Decision Support System for Site Layout Planning

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Abstract -

Construction Site Layout Planning (SLP) is one among the processes that consider decision-making as essential to achieving the desired project performance. In lack of decision support system (DSS), the project planners employ learnings from experience to make decisions that often lead to sub-optimal planning of site, resulting in congestion, safety issues and loss in productivity. Therefore, to mitigate such risks, the SLP targets to identify the temporary facilities (TFs) required to aid the construction and optimally locate these TFs. SLP usually requires all the stakeholders to reach consensus and to aid this a few operations research (OR) models are developed in past studies. While SLP is often viewed as an optimal allocation problem by present research, the decision-making aspect involving multiple stakeholders is understudied. As a result, state-of-art research in modelling and optimal allocation using OR methods are not implemented on site. Therefore, targeting the decision-making in SLP, an approach is demonstrated to enhance the process through efficient exchange of information. This study employs building information modelling (BIM) to make data available for the modelled optimization problem. In addition to this, to foster the decision-making during the SLP task, the study presents an augmented reality (AR) enabled site layout planning decision support system (SLP-DSS) framework to aid the construction practitioners in SLP. The developed DSS with the functionality of AR integrated optimization is designed to make understand the generated solutions to the stakeholders in an efficient manner and targets to ease out the SLP process with a clear perspective exchange.

Keywords -

Augmented Reality; Building Information Modelling; Collaborative Planning; Decision Making; Optimization; Layout Planning; Perspective Exchange; Visualization

1 Introduction and Motivation

Construction site layout incorporates positioning of TFs on a construction site. This task is approached at the initial project phase when information related to the project is scarce. To overcome this limitation, the construction practitioners employ the learnings from previous similar projects [1]. Another challenge comes in the form of site topology and to understand it better, the 2D representation of the site in the form of computer-aided drawings (CAD) is employed. This sort of representation of 3D space requires tailoring of plans and elevations from different CAD sheets. Thus, resulting in additional mental exertion in the process of layout planning. The stakeholders involved in the process of planning site layouts sometime does not have enough experience to understand the 2D site representation. This leads to inaccurate information exchange while discussing SLP making the process of decision making cumbersome. SLP task involves stakeholders with individual goals [2] and the limited site space brings them together to plan for efficient space utilization. Thus, requires an efficient method to plan site layouts collaboratively with optimum space utilization. Moreover, to collaborate effectively, the exchange of perspectives in an efficient manner is a must.

In an attempt to release SLP of some obsolete hindrances in efficient decision-making pertaining to the layouts for the construction site, this study utilizes and demonstrates the applicability of technological advancements like BIM and AR. In addition to approach SLP through these advanced technologies, the research highlights optimization-based solution visualized in AR environment to mitigate the psychological efforts in understanding the generated output results. The utilization of BIM is targeted to address the information requirements to plan site layouts. The developed quantitative approach aided with visual aid is expected to enable the stakeholders to make informed and efficient decisions resulting in enhanced site productivity and a safer work environment.

2 Literature Review

Existing research on layout planning has extensively studied the SLP problem as an optimization problem. The quantitative approach to SLP results into numerical based output, requiring manual interpretation of the obtained results. Considering these challenges posed by optimization-based SLP models proposed in earlier research, a few researchers have attempted to consider DSS for SLP. These efforts were because the resulted output of optimization-based models is of no use until verified. In attempts to develop DSS for SLP, approaches like fuzzy-based multi-criteria model was developed and found useful in terms when the required information is imprecise [1]. Another tacit-based approach was developed to plan site layouts. This was approached utilizing a combination of repertory grid technique and interviews of construction professionals [3]. These both research presented examples of quantitative and learnings from the past based methods, respectively. However, the exchange of perspective while planning site layouts is a prime component of decision-making task; this comes out as a limitation to the existing research. Thus, BIM and AR are utilized to address these impediments to efficient SLP. The former provides input data if the models are prepared to the required level of detail (LOD) and the latter augments the optimal solution of the quantitative approach developed in this study for better exchange of perspective among stakeholders.

2.1 BIM for SLP

The utilization of BIM in the construction industry has been profound in the past decade [4]. In existing SLP concerned studies BIM has been adopted as a source of input data and a few researchers have highlighted LOD 300 as the required level of detail [5]. The data related to the materials required for construction and quantity take-off interested researchers to adopt BIM for layout planning. Another research has demonstrated the implementation of BIM integrated AR to establish efficient collaboration among stakeholders [6]. As BIM is data intrinsic model, its utilization can benefit data-centric tasks like SLP in the construction industry.

2.2 AR for SLP

The development of AR was initially conceptualized as a visual enhanced assistance tool to perform certain tasks. Tasks that require instructions delivered or exchange of perspective were primarily targeted to be benefited from this technology [7]. Implementation of AR to visualize and organize construction worksite was approached utilizing marker-based AR to plan rule base site plan [8].

3 Development of Framework for DSS

The study employs BIM to enable data availability following which the inputs to the optimization module of the DSS allows the generation of results. The BIM model developed to demonstrate the working of the developed DSS conforms LOD 300. The model comprises a structural frame for an industrial setup where the site is adequate to accommodate the required temporary facilities. The temporary facilities required to aid the construction are identified from the quantity take-off generated from the BIM model utilizing visual programming tool Dynamo. The developed BIM model enabled the extraction of data pertaining to cost and the distances from the locations identified as possible options to accommodate the required TFs.

Following the task of acquiring inputs, the mathematical model for the site has been modelled as an optimization problem. The objective function is focused to minimize the material transportation cost along with satisfying the constraints related to the positioning of TFs and restriction on locations available to locate the TFs. In order to minimize the transportation cost, the objective function is modelled as a function of decision variable with coefficient as the product of transportation cost per unit distance 'C_{mq}' and the distance 'D_{lq}' between the points of supply 'l' and demand 'q' as shown in (1. The decision variable 'X_{ml}' is modelled as a Boolean variable representing the position of TFs 'm' at a location 'l'.

$$\text{Min} \sum_{l=1}^{L}\sum_{m=1}^{M}\sum_{q=1}^{Q} C_{mq}D_{lq}X_{ml} \quad (1)$$

The presented optimization model is adopted from existing research [9] presenting a discrete site layout planning problem. To present a better understanding, the following Figure 1 illustrates the points of material supply 'l' and demand 'q'.

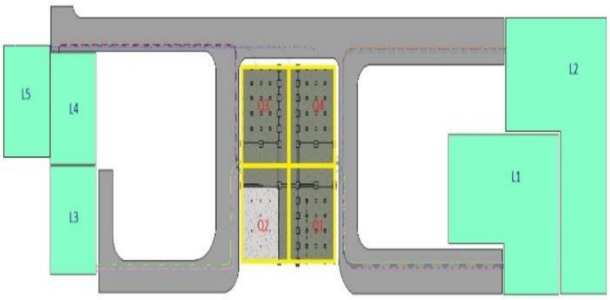

Figure 1. Description of supply and demand points

It indicates that the locations available to accommodate TFs are identified at prior and the continuous site space is divided into isolated areas to position the required TFs. The presented constrain in (2 is modelled to limit each identified location to accommodate a single TF. Similarly, each TF is allowed to occupy a single location on site satisfying the modelled constraint in (3.

$$\sum_{m=1}^{M} X_{ml} = 1 \qquad \text{Where, } \{l=1, 2\ldots L\} \tag{2}$$

$$\sum_{l=1}^{L} X_{ml} = 1 \qquad \text{Where, } \{m=1, 2\ldots M\} \tag{3}$$

The modelled optimization model is solved for the optimum value of the decision variable through genetic algorithm (GA). Thus, to obtain the optimum results the crossover and mutation operators are considered in this study. These operators helped in exploring and exploiting the search space in an effort to find the optimal solution. Once the optimal results are achieved, the AR rendering of the solution is generated to visualize the result. This visual aid in the augmented environment is prepared by integrating the code for optimization in the AR development software unity. The following Figure 2 elaborates the steps involved in the development of the AR-BIM enabled decision support system for SLP.

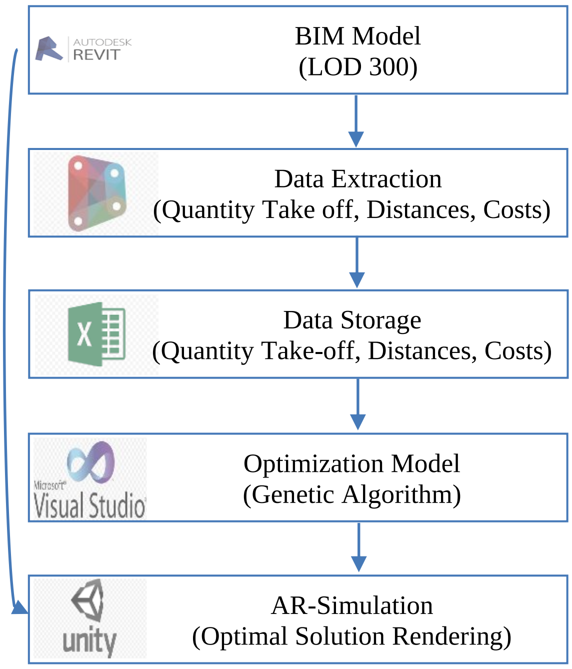

Figure 2. Schematic representation of framework for the proposed DSS

The AR visualization provides a simulation environment to test out the results generated through optimization model. This enhances the effectiveness of the mathematical model by transforming the numerical output of the optimization model to corresponding digital prototypes of the TFs located at the respective obtained locations. Thus, enables the informed decision-making in the process of SLP. A detailed elaboration of the usability of this developed approach is described in the following section.

4 Working of the Developed DSS for SLP

The developed DSS in this study comprises of three key components of any DSS framework i.e. data, model and graphical user interface referred in this research as data, solver and simulation. This section elaborates the approach to obtain efficient results from the developed DSS.

4.1 Data and Solver Component of SLP-DSS

The developed linear flow framework helps in eliminating iterations required for an efficient implementation. This task of developing a support system to aid construction professionals and other stakeholders in making decisions pertaining to SLP could be made as an integral part of the design. If did so, will cater the need of the detailed input data required for the DSS along with providing flexibility to alter certain aspects of design. The presented optimization model in this study targets minimization of the material transportation cost considering actual travel paths on construction site. Thus, for the purpose, the required information related to the materials to be transported, quantities to be handled and the distance travelled by respective material is extracted and stored as input to the optimization model. Table 1 and Table 2 presents the quantity take-off for respective material required for construction and the distance to travel from supply to the demand point on construction site, respectively.

Table 1. Material quantity take-off from BIM

Material	Q_1	Q_2	Q_3	Q_4
M_1 - Reinforcement Steel (Ton)	24.4	24.4	24.4	24.4
M_2 - Quantity of Prefab Steel (Ton)	0	702	0	0
M_3 - Quantity of Concrete (Cubic Meter)	406	405	405	406
M_4 - Quantity of Excavated Soil (Cubic Meter)	287	287	287	287
M_5 - Formwork Material (Ton)	21.5	21.5	21.5	21.5

Table 2. Distance matrix from BIM

	Q_1	Q_2	Q_3	Q_4
L_1	88	108	110	88
L_2	93	114	113	83
L_3	102	82	82	103
L_4	122	100	98	120
L_5	121	101	77	105

Once these inputs to the optimization model are available, a slight modification to the extracted quantities from the BIM model (Table 1) is done to find the required number of trips to be made by the transportation vehicle as shown in Table 3. Following this, the trips are converted to trip cost matrix for unit distance trips and then is multiplied with the distance matrix to obtain the transportation cost. A detailed explanation of the optimization model utilized in this study is available in the existing research [9].

Table 3. Trips required for material transport

Material	Q_1 Trips	Q_2 Trips	Q_3 Trips	Q_4 Trips
M_1	4	4	4	4
M_2	0	88	0	0
M_3	164	164	164	164
M_4	30	30	30	30
M_5	4	4	4	4

Thus, explained the working of the optimization model, the result obtained utilizing genetic algorithm in this research provided a Pareto front to choose a solution. However, the sophisticated approach of mathematical optimization is capable of providing an optimal solution in a reasonable time. The resulted output remains a challenge for the stakeholders discussing site layout if left with the solution as shown in Table 4. The interpretation of the optimal solution would be left upon the mental faculties of the practitioners involved in the task of layout planning. Sometimes these interpretations can be easy as can be perceived in Table 4, but with an increase in the number of materials required or locations available on site can complicate the resultant solution from the optimization model to understand.

Another challenge that is often tackled while planning site layouts is the dynamic nature of construction. This induces relocation of TFs on construction site such that the complexity in planning layouts manifold in multitude.

Table 4. Optimal solution from the optimization model

Optimal Position	Interpretation	Achieved Optimal Cost Unit
$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$	M_1 at L_2 M_2 at L_4 M_3 at L_3 M_4 at L_1 M_5 at L_5	84,36,400

4.2 Visualization Component in SLP-DSS

SLP is a data-centric task and efficient results are expected through collaborative planning. Thus, it needed an information management tool along with visual management to aid planning for 3D site space utilization. This study is an attempt to furnish the requirements of the primary components of a DSS. The optimization module is supplemented with the functionality of AR to provide a better understanding of the optimal solutions obtained from the optimization model. Improved visualization is expected to help the stakeholders in presenting thoughts in clear and perceivable manner. The stakeholders involved in the task of SLP jointly come together to fulfil individual objectives due to constraint of sharing space common for all on the construction site. The task is subjected to participation from owner representative, project manager of the main contractor, sub-contractor representatives and site supervisors. This diverse participation with different goals to achieve and varying site experience calls for a common mode to experience each other’s perspective. Thus, to enable this, the AR-enabled DSS is proposed in this research. The SLP-DSS in this research is developed as an android application that works with marker-less AR. Upon solving for optimal results in the SLP-DSS solver, the results are internally transferred to the unity platform for analyzing the position of respective TFs on the construction site. This internal information handling is achieved by formulating the optimization approach as part of a visualization script used to render the optimal results of optimization.

The application architecture performs in a cyclic manner as shown in Figure 3, enabling the user to initialize the scene and continue (Figure 3A). Once initialized the required TFs are automatically moved in the site space with coordinates at the origin of the scene and marking all the possible locations available for TFs green. The next step renders the site environment in the field of view of the handheld device used for the purpose (Figure 3B). The application is provided with a user interface to overlay information in the augmented scene required for the user to run the inbuilt optimization algorithm. Once the run is complete the processor renders the optimal solution while placing the TFs at the optimal locations received from the optimization module (Figure 3C). The corresponding cost associated with the rendered solution is displayed to the user on the interface at the handheld device, along with the allowance to the user to move around the scene and verify the implementation possibility of the proposed solution (Figure 3D).

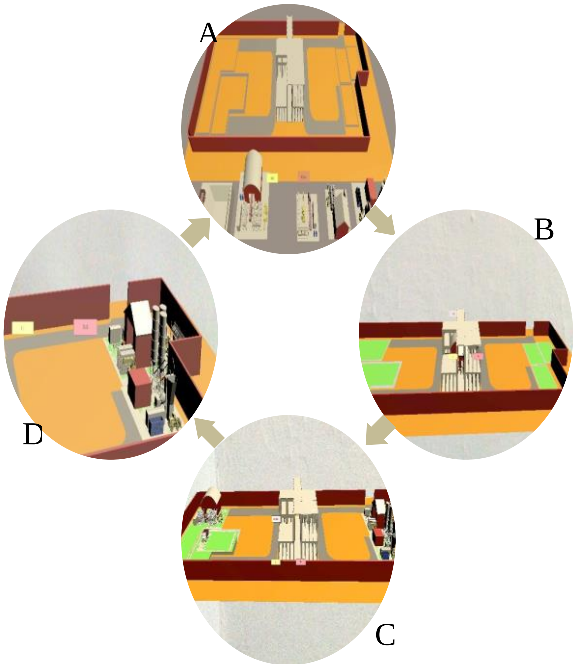

Figure3. Performance of the developed application

If unsatisfied with the results obtained, a rerun is available and the utilization of nature-inspired algorithm GA can be expected to provide another result from the Pareto optimal solutions as shown in Figure 4.

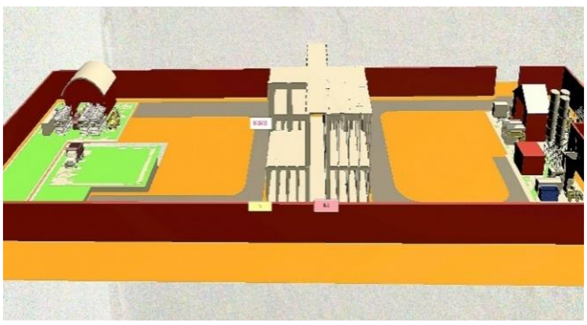

Figure 4. Visual interpretation of the optimal result

5 Limitations

The major limitation to this research comes from the objective function considered as static and discrete site layout example. In order to furnish full functionality of DSS it is proposed to consider other objectives relevant to SLP and the dynamic nature of the site is also needed to be captured. The functionality of the developed application for AR can be distributed among all the stakeholders, where inputs to the augmented scene are possible. This manipulative AR environment will reduce the search space and can provide opportunistic solutions in cases where specific objectives are not modelled as part of the optimization module for SLP-DSS.

6 Conclusion

There exist studies proposing optimization-based approaches to SLP. A few have attempted to come up with a DSS for SLP with a prime focus on the quantitative approach. This study provides a framework of a functional DSS for SLP. The integration of AR for the purpose of visual management is targeted to aid better perspectival exchange among the stakeholders involved in the SLP task. The developed approach illustrates a way forward to make sense of the data available in project designs and the BIM models.

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