Environmental Technology & Science Journal
Vol. 9 No. 2 December 201

Evaluation of the service life of external paint finish in Public Residential Buildings in coastal climatic zone of Nigeria

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Building facades are the most noticeable element of buildings and are directly associated to the quality of urban environment hence prone to the effects of climatic conditions. In Nigeria, the aesthetic appeal and the structural value of buildings easily depreciate, yet, paintusage for wallsin public and private buildings for decorative and protective functions remains the most aesthetic expression. The planning of maintenance works therefore is based on the information about the service life of building materials and components required. This paper assesses the degradation of external paint finish in some public residential buildings in coastal climatic zones of Nigeria with a view to predicting the service life 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 Lagos which fall under coastal climatic zone for architectural design in Nigeria. The total number of buildings in the study area was 962 and a sample size of 120buildings was used. The data used was collected through structured questionnaires and visual survey. The prediction of the paint coating service life was developed through regressionanalysis and findings revealed that the average service life for the external paint finish in coastal climaticdesign zone of Nigeriais 2-5 years contrary to the established research findings in different climatic zones different from Nigeria that stipulate 5-10 years.

Keywords: Building façade, coastal zone, degradation, external paint, service life,

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 even all 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. Therefore, 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 (i.e. building aesthetics) (Balarasetal, 2005). This has culminated into spending a lot of money for such maintenance activities.

Current global reality about climate change is exerting a negative influence on the built environment and 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 *et al.*, 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.

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 *et al*., 2010). 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.

Durability data can be obtained through accelerated ageing laboratory tests which 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 (Gasper & Brito, 2008). However, the processes are generally complex, time and resource-consuming and provide 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 information or data from such people that is used for this research is the best alternative (Morcillo, 1999; de la Fuente, 2006.; Yang *et al*., 2012).

Service life is defined in accordance with ISO 15686-1 (2000), as 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 & Vesikari, 1996). Any service life prediction method involves an understanding of the deterioration pattern. Such prediction methods can be classified into the following approaches (Clifton, 1993):

i. estimations based on experience;
ii. deductions from performance of similar materials;
iii. accelerated or non-accelerated testing;
iv. modelling based on deterioration processes; deductions from performance of similar materials; and
v. application of stochastic concepts.

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 with which a number of factors are associated, including the materials quality, the level of design and execution, the interior and exterior environmental conditions, the in-use conditions and the maintenance level (Hovde, 2004; ISO 15686-1:2000). 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 buildings and their service life prediction.

Such research processes are, therefore generally complex, time- and resource-consuming, and provide results that are not easily transposed to real life in-use situations; the tests therefore, lead to high costs (Shohet *et al*., 1999). However, field work assessment of existing buildings and structures depends on the atmospheric conditions at the time of the inspection. For example, 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 depends significantly on the experience/background and classification criteria of the surveyor. Straube (2003) argues that 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 (Straube, 2003). 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 *et al*., 1996; Shohet *et al*., 1999; Shohet *et al*., 2002, Shohet *et al.*, 2003; Teo *et al*., 2005; Balaras *et al*, 2005; Teo & 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). Various studies and findings carried out in the area of life span of paint used as external finish is as shown in table 1

Study Area

The study area for this study is Jakande Housing Estate, Isolo, Lagos. It was one of the first housing estate constructed in Lagos State, hence, had allowed for sufficient time for the external paint to have experienced the effect of climatic factors as regards degradation and exhibition of paint defects. Lagos State was created by the British in 1861 and covers an area of 3577 sq.km. with a population of 17 million. (Lagos State Government, 2011). The geographical location is between latitude 6°27′ and 6°45′ North of the Equator and on longitude 3°20′ and 3°39′ East of the Greenwich Meridian. It enjoys the equatorial type of climate and has two major seasons which are long raining and short dry seasons. The area (Lagos) enjoys abundant tropical rainfall, high humidity, sunshine, urban heat island from the Atlantic Ocean (Adepelumi *et al.*, 2009). The climate of Lagos is very demanding in its requirements of the performance and durability of all building materials, especially those used as external finishes because of its proximity to the Atlantic Ocean. These features enhance its choice for the research work as it represents a coastal climatic design zones of Nigeria.

Table 1: Previous researchers and findings on service life of external paint finish

S/N	Researchers	Location	Life Span
1	William and Feist (1993)	USA	5 – 7 years
2	Roy et al (1996)	Singapore	5 – 7 years
3	NAHB (2000)	USA	5 – 7 years
4.	ASTM (2005)	USA	5 – 7 years
5	Bliss (2006)	USA	5 – 7 years
6	Branz (2007)	New Zealand	5 – 7 years
8	Gasper (2009)	Portugal	9years
10	Gasper and Brito 2011, 2013	Portugal	10years
11	Chaiet al, 2015	Portugal	7 – 9 years

Research Methodology

The study is a survey research type conducted in the government residential estate that use paint as external finish in Lagos, which fall under coastal climatic zones for architectural design in Nigeria. The sampling frame for the study comprised the households and the paint manufacturing companies. Stratified random sampling technique, a sampling process that was suitable according to Boyd *et al*. (1989) was adopted for the study because of the different types of housing units that were within the three selected housing estates. Each of the estates 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 is 962 and a sample size of 120 was obtained using sample size calculator. The structured questionnaire welt 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, colour of paint applied, type of paint applied, number of storey height and portion of the defect. Each question addresses a research variable in this study.

Out of the 150 questionnaires administered, a total of 126 which represents 84% of the questionnaires recovered were retrieved and 119 were found suitable for statistical analysis for the study. This percentage was considered sufficient for the study based on the assertion of Moser and Kalton (1971) that the result of a survey could be considered as biased and of little significance if the return rate was lower than 30 – 40%. The data from the questionnaires returned form part of the basis for discussion in this study. The questionnaire for the paint manufacturing industries were administered on 5 different manufacturers to know the lifespan of their products.

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/dampness, nearness to industrial facility,sides ofthe building surrounded by other residential buildings, 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, method of paint application, 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* 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 wind effect, colour of paint, age of building, layout, rain effect, distance to river, façade, paint application, type of paint, surface after repaint, portion of defect and distance to vegetation significantly and jointly predicted the extent of defect of external paint finish. However, distance to road (coef = -0.817, ρ = 0.184 > 0.05), distance to industry (coef = -0.926, p = 0.359 > 0.05), being surrounded by other buildings (coef = -0.412, ρ = 0.625 > 0.05),) and number of storeys (coef = -0.400, ρ = 0.601 > 0.05) did not have significant independent prediction on the extent of defect of external paint finish.

The result ρ = 0.0000 < .05, Pseudo R^2 = .7998implied that 80% of the variance in the degradation of external paint finish is accounted for by the selected independent variables of age of building, façade, layout, distance to river, distance to vegetation, 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 *et al.* (2001), the multi-collinearity 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. The table 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 2: Summary of Ordinal Regression Analysis Showing the Effects of Building Characteristics on External Paint Degradation

Variables	Coef.	Z	ρ	Pseudo R^2	ρ
Age	**2.385**	**2.02**	**0.043**		
Façade	**1.219**	**3.02**	**0.003**		
Layout	**-0.223**	**-0.45**	**0.000**		
Distance to road	-0.817	-1.33	0.184		
Distance to river	**1.297**	**2.51**	**0.000**		
Distance to vegetation	**-0.439**	**-0.84**	**0.004**	.0.7988	**0.000**
Distance of industry	-0.926	-0.92	0.359		
Surrounded by buildings	-0.412	-0.49	0..625		
Wind effect	**3.075**	**4.68**	**0.000**		
Rain effect	**1.794**	**2.82**	**0.005**		
Surface after repaint	**0.531**	**0.92**	**0-036**		
Type of paint used	**-0.950**	**-2.70**	**0.007**		
Colour of paint	**3.013**	**3.28**	**0.001**		
Paint application	**0.782**	**2.61**	**0.009**		
Number of storeys	-0.400	-0.52	0.601		
Potion of defect	**-3.348**	**-7.54**	**0.000**		

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

Variables	Coef.	Z	P
Façade	1.219	3.02	0.003
Layout	-0.223	-0.45	0.000
Distance to road			
Distance to River	1.297	2.51	0.002
Distance to vegetation	-0.439	-0.84	0.004
Wind Effect	3.075	4.68	0.000
Rain Effect	1.794	2.82	0.005
Surface after repaint	0.531	0.92	0.036
Type of paint used	-0.950	-2.70	0.007
Colour of Paint used	3.013	3.28	0.001
Paint Application	0.782	2.61	0.009
Portion of Defect	-3.348	-7.54	0.000

Table 4 shows the residual statistics of the multiple linear regression for the predicted service life in Jakande Estate, Lagos in coastal climatic design zone of 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 coastal design 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 Statisticsof the multiple linear regression for the predicted service life in Jakande Estate, Lagos State (Coastal Zone)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	**1.95**	**5.03**	**4.69**	.656	119
Std. Predicted Value	-4.167	.515	.000	1.000	119
Standard Error of Predicted Value	.033	.279	.055	.041	119
Adjusted Predicted Value	1.91	5.03	4.69	.653	119
Residual	-1.411	.805	.000	.301	119
Std. Residual	-4.595	2.621	.000	.979	119
Stud. Residual	-4.760	2.778	.001	1.027	119
Deleted Residual	-5.514	.905	.000	.333	119
Stud. Deleted Residual	-5.300	2.866	-.006	1.087	119
Mahal. Distance	.389	96.552	4.958	12.162	119
Cook's Distance	.000	.302	.020	.057	119
Centered Leverage Value	.003	.818	.042	.103	119

Table 5: Summary of the statistical indicators for the reference service life estimated using the proposed multiple linear regression model in Jakande Estate, Lagos State (Coastal Zone)

Statistical Indicator	Values (Years)
Average of the reference life	4.69
Maximum reference service life	5.03
Minimum reference service life	1.95
Range of reference service lives	3.08
Standard deviation of the reference service life	.656
Variance of the reference service life	.8

Maintenance Guilde for Paints in Coastal Region

The cost differential rate or consumer price index (CPI) in Nigeria is calculated monthly by the National Burau 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 1980-2015 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 2001-2005 is 0.27, 2006-2010 is 0.52 and 2011-2015 is 1.03 from the information supplied by Nigeria Historical inflation rate 2006-2017. This implies that the inflation rate doubles at every 5 years. Therefore, for this study, the inflation rate between 2010-2015 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. Therefore, 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 (removed at the expiration of the life of the building).
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)	833.78		
	Scaffolding	72.52	1122.29	636.83
	Labour	108.78		
	Profit and Overhead	145.04		
10	Material (Paint)	833.78		
	Scaffolding	72.52	2311.92	744.37
	Labour	108.78		
	Profit and Overhead	145.04		
15	Material (Paint)	833.78		
	Scaffolding	72.52	4623.84	844.78
	Labour	108.78		
	Profit and Overhead	145.04		
20	Cleaning and Repair	54.39		
	Material (Paint)	833.78		
	Scaffolding	72.52	10.395.67	1077.72
	Labour	108.78		
	Profit and Overhead	192.14		

Conclusion

The estimation of the service life of external paint finish for the coastal climatic zones of 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 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 coastal climatic zones 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. However, the result is contrary to the findings of other researchers who had established the service life of paint in other countries of different climatic zones which varies between 5-10 years.

The service-life prediction method can therefore be of use to the stakeholders in the building industry, and 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, as it 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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