APPLICATION OF GENETIC ALGORITHM TO REPETITIVE CONSTRUCTION PROJECT OPTIMIZATION: CASE STUDY OF OMOKU RESIDENTIAL ESTATE IN RIVERS STATE NIGERIA.

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ABSTRACT

Assessment of the use of genetic algorithm to optimize the parameters of the building project: project time, price and management of the resource crew: was investigated Project information regarding the quantity of works, the different resource options in terms of productivity and cost & the Line of Balance Schedule table for 15 activities have been included in a GA coded excel sheet on which the optimization was carried out. Total project completion time and cost of 136 days at $1,005,305.92 without resource interruptions along units of work was obtained compared to 150 days at $1,241,820.09 which was obtained at site using the conventional management techniques . The use of GA in construction project scheduling would aid the managers in managing resources towards efficient project delivery at low cost.

1.0   INTRODUCTION

The private sector plays a critical part in national development and is critical in strengthening the economy of a country like Nigeria. The advantages gained by both sides have sparked rivalry among businesses in terms of customer satisfaction, which in the construction industry entails project completion at the lowest possible cost and time. As a result, construction companies rely on the coordination of a variety of activities, as well as scheduling, which plays a critical role in the organization of human and technology resources to satisfy the client's needs. As a result, the company's efficiency and failures will have a significant impact on its client relationships. Different resource options are available for each activity in repetitious project work, and determining the optimal option (assignment) for an activity is a big difficulty for project managers who want to make decisions as rapidly as feasible. This study solves the problem by utilizing Genetic Algorithm to create an efficient timetable system for assigning resources to recurring building projects, reducing or completely eliminating construction delays and total project cost overruns.

2.0   LITERATURE REVIEW
2.1   Repetitive Construction Project Scheduling

Repetitive projects are defined as those that comprise multiple identical or comparable units. Construction projects that are repetitive can be split into two types (Hegazy et al, 2001): projects that are repetitive due to a uniform repetition of a unit task throughout the construction process and projects that are repetitive due to their geometrical arrangement The fundamental characteristics of all repetitive building project are the steady demand of resource workers to execute the same job in distinct units (place, section) through continuous motion in the project between units. Because of this frequent resource motion, it is essential to have an efficient project schedule plan to obtain maximum productivity from all resources and to prevent resource clashing. (Vanhoucke, 2006). For scheduling and controlling building projects, the Critical Path Method (CPM) has long been employed in the construction sector. When used to schedule repeating work, however, this technique has significant drawbacks (Arditi and Albulak, 2011). As a consequence, several traditional scheduling methods have been developed, the best of which is the Balance Line (LOB) method. (Arditi and Albulak, 2011), Line-of-balance (LOB) scheduling is a type of linear scheduling that allows operations to be balanced so that each activity is completed continuously. The primary advantage of the LOB methodology is that it presents production rate and duration data in a readily interpreted graphic manner. The LOB plot can highlight what's wrong

with an activity's progress at a glance, as well as anticipated future bottlenecks. A LOB schedule is graphically represented as an X-Y plot, with one axis representing units and the other representing time. The LOB approach has never been fully developed and applied by the Nigeria construction industry due to the enormous popularity of network scheduling techniques such as CPM (critical path method) in this nation. European contractors, on the other hand, have used this strategy at a larger rate (Dressler, 2010).

2.2   Construction Scheduling Optimization

By maximizing desired characteristics and decreasing undesired ones, optimization can be described as the act of finding an alternative with the most cost effective or greatest feasible performance under the given restrictions. It is a deliberate endeavor to increase profit margins and achieve the greatest results under specific conditions or circumstances (Anuja & Parag, 2016). Construction schedule optimization (CSO) is the process of scheduling building operations that are constrained by time and/or resources. The most significant component of scheduling is resource selection (e.g., labor, plant, and equipment), which should be done in accordance with site constraints and the job to be done (Jaskowski & Sobotka, 2006). The CSO's goal is to determine a feasible schedule of these activities to achieve certain predefined goals such as the shortest duration of the project, the lowest cost or the highest profit subject to the constraints of the problem. (Zhou *et   al*,   2013). The algorithms created to solve the CSO issue can be divided into three techniques: mathematical, heuristic, and metaheuristic. (Zhou *et al*, 2013). Genetic Algorithm is an example of the metaheuristic classification of developed algorithm for solving CSO problems.

GAs are a heuristic solution-search or optimization technique, originally motivated by the Darwinian principle of evolution through (genetic) selection. A GA uses a highly abstract version of evolutionary processes to evolve solutions to given problems. Each GA operates on a population of artificial chromosomes. These are strings in a finite alphabet (usually binary). Each chromosome represents a solution to a problem and has a fitness, a real number which is a measure of how good a solution is to the particular problem (Mccall, 2005). Starting with a randomly generated population of chromosomes, a GA carries out a process of fitness-based selection and recombination to produce a successor population, the next generation. During recombination, parent chromosomes are selected and their genetic material is recombined to produce child chromosomes. These then pass into the successor population. As this process is iterated, a sequence of successive generations evolves and the average fitness of the chromosomes tends to increase

until some stopping criterion is reached. In this way, a GA "evolves" optimal solution to a given problem (Mccall, 2005). A GA is constructed from a number of distinct components. These components are: the chromosome encoding, the fitness function, selection, recombination and the evolution scheme.

2.3 Past Studies on Optimization in Construction

To deal with the building time–cost trade-off scheduling challenge, Hegazy et al (2001) created a solution that merged GA and the commercial scheduling software Microsoft Project 4.1. The developed technique employs total cost as the objective function and incorporates project deadline, daily incentive, daily liquidated damages, and daily indirect cost as constraints. The project cost as a result was lower than that calculated using the typical CPM method. For building time–cost optimization challenges, Zheng et al (2004) developed a multi-objective approach. The method's main characteristic is that it uses a genetic algorithm to handle the trade-off problem between time and cost in order to minimize both at the same time. When compared to other time-cost trade-off models, it outperformed them while requiring less calculation time. El-Rayes and Kandil (2005) recommended using a GA to handle the problem of highway building scheduling. The goal of the optimization challenge is to reduce construction time and expense while maintaining the highest possible quality. The result showed a near-optimal solution when applied to an highway construction project, at cost lower than the actual project cost at higher quality

3.0 METHODOLOGY

The GA optimization system was developed in three phases; the phases are the problem statement, generation of initial population and design of chromosomes, and finally the fitness function.

3.1 Problem Statement

There are two significant variables in each optimization problem statement; the objective function and the limitations. Our goal is the objective function, while the constraints are the limitations by which our goal must be fulfilled. The objective function in this case is to minimize the total cost and time of the project. The mathematical representation is as follows;

Objectives

- Minimize project duration.

$$Z_1 = Min\{Max \sum_{i=1}^{M} \sum_{j=1}^{Q} (S_{ij} + d_{ij})\} \qquad (1)$$

- Minimize project cost. $C = (C_D + C_p + C_I)$

$$Z_2 = Min\left(\left(\sum_{i=1}^{M}\sum_{j=1}^{Q}\left[(C_{ij} + (l_{ij} \times p_i)\right] + (b \times T) + C_O\right)$$ (2)

- Minimize combined effect of both project cost and project duration.

$$TC = \sqrt{((W_t(\frac{T - T_{min}}{T_{min}})\textasciicircum 2) + (W_c(\frac{C - C_{min}}{C_{min}})\textasciicircum 2))}$$ (3)

Subjected to the following constraints

- Durations to complete activity i in unit j. (Quantity of work constraint)

$$d_{ij} = d_i \times w_{ij}$$ (4)

- Direct cost to complete activity i in unit j (Productivity constraint)

$$C_{ij} = C_i \times w_{ij}$$ (5)

- Lateness time of activity i in unit j (Precedence Constraint)

$$l_{ij} = Max(0, F_{ij} - DT_{ij})$$ (6)

- Precedence relationship among activities (Options Constraint)

$$S_{tj} + d_{tj} + lag_{t,i} \le S_{ij}$$ (7)

- Relationships among activities of different units

$$S_{ij} + d_{ij} \le S_{i(j+1)}$$ (8)

Where

i	is	Activity
j	is	Project unit
S_{ij}	is	Start time of activity i in unit j
F_{ij}	is	Finish time of activity i in unit j
d_{ij}	is	Duration of activity i in unit j
C_o	is	Original cost for the project
C_D	is	Direct cost for the project
C_I	is	Indirect cost for the project
C_p	is	Penalty cost for the project
C_{ij}	is	Direct cost to complete activity i in unit j
P_i	is	Penalty cost of activity i per day

Lij	is	Lateness of time of activity i in unit j
DTij	is	Due time of activity i in unit j
b	is	Indirect cost per day
T	is	Total duration for the project
C	is	Sum of direct, indirect and penalty cost for the project.
M	is	Total number of activities in the schedule network
K	is	The number of alternative options for performing activity i
Q	is	Total number of units(housing) in the network
d_i	is	Durations per unit activity of work of activity i
w_{ij}	is	Quantity of work of activity i in unit j
C_i	is	Direct cost per unit quantity of work of activity i
W_t	is	Weight assigned to importance of duration
Wc	is	Weight assigned to importance of cost

3.2 Generation of Initial Population and Design of Chromosomes

This research generates the original GA population randomly. Here durations per unit quantity of activity work are the variables of decision which are assumed to be the chromosome genes in populations. Each chromosome contains variables of m choice and represents a prospective solution that corresponds to a solution produced. The size of the chromosome depends on the difference between the maximum duration per unit quantity of activity work. (d_i^{max}) and minimum durations per unit quantity of work of activity (d_i^{min}) of all resources in an activity. For example, if the decision variable is in a range of (d_i^{min}, di^{max}), then the size of chromosone can be determined from the relation shown in Eq. (9)

$$2^{m-1} \le \left(d_i^{max} - d_i^{min}\right) \times 10^w \le 2^m - 1 \qquad (9)$$

Here w is the necessary accuracy which means that the range (d_k^{min}, d_k^{max}) is splted into at least ($d_i^{max} - d_i^{min}$) $\times$ 10^w ranges of equal size (Lew et al, 2001). Then discover the crew choice corresponding to each activity as per each chromosome's genes, as this was the variable used to choose the duration d_i and cost c_i. The value of X($_i$) which was used to determine each unit duration was encoded using the equation

$$X(i) = \sum_{k=0}^{m-1} x_{i(k)} \times 2^k \qquad (10)$$

Where the value of $x_{i(k)}$ is 0 or 1, and i= 1,2,3,…,M, k= 1,…, m-1

The activity duration(d_i) for activities with only one resource option was decided by the equation (11)

$$d_i = d_i^{min} + X(i) \times \left(\frac{d_i^{max} - d_i^{min}}{2^{m-1}}\right) \tag{11}$$

The duration(d_i) for activities with k resource options was determined using $Y(i)$ as follows;

$$Y(i) = X(i) \times \left(\frac{K}{2^{m-1}}\right) \tag{12}$$

The k resource option will be chosen if $k-1 \leq Y(i) \leq k$, and the assigned value of B_i^k is 1. B_i^k being the binary variable. By having $B_i^k = 1$, the values of di and ci is determined by Eq. (13) and (14) below

$$d_i = d_i^k \times B_i^k \tag{13}$$

$$c_i = c_i^k \times B_i^k \tag{14}$$

Where:

- d_i^k is the duration per unit quantity of work for option (k)
- Bi^k is a binary variable, if $Bi^k = 1$, then the option k is selected for performing activity (i)
- c_i^k is the direct cost per unit quantity of work for the option (k)
- k is the number of alternative options for performing activity (i)

From the values of (di, ci), the duration-d_{ij} and cost-c_{ij} to complete activity (i), i=1,…,M in units(j), j= 1,…,Q are calculated by Eq.(4) and Eq.(5) above. The values of d_{ij} and c_{ij} were then used to evaluate the fitness function.

3.3 Fitness Function Design

As it would determine the quality of the alternatives, the fitness function is the most significant component of the GA method. A scheduling algorithm was used as a fitness function in order to optimally arrange the iterated set of duratons-d_{ij} and cocts-c_{ij} so that minimal resource interruptions would occur along each project unit.. Then the scheduling algorithm calculates the length of the project and the complete price of the project incurred by the project crews used . The chromosomes generation, selection, recombination and mutation were programmed into an Excel 2016 workbook using VBA programming. The fitness function scheduling algorithm was programmed into the Excel workbook that contained the data extracted from the chosen site. The flow chart for the G.A process is shown in figure 1.
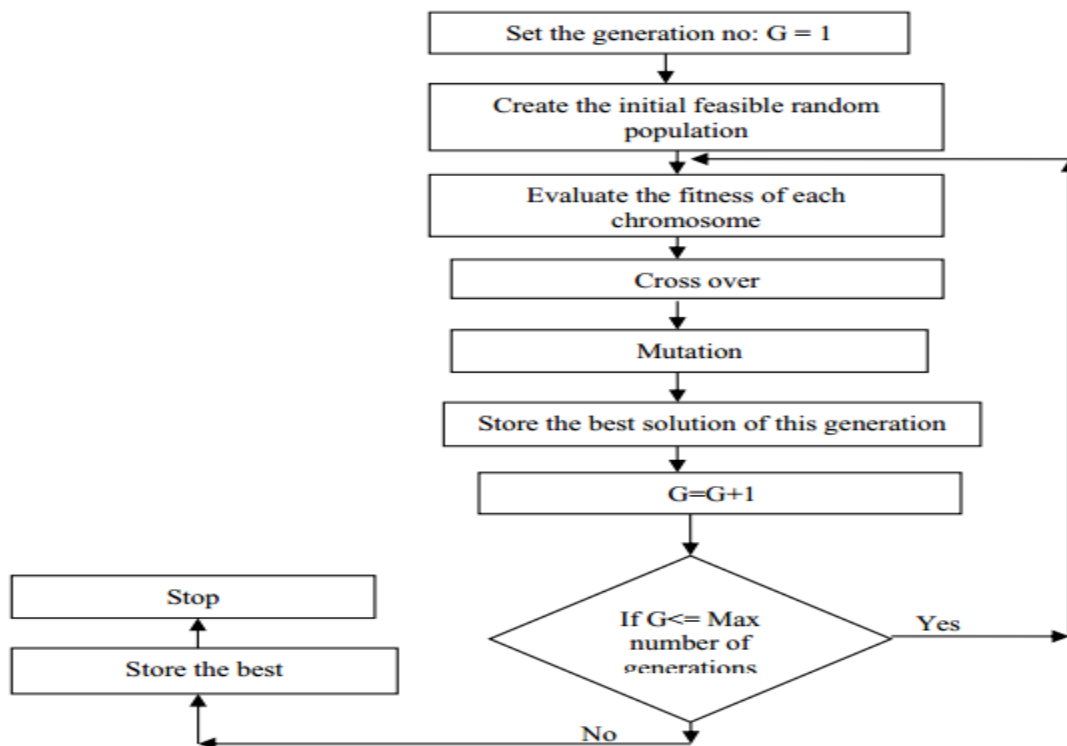
Figure 1: The Genetic Algorithm Mechanism

3.4 Application of The GA Optimization System

The GA System was validated by application to data gotten from the Omoku Multi-family Residential housing estate project. The contractual construction cost of the estate was $1258279.58 at duration of one hundred and sixty (160) days The estate consisted of five (5) different building type arranged in a particular order of nine (9) different work units. The construction started closed to the road side walk and moved in the following order. **Type A→ Type B →Type C → Type E→ Type E→ Type F→ Type F→ Type B→ Type A.** Data were extracted for the GA optimization included the quantity of works of selected activities that took place in the construction of the residential housing estate project, the various resource options and their prices and the schedule plan. These data were collected for the evaluation of the following activities.

- Excavation
- Foundation
- Formworks
- Reinforcements
- Fame elements (Column, Beam and slab)
- Blockworks

- Wall finishes

- Floor finishes

- Roofing

- Doors and Windows installation

- Fittings e.g. plumbing.

Table 1 showed the schedule plan for the researched section of the OMOKU residential housing project. Activity attribute of type Ω means that the activity must not be delayed whatsoever, while activity attribute of type ψ means the activity can be delayed

Table 1: The Schedule Plan for the Researched Site Section.

Activity ID	Activity name	Predecessors, Finishes	Activity Attribute
1	Excavations	_ , 1FS	Ω
2	Foundations	1FS, 2FS	Ω
3	Reinforcement	2FS, 3FS	ψ
4	Formwork	3FS, 4FS	ψ
5	Columns	4FS, 5FS	Ω
6	Beams	5FS + 3days, 6FS	ψ
7	Slabs	6FS + 3days, 7FS	ψ
8	Staircase&lintel	6FS, 8FS	ψ
9	Blockwork	7FS, 8FS	ψ
10	Wall Finishes	8FS, 9FS	ψ
11	Floor Finishes	8FS, 10FS	ψ
12	Roofing	10FS, 11FS	ψ
13	Ceiling Finishes	11FS, 12FS	ψ
14	Doors $ window	12FS, 13FS	ψ
15	FITTINGS	13FS, 14FS	ψ

Table 2 showed the excel table extract containing the project data provided on the project. The table contained the Options selector, Activity (i), Duration of activity i (di), cost(ci), quantity of works of each activity i in a particular unit j(wij), duration of activity i in unit j (dij), direct cost of activity i in unit j(cij), the different resource options in terms of their productivity i.e. day to the quantity of works done and options cost per work unit. The construction cost rate was that used at the time the project was being constructed at 2016.

However, apart from the quantity of works and the resource options, all other parameters had zero (0) value. This is due to the duration and cost having a zero value. The function of the G.A is to pick one out of the various resource options that would produce an optimized objective inputted

into it. Once the option selector cells had been filled up, it would automatically trigger up its corresponding duration and cost, which would then trigger up the remaining parameters. To achieve this, the duration and cost cells were linked to the options duration and cost using the "IF", "ISN" & "MAX" functions in excel. However, since no option resources had been generated yet, it remains at zero and served as the control template to generate the optimization result

Table 2: Control Parameters showing the different resource options duration, cost and types

Option Selector	Activity	d_i - Duration of Activity i (days)	c_i	Quantity of Work of each activity i in each repetitive unit j - w_{ij}									d_{ij} - Duration of activity (i) for unit (j) ($d_{ij} = d_i \ast w_{ij}$) (days)								
				Units Work									Units Work								
				1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
	Excavations	0	0	276	1489	2114	3458	3458	4816	4816	1489	276	0	0	0	0	0	0	0	0	0
	Foundations	0	0	200	1276	1414	1674	1674	2479	2479	1276	200	0	0	0	0	0	0	0	0	0
	Reinforcement	0	0	1849	17016	23224	30030	30030	74254	74254	17016	1849	0	0	0	0	0	0	0	0	0
	Formwork	0	0	403	2449	7492	9900	9900	11200	11200	2449	403	0	0	0	0	0	0	0	0	0
	Columns	0	0	10	34	45	72	72	90	90	34	10	0	0	0	0	0	0	0	0	0
	Beams	0	0	25	40	66	82	82	100	100	40	25	0	0	0	0	0	0	0	0	0
	Slabs	0	0	14	38	48	62	62	85	85	38	14	0	0	0	0	0	0	0	0	0
	Staircase&lintel	0	0	6	11	16	18	18	45	45	11	6	0	0	0	0	0	0	0	0	0
	Blockwork	0	0	508	1345	3324	5327	5327	6814	6814	1345	508	0	0	0	0	0	0	0	0	0
	Wall Finishes	0	0	1796	6090	9800	21304	21304	34628	34628	6090	1796	0	0	0	0		0	0	0	0
	Floor Finishes	0	0	384	862	1380	1770	1770	3261	3261	862	384	0	0	0	0	0	0	0	0	0
	Roofing	0	0	626	2025	2734	3347	3347	5863	5863	2025	626	0	0	0	0	0	0	0	0	0
	Ceiling Finishes	0	0	524	1252	1516	3490	3490	5968	5968	1252	524	0	0	0	0	0	0	0	0	0
	Doors $ window	0	0	46	60	120	200	200	280	280	60	46	0	0	0	0	0	0	0	0	0

Table 2: Control Parameters showing the different resource options duration, cost and types (contd.)

Activity	c_{ij} - direct cost of activity (i) for unit (j) ($c_{ij} = c_i \cdot w_{ij}$) (naira)									Different Crew fomation options and direct cost {d_i[day/work unit]; c_i[naira/work unit]}								Attribute type	is attribute type Ω ?
	Units Work									Options Duration - d_i				Options Cost - c_i					(1 - Yes, 0 - No)
	1	2	3	4	5	6	7	8	9	1	2	3	4	1	2	3	4		
Excavations	0	0	0	0	0	0	0	0	0	1/200	1/500	0	0	$0.55	$1.38	$0	$0	Ω	1
Foundations	0	0	0	0	0	0	0	0	0	1/200	1/250	1/350	0	$0.83	$1.51	$2.07	$0	Ω	1
Reinforcement	0	0	0	0	0	0	0	0	0	1/2000	1/3500	1/5000	0	$0.28	$0.30	$0.41	$0	ψ	0
Formwork	0	0	0	0	0	0	0	0	0	1/750	1/1200	1/1800	1/2200	$0.26	$0.28	$0.33	$0.34	ψ	0
Columns	0	0	0	0	0	0	0	0	0	1/10	1/20	1/25	1/30	$12.39	$13.77	$15.15	$16.53	Ω	1
Beams	0	0	0	0	0	0	0	0	0	1/20	1/30	1/45	1/50	$9.64	$11.02	$12.39	$13.77	ψ	0
Slabs	0	0	0	0	0	0	0	0	0	1/10	1/20	1/30	1/35	$13.77	$15.15	$16.53	$19.28	ψ	0
Staircase&lintel	0	0	0	0	0	0	0	0	0	1	1/2	1/3	0	$2.75	$4.13	$5.51	$0	ψ	0
Blockwork	0	0	0	0	0	0	0	0	0	1/500	1/1000	1/1500	1/2000	$2.62	$3.31	$3.58	$3.86	ψ	0
Wall Finishes	0	0	0	0	0	0	0	0	0	1/1500	1/3500	1/5000	1/7000	$2.75	$3.31	$3.86	$4.13	ψ	0
Floor Finishes	0	0	0	0	0	0	0	0	0	1/500	1/750	1/1000	1/1200	$4.96	$5.51	$6.06	$6.89	ψ	0
Roofing	0	0	0	0	0	0	0	0	0	1/725	1/1000	1/1500	1/2500	$4.13	$4.41	$4.96	$5.51	ψ	0
Ceiling Finishes	0	0	0	0	0	0	0	0	0	1/500	1/750	1/1000	1/2000	$4.96	$6.06	$6.89	$8.26	ψ	0
Doors $ window	0	0	0	0	0	0	0	0	0	1/50	1/60	1/80	1/100	$9.36	$9.64	$10.47	$11.02	ψ	0
FITTINGS	0	0	0	0	0	0	0	0	0	1/50	1/60	1/80	1/100	$5.51	$6.89	$7.71	$8.26	ψ	0
TOTAL COST = ₦0																			

4.0 RESULT & DISCUSSION

4.1 Site Validation Project data

Table 3 and Figure 1 showed the project result data and the line of balance plot of the resource crew movement for the Omoku Residential Estate Project. No optimization techniques or any other enhancing techniques were used. The choice of resources was based on experience of the project managers.

Table 3: Validation Project Parameters

Option Selector	Activity	di - Duration of Activity i (days)	ci	Quantity of Work of each activity i in each repetitive unit j - wij — Units Work									dij - Duration of activity (i) for unit (j) (dij = di*wij) (days) — Units Work								
				1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
2	Excavations	0.002	$1.38	276	1489	2114	3458	3458	4816	4816	1489	276	0.552	2.978	4.228	6.916	6.916	9.632	9.632	2.978	0.552
2	Foundations	0.004	$1.51	200	1276	1414	1674	1674	2479	2479	1276	200	0.8	5.104	5.656	6.696	6.696	9.916	9.916	5.104	0.8
2	Reinforcement	0.00028571	$0.30	1849	17016	23224	30030	30030	74254	74254	17016	1849	0.528286	4.86171	6.63543	8.58	8.58	21.215	21.215	4.861714	0.528286
4	Formwork	0.00045455	$0.34	403	2449	7492	9900	9900	11200	11200	2449	403	0.183182	1.11318	3.40545	4.5	4.5	5.0909	5.0909	1.113182	0.183182
3	Columns	0.04	$1.51	10	34	45	72	72	90	90	34	10	0.4	1.36	1.8	2.88	2.88	3.6	3.6	1.36	0.4
2	Beams	0.03333333	$1.10	25	40	66	82	82	100	100	40	25	0.833333	1.33333	2.2	2.73333	2.73333	3.33333	3.33333	1.333333	0.833333
3	Slabs	0.03333333	$1.65	14	38	48	62	62	85	85	38	14	0.466667	1.26667	1.6	2.06667	2.06667	2.83333	2.83333	1.266667	0.466667
3	Staircase&lintel	0.33333333	$5.51	6	11	16	18	18	45	45	11	6	2	3.66667	5.33333	6	6	15	15	3.666667	2
2	Blockwork	0.001	$3.31	508	1345	3324	5327	5327	6814	6814	1345	508	0.508	1.345	3.324	5.327	5.327	6.814	6.814	1.345	0.508
4	Wall Finishes	0.00014286	$4.13	1796	6090	9800	21304	21304	34628	34628	6090	1796	0.256571	0.87	1.4	3.0434	3.0434	4.9469	4.9469	0.87	0.256571
4	Floor Finishes	0.00083333	$6.89	384	862	1380	1770	1770	3261	3261	862	384	0.32	0.71833	1.15	1.475	1.475	2.7175	2.7175	0.718333	0.32
2	Roofing	0.001	$4.4	626	202	273	334	334	586	586	202	626	0.626	2.025	2.734	3.347	3.347	5.863	5.863	2.025	0.626

			1		5	4	7	7	3	3	5									
3	Ceiling Finishes	0.001	$6.89	524	1252	1516	3490	3490	5968	5968	1252	524	0.524	1.252	1.516	3.49	3.49	5.968	5.968	1.252	0.524
4	Doors $ window	0.01	$11.02	46	60	120	200	200	280	280	60	46	0.46	0.6	1.2	2	2	2.8	2.8	0.6	0.46
2	FITTINGS	0.01666667	$6.89	16	40	56	98	98	250	250	40	16	0.266667	0.66667	0.93333	1.6333	1.6333	4.1667	4.1667	0.666667	0.266667

Table 3: Validation Project Parameters (contd.)

Activity	cij - direct cost of activity (i) for unit (j) (cij = ci*wij) (dollar ($))									Different Crew fomation options and direct cost {di[day/work unit]; ci[naira/work unit]}								Attribute
	Units Work									Options Duration - di				Options Cost - ci				type
	1	2	3	4	5	6	7	8	9	1	2	3	4	1	2	3	4	
Excavations	275.43	2050.57	2911.28	4762.17	4762.17	6632.33	6632.33	2050.57	380.09	1/200	1/500	0	0	$0.55	$1.38	$0	$0	Ω
Foundations	275.43	1932.96	2142.01	2535.87	2535.87	3755.34	3755.34	1932.96	302.97	1/200	1/250	1/350	0	$0.83	$1.51	$2.07	$0	Ω
Reinforcement	550.86	5155.37	7036.22	9098.25	9098.25	22496.87	22496.87	5155.37	560.20	1/2000	1/3500	1/5000	0	$0.28	$0.30	$0.41	$0	ψ
Formwork	138.75	843.16	2579.39	3408.43	3408.43	3856.01	3856.01	843.16	138.75	1/750	1/1200	1/1800	1/2200	$0.26	$0.28	$0.33	$0.34	ψ
Columns	151.49	515.05	681.69	10906.99	1090.70	1363.37	1363.37	515.05	151.49	1/10	1/20	1/25	1/30	$12.39	$13.77	$15.15	$16.53	Ω
Beams	275.43	440.69	727.13	903.41	903.41	1101.72	1101.72	440.69	275.43	1/20	1/30	1/45	1/50	$9.64	$11.02	$12.39	$13.77	ψ
Slabs	254.50	690.78	872.56	1127.05	1127.05	1545.16	1545.16	690.78	254.50	1/10	1/20	1/30	1/35	$13.77	$15.15	$16.53	$19.28	ψ
Staircase&lintel	33.05	60.59	88.14	99.15	99.15	247.89	247.89	60.59	33.05	1	1/2	1/3	0	$2.75	$4.13	$5.51	$0	ψ
Blockwork	1652.57	4445.42	10986.31	17606.52	17606.52	22521.28	22521.28	4445.42	1679.01	1/500	1/1000	1/1500	1/2000	$2.62	$3.31	$3.58	$3.86	ψ
Wall Finishes	8262.87	25160.44	41314.35	88016.09	88016.09	143063.32	143063.32	25160.44	7420.06	1/1500	1/3500	1/5000	1/7000	$2.75	$3.31	$3.86	$4.13	ψ
Floor Finishes	2754.29	5935.49	9502.30	12187.73	12187.73	22454.35	22454.35	5935.49	2644.12	1/500	1/750	1/1000	1/1200	$4.96	$5.51	$6.06	$6.89	ψ
Roofing	2754.29	8923.92	1204.84	14749.77	14749.77	25837.44	25837.44	8923.90	2758.70	1/725	1/1000	1/1500	1/2500	$4.13	$4.41	$4.96	$5.51	ψ

Ceiling Finishes	2754.29	8620.93	10438.76	24031.18□	24031.18□	41094.00□	41094.00□	8620.93□	3608.12□	1/500	1/750	1/1000	1/2000	$4.96	$6.06	$6.89	$8.26	ψ
Doors $ window	5508.58	661.03	1322.86	2203.43□	2203.43□	3084.80□	3084.80□	661.03□	506.79□	1/50	1/60	1/80	1/100	$10.47	$11.02	$10.47	$11.02	ψ
FITTINGS	110.17	275.43	385.60□	674.80□	674.80□	1721.43□	1721.43□	275.43□	110.17□	1/50	1/60	1/80	1/100	$7.71	$8.26	$7.71	$8.26	ψ
					TOTAL COST = $**1241820.09**□													
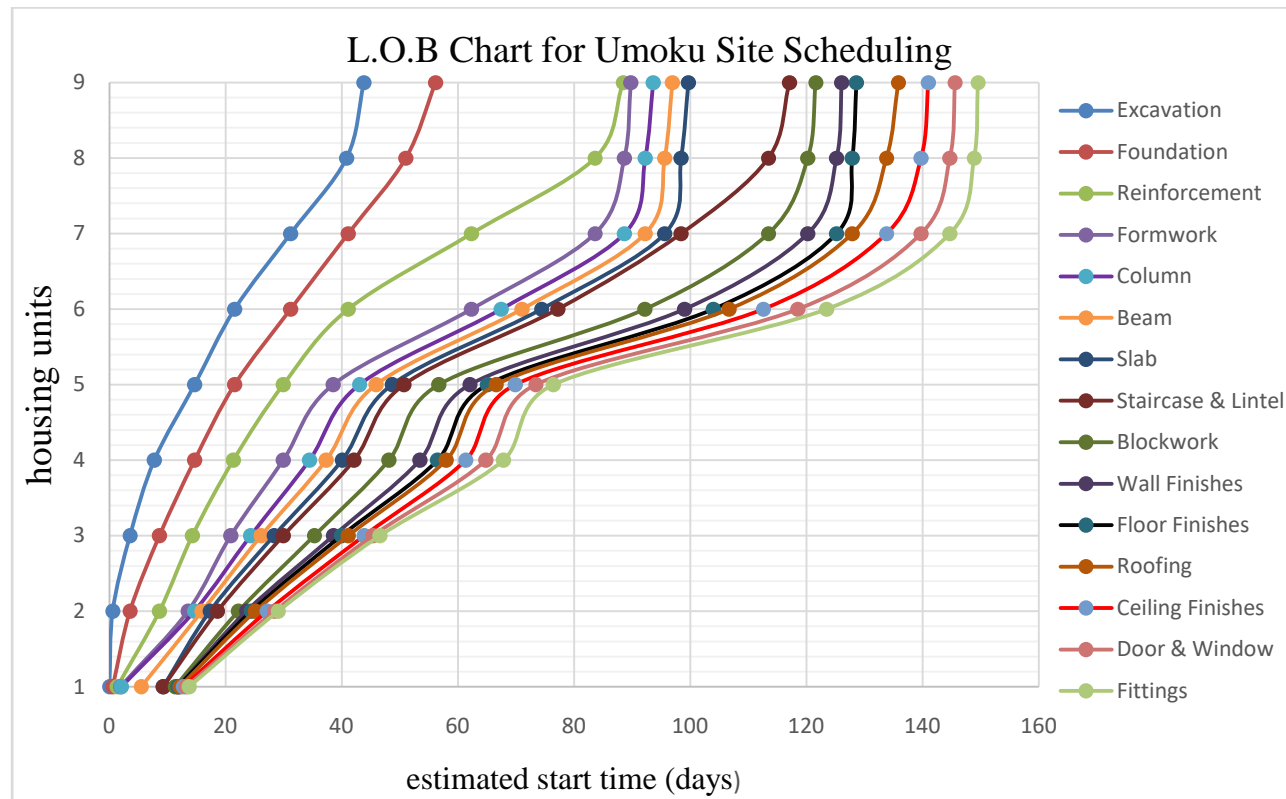
Figure 2: Line of Balance Plot showing the workflow movement of resource crew on site for the Site schedule Plan

From the results, the resource options chosen for excavation, foundation, formwork, reinforcement, column, beam, slab,

staircase & Lintel, wall finishes, floor finishes, roofing, ceiling finishes, doors & windows and fittings were 2, 2, 2, 4, 3, 2, 3, 3, 2, 4, 4, 2, 3, 4, 2 respectively . The total project duration of the project was 149.78 days , approximately 150 days . The cost at that completion time was $1241820.09 ▯▯

4.2 GA Time and Cost Optimization Result

Table 4 and Figure 2 showed the GA optimization results for minimization of total project cost and time and the line of balance plot of the resource crew movement for the Omoku Residential Estate Project

Table 4: GA Cost and Time Optimization Project Parameters

Option Selector	Activity	di - Duration of Activity i (days)	ci	Quantity of Work of each activity i in each repetitive unit j - wij									dij - Duration of activity (i) for unit (j) (dij = di*wij) (days)								
				Units Work									Units Work								
				1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
2	Excavations	0.002	500	276	1489	2114	3458	3458	4816	4816	1489	276	0.552	2.978	4.228	6.916	6.916	9.632	9.632	2.978	0.552
2	Foundations	0.004	550	200	1276	1414	1674	1674	2479	2479	1276	200	0.8	5.104	5.656	6.696	6.696	9.916	9.916	5.104	0.8
3	Reinforcement	0.0002	150	1849	17016	23224	30030	30030	74254	74254	17016	1849	0.3698	3.4032	4.6448	6.006	6.006	14.8508	14.8508	3.4032	0.3698
3	Formwork	0.00055556	120	403	2449	7492	9900	9900	11200	11200	2449	403	0.223889	1.36056	4.16222	5.5	5.5	6.222	6.2222	1.360556	0.223889
3	Columns	0.04	5500	10	34	45	72	72	90	90	34	10	0.4	1.36	1.8	2.88	2.88	3.6	3.6	1.36	0.4
3	Beams	0.02222222	4500	25	40	66	82	82	100	100	40	25	0.555556	0.88889	1.46667	1.8222	1.8222	2.2222	2.2222	0.888889	0.555556
2	Slabs	0.05	5500	14	38	48	62	62	85	85	38	14	0.7	1.9	2.4	3.1	3.1	4.25	4.25	1.9	0.7
3	Staircase&lintel	0.33333333	2000	6	11	16	18	18	45	45	11	6	2	3.66667	5.33333	6	6	15	15	3.666667	2
2	Blockwork	0.001	1200	508	1345	3324	5327	5327	6814	6814	1345	508	0.508	1.345	3.324	5.327	5.327	6.814	6.814	1.345	0.508
2	Wall Finishes	0.00028571	1200	1796	6090	9800	21304	21304	34628	34628	6090	1796	0.513143	1.74	2.8	6.0869	6.0869	9.8937	9.8937	1.74	0.513143
2	Floor Finishes	0.00133333	2000	384	862	1380	1770	1770	3261	3261	862	384	0.512	1.14933	1.84	2.36	2.36	4.348	4.348	1.149333	0.512
2	Roofing	0.001	1600	626	2025	2734	3347	3347	5863	5863	2025	626	0.626	2.025	2.734	3.347	3.347	5.863	5.863	2.025	0.626

2	Ceiling Finishes	0.00133333	2200	524	1252	1516	3490	3490	5968	5968	1252	524	0.698667	1.66933	2.02133	4.6533	4.6533	7.9573	7.9573	1.669333	0.698667
1	Doors $ window	0.02	3400	46	60	120	200	200	280	280	60	46	0.92	1.2	2.4	4	4	5.6	5.6	1.2	0.92
4	FITTINGS	0.01	3000	16	40	56	98	98	250	250	40	16	0.16	0.4	0.56	0.98	0.98	2.5	2.5	0.4	0.16

Table 4:   GA Cost and Time Optimization Project Parameters(contd.)

Activity	c_{ij} - direct cost of activity (i) for unit (j) ($c_{ij} = c_i \cdot w_{ij}$) (dollar)									Different Crew fomation options and direct cost {d_i[day/work unit]; c_i[naira/work unit]}								Attribute
	Units Work									Options Duration - d_i				Options Cost - c_i				type
	1	2	3	4	5	6	7	8	9	1	2	3	4	1	2	3	4	
Excavations	275.43	2050.57	2911.28	4762.17	4762.17	6632.33	6632.33	2050.57	380.09	1/200	1/500	0	0	$0.55	$1.38	$0	$0	Ω
Foundations	275.43	1932.96	2142.01	2535.87	2535.87	3755.34	3755.34	1932.96	302.97	1/200	1/250	1/350	0	$0.83	$1.51	$2.07	$0	Ω
Reinforcement	763.90	7030.05	9594.84	12406.70	12406.70	30677.56	30677.56	7030.05	763.90	1/2000	1/3500	1/5000	0	$0.28	$0.30	$0.41	$0	ψ
Formwork	133.20	809.43	2476.22	3272.10	3272.10	3701.76	3701.76	809.43	133.20	1/750	1/1200	1/1800	1/2200	$0.26	$0.28	$0.33	$0.34	ψ
Columns	151.49	515.05	681.69	1090.70	1090.70	1363.37	1363.37	515.05	151.49	1/10	1/20	1/25	1/30	$12.39	$13.77	$15.15	$16.53	Ω
Beams	275.43	495.77	818.02	1016.33	1016.33	1239.43	1239.43	495.77	309.86	1/20	1/30	1/45	1/50	$9.64	$11.02	$12.39	$13.77	ψ
Slabs	212.08	575.65	727.13	939.21	939.21	1287.63	1287.63	575.65	212.08	1/10	1/20	1/30	1/35	$13.77	$15.15	$16.53	$19.28	ψ
Staircase&lintel	33.05	60.59	88.14	99.15	99.15	247.89	247.89	60.59	33.05	1	1/2	1/3	0	$2.75	$4.13	$5.51	$0	ψ
Blockwork	1652.57	4445.42	10986.31	17606.52	17606.52	22521.28	22521.28	4445.42	1679.01	1/500	1/1000	1/1500	1/2000	$2.62	$3.31	$3.58	$3.86	ψ

Wall Finishes	5508.58	20128.35	33051.48	70412.87	70412.87	114450.66	114450.66	20128.35	5936.04	1/1500	1/3500	1/5000	1/7000	$2.75	$3.31	$3.86	$4.13	ψ
Floor Finishes	2203.43	4748.40	7601.84	9750.19	9750.19	17963.48	17963.48	4748.40	2115.29	1/500	1/750	1/1000	1/1200	$4.96	$5.51	$6.06	$6.89	ψ
Roofing	2754.29	8923.90	12048.37	14749.77	14749.77	25837.44	25837.44	8923.90	2758.70	1/725	1/1000	1/1500	1/2500	$4.13	$4.41	$4.96	$5.51	ψ
Ceiling Finishes	2754.29	7586.42	9186.11	21147.44	21147.44	36162.72	36162.72	7586.42	3175.14	1/500	1/750	1/1000	1/2000	$4.96	$6.06	$6.89	$8.26	ψ
Doors $ window	550.86	561.88	1123.75	1872.92	1872.92	2622.08	2622.08	561.88	430.77	1/50	1/60	1/80	1/100	$10.47	$11.02	$10.47	$11.02	ψ
FITTINGS	132.21	330.51	462.72	809.76	809.76	2065.72	2065.72	330.51	132.21	1/50	1/60	1/80	1/100	$7.71	$8.26	$7.71	$8.26	ψ

TOTAL COST = **$1005305.92**
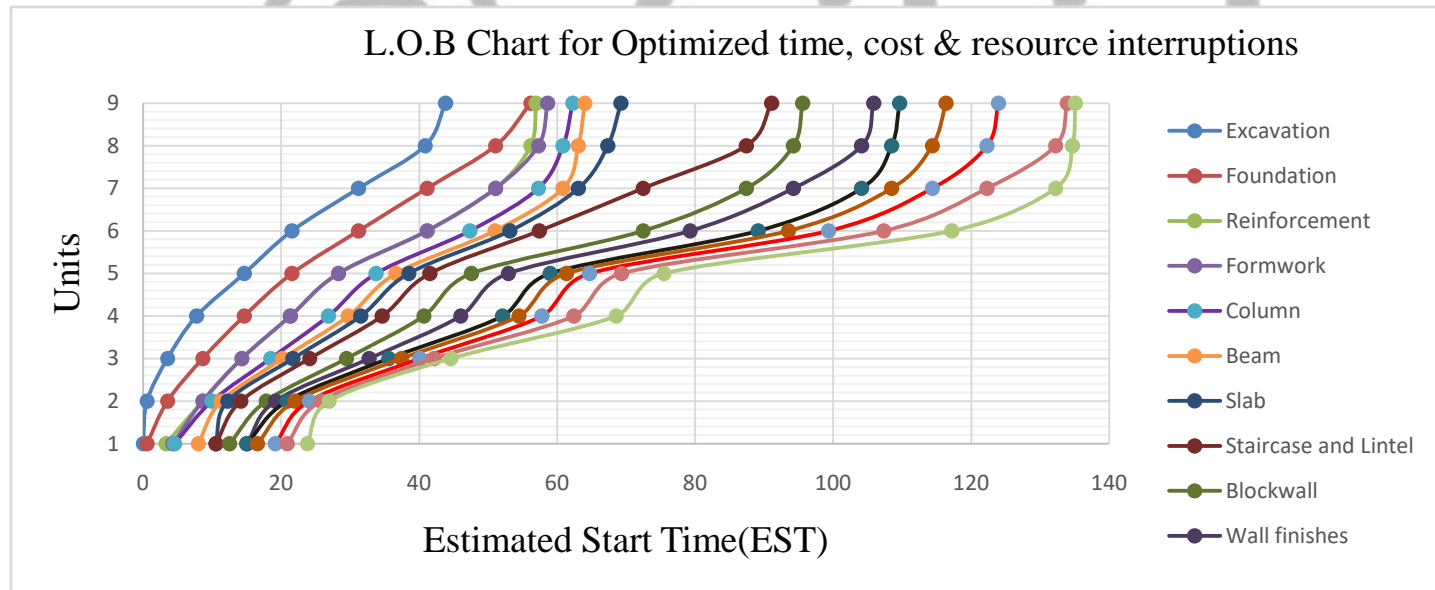
Figure 3: Line of Balance Plot showing the workflow movement of resource crew on site for GA Optimized time and cost schedule

From the results, the resource options generated for excavation, foundation, formwork, reinforcement, column, beam, slab, staircase & Lintel, wall finishes, floor finishes, roofing, ceiling finishes, doors & windows and fittings were **2, 2, 4, 3, 3, 3, 2, 3, 2, 2, 2, 2, 2, 1, 4** respectively. The total project duration after the GA cost and duration optimization was **135.26** days, approximately **136days**. This result is lower than that of actual project completion (validation) time of 150 days by close to two weeks. The project completion cost after the GA cost and duration optimization also was **$1005305.92**. Compared to the Bill of Engineering Measurement and Evaluation (BEME) contractual price of **$1258279.58** and duration of 160 days there would be large substantial savings of cost of $252,973.66 and time of 25 days on the project.

5.0   CONCLUSION

The cost and time GA optimization of the project produced a total cost of **$1005305.92** and project total duration of **136days.** When compared with the total cost of construction of **$1241820.09** and duration of 150days achieved on the site without any optimization method, there would have been cost savings of close to $236,514.17 if the GA optimized system were used. The use of GA in construction project scheduling would aid the managers in managing resources towards efficient project delivery at low cost and without resource interruptions as shown from the LOB plot.

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