International Journal of Industrial Engineering & Management Science, Vol. 8, Issue 1, (2021) 52-61

University of Hormozgan

International Journal of Industrial Engineering & Management Science

journal homepage: www.ijiems.com

Proposing a Building Maintenance Management Framework to Increase the Useful Life of the Building

Milad Ghanbari [a,*], Mastaneh Mojtahedzadeh Asl [b]

[a] *Assistant Professor, Department of Civil Engineering, East Tehran Branch, Islamic Azad University, Tehran, Iran*
[b] *M.Sc. Student, Department of Project and Construction Management, South Tehran Branch, Islamic Azad University, Tehran, Iran*

ARTICLE INFO

Article history:
Received: 2021-06-06
Received in revised form: 2021-11-19
Accepted:
2021-11-29

Keywords:
Building Maintenance
Life Cycle Cost
Maintenance Management
Economic Life
Technical Life
Checklist

ABSTRACT

Consideration of the global standards indicates that the life span of buildings in Iran is 25 up to 30 years and it reaches up to 100 years in developed countries. Preventive maintenance strategies should be designed to control depreciation and maintain the optimal performance of building components. This study, while reviewing maintenance-related research, aims to propose a framework of building maintenance management to increase the useful life of the building. To achieve this goal, each building needs a maintenance and implementation plan depending on its conditions. Implementing the life cycle costing (LCC) principles of any building requires inspection, repair, and recording of financial and technical data. The proposed framework of this research is based on finding the technical and economic useful life of the building by mathematical models such as LCC and comparing it with the age of the building. The existence and implementation of a maintenance checklist is the most basic way to increase the life of the building, which is divided into architectural, structural, electrical, and mechanical sections. In this research, in the end, a sample maintenance checklist is introduced by using the Delphi method.

1. Introduction

Most of the residential buildings in Europe are so old that date back before 1980 [1], the dominant part had reached or moved toward the degree of their service life. With the ever-developing lodging interest, today, there is a pressing need to go to the current lodging circumstance and satisfy current guidelines and necessities [2].

Around the world, it is more common for a government to invigorate maintenance and refurbishment of old houses than demolish them and construct new ones. This operation is rendered as assessing direction, endowments, and so on. The regulations and a few other archives, indicating the owner's duty for his property, compel the proprietors to care for the buildings they possess [3].

From the environmental security point of view, the demolishing of buildings is unsatisfactory, since it causes overwhelming contamination [4-7]. Quarrying, preparing for different crude materials, and generation of materials and structures as well as their transportation, building construction, and maintenance are regularly hurtful to the environment. Demolishing of buildings, with the ensuring squander treatment, too contaminates the environment. Hence, taking into consideration, legitimate building maintenance and restoration are regularly way better than the demolishing of old buildings and construction of new ones [3, 8, 9].

* Corresponding author.
E-mail address: milad.ghanbari@srbiau.ac.ir

The relationship between investment in new construction and maintenance and restoration of old structures generally relies upon the development of the public economy [10]. Generally, the more the nation is built up, the more additional living space per individual is given. This is the reason why non-industrial nations put more capital into new development and the augmentation of the accessible foundation than exceptionally created states [11, 12]. Innovative and social turn of events, just as the development sought after and buying limit of the populace, bring about more noteworthy solicitations for better structures. Positive social changes affect the advancement patterns in lodgings development and restoration. The proprietors, endeavoring to keep up or raise the estimation of a structure put forth the attempts to diminish its worn and out-of-date quality [3].

The application of the standards of complex analysis is pointed at cutting the costs exhausted on the brief, design, construction, and maintenance processes as well as accomplishing higher standards of quality of a building [12]. Moreover, its application can guarantee that the interface of all parties included is taken into consideration. Undertaking a complex examination is supportive of making the approach to a designer to a project more concrete when the points and purposes of all interested parties are taken into consideration in giving a productive lifetime of a building [13]. The use of complex investigation makes it conceivable to carry out economic, specialized, technological, administrative, consolation, and other sorts of optimization all through the lifetime of a building [14]. It ought to be noted, be that as it may, that to raise the proficiency in either of the stages (i.e. design, construction, or maintenance) is not continuously an advantage since it may cause the decrease of records characterizing other stages. In this manner, the ultimate assessment of the venture ought to take account of the interrelation and noteworthiness of all the project objectives and implies utilized to attain them [3, 15].

Building owners consider the arranged maintenance as a matter of genuine trepidation, and however, they cannot bear to destroy their buildings sooner. Because it is without a doubt unfeasible and indeed negative to reestablish all the older buildings, everybody uncertain with those buildings, whether as the proprietors, builders or the conclusion clients, got to take a genuine consideration in this unbounded problem of building. Building owners have a certain sum of budget to handle or cover this problem by maintenance. A maintenance policy can be categorized into two groups: unplanned and planned maintenance [16]. There are three sorts of maintenance which are corrective maintenance, preventive maintenance, and condition-based maintenance [13, 17-20]. The sorts of maintenance incorporate the service maintenance that maintenance items requested by the tenant or the tenant [12]. It moreover incorporates a few crisis things. Following is what we called schedule maintenance that incorporates wide or common sorts of maintenance to the common areas. These specific viewpoints are not asked by the occupant, but it is vital in arranging to keep the building in an excellent state [16].

Preventive maintenance is a basic portion of running commerce efficiently and financially [17]. Doing schedule reviews, tests, and servicing will not, as it was, remove the costs of the budget, but it can moreover indeed save the owner's cash within the long run. Presently, a great commercial building maintenance program ought to have a total checklist for one of the major building frameworks such as the lighting, HVAC, and plumbing [12, 15, 17, 21-23]. Certainly, the two facilities are not completely alike. The "facility" could be a plant, a commercial office, or indeed a rental property. That being said, some quality building maintenance steps can be connected to most circumstances [9, 12, 24].

The present study, while reviewing previous research, addresses the importance of building maintenance. As the positive impact on continuous maintenance of the building occurs in the future, it increases the lifetime of the asset. That is, it increases the useful life of the asset, which is the objective of the present study. Continuous maintenance of the building requires long-term planning, which is the same as preventive maintenance. Therefore, in this research, previous various models related to the useful life of the building, physical and economic life, maintenance, and demolition of the building are reviewed and examined so that through them and field research, a checklist for maintenance of the building can be collected. Certainly, each building and complex, depending on the type of building use and construction methods and details, requires a separate and unique checklist. In this research, the process of compiling a checklist can also be learned. This checklist can be divided into groups of structural, architectural, electrical, mechanical, etc. according to the building sections.

2. Literature Review

By researching and considering the long life of buildings in other countries, it can be concluded that one of the effective factors of increasing the useful life of buildings is the issue of building maintenance [8, 9, 12, 16, 22, 25-27]

If the maintenance is done at the right time, according to the usual plans in this area, and using the relevant checklists, the useful life of the building will be reasonably and economically longer. Of course, one cannot ignore the potential employment potential that maintenance creates; In particular, companies and activities related to this field are users and not investors [12].

As Ylen (2011) points out, According to value-based pricing business strategy the pricing of the service should be based on the customer's added value, not on the expenses service provider experiences. It would be useful to know the value in advance since it facilitates developing value propositions which in turn could motivate the customer. Unfortunately, determining the added value is challenging since the value is created in a complex system and arises from different sources, which may be difficult to measure [28]. As Brax (2009) points out, removing technological and operational risk from the customer is an essential value-generating mechanism [29].

Buildings are national assets, and the lack of necessary controls after their construction leaves irreparable damage to the economy of any country. Building components include various parts of architecture, structures, electrical installations, and mechanical installations during their useful life, may be affected due to weather conditions and natural hazards such as earthquakes, floods, and storms, maintenance failure, improper operation, lack of control Periodic inspections of the operating conditions of electrical and mechanical installations and the stability of facade components and other ancillary components of the building, non-control of foundation conditions, subsoil and walls of buildings adjacent to buildings under construction or reconstruction. Suffering from premature burnout and loss of proper function are surveyed in terms of safety and health. Therefore, to maintain the building and its components, it is necessary to formulate and promote rules and regulations so that the competent people designated for this article can control the correct operation of the building during its useful life and repair and strengthen damaged components if needed [30-32].

Various definitions characterize maintenance operation, for case, British Standard BS3811, characterize maintenance as an uncommon assignment set out in grouping to keep or reestablish each convenience such as each portion of a location, building, and substance to a palatable whereas, the chartered foundation of building characterizes, building control as work done to preserve, reestablish or liven up each office for a moment, each part of the building, the administrations and encompassed to a contracted model decided by the harmony between require and reachable assets [27, 31, 32]. Another definition of maintenance may be work done to control certain conditions of a building so that the layout lies inside particular districts; Figure 1 demonstrates the scope of maintenance [25]. Figure 1 describes the general cost classification that can be used to help define the specific application scope of the analysis provided there is a structured basis of comparative analysis. There are two major components that are effective; maintenance needs and a useful maintenance management system. In terms of maintenance needs, the essential endeavors are to maintain and protect that building from its preparatory organization such as attainable and efficient services on its purposes. As been specified prior, the core standards of building maintenance are to retain the esteem of the speculation, to maintain the building in a circumstance where it can fulfill its work, and to display fabulous appearances. Whereas the productive building maintenance management system embraces several skills included in identifying maintenance needs and in arranging to show the precise remedial work and their thoughts of the advanced management technique [24, 25].

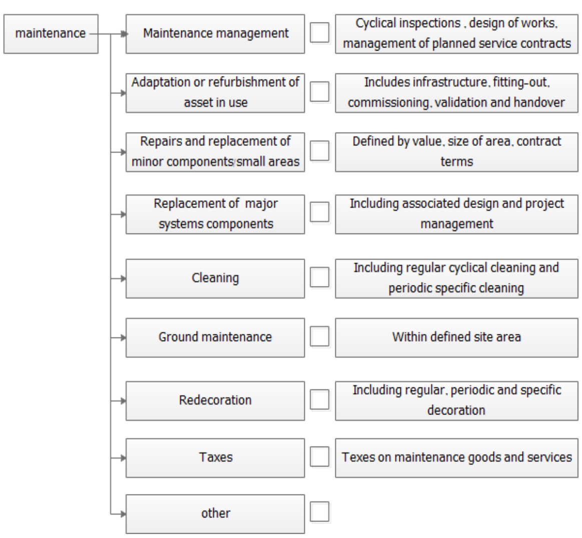

Fig. 1. Scope of Maintenance [25]

3. The Proposed Framework of Building Maintenance Management

The proposed building maintenance management framework in this research is based on the building maintenance manager. The person in charge of building maintenance must have the technical competence and be able to model building information. Because adopting any building management strategy requires reviewing the technical-financial records of the building. The duties of the person in charge of building maintenance based on this proposed framework are: 1- Compiling and updating the building maintenance checklist according to the use of the building 2- Performing periodic building inspections according to the maintenance checklist and registration in the building information management system 3- Registration Technical-financial data related to building maintenance 4- Annual evaluation of technical-economic useful life of the building according to mathematical and LCC models and recording of obtained information 5- Review and selection of appropriate strategy according to the current situation (continued operation of the building, repair, demolition and renovation, sale of building).

In fact, the person in charge of building maintenance should be informed of the technical-economic useful life of the building by performing continuous annual calculations, and based on this knowledge, inform the building owner about the future policy. If the current age of the building is less than the calculated technical-economic useful life, the operation of the building can be continued. At the discretion of the building maintenance manager, if necessary, the building can be continued with the necessary repairs or major renovation or reconstruction. If the age of the building has passed the technical-economic useful life of the building, it is time to demolish and rebuild the building. However, if the building is older than the economic useful life of the building and at the same time is less than the technical useful life, it is time to sell the building because maintenance costs have made the operation of the building uneconomical. Therefore, there is a need for periodic inspection of the building and technical-economic evaluation by the person in charge of the operation. The building maintenance management process according to the proposed framework of this research is shown in Figure 2.

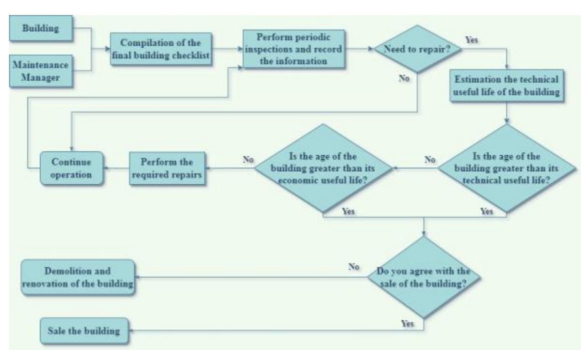

Fig. 2. Flowchart of the proposed framework of building maintenance management

4. Estimation Models of Technical-Economic Useful Life of a Building

In this section, mathematical models are introduced to calculate the technical and economic useful life of the building. In general, the variables affecting the technical useful life of the building are construction quality and method, quality of materials used, maintenance, environmental conditions, etc. Variables affecting the economic useful life of the building are the cost of repairs, the cost of maintenance manpower, the selling price of the building, depreciation rate, discount rate, and so on.

4.1. Service Life Planning

Based on ISO 15686-1, the concept of reference service life (RSL) is defined as the "service life of a product/component/assembly /system that is known to be expected under a particular set, i.e. a reference set, of in-use conditions and which may form the basis of estimating the service life under other in-use conditions" [33]. This is carried out by multiplying the RSL some factors, each of which reflects the difference between the two sets of in-use conditions within a particular factor class (Equation 1). The factor classes are given in Table 1.

$$ESL = RSL \times Factor\ A \times Factor\ B \times Factor\ C \times Factor\ D \times Factor\ E \times Factor\ F \times Factor\ G \quad (1)$$

Table 1. Factor classes of the service life planning method [33]

Factor class	Designation
A	Quality of components
B	Design level
C	Work execution level
D	Indoor environment
E	Outdoor environment
F	Usage condition
G	Maintenance level

It is necessary to predict the service life at the time of product design, i.e. by considering the environment and conditions during use and to be equipped with the specifications provided regarding quality and functional characteristics, and to predict the service life using Equation-1. Considering the estimated maintenance costs and service life, it can be decided whether to use this equipment or selected materials in the economic building.

Figure 3 illustrates scenarios of the development of the performance (bold line) of construction measures from the delivery of the maintenance and operation phase. There is a deviation (gap) in performance from the client's expectations and requirements from the brief (initial) phase to the delivery ("as-built") phase, often due to failures or damage during fabrication. The expectation gap is increased further due to the continuous rise in new requirements and upgrading, business development, etc. [33].

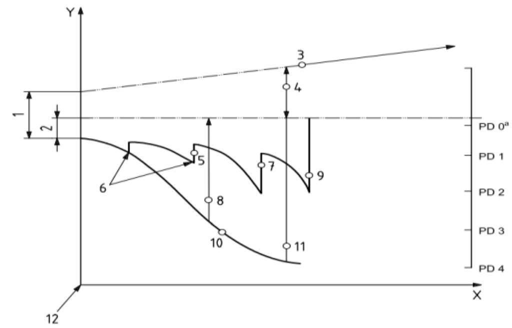

Fig. 3. Life cycle performance of construction [33]

That:

Y: quality/function
X: operation and management of building over time
1: expectation/achievement gap
2: building failure/damage
3: new requirements — public
4: development upgrading
5: preventative and periodic maintenance
6: limit states
7: refurbishment
8: repair
9: replacement — market
10: performance without preventative actions
11: renewal — business
12: "as built"
PD: Performance degrees

4.2. The Relationship between Economic and Physical Longevity of the Building

With a closer look at the construction life cycle, two important terms should be addressed, namely the physical lifespan and the economic lifespan of the building [34]. The life of the building starts from the beginning of the operation of the building. From this moment on, the process of building erosion begins. Even if the building is not used. In this time, periods are considered as the useful life of the building [35]. This time varies depending on the type of building, quality of materials, execution, and maintenance method [12]. This period of life is called the useful life or economic life of the building. The endpoint of the useful life of the building coincides with the end of the economic life of the building [11, 12, 24]. This is a point that somehow leads to conditions of sudden failure and reduction of quality, and from this point on, the building can function functionally, but the maintenance costs of the building increase, and the slope of the building deteriorates faster [14]. This slope includes the market price of the building. But in the current economic situation in Iran, there is another issue. In Iran, the inflation rate in the construction sector is higher than the general inflation rate, although the building is going through its physical depreciation, its market value is higher. Whenever the value function of the building falls below the value function of the land capital; Destruction is economically justified [36]. Figure 4 shows the time of economic justification for demolition in case of a decrease in the value of building capital and considering the value of land capital (based on Statistical Center of Iran).

Figure 5 shows the justifiability of building demolition at a time (A) when the building has not yet reached the end of its useful life (B) and accelerates the so-called accelerates the phenomenon of early demolition in the building industry. Among the effective factors of increasing the price of land are change into land use, increasing building density, providing urban facilities and facilities, implementation of improvement and reconstruction projects, allowing the separation of assignments and expanding the legal boundaries.

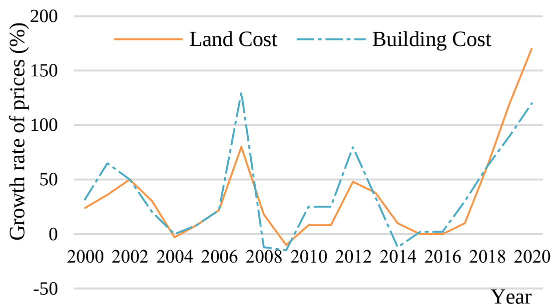

Fig.4. Economic time of demolition

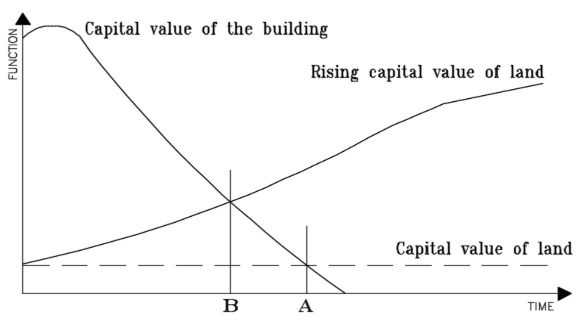

Fig.5. Time of economic justification of demolition (time-performance)

4.3. LCC Model

The results of life cycle costing (LCC) must, whatever the phase of the program, contribute to the process by which managers can make the best decisions on options presented to them. These options can include evaluation of future expenditure, comparison between alternative solutions, management of existing budgets, options for procurement, and evaluation of cost reduction opportunities. Life cycle costing is also used for affordability assessment and determining the cost drivers associated with the Key Performance Indicators or Key User Requirements [24, 37]. There are many methods and models available to conduct life cycle cost estimates. It is important to understand the applicability and boundaries of each method and model to use them appropriately [18, 38]. There are two key conflicts in establishing the economic life of capital equipment [39]:

(1) The increasing operations and maintenance costs of the aging asset.
(2) The declining ownership cost in keeping the asset in service, since the initial capital cost is being written off over a longer period.

These conflicts are illustrated in Figure 6, in which fixed costs (such as operator and insurance charges) are also depicted by the horizontal line. Fixed costs will not affect the economic life decision, so they can be omitted from the analysis [18, 38]. The asset's economic life is the time at which the total cost is minimized.

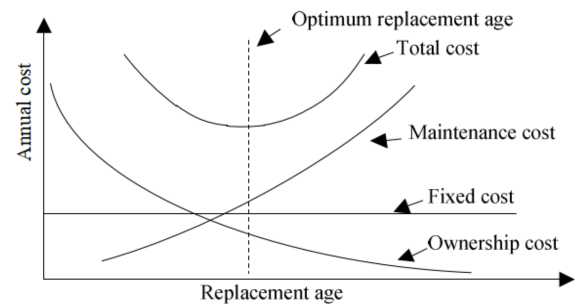

Fig.6. The economic life [39]

4.4. Demolition Model

The Adaptive Re-use Potential (ARP) model is a way to estimate the recoverability of a structure and reuse it without the need for demolition, reconstruction, and reconstruction. In the ARP model, a base curve is a basis for analyzing the current state of a structure. This chart is called deteriorates curve (Obsolescence process). In this research, this curve (Figure 7) has been used to plot the obsolescence process of the building. In this curve, the X-axis indicates physical life and the Y-axis indicates the degree of depreciation or ARP. If the useful life of the building is considered to be 40 years (as for Iranian buildings), then Equation (2) between X and Y is defined as follows [40]:

$$Y = 40 - \frac{X^2}{40} \tag{2}$$

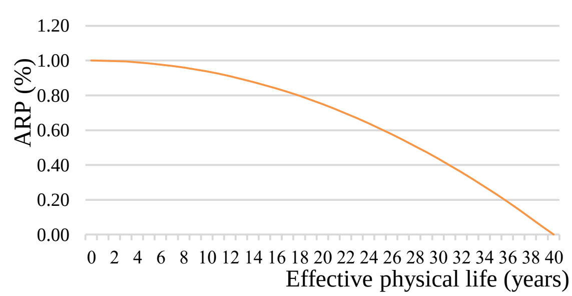

Fig.7. Building deteriorates curve

As it can be seen in Figure 6, the slope of the building deteriorates over time. This erosion can include materials used in the structure of the building (structure and architecture) or its installation equipment (electrical and mechanical installations). Examining the materials and equipment used in the building (library studies, Internet, equipment company data, etc.), it was found that with corrective and preventive maintenance, the process of component failure can be slowed down (slope speed). Descending slows down building wear). In periods of 10 to 15 years, by renovating expensive components and parts, the building can be made younger in terms of component quality. This is reflected in the deteriorate diagram of the building.

Figure 8. Shows the effective mutations of optimal reconstruction at 12-year intervals of the useful life of the building. The minimum accepted quality of the building is when the building reaches 20% of its safety and functional conditions. This is when the use of the building is unusable in terms of security and function. One of the main ways to increase the economic useful life of a building is to maintain the building. Maintenance and, if necessary, renovation of the building have a significant impact on the valuation of the building and the market price of the building. Because maintenance does not affect the failure path but restores the equipment to a healthy condition.

As it can be seen in Figure 8, the useful life of the building is 37 years, and the useful life of the building with repairs and Lifetime maintenance and renovation is 52 years for periods of 12 years. That means 15 years to increase the useful life of the building.

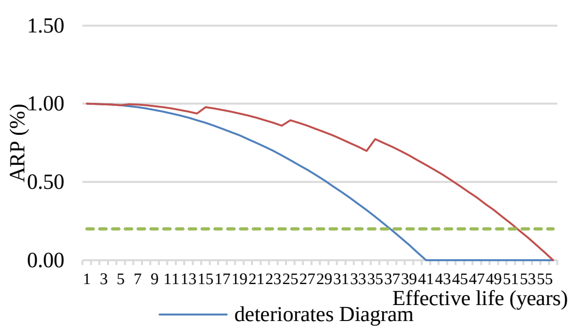

Fig.8. Diagram of the effect of maintenance on increasing the life of the building

5. The Design Process of Building Maintenance Checklist

In this research, to design a sample checklist, the Delphi method has been used and the opinions of construction and maintenance experts have been used. Updating a checklist and monitoring its periodicity is the responsibility of the building maintenance manager.

The person in charge of the maintenance manager of the building is responsible for implementing the requirements of the present research. This person has some responsibilities, such as preparing a maintenance checklist and contract, inspecting, obtaining approval and following up on all matters related to building maintenance, and archiving their documents in the building maintenance file [30].

5.1. Steps to Prepare a Maintenance Checklist

In this section, the process of preparing and compiling a checklist is shown. Initially, building elements to structural components, architecture, electrical installations, mechanical installations, firefight control, and gas supply installations in accordance with the categories of building design and implementation are categorized. After classification, the specifications of all equipment (type, model, useful life, etc.) are collected and archived from the manufacturing companies (catalog, questions from technical officials, etc.). In the last stage, it is necessary to compile the schedule of visits, separately in the form of daily, weekly, and other. Visual forms and provide them to the relevant official. The steps for preparing a checklist are shown in Figure 9. Important criteria in preparing a checklist are as follows:

- Can be used and understood by non-experts
- Specify the time of visits
- Cover all building components
- The sequence of visits should be based on construction categories to make it easier to search for visited sites

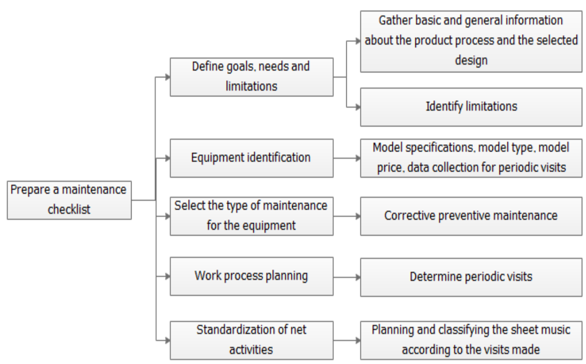

Fig.9. Steps to prepare a maintenance checklist

5.2. Key Areas of Maintenance

Key areas for optimal maintenance and replacement of equipment include 1- Required resources, 2- Investigating the replacement of capital equipment, 3- Inspection, and 4- Replacement of parts or components.

To access the mentioned areas, it is necessary to prepare a list for periodic visits and maintenance operations. A maintenance checklist, also known as a maintenance checklist, is a valuable security tool for keeping a building safe with periodic planning, inspections, and maintenance activities. The purpose of a checklist is to describe the condition of a building to provide a reliable basis for the building care team to make a decision, or in other words, to gather the information needed to decide on the choice of maintenance system using expert opinion. Failure to observe the building's care inspections causes mild problems in shorter periods and severe security problems and even threatens the lives of residents. A small problem can work to prevent people from doing their daily chores. For example, power outages in facilities without a generator endanger materials that must be stored in certain temperature conditions, and in turn, can have serious consequences for people's health or lives. Because there are frequent visits, the building attendant should establish a daily checklist and a monthly maintenance checklist of the facility. If a major commercial asset needs to be replaced, further annual reviews will be successful. Failure to create preventive maintenance checklists and timely care for hazards can save time and money in the short term but can lead to more damage in the long run if it does not lead to a serious accident [30].

5.3. Expected Results from a Maintenance Checklist

If in the checklist, all the angles related to the identity card, issues, and problems of devices and equipment are considered, the following results are obtained.

- Reduce maintenance costs
- Minimize downtime due to failure of equipment, facilities, and devices
- Always ready to operate equipment and facilities that are in Reserve or Standby mode.
- Minimize the number of times equipment and devices fail
- Non-interference of stop time for repair or operation schedule
- Increasing the productivity of equipment and devices
- Increase the reliability of equipment and devices

Cases that cover the preparation and implementation of checklists. In connection with the preparation of the checklist, four different axes are covered [30]:

(1) Repair and maintenance: As explained, the preparation of a maintenance checklist will play a very important role in the maintenance of equipment and facilities. Proper maintenance and repair will increase the useful life of the devices and reduce their costs.

(2) Energy: The International Energy Agency in Developed Countries, the Asian Productivity Organization in Developing Countries, and other small and large institutions were established with the aim of sound energy management. The main goal of these organizations was to save energy consumption, control energy supply and demand, optimize energy consumption, reduce emissions, and so on. One of the branches of performing and implementing optimization in energy consumption can be compiling a checklist related to equipment and facilities. Because the implementation of the clause of points mentioned in the checklist will play a very effective role in reducing energy consumption.

(3) Optimal operation: Adherence to the schedules provided for the checklist can play a very important role in the optimal operation of equipment and related facilities. The phrase "prevention is better than cure" applies not only in the field of health but also in this area. Proper preparation and implementation of a checklist for the maintenance of equipment and building facilities have a very decisive role in increasing the productivity of this equipment.

(4) Safety of persons and safety of equipment: The role of the checklist in observing the safety tips of people and equipment cannot be ignored. Due to the non-observance of these points, many dangerous accidents have occurred. It is no exaggeration to say that the necessary predictions about them have not been made and that they have ultimately led to catastrophes.

5.4. The Proposed Checklist of Building Maintenance

Field reports of authors of the present research that most building owners and managers do not have sufficient knowledge of building repairs and maintenance, and don’t know the maintenance of the building and repairing the damage that has occurred [31, 32]. Also, in case of failure, they use inexperienced specialists to reduce the cost of wages.

In the present framework, the building checklist is divided according to the categories of the building (structure, architecture, mechanical installations, electrical installations, gas supply installations, fire regulations) at the time of design and execution. The list of periodic inspections of the sample architecture section is summarized and shown in Table 2. Periodic inspections were collected from library resources (Topic 22 of Iran National Building Regulations, ISO-686-1 ~ 10 Standards, etc.) and questions from experts, equipment sales officers, etc by using the Delphi method.

Given that one of the most important items is the cost of equipment (especially with high amounts of energy costs) energy consumption, so in the division of different parts of maintenance, this part is also considered separately. To evaluate the eleven visits made in a specific period, two incomplete and healthy selections are included in the checklist. It should be noted that if the building component is healthy, the healthy part should be marked, and if any damage is observed, the incomplete cell should be marked and recorded in the visit report form (weekly, monthly, etc.). The maintenance responsible should inform the experts on the relevant field and fix the failure. A sample checklist of the architecture section is shown in Table 3. Due to a large number of checklist items, only one part of the checklist is mentioned in this article which is related to the architecture section of the building. The sample checklist has been implemented by authors in private sector buildings for over 5 years. Any building needs a special checklist based on the building’s condition and specifications, materials, etc. Designing, validating, and implementing each building’s checklist is one of the responsibilities of the building maintenance manager.

If there is a failure, it is necessary to use experts to fix the failure. Therefore, a form should be prepared after visiting to explain: causes of failure, cost, materials, and explanations of its elimination in the desired form. These forms record the condition of the building and the work done and specify for visits or information on the condition of the equipment, so it is necessary to file and archive all documents.

Table 2. List of Architectural Periodic Inspection

Monthly	Inspect the escape stairs and make sure of the roads leading to it
Monthly	Inspection of the internal condition of the building including (cracks, roof rise, leaks, etc.)
Monthly	Visits to relevant doors, windows, and fittings
Seasonal	Inspection of the building facade and elimination of existing defects

Seasonal	Inspection of roof insulation and condition of existing waterways
Seasonal	Visit the exterior and grounds of the building

Table 3. Architecture checklist

Visiting place	Row	Visits	Defective	Healthy	Periodicity of visits
Architecture					
Earth leveling	1	In complexes where the land has a slope, the necessary measures should be taken to prevent soil erosion and the accumulation of stagnant water			Every two years
	2	Trees and vegetation on the site, including trees that are dangerous to the building (roots that extend to the foundation or substructure, or trees may fall on the building)			
	3	All public thoroughfares, parking lots, entrances, and exits of people and cars, stairs and similar spaces must comply with the rules and without any barriers, always open for traffic, and in good health and Keep safe			
Roof and balcony	4	Clean the ridges and gutters of the roof and keep them dry			Every two years
	5	Clogging in roof gutters and gutters should be checked and removed.			
	6	Check the slope of the roof			
	7	Check the connections of the ceiling to the wall			
	8	Check the roof insulation. (Check for any bumps or cracks in the roof)			
	9	Inspect and repair cracks and seams			
	10	Repair joints and grouts as soon as possible			
	11	Ponds on asphalt or roof mosaic on the roof should be cleaned after rain			
	12	If moisture is observed in the ceiling, it should be checked as soon as possible by a competent expert and action should be taken to eliminate it			
	13	Control of non-clogging and proper operation of chimneys			
	14	Control of heating pipes and installations on the roof			
	15	Roof control cap roof			
	16	Fences should be inspected for connections, rust and, fire standards.			

6. Conclusion

The building is an asset and maintaining it, is very important in the long run. Buildings naturally deteriorate for a variety of reasons, including climate change, occupant use, the passage of time, and their quality level is lower than the standard level. When these issues are not taken seriously in the quality of the building, they can cause dangerous and irreparable problems. The costs of these events are often higher than the costs of maintenance.

The average life of a building in Iran is 30 years on average, while the average life of a building in the world is between 80 and 100 years. This causes premature demolition and reconstruction of structures during their lifetime, which leads to the production of construction waste. Generally, the life cycle costs of a building justify the existence of a building net program. Building maintenance, in addition to the benefits of maintaining or improving the quality of the building, can also create jobs.

The purpose of this research is to implement building maintenance management and for this purpose, it proposed a framework. The quality of implementation of this framework and its effectiveness depends on the building maintenance manager. Because all necessary measures must be implemented, monitored, and evaluated by the building maintenance manager.

This framework has several steps and is based on mathematical models. First, the building manager must design and update the appropriate maintenance checklist of the building according to the condition and specifications of the building. The manager must then conduct periodic inspections of the building on time and register the existing records into the building information management system. The manager should, if necessary, carry out repairs and renovations by expert teams. The technical and economic useful life of the building should be estimated and recorded annually using mathematical and life cycle cost (LCC) models, respectively. Based on the results of the evaluation, the policy of maintenance, repair, demolition, and renovation, or even sale of the building is determined.

In this research, using the Delphi method and conducting field research and purposeful interviews with building maintenance specialists, a sample checklist for building maintenance was introduced. The checklist was divided according to the grouping of construction categories in the design and implementation stages (structure, architecture, electrical and mechanical installations). The important point in building inspection is the time of periodic inspection which was determined as daily, monthly and seasonal.

References

[1] Monzón-Chavarrías, M., López-Mesa, B., Resende, J. and Corvacho, H. The nZEB concept and its requirements for residential buildings renovation in Southern Europe: The case of multi-family buildings from 1961 to 1980 in Portugal and Spain. Journal of Building Engineering, p.101918, (2020).

[2] Farahani, A., Wallbaum, H. and Dalenbäck, J.O. Optimized maintenance and renovation scheduling in multifamily buildings–a systematic approach based on condition state and life cycle cost of building components. Construction management and economics, 37(3), pp.139-155, (2019).

[3] E. Zavadskas, A. Kaklauskas, E. Bejder, "Raising the efficiency of the building lifetime with special emphasis on maintenance", Facilities, (1998), Vol. 16 Issue: 11, pp.334-340.

[4] Ghanbari, M., Abbasi, A.M. and Ravanshadnia, M. Production of natural and recycled aggregates: the environmental impacts of energy consumption and CO2 emissions. Journal of Material Cycles and Waste Management, 20(2), pp.810-822, (2018).

[5] Ghanbari, M., Monir Abbasi, A., & Ravanshadnia, M. (2017). Economic and environmental evaluation and optimal ratio of natural and recycled aggregate production. Advances in Materials Science and Engineering, 2017.

[6] Ghanbari, M., Abbasi, M. A., & Ravanshadnia, M. (2017). Environmental life cycle assessment and cost analysis of aggregate production industries compared with hybrid scenario. Applied Ecology and Environmental Research, 15(3), 1577-1593.

[7] Rajabi, R., & Ghanbari, M. (2017). Identifying and Prioritizing Green Building Parameters in the Implementation of Sustainable Development Management with an Energy Approach. In ICCREM 2016: BIM Application and Off-Site Construction (pp. 535-546). Reston, VA: American Society of Civil Engineers.

[8] D. Arditi, Member, ASCE, and Manop Nawakorawit, "Issueus in Building Maintenance: Property Manager's Perspective", Journal of Architectural Engineering, (1999).

[9] Silva, J.M. and Falorca, J. A model plan for buildings maintenance with application in the performance analysis of a composite facade cover. Construction and Building Materials, 23(10), pp.3248-3257, (2009).

[10] Nägeli, C., Farahani, A., Österbring, M., Dalenbäck, J.O. and Wallbaum, H. A service-life cycle approach to maintenance and energy retrofit planning for building portfolios. Building and Environment, 160, p.106212, (2019).

[11] Goulouti, K., Padey, P., Galimshina, A., Habert, G. and Lasvaux, S. Uncertainty of building elements' service lives in building LCA & LCC: What matters?. Building and Environment, p.106904, (2020).

[12] Kwon, S.H., Chun, C. and Kwak, R.Y. Relationship between quality of building maintenance management services for indoor environmental quality and occupant satisfaction. Building and Environment, 46(11), pp.2179-2185, (2011).

[13] Kobbacy, K.A.H. and Murthy, D.P. eds. Complex system maintenance handbook. Springer Science & Business Media, (2008).

[14] N. Kwon, K. Song, Y. Ahn, M. Park, Y. Jang, "Maintenance cost prediction for aging residential buildings based on case-based reasoning and genetic algorithm", Journal of Building Engineering, (2019).

[15] Rodriguez, B.X., Huang, M., Lee, H.W., Simonen, K. and Ditto, J. Mechanical, electrical, plumbing and tenant improvements over the building lifetime: Estimating material quantities and embodied carbon for climate change mitigation. Energy and Buildings, 226, p.110324, (2020).

[16] Mid Azree Othuman Mydin, "Significance of Building Maintenance Management System Towards Sustainable Development: A Review", Journal of Engineering Studies and Research - Volume 21 (2015) No. 1.

[17] Ferreira, C., A. Silva, J. de Brito, I. S. Dias, and I. Flores-Colen. "The impact of imperfect maintenance actions on the degradation of buildings' envelope components." Journal of Building Engineering 33 (2020): 101571.

[18] Dhillon, B.S. Life cycle costing for engineers. Crc Press, (2009).

[19] Wang, B. and Xia, X. Optimal maintenance planning for building energy efficiency retrofitting from optimization and control system perspectives. Energy and Buildings, 96, pp.299-308, (2015).

[20] Ben-Daya, M., Duffuaa, S.O., Raouf, A., Knezevic, J. and Ait-Kadi, D. eds. Handbook of maintenance management and engineering (Vol. 7). London: Springer, (2009).

[21] Au-Yong, C.P., Ali, A.S. and Ahmad, F. Improving occupants' satisfaction with effective maintenance management of HVAC system in office buildings. Automation in Construction, 43, pp.31-37, (2014).

[22] Yang, C., Shen, W., Chen, Q. and Gunay, B. A practical solution for HVAC prognostics: Failure mode and effects analysis in building maintenance. Journal of Building Engineering, 15, pp.26-32, (2018).

[23] Nzukam, C., Voisin, A., Levrat, E., Sauter, D. and Iung, B. A dynamic maintenance decision approach based on maintenance action grouping for HVAC maintenance costs savings in non-residential buildings. IFAC-PapersOnLine, 50(1), pp.13722-13727, (2017).

[24] Temeljotov, S.A., Bjoerberg, S., Boge, K. and Larssen, A.K. Increasing attractiveness by LCC facility management orientation. IFAC-PapersOnLine, 48(3), pp.149-154, (2015).

[25] Hou Yin Lee, H., Scott, D., Overview of maintenance strategy, acceptable maintenance standard and resources from a building maintenance operation perspective, Journal of Building Appraisal, vol. 4, (2009), p. 269-278.

[26] Md Azree Othuman Mydin., "Significance of building Maintenance Management system towards sustainable development: A review", Journal of Engineering Studies and Research, (2016).

[27] Sarbini, N. N., Ibrahim, I. S., Abidin, N. I., Yahaya, F. M., & Azizan, N. Z. N. (2021). Review on maintenance issues toward building maintenance management best practices. Journal of Building Engineering, 102985.

[28] Jokinen, T., Ylén, P. and Pyötsiä, J. Dynamic model for estimating the added value of maintenance services.

Proceedings of the International System Dynamics Society, (2011).

[29] Wilkinson, A., Dainty, A., Neely, A., Brax, S.A. and Jonsson, K., 2009. Developing integrated solution offerings for remote diagnostics. International Journal of Operations & Production Management, (2009) Apr 24.

[30] ONBR. "National building regulations, part 22: Maintenance of Buildings". Office of National Building Regulations, Tehran, Iran, (2013).

[31] Bucoń, R., & Czarnigowska, A. (2021). A model to support long-term building maintenance planning for multifamily housing. Journal of Building Engineering, 44, 103000.

[32] Abdul-Rashid, R., & Ahmad, A. G. (2011). The implementation of maintenance works for historical buildings-a review on the current scenario. Procedia Engineering, 20, 415-424.

[33] International Organization for Standardization. "ISO 15686?7: 2006-Buildings and constructed assets-Service life planning-Part 7: Performance evaluation for feedback of service life data from practice." (2006).

[34] Conejos, S., Langston, C. and Smith, J., 2011. Improving the implementation of adaptive reuse strategies for historic buildings. Le Vie dei Mercanti SAVE HERITAGE: Safeguard of Architectural, Visual, Environmental Heritage. Naples, Italy, (2011).

[35] Langstone, C, "Validation of the Adaptive Reuse Potential (ARP) Model Using IconCUR", Facilities, (2012), 4-3[30], pp. 123-105.

[36] SCI, "Iran Statistical Yearbook 2017-2018: Construction and Housing", Statistical Centre of Iran, Plan and Budget Organization, Vice Presidency, (2018).

[37] Milić, V., Ekelöw, K., Andersson, M. and Moshfegh, B. Evaluation of energy renovation strategies for 12 historic building types using LCC optimization. Energy and Buildings, 197, pp.156-170, (2019).

[38] Hartman, J.C. and Tan, C.H. Equipment replacement analysis: a literature review and directions for future research. The Engineering Economist, 59(2), pp.136-153, (2014).

[39] Ghanbari, M., Ramezani, S., Maquez, A. (2020). The Optimal Prioritization of the Replacement of Critical Equipment in Industrial Complexes by Combining LCC and NSGA-II. International Journal of Industrial Engineering and Management Science, 7(2), 64-72. doi: 10.22034/ijiems.2021.290126.1040.

[40] Langston, C. & Shen, L. Y. "Application of the adaptive reuse potential model in Hong Kong: a case study of Lui Sheg Chun", International of Strategic Property Management, 11, pp. 207-193, (2007).