Original Article

Maintainability indices for public building design

Received (in revised form): 5th January 2009

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ABSTRACT This paper determined the indices suitable for maintainability analysis with respect to public buildings so as to provide public developers a framework for the timely evaluation of their proposals and avert future maintenance disaster. The indices were drawn from theoretical concepts culled from the existing literature. Prominent features of maintainability analysis included mean time to respect estimates, accessibility analysis and technological feasibility of maintaining each of the composite components of a building. Manuals were advocated for to ease maintainability analysis.
Journal of Building Appraisal (2009) **4,** 321–327. doi:10.1057/jba.2009.2

Keywords: maintainability analysis; maintenance manuals; mean time to repair; reliability; public building design

INTRODUCTION

In engineering, not all products need be repaired when defective. Items such as filament lamps, glazed sashes and ceramic tiles, to mention a few, are not repairable. However, it is presumed that whatever is produced can always be replicated, altered or redesigned to radically improve the performance. This infers that all products can be replaced. If all engineered components can be replaced, then why the fuss about maintainability or its role in maintenance?

Maintainability does not just address reparability, but relates to the ease of restoring a defective item to its functional design state. The concept cannot be treated as discrete entities – maintainable or not maintainable – but as a continuum describing the extent to which the gamut of maintenance could be seen as being achievable. Smith (1981) defined it as the probability that a failed item will be restored to operational effectiveness within a given time frame, if maintenance actions follow the prescribed procedures. In quantitative terms, if maintainability is at zero level, then the life of the building reaches an end upon the failure.

Building failure is at times an inexact jargon, as it refers to the total collapse of a structure. This is often confused with the failure of any or a combination of the various components that make up the building. Maintainability of a building is therefore an aggregation of the estimates of the composite components of the building.

Therefore, the higher this estimate, the more likely that the building would survive in perpetuity. Indirectly, the utility or reliability of the components would depend on their maintainability.

Studies on maintainability over the years have produced algorithms that have given support to the electro-mechanical world, leaving out the built environment. Ikpo (1983) demonstrated the relevance of this concept to the building construction industry. Recently, the importance of maintainability studies to building construction has been strongly articulated. Bamisile (2004) explained how maintainability analysis could be carried out before construction, but did not capture or focus on the common indices. Currently, there is a serious proposition by the Nigerian Institute of Building that this sort of analysis be made mandatory during the design phase of building projects. Again, there are no set criteria for such analysis, except persuasive reasoning that such studies, if diligently undertaken, would provide the level of assurance that structures can be retained in their as-built states, the attending failures notwithstanding.

Maintainability analysis has not yet come to stay. Public buildings are still produced without accompanying manuals, and when defective, the entire structure or parts thereof, which cannot be maintained, are left to decay gradually. This study thus probed into the necessary ingredients of a maintainability analysis before the production of public buildings so as to establish the *prima facie* fate of such structures.

PUBLIC BUILDING DESIGN CONSIDERATIONS

Public buildings are those undertaken by the public authority (the National, State or Local Government) primarily for the benefit of the society at large. The distinguishing aspect of a public property from private estates is the right of any member of the public to access it. However, public housing conveys usufructuary rights to occupiers only, and are subject to all laws pertaining to trespass.

Design is a multi-faceted process. It transcends the traditional notion of working drawings or structural calculations. Following the format spelt out by the Royal Institute of British Architects, design combines all phases and features of building production. It includes the client's brief, the surveyors' estimates, the working drawings and the work plan, and continues to the date the certificate of practical completion is issued. Inherent in all these processes are peculiar qualities that have a direct effect on maintainability. These include the need for flexibility and user-requirement studies.

Flexibility of design

It is desirable that the design of public structures be flexible to accommodate future needs, particularly in terms of alterations. The collaborative and adaptive strategy in architecture is a well-known concept in which bays are kept at maximum levels in the functional distribution of space. Non-structural partitions are adopted for compartmentalisation. These units can easily be reassembled if there is any future need to change the spatial framework (conversion or alteration). This maintainability measure is common in public properties such as city halls, offices, hospitals and school buildings.

User-requirement studies

In the design of private properties such as housing estates, the client's brief provides adequate information on the needs of the occupier – usually the owner. However, with public buildings, the brief is far from satisfactory, as the ultimate user cannot be adequately represented by the client. The effect of this on maintainability is therefore enormous.

Public residential estates, for instance, may have kitchens designed to accommodate the use of gas or electric cookers. The end user may favour coal or firewood as the cooking medium. Redecoration of such walls would definitely exceed the design requirement. Similarly, in public estates, it is desirable that users determine the most favoured routes before embarking on the construction of walkways. Otherwise the landscape would be marred by tracks.

In the design of public buildings, it is important to reckon with the maintenance culture of the users. In Nigeria, there is the general tendency towards neglect, indifference or a vandalistic attitude regarding public government property as against print properties (Ikpo, 1990).

MAINTAINABILITY THEORY

Maintainability has to do with the time it would take to maintain a defective item. If this is as easy as conceived at the design stage, then less time would be required for repairs. The maintainability level in such a case would approach 100 per cent. The time required to effect the repair or replacement, technically termed the mean time to respect (MTTR), would be the same as the standard time estimated for initial construction or as determined by work study. This would be what a 100-rated operative would require to complete the work.

Maintainability becomes low if the MTTR increases from the predetermined figure. Caution should be exercised in evaluating maintainability in relating to MTTR so as not to confuse an increase in MTTR because of the operator performing at less than 100 rating. The latter is typical of public estates where operatives are not monitored but assigned various tasks to perform without a stipulated time frame. The expression for maintainability $M(t)$ as indicated by Reliasoft Corporation (2007) is

$$M(t) = 1 - e^{-\mu t}$$

In the expression, μ represents the repair rate and 't' the time frame. This repair rate represents the quantum of failed items that are repaired within a stated time frame. There are two aspects to any facility – the functional or available and the unavailable or down-time aspects. The unavailable aspect, which need be kept minimal, measures maintainability, whereas the available is a measure of reliability. Reliability may be expressed in relation to failure rate (λ). As Smith (1981) puts it,

$$R(t) = e^{-\lambda t}$$

The failure rate (λ) in this case is considered analogous to the repair rate (μ) in the maintainability model. In an ideal situation where the failure rate is matched by the repair rate, the expression for maintainability may be modified to

$$M(t) = 1 - R(t)$$

These models illustrate the fact that maintainability measures the probability of occurrence of an event (repairs or replacement), whereas reliability measures the probability of non-occurrence of a complementary event (failure of the item). Following

Smith (1981), the repair rate (μ) may be expressed as

$$\kappa = 1/\text{MTTR}$$

Where the maintainability level is low, then the MTTR would be high; the inherent availability (A_i) would be low. Conversely, if the reliability is high, then the mean time between failures (MTBF) would be high, hence the inherent availability. The relation in this regard is shown by Barringer and Associates (2001) to be

$$A_i = \text{MTBF}/(\text{MTBF} + \text{MTTR})$$

MAINTAINABILITY INDICES

As maintainability may be measured using a time-dependant variable (MTTR), basic indices may be needed for its evaluation. The indices identified below are essentially aspects that would directly inhibit maintenance or greatly affect the repair time, hence MTTR.

Accessibility

One of the problems of design is the provision of a structure in a complicated form. Complex buildings more often would have portions or appurtenances located where visitation after construction becomes an issue, if not totally impossible. Examples of this abound, but the most striking relating to public buildings is the headroom. The soffits of public buildings are usually beyond the reach of the routine cleaners. Cobwebs, plant life and dust deposits remain perpetual features. Overhead water tanks are also usually placed where periodic cleaning is not practicable, resulting in the formation of a progressive layer of scum towards the lid.

Maintenance manuals

Manuals are common features of electro-mechanical contraptions. Even with the position of the National Building Code, this feature eludes the building construction sector. Maintainability is defined with a proviso that the remedial measure must follow the prescribed procedures. These procedures constitute manuals, but are never considered in building production, except for items falling under services. The inference is that building surveyors require greater time to evaluate the defects before embarking on repairs in the absence of the basic guide – the manual. The choice of alternative materials or components to replace a defective unit equally becomes problematic.

Available technology

Manuals without appropriate technology would not enhance maintainability. Technological advancement contributes to accessibility in the form of moving trestles, underpinning equipment and even resins for concrete repairs. Technology makes maintainability take off from zero level. It provides solutions to the problems resulting from the combination of compatible and incompatible materials in building design. Technical knowledge and acquired skills on the part of artisans are a component of the technological index. In specifying building components, due consideration should be given to the possibility of procuring each one in the event of future failure, as well as the availability of installation skill. The total down-times of facilities may be significant if the diagnosis and spare procurement experience technical delays.

Economic index

It has been observed that one major inhibitor of maintainability in Nigeria is the financial capacity of owners or occupiers (Ikpo, 1990, 2007). The ideal practice to overcome this problem is the inclusion of projected maintenance cost in the total construction cost. Life cycle costing is not given prominence in the Nigerian construction industry. This makes the user or owner ill prepared to meet with future financial demands. For income-generating estates such as airports, stadia, hospitals and so on, a fair range of 10–30 per cent of the annual income is recommended to be set aside to meet maintenance needs where actual estimates are lacking (Johnson *et al*, 2005). Insufficient funds means postponing maintenance or improperly fixing defective items. The culture in Nigeria is to match the gains from executing the repairs with an alternative use of that fund.

Reliability of components

Reliability and maintainability are regarded as complementary features of a system (Barringer and Associates, 2001). Reliability measures the durability of an item, or building as a whole. It is the probability that an item would perform its design function within a stated time frame – usually the design life. Reliability has to do with the availability of the system, whereas maintainability measures the unavailability or unreliability.

It has been argued that poor maintainability (high MTTR) leads to high unavailability, which is undesirable in design. There must be a trade-off to achieve any given level of availability because if reliability is very high, then maintainability becomes unimportant even if it is poor, as availability would be very high. On the other hand, if maintainability were stepped up, the same availability level could be achieved even with a low reliability level.

DEVELOPING MAINTAINABILITY ALGORITHM

Rumage and Bennett (1998) expressed the need for an empirical approach to maintainability. They strongly advocated for an interplay of intuitive forces, rather than the predominantly MTTR-based models. An exploration of this empirical concept is pertinent in building design. Following the discussions above, the essentials of a maintainability evaluation algorithm are set below.

Identification of appropriate indices

The basic indices for maintainability analysis as shown in the review would include:

- MTTR estimates;
- assessment of technological level;
- assessment of accessibility;
- establishment of the legal framework regarding maintenance;
- reliability estimates on materials and components;
- tolerable down-time.

MTTR is often used as a single measurable parameter in the electronic circle. Buildings may also be limited to this, but the caveat there is that other indices, as listed, should be presumed adequate. The advantage of including other indices is that the critical parameter could equally be established.

In estimating MTTR, the repair rate (μ) is ideal only for tasks for which a number of cycles are achievable per hour. Examples are fixing of say 100 louver blades per hour and laying of 20 sandcrete blocks per hour and so on. Where this is not the case, other stochastic models such as the project evaluation review technique (PERT) and the Weibull distribution may be used for MTTR estimates. The estimates from these stochastic models were demonstrated by Ikpo (1998) to be comparable with those derived from time study observations.

Quantification of the level of technology is a subtle affair, and requires caution to eliminate elements of subjectivity. For the economic index, the actual or budgetary allocation may be translated into a percentage of the expected, actual or potential income from the building. The legal framework would examine the subsisting contractual relations that could sustain maintenance operations. Public buildings suffer tremendously from lapses in this regard. However, public housing tenancy agreements are explicit regarding repair burden.

An intriguing aspect of public building maintenance is the cultural setting. The dichotomy between the ideal and the tolerable is an important determinant of the technological, economic and legal indices.

The reliability index is crucial, as it remains the basis for maintainability analysis. If reliability is high, then maintainability is of no consequence. As important as accessibility is, its quantification could create serious problems. In addition, this should reflect on the damages likely to be introduced in order to access the component.

CONCLUDING MAINTAINABILITY ANALYSIS

Maintainability analysis for public buildings requires the identification and cataloguing of all the items or composite components. Each of these components would then be subjected to evaluation based on the listed indices. Finally, the independent assessment would be grossed to produce the overall maintainability level.

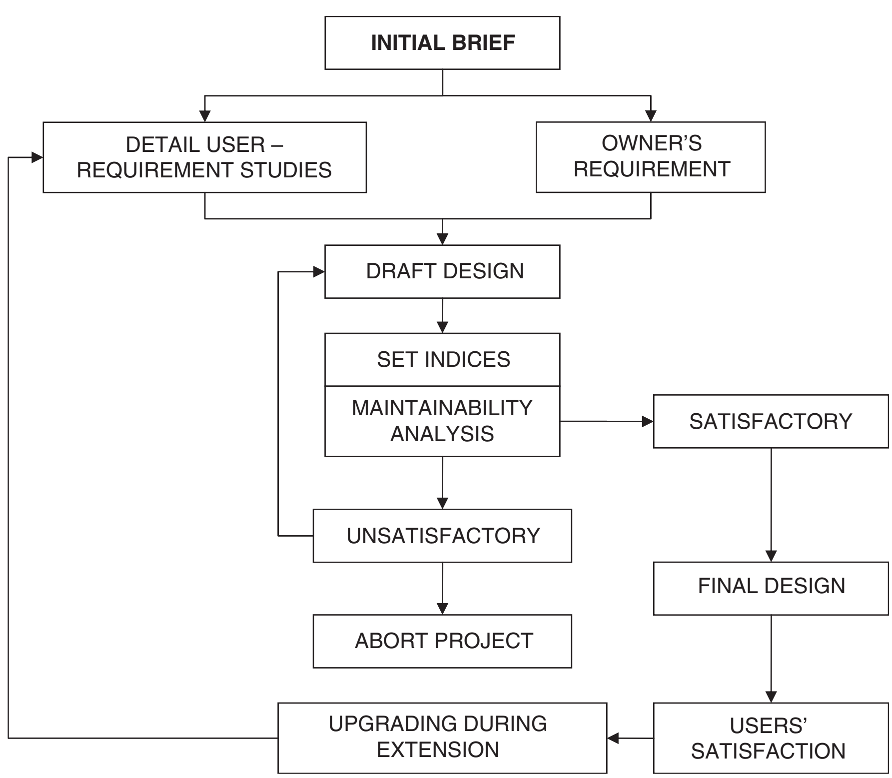

Figure 1: Maintainability processes for public buildings.

The process chart is shown in Figure 1.The result, if satisfactory, determines the final design. If unsatisfactory, the parameters may be reviewed, an alternative draft proposed, or the initial modified before another round of analysis. Excessive iterations would indicate the non-viability of the proposal, and aborting the project would seem a solution.

CONCLUSION AND RECOMMENDATION

Public buildings are observed to be prone to abuse. This means that mechanisms need to be put in place at the design stage not only to mitigate deterioration, but also to enhance maintainability, particularly if down-times have to be kept at a minimum. To achieve this, maintainability analysis is required before the commencement of construction.

Maintainability analysis may best be carried out by first specifying the appropriate indices and evaluating each component with respect to the set indices. The overall value would then serve as a guide to owners or stakeholders, especially on aspects that require attention.

Realistic maintainability appraisal depends on the available data. It is therefore recommended that designers make available the properties and characteristic features of items or components specified in design. Builders have an equal role to play in the provision of standard activity times for the most frequently recurring items of repair and replacement in public buildings, as well as their cost estimates. This could be set out at the inception of any public building as an integral part of the total construction cost. The decision to continue or abort any proposal would be on a well-informed basis.

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