THE WORKFLOW PLANNING OF CONSTRUCTION SITES USING WHALE OPTIMIZATION ALGORITHM (WOA)

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ABSTRACT
The interaction of the workspaces required for resources and sub-contractors with the evolving of construction components and also the limited available spaces of worksite lead to time-space conflicts. Alongside, Lack of coverage of workspace information in the classical scheduling techniques make workflow planning actually unrealistic and impractical. To help resolve the conflicts at the lowest time and cost, the tools and processes of Building Information Modeling (BIM) and optimization algorithms seem essential. Methods: In this investigation, the workspaces were created based on the analysis and shaping of construction resources and building elements. Then, the spatial conflicts between workspaces were identifies visually in a time based simulation tool. Finally Wale optimization algorithm (WOA) was implemented for optimizing the outputs variable such as time, cost and workspace simultaneously. The main objective of this research was to implement the integration of visual simulation modelling and optimization algorithm for planning of workspace conflicts. The implementation of the research on the case study showed that the project’s cost and time as well as the number of spatial conflicts decreased dramatically in relation to normal and initial schedule. Also, the 2D trend line of the obtained solution demonstrated that the number of the workspace conflicts decreased as the project’s cost increased. In fact, the visual and numerical techniques were combined to make a basis platform for workflow planning of construction resources and working teams in project sites. This system enables planners to completely understand the number and amounts of conflicts in each days of project, which is impossible without that circumstances.

Keywords: Building Information Modeling (BIM), spatial conflicts, Whale Optimization Algorithm (WOA), Workflow.

INTRODUCTION
Since the available workspaces in project sites are very limited, conducting parallel activities and using of the construction resources in upper-level can lead to time-space conflicts(Akinci, Fischen et al. 2002). Further space conflicts occur at the end of the work, due to the high-volume demand of simultaneous tasks related to several working-teams(Marx and Konig 2013). Therefore, planning these kind of workspaces plays a vital role in proper management of construction projects. On the other hand, the classical methods of construction planning consider only the time factor as the most important constraint in planning and don’t consider the workplace as a main one. These methods have poor performance in detecting the space conflicts in the planning and executive stage of
project (Mallasi 2006). In these techniques, the conditions of the workspaces and resources are coordinated by the users’ mind and cannot be observed on the graph or chart. Therefore, too much reliance on these methods has led to one-dimensional planning process, and the undetected executive conflicts (Heesom 2004).

In nowadays, the 4D CAD technology has advanced much from the 4D visualization stage and the collaborative working model "Architecture, Engineering and Construction," is progressing in the construction industry. Considering the fact that the 4D models have the advantage of the scheduling and design information connection, they play an important role in the construction projects planning (Rohani, Fan et al. 2014). The whole participants of the project may examine not only the three-dimensional model through the project information network, but also the exact time of the project's progress and the resource usage calculation and their costs during a particular period through these models (Wang, Zhang et al. 2004). These models can improve for the deficiency of the previous systems and upgrade the planning.

Lack of coverage of the workspace in the classical construction planning and the multi-dimensional and visual simulation capacity of the workspaces necessitate the visual and formulated planning of this issue. This research by combining Building Information Modeling (BIM) and Whale Optimization Algorithm (WOA) tries to resolve the spatial conflicts and provide the best project's workflow based on the total cost and time. The relation between visual simulation tools and numerical algorithms, not only creates an engineering and tangible basis for planning the work flow, but it also provides an executive and operational vision for the project managers and executive teams. This method also provides a novel approach in the visual management of the workflow using the volume analysis of the construction resources.

**RESEARCH BACKGROUND**

This section provides a widespread and growing review of the conducted studies in different aspects of workspace planning and management of construction projects. This area of research started since the 1990s, and the most prominent and outstanding investigations can be categorized into three complementary temporal stages. The main topics of workspace management during these three periods with regard to the growth of technology and the available tools include: (1) the workspaces definition and allocation, (2) per capita and the volume of resources, (3) space creation techniques, (4) graphical and non-graphical data linking, (5) the spatial congestions and conflicts detection and (6) the tools and techniques of visual simulation models. Since the 1994 – 2002 interval, most studies made use of 2D CAD models instead of the nD modeling in order to show the workspaces, because there were limited available visualization tools during that period. Many attempts were made during this period to define spaces (Thabet and Beliveau 1994, Riley and Sanvido 1995) and to classify them along with the spatial indicators. The suggestion to divide the workspaces into working regions, zones, and units was set forth at the micro level for the first time (Thabet and Beliveau 1997).

The second stage of these studies started in 2002 with the growth of Information Technology (IT) and the development of 4D CAD models. Different methods of semi-automatic workspace creation were presented with regard to the methods and resources of construction activities (Akinci, Fischer et al. 2002). Moreover, theoretical mechanisms were used with the help of geometric equations, for detection and categorization of spatial conflicts and congestion and the critical analysis of spaces (Guo 2002, Winch and North 2006). At this stage, networking techniques (Jang, Lee et al. 2007, Elmahdi, Chen Wu et al. 2011), breaking down the project sites to zones and sections (Jongeling and Olofsson 2007) were among the most widely used techniques that contribute to the simulation models. In some cases, tried to visualize the workspaces in detail using virtual prototyping and industrial simulation tools (Huang, Kong et al. 2007). In the end of this period, the optimization algorithm such as GA and other scheduling techniques such as Location-Based Scheduling (LBS) (Jongeling and Olofsson 2007) were used to quantify the visualization outputs and select the best strategies for the workflow (Jang, Lee et al. 2007, Mallasi 2009).
The third stage of these kind of researches started with the development of programming languages and coding for automatic creation of workspaces in virtual environment. In fact, workspaces required for construction activities were generated according to the construction components and spatial conflicts were identified automatically by combining programming and advanced visualization tools (Marx and König 2013). Coding was used in order to shape the workspaces and allocate hybrid geometric volumes based on the building products (Su and Cai 2014). Efforts were continued to formulate the workspaces creation and databases were used for defined spatial samples. Although this area has progressed toward more automated methods of creation, allocation, detection and removal of the workspace conflicts (Chavada, Dawood et al. 2012, Moon, Dawood et al. 2014), but the unique nature of each project necessitates the development of the fundamentals for the workspace planning. The schematic timeline of the performed investigations is depicted in Figure (1).

Although various researches were carried out about the time-space planning with visual modeling and optimization algorithms, there are still limitations in these methods. The implemented methods were involved more with the technical aspects of the visual and numerical data linking and the computer simulation techniques. In some cases (Zouein and Tommelein 2001, Kassem, Dawood et al. 2015), time and space have been considered as the main variables and the trade-off between them has been made, but the total project’s cost has not been considered. This research for the first time developed conflict resolution strategies by the help of optimization algorithm for finding the best workflow of construction operation.

![Figure 1. Schematic timeline of the conducted studies](image-url)

**RESEARCH METHODOLOGY**
The workspace creation process was performed on the analysis of required resources and their volumetric information. The rate of daily work done for the activities and the resources required for them were determined based on two systems of project daily reports and the resource analysis. Then, the calculated resources have been shaped as workspaces in Sketch up Software in the form of transparent volume and based on the building components axis. After creation of 3D workspaces, the relation of the scheduling data with geometric information was made in BIM-based software (Navisworks). In fact, the workspace has appeared corresponding to the activities at specific times based on the schedule, and it has disappeared with the ending of the activity and by appearing of building elements. By offering the simulation models, the geometric conflict detector of the visual software identified the number of the workspace conflicts for each pair of activities.

Finally, Whale Optimization Algorithm (WOA), which is a swarm-based method, was used to minimize outputs of this initial model. Each (scheduling) solution given by the algorithm has the calculated projects time and cost. Then, the schedule provided by the algorithm was implemented in the 5D simulation model and the number of conflicts in it were identified. Just then, the number of identified clashes were entered into the algorithm so that it could provide the next solution for the model based on its own process.

The total project's cost function was defined in WOA according to the direct and indirect costs. The project cost and the number of clashes changed consistent with applied strategies. The modification strategies of progress's direction and activities duration were included in each solution according the construction necessities and schedule-dependency constraints. Therefore, the WOA proceeded so as to find an optimal solution using the quantitative outputs of visual simulation. The combination of the workspace visual modeling and the WOA helped in resolving the spatial conflicts and choosing the best workflow based on the estimated cost. In this study, a case study was implemented at each stage and along with operational steps of research. In general, the tools and software used in this this research are as follow:

- Google sketch up pro 2015
- Microsoft Project 2013
- Naviswork Manage 2015
- Matlab R2014b

ANALYSIS AND DEVELOPMENT OF WORKSPACE FOR CONSTRUCTION RESOURCES

In this research, the significant rate of construction resources changes according to the nature of construction activities. In the analysis of human resources with different coefficients, the resource that had the greatest impact on the completion of a unit of work was selected as the main factor of a working team's activity in order to calculate the activities duration. Other human resources of working teams that have different coefficients are considered for that unit via conversion of the coefficient into number of resource. In construction an item such as exterior walls (Brick-laying with Cement Masonry Unit), the brickwork manpower was considered by a coefficient of 0.3 person-hours as a main source for the implementation of one square-meter of the task unit among the three factors of human resources (brickwork, assistant brickwork and simple worker).

The efficiency rate of the working team and the resources needed in a day (N) are assessed by dividing the time unit of one day which is 8 work hours (D) into the amount of time needed by a working team for production of a work unit (R). For instance, the production rate of a working team...
for brick-laying activity in a day (8 hours) is 26.7 square meters. Considering the conditions of the project and the working teams involved in the project, the average progress of brick-laying activity in a month were examined based on the daily reports of the project case and the efficiency rate of 27.9 square meters were recorded.

The proximity of the progress rate of the working-teams involved in the project based on the daily reports and the number obtained from the resource analysis showed the accuracy and validity of the experience and analysis in the planning and scheduling of activities. Subsequently, the volume which automatically recorded from the activity (Q) was divided by the quantity obtained from the daily progress rate of each working-team (N), and the duration of the activity was estimated. For example, the area of 418 m² for exterior wall was divided by the average daily progress rate of the working team (27.9 square meters) and the duration of brick-laying was calculated as 15 working days for the project case. The work volumes of several activities in the case study along with the duration estimated for performing them based on the resource analysis and the daily reports of project are presented in Table (1).

**Table1. Estimation of activities duration based on the resource analysis**

<table>
<thead>
<tr>
<th>Construction materials and method</th>
<th>Quantity (Q)</th>
<th>Hours needed for the work unit with one working-team (R)</th>
<th>One working day (D)</th>
<th>The amount of work done per day (N₁)</th>
<th>Duration of activity (day) (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior walls CMU</td>
<td>119 Meters in length, 418 Square meter</td>
<td>0.3</td>
<td>8</td>
<td>26.7</td>
<td>15</td>
</tr>
<tr>
<td>Construction and installation of the frame, doors and windows</td>
<td>20.12*7</td>
<td>0.062</td>
<td>8</td>
<td>129</td>
<td>12</td>
</tr>
<tr>
<td>Interior panel made of steel and gypsum board</td>
<td>103.3 Meters in length, 316.3 Square meter</td>
<td>0.33</td>
<td>8</td>
<td>24.2</td>
<td>12</td>
</tr>
<tr>
<td>Gypsum-plaster</td>
<td>136.1 Meters in length, 480.8 Square meter</td>
<td>0.222</td>
<td>8</td>
<td>36</td>
<td>12</td>
</tr>
<tr>
<td>Preparation and implementation of floor's lightweight concrete</td>
<td>678.02</td>
<td>0.634</td>
<td>8</td>
<td>84.1</td>
<td>8</td>
</tr>
<tr>
<td>Ceramic floor tiles</td>
<td>678.02 Meters in length, 0.305 Square meter</td>
<td>8</td>
<td>26.2</td>
<td>27.1</td>
<td>25</td>
</tr>
<tr>
<td>Piping and installation of fan coils</td>
<td>53.4 Meters in length, 0.264 Square meter</td>
<td>8</td>
<td>30.3</td>
<td>10.7</td>
<td>5</td>
</tr>
<tr>
<td>Cable tray as wide as 87 Meters in length</td>
<td>0.32</td>
<td>8</td>
<td>25</td>
<td>29</td>
<td>3</td>
</tr>
<tr>
<td>Installing the false ceiling panel</td>
<td>677.96 Meters in length, 0.21 Square meter</td>
<td>8</td>
<td>38.1</td>
<td>37.7</td>
<td>18</td>
</tr>
</tbody>
</table>

The time required to carry out the activities were estimated by analyzing the construction resources and the activities quantity take off. The type of relations and prerequisites defined between the activities as well as the delay and lag among them were specified by the experts' views and the construction necessitates. The project which was selected as a case study planned for 60 working days and included five critical activities and the rest had free slack. The highest free float was related to the procurement and installation of window framing which took 44 days, and the lowest pertained to the installation of fabric mate ceilings with a free slack of 6 days. The overall schedule along with the costs estimated based on the Iranians analysis resources were determined for the construction activities and entered in Microsoft Project (Appendix I).
In the end of this section, the workspace was shaped in the form of 3D transparent volumes on the basis of the calculated quantity of resources and the axis of the final component of the construction. These transparent geometric volumes of static and dynamic workspace were formed and composed based on the activity type. The static and dynamic workspaces were created parallel to and in coordination with the shape of building elements and the way of development. This axis of building products changes in different forms and corners, which influences the ultimate formation of the workspace. The final shape of the workspace was designed in the form of geometric volumes and in parallel with the axis. Figure (2) represents the typical workspace was created and produced for installation of fan coils in the virtual and actual environment.

**Figure 2. Typical workspace for the fan coils installation**

**DETECTION OF THE TIME-SPACE CONFLICTS**

The second stage of the methodology was implemented by importing the 3D components and schedules from the relevant applications and tools (Google SketchUp and Microsoft Project) to the Navisworks Manage software. The relationship and linking between the activities of scheduling and 3D components of the workspaces was established semi-automatically and the final model of simulation along with the estimated time and cost was formed. Volumes and three-dimensional objects of the workspaces designed in SketchUp software and saved separately for each activity in .fbx format. Then, each file of 3D volumes was entered into the visual simulation model (Navisworks Manage), and all of the volumes were coordinated on each other and saved in a BIM based software with .nwf format. In addition, the code of building objects and the workspaces corresponding with them by the defined properties and structures (PBS) were listed in the decision tree panel of simulation tool. On the other hand, the activities of schedule with a defined Work Breakdown Structure (WBS) and .mpp format from Microsoft Project software was added to simulation software information source and synchronized with it. By linking and connecting these two parts, the visual simulation model of the work flow and construction progress was created based on the schedule. Finally, the spatial conflicts were determined by the help of visual simulation tool for the working-teams and sub-contractors. Figure (3) shows an example of the recorded time-space clashes of the project.

We can come to a comprehensive understanding of the number and distance of spatial conflicts in each day of the project by specifying the number of activities with time overlapping. This system enables planners to completely understand the project days with the number and amounts of conflicts,
which is impossible without that circumstances. Then, Whale Optimization Algorithm was implemented to minimize the temporal and spatial variables.

**MINIMIZATION OF THE SCHEDULE USING WHALE OPTIMIZATION ALGORITHM**

A new nature-inspired and meta-heuristic algorithm with the name of whale optimization algorithm has been used in this part of research. This defined model has been on the basis of the hunting of humped whales by a network of bubbles and by use of shrinking and spiral movements towards the prey. This algorithm is based on particle swarm method which generally retain the information space obtained in each iterations, while evolution-based methods such as genetic method remove the search space of the obtained information at evolution stages upon the formation of new generation. This algorithm also uses the process of exploration and exploitation in order to find and search for local and global solutions and has great power in maintaining the balance between these two processes. The optimizer is randomly seeking to discover new spaces in the discovery process, whereas the exploitation process explores the details of the discovered regions and tries to locally search for optimal answers (Mirjalili and Lewis 2016).

In this research, the algorithm searched the minimal cost and the number of the workspace conflicts of the project by providing different scheduling solutions. Two modification strategies of progress's direction and start date of activities were generally implemented in each solution which the first is ineffective and the second one is effective in the project total cost and time. Although the both strategies were implemented together and simultaneously in each solution, but the first one was prioritized as it maintains the time, cost and the overall structure of the sequence and also due to the critical path of the project.

Changing the direction of progress of the working teams and sub-contractors leads to a change in the workspace configuration. Perimeter activities such as brick-laying and gypsum plastering progress in the clockwise and Counter Clock manner while the linear and surface activities such as ceramic tiling and piping take place in the four main directions, namely the North-South, South-East, North-West and West-East. Operational items which were done on the same surfaces do not have the capability of changing direction. This strategy is not applicable, if two activities which are prerequisites and dependencies to each other and have time overlapping in the schedule. Therefore, they have to be performed in one direction and applied to the schedule network as a limitation and constraint.

The second strategy is related to changing the duration of the activities construction, which results in the removal of some important spatial conflicts. This change of duration leads in some cases to the reduced possibility of conflict occurrence by reducing the time overlaps among the activities. The initial schedule was considered the normal answer with the execution duration of 60 working days...
with 19 conflicts and the cost calculated as 191330.3$. Each activity has a defined crash ability, which changes the direct costs of the project. On the other hand, changing the duration of the entire project resulted in changing the indirect costs and the total cost of the project. Therefore, with a change in the duration of activities in each solution and according to the relationships among the activities, the total time and cost of the project will change at each iteration. The duration of 9 activities (defined variables) changed from normal into a crashed mode in each applied strategy, and the project time and total cost in each solution will undergo a change in amount. The critical path and free float of the activities changed by implementation of each strategy.

Various solutions have been proposed by each simulator repetition, which includes the duration of activities in defined range and different directions based on the executive limitations. The relations and dependencies between activities together with the defined lag between them is constant and unchanging in the responses provided by the algorithm. Therefore, the changing of activities duration not only change the direct costs of the activities, but also lead to a change in the scheduling of the total project as well as in the indirect costs of the project.

Each scheduling solution has the specified time as well as the calculated cost, and the number of workspace conflicts were calculated from 5D visual simulation model and transmitted to the algorithm. The scheduling solution provided by the algorithm was implemented in the scheduling software (Microsoft Project) manually, then the new schedule was updated in the 5D visual simulation system (Navisworks Manage), in which the number of conflicts was identified. This number of conflicts for the original solution was entered into the algorithm so that it presented the next solution for the model based on its own process. This algorithm used Formula (1) to achieve the optimal or minimal response. In this formula, each particle updated its position relative to the best search agent, where t represents the number of repetitions, A and C represent the vector coefficients and \( \vec{X}^* \) represents the location vector from the best solution obtained so far (Mirjalili and Lewis 2016).

\[
D = |\vec{C}(t) - \vec{X}(t)|
\]

\[
\vec{X}(t + 1) = \vec{X}(t) - A \cdot \vec{D}
\]

The A factor decreases randomly from the value 2 toward zero during each stage of repetition. This index at the range of \( 1 \leq |A| \leq 1 \) is in search of a random point at the overall possible level of answers. However, this factor at the range of \( 0 \leq |A| \leq 1 \) is in search of any point between the original position of the agent and the position of the best current agent. The main function of this research which was considered to minimize the cost and number of the workspace conflicts is as follows:

- Duration of activities as the main variables

Consider \( x_i = \{x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}\} \)

\[
[x_i - \text{activity duration}] \]

- The normal duration of the project (day)

\( PT_{\text{normal}} = 60 \)

- The average daily of overhead cost ($)

\( C_{\text{daily overhead}} = 3.5 \)
The main function (sum of costs)

\[ \text{Minimize } f(x) = \text{Sum } (\text{Cost}_i) + C_0_i \]

- The direct costs of project

\[ \text{Cost}_i = C_{\text{IN}} + ((D_{i,\text{-Normal}} - D_{i,\text{-Crashed}}) \times C_{\text{-Slop}}) \]

- The indirect costs of project

\[ C_{0_i} = (P_{T_i} - F_{T_i}) \times C_{\text{daily overhead}} \]

\[ S_{T_i} = t \]

\[ F_{T_i} = \text{Max } (t + D_i - 1, t) \]

\[ P_{T_i} = \text{Max } (F_{T_i}) \]

- Range of activities duration from the normal up to the crashed mode (integer)

Variable Range: (Integer)

\[ x_{4-7} = 0, 9 < x_8 < 15, 6 < x_4 < 12, 4 < x_7 < 8, 13 < x_9 < 25, x_9 = 5, x_{10} = 3, 9 < x_{11} < 18. \]

- Defined relations among activities

Constraint:

\[ S_{T_3} = F_{T_2}, S_{T_4} = S_{T_3} + 4, \]
\[ S_{T_5} = F_{T_2} - 2, S_{T_6} = F_{T_5} + 1, S_{T_7} = F_{T_6} - 1, S_{T_8} = S_{T_7} + 1, S_{T_9} = F_{T_7} + 1, S_{T_{10}} = F_{T_8} + 1, S_{T_{11}} = F_{T_6,10} + 1. \]

As mentioned before, any activity at the micro level was performed either on a rotating direction or toward the four main Cartesian directions depending on the nature of the activity. Defined directions were provided for activities randomly and considering the constraints at each step in order to come to the optimal answer which is done by the main function and algorithm. Activities 3, 4 and 6 which were perimeter activities by nature can be clockwise or Counter Clock, while the other activities can have west-east or east-west direction. In the initial solution of the schedule, rotation activities were defined as clockwise, whereas other activities were defined as East to West by default. The brick-laying activity (3) and the installation of windows frames (4) as well as the flooring (7) and ceramic tiling activities (8) which were performed on a same surface and also have time overlapping must use the same direction of progress. This limitation should be applied to the schedule network as a constraint.

A solution with duration of 47 days and the total cost of 190760$ and 12 spatial conflicts was recorded as the best solution after repetition of 101 solutions. The total cost of the project as well as the total number of the workspace conflicts of the project decreased and the project cost reduced to 570.3$. All of the scheduling had conflicts and no solution without spatial conflict was found. In addition, the smallest number of conflicts among the answers was 10, while the lowest cost was recorded as 190556.1$. The two-dimensional coordinates of these points based on the number of conflicts and the total cost of the project are shown in Figure (4). The trend line of the coordinates shows that the number of the workspace conflicts decreases as the project cost increases.
The minimal solution selected in terms of time, cost and number of recorded conflicts of the entire project is better than the initial point of the schedule, and this system helps planners to move towards better planning. The movement and scheduling conditions for the obtained schedule are displayed in Table (2).

**Table2.** Characteristics of the minimal point of the project

<table>
<thead>
<tr>
<th>Activity</th>
<th>duration</th>
<th>Direction of progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. the total project</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>2. Structure completion</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3. exterior wall (CMU)</td>
<td>12</td>
<td>counter-clock</td>
</tr>
<tr>
<td>4. implementing window's framing</td>
<td>11</td>
<td>counter-clock</td>
</tr>
<tr>
<td>5. interior wall (drywall)</td>
<td>9</td>
<td>East-west</td>
</tr>
<tr>
<td>6. gypsum-plastering</td>
<td>11</td>
<td>counter-clock</td>
</tr>
<tr>
<td>7. flooring of Lightweight Aggregate</td>
<td>7</td>
<td>East-west</td>
</tr>
<tr>
<td>8. installing ceramic floor tiles</td>
<td>19</td>
<td>East-west</td>
</tr>
<tr>
<td>9. piping and installing fan coils</td>
<td>5</td>
<td>East-west</td>
</tr>
<tr>
<td>10. installing the cable tray</td>
<td>3</td>
<td>West-East</td>
</tr>
<tr>
<td>11. installing the false ceiling panel</td>
<td>18</td>
<td>West-East</td>
</tr>
</tbody>
</table>

Investigation of the numerical Spearman correlation between the cost and the number of spatial conflicts variables shows a negative correlation (-0.468) which is consistent with the trend line of results. It’s worth mentioning that 32% of the workspace conflicts were predictable based on the project time and cost and has a specific regression. The number of the workspaces conflicts cannot be precise and the response of visual simulation was needed for the final calculation due to the geometric position of the workspaces. Therefore, the interaction between WOA and visual simulation was needed for covering the three variables such as time, cost and spatial conflict. For example, the outputs of the visual simulations show that the number of spatial conflicts in the numerical range of 12 and 42 changes under the scheduling conditions of 47 days for the project and with different directions of progress, and the geometric conflict detector of
the visual simulation model is the only reliable source for the number of conflicts. All results of running WOA iterations and visual simulation models in regarding three variable of projects cost, time and spatial conflicts are presented in Appendix (II).

CONCLUSIONS

The project time, cost and workspace were regarded as three main factors of construction planning, and the relationship among them was based on the conditions of the construction resources. It’s possible to examine these three variables simultaneously and measure their impact on each other so that reach the best construction strategies through a correct quantitative and volumetric definition of resources needed for construction activities. In this regard, multi-dimensional models and optimization algorithm provided the planners with a proper tool by combining the visual simulations of the time-based workspaces and finding the minimum answers.

In the presented research, the 5D CAD model was created based on the numerical and volumetric of construction resources and the workspace conflicts of the initial schedule in a time interval and in the form of geometric clashes were identified and listed. Subsequently, the total project cost function was defined in whale optimization algorithm based on direct and indirect costs of project. The two modification strategies of progress direction and start date of activities were developed based on the scheduling and constraints of construction in each solution so that the algorithm can reach its minimum costs. In fact, the number of conflicts corresponding with each solution and the relevant strategies were extracted from the visual simulation system and implemented in optimization algorithm to find the best answer.

REFERENCES


**APPENDIX I**

Normal and initial schedule of project based on the resource analysis

<table>
<thead>
<tr>
<th>Activity name and number</th>
<th>Start-date</th>
<th>End-date</th>
<th>Prerequisite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. the total project</td>
<td>2015/08/11</td>
<td>2016/06/01</td>
<td></td>
</tr>
<tr>
<td>2. Structure completion</td>
<td>2015/08/11</td>
<td>2015/08/11</td>
<td></td>
</tr>
<tr>
<td>3. exterior wall (CMU)</td>
<td>2015/08/11</td>
<td>2015/22/11</td>
<td>2</td>
</tr>
<tr>
<td>4. implementing window's framing</td>
<td>2015/12/11</td>
<td>2015/23/11</td>
<td>3SS+4</td>
</tr>
<tr>
<td>5. interior wall (drywall)</td>
<td>2015/20/11</td>
<td>2015/01/12</td>
<td>3FS-3</td>
</tr>
<tr>
<td>6. gypsum-plastering</td>
<td>2015/02/12</td>
<td>2015/13/12</td>
<td>5</td>
</tr>
<tr>
<td>7. flooring of Lightweight Aggregate Concrete</td>
<td>2015/12/12</td>
<td>2015/19/12</td>
<td>6FS-2</td>
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<td>8. installing ceramic floor tiles</td>
<td>12/13/2015</td>
<td>1/6/2016</td>
<td>7SS+1</td>
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<tr>
<td>9. piping and installing fan coils</td>
<td>12/2/2015</td>
<td>12/6/2015</td>
<td>5</td>
</tr>
<tr>
<td>10. substructuring and installing the cable tray</td>
<td>12/2/2015</td>
<td>12/4/2015</td>
<td>5</td>
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APPENDIX II. Iteration properties of running WOA algorithm