Planned Preventive Maintenance Activities: Analysis of Guidance Documents

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Abstract Nowadays the management of public built assets gains a significant importance owing to their size, social relevance and the corresponding working, operational and maintenance costs. Since it is economically relevant to the total cost of a building, the activity of maintenance management cannot be done in an improvised and casual way. In this document some of the reasons for the increased interest and development of several researches works in the area of building maintenance in Portugal are presented. Documents that provide guidance to the planned preventive maintenance activities are analysed in a general way and four of them in detail. The information contained in these four documents was applied to the study of planned activities for some current components existing in primary school buildings, in Lisbon. The analysis revealed that these documents do not address all the construction elements, systems and equipments and exterior spaces equally. These discrepancies between documents can raise difficulties in carrying out benchmarking actions for LCC or LCA assessment purposes. It is important to continue the work under development to standardize this information and create national, European or international references databases.

Keywords Planned maintenance · Guidance documents · Databases · Elementary public schools

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1 Introduction

Nowadays the management of public built assets gains a significant importance owing to their size, social relevance and the corresponding working, operational and maintenance costs. Since it is economically relevant to the total cost of a building, the activity of maintenance management cannot be done in an improvised and casual way.

In this document some of the reasons for the increased interest and development of several researches works in the area of building maintenance in Portugal are presented. Documents that provide guidance to the planned preventive maintenance activities are analysed in a general way and four of them in detail: a French source "La maintenance des bâtiments en 250 fiches pratiques", a Spanish source "Fitxes rehabilitació of ITeC", an English source "Housing component life manual" and a North American source "The Whitestone facility maintenance and repair cost reference 2009–2010".

The information contained in these four documents was applied to the study of planned activities for some current components existing in primary school buildings, in Lisbon.

2 Building Maintenance in Portugal

The maintenance activity in Portuguese public buildings and infrastructures has been, over the years, underestimated. The shortage of available resources assigned to the governmental and municipal buildings' maintenance has led to an accelerated degradation of both physical and functional spaces, with negative impacts on services and user satisfaction, to property devaluation and to the declining image of the institutions themselves.

Some reasons for this traditional attitude are related to the absence of legislation requiring long-term consideration of maintenance, as for example, the Italian law 109/94 which requires the development of maintenance plans for every public work's design, providing the scheduled maintenance activities for guaranteeing over time the wanted functionalities, characteristics of quality, efficiency and economic value [1].

The new Portuguese building regulation, still under discussion, introduces requirements for durability and maintenance purposes. According to it, the development of an inspection and maintenance building manual as part of the execution project is mandatory. Three definitions are introduced in this new regulation: building service life, component service life and service life required by the owner/promoter. The building service life corresponds to the period during which the structure shows no degradation of materials. The building component's service life must be set by the manufacturer. The building's service life is a requirement set by the owner/promoter and, when it is not defined, it is considered, by default, 50 years.

Legislation relating to safety and health on temporary or mobile construction site forces the owner/promoter to provide a building technical compilation that includes all the necessary information to take into account in the use, conservation and maintenance activities, taking into consideration the safety and health of those who deliver them. This document shall include in particular:

- Complete identification of all actors;
- Technical information on the overall project and specialities, including written technical specifications, as built drawings and structural aspects, services, systems and materials that are relevant to the prevention of occupational hazards;
- Technical information relating to installed equipment that is relevant to risk prevention concerning its use, conservation and maintenance;
- Necessary information to plan the maintenance activities involving access and circulation with particular risks for the workers.

Although this legislation was published in 2003, the preparation of the building technical compilation is far from current practice. The existence of other priorities related with lack of time, meeting deadlines already short, the intervention of many actors with various scattered information, are presented as an obstacle to the development of this important document.

2.1 Reasons for the Turning Point

Nowadays there are more reasons for an increased attention to buildings operation and maintenance phases in Portugal. There is, in general, a very sharp decrease in the construction of new buildings, especially for housing purposes. Small construction companies have to adapt to this new market reality to survive.

In the public sector, the economic considerations associated with the management of property assets, are on the agenda in face of the present severe financial constraints. The public owners have been aware of the costs associated with the working, operational and maintenance activities. Since it is economically important to the building total cost, the maintenance management cannot be done in an improvised and casual way. It is necessary to start adopting practices aiming at a sustainable approach by rationalizing and optimizing the available resources through the implementation of integrated and cost-effective solutions, allowing an acceptable performance of buildings throughout its life cycle.

Finally, with the emergence of public–private partnerships for the health area in 2002 and the modernization program for the secondary school buildings in 2007 there was an increased need of knowledge on best practices in building maintenance.

2.1.1 Public–Private Partnerships

In 2002, a program of public–private partnerships (PPP) for the health area was created. The PPP model, established by Decree-Law No. 185/2002, provides for the hiring of a private entity to perform a global mission, covering design, construction, financing, maintenance and operation of building hospitals and also the general management of the hospital including the provision to clinical services.

This new procurement model requires a clear specification of the Operation and Maintenance Manual (O&M) and the definition of life cycle programs for the facilities, before its construction. The private facility management is responsible for establishing all the procedures, activities and resources deemed necessary to maintain the good performance of the buildings and the quality of the services provided throughout the duration of the contract. After 30 years (maximum period allowed) the building shall revert to the public partner in perfect conditions.

This innovative approach, forced the study of maintenance requirements, during the design phase, considering the building life cycle and its related costs. However, the lack of reliable information within the Portuguese construction industry also raised some relevant issues such as what types of planned maintenance work must be performed in order to keep the components and systems in good condition, with which frequency it must be performed or when is the end of the service live (total replacement).

2.1.2 Modernization of Secondary Schools

In 2007, the modernization program of secondary schools was launched by the government. This program aims to restore and modernize school buildings. The procurement format included the provision of maintenance services for a period of 10 years. Services to be provided by the contractor include preventive maintenance, corrective maintenance, functional maintenance and large conservation.

The preventive maintenance includes works to be completed according to Preventive Maintenance Plan and necessary to prevent and reduce the degradation of operability functions and of school spaces. The maintenance plan is drawn covering all the actions on a monthly, quarterly, semiannual and annual base.

The corrective maintenance includes works that aim to correct any anomalies resulting from misuse or natural degradation of facilities and equipments.

In functional maintenance the work to be done at the request of the school buildings' management entity is included. The large conservation includes the operations, to be held 5 and 10 years after the end of the building rehabilitation, to restore the functional, safety or accessibility conditions, if appropriate.

3 Collecting Planned Preventive Maintenance Information

Information on planned maintenance activities, currently performed in public buildings, is scattered in several divisions and governmental and municipal entities, responsible for its management and use. It is necessary to gather and process available information to use it in buildings' life cycle analysis, under real conditions.

The implementation of a monitoring system applicable to a sample of buildings would also be desirable. In 1980, Urien [2] referred to the research work conducted by CSTB, aiming at the development of methodologies to determine the maintenance and operational costs of several types of buildings and to relate these costs with technical solutions adopted at the design phase. An observation system covering 30,000 dwellings was set up, with construction age ranging from 10 to 46 years and about 190 different maintenance activities operations were collected. The results for exterior finishes, roofs and exterior openings elements and some related data for life cycle costs purposes were presented.

On the other hand, there is a lot of technical information in the Portuguese construction sector, but it is scattered in several study areas, such as materials, components or systems used in buildings. Much of this documentation include, for specific components, the main maintenance activities to be performed and the main factors that may affect their performance. So it is important to collect the scientific information covering the national regulatory documents and national maintenance recommendations, as a starting point for a national reference database.

Neely and Neathammer [3] presented in 1991 the methodology used in preparing four databases with the information needed for determining life cycle costs of building facilities depending on functional use. These databases were developed using expert knowledge and practical and professional experience. The study follows the governmental decision to construct army related facilities with the lowest life cycle cost and not facilities that have the lowest initial construction cost. The absence of maintenance data to support this kind of analysis involved a great initial work, including:

- Identify all of the possible components that could exist in buildings of different functionalities;
- Identify all tasks that had to be performed to maintain the component in standard operating order. This work was developed by professional in each trade. Task resource information was developed for each task and recorded in a format containing: labour hours, material costs and indirect labour hours to cover job planning, material collection or breaks. Three frequencies of task occurrence were developed. The high frequency is defined as the earliest time a task would have to be performed. The low frequency is defined as the latest time a task would have to be performed, and the average frequency is defined as the most probable time of occurrence.

This last information was introduced in the most detailed database containing the labour, equipment and material hours per square foot. The second database contains both yearly component replacement and annual reoccurring maintenance cost per square foot by building age and building use, e.g. aviation unit maintenance hangars, hospital or child support center. The third database contains the labour, equipment and material hours per square foot by building age and building use. An average cost by facility type, in costs per square foot (4th database content) and maintenance resources requirements were obtained for the first 120 years of building life.

Knowing this information allows determining useful data, namely:

- Predict an annual cost when only the building floor is known, when the floor area and the current functional use is known (different level of information during design phase development);
- Predict an annual cost when the floor area, current use and age of the facilities are known (important for building stock annual financial management).

Finally it is worth noting that one objective of this study was to determine the high-cost components and tasks that can be assumed to be cost drivers in building maintenance—the major cost and replacement tasks. This information could be used to determine the least amount of data required to be known about a building to develop accurate resource prediction and could also be used to identify possible areas of future research to reduce the total building maintenance cost (resource reduction through technologies advances or productivity improvements) [3].

3.1 Some Key Documents

In 1993, the Architectural Institute of Japan published the English edition of the "Principal Guide for Service Life Planning of Buildings" [4]. It concerns the fundamental concept of durability within each stage of the life cycle of buildings, such as planning, design, contract, construction, utilization, maintenance and modernization and demolition. Responsibilities are assigned to all stakeholders: owner, designer, constructor and user. It is stated that the maintenance planning to ensure the appropriate level of performance and the durability of a building is to be provided by the designer, and the characteristics of this planning are preferably notified to the client and the constructor.

The guide provides recommended classes of planned service life for whole building and different parts of building elements and components. This document takes into consideration not only the physical deterioration, but also aspects concerning the flexibility and obsolescence of the building [4, 5].

Since the prediction of the service life is an important item in the design for durability, it is stated that it involves difficult problems, to be solved in the future, and therefore at present there is no choice but to continue the efforts for estimating the service life as correctly as possible based on the present available knowledge and experience.

The guide provides some examples of the method for predicting service life of some building elements and components determined by deterioration factors: factors relating to the inherent durability characteristics (performance of materials, design level, works execution level, maintenance level) and factors relating to deterioration (site and environment conditions and building conditions).

The Canadian Standard S478-95 (R2007) [6] provides guideline on durability of buildings. Durability requirements and quality assurance are emphasized as an essential consideration in every stage in the design service life of any building as, for example, design (detail, specifications), tendering, construction, handover, operation and maintenance and renovation.

It contains generic advice on the environmental agents and other mechanisms that have an impact on the durability of building components and materials, and provides advice for incorporating requirements for durability in the design, operation, and maintenance provisions for buildings and their components. It identifies the need to consider long term costs.

The British Standard BS 7543:2003 [7] gives guidance on durability, required and predicted service life and design life of buildings and their components. It also gives guidance on presenting information on the service life and design life of buildings and their components and/or parts when a detailed brief is being developed. The various conditions that influence the durability prediction and building life include workmanship and maintenance and the practical problems of handling, installing and inspection of components in a building site. Annex A gives information on the prediction of durability for buildings and parts of buildings and guidance on the way agents can affect service life. Agents that can affect the service life of building components and materials: temperature, radiation (solar radiation, thermal radiation), water, normal air constituents, air contaminants, freeze/thaw, wind, biological factors, stresses factors, chemical incompatibility factors and use factors.

This standard says that the maintenance, repair and replacement of buildings and parts of buildings provide a wealth of experience on durability. However, in all but a few cases, there is a lack of systematically collated data that can form a basis from which durability can be predicted with any certainty.

The design life is defined by the designer in discussion with the client and aims to support the client's performance specifications and having the following information is essential:

- Time (or a time measure such as running time or cycles of use) against which durability is to be assessed;
- Conditions in which the item will have to perform (i.e. environmental conditions and levels of maintenance and use);
- Performance point at which functions become unsatisfactory.

The standards' family ISO 15686 provides the actual framework and guidance for buildings and constructed assets service life planning. It consists on:

- Part 1: General principles and framework. Identifies and establishes general principles for service life planning and a systematic framework for undertaking service life planning of a planned building on construction work throughout its life cycle. Reference service live (RSL) is defined as a documented period in years that the component or assembly can be expected to last in a reference case under certain well-defined service conditions. RSL is not defined and it is anticipated that national and international guidance will be developed through collaboration between owners, suppliers, materials specialists and constructors;
- Part 2: Service life prediction procedures. Describes generic procedures for testing the performance of components, materials and assemblies to provide service life predictions;
- Part 3: Performance audits and reviews. Deals with measures to ensure that the life care of a constructed asset is considered through each stage of decision making from initial briefing, through design and construction, to occupancy and eventual disposal and reinstatement of the site;
- Part 4: (under development) Service life planning using IFC based Building Information Modeling;
- Part 5: Life-cycle costing. Gives guidelines for performing LCC analysis of buildings and constructed assets and their parts;
- Part 6: Procedures for considering environmental impacts. Describes how to assess, at the design stage, the potential environmental impacts of alternative designs of a constructed asset. It identifies the interface between environmental life cycle assessment and service life planning;
- Part 7: Performance evaluation for feedback of service life data from practice. It aims to describe a generic methodology, including the terms to be used, that provide guidance on the planning, documentation and inspection phases, as well as on analysis and interpretation of performance evaluations, both on the object (single building) and network (stock of buildings);
- Part 8: Reference service life. Provides guidance on the provision, selection and formatting of reference service-life data and on the application of these data for the purposes of calculating estimated service life using the factor method. The standard gives the following criteria to the data records [8]:
  - General information;
  - Scope (including purpose);
  - Material/component;
  - Methodology;
  - Reference in-use conditions;
  - Degradation agents;
  - Critical properties and performance requirements;
  - Reference service life;
  - Data quality;
  - Reliability of data;

  - Additional information considered;
  - References;

    The standard also gives the rules for validation of data sources that are not fully in accordance with the standard. Depending on the quality of the data source, a laborious process with more extensive research and validation by experts has to take place [8];

- Part 9: Guidance on assessment of service life data. Gives guidance for the derivation and presentation of reference service-life data. It is applicable to manufacturers or producers that provide reference service life data for use in service life planning in accordance with ISO 15686-1; ISO 15686-2, ISO 15686-3, ISO 15686-5 and ISO 15686-6;
- Part 10: When to assess functional performance. Establishes when to specify or verify functional performance requirements during the service life of buildings and buildings—related facilities, and when to check the capability of buildings and facilities to meet identified requirements;
- Part 11: Terminology.

3.2 Some Available Databases

In 2003, Chew [9] presented a research carried out by the National University of Singapore (NUS) and the Building Construction Authority (BCA) in Singapore [10]. Some of the outputs of this study were:

- Database called "Defect library" with information about types of defects and their causes, maintenance and diagnostic methods, good practices and guidelines which can be applied during the design and the construction stage to control repetitive problems;
- Database called "Material manual" with information on the performances and durability of materials under tropical conditions;

This "Material manual" offers information about building materials used in façade, internal wet areas, basements and roofs. It focuses on the various performances including durability, sustainability and clean ability of materials under tropical conditions [9]. These two databases are available on the internet [11].

In the UK, The Building Life Plans (BLP), presented by Mayer and Bourke in 2005 [11], have made available on the internet a construction durability database comprising:

- Durability data on over 800 component types, listed for fabric and building services;
- Durability rankings for component types described generically by criteria which determine durability;
- Adjustment factors which may increase or decrease durability;
- Maintenance and inspection requirements;

- Design, installation, commissioning assumptions;
- Key failure modes and key durability issues;
- Notes about durability issues specific to components and related references;
- Detailed methodology for using durability rankings to determine expected service lives.

The BLP durability assessment was developed based on BLP's 15 years research and practices experience in assessing component durability for latent defect warranty purposes. Durability data which was already in a published format was inputted into a database and an opportunity was taken to cross link durability with construction industry standard codes. The information sources used was based on HAPM methodology and in information generally available in the public domain. Broadly listed in order of reliability [11]:

- International, European and British Standards;
- Authoritative publications and independent certifications;
- Trade associations;
- Manufacturers;
- Practical and professional experience.

For building services systems the "Building services component life manual" [12] presents a total of 20 components, divided into a number of subtypes which represent the most common types, materials and/or configurations available in the UK. For each component subtype, a series of distinct specifications benchmarks, or quality levels, is provided and each description is assigned a life assessment (ranging from 5 to 35+ years). A further life class (designated "U" for unclassified) is assigned to components that fail to comply with relevant British or European standards or are unsuitable for the purpose specified, or where there is insufficient information provided to enable a life to be allocated.

The life assessments assume compliance with good practice in design and installation, a normal level of maintenance, and typical exposure and use conditions. When the service life is likely to be affected by changes in these factors, positive and negative adjustment factors are provided to enable lives to be amended. This methodology is similar to the followed by HAPM and BPG Component Life Manuals.

For each component the expected service lives for a set of related durability factors and assumptions which are made explicit are presented. For each component, material or assembly the key failure modes and durability issues are presented, which provides a framework for failure mode effect and criticality analysis which underlies the durability rankings assessed for each component (see Table 1).

In the Netherlands, the Dutch Building Research Institute (SBR) published in 1995 a catalogue of the reference service lives of building components. It gives reference service lives of roughly 600 common building components and building services. Data was gathered from various sources and judged by experts. Only service lives on which consensus was reached by these experts were included [8].

Table 1 Extract of cold water pipe work of distribution pipe work table information [12]

Cold water pipe work	
Years	35+
Description	Stainless steel pipe work for water applications to BS 4127 (Specification for light gauge stainless steel tubes, primarily for water applications). Fittings to BS 4825 (Stainless steel tubes and fittings for the food industry and other hygienic applications)
Inspection	Long cycle inspection for external corrosion/damage and joint/fixing integrity
Maintenance	Generally, pipe systems require little or no maintenance if correctly specified. Any maintenance will be in the form of periodic repainting where materials such as cast iron and some types of plastic are exposed to the elements or are installed in a corrosive setting
Key failure modes	External corrosion; internal fouling, scaling, corrosion and vibration, leading to tube leakage and cracking; damage due to excessively high liquid velocity, temperature and/or pressure; reduced flow rate due to partially or fully blocked pipe work
Key durability issues	Corrosion resistance of base materials; overall water quality and suitability of water treatment used, quality of handling, installation and commissioning; quality of protection and/or protective coating on materials to prevent corrosion from the environment in which they are located
Adjustments factors	Installed in adverse (but not severely corrosive) environments: 5 years; Not sleeved through walls: 5 years (not cumulative: the factor that is the largest should be applied)
Assumptions list for design and installation and commissioning are provided	

A review of this service life catalogue is being made by expert judgements in order to publish a new Dutch service life database. This new publication provides service lives of 600 general buildings components, covering: substructure and frame, external walls, upper floors and floor finishes, roofs and roof finishes and window and external doors. Paints are not included as separate products as paintwork is an activity necessary to maintain the life of a large number of construction groups in external walls, and windows and external doors. Internal components, fittings, sanitary appliances and building services were left out of this document. Table 2 gives an extract of the example, provided by Straub [8], for flat roof coverings.

Table 2 Extract of an example of service lives of building components [8]

Flat roof coverings		RSL
Metals	Steel, trapezium, galvanized, coated	50
	Steel, trapezium, galvanized	15
	Aluminium, folded, enamelled	60
	Aluminium, folded, coated	40
	Copper, folded	75
	Zinc plates, 10 % overlapping	25
	Zinc	40

The CSTB and Politecnico di Milano are structuring an international RSL database-proposed tool for building materials and components data collection. This RSL database has been developed to collect a series of grids in which set of RSL are stored and indexed. The set of RSL consists of [1]:

- The duration in years, choosing among different type of RSL distributions;
- The failure mode;
- The selection of the several levels of factors in the grid, according to ISO 15686 factor method.

Complementary data such as year, place, sources, data quality and observations are also provided. RSL according to collected data can have various origins [1]:

- Experience;
- Ageing tests in natural environment;
- Accelerated ageing tests;
- Numerical simulation;
- Bibliographical studies.

3.3 Detailed Description of Four Guidance Documents

Four databases with data on maintenance activities were consulted: a French source "La maintenance des bâtiments en 250 fiches pratiques" [13], a Spanish source "Fitxes rehabilitació of ITeC" [14–16], an English source "Housing component life manual" [17] and a North American source "The Whitestone facility maintenance and repair cost reference 2009–2010" [18].

3.3.1 Spanish Source

The *Institut de Tecnologia de la Construcció de Catalunya—IteC* published in 1991 three books in the areas of building [14], services [15] and urban spaces maintenance [16], respectively. These documents are made available on line by the IteC website and its main goal is to provide in a simple and practical way, the basic information related with buildings maintenance in the Spanish province of Catalonia.

In the first volume, the building is divided into exterior elements, roof covering elements and exterior finishes, windows and doors, and interior elements, covering the finishes, the interior doors and the sanitary and kitchen equipments. A total of 67 elements information are presented in an individual sheet format containing four sections:

- List of the most common anomalies;
- The principal maintenance activities and their frequencies;
- The service life;
- The main factors that causes degradation of the element.

The list of the most common anomalies attempts, according to the authors, to give an idea of the common problems that can cause degradation of each element. This section has an informative function but it can also help detect the possible pathology of the element and find the best way to face the task of maintenance.

The exposure to specific environmental conditions or use factors, defines the risk of degradation of the element which can be high (H), medium (M) and low (L). The level of maintenance required (frequency of execution of maintenance activities) and the element service life, are related with the risk of degradation. Table 3 presents the main factors considered for the classification of the risk of degradation for different kind of elements.

In Fig. 1 an example of the information sheet for an anodized aluminium window [14] is presented. 0 in the periodicity column of a maintenance operation means that this is done regardless of the degree of maintenance.

The volume related to services maintenance includes: smoke evacuation installations, ventilation and waste disposal facilities, HVAC, kitchen facilities, water supply and sewer facilities, valves, pumps and pressure groups, electric and lighting systems, transportation facilities, fire protection facilities and installations of audio and video.

The volume of urban areas includes: fences and gates, paving elements, equipments, services and landscaping.

IteC developed two software packages, one of them for maintenance management of one or few buildings and the other for a large building stock. These informatics applications create all the information related with the buildings, such as the contractual information, stakeholders list, execution development report, products, systems and equipments installed. All technical specifications, containing service life information and use and maintenance instructions, and "as built" project must be included. The maintenance plan is generated according to the constructive solutions adopted, containing the schedule of all the maintenance, technical and human resources, costs, regulatory obligations, requirements for

Table 3 Type of factors considered in risk definition "Manteniment de l'édifici. Fitxes" [14]

Element	Factors defining the risk of degradation
Pitched roof claddings	Rainfall (high, normal or low), temperature range (sudden or smooth), risk of accumulation of leaves and debris (high or low)
Exterior finishes—mortar	Humidity and risk of erosion (high and low) and accessibility to people and cars
Doors/windows: anodized aluminium	Humidity (high, low), exposure to wind and strong winds (low exposure to wind) accessibility to people and cars and sun exposure (high or low)
Interior ceramic floor finishes	Stairs, public use, corridors, work areas and overloads (private use and particular house)
Interior wall finishes stone	Harsh environments for the stone composition, temperature range, humidity and light-coloured stones
Sanitary equipment	Public areas, private areas and occasional use (parking, stores)

WINDOWS. ALUMINIUM
ANODIZED ALUMINIUM WINDOWS

POSSIBLE ANOMALIES:
Surface dirt
Small deterioration in the finish
Joints sealing problems in opening elements
Defect in the functioning of mechanisms

MAINTENANCE ACTIVITIES:

PERIODICITY	H	M	L
Cleaning the frames and glass with appropriate product	0	1	0
Inspection of the state of the finish	0	1	0
Minor repairs in the finish	0	1	0
Inspection of the condition of ironworks	2	4	6
Inspection and lubrication of mechanisms	0	1	0
Inspection of the tightness of the joints	0	1	0
Inspection of drainage	0	1	0

SERVICE LIFE:

	H	M	L
Replacement of window	40	50	60

H High level of
High humidity
High exposure to wind
Acessble to people
High exposure to sun

M Medium level of maintenance

L Low level of maintenance
Low humidity
Low exposure to wind
Not acessible
Low exposure to sun

Fig. 1 Information for the anodized aluminium exterior windows [14]

certification of products, personnel or entities and conditions for hiring of maintenance.

3.3.2 French Source

The French book "La maintenance des bâtiments en 250 fiches pratiques" [13], published for the first time in 1995, presents maintenance activities for 270 elements, distributed in 9 major groups: structure, exterior envelope, roofing and waterproofing, interior construction, plumbing, HVAC, electrical equipments components, other electrical installations, basements and other services and external works and landscaping. Each sheet presents the following information:

- The maintenance activities and frequencies, broken down into five levels: inspection, cleaning and preventive maintenance, light intervention, heavy intervention and replacement;

- The cost of preventive and corrective interventions expressed in percentage of the cost of new construction;
- The regulations and normative references.

In Table 4 an example of the information sheet for an aluminium window [13] is presented.

This guide also presents an evaluation grid to use in building condition assessment. Knowing the building physical condition is an important indicator (among others) to be used in the implementation of a maintenance management system.

Ten summary tables are also provided in this book to help in the analysis of buildings with regulations, covering: asbestos, disabled person, *legionella*, plumbing and painting with lead, fire safety and electrical installations. This analysis gives an important feedback for the definition of maintenance activities, requiring a periodic monitoring by the building stock manager.

Table 4 Aluminium windows sheet information adaptation from Albano [13]

Maintenance operations	Periodicity	Ratio (%)
Inspection	Semester	1
Detailed examination of the windows		
Mechanical resistance and finish window (frame, openings and glazing) inspection		
Control the proper functioning of all mechanisms and hinges		
Open the windows to check its functionality		
Check the water drainage mechanisms		
Preventive maintenance	Annual	1
Cleaning the frames and openings with proper product		
Mechanisms and hinges should be lubricated according to manufacturers recommendations		
If the opening is difficult adjustments should be made in mechanisms (hinges, rollers, sliding components)		
Clean and unclog drains and ducts		
Minor intervention	Whenever necessary	5
Diagnosis: poor orthogonality and difficult in opening movement		
Intervention: verification and if necessary replacement hinges		
Heavy intervention	10 years	35
Diagnosis: cracks between the frame and masonry; infiltration (frame and sill interface); poor orthogonality and difficult in opening movement		
Intervention: treatment of joint between frame and masonry and frame and sill and mechanisms treatment/replacement if necessary		
Replacement	25 years	100
References DTU 36.1 and DTU 37.1		

3.3.3 UK Source

The HAPM (Housing Association Property Mutual Ltd) manual was produced by Construction Audit Limited and published in 1999 in the UK [17].

Although this document has been prepared specifically for insurance purposes its use goes far beyond them. The information is structured into the seven following groups of components: flooring components, walling and cladding components, roofing components, doors, windows and ironworks, mechanical equipment components, electrical equipment components and external works.

In general, each group is divided into types and sub-types that are assigned a score corresponding to one of the following insured lives classes: A = 35+ years, B = 35 years, C = 30 years, D = 25 years, E = 20 years, F = 15 years, G = 10 years, and H up to 5 years. There is also a life class designated "U" (meaning uninsured) which is used where the component does not comply with British Standards or is unsuitable for the purpose specified, or where there is insufficient information presented to allocate an insurance life class.

The life classes embrace good practice, a normal amount of maintenance and typical exposure. General guidelines also include installation in accordance with manufactures' direction, relevant code of practice and British standards and the use of appropriate design details. When non-typical or extreme conditions prevail, adjustments factors are provided. These may be negative or positive depending on whether the deviation from the norm is detrimental or beneficial. Examples of such conditions are indicated in Table 5. Where the life of a component may vary depending on its location in the building (e.g. ground floor, intermediate floor) alternative component life columns are given for different locations.

Data sheets on each component group include a description of each component type, adjustment factors, assumptions, locations, typical maintenance, and specific notes. Table 6 presents an extract of the data in HAPM for aluminium windows.

Table 5 Definitions for the adjustments factors [9]

Conditions	
Normal environment	Inland, with normal urban atmospheric pollution only
Polluted/industrial environment	With airborne sulphur dioxide, acid or alkali pollution, normally from an industrial source
Marine environment	Coastal areas subject to salt spray and/or sea water splashes. It may extend up to 3 km from the coast or tidal estuary depending on prevailing wind and topography
High risk frost locations	Coastal areas subject to salt spray and/or sea water splashes. It may extend up to 3 km from the coast or tidal estuary depending on prevailing wind and topography
With 3rd party assurance	A product with a certificate indicating that ongoing testing and assessment of the product's suitability and/or adherence to claimed standards has been carried out by an independent 3rd party such as the BBA or others

Table 6 Aluminium windows sheet information adaptation from HAPM [17]

Type: windows	Sub types: aluminium
Description	Aluminium windows kite marked to BS 4873 (Specification for aluminium alloy windows); Anodised or liquid organic coated or polyester powder coated. Windows supplied under LHC (London Housing Consortium) bulk quotation arrangement A1
Years	35 (Location: external masonry walls)
Years	35 (Location: external walls timber framed)
Maintenance	If painted, repeat every 5 years. Renew weather-stripping and gaskets every 10 years. Renew hardware every 10 years

3.3.4 USA Source

The "Whitestone Facility Maintenance and Repair Cost Reference 2009–2010" [18] provides maintenance and repair costs from various sources of information and various types of North American establishments. This reference represents the result of 14 years of continuous work from the Whitestone Research Company with several US government agencies and consulting firms that work in this area. This collaboration yielded the information needed to calculate the cost of maintaining a building over its service life, the amount and type of resources associated with this maintenance and the lifespan of the various constituents of the building.

The document uses the North American classification system UNIFORMAT II (classification of asset elements), published by *ASTM*—American Society of Testing and Materials (ASTM E1557 2009 [19]), which includes the following items: substructure (foundation and basement construction), shell (super structure, exterior envelope and roofing), interiors (interior construction, stairs and interior finishes), services (lift, plumbing, HVAC, fire protection and electrical) and equipment and furnishings.

The data presented refer to maintenance and repair activities (M&R) and are divided into: preventive maintenance (PM), unscheduled maintenance (UM) and replacement (R). PM and minor repair consists on scheduled tasks that sustain a component's level of service during a prescribed service life. The UM consists of service calls, emergency response, and other tasks that cannot be individually anticipated and replacement consists of component overhaul or major replacement tasks. These tasks extend a component's service life, and reset the schedule of PM and minor repair tasks. Activities related to facilities operation, such as landscape maintenance, are not included in this book.

The book features 72 maintenance profiles for various types of facilities and equipment, for a study period of 50 years, with the costs of maintenance and repair, per m^2 of building area and as a percentage of replacement value. An example of a maintenance profile of a North American primary school is given in Table 7. The school, of 3.7 m height, has a gross internal floor area of 4,360 m^2, built of reinforced concrete, screed, carpet and vinyl floor tiles and ceilings with

Table 7 50-Year M&R cost summary for an elementary school [18]

Task type	50 year total cost	Annual cost per GSFT	Annual cost as percentage of replacement (%)
PM & minor repair	$1,389,231	$0.59	0.29
Unscheduled maintenance	$1,070,522	$0.46	0.22
Renewal & replacement	$5,470,564	$2.33	1.13
Total	$7,930,317	$3.37	1.63

plaster finish. The building has a replacement cost of $ 9,701,531 [18]. Distribution of maintenance and replacement cost is presented in Fig. 2.

Table 8 present an extract of the information contained in the USA source for aluminium windows.

3.3.5 Summary of the Collected Data and the Main Application Fields

In Table 9 a summary of the data and the main application fields for planned maintenance activities are presented.

4 Preventive Maintenance Activities: Case Study

A study was carried out by Raposo [20] to develop an analysis tool that integrates technical, economic and organizational factors in the implementation of a Maintenance Management System (see Fig. 3).

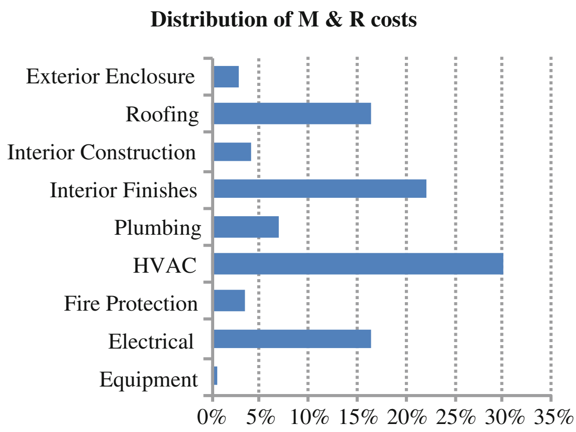

Fig. 2 Distribution of maintenance and replacement cost [18]

Table 8 Exterior aluminium windows sheet information

Aluminium operable window, 24 square feet					
Labour hours	Material costs	Equipment type	Frequency	Task type	Replacement task
Repair (replace) 1st floor—each—trade: carpenter—labour type: contract					
0.330 (2.540)	4.99 (909.66)	None	15 (75)	Major	No (yes)
Repair (replace) 2nd floor—each—trade: carpenter—labour type: contract					
0.330 (3.240)	4.99 (909.66)	None	15 (75)	Major	No (yes)
Repair (replace) 3rd floor—each—trade: carpenter—labour type: contract					
0.330 (3.940)	4.99 (909.66)	None	15 (75)	Major	No (yes)

Adaptation from Whitestone [18]

Table 9 Type of data available in the references listed and application fields in the research study

Type of information available	[18]	[13]	[17]	[14–16]
Service life	Yes	Yes	Yes	Yes
Factors influencing the service life	No	No	Yes	Yes
Description of maintenance activities and their periodicity	Yes	Yes	Yes	Yes
Factors that influence the maintenance activity	Yes	Yes	No	No
Human resources and labour hours per maintenance activity	Yes	No	No	No
Data to calculate the maintenance activity cost	Yes	Yes	No	No
Most frequent anomalies in components and building systems	No	No	No	Yes

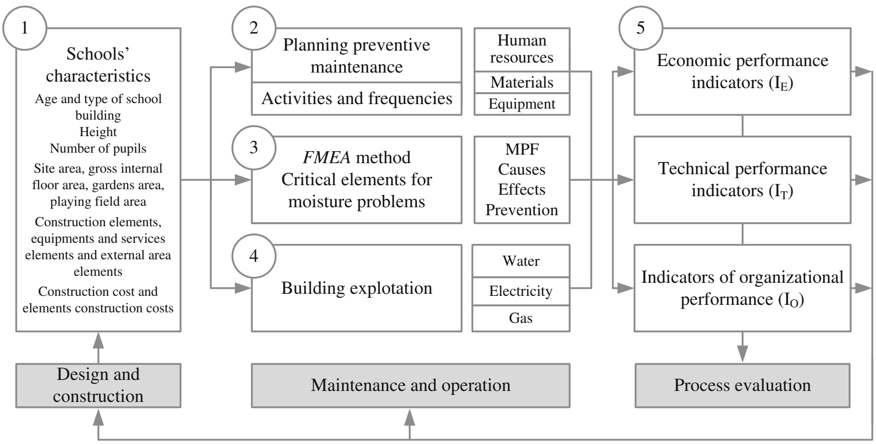

Fig. 3 Maintenance management system (MMS)

In total 17 key performance indicators were defined covering economic and technical performance (IEE, ITT), organizational development (IOO). This methodology was tested on a sample of five primary schools (EB1) in Lisbon.

The planned preventive maintenance activities and the statutory planned preventive activities were established through international references and national regulations consultation and national manufacturer's opinion.

The four databases referred to in detail were consulted and information on preventive maintenance activities was collected, including routine inspections (I), maintenance and cleaning routine (M), and component replacement (R).

4.1 Building Envelope Components

In the five schools studied the exterior envelope is made of double walls with hollow ceramic brick masonry and thermal insulation and exterior windows/doors with anodized aluminium frame and colourless single-pane glass (Fig. 4).

The walls should be subjected to regular inspections every three years and the windows and doors every six months. The condition state of the finishing of the frame, operation and state-setting mechanisms for openings and fittings, condition of gaskets and mastics and verification of clearance at outlets for water flow should be followed [13].

Preventive maintenance of the exterior walls consists in their cleaning and eventual closing of cracks and joints, whenever the conservation status of the walls requires it or once every 10 years [18].

The exterior walls service life exceeds 50 years of the research study, and according to Abate et al. [18] it exceeds 75 years, whereas Albano [13] does not mention any period. The outer openings require a yearly maintenance of hardware replacement, lubrication of door locks and joint replacement. The replacement of windows and doors is indicated every 25 years in Albano [13], with replacement of mastics to occur between 10 and 15 and the fittings around 15 years. The HAPM [17] and Abate et al. [18] differ in terms of the service life of window elements, indicating 35 and 75 years respectively, and of the service life of exterior doors, proposing 30 and 50 years respectively.

Roofs are predominantly of sheet steel and reversed flat roof types. The former must be annually inspected, performing at the same time preventive maintenance activities, such as cleaning the surface and checking the tightness of fasteners;

Fig. 4 **a** São Bartolomeu school and **b** Windows and façade

unclogging the rainwater plumbing and checking the proximity of tree branches. For the latter, inspections should be carried out every six months with maintenance activities to be held annually.

The metal roof's service life is 25 years [13], whereas IteC [14] makes a distinction between the roof metal covering's service life (30 years) and the support structure repair (50 years). The service life of flat roofs depends primarily on the conservation status of the layers of support, thermal insulation and waterproofing; Albano [13] suggests 20 years.

Skylights should be inspected annually by verifying the conservation status of the window frames, glass, gaskets condition and mechanisms for opening and closing the windows. Maintenance activities, to be held twice a year, consist of cleaning, lubrication and adjustment of all moving parts.

The rain water drainage system should be inspected and cleaned every six months, checking the condition of connections and pipes and all system performance, namely the water flow. Albano [13] refers the entire system replacement after 15 years, whereas Abate et al. [18] mentions the need to replace up to 20 % of pipe after 30 years and total replacement after 40 years.

4.2 Building Interior Components

The interior walls are in general made of single pane perforated ceramic brick masonry (in thicknesses ranging 0.20–0.35 m) and should be subjected to regular inspections every three years checking the cracking widths, deformations and moisture stains.

Ceilings in gypsum board are an uncommon solution in school buildings, appearing occasionally in recent schools in circulation areas or in the lobbies of the classrooms. Annually one should proceed with a visual inspection/maintenance, to check the aspect and the attachment to the support structure. Replacement occurs after 20 years, during which one should be aware of its possible deformation or the existence of water originating from the underlying services.

The interior openings are mostly in wood finish, with sliding doors in the separation between the classrooms and areas of artistic expression. Control inspections should be performed annually, in general checking all moving elements. Maintenance should be held biannually with the lubrication and adjustment of the moving parts and hardware. The service life of the doors was considered to be in general 20 years and that of sliding doors 15 years.

4.3 Exterior and Interior Finishes

The exterior cladding of the facades' schools is predominantly painted plaster. The control inspections should take place every three years, checking the general appearance of walls, in particular the aspect of painting and the existence of cracks and spots [13]. The current maintenance activities include cleaning stains and dirt in localized areas. IteC [14] refers a periodicity of 15 years for repainting walls and ceilings and at 40 years a more in-depth intervention on the plaster must be performed before repainting.

In external walls, ceramic tiles, varnished concrete and wood panels are used less frequently. In ceramic tiles the superficial appearance of walls, joints and the flatness of the surfaces should be checked. The main maintenance activity consists on cleaning surface dirt and efflorescence stains. The replacement of this type of coating is usually not considered.

Walls in exposed varnished concrete require regular monitoring at 10 years intervals, to determine the need for surface treatment with waterproofing products, and cleaning maintenance every 20 years. Normally their replacement is not considered [14]. Wood panelling demands an annual monitoring inspection to check the surface condition of the panels, the performance of the support elements and the integrity of joints. It should be cleaned periodically [14]. Replacement of the support elements occurs around 40 years.

The most common coating for walls and ceilings is painted render. There should be an inspection every year to check for cracks or other damage and the adherence condition to the support. For paint coating, the surface appearance and the presence of moisture, dirt stains or detachment of material must be verified. Washing the surfaces is the appropriate maintenance procedure to be carried out once every 3 years. Repainting should occur every 15 years, including the repair of the support. In wet areas and in circulation areas, ceramic wall cladding is used requiring an annual inspection control of the surface aspect of the wall and cleaning of surface dirt and efflorescence stains, where necessary.

The flooring currently adopted for the classrooms and corridors is linoleum (see Fig. 5). In the older schools ceramic or wood flooring can be found. The inspection

Fig. 5 School n.° 34—Alta de Lisboa. Floor finishes

Table 10 Summary of information on preventive maintenance (extract) [20]

Element		I	M	R (years)	NI
Building envelope					
	Exterior walls	3 year	10 year (W)	NC	I = 16; M = 5; R = 0
	Windows	6 m	1 year	25;35(H); 75(W)	I = 100; M = 50; R = 2; 1(H); 0(W)
		1–4 year(I)	1 year(I)	50(I)	I = 50/12; M = 50; R = 1(I)
	Doors	6 m	1 year	25; 30(H); 50(W)	I = 100; M = 50; R = 1(H); 1(W)
		1–4 year(I)	1 year(I)	50(I)	I = 50/12; M = 50; R = 1(I)
	Mastic			10/15	R = 5/3
	Ironworks			15	R = 3
	Joint			10	R = 5
Roofing					
	Metal roofing	1 year	1 year(I, H)	25; 30(I); 40(W)	I = 50; M = 50; R = 2; 1(I, W)
	Flat roof	6 m	1 year (A; I)	20	I = 100; M = 50; R = 2
		5 year(W)	1 year(W)	35(W)	I = 10; M = 50; R = 1(W)
	Skylights	1 year	6 m	20/30; 40(W)	I = 100; M = 100; R = 2/1; 1(W)
	Rain water system	6 m	6 m	15; 40(W)	I = 100; M = 100; R = 3; 1(W)
Interior elements					
	Walls	3 year	10 year(W)	30	I = 16; M = 5; R = 1
	Gypsum board	1 year	2 year	20	I = 50; M = 25; R = 2
	Interior doors	1 year	2 year	20; 50(I); 40(W)	I = 50; M = 100; R = 2; 1 (I;W)
	Ironmongery		5 year	10(W)	M = 10; R = 10(W)
	Sliding doors	1 year	2 year	15; 40(W)	I = 50; M = 25; R = 3; 1(W)
Finishes					
	Painted wall render	3 year	3 year	15(A; I); 10(W)	I = 16; M = 16; R = 3; 5(W)
	Ceramic wall cladding	1 year; 5(I)	20 year(I)	NC	I = 50; 10(I)M = 2; R = 0
	Concrete	10 year(I)	20 year(I)	NC(I); 75(W)	I = 5; M = 2; R = 0(I; W)
	Wood panelling	1 year		30(I)	I = 16; R = 1(I)
	Linoleum flooring	1 year		10; 18(W)	I = 50; R = 5; 2(W)
		3 year(I)		20(I)	I = 16; R = 2(I)
	Wood parquet flooring	1 year	2–5 year	40(A; W)	I = 50; M = 25/10; R = 1(A; W)

of the linoleum flooring is to be done annually (every three years according to IteC) focusing on the verification of the pavement condition in current areas (flatness) and localized areas (adherence and mechanical performance). Flooring requires periodic cleaning and its service life varies from 10 [13], 18 [18] to 20 years [14].

Wood flooring is a solution currently adopted for administrative areas and the monitoring inspection should be held annually, noting the state of conservation of surfaces and signs of moisture. The application of suitable surface products such as varnishes or wax is part of cleaning and routine maintenance. The referred service life of this pavement is 40 years [13, 18].

The floor finishing used in wet areas is ceramic tiles that have a service life of 50 years [14, 18]. It is a type of floor finishing that does not require great frequency of inspection but must be subjected to a weekly cleaning with products suited to its surface.

Table 10 presents a summary (extract) of the information collected on different elements preventive maintenance activities and frequencies and their impact in the number of intervention in building (technical performance indicator-NI). The Albano [13] source was chosen as a basis for the study and the Whitestone-W [18], IteC-I [14] and HAPM-H [17] sources were used to assess the former information.

5 Conclusions

There is a great need for reliable information in the area of building maintenance. Information on maintenance activities in Portugal is still scattered in different study areas that relate to building elements and components and in the various government agencies that manage building parks. In some regulated areas, such as the electrical equipment components or gas installations, Portuguese legislation is unclear on neither the type of maintenance activities nor their frequency of application. Lifts, fire protection and HVAC systems are subject to specific regulations, recently published, which require the existence of user manuals and maintenance plans.

Several countries have developed guides and documentation to support the maintenance activities in its various aspects, such as:

- Common buildings components and buildings services used;
- Performance and durability of materials in normal conditions;
- Service life;
- Factors influencing the service life;
- Maintenance activities description and related frequencies;
- Factors that influence the maintenance activity;
- Human, materials and equipment resources related with maintenance;
- Data to calculate the maintenance activity cost;
- Most frequent anomalies in components and buildings systems.

By consulting various databases, it was found that would be very helpful to have all this information concentrated in one document for a more comprehensive analysis and maintaining the consistence and integrity of the information.

It is known that the major maintenance costs that are incurred over the 50 years of a building's service life result from the renewal and replacement of components and elements at the end of their service life. This information is not always coincident in the different consulted sources and can considerably change the results of a life cycle cost analysis. It appears that there is a difficulty in carrying out benchmarking actions for LCC or LCA assessment purposes. It is important to continue the work under development to standardize this information and create national, European or international references databases.

At a national level, it was found that material specifications are generally poorly detailed (design specification and lack of as built information), which may reflect the adoption of traditional technical solutions with no durability or economic concerns.

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