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Construction site layout optimization and 3D visualization through BIM tools

Visualización 3D y optimización a través de herramientas BIM aplicado a los planos de proyecto

OLUSEYE OLUGBOYEGA
BSc. Building, MSc. Construction Management. Department of Building, Obafemi Awolowo University, PMB. oolugboyega@oauife.edu.ng

OLORUNFEMI TIMOTHY WEMIMO
BSc. Building. Department of Building, Obafemi Awolowo University, PMB. olorunfemiwemimo@gmain.com

- Site layout plan is required for the management of the construction site and operations.
- A well-developed site layout has positive impact on workers, working environment, productivity and eventual success of a project.
- This paper developed a site layout model using BIM tools with construction methodology integration. The assumptions and processes adopted in the site layout model were expounded.
- An illustrative example was presented to substantiate the need to incorporate construction methods for projects in BIM-based modelling.

Site layout plan is required for the management of the construction site and operations. A well-developed site layout has positive impact on workers, working environment, productivity and eventual success of a project. Moreover, the proposed construction methods for a project have the most significant impact on productivity, quality and cost of construction projects. This paper proposes a site layout model through BIM and construction methodology integration. An illustrative case study method was adopted for the study, where the assumptions and processes adopted in the site layout model were expounded and illustrative example was presented. The study substantiated the need to incorporate construction methods for projects in the BIM-based modelling of construction site layout plan; and the need to reinforce the possibility of re-thinking the processes of planning, construction, and management of projects.

BIM; Construction methods integration; Site layout model; Site facilities; Site layout plan

- Es preciso planificar la implantación y ejecución de la construcción para una adecuada gestión de la construcción.
- Una buena planificación de la implantación tiene un impacto positivo en los trabajadores, en el ambiente de trabajo, en la productividad y en el éxito del Proyecto.
- En este estudio se propone utilizar las herramientas BIM integrando metodología de construcción para desarrollar la planificación de la implantación y ejecución de la construcción.
- Este estudio ilustrativo demuestra la necesidad incorporar los métodos constructivos en los modelos BIM.

Es preciso planificar la implantación y ejecución de la construcción para una adecuada gestión de la construcción. La implantación y distribución de los espacios de acopios y servicios tiene un impacto positivo en los trabajadores, en el ambiente de trabajo, en la productividad y en el éxito del Proyecto. Tener en cuenta en la planificación de la construcción los métodos y soluciones constructivas definidos en el Proyecto de Ejecución tienen un gran impacto en la productividad, calidad y coste del Proyecto. En este estudio se propone utilizar las herramientas BIM integrando metodología de construcción para desarrollar la planificación de la implantación y ejecución de la construcción. Para ello se utiliza un caso de estudio ilustrativo en el que se exponen los supuestos y los procesos adoptados. El estudio confirma la necesidad de tener en cuenta e incorporar los métodos y soluciones constructivas en el modelo BIM de la implantación de la construcción para estudiar con antelación la planificación, la ejecución y la gestión del proyecto.

***BIM; Métodos integrados de construcción; Modelo de la implantación del proyecto; Planificación* de la implantación del proyecto.**

1. INTRODUCTION

Site facilities and utility spaces support construction activities and if they are not properly positioned, the efficiency of construction activities would be affected.

In order to ensure proper and optimal positioning of site facilities and utility spaces, a number of authors have proposed the usage of artificial intelligence, linear programming, generic algorithm, ant intelligence, and geographic information system for site utilization planning.

These approaches lack visualization and data-exchange capabilities, which hinder the incorporation of construction methodology in the planning process. To improve the process of site layout planning, usage of Building Information Modelling (*BIM*) was introduced; and this changed the process from site layout planning to site layout modelling.

Site layout modelling is the process of developing site layout model (*SLM*) of site facilities and utility spaces organization within the construction site boundary. [25] noted that SLM is required for internal and external logistic arrangements of the construction site and operations.

A well-developed *SLM* has been described as having positive impact on workers and working environment [23], and having direct impact on the productivity and eventual success of a project [8].

Site layout modelling has been examined by [31, 17, 2, 5, 25, 18]. [17] focused on site layout in relation to scheduling, path interference, and space constraints. The study developed a 4D site layout planning system to solve space constraints on construction site. [5] proposed an automated framework for creating dynamic *SLM* in *BIM* based on genetic algorithm heuristic method. [2] developed a *3D*- parametric library and an agent-based simulation model for planning the building construction site, by taking into consideration the real dimensions and shapes of the site facilities.

The study focused on tower cranes as the major transporters of the materials on construction sites. [25] carried out a site layout modelling test for a 3-storey residential building project. The study developed a component library for use in *BIM*-based site layout planning.

The model was developed as static plan in different perspectives. [18] focused on *BIM*-based automatic assignment of spatial requirements of construction processes and site safety. A decision support system for the planning process of site layout with regard to productivity and safety was developed by the study.

The proposed *SLM* by these studies did not consider the realities of construction site operations and the resulting spatial relationships among site facilities. Moreover, the average human walking speed was not considered for time optimization and explanation was not made available on how the *SLM* will ensure safety.

As noted by [14,18], the proposed construction methods for a project is of more value in project planning than programming and optimization techniques. Also, [26] reported that construction methods have the most significant impact on productivity, quality and cost of construction projects.

The purpose of this study is to propose a construction site layout model that incorporates knowledge of construction methods and *BIM* tools integration. Toward this effort, this study will examine the state of the art optimization models for site layout planning and modelling methods for construction site layout.

Further, methods of determining the spatial relationships and sizes of site facilities will be investigated. An alternate method of construction site layout optimization and modelling will be offered based on the constraints of construction site operations and construction methods. Finally, the proposed site layout model will be applied through an illustrative case study.

2. LITERATURE REVIEW

2.1 OPTIMIZATION MODELS FOR SITE LAYOUT PLANNING

The existing optimization models for site layout plan can be classified as artificial intelligence-based models [29,4,16,27], linear programming-based models [33,11], genetic algorithm-based models [9,19,24], Geographical information system (*GIS*) based models [6,7,20], ant intelligence-based models [21,28], and *BIM*-based models [5,25,31]. Linear programming-based model, genetic algorithm-based model, and ant intelligence-based model focused more on mathematical optimization.

GIS-based model only provides decision support information in site layout modelling; only *BIM*-based model allows optimization to be visualized which gives freedom for construction methodology to be incorporated into the optimization model.

A construction site is not just a space; although, it is static geographically but dynamic in terms of construction activities and workers. The interaction between the workers, the work, and the site facilities to be positioned on the site space demands that the predicted flow of work based on the proposed construction method, geometry of the building, material and time schedule for the work scenarios, should affect the optimization model [18].

[24] attempted to develop a multi-objective optimization models capable of generating global optimal solutions. Two optimization models were developed to minimize travel and relocation costs, and to comply with boundary, overlap, distance, and zone constraints. The first model is a genetic algorithm based optimization model, while the second model is an approximate dynamic programming based optimization model that incorporates the long-term effect of the current position of site facilities on the future positioning in the subsequent work stages.

However, not all site facilities are stationary, some site facilities are movable or fixed; and this factor should be incorporated in the optimization model. Also, construction work is carried out in phases, and the positions of site facilities change with the work phase.

This means that each of the work phase should have a distinct optimization model, depending on the duration of the work phase and the number of site facilities required for the work phases. More so, the optimization models as proposed by [24] are tedious, not practical, used Euclidian distances, did not consider spatial relationships, and were not based on knowledge of construction methods.

[5] proposed a BIM-based optimization model capable of minimizing the total inter-facility transportation cost of

materials and labour and capable of ensuring safety.

This optimization model as proposed by [5] is more practical than and not as time-consuming as those of [24]. Also, the proposed model use travel distance and not Euclidian distance. However, the travel distance as used by [5] was computed using A* algorithm and the travel path was limited to move in eight directions. This assumption reduced the accuracy of the travel distance.

The travel distance should have been computed for each of the grid cells with reference to the building area. Also, the optimization model was developed without consideration for the total number of workers on site and the spatial relationships among site facilities. In addition, no explanation was provided on how the optimization model will account for safety.

Minimization of cost in the optimization models is not necessary, as it only makes the models more tedious and unrealistic. Besides, studies have shown that optimization models that minimizes total travel distance are the best [5, 32]. Nevertheless, the travel distance should be converted to travel time using the average human walking speed.

Construction operations could be delayed as a result of lack of free flow of construction activities and by dint of spending long time in moving around the construction site space. Hence minimizing walking time on construction sites takes priority over minimizing cost in *SLM*, since the cost incurred over relocation of site facilities cannot be compared to the cost that would be incurred as a consequence of time overrun of projects. Also, SLM has an indirect effect on construction costs since it affects efficiency, productivity, utility and mobility of labour.

2.2 SIMULATION AND MODELLING

Site layout plans have been simulated using Monte Carlo Simulation [17], Flow chat based Simulation [13], and Discrete -Event Simulation [30]. Monte Carlo and Flow chat based Simulations are types of static simulation and are applicable only where time-varying interactions are not considered. In SLM, time-varying interactions must be considered between the site space and the site facilities.

Discrete-Event simulation (*DES*) is applicable for *SLM* because it can capture significant changes that occur at discrete time instances or workflow scenarios.

However, there are various types of *DES* with different applications. Petri Net-based Simulation is a type of *DES* that employs static simulation network and dynamic simulation system. The static and dynamic simulation systems of petri net-based simulation can be used to simulate locations, transitions, directions, and current status of a system.

Agent-based simulation is another type of *DES* which can be used to simulate actions and interactions of autonomous individuals. It is major application is for investigating the influence of autonomous individuals on a system and the efficiency of the system. Geometric-based Simulation is also a type of *DES* which is applicable in manipulating, reorganizing, analyzing, and describing static trajectories for geometric models and the crew performing work on the project.

The construction site space is forever in a static state and some site facilities are fixed in positions. However, construction is carried out in stages, thereby requiring different work scenarios which also cause dynamic interactions among the site facilities and requires them to change positions as the construction work progresses.

A system of simulation that combines static and dynamic simulation systems is therefore required for site layout plan. Petri net based simulation is best suited for simulating site layout plans. It is a system of simulation where the site space and fixed site facilities could be simulated as static; and the dynamism of the construction processes as affecting the availability of space and positioning of stationary and movable facilities could also be simulated.

Modelling of site layout is about visualization and presentation of the simulated site layout plans. [3] asserted that the simulated site layout plans can easily be visualized and presented using *BIM*. This assertion was based on the argument that *BIM* will easily capture the interactions among the site facilities and evaluate the location and transitions of the site facilities.

A study by [5] argues that construction activities should be split into multiple phases and that site layout plan should be developed for each phase. In support of this argument, [18] noted that not all site facilities are required at each construction stage; for this reason, the construction process be divided into discrete phases and site facilities required for each phase should be identified, optimized, and modelled.

In addition, [12] noted that construction sites are dynamic owing to transient workforce, physical structure, changes in spaces, and changes in environmental conditions and that these changes should be considered in the planning of site layout. [8] claimed that *BIM* can effectively capture the dynamic nature of construction activities and also help in the development of a highly functional *SLM*.

Applying *BIM* for site layout plan makes site management plans visually illustrative and realistic [25], facilitates site utilization at different work scenarios and gives a clear and dynamic view of work space [32], optimizes time and safety measures in site layout plans and improves the efficiency, quality and information depth of site layout plans [18], digitalizes simulation process of site layout plans [12], beneficial in managing the characteristics of site layout plans and provides the best tool for managing site space information and site facilities mobility [23], and helps in meeting the data exchange requirements in *BIM* processes and checking *SLM* against pre-defined rues and constraints [25].

2.3 SIZING OF SITE FACILITIES

According to [5], the sizes of site facilities should be determined based on work contents, peak rate of consumption of resources, number of workers and site areas. However, there are other factors that can affect the sizing of site facilities, such as time schedule, safety, construction methodology, procurement and delivery plan, and phase of work.

2.4 SPATIAL RELATIONSHIPS AMONG SITE FACILITIES

Site layout plan is unique for each project, but site constraints are similar in a way. [10] observed that site constraints for site layout plan should be limited to spatial relationships among site facilities and the site exclusions.

The characteristics of the site exclusions such as immediate surroundings, adjoining streets, walkways, traffic situation, power and water supply will restrict the site space, which is a form of constraints, known as space constraints. In spite of space constraints, the spatial relationships among the site facilities will determine the relative positions of site facilities to one another.

According to [9], the ideal way to address spatial relationships among site facilities is to divide the site space into central, inner, outer, and neutral zones. The central zone is for primary or fixed site facilities such as tower cranes, lifting plants, and building area.

Central zone represents the primary area of work. Other zones are secondary area of work, and should be allocated thus: inner zone for site facilities that are often required or very active site facilities; examples are batching area, gravel depot, block depot, and sand depot.

The outer zone represents the not very active area and it is suitable for site facilities such as workshops, material storage, fabrication area, and equipment yard.

The neutral zone is the area surrounding the outer zone but still within the construction site. Facilities such as project offices, consultant offices, subcontractors' offices, parking spaces, test labs, waste dump, toilet, security post, formwork depot, and site accommodation should be positioned in the neutral zone.

Some site facilities need to be located far from each other, some need to be in line of sight with each other, while some need to be inside or outside each other. These requirements are realities of construction site operations and constitute the spatial relationships among site facilities.

A *SLM* that incorporates spatial relationships among site facilities will meet the requirements of the construction site and will also enable assessment and validation of the model. [32,8] noted that in site layout modelling, the applicable site constraints should be investigated because if left unaddressed, site constraints could result in unproductive interactions between site facilities, delays and cost overruns, and buildability problems.

Examples of site constraints that should be considered in site layout modelling include: site boundary constraints, spatial conflicts or limited land space, topographical constraints, physical overlap between facilities, building area, maximum/ minimum distances between site facilities, zone constraints for facilities placement, site objects, safety zone in workplaces, offset for scaffolding around the building area, frequency of travel on site, number of workers on site, walking speed, and operation spaces for site equipment and vehicles.

3. MODEL ASSUMPTIONS

SLM developed in this paper is developed using *BIM* tools together with the realities of construction site operations, spatial relationships among site facilities, and other construction methodology constraints. The assumptions and processes adopted in developing *SLM* in this paper are as follows:

a) Identify the workflow scenarios: the workflow scenarios should be identified based on the proposed construction program. Petri-net-based simulation method should be adopted to model the workflow scenarios.

   This method is appropriate owing to the dynamic interactions between the site facilities and the site space.

   The work should be divided into scenarios because construction work is dynamic; while the site space should be simulated as static. The position of site facilities change with change in work.

b) Identify the site facilities required: The site facilities required for each workflow scenarios should be determined based on the nature of work in each scenarios.

c) Determine the sizes and number of site facilities required: Offset should be allowed for scaffolding around the building area and for safety around work spaces such as depots (block, formwork, and rebar), batch plants, workshops, material store, fabrication yard, site equipment yard, delivery area, site access, and power generation.

   The incorporation of offset for safety or scaffolding in the determination of the sizes of site facilities will require the use of theoretical size for the simulation processes; while the actual size will be used in the optimization and modelling processes.

   The length of the offset should be informed by the availability of space on construction site; however, the offset-length should not be too much. Therefore, this study recommends 1m for safety offset (Figure 1) and 2m for scaffold offset. The number of site facilities should be based majorly on types of materials and sizes of materials as contained in the construction methodology of projects.

To determine the actual size for the site facilities, the site facilities should be grouped into three: site facilities accommodating materials as a predominant occupier (SAM), site facilities accommodating plants as a predominant occupier (SAP), and site facilities accommodating workers as a predominant occupier (SAW).

The following formulas were suggested for computing the actual sizes for the required site facilities in each group:

Actual size required for SAM = $\frac{Q}{T.H}$ (Equation 1)

Where:

- *Q = quantity of resources required for an activity*
- *T = time allowed for the activity*
- *H = safe storage height for resources*

For rebar depot (Figure 2), actual size required for:

rebar depot = $Lr \times Er$ (Equation 2)

Where:

- *L_r = maximum length of rebar among the rebar in the depot = 6m*
- *$E_r = \sum_{i=1}^{i=m} Ri,m$ = number of rebar diameter in a rebar group*
- *R_i=3m. It is logical to store rebar in groups. Rebar with diameter less than 20mm should be grouped together and rebar with diameter above 20mm should be grouped together*

Actual size required for SAP = $lv \times Ev$ (Equation 3)

Where:

- *L_v = maximum length of site vehicles.*
- *$E_v = \sum_{i=1}^{i=n} wi$*
- *n = number of plants / vehicles proposed in the construction methodology*
- *wi = width of site vehicles*

Actual size required for SAW = $\frac{nV}{h}$ (Equation 4)

Where:

- *V = average room volume required per person = 11m^3 [1]*
- *n = number of workers per site facilities*
- *h = average roof height required per person [1]*

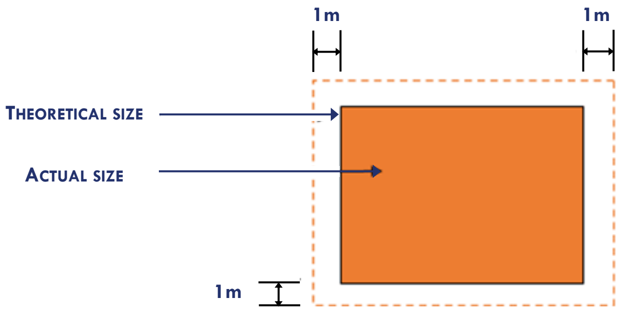


Figure 1: Offset for safety

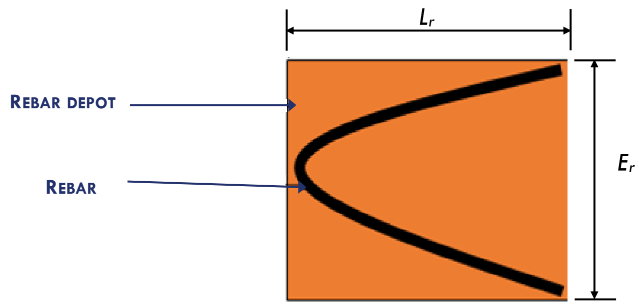


Figure 2: Sizing rebar depot

d) Determine the spatial relationships among the site facilities: The site should be planned by dividing the site space into cells using an orthogonal grid system based on zones (central, inner, outer and neutral zone). The size of the grid cells should be determined by using the size of the largest site facility in each zone. The central zone should comprised strictly of the building area and site access. The zone that a site facility belongs to could change as work scenarios change and more space becomes available. The zone should be used to allocate the site facilities and any constrained end of the construction site should be allocated to the zones based on the number of site facilities in each zone. The site facilities can be arranged as follows:

i. Site facilities that are in high demand such as on-site batching plants and block depots, should be located in two or more different locations or at opposing ends of the building area.

ii. Rebar should be stored in groups.

iii. Site facilities that serve all other facilities, for example; material store, should be centrally located so that they easily accessible.

iv. Dependent site facilities should be located close to site facilities that they are dependent on, for example; rebar depots and fabrication yards, formwork depots and fabrication yards, fabrication yards and waste dump, delivery area and material store, and power supply and fabrication yard.

v. The location of toilets should not be too remote.

e) Determine the travel paths between the site facilities and the reference point: Travel paths should follow the work paths which should be taken as the sum of the shortest gridline from a grid cell to the building area. This will define in reality the distance per metre between the site facilities and the building area and will also take care of the need to circumvent obstacles (Figure 3).

Work paths represent the flow areas between site facilities and the building area. They are paths that could be used as exit path, access path, transportation path, navigation path, material path, and material handling equipment paths.

f) Determine the walking time between the site facilities and the reference point: Using the average human walking speed of 5000 m/h recommended by [22], the walking time between the site facilities and the building area could be determined using this formula:

$$\text{Walking time between site facilities and the building area} = \frac{Dsa}{Sav} \quad \text{(Equation 5)}$$

Where:

- D_{sa} = *Distance per metre between the site facilities and the building area*
- S_{av} = *Average human walking speed = 5000 m/h*

g) Optimize the site utilization plan for each workflow scenarios: The optimization models could be computed using MS Excel. The proposed construction methodology will provide the knowledge of the flow of construction activities, and this factor has the greatest impact on productivity, cost and safety on construction sites.

The positioning of site facilities should minimize walking time on construction site. The minimization of the walking time should be done on zone basis (equation 6), work phase basis (equation 7), while the overall optimized walking time for the project using equation 8.

Also, the dynamic interactions among site facilities, site space, and construction work should be taken advantage of in optimizing walking time on construction sites.

As construction work progresses, the state of the site will change and spaces will become available for site facilities to occupy. The available site space should then be occupied by site facilities that are not fixed in positions.

Optimization model for site facilities,

$$Z = min \sum_{j=1}^{j=n} N_L T_P F_{IJ} W_{IJ} \quad \text{(Equation 6)}$$

Optimization model for work phases,

$$Z = min \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} N_L T_P F_{IJ} W_{IJ} \quad \text{(Equation 7)}$$

Optimization model for SUM,

$$Z = min \sum_{P=1}^{N} \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} N_L T_P F_{IJ} W_{IJ} \quad \text{(Equation 8)}$$

Where:

- N_L = *number of labour on site*
- T_P = *time (in days) of work phase*
- F_{IJ} = *frequency of travel per labour per day from site facility (i) to building area (j)*
- W_{IJ} = *walking time between site facility (i) and building area (j)*
- *N = total number of work phases*
- *P = work phases*
- *n = number of zones*
- *m = number of site facilities in each work phase*

f) Develop the *SLM*: The *3D* objects required for modelling the *SLM* could be authored using appropriate *BIM* authoring software such as Autodesk Revit or downloaded from www.revitcity.com, www.seek.autodesk.com, or www.bimstop.com.

4. NUMERICAL EXAMPLE

The site for the construction of the new Obafemi Awolowo University (OAU) Senate Building was selected as the case study for this study. The site is situated close to existing buildings and roads on OAU campus.

The physical features restricting operational spaces for construction activities on the selected case study include: electricity poles around the site boundary, tree, and spatial conflicts between the site facilities and physical overlap between the site facilities. Other constraints observed on the site include: underground power cable, and existing road around the site.

The proposed site equipment and vehicles in the construction methodology are aero poles, scaffolding chips, circular machine, Gee-saw, cutting machine, truck, bulldozer, Grader, and pay loader. Tower crane was not considered for use in the project because of electricity poles around the site boundary.

Other plans as contained in the construction method for the project are in-situ concreting, on-site batching plants, on-site fabrication of materials, on-site treatment of waste, and re-use of material waste. A total of 43 workers is expected on site and the frequency of travel between site facilities and building area per person per day is based on the experience of the site managers.

4.1 Simulation processes

4.1.1 Workflow scenarios in the project time schedule

The required site facilities for work scenarios as shown in Table 1 were determined based on the work content in the work phases. Table 1 shows the work scenarios and duration as extracted from the construction methodology for the project. The workflow were grouped into six scenarios according to the time schedule for the project.

4.1.2 Number and sizes of site facilities required for workflow scenarios

As explained in Table 2, the proposed construction methods was used to determine the number of the required site facilities identified in Table 1.

An offset 1m and 2m were allowed around the site facilities and the building area respectively. The required sizes for the site facilities were determined by using Equation 4 – 7.

Workers on construction sites will travel between site facilities and the building area in order to move materials and equipment. The frequency of travel between a site facility and building area depends on importance of the materials being produced in that site facility and the experience of the construction site manager. Therefore, the frequency of travel between site facilities and building area per labour per day was extracted for each of the site facility from the proposed construction methodology for the project.

Phase	**Workflow scenario**	**Time in days**	**Required site Facilities**
Phase One	Site organization	15	Site office (project manager/project office), Building area, Security post, Water supply ,Power supply, Site access
Phase Two	Foundations	22	Gravel depot, Block depot, Sand depot, Workshop, Batch plant, Consultant's office, Subcontractor's office, Material store, Rebar depot, Fabrication yard, Formwork depot, Equipment yard and Car park, Delivery areas, Waste dump, Toilet and bathroom, Site accommodation, Site access, Site office, Security post, Water supply, Power supply, Building area
Phase Three	Building structure	46	Gravel depot, Block depot, Sand depot, Workshop, Batch plant, Consultant's office, Subcontractor's office, Material store, Rebar depot, Fabrication yard, Formwork depot, Equipment yard and Car park, Delivery areas, Waste dump, Toilet and bathroom, Site accommodation, Site access, Site office, Security post, Water supply, Power supply, Building area
Phase four	Building envelope	25	Gravel depot, Block depot, Sand depot, Workshop, Batch plant, Consultant's office, Subcontractor's office, Material store, Equipment yard and Car park, Delivery areas, Waste dump, Toilet and bathroom, Site accommodation, Site access, Site office, Security post, Water supply, Power supply, Building area
Phase Five	External works	61	Gravel depot, Block depot, Sand depot, Batch plant, Toilet and bathroom, Site access, Site office, Security post, Water supply, Power supply, Building area
Phase Six	Inspection and Handing over	14	Building area, Security post, Site access, Equipment yard and Car park

Table 1: Required Site Facilities for Workflow Scenarios

Site facilities	No	Variable(s) considered	Required size (m)	Frequency of travel between site facilities and building area per labor per day
Gravel and Sand depot	2	Safety offset	17 x 16.5	10
			15 x 12.8	
Block depot	2	Safety offset	8.2 x 6.9	10
			9.6 x 7.2	
Workshop	1	Safety offset	7.1 x 14.2	6
Batch plant	2	Safety offset	3.1 x 5	30
			9.75 x 5.4	
Consultant's office	1		15.4 x 3.4	5
Subcontractor office	1		4.7 x 2.75	5
Site office	1		3.5 x 2.7	10
Material store	1	Safety offset	6.7 x 9.75	10
Rebar depot	2	Safety offset	13.7 x 7.7	7.2
			16.3 x 7.6	
Fabrication yard	1	Safety offset	7.1 x 14.3	5
Work paths	---	Safety offset	4.1	
Formwork depot	1	Safety offset	9.5 x 5.4	12
Equipment yard and Car park	1	Safety offset	12 x 28.1	5
Delivery area	1	Safety offset	9.5 x 10.5	3
Waste dump	1		6.2 x 5.3	3
Toilet and Bathroom	1		4.55 x 2.75	5
Site accommodation	1		15.25 x 7.5	3
Building area	1	Safety and scaffolding offset	33.83 x 51.03	
Security post	1		2.7 x 3.1	2
Water supply	1		2 x 2.4	5
Power supply	1	Safety offset	4 x 4.1	1
Site access	1	Safety offset	9.3	---------

Table 2: Number and sizes of site facilities required for workflow scenarios.

4.1.2 SPATIAL RELATIONSHIPS, TRAVEL PATHS AND WALKING TIME

The site space was divided up into the central zone, inner zone, outer zone and neutral zone. Each of the zones was divided up into grid cells (Figure 3).

In the workflow scenarios, the site facilities required were allocated to the appropriate zones based on the recommendations of [9] (section 2.4 and Table 3). The size of the largest site facilities in each zone was used to determine the size of the grid cells as explained in Figure 3 and Table 4.

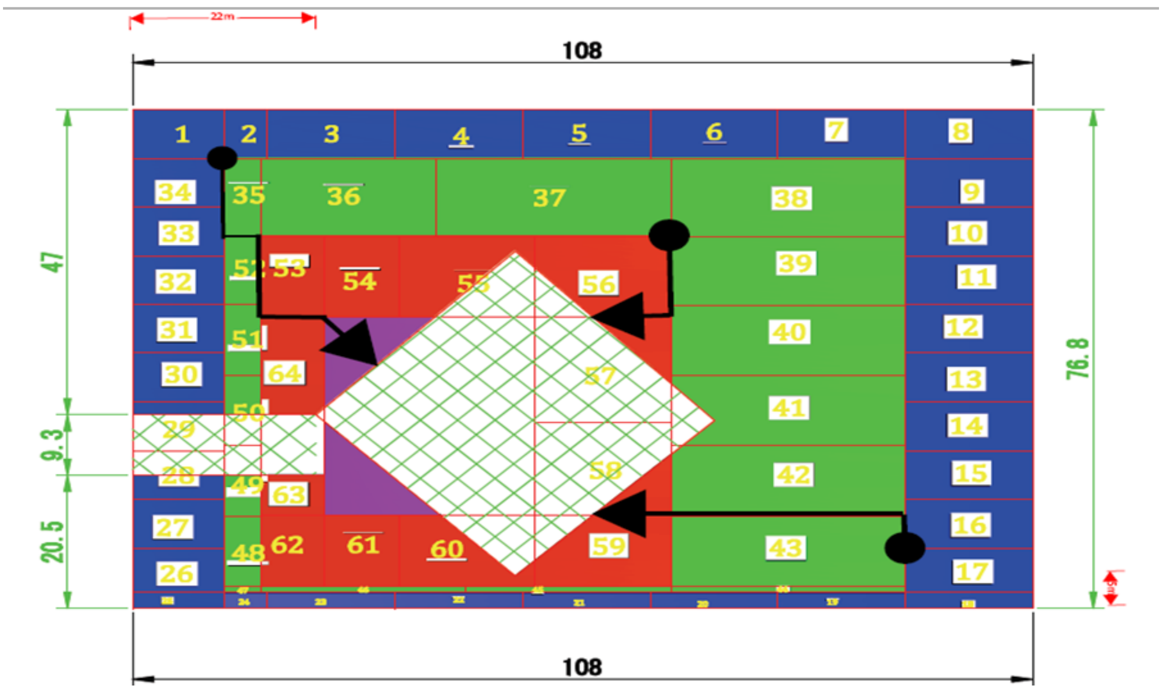
The site has two constrained ends at the 22 m side and 5 m side (Figure 3). In order to share these constrained ends among the zones, the number of site facilities in each zone was used to determine the ratio of allocation for each of the zones. For the 22 m side of the constrained ends, 6.6 m was allocated to the inner zone, 4.4 m was allocated to the outer zone, and 11 m to the neutral zone (Table 4).

The travel path between the site facilities and the reference point (building area) was determined by extracting the dimensions of the grid cells in each zone from the site space. The shortest gridlines in distances per metre from grid cells to the building area were identified from Figure 3.

These were denoted using arrow symbol in Figure 3 and were itemized as travel paths in the third column of Table 5. The time it will take the workers to walk from the grid cells to the building area was determined using Equation 5.

Workflow scenario	Central Zone	Inner Zone	Outer Zone	Neutral Zone
Site organization	Building area, Site access			Site office, Security post, Water supply, Power supply
Foundation	Building area, Site access	Block depot, Batch plant, Rebar depot	Gravel and Sand depot, Workshop, Material store, Equipment yard and Car park, Fabrication yard	Consultant's office, Subcontractor office, Formwork depot, Delivery area, Waste dump, Toilet and Bathroom, Site accommodation
Building Structure	Building area, Site access	Block depot, Batch plant, Rebar depot	Gravel and Sand depot, Workshop, Material store, Equipment yard and Car park, Fabrication yard	Consultant's office, Subcontractor office, Formwork depot, Delivery area, Waste dump, Toilet and Bathroom, Site accommodation, Site office, Security post, Water supply, Power supply
Building Envelope	Building area, Site access	Block depot, Batch plant	Material store, Equipment yard and Car Park	Consultant's office, Subcontractor office, Delivery area, Waste dump, Toilet and Bathroom, Site accommodation, Water supply, Site office, Power supply, Security post
External works	Building area, Site access	Block depot, Batch plant	Gravel and Sand depot, Equipment yard and Car park	Delivery area, Toilet and Bathroom, Water supply, Site office, Power supply, Security post
Inspection and Handing over	Building area, Site access		Equipment yard and Car park	Security post

Table 3: Zoning of Site Facilities



Legend	Neutral zone	Outer zone	Inner zone	Central zone	Travel path

Figure 3: Zoning of site space.

Zones	Size of cell grid	Number of site facilities in zone	Ratio of allocation	Allocation of constrained end of the site	
				22 m side	5 m side
Inner zone	17 m x 16.5 m	6	30%	6.6 m	1.5 m
Outer zone	12 m x 28.1 m	4	20%	4.4 m	1.0 m
Neutral zone	15.25 m x 7.5 m	10	50%	11 m	2.5 m
		∑ = 20			

Table 4: Sizing of cell grids and allocation of constrained end of site.

Cells	Dimension	Travel path (distance/ meter)	Walking Time (sec)
		Neutral Zone	
1	11 x 7.5	58.00	41.76
2	5.2 x 7.5	37.66	27.11
3	15.3 x 7.5	34.75	25.02
4	15.3 x 7.5	34 75	25.02
5	15.3 x 7.5	36.50	26.28
6	15.3 x 7.5	45.60	32.83
7	15.3 x 7.5	54.90	39.53
8	15.3 x 7.5	70.20	50.54
9	15.3 x 7.5	54.40	39.17
10	15.3 x 7.5	39.35	28.33
11	15.3 x 7.5	36.35	26.17
12	15.3 x 7.5	31.85	22.93
13	15.3 x 7.5	28.10	20.23
14	15.3 x 7.5	22.85	16.45
15	15.3 x 7.5	26.60	19.15
16	15.3 x 7.5	37.10	26.71
17	15.3 x 6.8	42.35	30.49
18	15.3 x 2.5	47.40	34.13
19	15.3 x 2.5	35.30	25.42
20	15.3 x 2.5	18.30	13.18
21	15.3 x 2.5	3.00	2.16
22	15.3 x 2.5	3.00	2.16
23	15.3 x 2.5	18.30	13.18
24	5.2 x 2.5	33.60	24.19
25	11 x 2.5	13.50	9.72
26	11 x 6.8	16.25	11.70
27	11 x 7.5	14.00	10.08
28	11 x 7.5	Not Available	-------
29	11 x 7.5	Not Available	-------
30	11 x 7.5	12.25	8.82
31	11 x 7.5	20.75	14.94
32	11 x 7.5	27.76	19.99
33	11 x 7.5	23.00	16.56
34	11 x 7.5	30.55	21.99

Table 5.a: Travel Paths and Walking distance between Cells and Zones (Neutral Zone).

Cells	Dimension	Travel path (distance/ meter)	Walking Time (sec)
		Outer Zone	
35	4.4 x 12	20.90	15.05
36	21 x 12	18.80	13.54
37	28.1 x 12	18.80	13.54
38	28.1 x 12	21.80	15.69
39	28.1 x 10.76	11.25	8.10
40	28.1 x 10.76	2.25	1.65
41	14.05 x 10.76	8.80	6.34
42	28.1 x 10.76	4.50	3.24
43	28.1 x 10.76	9.75	7.02
44	28.1 x 1.0	20.05	14.44
45	24.60 x 1.0	9.00	6.48
46	24.40 x 1.0	9.00	6.48
47	4.4 x 1.0	26.10	18.79
48	4.4 x 10.76	22.35	16.09
49	4.4 x 10.76	Not Available	------
50	4.4 x 10.76	Not Available	------
51	4.4 x 10.76	13.60	9.79
52	4.4 x 10.76	20.10	14.47

Table 5.b: Travel Paths and Walking distance between Cells and Zones (Outer Zone).

Cells	Dimension	Travel path (distance/ meter)	Walking Time (sec)
		Inner Zone	
53	6.6 x 7.6	9.75	7.02
54	10 x 7.6	2.25	1.62
55	18.15 x 7.6	2.25	1.62
56	8.15 x 7.6	5.25	3.78
57	16.3 x 10.9	Not Available	------
58	16.3 x 7.6	Not Available	------
59	8.15 x 9.4	4.00	2.88
60	16.3 x 10.9	1.50	1.08
61	16.3 x 10.9	5.25	3.78
62	10 x 10.9	10.50	7.56
63	7.6 x 10.9	18.00	12.96
64	7.6 x 9.4	11.25	8.10
65	7.5 x 7.6	Not Available	------
66	7.6 x 14.30	7.00	5.04

Table 5.c: Travel Paths and Walking distance between Cells and Zones (Inner Zone).

4.2 Optimization and modelling processes

4.2.1 Optimization model

The objective of the optimization process for the site utilization plan is to minimize the walking time from the site facility to the building area. From Table 5, the grid cells with the minimum walking time were identified in each zone and were allocated to site facilities based on the required sizes of the site facilities and the phase of work. As explained in Table 6, four site facilities are required in phase1 (site organization) of the project.

According to Table 3, all of these site facilities belong to the neutral zone, and in Table 5, cells 21, 22, 25 and 30 have the minimum walking time in comparison with the other cells in the neutral zone. Based on the understanding of the flow of construction activities on construction sites, knowledge of the construction site constraints, sizes of the site facilities, dimensions of the grid cells, and availability of space.

Cell 30 was allocated to security post, c3ll 21 to site office, cell 22 to water supply, and cell 25 to power supply. In phase 2 (foundation) of the project, new site facilities are required because the nature of work has changed.

The zones of the required site facilities in phase 2 as explained in Table 3 were used to allocate cells to the site facilities as shown in Table 6. The allocation of cells to site facilities required in phase 2 of the project was also based on the understanding of the flow of construction activities, knowledge of the construction site constraints, sizes of the site facilities, dimensions of the grid cells, and availability of space.

These processes was repeated for phase 3, 4 and 5 of the project. Movable site facilities changed positions with change in work progress; for example, gravel and sand depot occupies cell 42 and 37 in phase 2; but moves to cell 42, 48 and 59 in phase 3. Also, batch plant occupies cell 53 in phase4, but moves to cell 55 in phase 5. This illustrates the dynamic interactions among site facilities, site spaces and construction works.

The optimization model for the site layout plan was computed at three levels. The first level of computation was done for each of the site facilities using equation 6, the second level was done for the phases of work using equation 7, while the third level was done for the project as a whole using equation 8.

Table 6 shows the computation of the optimization models. In phase 1 of the project, the optimized walking time from the security post to the building area is 11377 seconds, from site office to the building area is 85011 seconds; while it will take workers 6966 and 6269.4 seconds to walk from water supply and power supply to the building area respectively. Z_{p1} represents the optimized walking time for phase 1 and it was computed to be 109623.4 seconds. $Z_{p2} - Z_{p6}$ represent the optimized walking time for phase 2 – 6; while the optimized walking time for the project is represented by Z_{TOTAL}.

Phase	Site Facility (SF)	Allocated Positions of SF			Optimization Model (sec)
		Inner Zone	Outer Zone	Neutral Zone	Z
1.	Security post			Cell 30	11377
	Site office			Cell 21	85011
	Water supply			Cell 22	6966
	Power supply			Cell 25	6269.4
					Z_{p1}=109623.4
2.	Security post			Cell 30	16687.44
	Site office			Cell 14	155617
	Water supply			Cell 21	10216.8
	Power supply			Cell 25	9195.12
	Gravel &Sand depot		Cell 42&37		158738.80
	Block depot	Cell 59&61			372913.2
	Workshop			Cell 3	142013.52
	Batch plant	Cell 53&57			127710
	Consultant's office			Cell 15	90579.5.
	Sub contractor's office			Cell 13	95687.9
	Material store			Cell 40	15325.2
	Rebar depot	Cell 53& 54			36780.48
	Fabrication yard			Cell 4	372686.16
	Formwork depot			Cell 4	372686.16

Table 6.a: Allocation of Cells to facilities for Optimization (phases 1 and 2).

Phase	Site Facility (SF)	Allocated Positions of SF	Allocated Positions of SF	Allocated Positions of SF	Optimization Model (sec)
		Inner Zone	Outer Zone	Neutral Zone	Z
	EYCP		Cell 35& 36		64044.20
	Delivery area			Cell 32& 33	99131.34
	Waste dump			Cell 10	80400.54
	Toilet & bath			Cell 19	120236.60
	Site accommodation			Cell 17	8653062
					Z_{p2}=10993678.96
3.	Security post			Cell 30	32439.20
	Site office			Cell 21	42724.80
	Water supply			Cell 22& 5	281271.60
	Power supply			Cell 25	19226.16
	Gravel & sand depot		Cell 42, 48&59		542565.40
	Block depot		Cell 61		299073.60
	Workshop			Cell 3	296937.36
	Batch plant		Cell 53,57&61		747684
	Consultant's office			Cell 15	189393.50
	Sub-contractor			Cell 13	20074.80
	Material store			Cell 40	32043.60
	Rebar depot	Cell 54&53			53833.25
	Fabrication yard			Cell 4	12112.48
	Formwork depot			Cell 6	247447.80
	EYCP		Cell 35& 36		282755.1
	Delivery area			Cell 32 &33	262994.88
	Waste dump			Cell 10	168110.22
	Toi &Bath			Cell 19	251403.80
	Site Accommodation			Cell 17	180927.66
					Z_{p3}=3963019.21
4.	Site office			Cell 30	23220
	Security post			Cell 14	10963
	Water supply			Cell 21	11610
	Power supply			Cell 25	10449
	Block depot		Cell 61,67,59&54		638550
	Sand depot		Cell 42& 37		180385
	Workshop			Cell 3	52245
	Batch plant	Cell 53			102931.25
	Consultant's office			Cell 15	217472.50
	Sub-contractor			Cell 13	17515
	Material store			Cell 6	352922.5
	EYCP		Cell 35& 36		153677
	Delivery area			Cell 32& 33	117873.75
	Waste dump			Cell 10	91364.25
	Toilet &Bathroom			Cell 19	136632.50
	Site accommodation			Cell 17	98330.25
					Z_{p4}=2186141
5.	Site office			Cell 34	576797.70
	Security post			Cell 30	46269.72
	Water supply		Cell 37		177577.10
	Power supply			Cell 25	25495.56
	Gravel & Sand depot			Cell 31	391878.20
	Block depot			Cell 32	1175628.60
	Batch plant	Cell 55			124777.80
	Toilet & bathroom			Cell 1	547682.40
					Z_{p5}=3056106.72
6.	Security post			Cell 30	10619.28
	EYCP			Cell 31& 32	105139.30
					Z_{p6}=115758.58
					Z_{TOTAL}=20424327.87

* EYCP = Equipment Yard and Car Park

Table 6.b: Allocation of Cells to facilities for Optimization (phases 3 to 6).

4.2.2 Site layout modelling

The optimized site layout plans prepared in Table 6 were developed into SLMs using BIM tools. This was done so as to make the site layout plans to be illustrative and functional. The SLMs were developed on Autodesk Revit 2010 version.

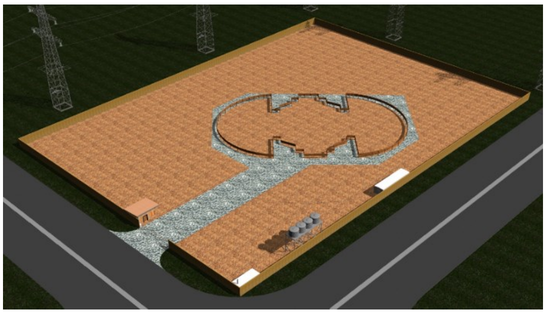
The modelling process was done according to the site utilization plans presented in Table 6. Figure 4 shows a number of different SLM for different work phases as the site and nature of work changes.

The work phases were modelled in 4-different views of north, east, west and south. The modelling process followed the principles of Petri-net based simulation.

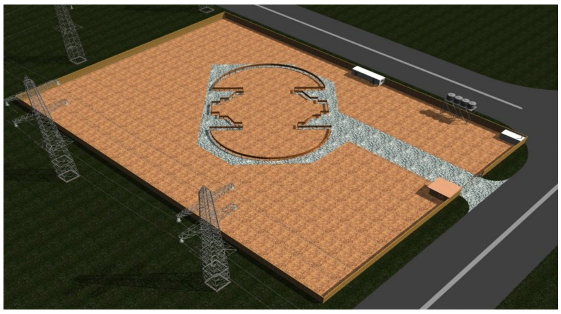
The site space, site facilities and nature of work were modelled in static form in each phase of work. The transitions of the work and site facilities were modelled in dynamic form by modelling the whole work scenarios as portrayed in phase 1- 6.

Phase 1: Site organization

North view



East view



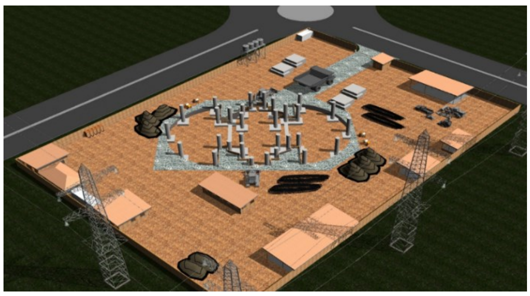
West view

South view

Phase 2: Foundation

North view

East view



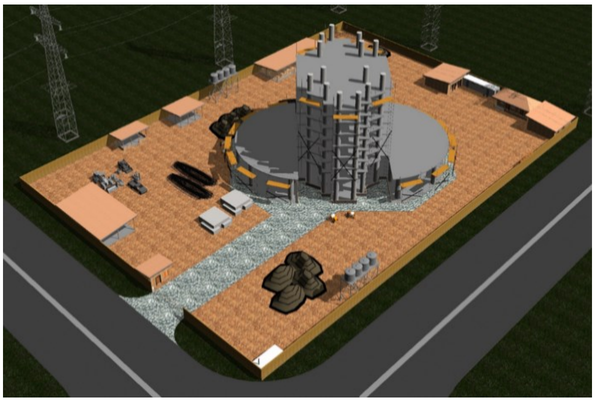
West view

South view

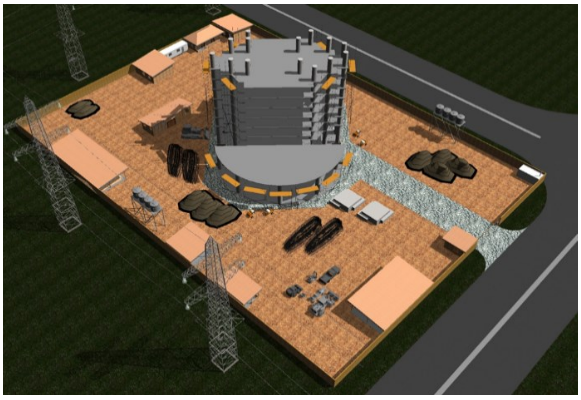
Figure 4.a: SLMs (phases 1 and 2).

Phase 3: Building Structure

North view



East view



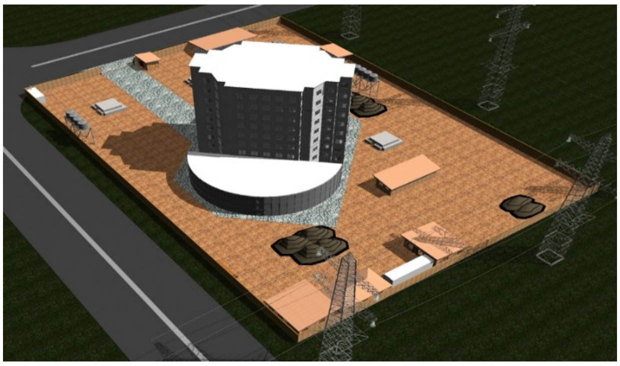
West view

South view

Phase 4: Building Envelope

North view

East view



West view

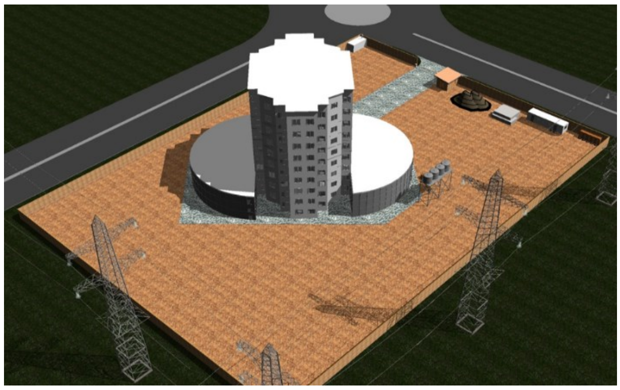
South view

Figure 4.b: SLMs (phases 3 and 4).

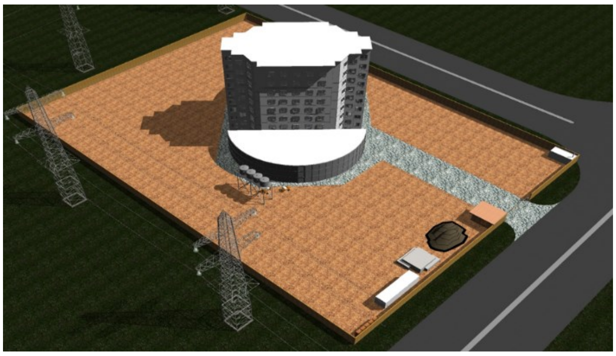
Phase 5: External Works

North view

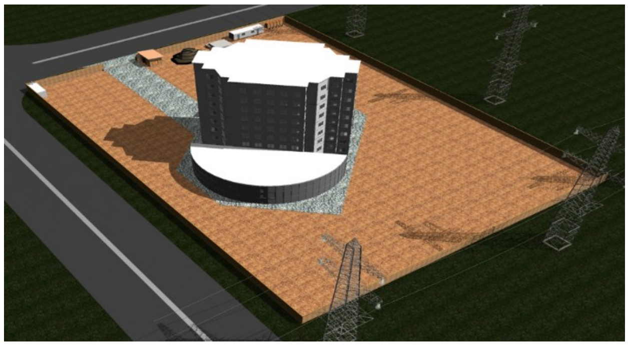
East view



West view

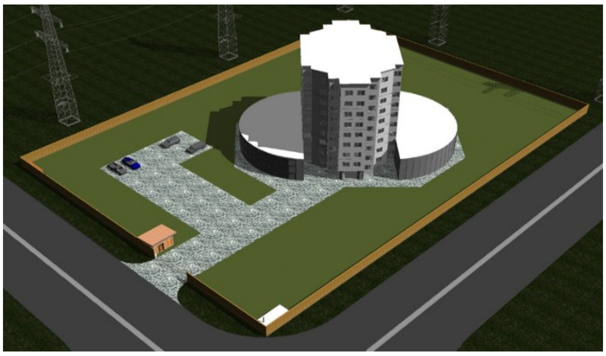


South view



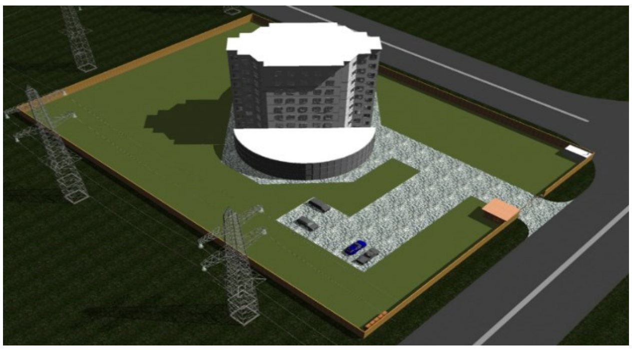
Phase 6: Inspection and Handing over

North view



East view

West view



South view

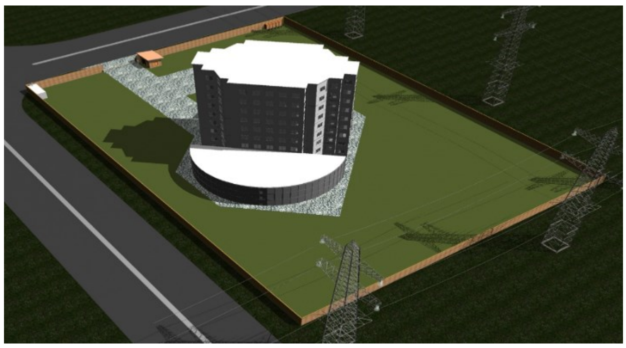


Figure 4.c: SLMs (phases 5 and 6).

5. CONCLUSION

The example in this paper implies that construction site layout modelling through BIM tools and construction methods integration is an all-round illustrative and practical system of developing site layout models for construction projects.

It demonstrates that site layout model is expedient and essential for setting up and managing construction sites. The site layout modelling system proposed in this paper can be adopted for BIM-based site planning that seeks to be in sync with a particular construction methods.

Nevertheless, the system is limited considering that it did not consider the location and utilization dynamics of construction equipment such as tower crane. The system approached the modelling of construction sites utilization in one piece. Another approach would have been to model the utilization of site facilities and equipment proposed in construction method section by section.

However, the system proposed in this paper is an improvement on the existing system, and it has substantiated the need for incorporating the proposed construction methods for projects in BIM-based modelling of construction site utilization.

The proposed site layout modelling system reinforces the need for and possibility of re-thinking the processes of planning, constructing and managing construction projects.

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