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CONSTRUCTION AND BUILDING PERFORMANCE

BUILDING AND DESIGN TECHNOLOGIES

DEMOLISH OR REBUILD? LIFE CYCLE COST ANALYSIS AND MAINTENANCE PLAN FOR THE PRO-GET-ONE CASE STUDY

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Abstract

It is well known that a large part of the existing Italian and European building stock needs to improve its seismic and energy performances through deep renovation projects. Both seismic safety renovation and energy rehabilitation projects have high initial costs; therefore, owners and property developers often prefer the strategy of a complete demolition and reconstruction of the building. Perhaps this can be the easiest choice, but sustainability must be assessed from an environmental, social, and economic point of view. A Life Cycle Analysis using the Global Cost method, considering initial, operating, maintenance, and end-of-life costs, can provide important information to help key players identify the best intervention strategy for the selected case.
Therefore, a strategic feasibility analysis is needed for each deep renovation building construction project to evaluate the efficiency of the proposed alternative approaches, i.e., deep renovation or demolition and reconstruction, in terms of cost and building sustainability. With the Life Cycle Cost analysis (LCC) technique, the two project alternatives have been evaluated, also with the aim of optimizing detailed design choices to minimize Life Cycle Cost. The LCC minimization plays a fundamental role in the strategic planning of the project approach, and the Cost Breakdown Structure of building maintenance activities detects the most significant elements, termed central elements, that have a major impact on maintenance costs. The optimization of maintenance costs of central elements can increase the economic sustainability of the deep – renovation or reconstruction alternative projects.
The case study of the "ProGETonE - Proactive Synergy of Integrated Efficient Technologies on Buildings' Envelopes" has been analyzed. ProGETone is a European research project concerning a deep renovation of an existing university building via the construction of a prefabricated steel exoskeleton.

Keywords

Building maintenance, Life Cycle Cost, Global cost, ProGETone, Deep renovation.

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1. INTRODUCTION

It is well known that a large part of the existing Italian and European building stock requires performance improvements concerning seismic safety and energy consumption [1]. Structural rehabilitation is generally an invasive intervention involving important processes on the structural sub-system, while energy refurbishment is less invasive but equally economically considerable. Therefore, the high renovation costs and the limitation of the usability of the building during the on-site renovation processes often lead owners and property developers to choose an alternative strategy, i.e., the complete demolition and reconstruction, more direct intervention that surely increases the performance of the building. This is perhaps the easiest choice, but it can be the least sustainable one from an environmental, social, and economic point of view [2]. The theme of the strategic choice between demolition and reconstruction or deep renovation of the existing building can be approached through the strategic planning of the building life cycle with the Method of Global Cost and Life Cycle Cost Analysis (LCCA) [3–5], as LCC provides a detailed estimation of the initial costs, the operation and maintenance costs and the end-of-life costs that can be of paramount importance in providing specific indications and provisions to design and identify the best intervention strategy for the selected case study.

The research work under this paper also focuses on maintenance costs, which are of complex evaluation but can greatly affect the cost-related building performance throughout the life cycle. Building maintenance is a fundamental task of the building life-cycle as it guarantees the performance of the functions and services provided by the building itself. Building maintenance consists of the combination of technical, administrative, and management actions foreseen during the life cycle of a building, intending to maintain it or return it to a condition in which it can perform the required functions [6]. As part of the European H2020 research project "ProGETonE" (Proactive Synergy of Integrated Efficient Technologies on Buildings' Envelopes), coordinated by the Department of Architecture of the University of Bologna, the Life Cycle Cost of a deep renovation project of a university dormitory for students has been studied. The research experiment is an innovative renovation project method consisting of a seismic, energy, and appearance retrofit with a prefabricated steel exoskeleton.

Nomenclature	
Symbols	
A	area [m2]
C	cost [€]
CA	annual cost
CBS	cost breakdown structure
CI	initial cost
CU	cost of use
CF	final cost/residual value
GC	global cost [€]
LCC	life cycle cost [€]
PV	present value [€]
RD	discount factor
r	discount rate
T	study period
V	Volume [m3]
Subscripts	
REC	reconstruction
D	demolition
DREN	deep renovation
GET	steel-based exoskeleton
AL	aluminum-based exoskeleton

Tab. 1. *Nomenclature.*

2. LIFE CYCLE COST-BASED MAINTENANCE PLANNING

The introduction of the Life Cycle Cost Analysis (LCCA) for the improvement of energy efficiency of buildings dates back to the 1970s. In the event of the energy crisis and on the basis of regulations previously enacted by individual states, the Federal Government of the United States of America issued in 1978 the *National Energy Conservation Act (95-619)* which required verification of the fulfillment of energy-saving requirements for federal public buildings through the analysis of the Life Cycle Cost (LCC). The first version of the ASTM E-917 standard "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems" was issued in 1983 (February 25th) [3], which still is a fundamental reference for the calculation and measurement of the LCC, in addition to the ISO 15686 standard [4]. The LCC for construction is an economical method for evaluating design alternatives in which all costs arising from a property to the owner, related to construction, operation, maintenance, and final disposal are added up in a study period and discounted to the present value (PV) to be used as a decision support system for design choices [3]. Indeed, the technological design of both the new construction and the energy renovation of existing buildings often requires the implementation of decisions that must be supported by multiple variants such as sustainability, quality and performances, investment costs. In this case, the LCC economic parameter can be a valid support to the designer, project manager, or client for the choice of the most suitable design solutions. The LCC can be applied both in the design of new interventions and in the energy renovation of existing buildings with the aim of minimizing costs and energy consumption in the life cycle.

2.1. THE GLOBAL COST METHOD

European regulation 244/2012/EU of January 16th, 2012 [8] defines the Global Cost (GC) as the sum of the present value of the initial investment costs, management costs, and replacement costs (referring to the year of the base date) as well as disposal costs. The reference for the term "Global Cost" can be found in the European standard EN 15459 [9] and is based on the Life Cycle Cost approach. Global Cost is, in fact, a slightly different definition from the one given by the international ISO 15686-5 standard of 2008 that defines the global cost as the "Whole-Life Cost" (WLC) of a building system as a total cost that takes into account all significant and considerable costs, benefits, the cost of the life cycle - LCC, and also non-construction-related costs or incomes such as financial costs, sales, and rental income, operation and maintenance costs and externalities. If the Global Cost analysis is carried out at the "financial" level, there are no differences between Global Cost and WLC, but if the analysis is carried out at the "macroeconomic" level, as indicated by the EU regulation (and the guidelines of Annex 2102/C 115/01), the new category of "cost of greenhouse gas emissions" needs to be added [8].

Actually, the European Regulation follows the standard EN 15459 and indicates the following basic costs for the study of the Global Cost:

- initial investment cost;
- energy costs;
- operation costs;
- maintenance costs;
- replacement costs;
- disposal;
- cost of greenhouse gas emissions.

All costs awarded to the building or building element, ready for use, are considered as the costs of the initial investment. Energy costs are annual costs and energy expenditures. Operational costs are all costs related to the operation of the building, including annual expenses for insurance, utilities, other fixed charges, and taxation. Maintenance costs are the annual costs of activities needed to preserve and restore the desired quality of the building or building element. They include inspection, cleaning, repair costs, etc. The replacement cost is the cost of replacing a building element based on its economic life cycle. Running costs include energy, operational, and maintenance costs. They may include, where appropriate, the revenue generated by the energy produced. Disposal costs are the costs of decommissioning at the end of the life of a building system. These costs include dismantling, removing elements that have not yet reached the end of their service life, transportation and recycling. The cost of greenhouse gas emissions is the cost of the monetary value of the environmental damage caused by CO2 emissions related to energy consumption in buildings. It reflects the quantified, monetized, and discounted operating costs of CO2 from greenhouse gas emissions in tonnes of CO2 equivalent over the study period. The European regulation recommends an ordinary study period of 30 years for residential and public buildings and 20 years for non-residential commercial buildings. Concerning the service life of individual building energy sub-systems, some data can be gathered in the EN-15459 documentation [9]. The overall "financial" cost of a technical solution is calculated using the formula:

$$GC(T) = CI + \sum_{j}\left[\sum_{i=1}^{\tau}(CA,i(j) \times RD(i)) - CF,\tau(j)\right]$$

Where: T is the study period; GC(T) is the global cost in the study period for the initial year; CI is the initial cost of the investment for element j; CA,i(j) is the annual cost for year i of element j; CF,j is the residual value of the element j; RD(s) is the discount factor for year i based on the discount rate r to be calculated (Tab. 1). Global Cost is the present value PV of all costs estimated on a study period for a built asset.

The discount factor is calculated with the following formula:

$$RD(p) = \left(\frac{1}{1 + r/100}\right)^{p}$$

Where: p is the number of years from the initial period; r represents the real discount rate.

The Global Cost is a method to evaluate the performance of a building system that can be very useful in the design phase for the search for the most efficient design alternative. Since this is a comparative methodology, the invariant elements of the design alternatives, which do not give changes in cost and performance in the different solutions, can be overlooked or omitted in the calculation. The Global Cost method is based on the discounting of the forecast of future costs of construction, running, and disposal of the studied project alternative. The advantage of this method is that it relates to a real calculation period in which both the energy performance of building systems and sub-systems can be compared, taking into account sub-systems (e.g., mechanical and electrical systems) that have a longer lifespan by calculating their residual value at the end of the study period, and the expected maintenance costs.

2.2. MAINTENANCE STRATEGIES AND MAINTENANCE PLAN

Maintenance is a fundamental activity of the building life cycle as it permits the performance of the functions and services provided by the building during its service life. Building maintenance includes the combination of all the technical, administrative, and management actions foreseen during the life cycle of a building, intended to maintain it or return it to a state in which it can perform the required function [6]. The following maintenance strategies can be defined:

- fault-based or corrective maintenance: maintenance carried out as a result of the detection of a failure and aimed at returning an entity to a state in which it can perform a requested function;
- preventive maintenance: maintenance carried out at predetermined stages or according to prescribed criteria and provided to reduce the probability of failure or degradation of the functions of an entity, which in turn stands out in:
  - cyclical maintenance: preventive maintenance carried out according to established time intervals or a number of units of measurement of use, but without a previous investigation of the conditions of the entity;
  - condition-based maintenance: preventive maintenance that includes a combination of condition monitoring and/or inspection and/or testing, analysis, and the maintenance actions that result;
  - predictive maintenance: maintenance on condition carried out as a result of a forecast derived from repeated analysis or known characteristics and the evaluation of significant parameters related to the degradation of the entity.

Maintenance can also be distinguished in ordinary and extraordinary or forward [7]. Ordinary maintenance is the set of maintenance interventions needed to:

- maintain the state of integrity and the original/present functional characteristics of the good;
- maintain or restore the efficiency of goods;
- counteract normal degradation;
- ensuring the service life of the good;
- restore the availability of the asset as a result of failures and/or anomalies.

These actions do not change the original characteristics of the asset itself, leaving its essential structure and intended use unchanged. They are generally required as a result of fault detection (corrective maintenance), implementation of maintenance policies (preventive, cyclical, predictive maintenance, condition), or for the need to optimize the availability of the asset or to improve its efficiency (implementing small changes that do not increase the asset value of the asset).

Compared to the costs of ordinary maintenance and the value of reconstruction of the building, the extraordinary maintenance, or forward maintenance, produces non-recurring and high-cost for interventions). These are interventions which, in the case of a building system, have the following goals:

- improve the quality of the built asset or adapt it to new needs;
- increase adequacy to use or improve the performance of its functions;
- reduce consumption in operation;
- increase user safety and reduce environmental impacts.

These interventions extend the useful life of the building system but do not change its original characteristics. Please note that in the Italian context of the construction sector, article no. 3 of the Consolidated Building Law D.P.R. 380/01 contains some different definitions aimed to set the administrative procedures of building permits [10].

2.3. ESTIMATING MAINTENANCE COSTS

The quality of maintenance tasks is significantly affected by the budget allocated [11]. The estimate of maintenance costs must be presented in the Maintenance Costs Plan related to the building, divided into elements, functions, and building components to create a Work Breakdown Structure and a Cost Breakdown Structure (CBS) that allows the monitoring and control of maintenance costs. The underestimation or overestimation of maintenance costs can create problems both in the operation of the property and in the management of the same maintenance activities, as the objective of the Maintenance Costs Plan is to keep (precisely) the facility in an acceptable and adequate state for use.

The NRM3 standard "Order of Cost estimating and cost planning for building maintenance works" [12] identifies with the term "CROME" the cost categories of a property over the life cycle:

C – Construct costs
R – Renewal costs
O – Operation and occupancy costs
M – Maintain costs
E – Environmental and/or end of life costs

Maintenance costs can be broken down into forwarding (or extraordinary) maintenance and annualized maintenance costs. These are direct costs for labor, stocks, materials and equipment, machinery and equipment, and indirect administrative, management, and "operational" costs.

The maintenance cost plan [13] aims to:

- determine the target cost limit of the maintenance program;
- inform and adjust the annualized cost plan in relation to budget limits;
- provide a decision support system for maintenance;
- inform which investments are financed for each *asset* and then review the cost plan in the study period;
- assure the owner/client that the maintenance activities ensure the best value for the money spent on maintenance.

The estimate of maintenance costs can be carried out using one of the following methods [11]:

- floor *area method*;
- *functional unit method* (e.g., for each living room or square meter of commercial sales area);
- elemental *method*.

The total cost of maintenance is the sum of actual costs of preventive and corrective maintenance. A well-planned preventive maintenance strategy can reduce corrective maintenance costs to minimum levels of overall cost, the optimal cost zone (Fig. 1), where the sum of corrective and preventive maintenance costs is minimal and therefore optimized.

Douglas (2017) identifies five phases in the process of optimizing maintenance costs: identification of functions/elements/critical areas; analysis of fault modes and effects; evaluation of current maintenance practice; application of predictive maintenance; corrective actions to the maintenance strategy [14].

Le, Rasheed, Domingo, and Park (2018) indicate that generally, a limited number of components (interior and exterior finishes of vertical, horizontal, and inclined partitions, technological systems) are responsible for a large part of maintenance costs. These are works concerning plasters, ceilings, floors and coverings, paintings, roofing and waterproofing, doors and windows, mechanical, electrical, and data systems, drains, and ventilation. The

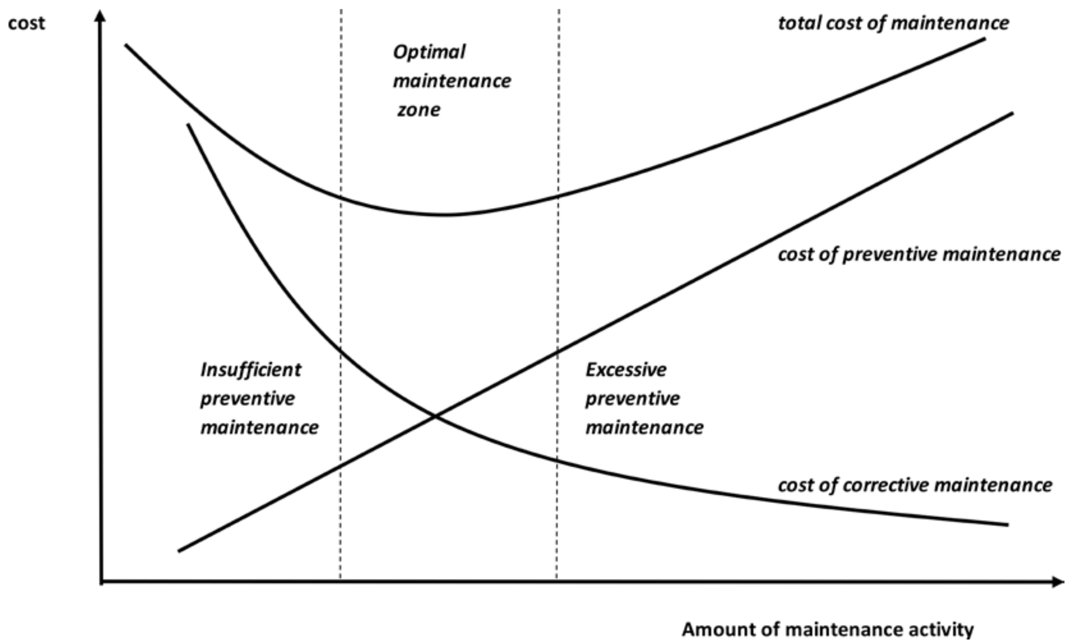

Fig. 1. *Optimization of maintenance costs © 2017, Douglas [11].*

identification of these significant – central – elements and the factors related to the type of building, the functions performed, the model of use and the actual operations and functions of users, the state of conservation and maintenance of the building allows the owner to control the maintenance costs [11].

Mirghani (2003) reports that according to usual practice, preventive maintenance costs can be estimated based on the performance demands of the owner; therefore, it is necessary to develop a maintenance plan of actions that can be cost-loaded, while usually corrective maintenance costs are based on a budget estimated on the basis of the historical costs of CBS and maintenance activities in general [15].

In the research work described in the following, a strategic maintenance cost model is developed with the LCC technique, based on standardized costs and the central elements identified in the Cost Breakdown Structure of the case study and the cost loading of the maintenance activities of the maintenance plan.

3. METHODOLOGY

3.1. THE PRO-GET-ONE RESEARCH PROJECT

The Pro-Get-One case study concerns the deep renovation project of a university student dormitory located in Zografou, Athens. The Pro-GET-onE research project was funded by the EU Horizon 2020 framework and is coordinated by the Department of Architecture of the University of Bologna. Pro-GET-onE aims at implementing a deep renovation of an existing building that includes seismic, energy, and aesthetic-formal improvement. The building was built in the 1980s and has not been refurbished since then. This type of building is generally characterized by interior spaces of large size but with very small outdoor spaces and now obsolete MEP systems. The envelope does not fit the current standards in terms of energy savings and has some maintenance deficiencies and problems of aesthetic-formal quality. The load-bearing structure does not comply with current technical standards on the seismic safety of buildings.

The super-structure of the existing building is built of longitudinal reinforced concrete frames connected by large section girders, while the envelope and internal partitions are of brick masonry. The building has four stories plus a basement; the roof is flat and not accessible. The ground floor is higher than the street level and has a reception, some offices and common halls, 24 single rooms and 2 double rooms. A similar architectural layout characterizes the upper floors, i.e., the standard floor layout consists of a long longitudinal central corridor that leads to 28 single rooms and two double rooms. There are the

Fig. 2. *The university student dormitory of Athens in the current state and in a render of the architectural design.*

Fig. 3. *Case Study: design of longitudinal and side facades and typical floor-plan, the main section with exoskeleton. © 2017, Pro_Get_onE.*

common kitchens at the ends of the corridor, while in the central part, on one side, there is a common area, and on the other, an additional kitchen. The vertical connections between the various floors, stairs, and elevators constitute a central core and are placed in a barycentric position with respect to the plan of the building and in a symmetrical position referring to the main access of the structure (Fig. 2).

The Pro-GET-onE has the aim of renovating the envelope by creating a statically independent external structure (exoskeleton) with different materials (steel or aluminum) or simply through the realization of external thermal insulation (Figs. 2 and 3).

The exoskeleton structure can allow users to extend the space of the housing units, both as an internal space (extra-room) and as an outdoor space (greenhouses and terraces).

In particular, the deep renovation project includes the following:

1. demolition and reconstruction of the roof;
2. insertion of steel (Get) or aluminum (Renovation) structures adjacent to the facades;
3. shielding of the existing enclosure walls, including air treatment systems;
4. installation of external coat insulation;
5. finishing works.

The roof will be completely demolished and reconstructed, including the top part of the new exterior steel structure. The new flat roof cover package includes a walkable and thermally insulated roofing system.

3.2. PARAMETRIC COST ANALYSIS

The study starts in the concept design stage with a parametric analysis that compares the overall cost of the demolition and reconstruction of a new building with the deep renovation, including operational costs for both projects, related to a study period of 20 years. Therefore, on the basis of the detailed design, the maintenance, and operational plan has been developed to estimate operation costs by identifying the "central elements" that have an overall significant impact on maintenance. Alternative technological solutions, which could, in any case, produce a similar performance, were then found for these central elements and compared to verify the impact of life cycle costs to maintain the same quality level during the study period.
The parametric estimate of the Global Cost was performed with the following data, as indicated by the Regional Observatories of Public Works [16, 17]:

Building input data:
- Gross area = about 4300.00 m^2
- Gross volume = about 8,700.00 m^3
- Demolition (gross volume) = 20 €/m^3
- Reconstruction = 1,800.00 €/m^2
- Renovation = 900,00€/m^2
- Study period 20 years

The cost of complete demolition, gross volume, C_D is:
C_D = 8,700.00 m^3 x 20 €/m^3 = € 174,000.00

The cost of re-construction C_{REC}:
C_{REC} = 4,300.00 m^2 x 1,800.00 €/m^2 = € 7. 740,000.00

On the other hand, the cost of deep renovation is CI_{DREN}:
CI_{DREN} = 4,300.00 x 900.00 €/m^2 = € 3,870,000.00

As previously described, the Global Cost (CG) is the result of the sum of three elements: the Initial Cost (CI); the Cost of Use (CU), which includes maintenance and operation costs; and the Final Cost (CF) at the end of the study period:

CG = CI + CU + CF

At the end of the study period (20 years), the building will start a new life cycle based on the residual quality. With the assumption of 50 years of service life, the residual value after 20 years has been estimated as a linear depreciation of the initial cost. Italian technical standards for building construction, NTC 2018, indicates that after a refurbishment or repair intervention, the service life should be considered almost completely restored; therefore, the same value of 50 years can be assumed for both the reconstruction and the renovation case [18]. Another assumption is a real discount rate of r = 0.1%. The initial costs are at time zero.

The Initial Cost of Reconstruction ($CI_{REC)}$ is:
$CI_{REC} = C_D + C_{REC}$ = 174,000.00 + 7. 740,000.00 =
= € 914,000.00

While the initial cost of deep renovation (CI_{DREN}) is:
CI_{DREN} = € 3,870,000.00

It is considered that for the deep renovation case, Usage Costs (CU_{DREN}) costs are equal to an annual parametric value of 40.00 €/m^2 as deduced by the Itaca guidelines for feasibility studies [19]. In the case of reconstruction, it is assumed a new building of the nZEB type, with almost zero energy consumption, so that the Usage Costs (CU_{REC}) are almost 15% lower than those of the refurbishment case [20]:

$CU_{REC\,=}$ 85% CU_{DREN}

So, annual usage costs are as follows:

CU_{DREN} = 4,300.00 x 40.00 = 172,000,00 €/year
CU_{REC} = 85% x 172,000.00 = 146,200.00 €/year

The discounting of costs at time 0 is equal to the following present value PV of the annual costs, with r = 0.1%. The discount factor is the one of the standard ASTM [3]:

$PV_{CU\,REC}$ = 146,200.00 x[$(1+0.001)^{20}$ -1]/[0.001 x
x $(1+0.001)^{20}$] = € 2,893,521.86

$PV_{CU\ DREN}$ = 172,000.00 x [(1+0.001)^{20} -1]/[0.001 x x (1+0.001)^{20}] = € 3,404,143.36

The present value of the final costs PV CF at the end of the study period are as follows:

$PV_{CF\ REC}$ = - 4,748,400.00 x 1/((1+0.001)^{20} = = € - 4,654,421.89

$PV_{CF\ DREN}$ = - 2,322,000.00 x 1/((1+0.001)^{20} = = € - 2,276,044.06

Therefore, the Global Cost of reconstruction (GC_{REC}) is determined as follows:

GC_{REC} = 7. 914,000.00 + 2,893,521.86 – 4,654,421.89 = = € 6,153,099.97

While the Global Cost of deep renovation (GC_{DREN}) is equal to:

GC_{DREN} = 3,870,000.00 +3,404,143.36 – € 2,276,044.06 = = € 4,998,099.30

From the above calculations, based on the assumptions of standard costs, it can be seen that the Global Cost for the Reconstruction of the university student dormitory involves an increase of about 25% compared to the Global Cost for deep renovation. The discussion of the study results will be presented in the final part of this work, after the exposure of the maintenance/management plan.

3.3. THE MAINTENANCE PLAN

The development of the maintenance and facility management plan starts from the fundamental tool of the Life Cycle Cost discipline, namely the Cost Breakdown Structure (CBS) of the building under study, based on the breakdown into sub-systems of technological category, technological units, and groups of technical components, according to the Italian standard UNI 8290 – "Residential construction. Technological system. Classification and terminology".

The CBS structure can be divided into three sections:

- Section 1 - Breakdown of the building according to UNI 8290 and quantity take-offs of deep renovation works, classified into groups of technical components, for each of which the service life and, therefore, the replacement times are defined.
- Section 2 - Determination of maintenance costs, referring to replacement costs, extraordinary maintenance costs, ordinary maintenance costs.
- Section 3 - Determination of the percentage of operating costs of each technological unit related to the total cost of management with the identification of "central elements". "Central element" is the class of technological unit that has a management cost in the reference service life of more than 2% compared to the total operating costs of the building.

For these elements, alternative design solutions can be studied and compared with the application of the discipline of the Life Cycle Cost (LCC), then the most convenient alternative solution can be chosen.

CBS Section 1 leads to detect the total amount of works required for the deep renovation of the building. For the quantification of the individual items, the schedule of rates of the Italian Emilia Romagna region of 2018 was taken as a reference [21]. Applying VAT to 22% and increasing the total amount by 30% for design, project supervision, administrative expenses, tendering costs, surveys and final tests, etc., a detailed priced Bill of Quantities was found. CBS Section 2 indicates the maintenance costs needed to maintain the level of quality of the building components set by the detailed design documents and specifications. The maintenance plan indicates the following contributions:

1. replacement costs;
2. extraordinary maintenance costs;
3. ordinary maintenance costs.

Replacement costs are related to the service life of the individual classes of technical components related to the base service life of the building, based on the number of replacement cycles. If the service life of the groups of technical components is greater than the building service life, the number of substitution cycles is zero, whereas it takes on a non-zero integer value when it is less than the building reference value.

The extraordinary maintenance costs are related to the reliability curve of the class of technical components under consideration and the reference performance level over time. In the maintenance plan, the groups of technical components that are going to be maintained during the service life of the building have been identified, such as, for instance, the exoskeleton or the external envelope or the floorings, and for each of them, the reliability curve for the study period and the level of quality over time have been defined. The ordinary maintenance cost is the set of recurring interventions with the aim of keeping the requested level of usability of the building and of counteracting obsolescence. Ordinary maintenance or planned maintenance also includes the costs related to cleaning services and all interventions carried out periodically for the single classes of technical components.

Section 3 of CBS deals with the identification of "central elements". The study showed that the central elements affecting the costs of use are mainly the classes of technical components connected with building finishes and services, which together account for about 83% of the total cost of routine and extraordinary maintenance and replacement. The central elements include the painting and related maintenance operations of the exoskeleton. In order to optimize running costs, intervention and detail design alternatives (including the use of different products) have been analyzed for these building components.

3.4. THE LCC STRATEGY FOR MAINTENANCE PLAN DEFINITION

Life Cycle Cost analysis is of capital importance for maintenance planning. A maintenance plan for the Pro-Get-One case study has been prepared, taking LCC analysis and results into account. The maintenance plan drawn up for the case study has been structured on the basis of Italian law concerning public works [22] and maintenance standards [23]. This is a specific document of the detailed design of the deep renovation project of the building. Therefore, it consists of the following parts:
1. maintenance manual;
2. under plan of maintenance activities;
3. reliability sheets of technical element classes.

1. Maintenance manual

The maintenance manual consists of the following parts: the general building datasheet and the technical datasheets. The building general data sheet summarizes all the main data of the building, from the more general data concerning the classification of the asset, such as location and function, to the data relating to the project under study (year of construction, name of designers, property developer, etc.), to the list of cadastral data and constraints that exist on the built asset. The technical data quantify site and building area (gross, net, cadastral area, etc.). Finally, a table describes whether the documentation, evidence, certifications related to the asset are available, whether they are complete or not, or non-existent. The datasheet also contains technical drawings of the plans, the facades, and sections of the building with codes that identify the classes of technical components identified by the CBS in order to have a unique coding of the documentation produced. The datasheets, as mentioned above, were completed for the classes of technical components that had an impact of more than 2% of running costs determined by CBS. The datasheet is a kind of identity card of each component or element and contains all the data and information needed to maintain the set quality level of the asset over time. It contains the description of the sub-system with its technical specifications that will have to be implemented in the construction stage with the choice of the single product purchased on the market. Then, the description of the building pathologies found with associated maintenance strategies planned for each component and their frequency of application. The types of activities, the methods of implementation, and their frequency are then defined.

2. Under plan of maintenance activities

It is the overall plan of the interventions of the groups of technical components contained in the maintenance manual, and for each component/element, the plan reports maintenance strategies and their frequency.

3. Reliability sheets of the groups of technical components

For each central element identified by CBS, the reliability sheets have been defined (Fig. 4). The reliability sheet shows the obsolescence curve of the technical/sub-system component/element, i.e., the trend of its quality during its life cycle in the absence of maintenance, and

MAINTENANCE STRATEGIES AND RELIABILITY FUNCTION R(t)

CODE	PFF-P2					
ACTIVITY	INTERNAL PAINTING					
PATOLOGY	DEGRADATIOIN AND WEAR OF THE SURFACE FINISH OF THE WALL					
MAINTENANCE STRATEGY life cycle = 20 years	ALTERNATIVE 1		ALTERNATIVE 2			
INTERVENTION TIME - t [yeras]	10		5			
TYPE OF MAINTENANCE INTERVENTION	INTERIOR REPAINTING OF THE MURARY SURFACE WITH ACRYLIC WATER - BASED PAINT		INTERIOR REPAINTING OF THE MURARY SURFACE WITH ACRYLIC WATER - BASED PAINT			
UNIT COST [€/m²]	8,38		8,38			
PRESENT VALUE OF UNIT COST [€/m²] - (r = 5%)	$t_1 = 10$	$t_2 = 20$	$t_1 = 5$	$t_2 = 10$	$t_3 = 15$	$t_4 = 20$
	14	23,38	10,83	14	18,09	23,38
AMOUNT [m²]	3.060,38		3.060,38			
TOTAL COST - TC [€]	114.397,95		202.903,19			
INIZIAL COST AT TIME t_0 - IC [€]	25.645,95		25.645,95			
PRESENT VALUE CG = TC + IC [€]	140.042,95		228.549,14			
% IMPACT OF MAINTENANCE COSTS ON THE TOTAL COST TC/CG*100	81,69		88,78			

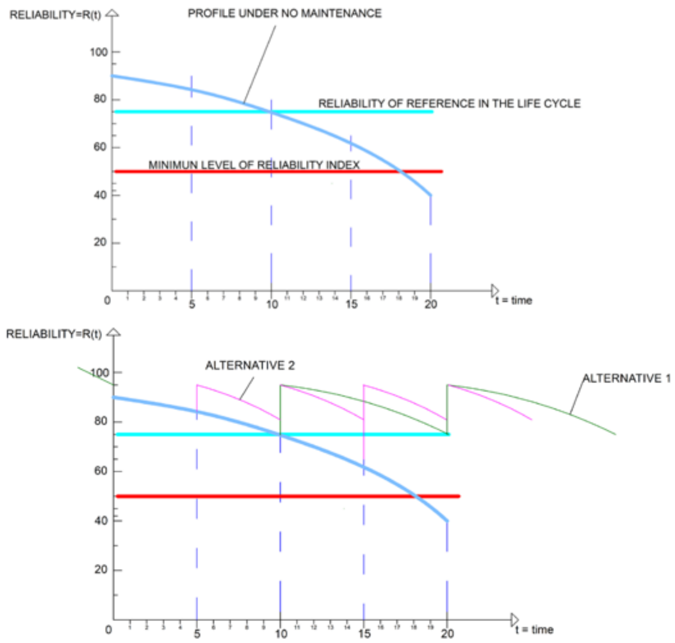

Fig. 4. *Reliability curves for internal wall paintings.*

the modified curves found applying the different maintenance strategies and the minimum level of quality required for the building. More than one maintenance strategy (both ordinary and extraordinary) and its costs have been identified in the reliability sheets, and the costs have been discounted to the base date. Therefore, the impact on the global cost during the service life has been assessed, and the best strategy in relation to the expected objectives, on the basis of the intervention cost/quality ratio, has been planned.

The development of the maintenance plan accompanies the building from the detailed design stage to its disposal. It is a dynamic tool that is updated and completed in all its parts during the life cycle of the building, which allows making the asset management choices that better optimize the cost/benefit ratio.

3.5. COST-BASED ANALYSIS OF ALTERNATIVE DESIGN SOLUTIONS FOR THE EXOSKELETON

The study of the deep renovation project focused on the design alternatives of one major central element of the CBS, the exoskeleton. Using different products and technologies, two design alternatives have been evaluated: a steel-frame (the so-termed GET part) and an innovative solution of an aluminum-based framework (termed renovation part). These two technologies will be planned to be constructed both in different parts of the building to be compared during the life cycle. The symmetry of the building with respect to the central vertical connection makes the comparison easier. By evaluating the estimates previously defined in paragraph 3.2, the two different design alternatives for the exoskeleton can be evaluated.

1. Deep renovation of the building with GET (steel) technology

The initial costs of redevelopment using steel technology, obtained from the elaboration of CBS SECTION 1 extended to the entire building amount to about € 2,000,000.00, considering an intervention equal to 60% of the total renovation of the building, this has a cost of about 465 €/m², because it was not planned to remove all the MEP systems of the building, but only to integrate them with the ones of the exoskeleton. In this case, a part of the interior finishes is not replaced.

Therefore:

$CI_{DREN\ GET}$ = € 2,000,000.00

The cost of use includes the following components resulting from Section 2 of the CBS:

- replacement costs (technical elements with a service life cycle of less than 20 years);
- extraordinary maintenance costs;
- technical management costs (ordinary maintenance, cleaning services, etc.) and annual administration costs.

The replacement costs during the service life cycle discounted to the base date amount to approximately € 275,000.00. The extraordinary maintenance costs during the service life cycle discounted are about € 405,000.00. While the annual operating costs of €180,000.00/year discounted are approximately € 3,560,000.00. The final value at the end of the study period can be estimated as in paragraph 3.2. Therefore:

PV $CU_{DREN\ GET-}$ = € 275,000.00 + € 405,000.00 +
+ 3,560,000.00 = € 4,240,000.00

with this information, the Global Cost cost of the design solution with GET (steel) technology will be:

$GC_{DREN\ GET}$ = 2,000,000.00 +4,240,000.00 – 1.176.250,16 =
= € 5,063.749,84

2. Deep renovation of the building with Renovation technology (aluminum)

The initial costs of redevelopment using steel technology, obtained from the elaboration of Section 1 and extended to the whole building, amount to approximately € 2,250,000.00 with an intervention equal to 60% of the total renovation, which has a cost of about € 525/m^2. Therefore:

$CI_{DREN\ AL}$ = € 2,250,000.00

The costs of use of the building and the final value can be estimated as similar to the one for the GET system; therefore, the Global Cost of the design solution with aluminum-based products is:

$GC_{DREN\ AL}$ = 2,250,000.00 +4,240,000.00 – 1.323,281,43 =
= € 5,166,718,57

With these assumptions, the aluminum-based exoskeleton has a higher global cost.

4. DISCUSSION AND CONCLUSION

The technological solutions adopted for the design of the deep renovation of the student dormitory involve a change in the initial costs of about 5% against the same management costs during the service life cycle. The cost of running the building over the 20-year service life calculated with CBS amounts to approximately € 4,240,000.00 and results in a parametric cost of about 50 €/m^2, of which about 80% is absorbed by the annual ordinary operational costs, which mainly concern cleaning services and energy supply. Therefore, good performance of the building from an energy point of view significantly affects the global cost, as higher initial costs to make the envelope more energy efficient and to ensure high levels of performance of the MEP services are balanced by lower running costs.

The cost of demolition and reconstruction of the case study building is higher than that relating to the deep renovation of about 20%, and at first glance, it could be inferred that, for a relatively higher cost, it would be better to replace the whole building because it would bring considerable benefits from the point of view of operation costs, as it will be certainly more performing if near-zero energy-consuming. However, some considerations related to the environmental sustainability of the building project can still be made. As mentioned in paragraph 2.1, the costs of disposal of demolitions debris of the existing building, including decommissioning of services and removal of elements that have not yet reached the end of their service life, their transport, and recycling, must be added to the costs of greenhouse gas emissions, i.e., the cost of the monetary value of the environmental damage caused by CO2 emissions. This means that the cost of replacing a whole building must be added to the environmental costs of CO2 emissions into the atmosphere. The research team involved in Pro-GET-onE is working to determine these costs through applying the Life Cycle Cost approach to assess the environmental impact of the reconstruction of the whole building.

Therefore, the initial research question "Demolish or renovate?" still needs a final answer because, in general, the choice depends on several factors such as: the specificity and role that the building has in the environmental and urban context in which it is located; the feasibility of the project; economic and capital aspects; etc. However, it is clear that for a certain building stock and, in particular for that of the 1970s and 1980s, the choice of urban regeneration through a renovation can guarantee sustainability for future generations both from the point of view of affordability, quality, and environmental sustainability.

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