Using a Tabu-search Algorithm and 4D Models to Improve Construction Project Schedules

Author(s):
García de Soto, Borja; Rosarius, Anton; Rieger, Jochen; Chen, Qian; Adey, Bryan T.

Publication Date:
2017

Permanent Link:
https://doi.org/10.3929/ethz-b-000227358 →

Originally published in:
Procedia Engineering 196, http://doi.org/10.1016/j.proeng.2017.07.236 →

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 196 (2017) 698 – 705

Procedia Engineering

www.elsevier.com/locate/procedia

Creative Construction Conference 2017, CCC 2017, 19-22 June 2017, Primosten, Croatia

Using a Tabu-search Algorithm and 4D Models to Improve Construction Project Schedules

Borja García de Soto[a]*, Anton Rosarius[b], Jochen Rieger[b], Qian Chen[a], Bryan T. Adey[a]

[a] *Institute of Construction and Infrastructure Management, ETH Zurich, Stefano-Franscini-Platz 5, Zurich, 8093, Switzerland*
[b] *ETH Zurich, Stefano-Franscini-Platz 5, Zurich, 8093, Switzerland*

Abstract

Construction project managers are interested in completing their projects on time and within budget. To do that, they often develop project schedules using a set of standardized tools, such as the Program Evaluation and Review Technique (PERT), the Critical Path Method (CPM) and bar charts. Although useful, these tools offer little help regarding the spatial context (i.e., visualization of conflicts among construction activities) as well as determining the optimal schedule with respect to time, cost and resources. The considerations of these two aspects are left to expert opinion, which can sometimes lead to unexpected conflicts during construction and, in turn, result in project delays and added costs. The main steps of the methodology presented here include 1) the determination of optimal schedules using Tabu-search algorithm that accounts for single or multiple objectives (e.g., duration, costs, resources) depending on the project requirements or project management needs, and 2) the integration of project visualization (i.e., 4D models). The visualization of the optimized schedules allows the project team to check the schedule for completeness and to ensure that sequencing and constructability requirements are satisfied. During the visualization process, further refinement of the schedule can be done. The proposed methodology is demonstrated by using it to create the schedule for a one-story steel-frame building. It is shown that the presented methodology results in an improved schedule for the example project over one that may be expected to be generated without this methodology. The best improvements that could be achieve corresponded to a 13% reduction in the project duration, 4% cost reduction, and 49% decrease in resource fluctuation.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2017

Keywords: 4D modeling technology; critical path method; multi-objective schedule; PERT; Tabu-search algorithm

*Corresponding author. Tel.: +41 44 633 92 30
E-mail address: garcia.de.soto@ibi.baug.ethz.ch

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2017
doi:10.1016/j.proeng.2017.07.236

1. Introduction

State-of-the-art scheduling tools include a number of building information modeling (BIM) software, such as Autodesk Navisworks, Bentley ConstrucSim, Vico Office Suite, or Synchro Professional. These tools can help different stakeholders and construction project managers control construction activities and check for conflicts during the design phase [1]. With a multi-dimensional perspective, the implementation of such software can facilitate major improvements in visualizing a whole construction process [2]. Different BIM software has been developed to support schedule decision-making, especially in terms of helping managers to obtain valuable insight into details of construction conflicts that were difficult to identify only using conventional scheduling tools or static 2D drawings.

However, the challenge and ability to recognize individual construction activities (i.e., tasks) and to analyze their associated scheduling data in the multi-dimensional model should be addressed over time. Several researchers have proposed automated schedule planning methods based on 4D schedules. The term 4D scheduling refers to the generation of a schedule by linking 3D model components with their corresponding tasks, including logic and duration [3]. 4D modeling techniques are no longer a simple combination of 3D elements with a rigid time dimension; in fact, they are expected to be a dynamic tool that can be used to improve the quality of construction schedules.

Various disadvantages have been revealed during real applications of 4D modeling (e.g., Shanghai Tower, Burj Khalifa mega project). One of the main problems lies in the way that 4D model-based project planning remains static, that is, it still separates building components in 3D models and a dynamic project schedule, which hardly shows consecutive tasks as a progression over the lifecycle of a project [4]. Another weakness was found when the information from the bill of quantities, extracted from the 3D models, is not efficiently used to support the decision making of scheduler planners [5]. A lack of optimization algorithms utilized for 4D models also causes it to fail to express precedential sequence of working units with the complicated finish-to-start relationships [6]. Although researchers have developed non-heuristic mathematical models, such as multi-objective fuzzy linear programming algorithms [7], for different scheduling problems, they do not produce necessarily feasible solutions due to their computational constraints (i.e., cannot guarantee the nearest optimal solution).

In fact, an increasing number of related studies have shown improvement in scheduling optimization with the use of modern heuristic algorithms, specifying multi-objectives. For instance, by combining the shortest processing time and ranking fuzzy numbers, heuristic methods can solve scheduling problems under uncertainty [8]. The Ant Colony algorithm has also been used as an example of stochastically building solutions, which considers heuristic information (i.e., scheduling data used for heuristic moves in order to find the optimal solution) of the construction scheduling network [9]. The Tabu-search algorithm, validated through comparison with other scheduling optimization techniques, shows a strong ability to handle portfolios of multiple large size projects [10]. The adaptive memory designs of Tabu-search also provide useful alternatives and supplements to the types of memory embodied in neural networks. Fuzzy Mathematics [11] and Genetic Algorithm theory [12], applied with a schedule simulator, have been proven effective in the generation of optimal schedules that can be visualized using 4D models. When comparing different optimization models, Pan et al. [13] found that the Tabu-search algorithm consistently gets better results for combinatorial optimization of construction schedules. Nevertheless, the results obtained from evolutionary algorithms should be seen as an optimized result, not the optimum result, since that cannot be guarantee with these methods.

With respect to current advanced scheduling techniques, some studies have offered new insights. The Precedence Diagramming Method (PDM) is the prevalent scheduling technique used for temporal planning of projects [14]. Another possibility is to integrate a decision-making system and BIM environments with an Industry Foundation Class (IFC) interface to automate the construction site management [15]. However, these studies suggest a desire to solve interoperability problems when integrating the decision making process of the schedules with the multi-dimensional visualization function of the 4D model. Although the focus of this study is not on interoperability issues, a simple framework is presented for the integration of these two parts.

With this background in mind, the main objective of this study was to develop a systematic approach for multi-objective scheduling optimization, which not only facilitates optimizing construction schedules by using modern heuristic algorithms, but also provides visualization of construction progress using 4D models. The proposed method does not only minimize the project completion time and cost while utilizing an appropriate resource allocation (as defined in [16]) using heuristic algorithms, but also consider implications on construction sequences and planning of the different project tasks. At the same time, the schedules developed using this method will provide decision makers with additional information that would allow them to consider key elements, such as constructability, accessibility, safety, and overall project coordination among different participants during the different phases of a project.

2. Methodology

The methodology contains two parts. In the first part, an optimized schedule is developed using a Tabu-search algorithm. In the second part, the feasibility of the optimized schedule is verified using a 4D model (i.e., visualization) and revised to account for specific project characteristics.

2.1. Step 1 – Extract project information from building information model in the required format

BIM provides parametric information of itemized construction materials and quantities. These sets of building information are associated with all the activities contained in a construction schedule. Due to different types of BIM software, the information can be extracted in various data formats. Construction project managers have several choices when deciding which type of data formats to be used. The most common format to store building information is the Industry Foundation Class (IFC), but to serve the purpose of executing the optimization algorithm, the required format of carrying the extracted data should be decided appropriately to fit its usage and avoid interoperability issues. Most CAD design software, allow construction material quantities to be exported directly to a spreadsheet, which can be used as a platform for utilizing building data for the optimization process.

2.2. Step 2 – Simulate critical path to generate an initial schedule

The initial schedule is generated as is normally done for construction projects, i.e., the project tasks and the sequential relationships between the tasks are identified, estimates of the length of time, resources and costs are made, and the critical path is determined using the Critical Path Method (CPM).

Using the Work Breakdown Structure (WBS) as a background, the main construction activities, and their sub-tasks (i.e., work packages), are specified. The lower level of the construction activities is used to define the network logic (i.e., precedence relationships). Task durations are determined using production rates (e.g., tons/man-hour for steel work, m^2/man-hour work for formwork, m^3/man-hour work for concrete work). To account for the variability of productivity rates (hence, task durations) the CPM is used in combination with the Program Evaluation and Review Technique (PERT). The stochastic consideration of task durations assumes that they have a beta-distribution.

Equation (1) is used to estimate the expected duration of each task. The standard deviation of duration of the activities was determined using Equation (2). Each task was resource and cost loaded. Then the critical path is simulated in every iteration with random durations according to the beta distribution. During each run, costs and resources of critical task are determined. This allows for the development of the initial schedule. The resource fluctuation is calculated based on the resource moment[†] method [17], according to Equation (3).

$$D_i = \frac{a + 4m + b}{6} \tag{1}$$

Where,
D_i = expected duration of task i
a = optimistic duration of task i
b = pessimistic duration of task i
m = most likely duration of task i

$$\sigma_i = \frac{b - a}{6} \tag{2}$$

$$M_t = \sum_{t=1}^{n} \frac{r_t^2}{2} \tag{3}$$

† The resource moment is an indicator to measure daily resource units that are consumed.

Where,
M_t = total resource moment
t = time interval index
n = total number of time intervals comprising the resource histogram
r_t = resource values of the t^{th} histogram interval

2.3. Step 3 – Set Tabu-search algorithm

Starting from the initial schedule determined in Step 3 (i.e., initial solution), the Tabu-search algorithm is set up in a way that searches for alternative solutions given some constrains. By changing iteratively and randomly the values of input variables, neighborhood combinations are generated and checked if they meet the predefined constraints. The primary elements of this step are summarized as follows:

- Simulation options: An activity has three time options. Each option has different values. The average option uses the random variable determined from PERT. The crash option allows activities to be conducted faster with higher costs. For simplicity, the crash option for each activity is defined proportionally to that of an average option. The delay option describes the number of working days that a task is shifted forward from an initial early start date to a later one. If a task is on the critical path, its delay would then result in an extension of the project duration.
- Objective function and search algorithm: the objective function (Z) is dependent on the item being optimized. It reflects how a new solution would meet the optimization goals. For every iteration of the Tabu-search algorithm the best solution is kept. Optimization targets are integrated using Equation (4) and standardized using Equation (5) (i.e., normalized between 0 and 1) to bring all of the variables into proportion with one another, taking care of the differences among parameters using different scales. The weights in Equation (4) are used to consider the effect of each factor during the schedule optimization (Step 4). The value of these weights should be chosen to allow for a sufficient variation of the scheduling goals, which depend on the project manager's requirements. Different combinations of weights for the factors used in the objective function are referred to as scenarios. Each scenario is meant to show the effect of the different factors when evaluating the scheduling goals. The objective function Z is optimized when x_i reaches a minimal value.

$$Z = Min(\sum w_i' * x_i) \;\; ; \;\; w_i' = \frac{w_i}{\sum w_i} \tag{4}$$

Where,
i = 1, 2, 3 for duration, cost and resource moment respectively
w_i = weight of duration, cost and resource moment respectively
w_i' = adjusted weight, so that the sum equals 1
x_i = normalized value of duration, cost and resource moment respectively

$$x_i = \frac{a_i - Min(a_i)}{Max(a_i) - Min(a_i)} \tag{5}$$

Where,
a_i = actual value of duration, cost and resource moment respectively

- Tabu-list: a Tabu-list is developed to prevent unfeasible solutions from being calculated again, which will avoid a cycle state of local optimal solution during the development process. Similarly, feasible solutions are stored in a space identified as a neighborhood structure. It is noted that a large Tabu-list size may lead to a rigid system that forbids many moves from being investigated, hence, finding an appropriate size for this list is important in order to perform efficient Tabu-search moves. The size of the Tabu-list was determined based on inherent characteristics of the construction project size and complexity.
- Memorizing function: in order to avoid stopping the search process before finding an optimal solution (i.e., being stuck in a local minimum), a memorizing function (step-back function) was used. This allows revisiting previous best solutions once the Tabu-list has reached its full capacity. This memorizing function allows the Tabu-search algorithm to step back and continue until a global optimum is found.

2.4. Step 4 – Determine optimal schedules for multi-objective functions

Using the settings from step 3, schedules considering different factors (i.e., cost, duration and resource moment leveling) are generated for each scenario, i.e., for different combinations of weights and factors.

The multi-objective function also considered cases when the weight for a given factor was set to 1 and the other weights to 0, i.e., the multi-objective function becomes a single-objective function.

The purpose for considering the single-objective schedule optimization is to determine the optimal value for the duration, cost and resource moment separately. As a special scenario of multi-objective function, the detailed optimizing process for each separate aspect is described as follows.

- Time optimization: in order to shorten the critical path, the crash option is used by applying more qualified construction labor or using different construction equipment. However, there is a time-cost trade-off since crashing activities results in higher costs. Also crashing one task may cause a change in the critical path; therefore, a recalculation of the network should be conducted after any crash option.
- Cost optimization: due to the time-cost trade-off relationship, cost should be optimized when no task was crashed in a network logic. Usually fixed and variable costs for everyday construction accounted for daily costs (e.g., usage of equipment, electricity and water, etc.). For a single cost optimization, the crash option is excluded, so the additional cost from crashing activities will be avoided.
- Resource optimization: resource leveling is calculated by using the minimum moment method (Equation (3)). By utilizing the free float of non-critical tasks, shifts in the original schedule are possible. The determination of the maximum and minimum value for resource moments is integrated in the iterative Tabu-search algorithm. The maximum number of construction workers onsite per day was provided as a constrain to avoid an overcrowding construction site and blocking of workspace.

2.5. Step 5 – Develop 4D model for visualization

For visualization purposes, the optimized schedule is integrated with the 3D model using 4D simulation software. The main objective of this integration is to develop a dynamic schedule storage interface, which can transfer the output of the Tabu-search results to the 4D scheduling software, to see modifications as they are being made. At the same time, any modifications made during the visualization (e.g., improper sequence or logic, missing tasks) are checked for cost-time-resources by the proposed algorithm (Figure 1).

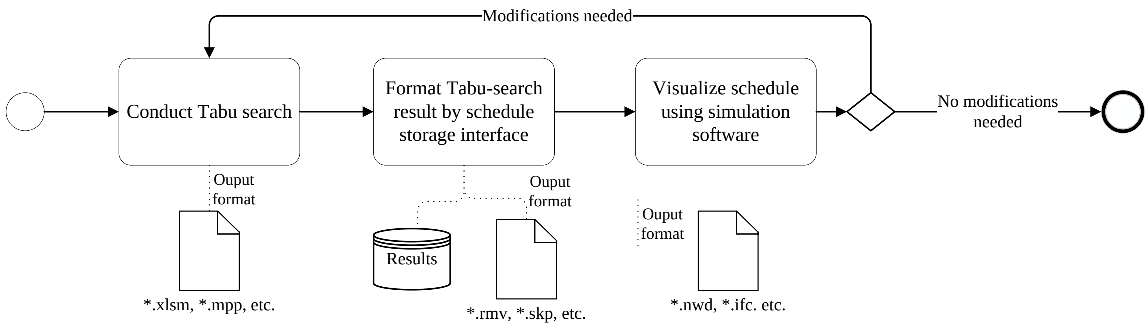

Figure 1. Framework of integrating optimized schedule with 4D models

To reduce interoperability conflicts, the pre-formatting process, task name, durations, cost and predecessor for each activity can be retrieved automatically with the help of a schedule storage interface program, which should adapt to the target file format of 4D scheduling software (e.g., visualization software). One of the major functions of the schedule storage interface is to change the file format by including a conversion process based on code checking. After that, the Tabu-search results can be translated into the 4D scheduling software. Construction project managers will find it user-friendly to convert Tabu-search results formats through the schedule storage interface.

3. Example

The proposed methodology to develop optimized construction schedules using 4D scheduling software (i.e., 4D models) was implemented using the 3D CAD model of a fictitious project. The example project consists of a one-story building with two separate functional units. It has a structural steel frame over spread footing and slab on grade and an underground cast in place service pit for the utilities. The exterior is mainly a brick veneer and glazing façade. The flat roof consists of lightweight steel framing waterproofed with conventional asphaltic sheets. The building contains a basic electrical and plumbing system and plaster interior finishes. The different components of the example project were organized in a 3-level WBS. The work packages from the last level were broken down in a total of 54 activities and sequenced to develop the project schedule.

The factors for optimistic and pessimistic duration used in PERT were 0.75 and 1.25, respectively. With these assumptions, the project duration was determined using the CPM method using a simulation of 1,000 iterations. The reference condition had a schedule with a duration of 35 days. The labor cost was for a project duration of 35 days was 74,220 CHF. Assuming everyday additional cost (fixed costs and variable costs) as 10% of the average labor cost per day, the estimated additional cost per day was 210 CHF and a total daily onsite cost of 81,570 CHF. The maximum number of construction workers onsite was set to eight. The corresponding resource moment for the reference schedule was 264. Due to space constraints, selected elements from steps 3 through 5 are presented.

3.1. Step 3 – Set Tabu-search algorithm

In order to use the Tabu-search algorithm, it was assumed that the total consumption of resources at any time during the project must be less than or equal to maximum number of available resource for the project. The Tabu-search algorithm was coded using VBA with the following characteristics.

- Simulation options: each task had a crash option and a delay option. In the case of crashing task, a group of three labors was assigned to one task with its crash duration reduced by 1/3 of its average duration, and the corresponding cost per hour per labor was assumed to be 1.2 times the average option. Regarding the delay option, the range of delay of each task was set from 0 to 5 days for further assessment.
- Objective function and search algorithm: for each scenario the value for the weights for the cost, time and resource moment factors were set between 0 and 2 (in increments of 0.2). This range provided sufficient variation of the factors used in the objective function and lead to the best weight-factor combination. Twelve scenarios were evaluated for each factor in Step 4, eleven to account for the multi-objective analysis (i.e., combination of factors and weights), and one to account for the single-objective scenario (i.e., when the weight for a single factor was set to 1 and the others to 0). For the multi-objective analysis, when a given factor was evaluated, the other factors were kept fixed.
- Tabu-list and memorizing function: In order to control the iteration for the Tabu-list, the size of Tabu-list was set as 20, which means 20 activities were tabooed at each iteration. Based on the initial solution, the Tabu-search algorithm searched its neighborhood solutions, which was determined by setting different input variable values, to generate objective value and conduct memorizing function to record each iteration.

3.2. Step 4 – Determine optimal schedules for multi-objective functions

The results from the Tabu-search showed the impact of the different weights to the overall optimization result for each scenario. Table 1 shows the percentage change for the different factors between the reference schedule and the one derived for each scenario in which the weights for the resource moment fluctuated between 0 and 2. Positive values in Table 1 indicate an improvement from the initial schedule. The other factors were evaluate in a similar way. The lowest value for the objective function (Z-value = 0.23) corresponded to a schedule with a reduction of 1%, 3%, and 24% for cost, time and resource moment (i.e., resource fluctuation), respectively.

Table 1. Multi-objective optimization (changing weights for resource moment between 0 and 2)

	Scenario number										
Factor considered	1	2	3	4	5	6	7	8	9	10	11
Time (days)	13%	13%	3%	2%	0%	0%	0%	-2%	-3%	1%	-3%
Cost (CHF)	-3%	-4%	1%	2%	4%	4%	2%	3%	2%	3%	3%
Resource moment	-22%	2%	5%	18%	24%	23%	27%	33%	23%	24%	27%
Z-value	0.30	0.29	0.33	0.30	0.28	0.27	0.26	0.24	0.26	0.23	0.24

3.3. Step 5 – Integrate optimal scheduled with 3D model

The optimal results from Tabu-search were transferred into the 4D scheduling software (in this case, Autodesk Navisworks). Every element in the 3D model was linked to a task in the project schedule. That facilitated the implementation of the schedule in the 4D scheduling software to allow the user to easily identify all the problems before the procurement and construction phases. The modifications from the visualization of the optimized schedule led to the revised optimized schedule that can be used for the construction of the project (Figure 2).

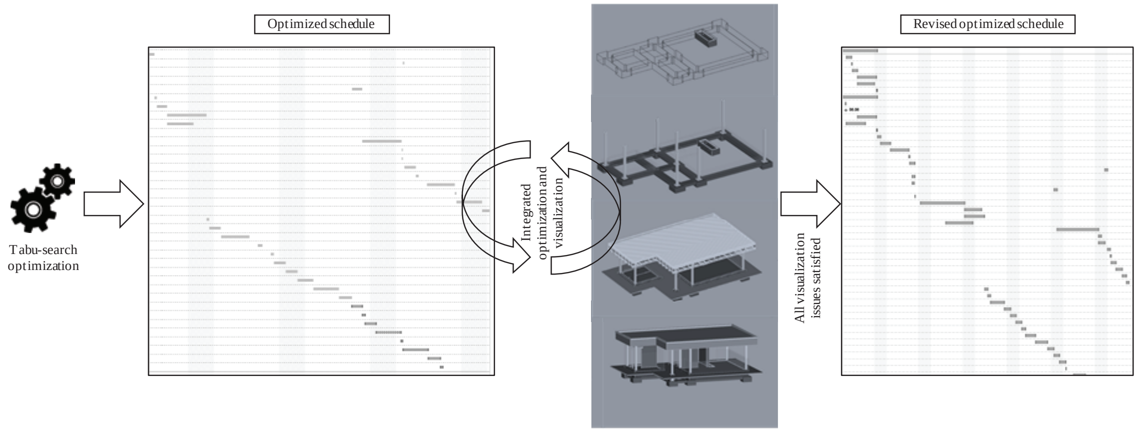

Figure 2. General process for the integration of the Tabu-search optimized schedule and visualization to develop revised optimized schedule

During the visualization process, different issues were identified. In some cases, they were due to a problem with the logic so revisions to the precedence relationship had to be made. In addition, coordination and sequencing was modified to improve the work of flow. Some specific problems found in different components of the building use for this example are summarized below.

- The underground service pit for the utilities was not casted simultaneously with the shallow foundation. Due to the small quantity of concrete (about 2 m^3), it did not make sense to cast the underground service pit for the utilities separately, especially when the concrete was delivered with a truck mixer that can carry up to 10 to 12 cubic meter of concrete. As the deep foundation used about 7.5 m^3 of concrete it would be better to shift the casting of the service pit so that it can be cast simultaneously with one concrete shipment. This modification did not affect the project duration.
- For safety reasons, the work at the façade was set as a successor of finishing the roof construction in the original logic. In case that the level of detail of the CAD file, as well as the construction plan, would be increased, this constraint could be neglected by introducing different parts of the roof and the facade to work on, allowing for a phased construction.
- It would be reasonable to start the concrete work in the foundation (which was on the critical path) on Thursday or Friday so that its curing process could take place over the weekend. As the curing of concrete is a task not associated to any crew, the resource fluctuation would not be modified.

These problems were visualized and corrected through 4D modeling software in an iterative process. Once all the conflicting problems were identified through this process, they were incorporated into the optimized schedule and checked for other constrains. The end result of this process was an optimized scheduled revised through visualization. The revised optimized schedule had several improvements when compared to the reference schedule, which in some cases improved the results from the multi-objective optimization alone. The optimization with visualization resulted in a 13% reduction in the project duration, 4% cost reduction, and 49% decrease in resource fluctuation.

4. Conclusion and outlook

Methodologies to determine optimal construction project schedules have been proposed by many researchers. Some of these make use of 3D modelling techniques. None of them, however, determine optimal construction project schedules using 4D modeling techniques and a Tabu-search algorithm. In this paper, such a methodology is proposed.

The presented methodology can be used to determine an optimal construction project schedule, where optimality is defined as the best trade-off between project costs, duration, and fluctuation of resources. It consists of the following basic steps:

- Extract project information from building information model in the required format
- Simulate critical path to generate an initial schedule (reference schedule or initial solution)
- Set Tabu-search algorithm
- Determine an optimal schedule for multiple objectives
- Develop 4D model for visualization
- Revise optimal schedule to address conflicts determined during visualization

In the multi-objective Tabu-search algorithm analysis, the weights of the objective function were set to different constants to check the sensitivity of each optimized schedule. The implementation of the integrated methodology shows that the Tabu-search can provide improved schedules when taking into consideration multiple objectives. The suggested 4D models then visualize the optimized schedules for decision makers to further identify potential conflicts and manage different construction schedule issues (e.g., constructability, network logic, resource availability).

Ongoing research is being conducted by using artificial intelligence to improve the development of project schedules that consider spatial constrains and main conflicts derived from human visualization of optimized schedules.

References

[1] Książek, Mariola Violeta, et al. Computer-aided decision-making in construction project development. Journal of Civil Engineering and Management 21.2 (2015): 248-259.

[2] Bui, Nam, Christoph Merschbrock, and Bjørn Erik Munkvold. A review of Building Information Modelling for construction in developing countries. Procedia Engineering 164 (2016): 487-494.

[3] Dang, Trang, and Hans-Joachim Bargstädt. 4D Relationships: The Missing Link in 4D Scheduling. Journal of Construction Engineering and Management 142.2 (2015): 04015072.

[4] Boton, Conrad, Sylvain Kubicki, and Gilles Halin. The challenge of level of development in 4D/BIM simulation across AEC project lifecyle. A case study. Procedia Engineering 123 (2015): 59-67.

[5] Wang, Wei-Chih, Shao-Wei Weng, Shih-Hsu Wang, and Cheng-Yi Chen. Integrating building information models with construction process simulations for project scheduling support. Automation in Construction 37 (2014): 68-80.

[6] Kim, Changyoon, Byoungil Kim, and Hyoungkwan Kim. 4D CAD model updating using image processing-based construction progress monitoring. Automation in Construction 35 (2013): 44-52.

[7] Russell, Alan D., and William F. Caselton. Extensions to linear scheduling optimization. Journal of Construction Engineering and Management 114.1 (1988): 36-52.

[8] Rajabinasab, Amir, and Saeed Mansour. Dynamic flexible job shop scheduling with alternative process plans: an agent-based approach. The International Journal of Advanced Manufacturing Technology 54.9-12 (2011): 1091-1107.

[9] Merkle, Daniel, Martin Middendorf, and Hartmut Schmeck. Ant colony optimization for resource-constrained project scheduling. IEEE Transactions on Evolutionary Computation 6.4 (2002): 333-346.

[10] Thomas, Paul R., and Said Salhi. A tabu search approach for the resource constrained project scheduling problem. Journal of Heuristics 4.2 (1998): 123-139.

[11] Ökmen, Ö., and A. Öztaş. A CPM-based scheduling method for construction projects with fuzzy sets and fuzzy operations. Journal of the South African Institution of Civil Engineering 56.2 (2014): 02-08.

[12] Fung, Ivan WH, Chun Huang, and Chi Ming Tam. Application of GA optimization for solving precedent relationship problem in project scheduling. Mathematical and Computer Modelling 57.9 (2013): 2067-2081.

[13] Pan, Nai-Hsin, Po-Wen Hsaio, and Kuei-Yen Chen. A study of project scheduling optimization using Tabu Search algorithm. Engineering Applications of Artificial Intelligence 21.7 (2008): 1101-1112.

[14] Hajdu, M., M. J. Skibniewski, M. Vanhoucke, A. Horvath, and I. Brilakis. How Many Types of Critical Activities Exist? A Conjecture in Need of Proof. Procedia Engineering 164 (2016): 3-11.

[15] Ma, Zhiliang, and Zhe Liu. BIM-based intelligent acquisition of construction information for cost estimation of building projects. Procedia Engineering 85 (2014): 358-367.

[16] PMBOK. Guide to the project management body of knowledge (PMBOK Guide)-Forth Edition. (2008) Published by: Project Management Institute

[17] Christodoulou, Symeon E., Georgios Ellinas, and Anastasia Michaelidou-Kamenou. Minimum moment method for resource leveling using entropy maximization. Journal of Construction Engineering and Management 136.5 (2009): 518-527.