QUALITY ASSURANCE AND SOFTWARE FOR MAINTENANCE MANAGEMENT IN HISTORICAL HERITAGE

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ABSTRACT

The maintenance of building heritage is a main strategy for assuring the sustainable growth of our cities. It bears out also in later laws on Public Works (Italy) through the plan of maintenance, elaborated in the construction phase project.

In order to have sustainable growth, public building heritage must not be considered an invariable endowment for financial reasons, but rather an endowment characterised by a rapid development. This requires a monitoring and control system in order to come to a decision about the maintenance of the building.

Computer technology allows one to manage a great deal of data on vast and different typologies of building heritages, and to monitor their status and value, and both in time the maintenance interventions consistent with the financial funds available. A computerised management of information collected to plan the building maintenance is required both to optimise the resources available to the Managing Organisation, and to co-ordinate operators, activities and interventions. Following these principles we have produced software to computerise maintenance booklets. It is provided with a data processing system, that uses periodically updated databases. The information are collected by periodical inspections and all the interventions are annotated. The software allows statement of the performances required after maintenance interventions, the intervention note-book, the foreseen costs and the operators. The software for maintenance assures an informative flow directed to the operators involved in maintenance activities. In fact, maintenance managers, officers working in building departments and users of the buildings can use different functions of the software, automatically selected by password, through the net connection.

In order to guarantee a high quality of maintenance, we have established the parameters for the evaluation of the building quality and the conditions in which the examination and the exchange of information among operators is to be carried out. The success of information exchange between management organisations and private citizens assures a timely maintenance intervention.

The software for the maintenance management includes a quality plan for the improvement of efficacy and efficiency of maintenance interventions. This plan forecasts: a) the procedure for limiting mistakes in the analysis, inspection, diagnosis and intervention phases; b) the singling out of responsibility on the part of the operators involved in maintenance activities; c) the suitability of the procedures and activities required by the software for the maintenance management.

KEYWORDS

maintenance; management; quality assurance; historical heritage; software.

INTRODUCTION

The goal of the present study is to project a maintenance management software in public building heritage. The purchasers are Italian Councils, owners of historical buildings. This software will be used by operators of technical bureaux, freelance architects and engineers, and the public.

Maintenance planning is an activity aimed to guarantee a high quality of building conditions in time and the sustainable growth of our cities. Financial investments in maintenance should be a prime consideration in order to assure the management of public building heritage. This aim requires specific rules for the management of buildings.

In recent Italian legislation on Public Works, maintenance is recognised as an activity indispensable in the management of public buildings with quality goals. In fact, the introduction of the plan of maintenance, that the Law 415/1998 requires in the construction phase project, is aimed to plan maintenance and to optimise the results of the interventions on the buildings.

For sustainable growth, public buildings must not be considered only as an endowment in financial terms, butrather as an endowment which gives the opportunity of cultural development to the environment. The promotion, the informing and the diffusion of planned maintenance are the main objectives of the public and private owners of heritage buildings, requiring research and interventions. Planned maintenance should not be left to choice, but should be adopted rigorously by all for the preservation of buildings and for their management, in order to guarantee the efficacy and the efficiency of their particular functional features. Maintenance management plans should allow and promote the co-ordination of public and private interventions on building heritage.

QUALITY ASSURANCE OF MAINTENANCE MANAGEMENT

The first step in performing the correct management of buildings is an analysis plan. This activity requires a monitoring and control system in order to analyse the levels of conservation, the performance of technical elements, the use of the buildings, and to come to a decision about maintenance. Interventions also require a plan of periodic controls, to guarantee, in time, the optimal use of the buildings. Systems of monitoring and control are the main tool for the success of this strategy. The choices, in the intervention plan, are founded on a continuous analysis of data collected by programmed inspections. These inspections allow the control of all the technological units and the analysis of building performance in time.

The management of information and its characteristics requires electronic tools and software to check choices and to plan interventions. Computerised management of information collected in order to plan building management is required to optimise the available resources, and to co-ordinate operators, activities and interventions. The software for maintenance requires a data processing system, which works on the data collected by the inspections and by the interventions carried out.

The first step to guarantee the quality of this software is the settling of the rules for maintenance management, starting with the analysis of the purchasers' aims. An analysis of needs is required for the knowledge of building purchasers, of their resources and specific needs. This information can be achieved by programmed briefing sessions between purchasers/users and researchers/software designers.

The "identity card" of potential users, expressing their capacity and their specific needs, was provided through an analysis of needs. We assessed a sociological analysis, setting up questionnaires aimed at the 50 Mayors and operators of technical bureaux, and at the 80 inhabitants, in order to identify the unexpressed needs of the users of the maintenance management software. The samples have been selected taking into account dimension, density of population and geographic location of the cities in Campania, a Region in South Italy.

The interviews set up with technical operators and Mayors have been articulated in groups of questions related to classes of needs previously defined by the researchers. Through interviews in the field, additional information regarding organisation and management of technical offices of the councils has been noted. The questionnaires provide knowledge, capabilities and training needs of the operators, in order to identify the operators' professional skills and the activities performed for building maintenance and management. Furthermore, managerial needs of technical bureaux were pointed out, in compliance with the rules and procedures prescribed by the Council in maintenance interventions.

The interviews set up with the public were focussed on building quality and requirements of maintenance interventions. The questions regarded users' needs, building performance, describing the buildings (shape, dimensions, materials, etc.) and their modifications occurring in recent years. The results show that the technical bureaux need more qualified staff and adequate equipment to perform their job. Often, training is required in computing and electronic techniques. Problems concerning filing data and drawings and the need for a frequent update of information on technical recommendations and laws are shown.

Control of purchasers' requirements has been guaranteed verifying the method of collecting and processing the information gathered through the interviews. This analysis has been formulated through the control of completeness and correct sequence of the activities required by the interviews and of the steps in data processing.

In order to obtain a high quality of maintenance interventions, it is necessary to establish the parameters for the evaluation of building quality and the conditions in which the checks and the exchange of information among operators must be carried out. Control tests have been planned in order to analyse the plan of the flow of information between councils and private citizens who live in public buildings. This information concerns the aims and strategies of the purchaser, conservation status of the building, users' needs and interventions required. This control procedure should be added to the quality control of the software production process during the whole process, and should report the results at the end of each production step.

Analysis models must be defined in order to plan activities, manage resources, and prevent and reduce defects and their costs. The project should be thoroughly revised, to analyse its weak points and to arrange checking systems. In addition, it is necessary to control that the instructions reported in the maintenance plan are effectively applied by the operators. In order to guarantee the correct realisation of inspections and interventions, checking activities should be performed by the Councils. These checks should include operators' professional skills, materials and equipment employed, timing of inspections and results of interventions.

Through analysing the design and the production process, risk factors should be defined. The quality plan divides the system of maintenance management into different parts, according to the steps of the maintenance plan. It includes the following points:

1. Analysis of the building;
2. Inspections;
3. Diagnosis;
4. Intervention.

The case showed in this study regards a maintenance plan of a block in Vairano, a little town in South Italy, with masonry buildings.

Analysis of the building

Building analysis should be carried out through collection of data in technical tables containing information about shape, dimensions, materials and construction techniques [Figure 1]. This data is recorded for each technical component, showing the relationship between users' requirements and building performance. Building analysis should help the operator to establish the reliability and durability of the building's elements.

TECHNICAL TABLE	Fig. 1

NAME: limestone supporting wall

CODE: 1.2.1 / 2.1.1.

CLASS OF TECHNOLOGICAL UNITS:

1 supporting structure / 2 external partitions

TECHNOLOGICAL UNITS:

1.2 structure in elevation / 2.1 vertical external partitions

CLASS OF TECHNICAL ELEMENTS:

1.2.1 vertical structures

2.1.1 vertical outside walls

DATE OF INSTALLATION: XVII century

PRODUCER: local workers

PROVIDER: local quarry

SHAPE AND DIMENSION: thickness 40-80 cm

CHARACTERISTICS: limestone supporting wall, mortar grouting

ASSEMBLING: "opus incertum"

EVALUATION OF CONSTRUCTIVE QUALITY: expert craftsmen

PERFORMANCE:

CLASSES OF NEEDS	STEPS OF THE LIFE CYCLE	CLASSES OF REQUIREMENTS	REQUIREMENTS OF THE TECNOLOGICAL SYSTEM
Safety Functional	Management Maintenance Use	Security Safety of intervention Usability	Security Safety of maintenance interventions Efficiency of the technical building elements Reliability of the technical building elements Restriction of heat loss Recoverability of heat loss Inspectionability Cleaning facility Repairability/ Replaceability
Economic requirements	Management Maintenance	Economic requirements of management Economic requirements of maintenance	Limiting costs of energy Limiting costs of cleaning
Durability	Management Maintenance Use	Durability of elements Maintenance of elements	Durability of components Durability of physical inter-face Durability of maintenance intervention
Control	Maintenance	Control of conditions	State of conservation

The risks in this kind of information lie in the reliability of data. This risk factor depends upon the following variables:

- *Method of data recording*: Methods of analysis should be selected on the basis of : financial resources; operator skill; available tools; etc. The analysis plan should optimise the available means, in order to collect only the building information necessary for maintenance management.
- *Surveyors competence*: The correctness and the accuracy of data can be obtained only if the operators are able to survey and collect building information competently. Surveyors should be trained in building maintenance and management, learning specific facts about historical construction techniques and materials.
- *Characteristic of equipment*: Sophisticated tools guarantee the precision of data. This equipment requires specific professional skills and precise settings, which could produce mistakes if this is not done correctly.
- *Classification of technical elements*: Each element should be geo-referenced and classified. This in order to include all the technical elements in the maintenance plan.

Planning of inspections

Inspection methods are reported through specific tables [Figure 2]. The information contained in these tables should allow the management of building component checking. Materials and construction, together with their conservation conditions should suggest kind of inspections necessary, aims and times. The quality plan checks the following risks, related to the inspection plan:

- *Environmental conditions*: Environmental conditions (e.g. pollution, traffic, acid rain, etc.) could be extremely variable in time. This means that the planning of inspections may be incorrect.
- *Accidental factors*: The plan can not foresee the happening of unexpected accidental factors. In this case the inspection should be carried out after the accident.
- *Accessibility of the elements of the building*: The whole building requires periodical inspections. Elements located in the building basement can be easily controlled, but some elements are located in places not easy to reach by the inspectors.
- *Instrumental control*: In order to control some parameters and performances, it is necessary to use specific equipment. These instruments could be unavailable or costly.

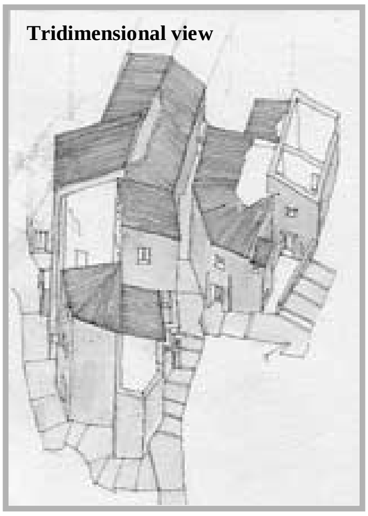
Diagnosis check

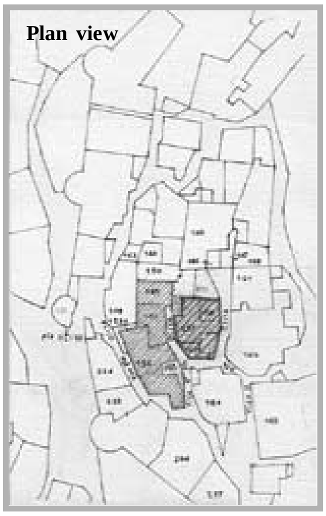
Diagnosis of technical building components should be executed on the grounds of the information collected regarding the building and its environment [Figure 3]. The results of the diagnosis depend upon the accuracy and the completeness of data, together with the competence of the operator analysing the information.

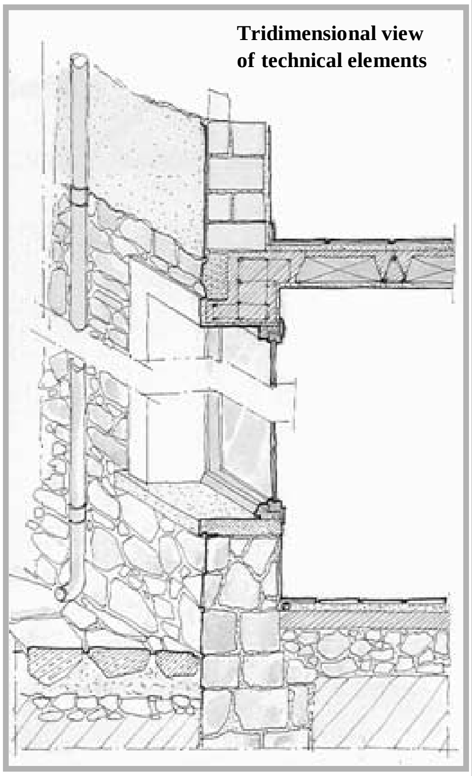
Diagnosis relates building conditions to possible causes of degradation or accidents, in order to foresee the maintenance intervention necessary to restore the efficacy and the efficiency of the building. Risks related to this step of maintenance planning could include the following:

- *Relationship between causes and phenomena of degradation*: These relationships could be unclear. Often there are many different factors that produce a single degradation phenomenon. In addition, phenomena could be related in a chain process.
- *Difficulty in foreseeing the evolution of the degradation process*: The degradation process can be conditioned by accidental factors. These factors are difficult to foresee. In addition, the presence of more causes can produce different types of degradation or damage.
- *Relationships between each technical element and the whole building*: Each element should be related to the other parts of the building. This means that diagnosis should be related to the condition of the building as a whole.

INSPECTION TABLE **Fig. 2**







DURABILITY PERFORMANCE:

With maintenance interventions : 300 years

Without maintenance interventions : 80 years

INSPECTION CRITERIA:

	CONDITION OF MATERIALS	**CONDITION OF JOINTS AND GROUTINGS**	**EFFICIENCY**
TIMING FOR INSPECTIONS	5 years	3 years	5 years
TYPE OF INSPECTION	• at sight If necessary: • non-destructive analysis • laboratory analysis	•at sight If necessary: • non-destructive analysis • laboratory analysis	•at sight If necessary: • non-destructive analysis • instrumental monitoring
AIM OF THE INSPECTION	To control: • alteration or degradation • latent changes • chemical, physical, mineralogical characteristics	To control: • alteration or degradation • latent changes • chemical, physical, mineralogical characteristics	To control: • joints and cracks • wall dampness

DIAGNOSIS **Fig. 3**

DATE OF INSPECTION: March 8, 2000
ORIENTATION: south – west

ENVIRONMENTAL CONDITIONS:
T° min. +20 T° max. +40

Humidity 70% (summer)

T° min. -10 T° max. +10

Humidity 55% (winter)

MONITORING			
INSPECTION	MATERIALS AND COMPONENTS	JOINTS	PERFORMANCE
	LIMESTONE	MORTAR	WALL SYSTEM
METHOD OF INSPECTION	TIES FOR THE CONSERVATION	GENERAL DIAGNOSIS	THOROUGH DIAGNOSIS
Standardized methods	To prefer non-destructive tests	**Analysis at sight:** • homogeneity of the material • cracks • alterations and degradations	**Instrumental non-destructive analysis :** • homogeneity of the material (thickness) • dampness ,presence of different materials • thermic conductivity • chemical , physical, mineralogical characteristics

RESULTS	CONDITION OF MATERIALS	CONDITION OF JOINTS	PERFORMANCE
ANOMALIES AND DEFECTS	• hairline cracks produced by work- tools	• efflorescence and fracturing due to the component of the mortar	• structural bowing • dampness
ALTERATIONS AND DEGRADATIONS	• surface deposit • biological coating • spots • holes	• surface deposits • biological coating • efflorescence • crumbling • erosion • cracking	
DAMAGES	• micro-cracking of the stone	• superficial cracking • deep cracking	• lack of staggering • dampness of the wall surface
ADVANCE OF THE DAMAGE	• flaking	• extension and deepening of cracking	• collapse • decrease of the thermal insulation in the wall

Intervention instructions

For each component of the building, the kind of intervention suitable to restore original performances is described [Figure 4]. In addition, the intervention table shows the frequency of interventions foreseen, the skill of operators and the time required for the work. All the necessary actions are described, together with the tools and the materials required. Finally, the table shows the risks of damage produced by the intervention (e.g. falling of materials from the building, water leakage, etc.) and the trouble for the users (e.g. windows that cannot be opened, blocked entrances, etc.).

Compatibility of the intervention with the building: On the grounds of building analysis and diagnostic results, instructions of intervention are defined.

- *Maintenance of intervention equipment*: In order to execute a successful intervention, all the equipment and tools should be periodically revised. Their efficiency is necessary to guarantee the quality of the intervention and the preservation of materials and technical elements.
- *Timing communication of the instructions*: Maintenance instructions should be diffused in time. This can be guaranteed through a large diffusion of the maintenance plan. A computerised system can be an efficient tool in the obtaining of information regarding users. For a timing diffusion of the plan, data bases and tables should be accessible through a web site.

QUALITY ASSURANCE OF SOFTWARE

Starting with the purchasers' requirements, a prototype of the software was produced. Furthermore, a software quality plan was designed to check for risks in electronic assistance to maintenance planning. This function is applied to the whole process of design and production. The main aims of the quality plan are both to guarantee quality to the purchaser and to minimise product defects.

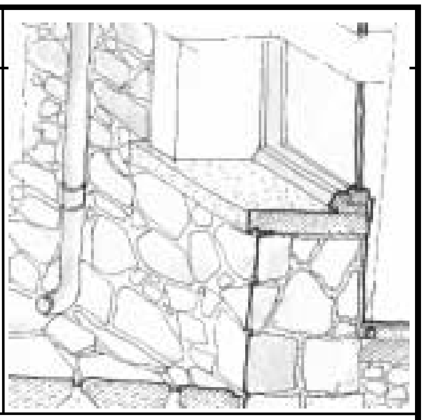
Thus the research must involve a quality control of software, performed both by software designers and by researchers, in order to verify the achievements of the project's aims. The check should include:

- *The project*: the rules used to produce the software.
- *The product:* the correct working of functions and user inter-face.

The check can be made on the prototype of the software, at the end of its production process. In addition, technical checks should be made at the end of each step of production of the prototype.

In order to guarantee the quality of the user inter-face, software should be provided with different access routes, dedicated to different types of users: information required by technical operators is different from that required by the public. The language and the contents of tables should be tailored to the skills of the user and personalised access should be achieved through a password. The wide diffusion of this computerised tool should be realised through the internet web. This guarantees the quality of the information diffused, allowing the users to access to the last version of the software, provided with constantly updated data-bases.

INTERVENTION	Fig. 4

KIND OF INTERVENTION		
• wall cleaning • resealing of cracks • wall reclaiming • interventions for the efficiency and the reliability of the wall	• mould killers • cleaning using water and micro-sand-blasting • slow transfusion against ascending dampness • resealing • tie rods	
DATE OF THE NEXT INSPECTION : ** March 2002; **TIME AND FREQUENCE: min. 3 max. 5 years		

SPECIFICATION OF INTERVENTIONS					
MAINTENANCE INTERVENTION	Stone cleaning using atomized water				
INCLUDED COSTS	• renting, carriage, setting of atomizer machine • hand-cleaning of the stone using natural fibre brush • renting, carriage, setting of de-ionization machine • dismantling and carriage				
EXCLUDED COSTS	• scaffoldings • protection sheets • water				
ACTIVITIES	**DESCRIPTION**	**OPERATORS**	**TOOLS**	**MATERIALS**	**TIMING**
• Scaffolding • Carriage and setting of the atomizer machine • Carriage and setting of de-ionization machine • Hand-cleaning of the stone • Dismantling and carriage	Intervention carried out from the top to the bottom of the wall	•Specialized worker • Semiskilled worker • Unskilled worker	• atomizer machine, compressor • de-ionization machine, compressor • natural fibre brush, containers	• water	• 0.40 – 0.82 h/m^2 • 0.40 – 0.82 h/m^2 • 0.40 – 0.82 h/m^2
RISKS OF DAMAGES: • falling of materials from the building • water leakage			**TROUBLE FOR THE USERS:** • windows that cannot be • blocked entrances		

CONCLUSION

A comprehensive analysis of the building is imperative, in order to guarantee the quality of future maintenance interventions. Quality policy in maintenance of public heritage requires correct, timely and faithful information. This information mainly regards technological and environmental systems (technical tables), the conditions (inspection tables), the causes of building degradation (diagnostic tables). On the basis of the building analysis, effective and efficient interventions can be guaranteed (intervention tables).

The software designed for the maintenance management has required two types of quality control. The quality control of information surveyed can be guaranteed by satisfaction of the following conditions:

1. specific training in management of public heritage for the operators (surveyors, researchers, users of the software);
2. reliability and fitness of tools and methods employed in the software project (information surveying, data processing, intervention planning and selection of technical solutions).

On the other hand, the control of software functioning is achieved by:

1. planning and control of procedures and actions in software design and production;
2. training designers in specific software techniques and in co-operation with researchers and operator of maintenance process.

Yet, each step of the maintenance plan can offer risks. These risks could compromise procedures, activities and results of interventions. An analysis of the various possible risks in programming a complete maintenance plan for public buildings has been performed.

The development of a maintenance management software should include a quality plan. This is in order to assure planning and control of quality requirements during the whole maintenance process. In each step we checked the results, analysing the objects to be controlled, the procedures and their criteria, in order to perform the next step and to guarantee the quality of the whole process.

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