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DETERMINATION OF REFERENCE SERVICE LIFE FOR REINFORCED CONCRETE MULTISTOREY RESIDENTIAL BUILDINGS: CASE STUDY OF AKURE, NIGERIA

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Abstract
The Service life of a building is the period from commencement of service to the time just before costly maintenance becomes necessary for continued meeting of minimum performance requirements. Knowledge of service life determines whether to demolish and replace a building or major repairs are required and the absence of information on this has led to many building failures. This research therefore aimed to determine the Reference Service Life (RSL); a parameter required for the evaluation of a building's Service Life. Twenty reinforced concrete multistorey residential buildings around the Federal University of Technology Akure (Nigeria) were assessed via visual inspection, material testing, and structural analysis. Information obtained from the assessment was used to develop a comprehensive open-ended service life database. Non-destructive tests were conducted on the buildings' structural elements and the results used to determine the service life of each of the buildings with the aid of Life 365 Software. Weighted factors which depend on the quality characteristics, operational conditions and the environment of the buildings were used as a grading system for the assignment of sub-factors for the adjustment of the Life 365 service life values, leading to a value of 29 years as the Reference Service Life (RSL) for the study area. The result obtained will benefit construction professionals and appropriate regulatory authorities in the study area while the procedure can be adopted for service life assessment in other locations lacking appropriate database.

Keywords: Grading system, Multistorey building, Reference Service Life, Reinforced concrete, Residential buildings, Weighted factors.

1.0 INTRODUCTION
In the Nigerian building construction industry, one of the important challenges encountered include the absence of a database for the service life of buildings. Since the service lives of buildings are unknown, it is often difficult to reach decision on whether to recommend the demolition of a building and its replacement with a new one or the repairs of the existing building. Service Life (SL) of a building is the period during which it fulfils the required performance for defined repair and maintenance [1]. Researchers, designers and regulatory bodies find it difficult to access the Reference Service Life (RSL) of buildings in order to obtain the expected service life of the building. This informed the need for this research, which is to determine the RSL of reinforce concrete multistorey residential buildings. A multistorey building is a building with multiple suspended floors. Requisite databases are employed to obtain the required input data for the prediction of the Service Life (SL) of each single building component to be a valid tool for designers [2].

According to [3] the factor method is suitable for estimating the service life of an individual component or assembly in a specific set of conditions. The factor method is based on RSL which is defined as the expected service life of a component or assembly suitable under a well-defined set of conditions [4]. Types of service life include; (i) technical service life which is the period measured from commencement of service until a defined unacceptable state is reached, such as spalling of concrete, safety level below acceptable or failure of element, (ii) functional service life which is the time in service until the structure no longer fulfils the functional requirements or becomes out-dated due to change in functional requirements such as the need for increased clearance, higher axle, or road widening; and (iii) economic service life which is the time in service until replacement of the structure is economically more advantageous than keeping it in service.

The knowledge of reference service lives of building components is a requirement for the application of the factor method, a fact that informs the necessity to provide a database of reference service lives that can help the designer in obtaining the estimated service life in each context of the application. The standard proposal [5] gives guidance on the provision, selection, and formatting of reference service life data as well as the application of the data to obtain estimated service life using the factor method. Estimated service life (ESL) is the service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, calculated by adjusting the reference in-use conditions in terms of materials, design, environment, use, and maintenance [6].

The RSL is the elementary value for the application of the Factor Method, together with specific values of the individual factors included [7]. According to [5], RSL is the service life that a building or parts of a building is predicted to have in a certain set of in-use conditions. The reference in-use conditions are the in-use conditions for which the data are valid. The in-use conditions include any circumstance that can affect the performance of a building or a constructed asset or a part thereof under normal use. The information of the in-use condition will be qualitative and collective judgment will be applied within a factor category according to [8] which is called in-use condition grading. A research work on estimating the service life of public buildings under Kuwaiti weather using the factor method is presented in [9]. Data were collected for the assessment of the structural behaviour of twenty-six multi-storey buildings that belong to Kuwait University. The buildings were assessed by visual inspection, material testing, and structural analysis. However, the reference service life used in computing the service life in the work was the one proposed by service life authorities.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used for this research work were Schmidt rebound hammer tester, Profometer tester, and recording sheet. The software used were: AutoCAD, Prota-Structure, and Life 365 Service Life.

2.2 Experimental Procedure

1. Identification of target buildings (that is, reinforced concrete residential multi-storey buildings ranging from two to four storeys at FUTA South and North Gates Axes) of which twenty buildings were identified.

2. Visual Inspection of the buildings was done to document any deflection, exposed reinforcement or any other indicator of deterioration which were needed to provide more details about the buildings. A typical assessed building is shown in Figure 1.

Figure 1: Typical assessed building

3. Preparation of as-built drawings; simple architectural drawings were prepared using AutoCAD software as shown in Figure 2 to illustrate the space of the building and its utilization.

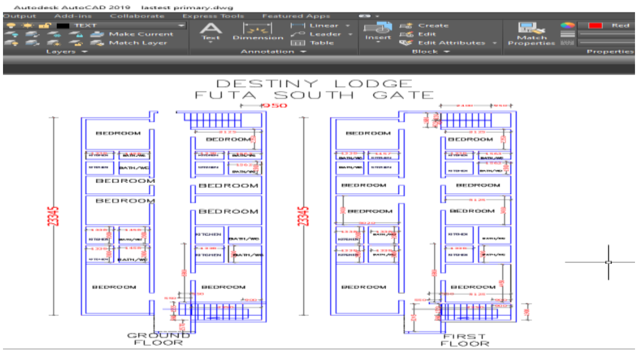

Figure 2: As-built plan view of a selected building using Auto-CAD software

4. Structural analysis and design; design information can be find on Table 1 which was generated according to [10].

Table 1: Design Information for Design of Twenty Buildings at FUTA North and South Gate

Purpose of use	Residential
Code	BS 8110 Part 1:1997
Design Stress	F_{cu}: 20N/mm^2 F_y: 410N/mm^2
Fire Resistance	One Hour
Concrete Cover	Slab & Beam: 20mm, Column: 25mm, Foundation: 50mm
General loading Conditions	Live Load: 1.5kN/m^2 Floor Finishes: 1.2kN/m^2 Wall and Rendering: 3.47kN/m^2 Roof (Live & Dead Load): 1.5kN/m^2

The structural analysis was done using Prota Structure software on each of the twenty buildings of which anticipated concrete dimensions and expected reinforcement were allocated in the structural drawings for the buildings. A screenshot of a sample analysis and design of a selected building using Prota-Structure is shown in Figure 3

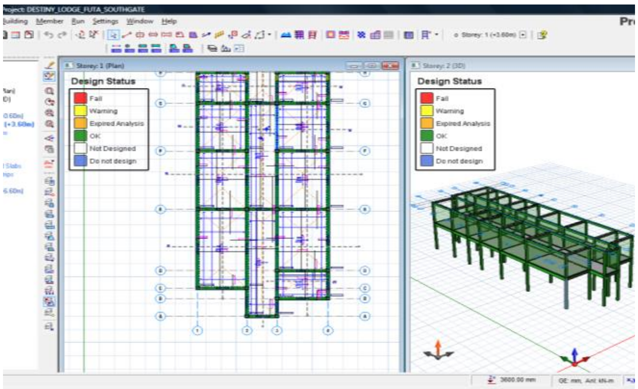

Figure 3: Analysis and design of a selected building using Prota-Structure

5. Non-destructive testing; this was carried out using the Schmidt Rebound Hammer and Profometer on the identified structural members of the buildings. The SRH test on the structural element (beam, column, slab, and stairs) was carried out as follows;

a. The test was carried out on the beams at three locations (Towards the ends of the beams (at both ends) and at the middle of the beams)
- Six readings were taken at each test point and the mean reading for each beam was determined and recorded for accuracy and reliability of the data. The rebound number was read off on the side of the hammer and the mean reading was determined and recorded.

b. The test was carried out on columns also at three locations (Towards the lower end, at the middle, and toward the upper end of the column).
- The tests were carried out similar to that of the beams.

c. For the slabs and stairs, the procedure for testing the above mention structural elements were followed.

The Profometer was used to determine the cover depth of structural elements which was used in the life-365 software as input data. Furthermore, the quality of workmanship and the level of design of the residential building were evaluated based on Profometer test result combined with the previously measured non-destructive tests (Schmidt rebound hammer). The test was carried out as follows;

i. For the beam and columns;
- Test was conducted on the elements at three locations just like in the Schmidt rebound hammer test.
- At each test location, the thickness of the concrete cover, the sizes, and the numbers of the reinforcement were determined.
- The mean value of the concrete cover was determined and recorded.

ii. For the slabs and stairs:
- Test was carried out on the elements at three locations
- At each test location, the thickness of the concrete cover, the sizes, and number as well as the spacing both in the x and y direction were determined.
- The mean of the concrete cover was determined and recorded while the spacing was used to identify the top and bottom reinforcement.

6. Determination of Reference Service Life (RSL) was based on the service life obtained from Life 365. The RSL is calculated using Equation (1) according to [11] and the Interface of life 365 service life software is shown in Figure 4.

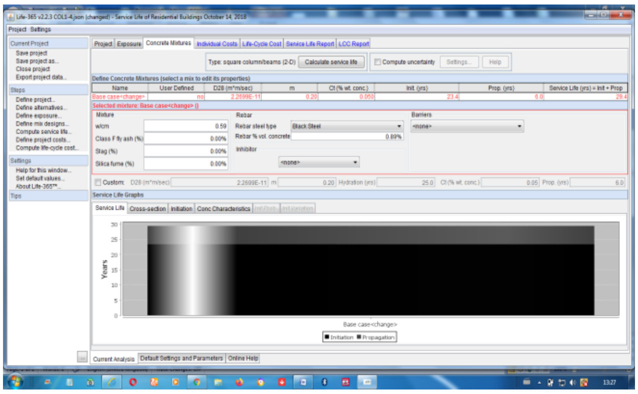

Figure 4: Interface of life 365 service life software

Reference Service Life (RSL):

$$RSL = \frac{Life\ 365\ predicted\ service\ life}{Adjusted\ factor} \quad (1)$$

Life 365 predicted service life is also known as the Estimated Service Life (ESL) which is expressed in Equation (2) obtained from [11]:

$$ESL = (RSL) * A * B * C * D * E * F * G \quad (2)$$

where: A, B, C, D, E, F, G are the various factors (sub-factors) whose product gives the adjusted factor of Equation (1).

The various factors have the following meanings:
A: Factor that depends on the quality of materials; B: Factor that depends on the quality of design; C: Factor related to the level of workmanship; D: Factor determined by the internal environmental conditions; E: Factor determined by the exterior environmental conditions; F: Factor that depends on the in-use conditions; G: Factor that depends on the level of maintenance.

The factors were assigned values in accordance with the procedure given in [12]. For this purpose, a Reference service life database (open ended) was created for all the buildings investigated. The database was employed in conjunction with Tables 2 and 3 of [12] to assign values to factors A to G. The database for two of the buildings is available as sample (see https://www.sldb.herokuapp.com). The product of factors A to G (Adjusted Factor) was used in Equation (1).

Tables 2 and 3 show the grading system recommended by [12] and provide a guide to measure the level at which parameters like crack, deflection, and corrosion were present in the structural members of each of the reinforced concrete multistorey residential buildings identified for this research. Table 2 provides a guide to measure the quality of each parameter; in the table, the column sub-titled, "Description" gives general information about the quality of the parameter. Table 3 provides a detail guide that explains the level or extent to which the parameter affects the structural component of the building as seen on the column titled, "Grading". It also provides a guide for converting the established qualitative parameters to quantities using the factor system.

This is thereafter used to obtain the sub-factors in table 5 so as to determine the RSL of the buildings. It also gives clarity in the measurement of parameters. For parameters like compressive strength, parameter intensity can be very high, high, low and extreme, while for cracks it can be very mild, mild, severe and very severe depending on the information obtained from visual inspection, non-destructive test result and structural analysis of the building.

Table 2: Recommended grading system

Factor	Description
0.8	The assessed parameters present a significant adverse effect on the lifetime of the materials or component
0.9	The parameters present an adverse effect on the lifetime of the material of component
1	The parameters present no effect on the lifetime of the material or component
1.1	The parameters present additional benefit to the lifetime of the material or component
1.2	The parameters present increased benefit to the lifetime of the material or component

Source: International Standard Organization 15686 (2000E) [12]

Parameter intensity (i.e., the level to which the parameter affects the structural component) was established from visual inspection of the building, non-destructive test carried out on the building structural component and structural analysis output of the building. The parameter intensity was taken from Table 3.

Parameter intensity is assessed as follows:
Compressive Strength: Concrete grade M15 (17-26MPa) was used as a benchmark in assigning grade for strength of structural members in the building, if less (1 and 2), if high (4 and 5) and if within range (3).
Crack: Plaster Crack; over 0-50% present (1-1.2), beyond plaster crack; 51% and above (0.9 and 0.8).
Corrosion: over 0-50% present (1-1.2), 51% and above (0.9 and 0.8).
Distress: over 0-50% present (1-1.2), 51% and above (0.9 and 0.8).

Table 3: Recommended factor system

Condition weighted rating	Factor	Rank, %	Grading
1	0.8	≤20	Very severe/extreme
2	0.9	≤40	Severe/Low
3	1	≤60	No effect (present or absent as the case maybe)
4	1.1	≤80	High/mild
5	1.2	≤100	Very high/very mild

Source: International Standard Organization 15686 (2000E) [12]

Finally, the various structural elements of each of the twenty investigated buildings were subjected to non-destructive tests with the use of Profometer. The instrument was used to obtain such quantities as the number, diameters and areas of steel reinforcement bars, structural concrete element dimensions, concrete cover sizes, and percentage volume of reinforcement. The values of the measured parameters (Table 4) were then fed into the Life 365 software to obtain the Life 365 predicted service life (see Equation (1)). Thereafter, Equation (1) was used to calculate the reference service life for each building and the average of the values was determined as the Reference Service Life (RSL) of the buildings in the study area.

3.0 RESULTS AND DISCUSSIONS

The Schmidt Rebound Hammer (SRH) Test results for the buildings identified at FUTA South and North Gate axes are presented in Figure 5 which is a graphical summary of the compressive strength obtained for each structural member of the multi-storey residential buildings using the rebound hammer with the conversion chart. This result was used in conjunction with the information obtained from the visual inspection carried out on each building to obtain a factor used to establish the RSL for the buildings [9].

The result obtained from the SRH for the structural members of the identified buildings represent the compressive strength of each structural member with the average used to assign grade for strength parameter of the building which is a sub factor in the factor system as prescribe by [9]. Concrete grade M15 (17-26Mpa was used to determine the intensity (i.e., the level to which the parameter affects the structural component) of the strength parameter of the building. According to the factor system building less than M15 represent an adverse effect on the lifetime of the building and a factor of 0.8 and 0.9 is assigned while building equal or greater than M15 represent a normal and additional effect on the lifetime of the building and a factor of 1, 1.1, and 1.2 are assigned to the quality characteristic which was grouped under factor A to C according to [9]. The Profometer test results are shown in Table 4. The information was inputted into life 365 software to determine the service life of each building.

The Proformeter test result obtained from the Profometer tester represent the structural information of the identified structural member. The information's are the diameter of the reinforcement, concrete cover, and numbers of reinforcement, area of reinforcement and percentage volume of reinforcement. These information was use to compare the information obtained from the structural analysis done using Prota structure design software. The quality characteristic (i.e. quality of component, design level and work experience level) was assign grade base on the parameter intensity of the sub factors in the factor system.

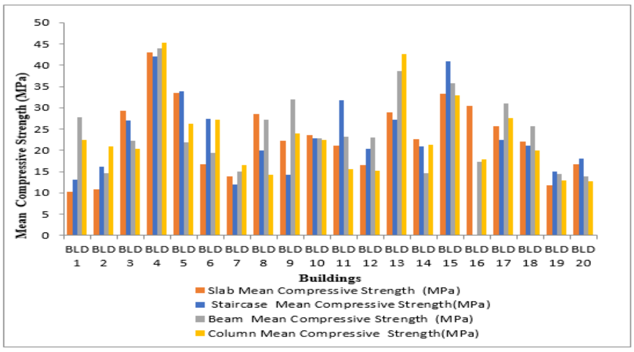

Figure 5: SRH test results for the identified buildings at FUTA South and North gate axes

The Reference service life database created is made available for two of the investigated buildings as sample (see https://www.sldb.herokuapp.com). This could be a very important tool for researchers, designers, service life authority if available to collect and exchange data to estimate the service life of buildings.

The service life results for the investigated twenty buildings are presented in Figure 6. It indicates the time during which each of the buildings will meet the required performance under defined repair and maintenance [13].

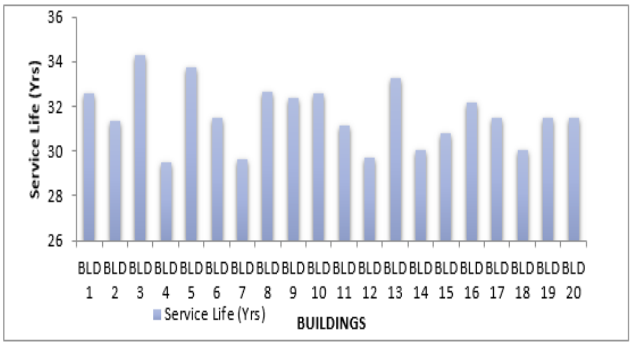

Figure 6: Service life obtain from Life 365 software for 20 multistorey residential buildings in Akure South Local Government Area

The degradation scale as shown in Table 3 was defined based on the defect type, severity, extension i.e., the length level of defect, intensity and effect of the defects detected as recommended in [12]. The field data were converted into a numerical indicator which allows quantifying the overall degradation of the sub-factors. The quantities of the overall degradation of the sub-factors are shown in Table 5. From the results in Table 5, the factors A to C are grouped under the quality characteristics which include; (A; quality of materials, B; quality of design, C; quality of workmanship), factors D &E are grouped under environment which include; (D; indoor environment, E; outdoor environment), factors F and G are grouped under operation conditions which include; (F; In-use conditions, G; maintenance level). The Adjusted factors (AF), which are the products of all the assigned quantitative data of the various factors A to G, were used to calculate the reference service life of each building which gave an average of 29 years.

Table 4: Profometer test results on structural elements of a sample building (Building serial No 17)

S/N	Structural Element Code	Reinf. No	B(mm)	D(mm)	H(mm)	Area of reinforcement (mm^2)	%Vol of Reinforcement	Diameter of Reinf.	Av. Cover (mm)	% Pass Rate
17	COL 1	4	300	300	3000	201.09	0.89	Y16	53.33	66.67
	COL 2	4	300	300	3000	201.09	0.89	Y16	45.67	26.11
	COL 3	4	300	300	3000	201.09	0.89	Y16	53.00	72.22
	COL 4	4	300	300	3000	201.09	0.89	Y16	47.00	86.67
	COL 5	4	300	300	3000	201.09	0.89	Y16	43.33	63.89
	COL 6	4	300	300	3000	201.09	0.89	Y16	59.00	48.33
	BM171	4	225	350	1325	201.09	1.02	Y16	26.00	0.00
	BM172	5	225	350	1325	201.09	1.28	Y16	31.00	25.00
	BM173	5	225	350	1325	201.09	1.28	Y16	58.00	80.00
	BM174	4	225	350	1325	201.09	1.02	Y16	60.00	25.00
	BM175	5	225	350	1325	201.09	1.28	Y16	61.00	25.00
	BM176	5	225	350	1325	201.09	1.28	Y16	48.00	80.00
	SB 171	20	1325	150	3805	113.11	1.14	Y12	42.00	100.00
	SB 172							Y12	38.00	80.00
	SB 173	20	1325	150	3805	113.11	1.14	Y12	46.00	100.00
	SB 174							Y12	48.00	100.00
	SB 175	20	1325	150	3805	113.11	1.14	Y12	43.00	80.00
	SB 176							Y12	44.00	66.67
	STR 171	31	2165	150	5425	113.11	1.08	Y12	38.50	70.83
	STR 172							Y12		
	STR 173	31	2165	150	5425	113.11	1.08	Y12	41.50	50.00
	STR 174							Y12		
	STR 175	31	2165	150	5425	113.11	1.08	Y12	41.67	65.56
	STR 176							Y12		
	STR 177							Y12		

Key: COL-Column; BM-Beam; SB-Slab; STR-Staircase; B-Breadth; D-Depth; H-Height; Y- High yield reinforcement steel bar; % pass rate represents the workmanship level indicating the level of internal arrangement of the structural element as obtained from the Profometer tester; S/N 17 denotes building No.17.

Table 5: Weighting values for the sub-factors with the Reference service life for each building

	Quality Characteristics			Environment		Operation Condition		Adjusted Factor (AF)	Life 365 predicted Service Life	Reference Service Life (years)
S/N	A	B	C	D	E	F	G	AF	SL	RSL
1	1	1.1	1	1	1.1	1	0.9	1.09	31.33	28.74
2	1	1	0.9	1.1	1.1	1	1	1.09	32.60	29.91
3	1.2	1	1	1.1	1.1	1	1	1.45	34.28	23.64
4	1	1	1	1.1	1	1	1	1.1	29.53	26.85
5	1	1	1	1.1	1	1	1.1	1.21	33.72	27.87
6	1	1	1	1	1	1	1	1	32.62	32.62
7	1	1	1	1	1	1	1	1	32.36	32.36
8	1	1	1	1.1	1	1	1	1.1	31.48	28.62
9	1	1.1	1	1.1	1	1	1	1.21	29.64	24.50
10	1	0.9	0.9	1	1.1	1	0.9	0.8	32.60	40.75
11	1	0.9	1	1.1	1.2	0.9	1	1.07	31.52	29.46
12	1	1	1	1.1	1.2	0.9	1	1.19	31.47	26.45
13	1	1	1	0.9	1.2	1	0.8	0.86	30.80	35.81
14	1	1	0.9	1.1	1.2	1	1	1.19	30.05	25.25
15	1	0.9	1	1.1	1.2	1	1	1.19	33.29	27.97
16	1	1	1	1.1	1.2	0.9	1	1.19	31.18	26.20
17	1	1	1	1.1	1.2	0.9	1	1.19	29.68	24.94
18	1	0.9	1	1.1	1.2	1	0.8	0.95	30.04	31.62
19	1	0.9	0.9	1.1	1.1	1.1	1	1.08	31.52	29.19
20	1	1	1	1.1	1	1	1.1	1.21	32.15	26.57
Average										28.97

The RSL of 29 years obtained indicates the time in service during which the buildings meet or exceed the minimum required performance under defined repair and maintenance until a defined unacceptable state is reached. At this stage the building is at optimum performance and building owners are likely to be more concerned with this stage (technical service life) as the cost and management time are likely to escalate as more maintenance issues arise beyond the technical service life of a building.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The following conclusions are drawn from the research; a Service Life database was created for the estimation of service life of reinforced concrete multistorey residential buildings in the study area by professionals, service life authority where available, and researchers. An average Reference Service Life (RSL) of 29 years was obtained, representing a basis value which must be multiplied by an appropriate adjusted factor in order to obtain the Service Life of any reinforced concrete multi-storey residential building located in the area of this study. The procedure employed in this research can be adopted for the evaluation of RSL in other locations where information on the parameter is absent.

4.2 Recommendations

From this study, it is recommended that;

i. The average reference service life obtained from this research should be used by Regulatory bodies like Council for the Regulation of Engineering in Nigeria (COREN) to estimate the service life of any reinforced concrete multi-storey residential building located within the area of study, by multiplying it with the adjusted factor which itself depends on quality characteristics, environment and operational conditions.

ii. The database created in this research should serve as a guide for the service life prediction of buildings in similar conditions.

iii. The RSL obtained with the service life data should be employed in deciding on the type and frequency of activities required to maintain, repair and replace building materials and system.

iv. The procedure employed in the determination of the RSL in this research for Southern Akure metropolis is recommended for adoption elsewhere for reinforced concrete multi-storey residential buildings.

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