CONDITION ASSESSMENT AND MAINTENANCE STRATEGIES FOR BUILDING AND BUILDING COMPONENTS

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SYNTHESIS REPORT

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0. PROJECT SUMMARY

The maintenance sector of the building industries in most EU countries is set to equal if not overtake the new built sector by the turn of the century. Productivity in the maintenance industry has traditionally been low. This is due to a combination of factors such as the particular vagaries of maintenance work, poorly organised contractors and the short-sighted attitude of building owners leading to lack of properly documented historical information on the performance and maintenance of buildings.

Current strategies adapted for maintenance range from cyclical maintenance to reactive maintenance; both methods are expensive due to the possibility of overmaintenance or sudden failures. Research has shown that condition based maintenance is most cost effective as work can be opportunely planned based upon actual observations.

The current practice of condition monitoring by building inspectors yields variable results due to subjective perceptions of inspectors. There is a case for creating objectivity in the inspection process thereby resulting in unambiguous information for maintenance production and management staff to perform more efficiently and effectively.

The research project sought to increase productivity and introduce high-tech into the maintenance industry. This is achieved via the development of an objective condition assessment methodology using condition scales determined by specific descriptions of defects and augmented by pictorial/photographic illustrations. The condition assessment process is automated, the data output in turn form a crucial input into a linked knowledge based expert system developed for the purpose of making strategic maintenance decisions within varying financial and economic constraints. In anticipation of a shortage of qualified inspectors as well as to bring the state of technology within the EU in step with that in USA and Japan, automation of the inspection process will be proposed through the specifications of on-site measurement instruments as built-in devices capable of continuous dynamic condition monitoring of buildings.

The research results are:

- objective condition scales by which the maintenance requirements of building component material combinations can be determined;
- data-entry software to automate the condition assessment process,
- a knowledge-based expert system for supporting decisions to derive an optimised maintenance strategy;
- specifications of on-site measurement instruments and aids for condition assessment and monitoring of buildings;

1.0 PROJECT TECHNICAL OVERVIEW

The underlying theory supporting this research lies in the fact that condition based maintenance represents the most cost effective method of maintaining and extending the service life of buildings as compared to the current practice of cyclical and reactive maintenance. The central thrust of the research thus lies in developing a methodology for objectively assessing the condition of a building/building component.

The research comprises of three integrally linked main tasks:

Task 1: Development of objective condition scales to determine the maintenance requirements of building components.

Task 2: Development of a knowledge based expert system to support decisions for determiningg an optimised maintenance strategy.

Task 3: Evaluation and specifications of on-site measurement techniques and instruments/equipment for condition monitoring.

Task 1 supplies the input for Task 2. The measured values from the instruments of Task 3 are reduced to condition values in conformity with Task 1, and as such also supply direct input for the expert system of Task 2. The main and supporting tasks in this project are described in detail in the following sections.

Task 1 Development of Objective Condition Scales

There are two main thrusts of work in this task viz. the development of an objective condition scale to be used by building inspectors for assessing the condition of a building/material combination and the development of data entry software to automate the building inspection data recording process.

The underlying theory for the first thrust of work in Task 1 lies in the concept that the degradation of a component/material in service is manifested in overt physical evidences/signs. These signs are discernably different at various stages in the life span of the component/material and can be categorised into distinct stages/conditions i.e. scales which describe on one extreme, a normal as new condition and on the other the end of its service life.

A six point Condition Scale has been developed in this project. The Condition Scales for each component investigated have been specified and explained in manuals together with examples and photographic references.

Practice has shown that the paperwork involved in building inspections is quite substantial. Inspectors have to fill pro-formas at the point of inspection and transfer this information to building records held in administrative offices.

The concept of automating the building process forms the second main thrust within Task 1. It involves the designing of a data entry program by which the building inspector can record the condition scores. Where necessary the program will supply the inspector with supporting information via help screens. The inspection data so recorded can be interphase into the building records held in the Expert System developed in Task 2, thereby obviating a considerable amount of paperwork, at the same time eliminating the possibility of errors which would otherwise occur when inspection records are transferred manually. As the data entry program is interlined with the Expert System in Task 2; the development of this program has been described in Task 2 of the project.

Task 2 Development of an Expert System for an Optimised Maintenance Strategy

The underlying theory for Task 2 lies in the concept that the formulation of a maintenance strategy for a building/group of buildings is dependent on an array of information/input data to support the decision, one such primary requisite being objective information on the technical condition of the building. The derivation of the most cost effective and appropriate maintenance strategy requires the decision maker to consider and reconcile often conflicting performance demands and financial constraints. The combination and interplay of the various classes of information to create 'what-if' situations can be more expeditiously undertaken with the aid of an Expert System.

The expert system developed in this task will seek to derive an optimised maintenance strategy based upon information on the existing condition of the building (derived from Task 1) and the desired level of performance within the constraints and resources available.

The expert system works at two levels:

- At the first level, information on the condition of building components allows maintenance activities to be programd. Policymakers are generally not involved at this level.
- At the second level, factors such as the desired performance of the building, the expected period of use, the functional and service life, financial and other resources available will be inputted by the policymaker to be taken into account in deciding a rational maintenance strategy.

Where a maintenance strategy is to be developed on building stock level (or on the level of partial stocks, for example sub-divided according to life span cohorts or fictional classes), the expert system will include options for abstracting the various maintenance strategies at building level to stock or part stock levels.

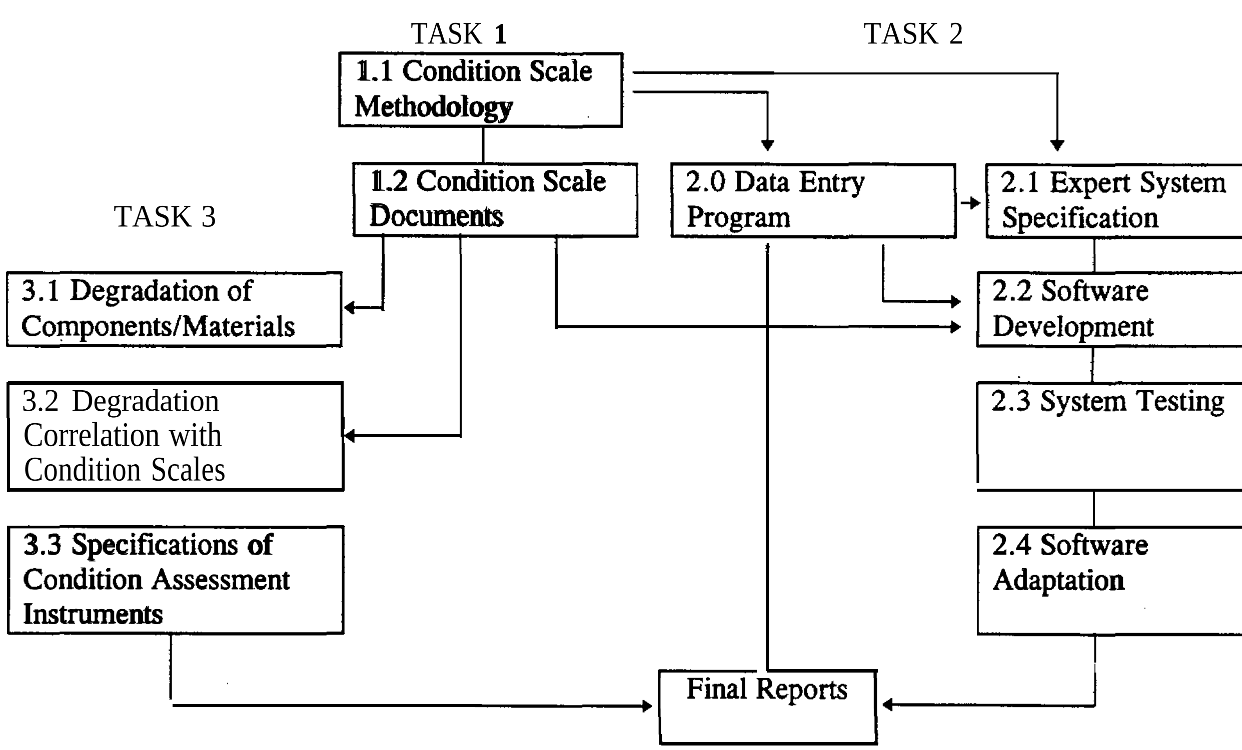
Task 3 Evaluation of Instruments for Condition Assessment and Monitoring

The need to introduce hightech into the maintenance industry through automation particular in the mainstay operation of condition inspection has been prompted by the removal of the element of subjectivity if instrurnents/equipment are used for inspections and, projections of manpower shortage to physically conduct inspections.

The underlying theory in Task 1 was that the degradation of a material component over its life span is manifested in overt signs/symptoms/observations which are discerningly different at various stages in the life span. This theory was used to categorise the process of degradation into 6 condition states/scales. The same underlying theory is now applied to the fact that when a component/material degrades, there are some specific measurable properties which vary with time and thus indicate the degradation. It should thus be conceptually possible to relate these specific measurable properties to each of the condition states established i.e. express the degradation as a function of six points in the time of the life of the component/material.

With the establishment of these measurable values, it should be possible to investigate the use of instruments to measure these values. Instruments could either be in-built into the component/material or brought to the component/material for measuring the properties. The measurements in turn could be undertaken at specific points in time throughout the life span of the component or, dynamically and continuously throughout the life of the component. These instruments could be used/mounted on the inside/outside of the building when external components/material properties are to be measured. Conceptually therefore instruments would fall under two main classes viz. static types, in-built into the component/material with measurements examined/read periodically or continuously and, mobile types either propelled by human being or by mechanical aids such as robots, brought to the component to be measured at desired time/intervals. This project did not physically develop the instruments but investigated the possibilities for use and propose specifications for them.

The flow chart below shows the technical tasks and sub-tasks in this project and their interdependencies.



2.0 RESEARCH METHODOLOGY AND RESULTS

2.1 Task 1 Objective Condition Scales

2.1.1 Conceptual Theory

Within the context of condition based maintenance philosophy, it is possible to assess the state of maintenance of building components to aUow extended, yet effective, cost benefit analysis of potential actions to be carried out. However, without a comprehensive knowledge of material pathologies accompanied by an adequate understanding of the consequences of inaction, decisions will always be made at component rather than strategic level.

Without an opportunity for inspectors or surveyors to make reference to established and unambiguous systems of rating defects and their degradation, problems can arise in ensuring consistency in approach. The availability of a condition referencing system, when established, can be used to provide well founded, flexible cost calculating techniques related to life expectancy of a material or component.

The subjectivity of a diagnosis undertaken by a building inspector or surveyor when considering the condition of a defect can lead to increased expenditure and over-specification of the work needed to maintain the building in acceptable condition. There is a need to develop an acceptable pan-European method of understanding how materials and components deteriorate with time and to be able to assess that deterioration consistently with respect to *service* life.

To establish a method by which a Condition Score system could be attached to the degradation rate of particular defects, it was first necessary to develop the theory of the research involved in Task 1.

2.1.2 Work Done and Research Results

The work undertaken in this task involved the design of a framework On which to develop the methodology for establishing the six point Condition Scale based on classifying overt signs of degradation for components and materials.

Literature reviews were undertaken to identify the most common defects occurring within the chosen material and component/material combinations. Investigations were carried out to establish the overt signs associated with the progression of each defect during the service life of the material or component.

Having established the feasibility of pinpointing the life span of a particular building component or material by means of applying a reference to condition, a five point scale was used to form the basis of the condition references. By applying a scale with values of 1 to 5 (where 1 = good and 5 = bad), a value can be allied to a comment on the condition of a component or material without the need to apply an actual qualitative value to the defect itself. Therefore, the use of such a scale registers the condition of the component or material in a neutral fashion allowing some limited flexibility in assessment.

When supported by typical examples of particular components and materials in various established stages of degradation, a neutral registration on a good/bad basis will assist in ensuring uniformity of decision making in the work of inspector and surveyors. In addition, condition scores developed in this way will allow comparisons to be made between the relative conditions of various components or materials either within one element or between elements.

It is considered that if a scale contains substantially more than five points problems occur in the graduation from one point to another. The scale becomes too fine to accurately assess condition and, in reality, gives diagnostic detail which is simply unnecessary in deciding maintenance work or strategic policy. Whilst a five point scale was chosen as the most suitable it was decided to add a further point, point 6. This decision was taken to ensure that the presentation of the scale requires an inspector or surveyor to make positive decisions around a neutral mid-point position. It also allows for two points within the scale to be dedicated to the condition of the component or material when it is either *'as new'* or when it has reached *'the end of its service life'*.

An overview of the Six Point Condition Scale which has been developed is provided below:

Six Point Condition Scale	
Condition 1	as new
Condition 2	very slight/no defects (some visible symptoms of the ageing process)
Condition 3	slight/some substantial defects (more than half of the service life has elapsed)
Condition 4	substantial defects (limited service life left)
Condition 5	very substantial defects (replacement or major repair is necessary)
Condition 6	the component has reached the end of its service life (replacement of the component is long overdue)

In determining the above six point scale it was also necessary to establish a methodology by which each individual Condition Document should be developed to meet all the objectives of the Task. A compact six stage methodology was evolved.

Stage 1.0 Introduction

1. Introduction to Cornponent/Element

   This section introduces the material and the background to the development of the component itself.

2. Maintenance

   Included in this section are descriptions of the possible life spans that can be expected from the component/material in use and identification of the main agents affecting those spans. The most common defects which are likely to occur are also identified.

Stage 2.0 Building Element Specifications

1. Element Description
   This section contains a description of the particular element under consideration.

2. Element Measurement

   The method by which a particular element should be measured is included in this section.

Stage 3.0 *Criteria for Condition Assessment*

1. Overview

   This section gives a general description of the factors which should be considered in determining the state, or condition, of a particular component or material.

2. Functional Criteria

   This section describes the fictional criteria which the component under consideration must satisfy in order to meet functional performance requirements.

3. Technical Criteria

   The main criteria necessary for satisfactory technical performance of the considered component are identified in this section.

4. Aesthetic Criteria

   Matters which may affect the ability of the component to satisfy any aesthetic functions are described in this section.

5. Basic Quality

   This section deals with the impact of a sub-standard original performance on the condition of a component in use with that when it was new.

6. Survey Position/Equipment

   The difficulty in determining precise levels of deterioration of a component are described in this section together with suggested techniques for surveying the component.

Stage 4.0 *Classifying and Measuring Defects*

The methodology of classifying defects is set around describing the presence of a defect in terms of:

– the *seriousness of the presence* of a defect (Minor, Serious, Critical)

– the *intensity* of that defect relative to its degradation pattern over the service life of tie component or material (Starting, Obvious, Advanced)

– *the extent* of the defect relative to the overall material or component (Localised, Sporadic, Widespread)

This information is described in tabular form for ease of reference and understanding relationships.

Stage 5.0 *Condition Descriptions and Condition Scores*

1. Allocating Condition Scores

   For each of the classifications specified above individual condition scores were allocated to the individual deterioration rates for each material or component under consideration.

2. Condition Descriptions

   This section offers potential descriptions of a component under the five headings described earlier, namely General, Functional, Technical, Aesthetic and Base Quality to permit a quantitative condition score to be allocated.

Stage 6 *Pictorial Illustrations of Conditions*

In this section, pictorial evidence has been collated to describe some, but not necessarily all,of the most common defects found in the components.

The condition scale document developed under Task 1 contains 78 individual and combined documents comprising 55 individual documents (e.g. related to Frames, Manholes etc.) and 23 combined documents (e.g. Finishes, Coatings etc.). In reality, the 23 combined Documents comprise groupings of 50 individual Documents bringing the overall number of component/material combinations contained within the final documentation to 105.

An overview of the Six Stage Methodology for development of the condition scales is provided below:

Six Stage Methodology for Development of Condition Scales	
Stage 1	1.0 Introduction 1.1 Introduction to Component/Element 1.2 Maintenance
Stage 2	2.0 Building Element Specifications 2.1 Element Description 2.2 Element Measurement
Stage 3	3.0 Criteria for Condition Assessment 3.1 Overview 3.2 Functional Criteria 3.3 Technical Criteria 3.4 Aesthetic Criteria 3.5 Basic Quality 3.6 Survey Position/Equipment
Stage 4	4.0 Classifying and Measuring Defects 4.1 Type of Defects 4.2 Measuring Defects
Stage 5	5.0 Condition Descriptions and Condition Scores 5.1 Allocating Condition Scores 5.1.1 Tables relating Minor defects to extent & intensity of defect 5.1.2 Tables relating Serious defects to extent& intensity of defect 5.1.3 Tables relating Critical defects to extent& intensity of defect 5.2 Condition Descriptions
Stage 6	6.0 Pictorial Illustrations of Conditions

2.2 Task 2 Expert System for an Optimised Maintenance Strategy

2.2.1 Conceptual Theory

The primary objective of introducing a planned maintenance system is to ensure that the maintenance process is planned in such a way that repair and replacement activities are undertaken at the time when they become necessary. This will enable the maintenance budget to be allocated more judiciously on a needs basis based on a system of prioritisation of the required maintenance activities. The current systems of maintenance planning and budget allocation in use range from the more commonly used response-based system, to the cyclical-based system and the least used condition-based system.

In condition-based maintenance systems, the required maintenance work and budget is determined after inspection of the actual condition of the building components in service. The pre-condition for implementation of an effective condition-based maintenance system is hence reliable inspection data. This has been realised with the development of the objective condition scales in Task 1.

Although the objective condition assessment methodology can enable a more accurate prognosis of the condition of the component and determination of the required maintenance action and costs, there will be the common situation of a shortfall between the available budget and the required maintenance budget. It will hence be necessary to develop a method for prioritizing repair actions within a condition-based maintenance system.

2.2.2 **Research Methodology and Results**

The normative maintenance approach adopted in this research consists of a number of guidelines (norms), on which inspection maintenance planning and budget allocation can be equivocally based. There are three areas of standardized procedures:

- Inspection Norms
- Maintenance Planning Norms
- Budget Allocation Norms

Inspection norms

Inspection norms are directed at the collection of consistent inspection information on the basis of the *standardised inspection methods* utilising the Condition Scales (described in Task 1) and the collection of the inspection data by a computerised Data Entry Program (DEp).

Maintenance planning norms

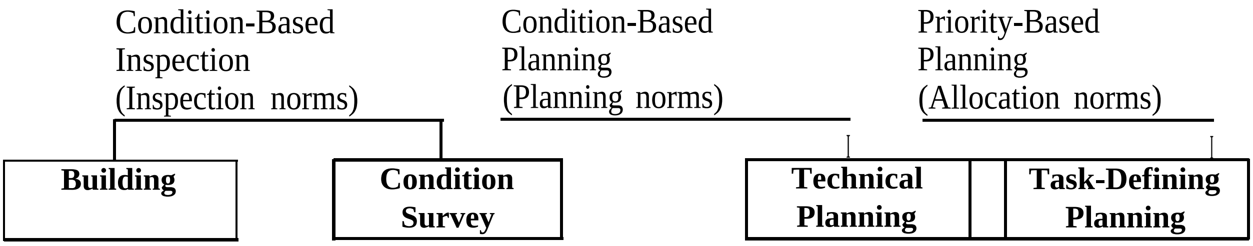
Planning norms are needed for computer-supported planning. The standards the planner implicitly applies are converted into a series of norms and algorithms that are implemented in the planning program. The computer proposes repair actions. These proposals can be accepted or overruled by the planner.

Budget allocation norms

Allocation norms aim at budget allocation where:

- the available budget and the maintenance priority (priority-based plans) are geared to each other at portfolio level;
- the task-defining budget is allocated to the various buildings in the portfolio according to a particular set of algorithms.

The overview of the Condition-Based Maintenance Planning System and Budget Allocation System and the various standardized computerised procedures developed is elaborated overleaf.



A - Inspection standardization - Conditon-Based Inspection Methodology	
Work location	: Field
Level	: Operational
Aimed at	: Inspector
Hardware	: Handheld computers/ laptops
Emphasis	:- determiningg objective parameters for defining data - making help information accessible for the inspection process - printing forms in text mode (character / concept-based)

B - Planning standardization - Condition-Based Planning Methodology	
Work location	: Regional office/ technical department
Level	Tactical
Aimed at	Planner
Hardware	: Stand alone desktop computers
Emphasis	: - computer-supported plans according to ‘overruling principle’ - user-friendly software (including mouse support) - printing forms in graphics mode (display-based)

C - Allocation standardization - Priority-Based Allocation Methodology	
Work location	: Head office/policy department
Level	: Strategic
Airned at	: Policy-maker
Hardware	:- Fast desktop computers - PC network - Client-server environment
Emphasis	:- implementation of maintenance strategy in planning - allocation systems - supporting attunement and converting process (technical → task-defining planning)

Four software programs have been delivered:

1. DEp

   This is a Data Entry Program in which all necessary survey data is collected, stored and transferred to the Expert System (ES).

2. ES PMR

   This is a Prediction Model to determine a realistic budget for maintenance for one or a few years. The model creates a cost reference on the basis of the probability that condition score 5 will appear over a specific component. This cost reference can be used to determine the budget to be spent on maintenance.

3. ES BAM

   This is Budget Allocation Module with optimisation routine (strategic level). The model relates cost-investments (maintenance efforts) to condition-improvement (resulting condition trend).

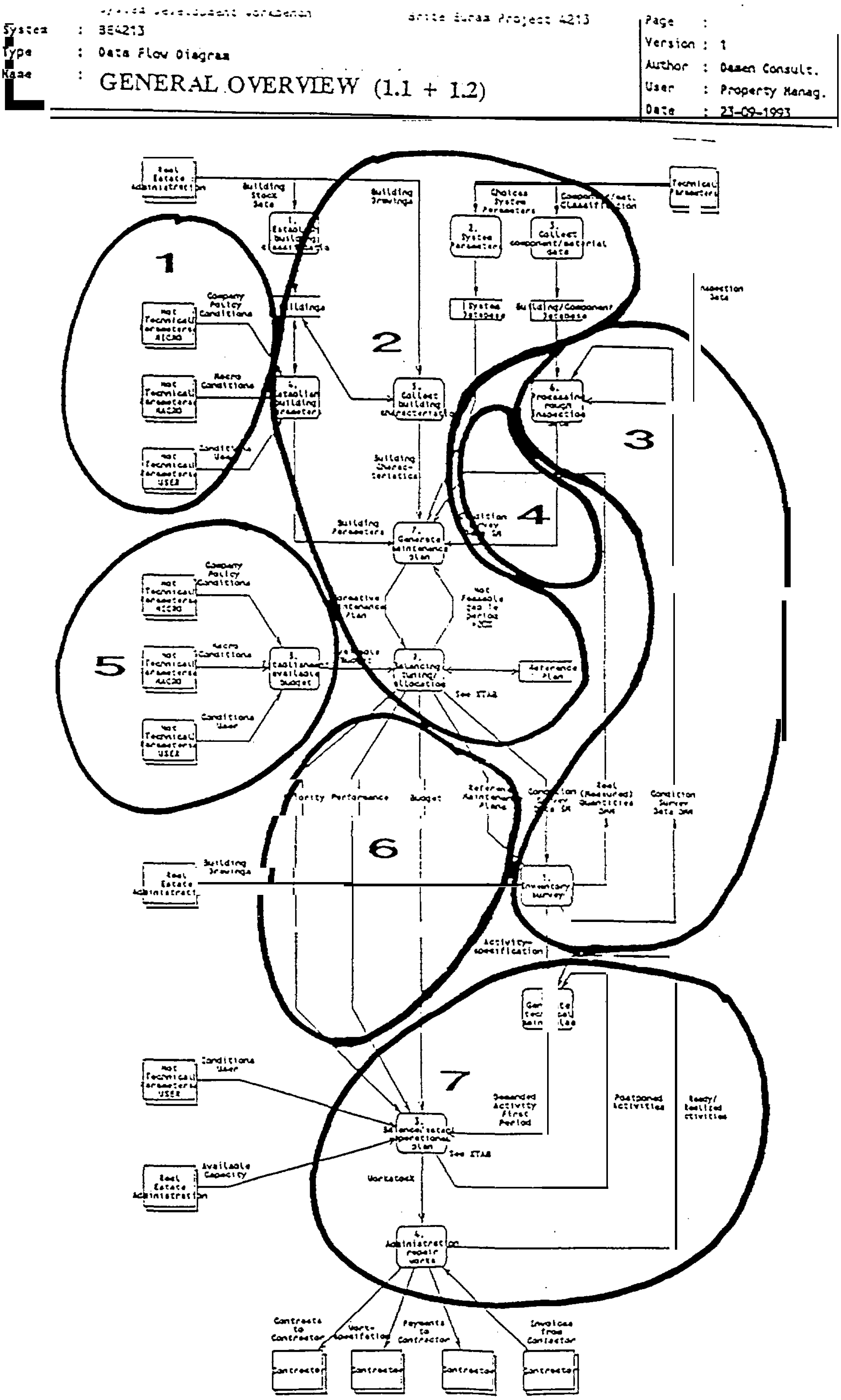
4. **00P**

   This is a Prioritizing Module with optimisation routine used at the operational level of a maintenance organisation. The module optimizes traditional maintenance planning by using priority-codes. As the operational part of the ES (OOP) will only be used at the operational level, this module has been implemented as a part of the DEp.

The software developed has been based on the Entity Relationship Model on the following page. The following functions are presented in the scheme overleaf:

Function:	*Part of:*	
Strategic level:		
1 - Create basic list of buildings	DEp	ES [customization]
2 - Establish global settings		ES [customization]
3 - Create basic list of comp/mat	DEp	ES [customization]
4 - Establish building parameters	DEp	ES [customization]
5 - Collect building characteristics		ES [customization]
6- Processing rough inspection data	DEp	
7 - Generate maintenance plan		ES [BAM]
8 - Establish available budget		ES [PMR]
9 - Balancing/tuning/allocation		ES [BAM]
Operational level:		
11- Inventory/survey	DEp	
12- Generate technical maintenance plan		**00P**
13- Balance/establish operational plan		**00P**
14- Administration repair works		**00P**

Entity Relationship Model showing the seven encircled areas



Referring to the encircled areas in the scheme, the following fictional parts can be distinguished:

1.	Subsystems for the deriving the Non Technical Parameters:	NTP
2.	Expert System (ES: BAM Budget Allocation Module Strategic level)	ES
3.	Data Entry Program (DEp)	DEp
4.	Download module survey data from DEp to the ES	DEp
5.	Expert System (ES: PMR module for accessing and working with data)	ES
6.	Expert System (ES: BAM Feedback Information from ES to Dep)	ES
7.	Optimisation Module Operational Plan	00P

Software module 2 and 3 are implemented in the actual Expert System called ES Solution.

The following user groups are regarded as potential target groups for the software system:

- financial managers (policy-makers at a strategic level)
- technical managers (responsible for managing and implementing maintenance)
- building inspectors

MS Access has been chosen as the software for developing the system. The relationship between the Software Programs is as follows :

1. ES - Expert System

ES-Solution is a Decision Support System (DSS) to assist the financial managers of a Building Property Owner (an organisation who owns and maintains buildings) in finding a solution for supplying and allocating budgets over a stock of buildings. ES-Solution enables the visualization consequences and comparison of different alternatives for the budget allocation.

Although the ES uses expert data (pre-defined databases with data filled by an expert) it is better qualified as a Decision Support System (DSS) which is Knowledge Based.

2. DEp - Data Entry program

The Data Entry program is developed with the aim to collect the necessary data for the ES and the 00P during a condition survey. The following types of surveys can be distinguished:

- Condition survey for the ES
- Operational survey for the 00P

3. NTP - Non Technical Parameters

The NTP systems represent small subsystems to give assistance to the user in assigning maintenance scenarios to objects. It provides the manager with figures to make decision on the level of the total building stock or on the level of separate buildings.

4. 00P - Optimisation Routine Operational Plan
The Optimisation Routine Operational Plan consists of a routine to postpone actions automatically within the Operational Plan on the basis of a simple priority sequence. The 00P is also meant to print reports for the Operational Level. For this reason it has been implemented as a part of the DEp.

2.3 Task 3 Instruments for Condition Assessment and Monitoring

2.3.1 Conceptual Theory

The underlying theory is Task 1 was that the degradation of a component/material over the life span is manifested is overt signs, symptoms or observations which are discerningly different at various stages in the life span. This theory was used to categorise the process of degradation into 6 condition scales. The same underlying theory has now been applied to the fact that when a material or component degrades, there are some measurable properties which vary with time and thus indicate the degradation. It was expected thus to be conceptually possible to relate these specific measurable properties to each of the condition states established i.e. express the degradation as a fiction of six points in the time of the life of the component or the material.

The procedure for investigating the degradation of the materials/components conducting the review has followed substantially the first two steps of the systematic methodology outlined by the joint committee CIB W80/RILEM 71PSL 'Service Life Prediction of Building Materials and Building Components'. The FMEA (Failure Mode and Effect Analysis) was used to survey all relevant degradation factors, mechanisms (processes) and the effects of the degradations. This approach is in line with the categories for non-destructive testing techniques: cause, process and effect related.

The overview of the approach adopted to study of the Degradation and Condition Assessment of Building Components/Materials is provided overleaf:

1. Definition 1.1 General description of the material 1.2 User needs that in general are fulfilled by the building material 1.2.1 The building context in which this material in general is used 1.2.2 Identification of possible performances 1.2.3 Relationship between the building context and the performances

2. Preparation 2.1 Identification of possible degradation factors and mechanisms by means of a FMEA 2.2 Qualitative description of the degradations 2.3 Quantitative data 2.4 Literature references 2.5 References to building codes 2.6 Maintenance information

3. Starting points for condition assessment 3.1 General information on design 3.2 Conditions 3.3 Inspection/monitoring 3.4 Available non-destructive testing techniques for conditions of building components

4. Discussion

2.3.2 Research Methodology and Results

A review was made of the available Literature and test results on the performance and degradation during service life. This review concerned all combinations of building components **and** materials researched in Task 1.

The state-of-the-art review provided information regarding the degradation properties of building components or materials that can be measured using in-situ measurement techniques involving non-destructive testing and monitoring.

The results of the review have been entered into a database in which the following aspects are distinguished:

- the detected phenomenon
- the building component on which the survey is focussed
- the building material
- the medium used for inspection
- the types of readout
- the type of sensor that has to be used
- the required contact between the sensors and the material
- the signal path
- the measuring can take place from one side of the structure or nom two sides
- the method which is used
- the equipment that has to be used
- the development stage

The following non-destructive condition assessment techniques were studied in relation with the selected component/materials:

- concrete corrosion tester offering the possibility to measure electric potentials and currents of the electro-chemical corrosion process
- laser scanning of the surface defects of coatings for measuring the geometry of large surfaces have been developed already
- impedance of metallic corrosion under organic coatings and other defects
- radar detection for corrosion of steel anchors in masonry walls
- pointing hardness testing in outdoor masonry walls
- ultra-sonic control of cracks in concrete element
- ultra-sonic control of debonding of thick coatings
- ultra-sonic control of airtightness of doors and windows
- built-in probes to follow the moisture content in wood
- built-in probes to follow the moisture content in plaster

The main consideration in the evaluation and proposal for condition assessment instruments was the need to automate the inspection process and particularly to address the inaccessibility problem. Other considerations such as using these instruments both for dynamic condition monitoring and to act as an early warning system of impending failure also have been evaluated. Architectural and other design aspects have been considered in general and specifically when proposing the specification of the instruments.

Developments to the existing instruments investigated to facilitate condition assessment involve in the main the use of computer techniques especially with respect to the number of measurements, data logging and interpretation of the measured signals. Other developments include sensors embedded in the structure connected with multi-plex cables or optical fibres to a central point where readout equipment can be connected at regular time intervals. Other options are to connect a self-contained data logging device or a modem which allows remote readout and logging. For automated instruments, possible solutions are automatic mapping, or scanning, or computer thermography or intelligent 'bug'. The 'bug' places the transducer at the desired location and a reading is transmitted and acquired by the computer. A more general approach to this problem is via robotics.

3.0 CONCLUSION

The project has been completed with the objectives realised. The benefits which will form the results of this project is expected to extend over several sectors of the industry.

For the construction industry at large, the condition assessment and resulting condition scales established will provide a standardised method of specifying the durability and expected degradation of a building/component from the time of commissioning and the preventive/corrective action required at each condition state over its service life. This unambiguous method of communicating the expected performance of a building/component will particularly benefit those parties who presently have to issue warranties for construction goods and services, be they manufacturers, designers, contractors and even insurance companies as the condition scales established will serve as industry references on what would be deemed normal defects and defects growth. This will lead to the technical benefits of being able to design, build and maintain to predictable levels of performance and the economic benefits of less defect liability disputes which is currently proving very costly to the industry and economy at large.

With regard to facilities management and maintenance for which this research project has been specifically directed at, the condition scales established provide vital information on the technical state of the building. When this information and the aid of the expert system, the facilities manager will be able to formulate the 'best' strategy for the maintenance and upkeep of the buildings based upon user requirements and within the constraints of the resources available. On the shop floor level, there will be a dramatic improvement in the condition appraisal process and objective results thus enabling timely and more cost effective maintenance action at the same time enhancing the durability of the building/component.

The practicability of utilising high tech for automation of the inspection and condition monitoring process of existing buildings for the purpose of maintenance has also been expounded in this research project, These technological developments when realised within the EU will contribute to closing the lead which USA and Japan has in the automating and robotising of construction processes.

It maybe pertinent to emphasize that this research project although conceived primarily for the maintenance industry has important applicability for manufacturers of instruments and products and the new built and civil engineering industry when considering durability and maintainability throughout the lifecycle of a building.