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Statistical Modeling of the Service Life of External Paint Finish in Public Residential Buildings in Savannah Climatic Design Zone of Nigeria

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***Abstract*:** The performance of building materials used for exterior finish cannot be ascertained precisely through simulation or laboratory experiments, however, it requires that the materials are applied on substrates and placed under natural environmental condition to experience the actual changes possible over a period of time. However, universal usage of paint for walls in public and private buildings for decorative and protective functions remains the most aesthetic expression in Nigeria. The planning of maintenance works is based on predictions of the time when the critical elements of the built assets will reach degradation levels that exceed acceptable values. This paper employed the use of statistical model in determining the service life of external paint finish in Wuse Housing Estate, Abuja which falls under savannah climatic zone for architectural design in Nigeria and developing a guide for maintenance planning of external paint finish. The study is a survey research type conducted in the Government Residential Estate that use paint as external finish in Abuja. The total number of buildings in the study area is 1,000 and a sample size of 114 buildings was used. Data was collected through structured questionnaires. Findings revealed that the average service year for the external paint finish in savannah climatic zone in Nigeria is 2 to 5 years. These findings also contradicted the established lifespan of paint in the temperate region put between 5 and10 years.

***Keywords*:** Degradation, service life, external paint, savannah zone, maintenance, building component

1.0 Introduction

Building materials, especially those used in the building envelope, are exposed to physical, mechanical, chemical, biological weathering and other factors acting in combination, or at the same time. The principal climatic elements that affect the external finishes are rainfall, solar radiation, wind and moisture which lead to rapid deterioration and ultimately reduce the life span of the finishes, especially in the tropics, necessitating frequent maintenance and have impeded the performance of these materials. The degradation of the exterior surfaces of buildings is one of the major concerns of building owners and maintenance managers since in most cases maintenance actions are often based on the outward appearance of the buildings (Balaras, Droutsa, Dascalaki, and Kontoyiannidis, 2005). This has culminated into spending a lot of money on such maintenance activities.

Current global reality about climate change is exerting a negative influence on the built environment but since buildings cannot be divorced from the environment, the effect of climate change is indeed obvious on the external surface of buildings. A growing demand has been the provision of suitable quantitative tools to predict the occurrences of defects and the ensuing damage to the external finishes. The prediction of service life of external finishes is therefore the cornerstone of any such quantitative tool as it helps to establish the planning horizon over which the various costs, that arise during the intended lifetime of the finishes, are incurred (Teo, Chew and Harikrishna, 2005) and since the degradation of exterior finishes is dictated by material selection criteria, method of application and environmental factors. The paper identifies the different nature and influence of these factors and particularly their degradation on the external paint finish and comes up with a maintenance guide arising from the service life studies of the paint used as external building finish.

2.0 Service Life Studies and Degradation of Building Components

The durability of constructions is essential to the quality of everyone's life and is a critical component of the social and economic stability of contemporary societies (Wekesa, Steyn and Otieno, 2010). In general, an attitude of "build and let decay" is adopted in construction and this result to the loss of building's performance. Marie (2013) summarises a building's life cycle into three phases: design, construction and operation or service, which represents 95% of the life time of a building. Rikey and Cotgrave (2005) further report that the process of building decay starts as soon as they are built. ISO 15686-1 (2000) defines durability as the capability of a building or its parts to perform above a required critical limit over a specified period of time, for a set of in-use conditions deemed to apply in terms of materials, design, indoor and outdoor environment, use and maintenance

Data on building material durability can be obtained through accelerated ageing laboratory tests which follow an analytical methodology, in which the full complexity of natural ageing phenomena is subdivided into degradation agents that are individually studied to a high level of accuracy. However, the processes are generally complex, time and resource-consuming that provides results that are not easily transposed to real life in-use situations. Other techniques are statistical, accelerated or non-accelerated techniques to simulate the deterioration processes.

The performance of building materials used for exterior finish cannot be ascertained precisely through simulation or laboratory experiments. It requires that the materials are applied on substrates and placed under natural environmental condition to experience the actual changes possible over a period of time. The best alternative is to assess the changes through users who have lived with the changes over a long period of time. A good number of such users may not even take notice of the situation until questions are posed to them. The survey method that gathers data from such people that is used for this research is the best alternative (Morcillo, 1999; de la Fuente, 2006 and Yang Wang and JU, 2012).

Service life, as defined in accordance with ISO 15686, is the period of time after construction during which buildings and their materials equal or exceed the minimum performance requirements. Service life is defined as the period during which an element is in 'service' and fulfils all necessary performance requirements (Sarja and Vesikari, 1996). A service life prediction method involves an understanding of the deterioration pattern. According to Clifton (1993), such prediction methods can be classified into estimations based on experience; deductions from performance of similar materials; accelerated or non-accelerated testing; modelling based on deterioration processes; deductions from performance of similar materials; and application of stochastic concepts.

2.1 Methods of Estimating Service Life of Building Finishes

Predicting the service life of a building or its components can be a complex and time-consuming process especially in respect of the quality of material, the level of design and execution, the interior and exterior environmental conditions, the in-use conditions and the maintenance level (Hovde, 2004; ISO 15686-1:200). In the last few years, many international codes and regulations have been published in order to establish methodologies that allow the evaluation of the durability of and their service life prediction.

Durability data can be obtained on buildings through accelerated ageing laboratory tests or field work assessment of existing buildings and structures (Gasper and Brito, 2008). Laboratory testing follows an analytical methodology in which the full complexity of natural ageing phenomena is subdivided into degradation agents that are individually studied to a high level of accuracy. Such research processes are generally complex, time- and resource-consuming, and they provide results that are not easily transposed to real life in-use situations. Such tests therefore, lead to high costs (Shohet, Rosenfeld, Puterman and Gilboa 1999). However, field work assessment of existing buildings and structures depends on the atmospheric conditions at the time of the inspection, e.g. the difficulty of detecting anomalies in smooth and dark claddings when sunshine is hitting the buildings directly. Even though the method is easily grasped, visual inspections, nonetheless, have some limitations, since their accuracy depend significantly on the experience/ background and classification criteria of the surveyor. A straightforward visual inspection is enough to evaluate the degradation state of a building or its elements, and it is sufficient for the surveyor to collect, in situ, the data on the anomaly type, its intensity and extension.

There are several methods of assessing the degradation state of buildings and their components and these vary in accordance with the importance rating of the construction elements, the rating of the anomalies and the definition of the condition parameters associated with the anomalies. A number of authors have established classification systems for defects and degradation ratings in order to express the physical and functional degradation of the elements under analysis (Roy, Thye and Northwood, 1996; Shohet, Rosenfeld, Puterman and Gilboa, 1999; Shohet, Puterman and Bilboa, 2002, 2003; Teo, Chew and Harikrishna, 2005; Balaras, Droutsa, Dascalaki and Kontoyiannidis, 2005; Teo and Harikrishna, 2006). Most classification systems consist of rating the anomalies according to a scale of discrete variables that vary from the most favourable condition level (no visible degradation) to the least favourable one (extensive degradation or loss of functionality).

William and Feist (1993), NAHB (2000); ASTM (2005); Bliss (2006) carried out various researches in United States of America and put the life span of paint used as external building finish between 5 and 7 years. Gaspar (2009); Chai, Brito and Silva (2015) researched into the lifespan of paint used as external finish in buildings in Portugal and the output of the study revealed 7 to10 years. Roy, Thye and North wood (1996) found that the lifespan of paint used as external finish in Singapore was 5 to 7 years in Singapore in line with Branz (2007) findings too in New Zealand.

3.0 Study Area

The study area for this study is Federal Capital Development Authority (FCDA) Housing Estate, Abuja. FCDA Housing Estate is one of the earlier public residential buildings that were constructed in Abuja, Nigeria. It occupies a total land area of 800 square kilometres. It is bounded by Kaduna State in the North, South-west by Kogi State, on the West by Niger State and in the East and South-east by Nassarawa State. Abuja experiences three weather conditions annually. These include a warm, humid rainy and an extremely hot dry seasons. In between these seasons, there is a short period of harmattan accompanied by the North-East trade wind, with the main feature of dust haze, intensified coldness and dryness.

The rainy season begins from April and ends in October of each year when daytime temperature ranges between 28 and30°C and night time ranges between 22 and 23°C. In the dry season, daytime temperatures do soar to 40°C and night time temperatures do drop to 12°C, resulting in chilly evenings. Even the chilliest nights can be followed by daytime temperatures well above 30°C. The high altitudes and rolling terrain of the FCT act as moderating influence on the weather of the territory. Rainfall in the FCT reflects the territory's location on the windward side of the Jos Plateau and the zone of rising air masses. The annual total rainfall ranges between 1100 mm and 1600 mm.

4.0 Research Methodology

The study is a survey research type conducted in the government residential estate that use paint as external finish in Abuja under savannah climatic zone for architectural design in Nigeria. The sampling frame for the study comprised of heads of households and the paint manufacturing companies. Stratified random sampling technique was adopted for the study because of the different types of housing units that were within the housing estate. The estate was stratified based on the number of building typologies that were present. Each sub-stratum was then randomly sampled and grouped into households. The heads of households were the basic focus of questionnaire administration. The research population was 962 and a sample size of 120 was obtained using sample size calculator. The structured questionnaire dwelt on the characteristics of buildings that cause external paint degradation. The extent of defect shown on the surface was the dependent variable while the independent variables included building age, façade orientation, building layout, road proximity, nearness to water body, proximity to vegetation, proximity to industrial facilities, closeness of other buildings, wind effect, rain effect, surface preparation of the painted surface, paint type, colour of paint applied, type of paint applied, number of storey height and portion of the defect. Each question addressed a research variable in this study

Out of the 110 questionnaires administered, 96, which accounted for 87% success rate were returned. However, only 84 questionnaires were found suitable for statistical analysis for the study. The questionnaire for the paint manufacturing industries were effectively administered on 5 different manufacturers to know the lifespan of their products in other to validate the result of the study.

5.0 Data Analysis, Findings and Discussions

The variables that caused degradation of external paint finish were characterised as age of building, layout of building, distance of building from the road, distance of building from the water body, distance of building to the forest/vegetation, level of exposure of building to wetness/dampnessIs, building near any industrial facility, how many sides is a building surrounded by other residential blocks, effect of wind action, effect of rain action, description of surface after the paint had been applied, type of paint used, description of the colour of paint after it had been applied, how was the paint applied, number of storeys, the extent of defect(s) shown on the external surface of the building and the portion of the external surface where the defect is shown.

Ordinal Regression Analysis was carried out to estimate the factors responsible for the extent of defects of external paint finish. Accordingly, model fitting information and pseudo R^2 were generated as shown in Table 2. The dependent variable which measures the extent of defect of external paint finish is DEFECT_EXTENT. DEFECT_EXTENT which is equal 1 if the respondent perceives the extent of the defects as no visible defects, 2 as few signs of defects, 3 as general defects and 4 as severe defects. Since dependent/outcome variable is ordinal and building characteristics (independent/predictors) are ordinal/nominal variables, the ordinal regression model was used to estimate the building characteristics that are responsible for the extent of defects of external paint finish. A total of sixteen predictor variables were fed into the model.

Table 2 shows the regression coefficients of the building characteristics responsible for the extent of defects of external paint finish. The coefficients are based on scale model, which depends on the main and interaction effects. The table reveals that all the selected building characteristics of age of building (coef=.197, $\rho = 0.000 < 0.05$), façade (coef = -.635, $\rho = 0.001 < 0.05$), layout (coef = 1.855, $\rho = 0.012 < 0.05$), wind effect (coef = -.200, $\rho = 0.001 < 0.05$), rain effect (coef = 4.355, $\rho = 0.005 < 0.05$), surface after repaint (coef = -.497, $\rho = 0.000 < 0.05$), type of paint (coef = .173, $\rho = 0.049 < 0.05$, colour of paint (coef = 1.354, $\rho = 0.005 < 0.05$) and paint application (coef = 1.485, $\rho = 0.033 < 0.05$) significantly predicted the extent of defect of external paint finish. However, distance to road (coef = -.372, $\rho = 0.093 > 0.05$), distance to river (coef = .505, $\rho = 0.142 > 0.05$), distance to vegetation (coef = -1.016, $\rho = 0.184 > 0.05$), distance to industry (coef = 0.201, p = 0.359 > 0.05), surrounded by other buildings (coef = .321, $\rho = 0.621 > 0.05$), number of storeys (coef = -.760, $\rho = 0.507 > 0.05$) and portion of defect (coef = .234, $\rho = 0.073 > 0.05$) did not have significant prediction on the extent of defect of external paint finish.

Table 2: Summary of Ordinal Regression Analysis Showing the Effects of Building Characteristics on External Paint Degradation

Variables	Coef.	Z	ρ
Age	.197	0.46	0.000
Façade	-.635	-0.97	0.003
Layout	1.855	0.66	0.012
Distance to road	-.372	-0.60	0.093
Distance to river	.505	1.36	0.142
Distance to vegetation	-1.016	-2.15	0.184
Distance of industry	0.201	0.46	0.359
Surrounded by buildings	.321	0.49	0.621
Wind effect	-.200	-0.28	0.001
Rain effect	4.355	3.20	0.005
Surface after repaint	-.497	-0.49	0.000
Type of paint used	.173	0.16	0.049
Colour of paint	1.354	1.78	0.005
Paint application	1.485	1.58	0.033
Number of storeys	-.760	-1.96	0.507
Portion of defect	.234	0.30	0.073

[The result $\rho = 0.0000 < .05$], Pseudo $R^2 = .6004$ implied that 60% of the variance in the degradation of external paint finish is accounted for by the selected independent variables of age of building, façade, layout, wind effect, rain effect, surface after repaint, type of paint, colour of paint, paint application and portion of defect.

The step-by-step (Stepwise) method used to define the explanatory variables. In this method, the basic regression assumptions were revised and the variables that were not significant or explanatory of the dependent variables were excluded. According to Leung, Tam, Liu (2001) the multicollinearity effects were also eliminated. Multiple linear regression allows identifying the characteristics that influence the durability of paintings and also establishes a hierarchical distinction between the different characteristics, evaluating which variables are more relevant to the degradation of painted surfaces. The model presents a very strong correlation between variables, deemed appropriate to model the durability of painted surfaces.

Eight independent explanatory variables analysed using this model were façade, distance to river, effect of wind, effect of rain, type of paint used, colour of paint, paint application and portion of external surface where defect is visible as shown in Table 3. SPSS (Statistical Package for Social Science, version 16) was used to run the analysis.

The result which is statistically significant at 0.05 (95%) confidence interval indicates that as the ratings of the building characteristics increase, the extent of defects of external paint finish increases. Table 3 reveals that building characteristics of wind effect, colour of paint, age of building, rain effect, distance to river, façade, paint application, type of paint and portion of defect had significant prediction on external paint degradation in the selected locations

Table 3: Summary of regression analysis showing the effects of defect factors on external paint degradation

Variables	**Coef.**	**Z**	ρ
Façade	**-.635**	**-0.97**	**0.003**
Layout	**1.855**	**0.66**	**0.012**
Wind effect	**-.200**	**-0.28**	**0.001**
Rain effect	**4.355**	**3.20**	**0.005**
Surface after repaint	**-.497**	**-0.49**	**0.000**
Type of paint used	**.173**	**0.16**	**0.049**
Colour of paint	**1.354**	**1.78**	**0.005**
Paint application	**1.485**	**1.58**	**0.033**
Portion of defect	**.234**	**0.30**	**0.073**

Table 4 shows the residual statistics of the multiple linear regression for the predicted service life in FCDA Housing Estate at Wuse, Abuja in Savannah climatic zone for architectural design in Nigeria while Table 5 provides the summary of the statistical indicators for the reference service life estimated, which includes a maximum value, a minimum value, a range and a standard deviation of the reference service life for the Savannah climatic zone of Nigeria. The estimated reference service life (5 years) is given by this model. The minimum reference service life is 2 years, while the maximum service reference life is 5 years.

Table 4: Residuals Statistics of the Multiple Linear Regression for the Predicted Service Life in FCDA Housing Estate Wuze, Abuja (Savannah Zone)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.87	4.76	3.47	.907	84
Residual	-3.312	1.437	-.087	1.069	84
Standard Predicted Value	--1.971	2.112	.000	1.000	84
Standard Residual	-2.863	1.929	-069	.977	84

Table 5: Summary of the Statistical Indicators for the Reference Service Life Estimated Using the Proposed Multiple Linear Regression Model in FCDA Housing Estate Wuze, Abuja (Savannah Zone)

Statistical Indicator	Values(Years)
Average of the reference life	3.47
Maximum reference service life	4.76
Minimum reference service life	1.87
Range of reference service lives	2.89
Standard deviation of the reference service life	.907
Variance of the reference service life	1.0

5.1 Maintenance Guide for Paints in Savannah Region

The cost differential rate or consumer price index (CPI) in Nigeria is calculated monthly by the National Bureau of Statistics, based on the consumption habits of Nigerian households (based on monthly expenditure on food, housing, education, health, transport, and so on). In this study, a discounted rate of 12% is adopted for the cost differential rate (an average computed by the CBN between 1980 and 2015 is 11.38%). The difference between CPI of one month in a preceding year over the CPI of the same month in the current year is known as inflation rate. Based on this, the average inflation rate computed between 2001 and 2005 was 0.27, between 2006 and 2010 was 0.52 and between 2011 and 2015 was 1.03 from the information supplied by Nigeria Historical inflation rate for period 2006 to 2017. This implies that the inflation rate doubles every 5 years. Therefore, for this study, the inflation rate between 2010 and 2015 was used as the basis to project the inflation rate for the next 20 years.

Paint, in most cases in Nigeria, is applied on rendered surfaces hence its removal may aggravate their degradation. Due to this, repair of the renderings needs to be well thought-out every time paint is removed. In the maintenance plan being considered, it is expected that rendering is in perpetuity.

Present-value cost of the maintenance plan over a period of 20 years is thus determined as maintenance every 5 years in accordance with the results in terms of the paint estimated service-life for quality paint. The repair and maintenance costs presented in Table 6 for quality paint were calculated with the help of a Quantity Surveyor in accordance with Nigerian reality.

Table 6: Cost of the Maintenance Works

Periodicity (Years)	Maintenance Actions	Cost in year 0 (N/m^2)	Current cost (N/ m^2)	Present Value cost (N/m^2)
5	Material (Paint)	900.00		
	Scaffolding	78.28	1369.63	777.11
	Labour	117.42		
	Profit and Overhead (25%)	273.93		
10	Material (Paint)	900.00		
	Scaffolding	78.28	2534.38	815.99
	Labour	117.42		
	Profit and Overhead (25%)	273.93		
15	Material (Paint)	900.00		
	Scaffolding	78.28	4623.84	895.23
	Labour	117.42		
	Profit and Overhead (25%)	273.93		
20	Cleaning and Repair	58.70		
	Material (Paint)	900.00		
	Scaffolding	117.42	10.395.67	1114.54
	Labour	273.93		
	Profit and Overhead (25%)	337.51		

6.0 Conclusion

The estimation of the service life of external paint finish for the savannah climatic zone for architectural design in Nigeria presented in this study is based on the field appraisal of the anomalies, rate of degradation, quantification and transportation of the results into statistical model. In the analysis of the degradation factors, the most influential factors were age of building, facade, layout, distance to road, distance to river, distance to vegetation, distance to industry, number of surrounded building, rain defect, wind effect, surface after repaint, type of paint used, colour of paint, paint application, number of storeys, and portion of defect. These data make it possible to conclude that, given similar circumstances to those of the sample analysed, the average service life of external paint coatings in the savannah climatic zone of Nigeria is 5 years given by this model. The minimum reference service life is 2 years while the maximum reference service life is 5 years. These findings also contradict and are more frequent than established lifespan of paint in the temperate region based on earlier studies by Roy, Thye and North wood (1996).; NAHB (2000); Bliss (2006); Chai, Brito, Gasper, and Silva (2015) which put same between 5 and 10 years where all elements of climate are in action.

The service-life prediction method can therefore be of use to the stakeholders in the building industry. Since maintenance has substantial economic repercussions on the lifecycle of constructions, an accurate knowledge of the expected service-life of a building's components is necessary. This process allows for more valuable maintenance strategies to be devised since the works can be better planned, and unnecessary expenditure can be avoided.

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