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AN AUTOMATED SYSTEM FOR DYNAMIC CONSTRUCTION SITE LAYOUT PLANNING

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ABSTRACT

The effective and efficient management of construction resources is the essence of success for any construction project. Nonetheless, one of the most important construction-related resources has been for long overlooked; that is site space. In order to properly manage this vital resource, the layout of construction sites must be carefully planned. This involves the appropriate positioning of facilities needed to support the construction operations within the site boundaries. However, the dynamic nature of construction projects and its direct reflection on site requirements complicate this layout planning process. Space requirements and site constraints vary as the construction process progresses. Thus, site layouts must be dynamic in nature to be able to account for these changes. This paper introduces *EDSLP (Evolutionary Dynamic Site Layout Planner)*, a newly developed automated computer system that can be used for assigning temporary site facilities in their optimal positions while taking into consideration the dynamic nature of construction projects. EDSLP consists of a data input facility, a CAD user interface, and an evolutionary optimization engine based on the principles of genetic algorithms. The system utilizes the widely used AutoCAD™ for its graphical input/output interface. In performing the dynamic site layout planning, the system employs a new approach called “the Mini-Min Approach”. Given project and facility related data, the system provides as output a sequence of layouts spanning the entire project duration. An illustrative 15000 m^2 project is used to demonstrate the functioning of the presented system. It further shows that such automated system can be of significant aid to construction managers as they plan for their construction projects.

Keywords: Construction Sites, CAD, Dynamic Layout Planning, Optimization, Genetic Algorithms

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INTRODUCTION

The construction site layout problem involves dimensioning and locating temporary construction support facilities. Examples of temporary facilities include material storage areas, fabrication yards, site offices, etc. These facilities usually exist for a limited time period ranging from the duration of a single construction activity to the duration of a major construction phase. Some temporary facilities are required throughout the project duration. Generally, temporary facilities are dismantled after project completion (Choi 1996). The process of site layout planning in the construction industry normally takes place after the layout of permanent facilities. The shaded area in Fig. 1 indicates the time spent on site layout planning in the project lifecycle.

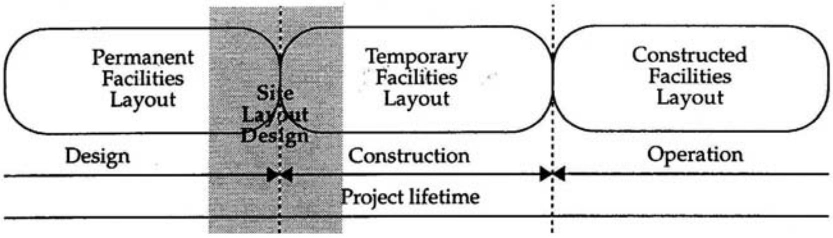

FIG. (1) Site layout planning in the project lifecycle (Choi 1996)

In the field of site layout planning, two distinct problem solving approaches exist, i.e., static layout planning and dynamic layout planning. *Static* layout planning creates only one site layout that will span the entire project duration. Usually, due to the constantly changing nature of construction sites, this static layout will become obsolete after any significant progress in the project. *Dynamic* layout planning, on the other hand, is an approach that creates several site layouts that evolve as site conditions change. The difference between individual layouts reflects the change in construction operations and available site space from one construction phase to another. It is evident that the dynamic layout planning is the more practical of the two problem solving approaches.

DYNAMIC SITE LAYOUT PLANNING

Layout Optimization Objective

Site layout planning is usually dealt with as an optimization problem of allocating a set of temporary facilities in a construction site space while maintaining its geometrical constraints. Various formulations have been used in the literature to represent the objective function of this optimization problem; though the majority of them aim at minimizing the transportation costs between facilities - whether fixed or temporary - within the construction site. One study, for instance, considered minimizing the cost of construction-personnel transportation within the site (Li 1998). Another study considered minimizing the transportation costs of the various resources utilized in a precast production yard (Cheung 2002).

In this study, the objective function to be minimized in the case of dynamic site layout planning takes the form:

Minimize (Transportation Costs + Relocation Costs) (1)

$$T.C. = \sum_{i=1}^{P-1} \sum_{j=i+1}^{P} W_{i,j}^{t} * d_{i,j}^{t} \quad (2)$$

$$R.C. = \sum_{i=1}^{P} R_i * Oc_i^{(t-1)t} \quad (3)$$

Where:

P: Total number of fixed and temporary facilities present.

$d_{i,j}^{t}$: Distance between facilities i and j during phase t

$W_{i,j}^{t}$: Transportation costs per unit distance between facilities i and j during phase t

R_i: Relocation cost of facility i

$Oc_i^{(t-1)t}$: Occurrence of relocation from phase *t-1* to phase t. If facility i has been relocated from phase *(t-1)* to phase t, then $Oc_i^{(t-1)t} = 1$ and if no relocation has occurred $Oc_i^{(t-1)t} = 0$.

Site layout planning usually takes place during the pre-construction phase (Fig. 1). Inter-facility transportation costs ($W_{i,j}$) may not necessarily be available at this stage. Thus, researchers have instead adopted what is called "*proximity weights*". A proximity weight reflects the desired closeness between any two facilities. In the absence of reliable inter-facility transportation costs, layout planning can be performed using these weights. One of the commonly used proximity weight scales is shown in Table 1. When performing layout planning based on proximity weights, a tangible objective is not quite apparent as in its transportation cost equivalent. Performing site layout based on proximity weights places temporary site facilities in positions that reflect the required closeness expressed in the proximity weight scale. Researchers in the field of construction site layout planning have also utilized the proximity weight scale (Hegazy 1999).

TABLE 1 The six value scale used in industrial facility planning (Askin 1993)

Desired relationship between facilities	**Proximity weight**
Absolutely necessary (A)	81
Especially important (E)	37
Important (I)	9
Ordinary closeness (O)	3
Unimportant (U)	1
Undesirable (X)	0

Dynamic Layout Approaches

In the past, researchers who tackled the problem of dynamic site layout planning proceeded in chronological order (Zouein 1999). Their approach starts by creating the layout of the first project phase based solely on transportation costs and creating subsequent layouts taking facility relocation costs into consideration. This approach has its drawbacks. The main weakness lies in the fact that facilities that are assigned positions in early phases may:

1- Be placed in positions that will subsequently be occupied by permanent facilities, thus they will be forced to relocate.
2- Be placed in positions that minimize the transportation costs during early phases but in subsequent phases be in unfavorably far positions from other facilities.

The researchers propose an approach that mitigates costs of assignment of facilities in positions that may seem favorable in early phases, but could turn out very costly in phases to come. It is evident that the choice of the first phase to be the initial phase (where no relocation costs are calculated) may not necessarily yield the most optimum transportation and relocation cost for all phases combined. The key to finding the optimum solution for all phases lies in identifying which phase to consider as the initial phase. Dynamic optimization should then proceed in forward chronological order for succeeding phases and backward chronological order for preceding phases.

The researchers' approach considers all possibilities for choosing the initial phase. It performs the dynamic optimization of all phases n times, n being the number of phases. It calculates the total costs for all phases n times and chooses the trial having the least cost as the *Minimum-Minimum* solution. Thus, the approach is named the *"Mini-Min"* approach. It may seem that the Mini-Min approach performs the dynamic optimization problem far too many times and that this may be computationally exhaustive. In fact, it is. For a project comprised of n phases, our system is required to solve n^2 optimization problems. It will be shown in the final section of this paper that performing Mini-Min optimization is computationally feasible on common PC's.

THE AUTOMATED COMPUTER SYSTEM: EDSLP

The functionality of the automated computer system relies on the integration between AutoCAD™, the widely used CAD platform, and genetic algorithms (GA), the evolutionary optimization technique introduced by John Holland in the late 1970's. The novelty of the system lies in its utilization of CAD capabilities as input/output media. The fact that AutoCAD™ is the most widely used CAD platform in Egypt facilitates the use of this system.

System Architecture

The automated site layout planning system is comprised of three main components (Fig. 2):

<u>1- An input facility that incorporates various types of data:</u> Four main groups of data are utilized in the system, namely:

Schedule data: Main project phases. Phases are grouped based on temporary facility requirements.
Temporary facility data: Temporary facility requirements in each phase in addition to the expected sizes of these temporary facilities.
Site geometrical data: CAD drawings representing site boundaries and the layout of fixed facilities in each project phase.
Facility cost data: Inter-facility transportation costs between facilities for each phase in addition to the expected cost for relocating temporary facilities.

2- An optimization engine based on the concepts of genetic algorithms: The optimization engine minimizes the objective function as depicted in Eqs. 1, 2 and 3. Genetic algorithms are used to perform the optimization process, which proceeds in two stages. Firstly, static layout is performed and each phase is considered completely separate. Secondly, dynamic layout is performed taking layout continuity into consideration.

3- An output facility that utilizes the programmable features of AutoCAD™: Following the optimization process, the system delivers a series of AutoCAD™ drawings each depicting a particular construction phase with all temporary facilities placed in their optimal positions.

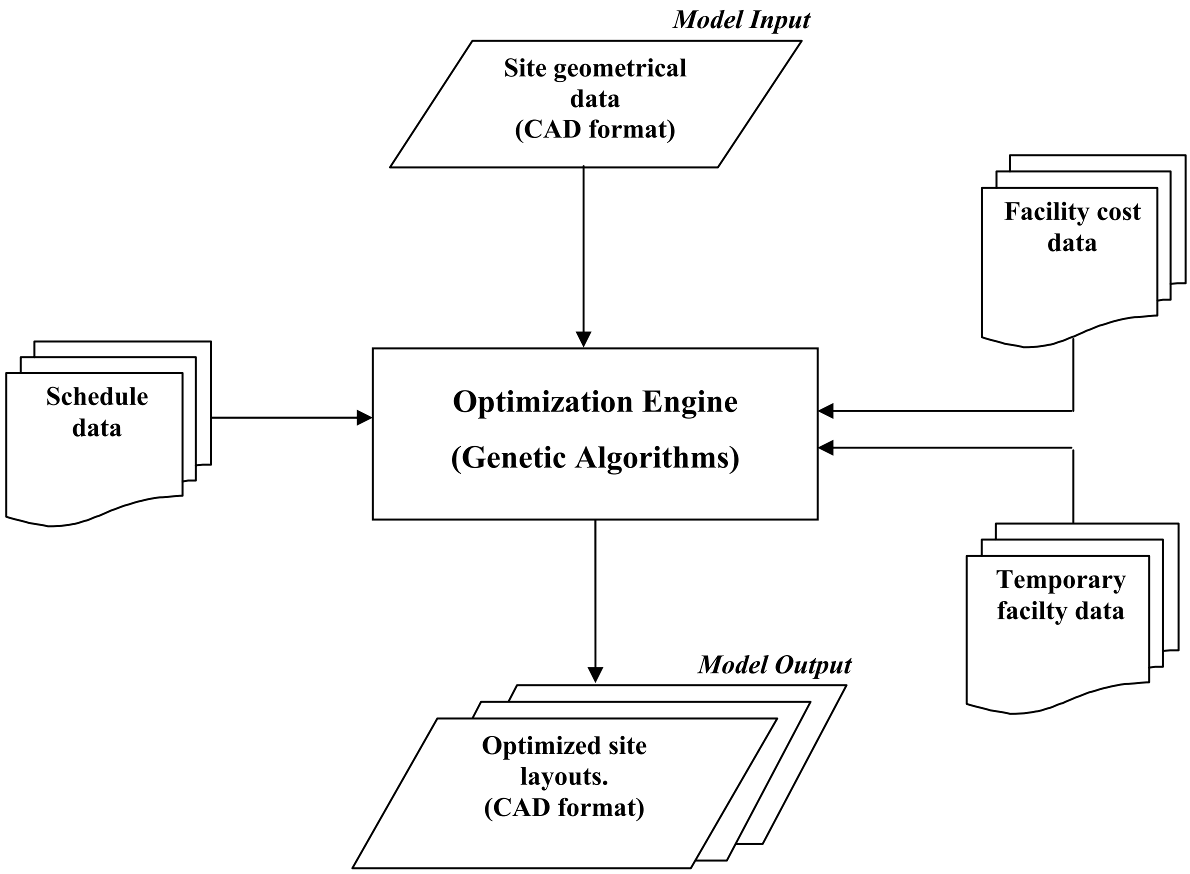

FIG. (2) Architecture of the automated site layout planning system

CAD-based GA optimization engine

The automated system integrates the powerful graphical capabilities of CAD with the intricate search and optimization abilities of genetic algorithms for the purpose of solving the site layout problem. GA's are algorithms that encode a potential solution to a specific problem on a simple chromosome like data structure and apply recombination operators to these structures so as to preserve critical information (Chan 1996). GA's are highly applicable in optimization problems having non-differentiable functions and a very large solution space (Whitley 1993).

CAD platforms have been particularly utilized because of the graphical nature of the site layout problem. Site boundaries, existing buildings on site, obstacles, and temporary site facilities all occupy space and have distinct shapes. Thus, the need to represent the relationship between all aforementioned entities in some sort of graphical format can be quite advantageous.

The CAD platform is utilized in two main tasks, namely space detection and constraint satisfaction. Space detection involves the process of identifying all empty areas within the site boundaries. These areas are the feasible solution space that the optimization engine assigns temporary facilities in. Space detection occurs once as a preamble to the optimization process. On the other hand, constraint satisfaction is utilized by the optimization throughout the optimization process. During the generation of any solution it must be checked against certain geometrical constraints. Two modules *CheckSite* and *Checkoverlap*, attain this function. They make sure that during assignment, all temporary facilities: (1) Lie within the site boundaries, (2) Do not overlap with any of the fixed facilities present on site, and (3) Do not overlap with each other.

Details of the integration between the genetic algorithms optimization engine and the CAD platform can be found in the authors' other publications (Osman, 2002).

System Implementation

The automated computer system, EDSLP (*Evolutionary Dynamic Site Layout Planner*) has been implemented via MS Visual Basic 6.0. The CAD interface has been made possible through the programmable features of AutoCAD™ in the VBA environment. Utilizing these features, it is possible to have complete control over the operation of AutoCAD™ from within the main program. The four main groups of data are input from within different program environments. Schedule and temporary facility data are input form within the main program's environment as in Fig. 3. The programmable features of AutoCAD™ are used in the input of the site's geometrical data as in Fig. 4.

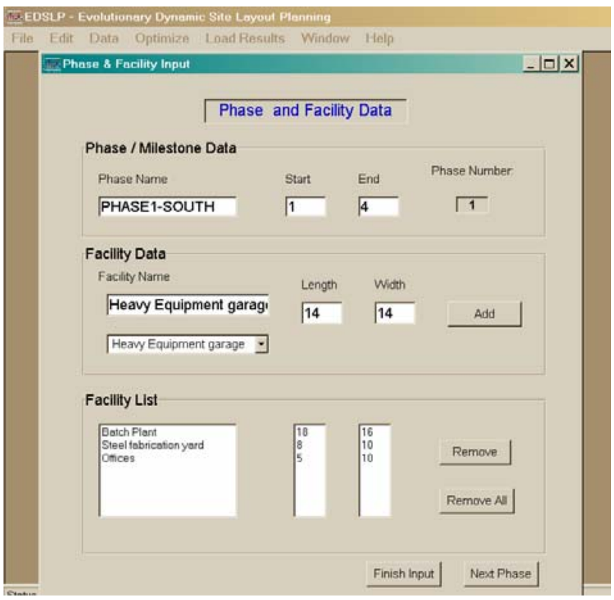

FIG. (3) Schedule & temporary facility input screen

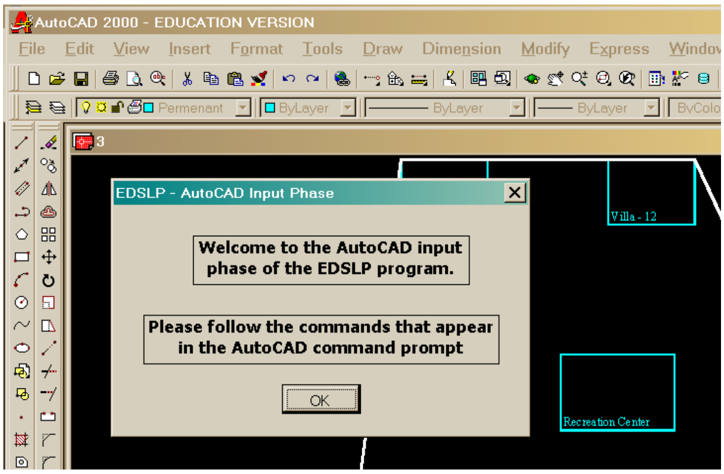

FIG. 4 AutoCAD™ VBA macro for space detection of site layouts

ILLUSTRATED EXAMPLE

The following example of a 4-phase project is used to demonstrate the system capabilities and evaluate the output. The project is comprised of a 15,000 m^2 residential compound of 4 villas, a swimming pool, in addition to the necessary infrastructure. The project is scheduled to be completed in 12 months. The first phase lasts for 2 months and involves the construction of the necessary infrastructure for the compound. The second phase involves the construction of the large southern villas and lasts for 5 months. Construction operations during the third phase of the project are mainly located towards the northern boundaries of the site where the smaller villas are being constructed. This phase lasts for 3 months. The fourth phase of the project starts after the 10^{th} month of the project and involves the construction of a swimming pool in the center of the compound. The evolution of the site layout is shown in Fig.5.

Schedule & Temporary Facility Data

To sustain the required construction operations, 7 temporary facilities are required. Not all temporary facilities will be required throughout the project (Table 2). When infrastructure works are underway, only the caravans and the electromechanical warehouse are required. During phases 2 and 3, all temporary facilities are required. The aggregate storage area can be dismantled during the last phase, when no major concrete works will be underway.

Facility Cost Data

The anticipated inter-facility transportation costs are input for each phase of the project. These costs are represented in a lower-triangular matrix. The expected cost of relocating a facility from one place to another is also input. Facility cost data can be found in the appendix (Table A-1 and Figs. A-1, A-2, A-3 and A-4).

Site Geometrical Data

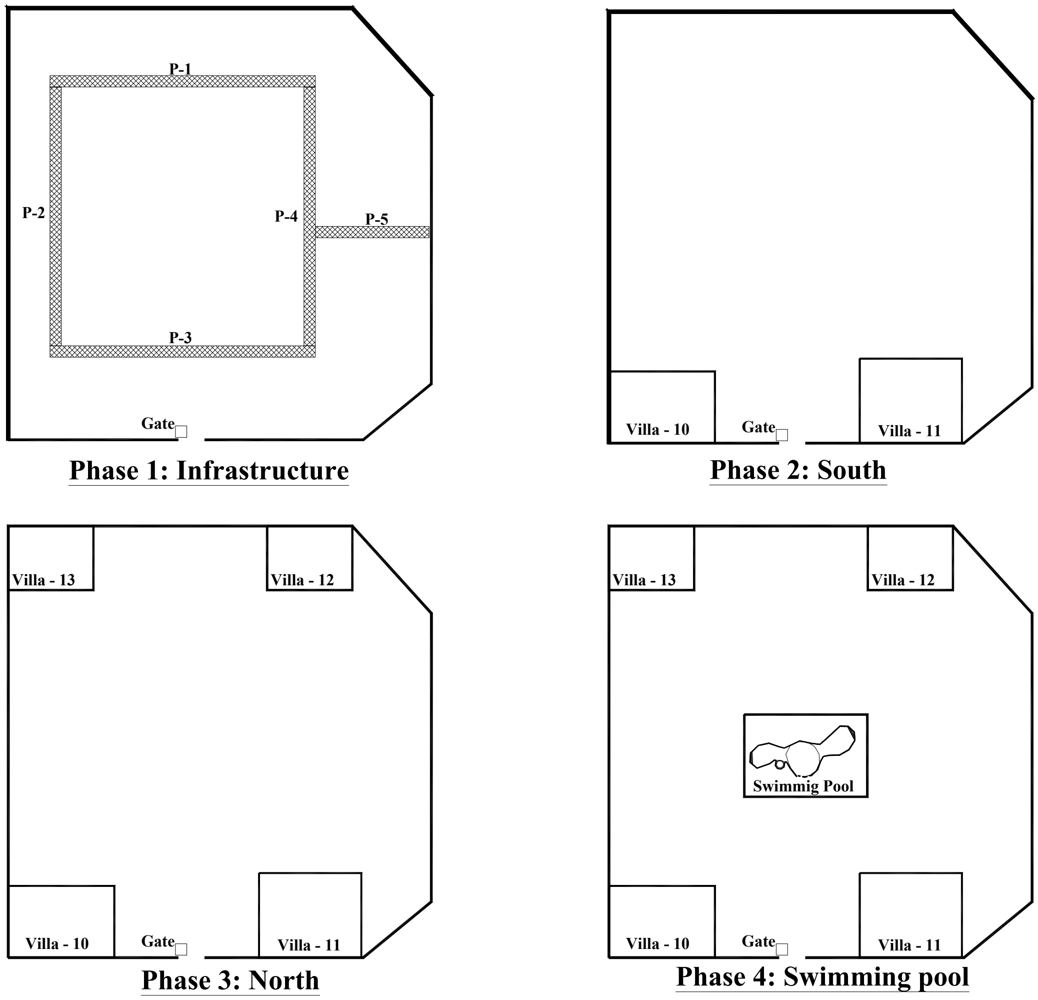

FIG. (5) Evolution of the construction site throughout different phases

TABLE (2) Schedule and temporary facility data

Temporary Facility	Dimensions (m)	Phase1 Infrastructure	Phase2 South	Phase3 North	Phase4 Swimming pool
		2 months	*5 months*	*3 months*	*2 months*
Administrative Caravans	10x8	━━━	━━━	━━━	━━━
Engineer's Caravans	10x5	━━━	━━━	━━━	━━━
Steel Fabrication Yard	14x14		━━━	━━━	━━━
Concrete Mixer	10x10		━━━	━━━	━━━
Aggregate Storage	12x6		━━━	━━━	
Electromechanical Warehouse	12x6	━━━	━━━	━━━	━━━
Wood Warehouse	10x10		━━━	━━━	━━━

Optimization Results

The GA-based optimization process takes place after input of all required data. First, the static optimization proceeds based solely on inter-facility transportation costs. The system produces completely independent layouts at this stage, as no chronological continuity has been taken into consideration. Performing dynamic optimization is the next step. Dynamic optimization takes into account both transportation and relocation costs; thus attaining the required continuity from phase to another.

Performing the GA-based optimization using the Mini-Min approach took nearly 122 minutes running on a P-3 800 MHz processor. It is noted that this approach solves the layout problem n^2 times, n being the number of project phases. In our example, the GA solved each layout problem in an average of 7.5 minutes. In this example, results of the Mini-Min approach are presented in Table 3 and Fig. 6.

TABLE (3) Optimization results – Mini-Min approach

Initial Phase	Phase	Transportation Costs (L.E.)	Relocation Costs (L.E.)	Total Costs (L.E.)
Phase-1	Phase-1	25993	0	25993
	Phase-2	69964	2500	72464
	Phase-3	63690	4300	67990
	Phase-4	12367	8000	20367
	Total Costs	172013	14800	186813
Phase-2	Phase-1	31043	2500	33543
	Phase-2	72012	0	72012
	Phase-3	72178	3300	75478
	Phase-4	10999	8300	19299
	Total Costs	186233	14100	200333
Phase-3	Phase-1	29396	2500	31896
	Phase-2	98012	6800	104812
	Phase-3	62174	0	62174
	Phase-4	16874	3300	20174
	Total Costs	206456	12600	219056
Phase-4	Phase-1	29396	2500	31896
	Phase-2	98012	6800	104812
	Phase-3	62174	0	62174
	Phase-4	16874	3300	20174
	Total Costs	176929	8600	185529

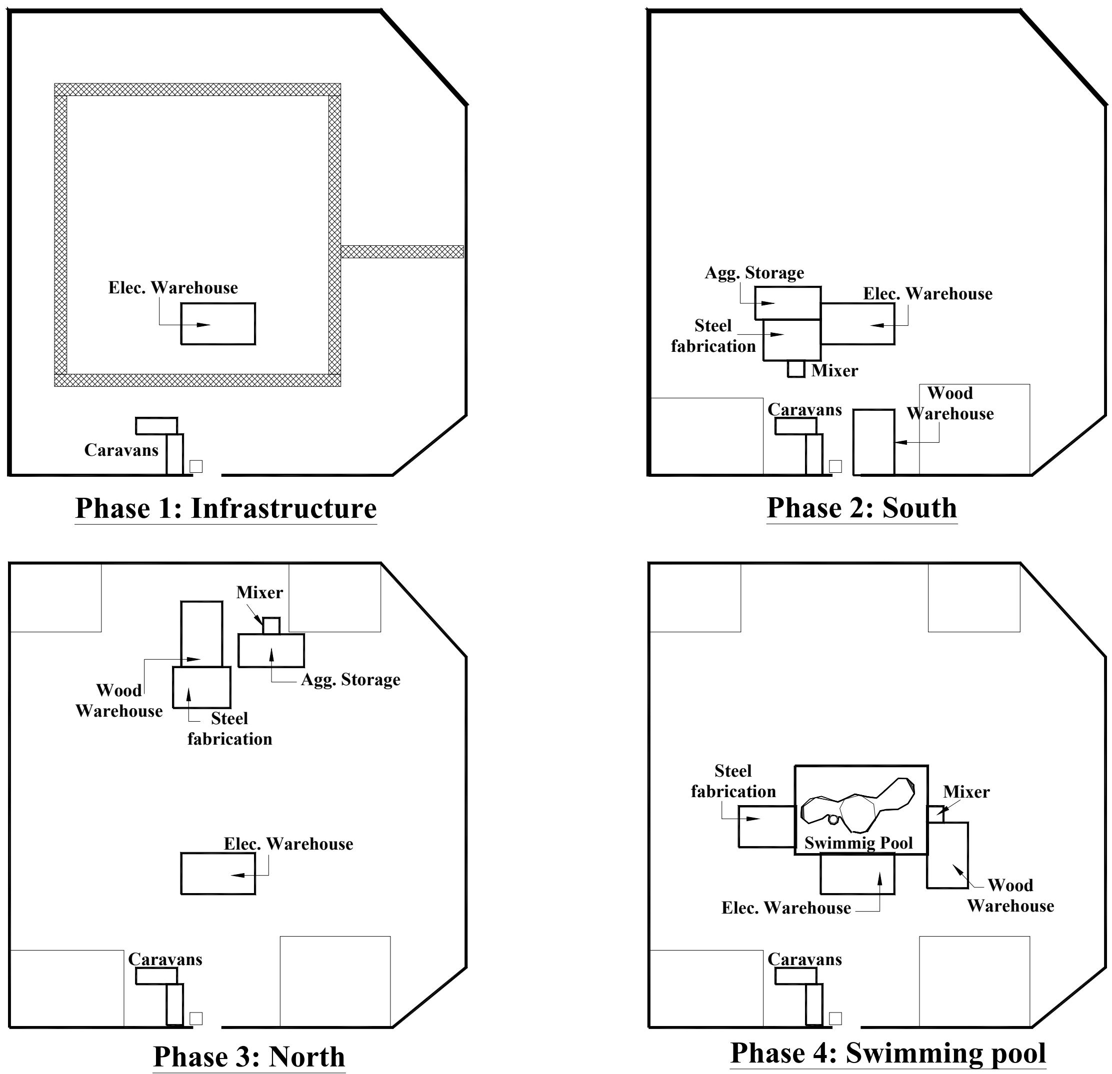

FIG. (6) Automated system generated layouts – Mini-Min approach

Comment on results

- The Mini-Min solution occurs when taking Phase-4 as the initial phase, with a total layout cost of 185,529 L.E. Adopting the traditional approach of taking Phase-1 as the initial phase yielded higher total layout cost.
- Taking Phase-1 as the initial layout yielded a relocation cost of 14,800 L.E. compared to only 8,600 L.E. when taking Phase-4 as the initial phase. This is consistent with our argument that early assignment may lead to costly relocation in subsequent phases.
- In each phase, most temporary facilities are placed close to the areas where most construction operations take place.
- The automated system did not relocate any of the facilities having high relocation costs (Caravans and Electromechanical warehouse). Relocation occurred for those facilities having relatively low relocation costs. These facilities were relocated to locations where major construction operations were taking place, so as to minimize transportation costs during that phase.

SUMMARY & CONCLUSIONS

This paper is divided into three main sections. The first section presented the concept of dynamic layout planning of construction sites. A novel approach for performing the dynamic layout process, called the Mini-Min approach, is introduced. The second section of the paper presented EDSLP (*Evolutionary Dynamic Site Layout Planner*), the automated computer system that performs dynamic layout planning of construction sites using genetic algorithms. In the final section, an illustrated example is presented. The construction project is a 15000 m^2 compound comprised of 4 villas, a swimming pool, in addition to the necessary infrastructure. All relevant data is input to the system and the final optimized layouts are presented.

REFERENCES

Choi, B. and Flemming, U. (1996), "Adaptation of a layout design system to a new domain: construction site layouts," Proceedings of the 3rd Congress on Computing in Civil Engineering (III-CCCE), June 17-19, Anaheim, California, 711-717.

Li, H. and Love, P.E. (1998), "Site level facilities using genetic algorithms," Journal of Computing in Civil Engineering, ASCE, 12(4), 227-231.

Cheung, S.-O., Tong, T., and Tam, C.-M. (2001) "Site pre-cast yard layout arrangement through genetic algorithms" Automation in Construction , 11(1), 35-46.

Hegazy, T. and Elbeltagi, E. (1999), "EvoSite: Evolution based model for site layout planning," Journal of Computing in Civil Engineering, ASCE, 13(3), 198-206.

Askin, R.G. and Standrige, C.R. (1993), "Modeling and analysis of manufacturing systems," John Wiley & Sons.

Zouein, P.P. and Tommelien, I.D. (1999), "Dynamic layout planning using a hybrid incremental solution method," Journal of Construction Engineering and Management, ASCE, 125(6), 400-408.

Chan, W.T., Chaua, D.K., and Kannan, G. (1996), "Construction resource scheduling with genetic algorithms," Journal of Construction Engineering and Management, ASCE, 122(2), 125-132.

Whitley, D. (1993), "A genetic algorithm tutorial," Tech. Rep. CS-93-103, Colorado State University, Fort Collins, Colorado, USA.

Osman, H.M. (2002), "CAD based dynamic layout planning of construction sites using genetic algorithms," M.Sc. Thesis, Faculty of Engineering, Cairo University, Giza, Egypt.

APPENDIX A

Table (A-1) Relocation costs of temporary facilities

Temporary Facility	Relocation Costs (L.E.)
Administrative Caravans	5000
Engineer's Caravans	5000
Steel Fabrication Yard	1000
Concrete Mixer	300
Aggregate Storage	1000
Electromechanical Warehouse	2500
Wood Warehouse	2000

	Elec. Warehouse	Caravan 1	Caravan 2	P-1	P-2	P-3	P-4	P-5
Caravan 1	0							
Caravan 2	0	37						
P-1	81	0	37					
P-2	81	0	37	0				
P-3	81	0	37	0	0			
P-4	81	0	37	0	0	0		
P-5	81	0	37	0	0	0	0	
Gate	37	81	9	0	0	0	0	0

FIG. (A-1) Inter-facility cost matrix – Phase 1

	Elec. Warehouse	Wood Warehouse	Steel fabrication yard	Agg. Storage	Caravan 1	Caravan 2	Mixer	Villa - 10	Villa - 11
Wood Warehouse	0								
Steel fabrication yard	0	0							
Agg. Storage	0	0	0						
Caravan 1	0	0	0	0					
Caravan 2	0	0	0	0	37				
Mixer	0	0	0	81	0	0			
Villa - 10	37	81	81	0	3	37	81		
Villa - 11	37	81	81	0	3	37	81	0	
Gate	37	37	9	37	81	9	0	0	0

FIG. (A-2) Inter-facility cost matrix – Phase 2

	Elec. Warehouse	Wood Warehouse	Steel fabrication yard	Agg. Storage	Caravan 1	Caravan 2	Mixer	Villa - 10	Villa - 11	Villa - 12	Villa - 13
Wood Warehouse	0										
Steel fabrication yard	0	0									
Agg. Storage	0	0	0								
Caravan 1	0	0	0	0							
Caravan 2	0	0	0	0	37						
Mixer	0	0	0	81	0	0					
Villa - 10	0	0	0	0	0	0	0				
Villa - 11	0	0	0	0	0	0	0	0			
Villa - 12	37	81	81	0	3	37	81	0	0		
Villa - 13	37	81	81	0	3	37	81	0	0	0	
Gate	37	37	9	37	81	9	0	0	0	0	0

FIG. (A-3) Inter-facility cost matrix – Phase 3

	Elec. Warehouse	Wood Warehouse	Steel fabrication yard	Caravan 1	Caravan 2	Mixer	Villa - 10	Villa - 11	Villa - 12	Villa - 13	Swimming Pool
Wood Warehouse	0										
Steel fabrication yard	0	0									
Caravan 1	0	0	0								
Caravan 2	0	0	0	37							
Mixer	0	0	0	0	0						
Villa - 10	0	0	0	0	0	0					
Villa - 11	0	0	0	0	0	0	0				
Villa - 12	0	0	0	0	0	0	0	0			
Villa - 13	0	0	0	0	0	0	0	0	0		
Swimming Pool	81	81	81	3	37	37	0	0	0	0	
Gate	37	37	9	81	9	0	0	0	0	0	0

FIG. (A-4) Inter-facility cost matrix – Phase 4