical support was formed, the principle of modular organization and packages of applied programs began to be applied. At the initial stage of the development of software methods, preference was given to top-down programming (from general to specific), which was subsequently replaced by object-oriented programming aimed at developing large systems. Dozens of conceptual solutions, platforms, processes and methods of software development have been developed and applied, including problem-oriented and aspect-oriented methods. Some of these methods have prospects for improving production management methods, the other part can hardly be applied in other industries and industries.

4. Conclusions
In general, an analysis of the organizational and technological features of large-scale construction projects as a management object showed the need to separate two classes of projects in construction - local (or internal) projects, the participants of which belong to the same organization, and object (or external) projects that are carried out under concluded contracts and a large number of contractors. Domestic and foreign experience in managing large-scale projects is considered, on the basis of which methods are identified that are most suitable for managing internal (local) and external (object) projects in construction. Management methods applicable in large-scale construction projects are systematized by phases of the project life cycle and management processes.

The analyzed patterns of the development of new specific management methods showed that they follow the intensive development of technologies and production conditions. A large number of methods, on the one hand, testifies to a wide range of management tasks, on the other hand, to an
insufficiently substantiated concept and scope of application of certain methods. At the same time, the accumulated successful experience in production and project management in other industries and the corresponding methods and tools can be used to improve the management of construction projects and should be integrated into the construction management system. The proposed systematization can be recommended to design and construction organizations, municipal and state customers, other project participants for the effective solution of applied management problems.

References
[1] Grabovy P G, Lunyakov M A 2015 Performance management in the investment and construction complex: planning, monitoring and level improvement Real Estate: Economics, Management No 2 S 11-13
[2] Ginzburg A, Kachanov S 2016 Methodology for Building Automated Systems for Monitoring Engineering (Load-Bearing) Structures, and Natural Hazards to Ensure Comprehensive Safety of Buildings and Constructions International Journal of Applied Engineering Research (IJAER) No 3, Vol 11, pp 1660-1665
[3] Ilyina O N 2016 Project management methodology: formation, current status and development Infra-M 208 p
[4] Polkovenikov A V, Dubovik M F 2015 Project Management Full MBA course Olymp-Business CJSC, 2015 – P 552
[5] Eken G, Bilginrem G, Dikmen M, Birgonul T A lessons-learned tool for organizational learning in construction Automation in Construction, Vol 110, February 2020, 102977, doi org/10.1016/j.autcon.2019.102977
[6] Bahramian M, Yetilmezsoy K 2020 Life cycle assessment of the building industry: an overview of two decades of research (1995–2018) Energy and Buildings, March 2020, 109917, doi org/10.1016/j.enbuild.109917
[7] Mok M K, QipingShen G A network-theory Based Model for Stakeholder Analysis in Major Construction Projects Procedia Engineering, Vol 164, 2016, Pages 292-298, doi org/10.1016/j.proeng.2016.11.622
[8] Ashish G , Ganesh L S , Arshinder K 2019 Sustainability integration in the management of construction projects: A morphological analysis of over two decades’ research literature Journal of Cleaner Production Vol 236, 117676, doi org/10.1016/j.jclepro
[9] Orlov A K 2015 Organizational and economic aspects of the implementation of investment construction megaprojects Economics and Entrepreneurship No 6-3 (59-3) S 545-548
[10] Malik S, Fareena F , Asma I, Lai F 2019 Improved project control for sustainable development of construction sector to reduce environment risks Journal of Cleaner Production, Vol 240, 2019, 118214, DOI org/10.1016/j.jclepro.118214
[11] Srinivasan N P, Dhivya S 2019 An empirical study on stakeholder management in construction projects Materialstoday PROCEEDINGS, Vol 21, Part 1, 2020, Pages 60-62, DOI org/10.1016/j.matpr.05 361
[12] Gusakova E A 2018 Organizational and technological genesis as a tool for strategic planning of large-scale real estate development projects “Business Technologies for Sustainable Urban Development” MATEC Web of Conferences Vol 170 6 p DOI: https://doi org/10.1051/mateconf/201817001015
[13] Guido Araújo A, Carneiro A M, Palha R P 2020 Sustainable construction management: A systematic review of the literature with meta-analysis Journal of Cleaner Production, Vol 256, 120350/ DOI: org/10.1016/j.jclepro.2020.120350
[14] Pavlov A S, Ginzburg A V, Gusakova E A, Kagan P B 2019 Management of large-scale projects for the construction of industrial facilities Monograph - Ministry of Science and Higher Education of the Russian Federation, National Research Moscow State University of Civil Engineering - Moscow: Publishing house MISIS - MGSU, 188 p
[15] Zhihun Ding Z, Liu Z, Liao L, Zhang L 2019 A digital construction framework integrating building information modeling and reverse engineering technologies for renovation projects Automation in Construction, Vol 102, 2019, Pages 45-58 DOI: org/10 1016/j autcon 2019 02 012

[16] Öncü H , Gündüz U 2019 A classification and review of approaches and methods for modeling uncertainty in projects International Journal of Production Economics, 107522, doi org/10 1016/j ijpe 2019 107522

[17] Stepanchuk O, et al 2017 Procedia Engineering 187 14–21. doi:10.1016/j.proeng.2017.04.344

[18] Goel Ashish L S, Arshinder K G 2019 Sustainability integration in the management of construction projects: A morphological analysis of over two decades’ research literature Journal of Cleaner Production, Vol 236 117676 DOI org/10 1016/j jclepro 2019 117676

[19] Ma L, Le Y, He Q, Zhang J 2013 Research on Organization Integration System towards Large and Complex Building Projects-From Life Cycle Perspective Procedia - Social and Behavioral Sciences Vol 74 Pp 31-40 DOI: 10 1016/j sbpro 2013 03 043

[20] Niknazar P, Bourgault M 2017 Theories for classification vs classification as theory: Implications of classification and typology for the development of project management theories International Journal of Project Management, Vol 35, Issue 2, Pages 191-203, DOI org/10 1016/j ijproman 2016 11 002

[21] Pérez G, Cabeza L 2017 Buildings Life Cycle Assessment Encyclopedia of Sustainable Technologies Pp 275-290 DOI org/10 1016/B978-0-12-409548-9 10194-0

[22] Picciotto R 2019 Towards a ‘New Project Management’ movement? An international development perspective International Journal of Project Management, DOI: org/10 1016/j ijproman 2019 08 002

[23] Patanakul P, McCarron R 2018 Transitioning to agile software development: Lessons learned from a government-contracted program The Journal of High Technology Management Research Vol 29 Issue 2 Pp 181-192 DOI.org/10 1016/j hitech 2018 10 002

[24] Nagata M, Marginelli J Scott P E, Trauner T 2018 Delay Analysis Using Critical Path Method Schedules Chapter Seven - Construction Delays (Third Edition) Imprint Butterworth-Heinemann Pp 133-202 DOI org/10 1016/C2015-0-00387-2

[25] Ozkan O, Kilic S A 2019 Monte Carlo Simulation for Reliability Estimation of Logistics and Supply Chain Networks IFAC-PapersOnLine Issue 13 Vol 52 Pp 2080-2085 DOI org/10 1016/j ifacol 2019 11 512

[26] Osterloh M 2006 Frost J Process management as a core competence: how you can use business reengineering strategically 5th edition - Wiesbaden: Th Gabler | GWV Fachverlage GmbH, 2006 302 pp (in German)

[27] Papadakis E, Tsironis L 2018 Hybrid methods and practices associated with agile methods, method tailoring and delivery of projects in a non-software context Procedia Computer Science 2018 Vol 138 Pp 739-746 DOI org/10 1016/j procsc 2018 10 097

[28] Yifan Yang Y, Thomas S, Xu F J, Skitmore M 2018 Towards sustainable and resilient high density cities through better integration of infrastructure networks Sustainable Cities and Society Vol 42 Pp 407-422 DOI org/10 1016/j scces 2018 07 013

[29] Lei H, Ganjeizadeh F, Kumar P, PinarOzcan J 2017 A statistical analysis of the effects of Scrum and Kanban on software development projects Robotics and Computer-Integrated Manufacturing February Vol 43 Pp 59-67