A Simplified Framework for Condition Prediction of Building Components

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ABSTRACT ; *Infrastructural facilities represent a major part of any urban development and irrespective of their contribution to the social-economic life of the community; it is evident that most of these infrastructures are in a deteriorating state especially in the developing world like Nigeria. The art maintaining a building is very essential in order that the building is able to perform and function adequately and for a longer time even after its design life. The main input in this research which is also aimed at filling a gap in available literature is the development of a condition assessment system that incorporates both physical and maintenance cost condition which related to available work orders for the different components that make up building. It is estimated that most of the building facilities belonging to the government have exceeded about 70% of their service life and it is expedient to formulate a simplified frame work that would assist in prioritizing the maintenance of the critical components of the a building infrastructure. In this research reliable data are collected from facility experts through questionnaires in order to assign reliable condition index to the components adopting the USACERL method and also relative weights obtained through an analytical component hierarchy system (ACHS), where the components in the building are rated based on their total number of work orders. The proposed method was implemented and tested using data collected from facility experts employed as works officers in facility. A general condition of the building was put as 47% rating which compared favorably with a value of 42% predicted with the developed condition assessment framework which has to great extent validated the method as a potential model framework for assessment of building infrastructures.*

1.0 INTRODUCTION

Infrastructure plays a great role in urban development as they provide basic facilities, support services and shelter for the community or society. Despite the significance of infrastructure to the economic and cultural development of the society, there is growing concern over the deteriorating condition of existing infrastructure due to age, environmental factors, lack of funds for maintenance and mismanagement and as a result these infrastructures are not able to meet the rising demand due to population growth[1-4]. The required maintenance and repair cost for countries like the U.S.A. and Canada runs into over a trillion dollars [1],[5]**.** In this part of our world, specifically Nigeria in West Africa, a lot of emphasis is to developing new constructions without adequate renewal measures on existing facilities may be due to the huge cost involved when the facility is in the worst case of decay. It means that in the near feature the country would have more facilities than it can actually meet their maintenance cost. Hence it is pertinent to note that the resulting deteriorating condition of infrastructure would require a good asset management procedure that would track the level of deterioration of the elements in the infrastructure or the rate of deterioration of different infrastructure to determine when to allocate funds for repairs or rehabilitation of the building or an element in the building. There is a need develop a method to predict the condition of a building infrastructure towards effective deployment of funds for maintenance within the limited resources available to organizations and the government.A lot of public office (non-residential) buildings in Nigeria are deteriorating and would require attention. Most of the public office buildings that were built in the 1970s are now more than 40 years old and would require adequate asset management system in order last long and also satisfying its intended use and also the needs of the growing population. There are some researches made in this area which has led to a lot of asset management systems which includes assessing present condition of the building, projecting future deterioration, determining repair strategies, selection of building component to be repaired due to limited funds, etc. A good method for predicting the condition of a building would include a procedure for make prompt decisions on repair and maintenance of specific component of the building infrastructure which depends on the physical condition and the cost implication.

From literature, most of the contributions made in this area has not related physical condition to cost implication, hence this study intends to fill that gap by developing a model that incorporates the physical condition and the repair/maintenance cost to predict the condition of building infrastructure to facilitate organizations and government to make renewal/maintenance decisions. The main objective of this research is to develop model framework which incorporates the physical condition factors and cost implication to make renewal or maintenance decisions on the building or components of the building. The framework to develop the model will consist of visual inspection system and a method for condition assessment and prioritize maintenance based on available data. In general the research is aimed at developing a model to support the adequate maintenance system which would reduce the lost time and cost due to field inspection and present a simplified framework for condition assessment and decisions. The proposed study focuses physical inspection and developing of a model to predict the condition assessment and make renewal decisions on a selected case study, which is an office complex (Block C of the Rivers State Secretariat Complex, Port Harcourt, Nigeria). The model can serve for other building infrastructures such as hospitals, school buildings, shopping malls, etc. It should be stated that the major aim of the condition assessment is to make maintenance decisions only. Assessments for other requirements like insurance and purchasing are not covered in this research.

2.0 FRAMEWORK FOR CONDITION PREDICTION AND MODEL DEVELOPMENT

A new framework is proposed in this chapter that will take care of some short comings associated with the traditional condition assessment procedures for buildings. As explained in the literature, the main drawbacks of the current condition inspection and assessment procedure and improvement proposed in this research are as follows

a) Inspection process is resource-intensive, costly and time-consuming. Hence a method should be considered to channel limited resources to components that are absolutely necessary for maintenance.
b) Data obtained from inspection are recorded in an implicit narrative text format at the inspection site and actual assessment done later. A simplified method is considered where the condition is rated to conventional condition index.
c) The current systems for condition assessment for building components are very subjective. A visual guidance system that would guide the assessors and limit the number of sites for physical visual inspection and assessment is considered in this research.
d) The present condition assessment systems in most cases do not consider the physical and maintenance cost factors of the infrastructure. In this research a condition assessment model is developed to relate the physical condition to the maintenance /repair cost

2.1 Proposed Model for Condition Prediction

It is clear the condition assessment tools available do not present integration between the maintenance/repair cost and the physical condition factor of the building infrastructure. However, several asset management systems such as BUILDER, RECAPP and TOBUS are available to support renewal decisions for assets or a group of similar components of assets [6-9]. Such systems lack integration of the maintenance cost to the physical condition. In addition also, they do not incorporate functions that would address the short comings reported early necessary for asset management. This research focuses on supporting a maintenance system appropriate for organizations and government for suitable capital renewal programs. Considering the limited funds available to organizations capital renewal decisions are not easy to make. Also considering a major short coming of the current condition and asset management systems, the procedure for inspection and assessment is a resource-driven and time demanding task. The proposed system is aimed to deduce the present condition from existing data to reduce the time and cost from frequent inspection. The proposed system therefore considers the relationship between the physical condition of the component needed for renewal and the number of repair work orders which represents the reactive-maintenance record in a year. This relationship gives an indicator of the physical condition of the building components so that frequent inspection is reduced. In order to achieve the goals of this research, the research methodology is divided into three main subdivisions in order to achieve the proposed condition assessment prediction model as follows:

(i) The components in the building are rated in terms of their usage and work orders
(ii) Physical condition of component
(iii) Cost implication due to maintenance

2.1.1 Model Data Collection and Analysis

In this research, the commonly recognized building elements will be clearly defined, and used as the basis for data collection of condition information of building infrastructure, and condition rating of the components. The building under consideration would be subjected to condition assessment under major components as follows:

1. Substructure
2. Concrete frame
3. Upper floors and staircase
4. Roof truss
5. Roof covering
6. External walls
7. Internal walls
8. Doors and ironmongery
9. Windows
10. Floor finishes
11. Wall Finishes
12. Ceiling Finishes
13. Paintings and Decoration
14. Mechanical services
    a) Plumbing installations
    b) Lifting system
15. Electrical services
16. External works
    a) Civil works
    b) Electrical works
    c) Mechanical works
17. Fixed Fittings and Furnishings

Since there is no available data for the rating of components enlisted as well as the maintenance cost in Naira, the study adopted an analytical component hierarchy system (ACHS), where the components in the building are rated based on their total number of work orders. The preliminary data is indentified under 17 building components. The components are described in terms of their work orders as the amount of work orders is an adequate indicator to assess the condition of the component of a building.

2.2 Components Rated in Accordance with Work Orders

Every building consists of a number of components which performs different functions in the building. These components can be represented by C_i where i represent the component type or particular function. Hence different functions representing the components in the building can be expressed as C = {C_1, C_2, C_3…..C_n}. Each Component consists of a particular function and characteristic. Also each component has its particular importance as regards maintenance which can be a function of the total repair work orders available. A probabilistic method is now used to obtain the relative weight of the component work orders as follows.

$$W_{R1i} = \frac{C_1 + C_2 + C_3 + \dots\dots\dots\dots C_n}{N} \quad (1)$$

Where C represent total work order for a particular component

W_{R1i} is the weight for a particular component

N represents the total number of components under consideration

Physical Condition Assessment of Component

The physical assessment of the existing building is represented by the expression PA which is a function of the physical condition of different components of the building, PA= {PA_1, PA2, PA_3…..PA_m}. Determining the physical condition of each component will provide meaningful information to an asset manager. The asset hierarchy of each building component is determined to help assess the physical condition of building. In this research the USACERL method which has been developed for physical condition assessment is adopted out of the several methods developed. It provides a comprehensive guideline for assessing the physical by determining an interval that defines the actual condition index (CI) value within a scale[10]. The condition index gives uses a scale to describe suitability of a component as regards the needs for maintenance or repairs. The main attributes of the several methods as described in Table 1 are as follows;

i. quantitative judgment and comprehensive description about the condition of the component can be made by the required number of assessors
ii. An assessor can express her judgment directly on interval scale which represents an index value;

Observing Table 1, the USACERL method has terms described for assessing the component system.

The approach gives a detailed condition description for assessment of components based on the assessor's experiences in field during its service life. The method makes use of seven condition indexes categories measured from 0 to 100 for adequate prediction of component condition in a building infrastructure, hence results obtained are more obvious and more reliable in accurate simulation of condition assessment prediction process of the components [11].

Table 1: Description of Different Component Condition Index System

Methods	Types of project	Condition description	Number of scale	Extendable of scale
TOBUS	Building systems	No	4	No
DFES	Building systems	No	4	No
Pontis	BNon-building systems	No	5	No
Greiman	Non-building systems	No	3	Yes
ADOE	Building systems	No	4	No
WSDT	Non-building systems	No	3	No
USACERL	Building and Non-building systems	Yes	7	Yes
Elhakeem	Building systems	No	5	No
Lee	Non-building systems	No	4	No
NCES	Building systems	No	8	No

Note that the initial condition index of a component in a building is 100 (excellent). Then as the component serves overtime the condition index will reduce to a value below 10. Based on the description of the CI scale, a reliable component failure will occur at an index of about 10.A guideline is also required to classify components according to the seven condition categories of the index scale, which also helps to determine the repair time for a component in line with condition description for each CI values adopted by USACERL method. Table 2 shows these guidelines with reference to Uzarski [11].

Table 2: Component Index Description for USACERL Method

Index	Category	Condition Description
86-100	Excellent	Very few defects on components. No immediate work action is required, but routine or preventive maintenance could be scheduled for accomplished.
71-85	Very Good	Component function has minor deterioration. No immediate work action is required, but routine or preventive maintenance could be scheduled for accomplished.
56-70	Good	Moderate deterioration. Component function could be impaired. Routine maintenance or moderate repair may be required.
41-55	Fair	Significant deterioration. Component function not seriously impaired. Routine maintenance for minor repair is required.
26-40	Poor	Major deterioration over some of the components. Less major deterioration could be present in some other components. Component function is impaired seriously. Major repair/maintenance is required.
11-25	Very Poor	Critical deterioration observed over a large number of the components. Component, barely functional. Major repair or close to total reconstruction is recommended
0-10	Failed	Extreme deterioration seen on nearly all components. Component regarded as not functional. Major repair to total reconstruction is recommended.

The physical condition of a particular component is obtained by multiplying the weight of the component inside the building by its condition index obtained from the USACERL method as given in equation 2 below.

$$PA_i = W_{R1i} \quad X \quad CI_{1i}$$

2

Where PA_i is the calculated physical condition of a particular component

W_{R1i} is the relative weight of the particular component

CI_{1i} is the condition index of the particular component base on USACERL method.

2.3 Cost Implication Due to Maintenance

To achieve the proposed condition assessment prediction model the effect of the maintenance or repair cost is used to factor the estimated physical condition of the components. Hence the maintenance cost factor is simply related to the component condition index 2, which is based on the weight of the component as a result of the maintenance cost of the component. Again a probabilistic method used to obtain this condition weight due to the maintenance cost

from which the condition index from which the condition index based on total work order maintenance cost can be deduced.

$$WR_{2i} = \frac{M_{C1} + M_{C2} + M_{C3} \ldots\ldots\ldots\ldots\ldots + M_{Cn}}{TMC} \qquad 3$$

Where W_{R2i} is condition index base on maintenance cost

M_{Ci} represents the total maintenance cost on a particular component

TMC is the total maintenance cost for the building

2.4 Proposed Condition Model of Component

The condition model of the component CM_i is related to the physical condition PA_i and the influence of maintenance cost factor CI_{2i} of the component under consideration. The condition prediction of the component is calculated as shown below in equation 4.

$$CMi = \left(W_{R1i} \ X \ CI_{1i}\right) \ CI_{2i} \qquad 4$$

From the forgoing the condition assessment of a building *C(B)* is the integration of the condition assessment the components in the building calculated from equation 4 and expressed mathematically in equation 5.

$$C(B) = \sum_{i=1}^{n} W_{R1i} \ X \ CI_{1i} \ X \ CI_{2i} \qquad 5$$

3.0 RESULTS AND DISCUSSION

The result from the case study is presented to demonstrate the application of the developed framework for a building. In order to apply the methodology for a building, it should be identified first via opinions survey with the relative condition index of components in the building, considering the physical condition and condition due to maintenance cost. The office is a six storey office complex which consists of different components and subcomponents as shown in the Table 3 below. We now consider the condition assessment due to physical condition and maintenance cost of the building system. The building systems will be assessed by the direct condition rating technique through the building inspection process, as each building Component has its own evaluation scheme; those evaluation schemes are based on the methods stated in section 2. In Table 3; the condition rating of a component based on the Physical condition $[PA_i]$, calculated using equation 2 and the unified condition model of the Component [CMi] calculated using equation 4 is shown. This equation combines both, the physical and cost implication condition from which the general condition assessment of the building [C(B)] is evaluated using Equation 5.

Table 3: Procedure for Rating and Condition

Estimation of Components

Component Number	Component	Total Work Orders/Component Weight 1(W_{R1})	Total Cost (₦)/ Component Weight 2 (W_{R2})	Condition Index(CI_1) Based on USACERL Method	Condition Index(CI_2) Based on Maintenance Cost	Physical Conditon (PA_i)	Proposed Condition Model Value(CM_i)
1	Substructure	3 (0.94)	100,000 (0.00053)	85	0.90	79.90	88.77
2	Concrete frame	1 (1.0)	150,000 (0.00080)	85	0.90	85.00	76.50
3	Upper floors and staircase	5 (0.88)	200,000 (0.0010)	80	0.85	70.4	59.84
4	Roof truss	10 (0.82)	1,000,300 (0.0053)	50	0.80	41.00	32.80
5	Roof Covering	12 (0.76)	1,000,050 (0.0053)	65	0.80	49.40	39.52
6	External Walls	40 (0.65)	2.600,000 (0.014)	70	0.80	45.50	36.40
7	Internal Walls	30 (0.70)	4,000,000 (0.019)	75	0.80	52.50	42.00
8	Doors and Ironmongery	101(0.29)	3,510,000 (0.018)	45	0.80	13.05	10.44
9	Windows	90 (0.41)	4,500,000 (0.019)	55	0.80	22.55	18.04
10	Floor Finishes	50 (0.58)	12,700,000 (0.067)	50	0.60	29.00	17.40
11	Wall Finishes	100 (0.35)	17,000,000 (0.09)	55	0.80	19.25	15.40
12	Ceiling Finishes	85 (0.47)	21,000,000 (0.11)	60	0.60	28.20	16.92
13	Painting and Decoration	130 (0.18)	27,700,000 (0.15)	40	0.55	7.20	3.96
14	Mechanical Services	119 (0.23)	14,230,000 (0.075)	40	0.80	9.20	7.36
15	Electrical Services	135 (0.12)	19,400,000 (0.10)	45	0.60	5.40	3.24
16	External Works	67 (0.52)	45,400,000 (0.24)	30	0.50	15.60	7.80
17	Fixed Fittings and Furnishings	177 (0.05)	13,850,000 (0.073)	50	0.80	2.50	2.00

3.1 Validation of Results

The results of the case study were validated by comparing with building condition assessment method developed previously by a team of building facilities managers. The method involves condition assessment grade from 0 to 100, with 0 representing failure and 100 an excellent case. A calculated condition for the roof covering for instance is 45% while the research proposed model on the case study arrived at an assessment of 39.52% for the current physical condition of the roof covering. It is clear that the two results are very close. The current physical condition as a result roof covering estimated using the proposed model was 49.40% without the integration of the condition due to the maintenance cost. This shows the effect of the contribution of the condition due to maintenance cost.Validating the methodology used in this research we should note that there is no hypothesis or data analysis to which we can adequately evaluate the method [14], as well as formal model framework for condition assessment that considers both physical and maintenance cost factor for validation of the method. In other words, any method can only be evaluated based on its success in practice [15], provided the practical success which includes the efficiency and effectiveness with which a method achieves its objectives is guaranteed by the developed framework.

A relationship between a method Evaluation Model (MEM) which was specifically conceived for IS design methods and the causal relationships between them was obtained. Although the MEM is usually adopted in practice as a criterion to measure the success of a method, other common variables such as efficacy and effectiveness [15], can be estimated to evaluate acceptability of a method.The format for a complete questionnaire for structured interview for 30 Nos. facility/maintenance officers employed by the Rivers State Ministry of works was obtained. This is aimed at assisting in the validation of the model with respect to previous attributes. Each officer entered the their response based on their individual units providing the assessment of each attribute on a scale from that shows the level at which expectations were made. The collected responses were analyzed and mean values for the six selected components of the infrastructure used to validate the methodology. The results are illustrated in Figure 1 and it shows the attributes scores ranged in most cases around the estimated value of the model, which was to meet the expectation of the facility officers who are seen as experts in this case. Hence the methodology and model have been shown to serve as a useful condition assessment model in building facilities.

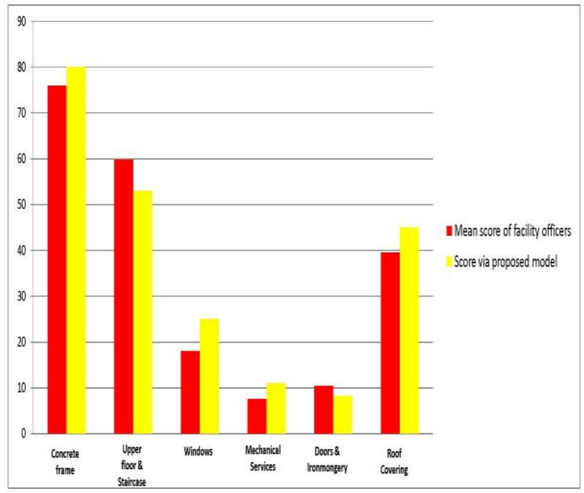

Figure 1: Comparison of Scores for Validation of the Model

4.0 CONCLUSION

The aim of this research which is to develop a framework for condition assessment of building componentswas achieved. The basic input made in the method is to consider the effect of maintenance cost on the condition assessment of the building. Hence the model framework integrated both the physical condition and the condition due to maintenance cost. Several types of surveys were conducted in order to assign the condition index of the components of the building and the data collected from the questionnaires verified for validation of the method. The study adopted an analytical component hierarchy system (ACHS), where the components in the building are rated by weight based on their total number of work orders. The reliability of the results of this research shows that the integration of condition assessment of building components based on physical condition and maintenance cost can be used to improve other current methods such as the USACERL method which was adopted for establishing the condition index of the components.

The results obtained from the case were validated by comparing with that predicted by facility officers employed at the facility where the general condition of the building was put as 45% rating which compared favorably with a value of 39% predicted with the developed condition assessment framework. The developed method can be implemented to guide the design and construction processes and as well assist in the prioritizing process in facility management.

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