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Developing Regression Based Approximate Quantities Models for Quantification of Electrical Cables for Residential Building Construction in Nigeria

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Abstract: In quantity surveying practice, the building and engineering standard method of measurement 4th edition stipulates that electrical final circuits should be enumerated during quantity take-off of electrical cables. This approach poses challenges during estimation and material scheduling because it does not readily provide the quantity (length) and estimate of cables needed for the electrical installation works. This study was aimed at developing regression based approximate quantities models which can be used by quantity surveyors to predict lighting and power electrical cables quantities for proposed residential building projects. Take-off(measurement) of thirty architectural and electrical drawings designed by registered architects and electrical engineers was carried out to obtain data on the number of lighting points and socket outlets as well as the corresponding length of cables, which was further validated by an experienced quantity surveyor and electrical engineer and analysed using linear regression. Two linear regression models were generated as follows (1) PC qty = 317.237 + 14.358 SO_{qty}, Where: PC qty = power cable quantities (in metres); SO_{qty}= number of socket outlets (2) LC qty = 363.867 + 13.518 LP_{qty} Where: LC qty = Lighting cable quantities(in metres); LP_{qty}= number of lighting points. These models have time saving potentials, but their efficacy relies heavily on the accurate measurement of the number of lighting and power points. These models are recommended for use by practicing quantity surveyors to generate realistic feasibility estimates of electrical cables and beat short tender deadlines.

Keywords: Approximate Quantities, Electrical cables, Quantification, Nigeria, Regression Models, Residential Buildings.

I. INTRODUCTION

According to Ashworth[1] , quantification of construction works has an important role in the project-planning phase since many cost relevant decisions (such as materials selection and pricing) are made at this stage. Unfortunately, accurate quantities and estimates are hard to obtain at that stage due to the fact that construction projects are recently becoming highly complicated diversified and even bigger, with the level of uncertainty of the success is rising.

The afore-mentioned scenario applies to a large extent to electrical installation works. These works are specialized construction works performed during the erection or reconstruction of buildings or structures intended for various purposes and that entails the installation of electric wiring and electrical equipment. In addition to this, cables and wires are laid and are connected to the installed electrical equipment.

Taking-off or Measurement of electrical works from electrical drawings which is aimed at generating the quantities and cost of such works is carried out by the quantity surveyor(QS).The Nigerian Institute of Quantity Surveyors (NIQS)[2,3]defines the QS asa cost and procurement management expert who is concerned with financial probity and achieving value for money in the conceptualization, planning and execution of development projects for both new and rehabilitation/refurbishment or maintenance works. He is thus the development cost adviser in the building, civil and other engineering projects. Lee, Trench and Willis[4] surmise that the training and knowledge of the modern Quantity Surveyor equips him to provide services in all aspects of procurement, contractual and project cost management. The quantity surveying profession is primarily concerned with the detailed calculations and assessment of quantities of materials and labour required for all construction activities such as building, civil and heavy engineering works. The QS uses the Standard Method of Measurement (SMM) as a technical guide for measurement of construction works. The SMM currently used in Nigeria is the Building and Engineering Standard Method of Measurement, 4th edition (BESMM[4]) which encompasses measurement of Building and engineering works.

Engineering services in building projects comprise of mechanical and electrical services. Basic categories of electrical services include; normal and emergency systems, life safety systems, audio and video systems, electric heating, specialized grounding systems and items associated with these categories. NIQS[5] categorizes electrical installation basically into electrical supply/power/light systems and communications/security/controls systems as specified in appendix B of the BESMM4.

The consumer's controller circuit(final circuit) starts from a service cable which enters the building to consumer's unit or distribution board. Part of consumer's controller consists of service fuse, main switch. The final circuit starts from the consumer's unit or distribution board to load. This part consists of fuse circuit breaker, socket outlet, ceiling rose, and lamp holder. The number of final circuits will depend on the types of load supplied, and must be designed to comply with the requirements for over current protection, switching and the current-carrying capacity of conductors. Every circuit must be separate from others and must be connected to its own over current protective fuse or circuit breaker in a switch fuse, distribution board, and consumer's unit.

The BESMM4; a publication of the NIQS[5] stipulates that final circuits' measurement should be enumerated (*see Table 1*) and this is the practice that quantity surveyors in Nigeria rely on when measuring or taking-off electrical works. For short pre-tender durations or when there is limited time to submit tenders, this often poses difficulty in quantifying and pricing or estimating the length of cables needed because it cannot be readily obtained except with vast experience in electrical measurement. Quantities of cables in buildings vary from project to project considering the nature, type or use of the building, hence, the need for models to quantify for the cable for pricing in different scenarios**.** To make matters worse, there are no currently easy-to-measure techniques for electrical components in existence especially in Nigeria's quantity surveying practice.

It is against this backdrop that this study sets out to develop models that can be used to quantify the length of lighting and power cables where the number of lighting points and socket outlets are known. It is pertinent to note that the models developed in this study are very useful, especially in its time saving potential, simplicity and ability to be handled with a calculator or a simple computer program. It is beneficial in estimating the cost of cables at early stages of a residential building construction since the information needed could be gotten at the sketch design stage.

Table 1: Page extract of measurement of electrical final circuits from the BESMM4

ITEM OR WORK TO BE MEASURED	UNIT	FIRST DIVISION	SECOND DIVISION	THIRD DIVISION	MEASUREMENT RULES	DEFINITION RULES	COVERAGE RULES	SUPPLEMENTARY INFORMATION
7 Final circuits	nr		1 Cable type, rating, size, material, sheathing, number and type of points.	1 Location of installation – roofs, high or low level in plantrooms, risers or service ducts, high or low level on floors.			C11 Includes all containment not measured separately, junction boxes, terminations, pots, seals, glands, lugs, connector blocks and shrouds. C12 Includes fixing containment or cables in chases, surface or suspended from soffits.	

II. AIM AND OBJECTIVES OF THE STUDY

The aim of the study is to develop models for predicting cable quantities of residential buildings. This aim will be achieved via the following objectives

1. To determine the relationship between the number of lighting points and length of lighting cables.
2. To determine the relationship between the number of socket outlets and length of power cables.
3. To develop predictive models for estimating the quantity(lengths) of lighting and power cables based on number of lighting points and socket outlets respectively

III. METHODOLOGY

The methodology (comprising data collection sources/ instruments, methods of analysis and analysis software) adopted in addressing the objectives of this study is summarised as shown in Table 2. However, data was analysed using Pearson correlation and regression analysis which is briefly described as follows:

A. Pearson Correlation and Regression Analysis

Pearson correlation analysis is a widely used statistical tool that is used to measure the extent or degree of relationship between two variables. For this study, Pearson Correlation analysis was used to investigate the relationship between the number of lighting points/socket outlets and the lengths of lighting/power cables obtained from measurement. The formula for Pearson correlation coefficient is expressed as:

$$R = \frac{N\sigma x y - \Sigma x \Sigma y}{\sqrt{[(N\sigma x^2 - (\Sigma x^2)(N\sigma y^2 - (\Sigma y)^2)]}} \quad (1)$$

When y<+ 0.5, a weak positive relationship exists
When y ≥ + 0.5, a strong positive relationship exists
When y< - 0.5, a strong negative relationship exists
When y ≤ - 0.5, a weak negative relationship exists
When y = + 1, a perfect positive relationship exists
When y = - 1, a perfect negative relationship exists
When y = 0, no relationship exists.

Regression analysis on the other hand is used to predict one variable based on another variable. It may also be said to be a technique that will find a formula or mathematical model which best describes some set of data collected. The factor whose value we wish to estimate is referred to as dependent variable and denoted by Y. the factor from which these estimates is made is called the independent variable and is denoted by X.

Therefore the relationship between the dependent and independent variables could be expressed with the generic linear regression model as shown in equation 2

$$Y = a + b x \quad (2)$$

Where: Y is the dependent variables or quantity being predicted.
X = the independent variables
a = the value of Y when = 0, i.e. the interceptor of the line with Y – axis
b = the slope or gradient. It estimates the rate of change in Y for a unit change in X. It is positive for direct and negative for inverse relationships.

Table 2: Summary of methodology of the Study

S/N	Objective	Research method		
		Data source/collection instrument	**Data analysis method**	**Data analysis soft ware**
1	To determine the relationship between the number of lighting points and length lighting cables.	Quantity take-off(measurement)of thirty architectural and electrical drawings validated by an experienced QS and electrical engineer	Correlation analysis	SPSS (Statistical Packages for the Social Sciences) version 22
2	To determine the relationship between the number of socket outlets and length of power cables.	Quantity take-off(measurement)of thirty architectural and electrical drawings validated by an experienced QS and electrical engineer	Correlation analysis	SPSS version 22
3	To develop predictive models for estimating the quantities(length) of lighting and power cables	Quantity take off (measurement)of thirty architectural and electrical drawings validated by an experienced QS and electrical engineer	Regression analysis	SPSS version 22

IV. DATA PRESENTATION AND RESULTS

Data for lighting points obtained from the taking-off/ measurement of the surveyed electrical drawings are shown in Table 3.

Table 3: Measured quantities of selected electrical items for lighting points in surveyed residential buildings

Project ID	Floor ID	Cable size	Number of lighting points	Cable quantity(m)
1	gf &ff	$2x1.5mm^2$	33	780
2	gf &ff	$2x1.5mm^2$	35	789
3	gf &ff	$2x1.5mm^2$	60	1413
4	gf	$2x1.5mm^2$	22	624
5	gf&ff	$2x1.5mm^2$	46	976
6	gf&ff	$2x1.5mm^2$	48	985
7	gf&ff	2x1.5mm2	50	988
8	gf &ff	2x1.5mm2	40	890
9	gf &ff	2x1.5mm2	49	987
10	gf	2x1.5mm2	27	685

11	gf&ff	2x1.5mm2	37	879
12	gf &ff	2x1.5mm2	49	980
13	gf&ff	2x1.5mm2	32	788
14	gf&ff	2x1.5mm2	34	930
15	gf&ff	2x1.5mm2	15	560
16	gf&ff	2x1.5mm2	21	742
17	gf &ff	2x1.5mm2	48	986
18	gf &ff	2x1.5mm2	41	897
19	gf&ff	2x1.5mm2	30	770
20	gf	2x1.5mm2	22	674
21	gf &ff	2x1.5mm2	30	940
22	gf&ff	2x1.5mm2	25	650
23	gf&ff	2x1.5mm2	37	890
24	gf	2x1.5mm2	20	620
25	gf&ff	2x1.5mm2	32	870
26	gf&ff	2x1.5mm2	28	691
27	gf &ff	2x1.5mm2	55	990
28	gf &ff	2x1.5mm2	35	800
29	gf&ff	2x1.5mm2	36	790
30	gf&ff	2x1.5mm^2	17	600

gf = ground floor; ff= first floor

Furthermore, data for power points obtained from the measurement of the selected electrical drawings are shown in Table 4.

Table 4: Measured quantities of selected electrical items for power points in surveyed residential buildings

Project ID	**Floor ID**	**Cable size**	**Number of Power points**	**Cable quantity(m)**
1	gf &ff	2x2.5mm^2	47	963
2	gf &ff	2x2.5mm^2	45	900
3	gf &ff	2x2.5mm^2	30	768
4	gf	2x2.5mm2	32	811
5	gf&ff	2x2.5mm2	25	679
6	gf&ff	2x2.5mm2	49	973
7	gf&ff	2x2.5mm2	49	973
8	gf &ff	2x2.5mm2	75	1440
9	gf &ff	2x2.5mm2	35	880
10	gf	2x2.5mm2	60	1122
11	gf&ff	2x2.5mm2	50	984
12	gf &ff	2x2.5mm2	50	990
13	gf&ff	2x2.5mm2	33	798
14	gf&ff	2x2.5mm2	49	980
15	gf&ff	2x2.5mm2	52	1006
16	gf&ff	2x2.5mm2	38	892
17	gf &ff	2x2.5mm2	28	765
18	gf &ff	2x2.5mm2	64	1180
19	gf&ff	2x2.5mm2	39	895
20	gf	2x2.5mm2	30	800
21	gf &ff	2x2.5mm2	45	905
22	gf&ff	2x2.5mm2	40	875

23	gf&ff	2x2.5mm2	37	894
24	gf	2x2.5mm2	77	1550
25	gf&ff	2x2.5mm2	20	568
26	gf&ff	2x2.5mm2	33	832
27	gf &ff	2x2.5mm2	79	1500
28	gf &ff	2x2.5mm2	31	782
29	gf&ff	2x2.5mm2	20	641
30	gf&ff	2x2.5mm^2	18	549

A. Power Points

Table 5: Descriptive statistics of power points and power cables

	N	Minimum	Maximum	Mean		Std. Deviation
					Std. Error	Statistic
Power Points	30	18.00	79.00	42.6667	2.97473	16.29329
Power Cable	30	549.00	1550.0	929.83	43.6225	238.930

Table 6: Table of coefficients of the model for power points and power cables

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	317.237	25.693		12.347	.000
Power Points	14.358	.564	.979	25.468	.000

From Table6, the model showing the relationship between the power cable quantity and corresponding number of power points is thus generated as follows:

$$\text{Power cable qty} = \alpha + \beta\,(\text{number of socket outlets}) \quad (3)$$

Where α and β are constants that are gotten from the Table of coefficients.

Model (1) can thus be fitted as:

Power cable quantity = 317.237 + 14.358 SO_{qty} (4)

Where: SO_{qty}= number of socket outlets

Table 7: Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.979	.959	.957	49.46511

Table 7shows that the coefficient of correlation R = 0.979and the coefficient of Determination (R Square) = 95.9%. These imply a very high relationship between number of socket outlets and length of power cables and that only 4.1% (1-0.959) of change in the number of socket outlets is not explained by change in length of power cables. Thus, the predicted equation 7 can be considered statistically significant.

Table 8: ANOVA result of model adequacy of power points

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	1587035.839	1	1587035.839	648.618	.000
	Residual	68510.327	28	2446.797		
	Total	1655546.167	29			

The ANOVA Table above was used to test the model adequacy, and a significant value 0.000 shows that the model is adequate, and can be used to generate a reliable quantity of power cables.

B. Lighting Points

Table 9: Descriptive statistics of lighting points and lighting cables quantities

	N	Minimum	Maximum	Mean		Std. Deviation
					Std. Error	
Lighting points	30	15.00	60.00	35.1333	2.12794	11.65520
Lightning cable	30	560.00	1413.00	838.800	31.6582	173.3993

Table 10: Coefficients of the model of lighting points and lighting cables quantities

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	363.867	43.390		8.386	.000
	Lighting points	13.518	1.174	.909	11.513	.000

From Table 10, the model showing the relationship between lighting cable quantity and corresponding number of lighting points is expressed as follows:

$$\text{Lighting cable qty} = \alpha + \beta\,(\text{no.of lighting points}) \qquad (5)$$

Where α and β are constants that are gotten from the Table of coefficients.

Model (2) can be fitted as:

Lighting cable quantity = 363.867 + 13.518 LP_{qty} (6)

Where: LP_{qty}= number of lighting points

Table 11: Coefficients of the model for lighting points and lighting cables quantities

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
2	.909	.826	.819	73.69501

Table 11 indicates that the coefficient of correlation R = 0.909 and the coefficient of Determination (R Square) = 82.6%. These imply a very high relationship between number of lighting points and length of lighting cables and that only 17.4% (1-0.826) of change in the number of lighting points is not explained by change in length of lighting cables. Hence, the predicted equation 6 is statistically significant.

Table 12: ANOVA result for model adequacy of lighting points

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	719886.080	1	719886.080	132.552	.000[b]
	Residual	152066.720	28	5430.954		
	Total	871952.800	29			

The ANOVA Table (Table 12) above was used to test the model adequacy, and a significant value 0.000 shows that the model is adequate, and can be used to generate a reliable quantity of lighting cables.

V. SUMMARY, CONCLUSION AND RECOMMENDATIONS

This study developed two time saving models for estimating cable quantities in residential buildings construction in Nigeria using a linear regression technique. These models attempts to contribute to existing bodies of knowledge on approximate quantification in the discipline of quantity surveying by proving that strong positive statistical relationships actually exist between lighting points/socket outlets and length of lighting and power cables. The models used data from taking-off/measurement of thirty architectural and electrical drawings, collected from registered architects and electrical engineers.

These models will undoubtedly prove useful to quantity surveyors and other construction cost professionals, especially in its simplicity and ability to handled using the calculator or a simple computer program. It has a good benefit in estimating the cable cost at early stages of the residential building projects since the information needed could be gotten at the sketch design.

It should however be borne in mind that to determine the quantity of the cables, the quantity surveyor or user of the model should;

- First determine the number of points in each cable (for lighting and power points)
- Then put in the number of lighting points/socket outlets in the model for lighting points/power points to determine the quantity of cables needed.

The accuracy or efficacy of the generated models relies heavily on accurate determination of the number of lighting points and socket outlets. In view of this, the study recommends that quantity surveyors who intend generate reliable approximate quantities, material schedules and beat tight tender deadlines must not only employ the model, they should also exercise care and be judicious in taking off(measurement) of lighting and socket points quantities of light from the relevant drawings.

VI. ACKNOWLEDGMENT

This study was carried out by the authors independently to demonstrate their skills as researchers in Quantity surveying. This study was done on a self-supporting basis.

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