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Maciej BANACH, Roman MARCINKOWSKI[1]

Faculty of Civil Engineering, Mechanics and Petrochemistry, Warsaw University of Technology

Supporting the planning of assembly works using computer techniques

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Introduction

Planning construction works is a creative process aimed at defining goals and determining ways to achieve them (Marcinkowski, 2002). It is the most important element of effective management of construction production, having a key impact on the final financial result of completing a construction project. Therefore, the right organization of construction works, closely related to the pace of construction works, minimizing downtime in brigades work, Jaśkowski and Tomczak (2017) should be seen as the possibility of achieving measurable benefits from construction production. Therefore, in the scientific activity, it is necessary to look for organizational techniques that allow to optimize decisions and plans for the implementation of construction processes. This optimization may take place in relation to various criteria (cost, time of work, safety of work, degree of use of machines, reliability of the plan adopted, etc.). The weight of these criteria will also vary depending on the individual situation of the decision maker. The planning methods must be flexible in this respect – leaving the assessment of the quality of organizational solutions to the planner. The search for optimal solutions in the planning of construction works is, however, an overriding issue that should be taken into account by every creator of the new method or organizational technique.

Building objects using assembly techniques has been used for a long time. There was always an opportunity sought in prefabrication for facilitating the construction process, reducing costs and improving the quality. In recent years, a definite return to precast technology in Central and Eastern Europe has been observed. In Poland, prefabrication dominated the market of industrial facilities, it is also popular in the service construction. The smallest share of prefabrication is reflected in multi-family housing due to bad past experience related to the so-called big block. Nevertheless, the first pilot investments of multi-family housing are being made entirely in the technology of modern prefabrication (Fedoruk, 2017). The currently observed development of prefabrication will be a permanent trend in the 21st century in construction and will meet the technical, economic, ecological and social expectations (Adamczewski & Woyciechowski, 2015).

In the construction of prefabricated objects, means of transport and lifting equipment play a crucial role. Modern standards of this equipment and its high availability on the construction market set new challenges for the organizers of construction works. When building large-scale objects, several, or even a dozen or so lifting devices can be used on the construction site at the same time. In such cases, the planning of assembly works, the selection of types of lifting devices, their number, size and distribution become significant, and its solution is difficult, because it depends on many variables. A rational set of machines may be specified for specific technological and organizational solutions. It is necessary not only to specify a set of machines, but also details of organizational solutions (schedules, costs, assembly plans, etc.).

The literature presents many solutions related to the methodology of planning the work of construction cranes, but mainly works with one type of construction cranes – tower cranes (Tork, 2013; Frenz, Kessler & Günthner, 2014). The issues of planning is often reduced to the problem of a travelling salesman who is a good representation in the case of works in monolithic technology, but does not reflect the way of conducting assembly works.

The purpose of the undertaken research and analyses is to develop a system supporting the planning of assembly works in cubature construction, the outline of which is presented in this paper.

Determinants of organizational solutions

Preparation of a tool for planning a specific construction activity is associated with the need to identify conditions that may be important for its organizer. Undoubtedly, the pace of work (production) and costs are important in organizing each production activity. In translating the construction as an assembly method, it will be the rate and costs of the building assembly. The condition for the organizer may include the defined date of completion of works and budget of the undertaking. However, in many planning situations, the implementation cycle and costs of carrying out works will be the criteria for assessing the quality of the organizational solution. However, it must be realized that building constructors have different preferences in the assessment of organizational solutions than investors. They strive to minimize the costs of works through the prism of their production potential. Therefore, their goal is not to quickly implement works on one (planned) construction, but to effectively use the existing production potential – construction equipment and workers (especially specialists).

In the assembly technique construction, planning works in the situation of using many assembly machines is a key element of effective management of the construction project. Logistics related to the delivery of materials for the construction, their storage, delivery to the place of installation and assembly is a difficult organizational issue. The software for planning assembly works, taking into account the aspects of reflecting this work in reality, the impact of weather on the ability to conduct work, valuing various organizational solutions, monitoring the technical conditions for the implementation of works is needed.

With regard to the problem of planning the transport of prefabricated elements to the construction site, the identification of transport situations and cycles in prefabricated construction results in the conclusion that in reality this transport is not continuous. Thus, it is not possible to import the problem of existing transport system models, such as queue theory (TOM), or some scheduling systems (CYKLONE). Therefore, in the model of the transport system, it is necessary to take into account the specific boundary conditions of the transport cycle, specifying the amount of transportable goods, due to two criteria: load capacity and the size of the cargo space. It became necessary to carry out observational studies in order to determine the loading/unloading times of individual prefabricated elements and average speed of transport vehicles, as well as surveys to determine the labour costs of transport means. These data are necessary to build a transport measure work plan model minimizing the cost of transport operations and ensuring the continuity of cargo deliveries to the construction site. It was assumed that in the planning of transport, we determine the type and ranking of means of transport in the transport system and the number of transport means ensuring the continuity of assembly machines.

The main problem to solve in the organization of assembly works is the optimal selection of types, number and locations of assembly machines. The model system of assembly management on the construction site should be based on cost-effective unitary cranes carrying out the main work, placed as far as possible in the centre, to cover the largest area of the construction site. However, places not served by these cranes, or requiring service by a larger number of assembly machines should be supported by mobile cranes.

Depending on, for example, the size of the building or the space it occupies, it can be profitable to use only one type of cranes: stationary or mobile. Nevertheless, as an assumption, the computer system algorithm should make it possible to plan the cooperation of both types of cranes. This approach is the main problem for building a mathematical model supporting organizational decisions. It was assumed that the decision of the planner will be made to determine preferences whether economic stationary cranes should be used for work first, and if there is not enough capacity, include mobile cranes or separate elements for assembly parallel to all assembly machines. An important issue to be solved is the possibility of moving mobile cranes. The algorithm should search for the next place declared by the planner as possible locations of assembly machines and other mobile cranes in order to search for the location enabling the assembly of the given element, in the order resulting from the permutation of accepted sets for each planning sample. This approach significantly increases the number of solutions. The construction of the model requires setting the characteristics of the working processes, e.g. assembly times for individual types of elements, or switching times of moving assembly machines. Therefore, it was necessary to carry out studies on observational working processes of assembling prefabricated elements.

Outline of the planning decision support system

The solution of the problem was based on mathematical models supporting both the selection of transport means to perform the transport task and the selection of lifting devices to perform the assembly task. These models proposed the use of the Monte Carlo method and logic algorithms based on observational studies and questionnaire regarding assembly works. It was found that in order to increase the usability of the planning tool being created, it should be enriched with expert knowledge supporting the planner in the initial choice of solutions. This allows you to approximate the computer analysis system to the construction practice. The block diagram of a computer application prepared to support the planning of assembly works is shown in Figure 1. The editorial limitations of this article do not allow the presentation of the details of the analysis of the planning decisions. Therefore, we only present the functional structure of this tool.

The output data is the starting point for work planning. These are the characteristics of prefabricated elements, spatial data of the object, data sets on transport means and assembly machines – available for the contractor of the planned works. The organizational conditions have a closed form in the adopted concept. The planner can activate them by selecting them from the list. Then, computer planning of works begins. They are preceded by a draw of permutations: means of transport, assembly machines and locations of assembly machines. These permutations determine the order of elements (means, machines and places) to be considered in programming the work of transport means and assembly machines, taking into account their location.

Programming the assembly organization is the main block of the computer system. It is equipped with databased and knowledge bases obtained during the research of assembly and transport processes. Analyses are carried out according to algorithms developed on the basis of knowledge obtained from entrepreneurs and logical elimination of unused/unacceptable solutions. The programming of the assembly may be conditioned by transport, or the transport may be conditioned by the organization of assembling prefabricated elements on the site. For each planning test, permutations (the “Draw” block) are set, programming of the assembly organization, and the result – the schedules, the completeness of the assembly, the assessment of the plan quality (costs, use of machines)

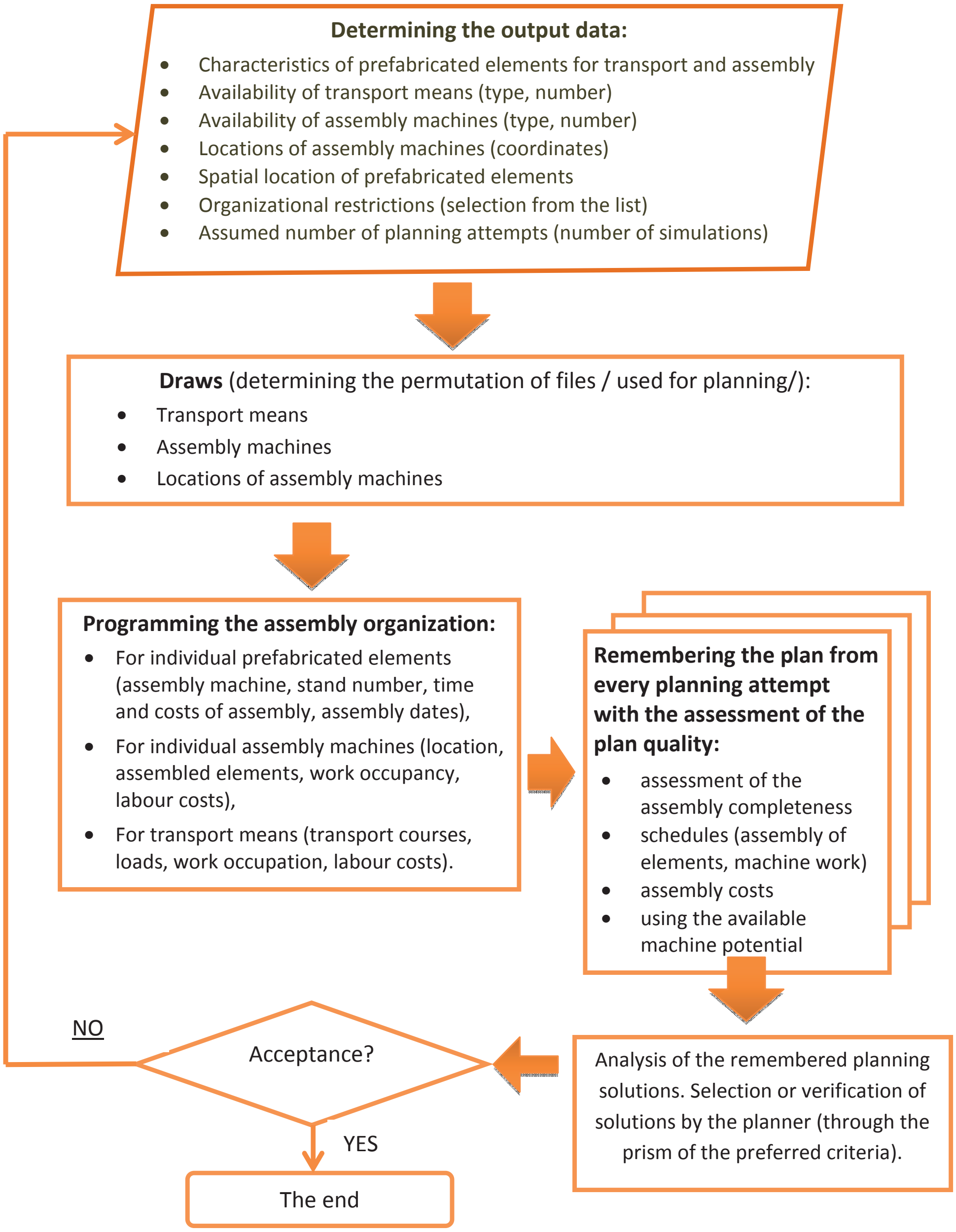

FIGURE 1. A block diagram of a program supporting the planning of assembly works (own elaboration)

are saved. The planner decides about the number of draws, bearing in mind the quality of the result resulting from the large number of attempts, and on the other hand the limitations resulting from the efficiency of the computer unit and the related planning assembly size and complexity.

The saved planning results are evaluated and verified by the planner. He can change the preferences for using the machines, some restrictions, and undertake another planning attempt. The planner can choose several solutions and try to further analyze the risk related to meeting the deadline and expected costs, e.g. using the theory of fuzzy logic or methods of multi-criteria comparative analysis. He can also complete the planning process by selecting one of the saved planning solutions.

Software supporting work planning

The computer program supporting the planning of assembly works is the final result of the research, analyses and assumptions. The developed tool consists of two independent, but cooperating parts. The first one is devoted to the planning of transport of prefabricated elements to the construction site. After the planner determines the output data, the program returns solutions in the form of the number of transport means used, the cost and time of the transport operation as well as the degree and schedule of using loading and unloading brigades. The planner has the ability to sort results and make changes and perform recalculations in order to search for a more favourable solution in a given situation.

The results from the first part of the program, taking into account the delivery times of prefabricated elements to the construction site, may form the basis for commencing the planning assembly, or *vice versa*, their transport planning should depend on the basis of the desired delivery dates for prefabricated elements to the construction site.

The second part of the developed tool allows for the planning of assembly works using construction cranes. Planning starts with the introduction or import of a list of elements to be assembled along with the array (matrix) of the necessary characteristics. Ultimately, the import function is planned to be coupled with BIM software to automate the work planning process. Secondly, the stationary and non-stationary assembly machines should be selected for work from machines that were imported to the program along with the characteristics. It is possible to update variable data, such as: the distance between the location of the crane from the construction site, the cost of assembly and disassembly of a crane, the unitary cost of the crane and the border stopping time, i.e. crane breaks at work above which the program does not charge crane costs.

Programming the organization of assembly takes place in the module/ /program tab, the generalized view of which is shown in Figure 2. In this tab, first, one has to determine the number of draws, start and end time of works, safe distance between the assembled structure and assembled elements and the priority of using stationary machines. It

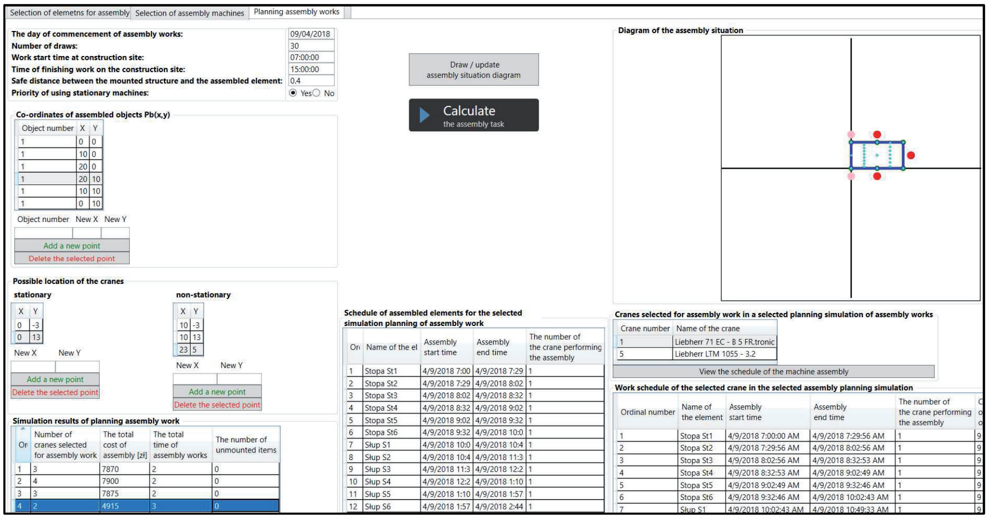

FIGURE 2. Tool supporting planning assembly works. View of the main assembly planning tab (own elaboration)

is necessary to define the coordinates of the corners of the assembled objects and the possible locations of stationary and non-stationary assembly machines. After clicking the "Draw/update assembly situation diagram" button, the data entered is shown in a simplified scheme of the assembly situation, where alongside the assembled objects, potential locations of assembly machines, elements for assembly are also marked. After entering the discussed data, start the calculations with the "Calculate the assembly task" button. If it is not possible to assemble with the available assembly machines in the selected spots for their locations, the window for selecting a stationary crane and its location is activated in order to check the assembly possibilities. The planner has the opportunity to search for a solution on his own or can rely on an algorithm that searches for available cranes and their locations.

The results for individual numbers of draws are visible in the form of a table. The program enables the sorting of results in terms of costs and time of completing the assembly task, the number of unmounted elements or the number of cranes used for work. For each simulation, it is possible to display the order of assembled elements with information about the date of commencement and completion of assembly and about the crane planned to perform the assembly of the given element and its location. In addition, it is possible to display a work schedule for each crane employed to perform assembly works for a selected draw number in tabular and graphical form.

The planner can obtain increasingly better planning results (in relations to the selected criteria) through work in the program, which consists in introducing new locations of the cranes, changing the range of available cranes, changing the priority of stationary machines' operation.

Recapitulation

The development of computer techniques for planning construction activities requires a lot of research, analyses, programming approaches and practical verification. The paper presents the selected aspects of the construction of a tool for planning the work of assembly machines in the construction of prefabricated cubature buildings. Detailed research was carried out on the work processes related to the execution of assembly works. Using surveys, the market characteristics of assembly machines and criteria for tenants in their selection were determined, observational studies were carried out for various types of assembly machines and various types of prefabricated structures. The pace of their work, assembly and disassembly times, preparation for work, shifts (in the case of self-propelled cranes) were subjected to observations. The times of loading and unloading along with the assembly and disassembly of typical prefabricated elements were also estimated, which are supposed to be a hint for the planner. As part of the surveys conducted among contractors of assembly works and renters, the availability and demand for particular types of assembly machines was determined, along with the criteria and their significance level (used in the selection of machine types) as well as costs related to their transport, assembly and current work. This knowledge allowed to define the concept of a system supporting planning decisions related to the organization of assembly works.

Simulations of planning assembly works using the proposed planning tool confirm the effectiveness of computer support. It is advisable to continue its improvement after verification of assumptions, knowledge bases, planners' requirements, and construction conditions.

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Summary

Supporting the planning of assembly works using computer techniques. The paper presents the selected aspects of the construction of a tool for planning the work of assembly machines in the construction of prefabricated cubature buildings. The solution of the problem is based on mathematical models supporting both the selection of transport means for carrying out the transport task and the selection of lifting equipment to perform the assembly task. The functional structure of the developed tool, the scope of research and a description of the planner's cooperation with the computer system are presented.

Authors' address:
Maciej Banach, Roman Marcinkowski
Politechnika Warszawska
Wydział Budownictwa, Mechaniki i Petrochemii
ul. Łukasiewicza 17, 09-400 Płock
Poland
e-mail: Maciej.Banach@pw.edu.pl
Roman.Marcinkowski@pw.edu.pl