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TIME MANAGEMENT & RESOURCE LEVELING OF MASS HOUSING PROJECTS USING INCORPORATION OF BUILDING INFORMATION MODELING AND METAHEURISTICS

GERENCIAMENTO DE TEMPO E NIVELAMENTO DE RECURSOS DE PROJETOS DE HABITAÇÃO EM MASSA USANDO A INCORPORAÇÃO DE MODELAGEM DE INFORMAÇÕES DE CONSTRUÇÃO E METAHEURÍSTICAS

GESTIÓN DEL TIEMPO Y NIVELACIÓN DE RECURSOS DE PROYECTOS DE VIVIENDAS MASIVAS MEDIANTE LA INCORPORACIÓN DE MODELOS DE INFORMACIÓN DE CONSTRUCCIÓN Y METAHEURÍSTICAS

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ABSTRACT

In the last few decades, construction industry has faced numerous challenges such as low productivity and low invest return rate compared to other industries, increased cost of labor, unpredicted costs due to lack of coordination between beneficiaries, high time-consumption of managing changes in projects and delayed and inappropriate decisions. These factors led to the development of new fields such as Information Technology (IT) and integrated project delivery systems in this industry. "Building Information Modeling" is one of the most important new concepts in overcoming these challenges. A project's success is one of the biggest and most important goals and concerns of managers and all the persons involved in that project. Success is what unites all the efforts of team members. Building information models, as one of new technologies in the construction industry, uses precise outcome, visual models and information totally understandable by the members to minimize decision-making errors regarding construction problems. In this study, considering the importance of decision-making in construction workshops and especially projects with mass amount of materials, labor and machinery (such as mass house building projects), the incorporation of building information modeling and metaheuristics has been used in times when the required resources exceed available resources. In order to simplify problem-solving for project's used resources, concrete was considered as the most used material and in times when requested concrete was more than the produced concrete, the scenario of levelling the resources were considered in order to equalize the requested concrete with the batching's maximum producible amount. Considering the factors of time and quality that each scenario imposed on the project, this scenario was confirmed by an expert group.

Keywords: Building Information Modeling, Workshop Decision-Making, Metaheuristics, Mass House Building Projects.

RESUMO

Nas últimas décadas, a indústria da construção enfrentou inúmeros desafios, como baixa produtividade e baixa taxa de retorno de investimento em comparação com outras indústrias, aumento do custo da mão de obra, custos imprevisíveis devido à falta de coordenação entre os beneficiários, alto consumo de tempo de gerenciamento de mudanças em projetos e decisões atrasadas e inadequadas. Esses fatores levaram ao desenvolvimento de novos campos, como Tecnologia da Informação (TI) e sistemas integrados de entrega de projetos nesta indústria. "Building Information Modeling" é um dos novos conceitos mais importantes para superar esses desafios. O sucesso de um projeto é um dos maiores e mais importantes objetivos e preocupações dos gerentes e de todas as pessoas envolvidas nesse projeto. O sucesso é o que une todos os esforços dos membros da equipe. A construção de modelos de informação, como uma das novas tecnologias na indústria da construção, usa resultados precisos, modelos visuais e informações totalmente compreensíveis pelos membros para minimizar erros de tomada de decisão em relação a problemas de construção. Neste estudo, considerando a importância da tomada de decisão em oficinas de construção e principalmente em projetos com grande quantidade de materiais, mão de obra e maquinários (como projetos de construção de casas em massa), a incorporação de modelagem de informações de construção e metaheurísticas tem sido utilizada em tempos em que o os recursos necessários excedem os recursos disponíveis. A fim de simplificar a resolução de problemas para os recursos utilizados do projeto, o concreto foi considerado o material mais utilizado e nos momentos em que o concreto solicitado era maior do que o concreto produzido, foi considerado o cenário de nivelamento dos recursos de forma a equalizar o concreto solicitado com o quantidade máxima de produção em lote. Considerando os fatores de tempo e qualidade que cada cenário impôs ao projeto, este cenário foi confirmado por um grupo de especialistas.

Palavras-chave: Modelagem de Informações de Construção, Tomada de Decisão em Oficinas, Metaheurísticas, Projetos de Construção de Casas em Massa

RESUMEN

En las últimas décadas, la industria de la construcción se ha enfrentado a numerosos desafíos, como baja productividad y baja tasa de retorno de inversión en comparación con otras industrias, aumento del costo de la mano de obra, costos imprevistos debido a la falta de coordinación entre los beneficiarios, alto consumo de tiempo en la gestión de cambios en los proyectos y decisiones tardías e inapropiadas. Estos factores llevaron al desarrollo de nuevos campos como la tecnología de la información (TI) y los sistemas integrados de entrega de proyectos en esta industria. El "Modelado de información de construcción" es uno de los conceptos nuevos más importantes para superar estos desafíos. El éxito de un proyecto es uno de los objetivos y preocupaciones más grandes e importantes de los gerentes y de todas las personas involucradas en ese proyecto. El éxito es lo que une todos los esfuerzos de los miembros del equipo. Los modelos de información de la construcción, como una de las nuevas tecnologías en la industria de la construcción, utiliza resultados precisos, modelos visuales e información totalmente comprensible por los miembros para minimizar los errores en la toma de decisiones sobre problemas de construcción. En este estudio, considerando la importancia de la toma de decisiones en los talleres de construcción y especialmente en proyectos con gran cantidad de materiales, mano de obra y maquinaria (como proyectos de construcción de viviendas en masa), la incorporación de modelado de información de construcción y metaheurísticas se ha utilizado en tiempos en los que la los recursos necesarios superan los recursos disponibles. Con el fin de simplificar la resolución de problemas de los recursos utilizados en el proyecto, se consideró el hormigón como el material más utilizado y en momentos en que el hormigón solicitado era más que el hormigón producido, se consideró el escenario de nivelación de los recursos con el fin de igualar el hormigón solicitado con la cantidad máxima producible por lotes. Considerando los factores de tiempo y calidad que cada escenario imponía al proyecto, este escenario fue confirmado por un grupo de expertos.

Palabras clave: Modelado de información de construcción, Taller de toma de decisiones, Metaheurística, Proyectos de construcción masiva de viviendas.

1. INTRODUCTION

Statistics demonstrate that during the last two decades, different industries have experienced improved productivity due to the improvement of information and communication technology. However, in the construction industry, this progress is not observable. For example, in the US and between the years 1965 to 2004, the efficiency rate in rate in construction has only grown by 33 percent which is very little compared to other other industries [1]. Also, statistics show a growing trend in the last 4 decades in the labor productivity of all the industries except for agriculture in the US, while this amount was almost invariant in the construction industry [2]. National Institute of Standard and Technology has conducted a research in order to investigate the problems facing interoperability of beneficiaries and various systems and information. The results of this research indicate that inefficient cooperation between the involved groups in a project will cost the project 6.12$ for each square foot in the construction process and 0.23$ in the operational and maintenance process which will lead to an annual cost of 15.8 billion dollars [3]. Since long time ago, many civil projects work like this: employer or the investor selects the desired area and obtains the ownership and necessary permission; then in the designing phase, first the designing team is chosen in a call for tenders or based on recognition in the private sector and starts working. At first, the architect engineers provide the building plans and present them to the accountant engineers to confirm the plan in terms of structure. These maps should also be confirmed and reviewed by the electrical and mechanical engineers. After the confirmation of plans by the employer or the investor, the execution phase starts with the contractor’s choice. The contracting body consists of the project manager, administration manager, workshop supervisor, machinery officer, sub-contractors, sellers, workers and etc. which is a group consisting of managers, executive experts, planning and project control experts, simple and skilled workers, machinery technicians and providers of raw materials and facilities. This body was very complex considering the number of roles and the long time they are on the job. In many references, the project goals mean the project’s completion time, work quality and safety. The presence of these challenges has led the construction experts to think about change in the design and construction process structure and introducing methods to mitigate the problems. In this research, we analyzed one of the problems in the construction phase of mass house building projects (lack of resource in a period of time) using building information modeling and metaheuristics and different scenarios have been reviewed and the best one is presented. Usually, a project’s success means achieving some of the project’s pre-determined goals including parameters such as cost, performance, quality and safety. One of the factors in a project's success is decision-making of project's managers and beneficiaries in different stages of the life cycle especially in the construction phase.

2. LITERATURE REVIEW

Fisher and Peterson (2009), conducted a study on different methods of monitoring the progress of projects. In this study and based on the gauging, it was determined that in massive civic projects, almost 10% of progress-related measurements are estimations [4] and this leads to error in decision-making. In this study, we categorized different methods of progress monitoring: 1) vision-base 2) machine-base 3) micro-electro mechanic 4) hand-held computers (HHC) 5) incorporation of different methods. Visualizing a project progress is considered a vision-base method in progress monitoring.

Most of the researches in the field of 4D modeling face deficiencies in developing an integrated system which include other construction aspects such as resource management, relationship between different data sources and totally automatic bilateral exchange between 4D models and extracted data from the schedule. In order to overcome these deficiencies, Chau, Anson and Zhang presented a model named 4DGCPSU in which each task is connected to its required resources (including materials, equipment and machinery, labor, work environment and cost).

In different phases of the project, site layout will change due to necessary accordance with the amount of requested materials. Therefore, site layout cannot have a 2D and static nature and needs dynamism in a 3D space. Thus, Ma, Shen & Zhang introduced a 4D integrated site planning system. A system in which schedules, 3D model, resources and available spaces in the site were designed using 4D CAD technology and with the aim of 4D graphic visualization of site planning [5].

In order to investigate the fields applying 3D & 4D models in projects constructions, Hartman, Gao & Fischer analyzed and detected the limitations of various frameworks of categorization of these applications. This team incorporated available frameworks and by considering the limitations presented a new categorization for applications of these models in 3 phases of planning, design and construction [6].

Reizgevičius & et al (2013) compared the productivity of students in designing a building model with specific number of Legos using 4D models and 2D plans. A group of students were given 2D building plans and the other group was given software 4D model. The results indicate that the productivity of the 2nd group was 2 times higher than the first one. Also, employing 4D models reduced the errors of the 2nd group significantly [7]. With the advances of laser scanning technology, various applications of this technology in construction industry and especially in the fields of construction management and 4D modeling have received attention. This technology has been used in creating plans of construction and monitoring gradual destruction of infrastructures (bridges, highways, skyscrapers, historical buildings and etc.) [8].

3. THE NECESSITY OF CONDUCTING RESEARCHES

Considering the advances of science based on persisting problems, nowadays considering the complexity of problems and decisions in civic projects, visual and information-rich systems such as workshop images, 3D maps, augmented reality and building information modeling are used instead of mathematical and statistical methods for more proper and on-time decision-makings. The current process of construction projects contains inaccurate resource management for every moment in the project. Whereas we could create a more integrated planning for the construction phase by predicting the provision of requirements, materials and resources and determining their exact delivery time in the site and also the precise time for each group to use the resources. In this study, a method was presented for decision-making in line with a project’s success which incorporates field operations, modeling and coding by using building information models along with scheduling plan and metaheuristics for planning and materials management in times when the use of materials exceeds the available amount.

4. BIM INTRODUCTION

In order to overcome construction problems, creating a computer system capable of storing information, designing detail, construction and utilization is necessary. This computer system was first named Building Description System but changed its name during its development to Building Information Modeling. BIM is not a new concept and its concepts were founded 4 decades ago [9]. National BIM Standard, considers BIM as a virtual representation of functional and physical specifications of the facilities from the beginning to the end, such that project databases employs it for collaboration of during the building's life cycle [10]. Building SMART treaty defines building modeling as:

A set of organized information that can be shared. BIM is a digital model of the structure which stores the project information. A model that can be 3D, 4D or nD (containing every information necessary in the project's life cycle.). The goal of BIM is collaboration of beneficiaries, reducing the time necessary for documentation and creating estimable results from the project [11].

4.1. BIM Capabilities

BIM is (more than anything) a comprehensive concept that monitors all the phases of a project's life cycl details required by the parts manufacturer in the end of the designing stage. A project manager can present a comprehensive model of building information to the employer in the end. This model consists of changes made in plans such as construction of sub-contractors. The registered model can include safety and security information such as lighting, electric energy provision, fire extinguishing system alarm and smoke detectors in emergencies.

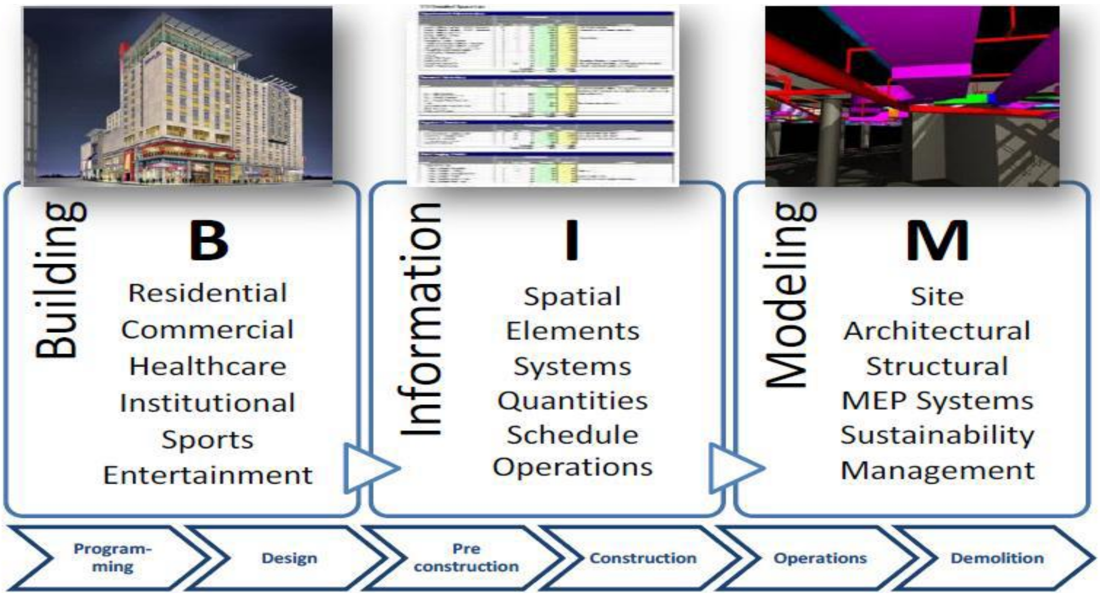


Figure 1 – The concept of BIM different parts

4.2. 4D Simulation

A 4D model is the result of integration of 3D graphic images with the time dimension [14]. 4D modeling will result in reduction of misunderstandings that result from difference in interpretation of the concept of scheduling between beneficiaries [15]. In 3D modeling, the graphic model is connected to 3 spatial (physical) dimensions or the scheduling dimension; thus, the order and sequence of different stages of the project and how they occur are shown in reality. This coordination helps the managers to detect the possibilities of occurring problems in the execution stage and also helps them plan preventive actions. 4D simulation has been employed by planners, designers and engineers with the goal of analyzing and representing construction projects in order to make correct decisions regarding design, analyze the constructability of projects, estimate the costs, manage the required resources and to properly create communications and collaboration between the employer and other beneficiaries [16].

4.3. 5D Modeling

A building information 5D modeling requires the integration of its 3D model with project's time and cost. This enables prediction of and follow-up on the project's cost based on the schedule during all the various phases. In this system, extraction of work volumes and values and required materials from the 3D model along with other dimensional features (length, area, volume and ...) can easily be done.

4.4. Facilities Management

From the most important applications of BIM in facilities management, we can mention collection and insertion of information from the members and the items used in the project for the utilization period. Information about the manufacturer, performance inspection date, warranty period, properties of materials and equipments and similar data can contribute significantly to facilitation of utilization and maintenance process. Also, with growing advances of dynamic building performance monitoring systems such as building management systems (BMS), wireless sensor networks and image processing and creating a connection between those systems and BIM, a new window has opened to facilitation of utilization and maintenance processes using BIM. One of BIM's proven abilities is enhancing coordination between different design groups (architecture, structure and facilities) which leads to more conformity between design and construction. This will have a significant effect on time and cost reduction of the project's execution.

5. RESEARCH METHODOLOGY

Nowadays, the need for proper planning in order to accurately estimate the project time and execution is evident for everyone. Often, planning for the project gets ignored due to huge attention given to operational works. Using building information modeling in workshop decision-makings, many problems in the construction phase and workshops are solvable. Since decisions taken in the construction phase are in line with the project's success, first studies regarding the effective factors in projects' success were conducted. Considering the researches, time and quality were detected as key factors in a project's success and these factors were considered as key fields of workshop decision-making.

5.1. Designing the Survey Form

First, a comprehensive, simple and understandable framework was designed in order to employ the opinions of expert to determine the importance of key fields of workshop decision-making. In this questionnaire, we ask the experts to rate the relative importance of each factor over another factor based on the problem's purpose which is workshop decision-making based on Table 1.

Table 1

The Standard Scale for Pairwise Comparisons

Amount	Equivalent	A bit more important	More important	Very more important	Extremely more important	Values in between
Importance Intesity	1	3	5	7	9	2,4,6,8

The following criteria ware considered for selecting certified persons:

1. Doctorate degree in architecture or civil engineering
2. M.A. in architecture or civil engineering and minimum of 5 years of executive experience in construction projects.
3. Bachelor degree in architecture or civil engineering and minimum of 15 years of executive experience in construction projects.

Time limitation and required capacity for conducting a research of this scale do not allow to use more expert opinions on the matter. The survey forms were distributed to the members using Delphi model and in two stages. In the first stage, we tried to make the respondents understand the issue better by continuous phone calls, meetings or using e-mails. In the 2nd stage of Delphi technique, we ranked different fields by reviewing the results (Table 2).

Table 2
Matrix of Pairwise Comparisons of decision-making field

Criteria	Increasing the Project Speed	Increasing Operational Efficiency	Quality Improvement	Workshop Economization	Sustainable Construction	Weight Value
Sustainable Construction	2	1	1	3	1	**13.2%**
Workshop Economization	1	2	2	1	0.33	**30.6%**
Quality Improvement	2	3	1	0.5	1	**24.3%**
Increasing Operational Efficiency	1	1	0.33	0.5	1	**12.9%**
Increasing the Project Speed	1	1	0.5	1	0.5	**19%**

5.2. Case Study

The project under study is a 700-unit housing project located in pieces number 86, 90 & 91 of District 2 of Phase 7 of the New Town of Hashtgerd, located in kilometer 65 of Karaj-Qazvin Freeway and it contains an area of 43452.12 square meters. This project includes 35 blocks containing 20 units in two brigades. The delivery date for this project was 2010/4/18 and it had a one-year contract. Construction type was in situ reinforced concrete with integrated forms (industrial method). Based on article 3 of agreement of land preparation, construction and transferring the residential units, the price for each square meter of gross infrastructure of these units (in the project's end) was 3.000.000 Rials.

6. Project Modeling

Revit Suite is one of the most important modeling software in the world which enables modeling of structure, architecture and mechanical, electrical and piping facilities in an integrated framework. Modeling the architecture and structure of components or the above

LOD in the framework of a study will only lead to unnecessary complications and increased time-consumption in the modeling process. Thus, in the model under study, modeling of some elements (architecture, flooring and facilities) was neglected and only concrete structure elements were modeled in order to achieve the goals. The project model was modeled in Revit Structure Software and the types of materials used were defined for each structural element.

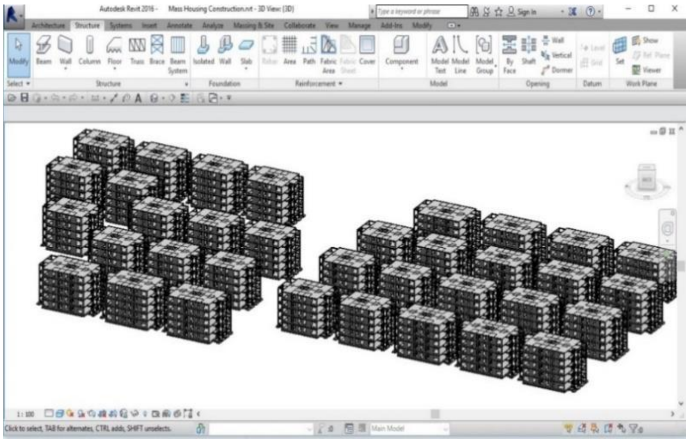


Figura 3 – Project's model in Revit Structure

6.1. Scheduling

One of the big problems we were facing during the research was non-cooperation of different mass builder companies in handing over their execution plans and schedules. Scheduling requires estimation of project values (quantity surveying) and using the experiences of previous contractors. Thus, the required values were extracted from Revit and Nawisworks software.

Table 3
Volumes of the used concrete

Title	Quantity surveying of each story of block A	Quantity surveying of each story of block B	unit
Lean concrete	41.27	35.01	**m^3**
Foundation Concreting	170.12	148.22	**m^3**
Concreting of Walls	77.55	65.18	**m^3**
Concreting of Pillars	2.89	2.88	**m^3**
Concreting of Bars	4.16	4.23	**m^3**
Concreting of Ceiling and stairways	62.4	55.23	**m^3**

Considering the duration of the project's contract and also limitations such as the number of tower cranes, the scheduling was divided into 6 phases. In the schedule, 142 main tasks were considered. The time needed for each construction stage from the beginning to the end of block skeletons was estimated. Work environments improvement, analysis of hotspots in the workshop, detection of non-matching spots in tasks schedule, planning for using resources, progress monitoring, discovering safety problems, discovering hazards in the workshop space and presenting schedules were all progresses that became possible due to BIM increased facilities.

Table 4
Project Phasing

Phase	Blocks
1	A_8-A_9-A_{10}-A_{11}-A_{12}-A_{13}
2	A_1-A_2-A_3-A_4-A_5-A_6-A_7
3	B_{14}-B_{15}-B_{16}-B_{17}-B_{18}-B_{19}
4	A_{14}-A_{15}-A_{16}
5	B_7-B_8-B_9-B_{10}-B_{11}-B_{12}-B_{13}
6	B_1-B_2-B_3-B_4-B_5-B_6

6.2. Creating a 3D model

In this stage, the schedule from MS Projects enters Nawisworks to assign each task its required members and resources. Figure 4 shows the process of information flow from the beginning of the model entrance to the end of 4D modeling in Nawisworks [18]:

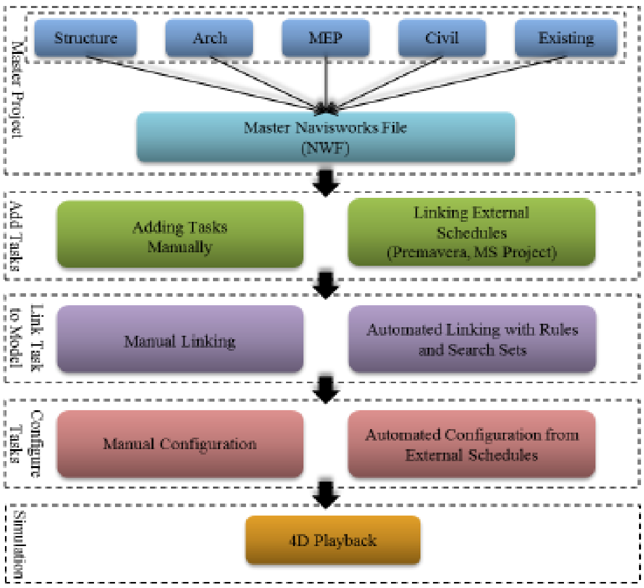
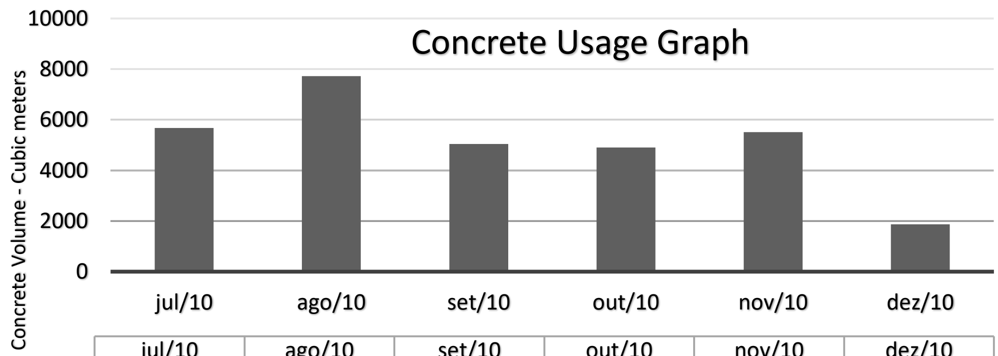


Figure 4 – Information Flow process in Nawisworks from the beginning to the end.

The process of adding members to tasks in Nawisworks is done manually and automatically.

After creating a 4D model, reviewing the construction stages, order of tasks and scheduling problems were reviewed and solved. Then, by applying the changes in the scheduling and considering the amount of concrete extracted from the Revit model, the diagram for concrete used was calculated for each moment of the project.



	jul/10	ago/10	set/10	out/10	nov/10	dez/10
■ Série1	5678,34	7719,3	5047,79	4906,1	5511,96	1876,41

Figure 5 – Diagram for Concrete Usage in Different Months of Implementing the structure skeleton

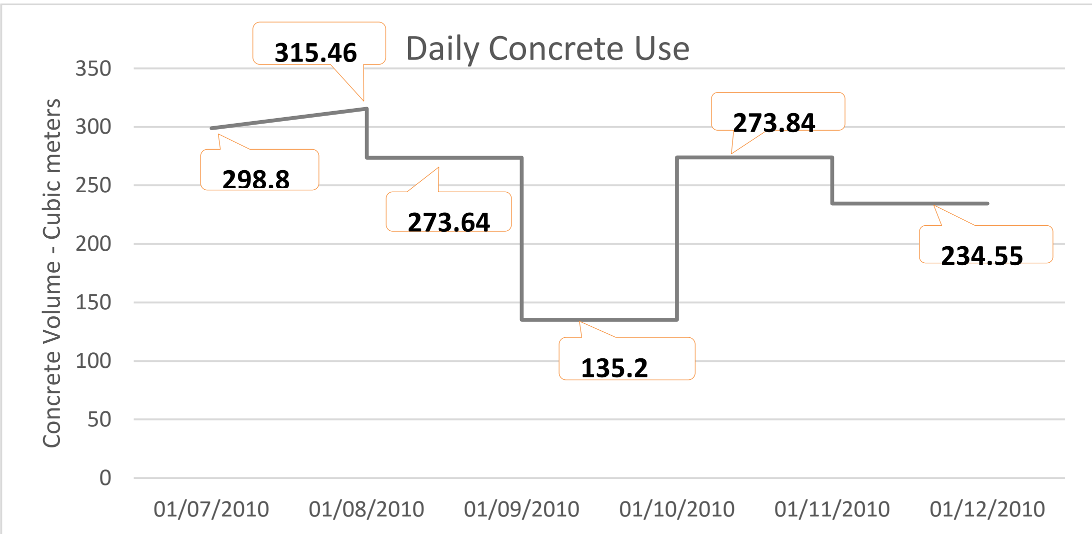


Figure 6 – Daily Use of Concrete in the Project

Considering the production capacity of the project's batching (30 cubic meters in every hour) and assuming 8 working hours, the daily production capacity of the batching is approximately 250 cubic meters.

6.3. Resource Leveling to Equalize the Maximum Concrete Usage in Each Moment with

the Batching's Production Capacity

One of the solutions for this problem is leveling the resources and considering the resource limitation in the scheduling

6.4. Scheduling Optimization Considering the Resource Constraint

Generally, a project's schedule looks for a proper sequence for a project's tasks in a way that satisfies both limitation of the project network and various types of resource constrains in the project and becomes a measurement scale for project execution time, cost, and number of delayed tasks. Using project scheduling, cases such as assigning resources to tasks, contactors' obligations, preventive repairs and delivery to foreign or domestic customers will be easily controllable. Finishing a project in maximum time and cost efficiency requires optimal resource scheduling. A project manager should plan for long-term and short-term resources for them to become available when needed. One of the problems in the country's construction industry is improper prediction of project's time based on available resources. In the project under study and during a construction time period, the required concrete exceeds the available concrete (the batching's capacity); one of the solutions for this problem is resource leveling. In fact, we are faced with a scheduling problem with limited resources and by solving this problem and by changing the time for start of some tasks, the required concrete can be made equal to the batching's capacity.

6.5. Resource Constraint Project Scheduling Problem

In this problem, each project consists of some tasks; in addition, there are limited resources in each time period. Some tasks have priority over others and are limited in using resources. The goal is usually to minimize the project completion time in a way that solves priority and resource limitations. To solve this problem, Matlab coding was used. Parameters that were used in problem coding include:

Table 5
Parameters in problem coding in Matlab

t	Each Task's time
N	Number of Tasks
PredList	Prerequisite list of tasks
n_R	Number of Resources
$r = 1,2,...,n_R$	Resources Subscript
$R_{max,r}$	Maximum for Each Resource
$R_{ir} \geq 0$	The Need of Task i to Resource j
ST	Start Time of Each Task
FT	Fishing Time of Each Task
URr	Amount of Used Resources
RRr	Amount of Available Resources

6.6 Stages of Implementing the Model Core

Figure 6 illustrates stages of implementing the model core. In the repair mechanism, the permutation created from the number of tasks becomes a scheduled plan by abiding the priorities between the tasks. Figure 7 shows the flow-chart of modifying the primary permutation.

6.7. The Main Conditions of the Problem's Mathematical Model

The condition for the start of a task:

1. All the pre-requisites are done.

$$ST_i \geq max\{ FT_i \mid i \in PL_i \} \rightarrow T_1$$

2. There are enough resources for the start of a task.

$$ST_i \geq \min\{ t \mid RR_r(t+d) \geq R_{ir} \} \rightarrow T_2$$

$$r = 1,2,\dots,nR \; and \; d = 0,1,\dots,T_i - 1$$

$$ST_i = \max(T_1, T_2) \; and \; FT_i = ST_i + t(i)$$

The goal of the model is to minimize the project's maximum completion time and this objective function can be calculated by this relation:

$$T = \text{minimize } (\max (FT_j))$$

After calculations and creating a mathematical model, the problem of minimizing the objective function gets connected to optimization algorithms. In this research, optimization of the problem was done using simulated annealing algorithm. In the following, we introduce this algorithm and the results from the model optimization.

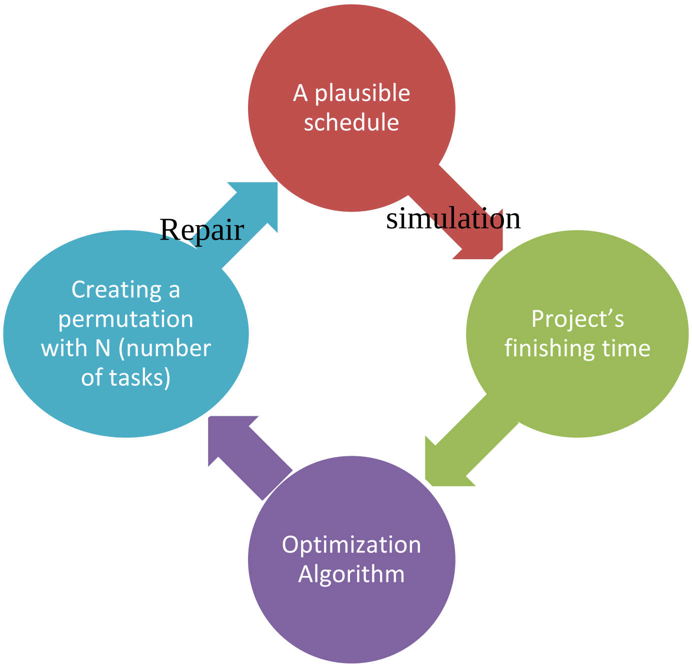


Figure 6- Stages of Implementing the Model Core

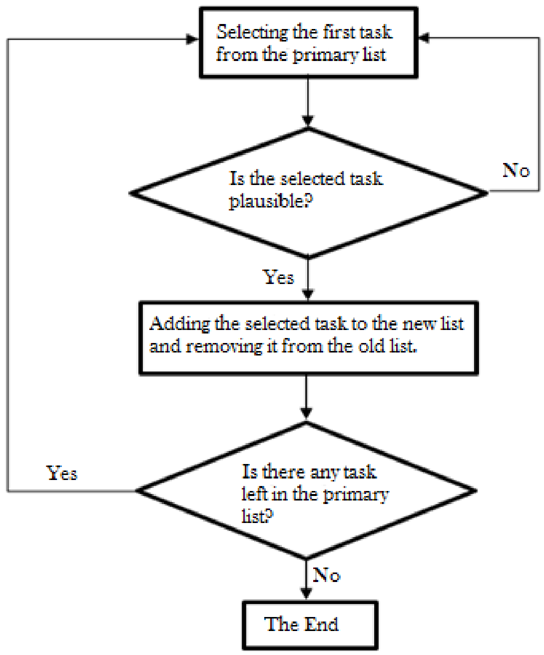


Figure 7 – Mechanism of Modifying the Schedule

6.8. Simulated Annealing Algorithm Structure

The stages of simulated annealing algorithm are as the following [19]:

- Reading the input information
- Creating the plausible answer of z and calculating the value of the its corresponding objective function f(z)
- Saving z as the best answer (z_{best}) and f(z) as the best value for the objective function (f_{best})
- Receiving the parameters of the simulated annealing algorithm.
- Repetition for k times (repeating the outer loop)
- Repeating for 1 neighbor (repeating the inner loops)
- Crating the vicinity of n from z
- Calculating f (n)
- Calculating $\Delta = f(n) - f_{best}$
- Otherwise, if $p = e^{\frac{-\Delta}{T}} > Z_{random}$, then $Z_{best} = n$
- If Z_{best} does not change in 50 repetitions, get out of the loop
- Finishing repetition 1

- Reducing the current temperature to $T_r = \alpha.T_{r-1}$
- If Z_{best} does not change in 100 repetitions, get out of the loop
- Finishing repetition k
- The end of algorithm and displaying the results (Z_{best} , F_{best})

Input data consist of two categories of general data related to the problem and control parameters of SA algorithm.

Table 6
Algorithm Parameters and Problem's General Data

	Parameters	Data Value or Method of Production
Control Parameters of SA Algorithm	Set of Task's Pre-requisites	$PredList_j$, obtained from the schedule
	Set of Task's needs	H_j, obtained from the schedule
	Task duration	t_j, obtained from the schedule
	Amount of required resources for each task	R, obtained from the BIM model
	Number of tasks	142
	Maximum available resources	R_{max}, considering the batching's capacity
	Number of required resources	1
Control Parameters of SA Algorithm	Maximum repetition in each temperature	50
	Maximum number of change in temperature	100
	Primary temperature	10
	Coldness coefficient	0.9

7. DISCUSSION

In the end and after finishing the algorithm run and converging in the repetition of number 35 (the convergence diagram is presented in Fig 8.), the value of the final objective function was obtained along with the starting time of tasks. In order to validate, the model ran once without any resource limitations and the result has a 96% match with the results of scheduling in MSP software. The problem-solving findings are shown in Table 7.

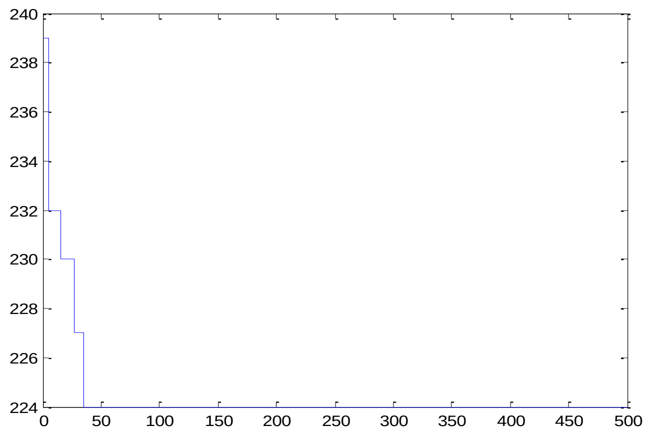


Figure 8 – The convergence diagram of SA algorithm in resource limitation to reach the optimal result.

Table 7
Problem Solving Results

Solving Type	Solving the problem considering resource limitation	Solving the problem without considering resource limitation
Project's finishing time (Cmax) (days)	224	189

When we have resource limitations and in times there are not enough resources to solve this insufficiency, resource leveling is used. The start time for tasks that don't have sufficient resources should be delayed until sufficient resources are provided. One of the factors we are facing in this scenario is a delay for which the contractor is responsible such as low production capacity, lack of coordination between work components and lack of proper planning to provide the necessary resources during the project which are non-negligible. Contractor cannot ask for extra time for these delays. Another category of delays is compensable; delays for which the employer is responsible. When both the contractor and the employer don't answer for a delay, that delay is considered irrecoverable. Natural disasters and bad weather conditions are of these delays. When resources are leveled, the delays are considered non-negligible and impermissible which will lead to increased project duration and will also result in some costs for the project. Based on the article 50 of general agreement terms regarding delay penalties, when the sum of delays do not exceed one tenth of the contract duration, for each day, 1/2000 of the remaining sum of work which was delayed will be considered as the measurement criterion. This article matches the general conditions for delays resulted from resource leveling. Also, considering the clause 3 of article 3, the treaty of preparation, construction and delivery of residential units will subtract the delay penalties (0.5% of tasks that include unauthorized delay) from the final price. The maximum of these percentages should not exceed 5% percent of this agreement (based on clause 2 of article 3)

Clause 2, Article 3: The price for each square meter of gross infrastructure of these units (in the project's end) is 3.000.000 Rials.

Clause 2 of Article 3:

Delay Penalty based on the contents of article 50 of the general agreement (Rials)	**Delay Penalty based on clause 2, article 3 (Rials)**
1.2000×3230×60000035×=33915000	0.005×30740×600000=92220000

Considering the proposed scenario, despite increased project duration, the contractor will earn more profit even with the delay penalty resulting from selecting this scenario and the employer will look for minimizing the delay; but based on the clause 3 of article 3 regarding the penalty for contractor in case of unauthorized delay during the project, this penalty is not enough to make the contractor select another scenario and prevent increased duration.

8. CONCLUSION

A precise analysis of used resources in each moment of the project can prevent numerous problems such as materials shortage during the execution, delay, increased project costs and even claims between the contractor and the employer. Building information models, as one of the newest concepts in the construction industry, enables us to accurately predict the amount of materials usage in project's time periods. The proposed scenario emphasizes on the scheduling problem with consideration of resource limitations as one of NP-Hard problems using building information modeling in order to provide accurate inputs for SA optimization algorithm and model to minimize the project's duration by considering this limitation.

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