CRITICAL LOSS OF PERFORMANCE - WHAT FAILS BEFORE DURABILITY

Critical loss of performance

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Abstract

Empirical research has been carried out to find out the actual reasons for initiation of repair projects on buildings. This research has shown that the owners of the buildings actually experienced the user requirements predominantly outside of the range of durability failures. Only 17 % of the repair projects were initiated primarily because of deterioration. The critical loss of performance seems to primarily be in the range of subjective perceiving of the building. Very little technical or economical rationality can be seen in the actual decisions made on building refurbishment. In most cases the limiting factor for service life is not durability.

Life cycle economics of the buildings are (according to the empirical findings) covered by technically/economically irrational basis. Decision-makers pay little attention to the condition and remaining potential for service life of the building components. They pay very limited attention to economical expectations. Optimization of economical factors of the buildings is the primary goal in less than 10 % of repair projects.

If service life is seen as the actual time in service of the building components, the basis of service life prediction models should not be based on durability or economics of the building components only. Durability is of course the limiting factor for service life in the sense that service life can not exceed the limitations set by durability, but in fact the actual service life seldom reaches the full potential life time of the components limited by durability. The forecasting of the timing of the refurbishment projects should not rely on the durability-based concepts only. Asset and maintenance management should pay more attention to the more critical perceived quality of the buildings.

Keywords: failures, technical rationality, economical rationality, optimization, actual service life, forecasting, service life prediction models

1 Introduction

In this paper refurbishment is seen as an option at the end of the service life of a building. The end of service life occurs when the building fails to perform as required. This failure can be a result of three causes: 1) failure resulting from change(s) in performance (deterioration based failure); 2) failure resulting from change(s) in requirement(s) (obsolescence based failure) or 3) failure resulting from change(s) in use.

If the failure is due to changes in performance of the building, it is possible to:

i. have a corrective refurbishment to restore performance to its former level, or
ii. change the use of the building to match lower performance requirements or
iii. discard the building.

If the refurbishment is due to changes in the requirements, it is possible to:

i. have refurbishment according to new requirements or
ii. change the functional use of building so that its performance will meet the requirements of the new use or
iii. discard the building.

If the failure is due to change in space use, it is possible to:

i. have a refurbishment to match the spaces with the changed use or
ii. find another use for the building as it is or
iii. discard the building (perhaps temporarily until it is put to a new use).

A refurbishment project may be initiated suddenly because profound damage has occurred, or its initiation may be planned in advance for a chosen time according to the expected rate of deterioration. The damage-based refurbishment is most obviously due to the properties of the building (especially durability features). The other route to refurbishment is via changes in the use and the user of building with the normal wear and tear of the building itself. The theory of economy considers rational the project that maximizes economic utility. One may endeavor to do this directly through attempting to increase profit, or indirectly through minimizing expenditures in order to add profit potential (cost-reduction expenditure). A refurbishment initiated without deterioration of building on the basis of subjective valuations only can be seen as a counterpart of failure in building. A marginal factor for initiation of refurbishment projects can be anticipated to be a change of circumstances (e.g. change of energy price).

According to this, the reasons for demand of various refurbishment projects can be classified as follows:

1 Failure in building: corrective refurbishment
2 Change in use: space-altering refurbishment
3 Optimization of economical factors: optimizing refurbishment
4 Subjective features: pleasure refurbishment
5 Change of circumstances: opportunity refurbishment

Durability is the main concern of service life studies. Durability related deterioration is often seen as the process leading to the end of service life of structures. Service life prediction methods are based on assessing the extent of deterioration in some specific measurable properties chosen to be indicators of degradation (Sjöström 1985). The aim of service life prediction is to estimate the performance over time as the function describing how the measured values of the chosen properties vary with time. All this is related to the durability of materials. Durability itself is a complex issue. Deterioration, of course, impairs the capability of a system to meet the given requirements. But the requirements are not entirely covered by the capability of a system to maintain its performance. In the following, items other than deterioration are discussed as a counterpart to it as the criteria for refurbishment, and their power to explain the refurbishment projects is viewed.

2 Obsolescence and deterioration

There are two considerations in the process leading to refurbishment. On the one hand there are the requirements (which can be seen as the demand) and on the other hand there is the performance of the object (the supply). But what are the requirements that actually launch the refurbishment project? Or in other words, how is the demand for refurbishment initiated?

The refurbishment project of a building may be initiated for various reasons. Flanagan et al. (1989) who includes the following items makes one summary of the reasons from the life cycle analysis point of view:

- physical deterioration
- economic obsolescence
- functional obsolescence
- technological obsolescence
- social obsolescence
- locational obsolescence
- legal obsolescence
- aesthetic and visual obsolescence (fashion/image obsolescence)
- environmental obsolescence

Equivalent lists with to some extent different points of view have been written in a number of publications.

The level and to some extent also the character of requirements change over time. In general the requirements both rise and increase (for example the case of thermal insulation requirements in structures clearly shows this kind of development). Simultaneous to the rise in requirements is the decline in performance due to the deterioration of structures. The process of becoming discontent with the object accelerates. And even if a building could maintain its original properties, the refurbishment will finally be inevitable only because of the change in requirements due to the comparison between the existing situation and the new substitution available; in other words, there will be demand for obsolescence based refurbishment. Pullar-Strecker (1990) illuminates dearly the origin of the demand for refurbishment in his definition of building defects: "Building defects will always be with us because there will always be aspects of building performance that are less good than the best, or even average, or less good than we feel we have a right to expect." Thus the demand is derived from the comparison of the existing building performance with either standard performance criteria or personal expectations. It can be concluded that the defects are relative, not absolute, and therefore difficult to measure objectively. The refurbishment due to obsolescence is not technically rational since it does not optimize the use of structures until the end of their durability. Since corrective refurbishment is defined as the project aimed at deteriorated structures (an unacceptable physical condition), obsolescence based projects do not belong to this category. On the other hand, quoting Taylor (1980), deterioration has no part in the accumulated inferiority caused by obsolescence. Thus deterioration and obsolescence are two separable issues. Both Taylor (1980) and Flanagan & al. (1989) have categorized the causes of replacement into these two classes: deterioration and obsolescence.

3 Economic life - service life

The concept of economic life is defined by Taylor (1980) as the period of time that will elapse before the equipment - either present or proposed - is displaced from the intended service by more economically viable equipment. Or, restated, economic life is the period over which the equipment will continue to have the lowest annual cost compared to any contender for the service. Further, Taylor states that the concept of economic life is therefore inseparable from consideration of replacement. Replacement or displacement is the result of a successful attempt by superior equipment to terminate the service period of its predecessor.

In the technical-economical sense, maximization of utility means using an item until its failure so that the annual costs will be at their lowest. A normative definition for technical rationality can be expressed as: use as long as the item endures, maintaining its performance. Accordingly, a technically rational refurbishment project is initiated at the failure of the object. This area is handled in service life theory, which seeks to explain the relationship between deterioration and failure. According to service life theory, a technically rational refurbishment project will be initiated when service life meets its limiting lifetime.

4 Definitions and some aspects of service life studies

Service life is defined (by ASTM, 1990) as the period of time after installation during which all properties meet or exceed the minimum acceptable values when routinely maintained. Thus the object fails when property being assessed falls below the minimum acceptable value. In the following text, service life refers to the time of usage before failure of a building material, component or preferably the failure of a well-described system of building materials and components in an environment. Failure can be defined as the state of being where the object fails to meet the given performance requirements.

The shortest definition of performance requirement is given by ISO: performance requirement is the user requirement expressed in terms of the performance of a product. Performance is behavior (of a product) related to use (ISO 6241, 1984).

Performance criterion has been defined in slightly different ways. ASTM (1990) defines performance requirement as a qualitative statement of the performance required from a building component or material. Accordingly performance criterion is a quantitative statement of a level of performance for a selected performance characteristic of a component or material needed to ensure compliance with a performance requirement. RILEM (Technical Committee's TC 31-PCM Summary of Work, 1987) defines performance criterion as the limiting value or value range which satisfies the requirement for a given lifetime. (Here is the major difference between ASTM and RILEM definitions: ASTM determines the performance without any time concepts, whereas RILEM determines performance for a specific period of time.) Furthermore, for a defined requirement, the performance of a material is its response to the action of extrinsic factors. The nature of the response is due to the intrinsic properties of the material.

In other words these performance criteria are given as the minimum or maximum values of the properties vital to usability of the object. These kinds of definitions don't state either the properties or their acceptable values to be measured. Both properties and their limit levels are open to decision making. Thus it is obvious that, since the requirements are given according to standards with more or less variation, the definition of failure includes some non-absolute evaluation. Even the standards, which are given in legislation, vary in the course of time. This shows clearly that no estimate of service life can be absolute or final because it is a result of non-absolute and changing factors.

While trying to gain a service life estimate for a system, the first step has to be the identification of the requirements, which the system has to meet. After receiving information on the requirements, the performance criteria can be formulated. This is the phase where requirements are translated into levels of properties desired or demanded from the system. The use of the values of physical and chemical properties is essential for the practical task to gain a service life estimate, since the only things that can be physically measured in the system are its properties or the changes in the properties. In terms of the performance of an existing material system, we talk about the properties of the system. In terms of performance criteria, we talk about the requirements; these two modes have to be consistent.

The need of transforming the requirements into demanded levels of physical and chemical properties implies that the methodologies to study service life are indirect. This can be a source of inaccuracy for service life estimates since it is to some extend a matter of choice of how to describe the requirements in the terms of properties. Nevertheless, as soon as the properties have been identified, the measurements can be carried out more objectively.

The definition of service life as a period of use before failure implies that the service life studies actually seek to determine the length of time until the occurrence of failure and concentrate rather on the deterioration rate than on the remainder of beneficial properties of the system. That is indeed the case. The challenge in service life prediction is to determine or predict how long time a system will be able to maintain its desired or demanded properties above a level of acceptance. Usually systems are designed to meet some given requirements at the end of their construction or at the beginning of their usage. Hardly ever does improvement occur in the way in which the system is able to meet these requirements during its use. On the contrary, the usefulness of the system is usually susceptible to degradation both because the standards of the requirements tend to rise and, at the same time, the capability of the system to meet even the original requirements deteriorates.

A system meets its requirements according to its properties. Failure is usually expressed as the exceeding of a maximum or falling below a minimum required level of the properties which have been chosen to be characteristic of and demanded for proper performance of the system. The information on the in-use-behavior of the system is derived from the measurements of the changes in these properties. Time can be connected to the measurements as the rate of changes or, since the changes usually are to the worse direction, the rate of deterioration.

5 Empirical findings

The method chosen for empirical study was to identify the prime cause of refurbishment by means of a written questionnaire sent to those who have made a decision to initiate a refurbishment project. The method of asking decision makers directly was chosen because it could be directed at the origin of the information: only those who actually made the refurbishment project decisions are qualified to name their specific reasons. The written questionnaire was formulated in such a way as to gather facts about the background of the refurbishment and to pose the question of the motive. Since the motive question is crucial, it was asked both as a multiple-choice question and as a freely expressible question.

In this case, the empirical study was aimed at the whole population of private sector refurbishment projects permitted during the period from the 1st of July 1990 to 30th of June 1991 in the city of Oulu (Aikivuori 1994). There were the total of 270 cases including 140 private individuals, 91 housing corporations, 10 real estate corporations, 22 companies and 7 communities. The total answering percentage was 67 % and the total loss 33 %. Considering the reliability of the results, this answering percentage is dependable enough.

The empirical findings as to the prime causes for the refurbishment projects of this study are:

(1) failure due to deterioration: 25 cases, 17 %
(2)change in use: 38 cases, 26 %
(3)optimization of economic factors: 14 cases, 9 %
(4)subjective features of the decision maker: 65 cases, 44 %
(5)change of circumstances: 6 cases, 4 %

This distribution is valid only locally and only at the time of the study, each decision environment gives its own results.

Service life prediction based on the deterioration rate of structures covers 17 % of the observed cases (only 17 % of the refurbishment was initiated primarily because of deterioration). Based on the discussion above in the chapter 4, it can be said that deterioration based service life prediction methods give the maximum expected service life rather than a period to use in life cycle costing analyses.

The average periods of use before refurbishment in the categories are:

(1) failure due to deterioration: 28.7 years

(2) change in use: 26.8 years

(3) optimization of economic factors: 17.7 years

(4) subjective features of decision maker: 17.2 years

(5) change of circumstances: 24.7 years

The overall average time in use before refurbishment of all the cases is 22.0 years.

It can be seen here that the deterioration-based refurbishment occurs in average clearly later than its subjectively based counterparts. Changes in use or circumstances confirm the widely used period (in life cycle analyses) of 25 years, and the overall average 22.0 years is also reasonably close to it. According to these empirical findings, obsolescence based refurbishment occurs much earlier (in average, after 20.6 years in use) than deterioration based refurbishment (occurring in average after 28.7 years in use).

6 Discussion and results

These results indicate that the service life of a building component is more frequently determined by factors other than durability failure. Refurbishment projects causing the replacement of a building component occur prior to discarding of the component on technically or economically rational basis. It seems that decision-makers don't conduct in technically economically rational manner. The rationality in the majority of refurbishment decisions is very subjective in nature.

The study of the empirical material demonstrated that human behavior related to decision making in refurbishment projects is not a clear case of seeking a technical-economical optimum. Even if human behavior is not rational in terms of technology or economy, it is intended to be rational when choosing the best among alternatives. Obviously the greatest expected utility has been subjective in nature. The aspiration to seek pleasure seems to be a strong motivator for refurbishment. It also indicates that the built environment does not offer such pleasure, as people feel is their right to expect from it. Construction companies should benefit from the innovation and development of comfort providing items (such as the glazing of balconies in some environments) offered to the market.

The importance of failures in durability as a prime cause of refurbishment is surprisingly moderate (17 % of the observed cases). This low proportion is probably an indication of maintenance work being effective to repair a large portion of deterioration based failures.

If the occurrence of a refurbishment project in the life cycle of a building is seen as a forecasting problem, it is obvious from the empirical findings that the long established period of 25 years is a good estimate. On the whole, refurbishment projects take place on average when the building is 25 years old, and occurs again after another period of 25 years. The observed deviations from the average are however large, thus it is rather difficult and inaccurate to try to estimate the exact time at which a specific building will be encountering its refurbishment. For design periods and cost estimation purposes 25 years with its multiples is a solid basis, even regardless of whether the project is due to deterioration or obsolescence.

Service life prediction based on the deterioration rate of structure covers 17 % of the observed cases. Therefore it can be said that deterioration based service life prediction methods give the maximum expected service life rather than a period to use in life cycle costing analyses.

It is also apparent that the empirical information about both the reasons and timing of refurbishment projects is valid for statistical considerations only whereas it might be difficult to find single cases that exactly obey the averages of the findings.

Obsolescence is overwhelmingly a more important basis for refurbishment than deterioration (whereas deterioration may be the dominant cause for maintenance activities; this also implies that most durability failure costs appear as maintenance costs and not as refurbishment costs). To maximize the utilization of structures, factors causing early obsolescence should be identified and improved.

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