INFORMATION ANALYSIS FOR ROOFING SYSTEMS MAINTENANCE MANAGEMENT INTEGRATED SYSTEM

Information analysis for roofing maintenance

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Abstract

The Building Envelope Life Cycle Asset Management (BELCAM) project, lead by the National Research Council Canada (NRCC) and Public Works and Government Service Canada (PWGSC), is a "proof of concept" project aimed at helping asset managers to predict the remaining service life of building envelope components and to maximize the return on their maintenance expenditure. The BELCAM project focuses on flat or low-slope conventional roofing systems as a representative domain. This paper focuses on maintenance management, which is primarily concerned with the management of all technical and administrative tasks involved in maintaining a building element in, or restoring it to, a state in which it can perform its intended function. A framework for the integration of the process of managing maintenance of roofing systems is proposed. The framework consists of five sequential steps: (1) Identification of roofing system components requiring assessment, (2) Identification of roofing system performance requirements, (3) Identification of performance assessment methods, (4) Roofing system maintenance planning, (5) Roofing system maintenance operations management. This paper introduces a framework for roofing systems maintenance management. It presents a preliminary analysis of an integrated information system to support maintenance management. The paper follows the development methodology adopted by the International Alliance for Interoperability (IAI) to represent the high-level information within the proposed framework of maintenance management. IAI projects follow a standard process-oriented development methodology, involving the following steps: usage scenarios, process definitions, information analysis and information modeling and validation.

Keywords: Maintenance management, roofing systems, performance requirements, condition assessment, planning, operations management, IAI, process analysis, product modeling

1 Introduction

The Building Envelope Life Cycle Asset Management (BELCAM) project, lead by the National Research Council Canada (NRCC) and Public Works and Government Service Canada (PWGSC), is a "proof of concept" project aimed at helping asset managers to predict the remaining service life of building envelope components and to maximize the return on their maintenance expenditure. The BELCAM project focuses on low-slope conventional roofing systems as a representative domain. Some of the reasons justifying choosing this domain as an area for investigation include: roofing repairs are expensive and form a large portion of maintenance budgets; there is a considerable literature dealing with roofing durability; and it is a well-defined domain with some well-known links to other subsystems. The BELCAM project centers around six enabling technologies, namely; life cycle economics, service life prediction, user requirement models, risk analysis, product modeling and maintenance management. This paper focuses on one of the enabling technologies, namely maintenance management, which is primarily concerned with the management of all technical and administrative tasks involved in maintaining a building element in, or restoring it to, a state in which it can perform its intended function.

2 Proposed framework of maintenance management

The proposed framework for managing maintenance operations of roofing systems consists of fives sequential steps (processes). The framework starts with the current condition of a roofing system in hand, and ends with updating as-built records. Fig. 1 is a process flow diagram that illustrates the sequential flow of these steps. The following five subsections describe the proposed framework.

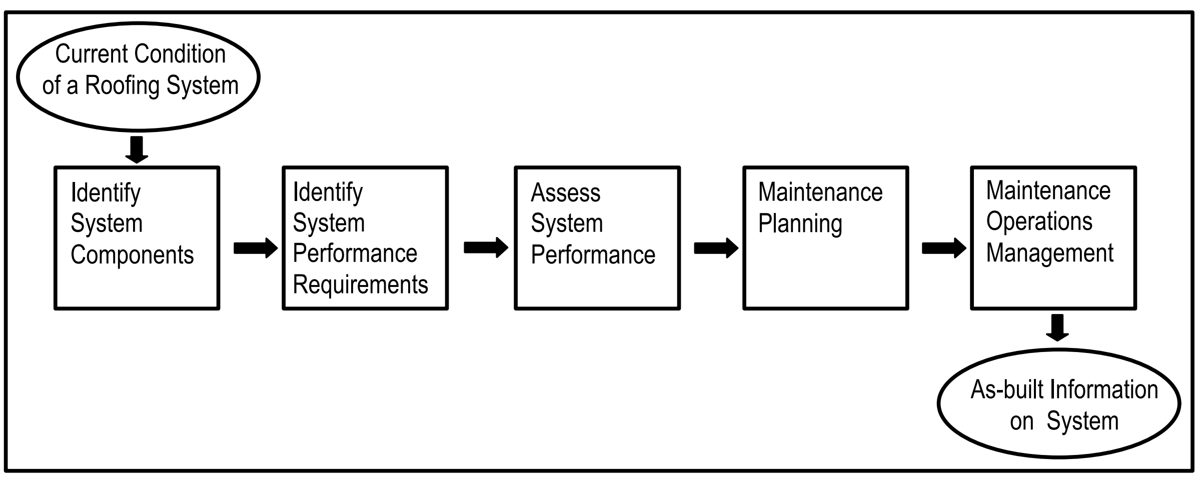

Fig. 1: Five general steps (processes) in proposed maintenance management framework

2.1 Identification of roofing system components requiring assessment

A typical flat or low-slope roofing system is comprised of a roof deck and supporting structure, vapor and/or air retarder, thermal insulation, roof covering, flashing materials, and top cover. There are two types of roofing systems, depending on the position of the insulation within the roofing system assembly. These are: exposed (conventional) membrane roofing systems, in which the insulation is below the roofing membrane, and protected (inverted) membrane roofing systems, where the insulation is above the roofing membrane. The BELCAM project is placing an emphasis on exposed roofing systems for which the roof covering material is single-ply, modified bitumen (mod-bit), and built-up roofing (BUR) membrane.

In the first regional survey (one of the BELCAM project deliverables) that took place in the Ottawa region in the summer of 1998, three main components within the roofing assembly were identified and targeted for visual inspection. These components are roofing membrane, flashing materials, and insulation.

2.2 Identification of roofing system performance requirements

Performance requirement is a statement of the needs to be fulfilled during the service life of a product (e.g. roofing system). Some of the efforts made to identify performance requirements of roofing systems include work by Booth (1987), Rissmiller (1981) and May (1984). Table 1 summarizes some these performance requirements along with their applicability to roofing system components and the associated evaluation technique. Griffin (1970) presented the performance requirements and their corresponding applicability to roofing systems' components along with the evaluation technique followed.

Table 1: Roofing system performance requirements (Griffin 1970)

Performance Requirement	Applicability				How Evaluated?
	Deck	Vapor Barrier	Insulation	Membrane	
Weather resistance				X	Test
Wind resistance	X	X	X	X	Test
Fire resistance	X	X	X	X	Test
Bitumen flow resistance				X	Test
Appearance				X	
1. Permanent deformation					Judgement
2. Surface defects					Judgement
3. Non-uniform color					Judgement
Thermal insulation			X		Test

Discussions with roofing experts and literature review indicated that carrying out tests for the purpose of evaluating roofing system performance is an expensive exercise and would normally only be carried out for problematic roofs. Since visual inspection is the most popular and economical means of condition assessment, and value judgment is widely employed as a way of evaluating performance requirement.

2.3 Identification performance assessment methods

There are two main categories of inspection techniques exist that are currently used in practice today:

External (visual) inspection: examination procedures from above the roof must be geared to the particular system and materials used in the roofing assembly. The BELCAM project is mainly concerned with the visual inspection of flashing and membrane of low-slope single-ply, modified bitumen and built-up roofs and determining their potential failure modes. The project is adopting the methodology of MicroRoofer (Bailey et al. 1989) for establishing procedures for consistent and objective measurements of roof baseline and condition assessment data, as well as for recording data on severity levels of each flashing and membrane distresses and defects.

Internal (empirical testing) inspection: while the roof may appear to be in good condition, there may be problems under the surface. Two categories of tests can be performed to inspect and determine the moisture content in an insulated roof system: Destructive Moisture Tests, including Roof Cuts Test (Dworkin 1990) and Moisture Meter Test (Monterose 1986); and Non-destructive Moisture Tests, including Infrared Thermography (IF), Nuclear Moisture Detection and Capacitance Radio Frequency Scanning (CRF) (Monterose 1986).

2.4 Roofing system maintenance planning

This step presents a method to recommend a specific management option based on analysis that encompasses and compares all relevant criteria throughout the life cycle of various roof management options. Alternative management options for roofing systems are:

1. **Maintenance**: includes general activities such as cleaning drains.
2. **Repair**: includes performing localized repairs to rectify situations of distresses such as repairing splits, holes and tears.
3. **Renewal**: includes installing a new assembly of roofing system either above the existing system, after disposing of the old roofing system.
4. **Do nothing**: includes postponing or ignoring maintenance, repair or renewal.

The selection of a waterproofing system for a building is one of the important decisions that an architect or a specifier make in a project. In some cases, the owner would prefer the system with the lowest initial cost due to budgetary constraints. However as indicated by Herbert (1989), many owners have found out the hard way that initial cost should not always be the determining factor in selecting a roof system. It can be argued that life cycle cost is the criterion that should be examined when recommending a specific maintenance management option. A conclusion can be made that the decision for the maintenance scenario for the waterproofing system is a process that depends on quantitative and qualitative judgment. The listing below presents four design decision variables or criteria that should be considered when deciding upon implementing a specific roofing system:

2.4.1 Performance and service life prediction

The BELCAM project is proposing the use of a probabilistic Markovian chain model to predict the performance of roofing membranes through modeling the deterioration and repair processes. The model accounts for time-dependence, uncertainty and variability of roof section performance (Lounis et al. 1998).

2.4.2 Life cycle costing (LCC) analysis

In addressing LCC implications of roofing decisions, literature indicates that one major difference between roofing decisions and other business investment decisions is that roofing investments rarely produce a revenue stream like other business investments. Roofing investments only produce a cost stream. Typical types of economic analysis decision-making criteria include: Net present value (NPV), Payback period, Savings to investment ration (SIR) and internal rate of return (IRR) (Doshi 1997).

2.4.3 Risk-based multi-objective decision analysis

The multi-objective optimization analysis is a procedure for decision making under conflicting management objectives: namely, minimization of maintenance and repair costs, maximization of roof section performance and minimization of risk of failure (Lounis et al. 1998).

2.4.4 Value-engineering (VE)

VE principles are used as a decision-making tool. It is based on a qualitative analysis, which employs quantitative analysis within. VE principles are used to evaluate different feasible options and to choose the most optimal one among a set of economically feasible alternatives as obtained from the economic analysis.

2.5 Roofing system maintenance operations management

In arriving at this final step of five in the framework, it has been firmly established that maintenance management practice such as carrying out regular condition assessment, general maintenance, localized repair and systematic renewal, or some combinations of these practices, was found to be the best option for minimizing life cycle costs, maximizing performance, and minimizing risk. The management of the maintenance operations required to complete these activities then can take place. This includes planning, scheduling, budgeting of in-house or procured resources, identifying work methods, managing the associated document flow, etc. It is thought that assigning priorities and allocating resources in carrying out a maintenance management practice for roofs would depend on several factors. Some of these factors are probability of facility shutdown, importance of occupancy affected and consequences of failure which are translated into cost figures, including: cost of disruption, cost due to relocation, and cost due to damaged contents under the faulty roof. In case of general maintenance, the planning of roof management operations may be minimal since the magnitude of the work is limited to the areas where roof distresses are found. In the case of roof renewal, the planning activities are similar to those of new roof construction.

3 System development

An information system is proposed to integrate the five steps forming the framework of maintenance management. The development methodology for the integrated information system follows the process-oriented methodology set by the International Alliance for Interoperability (IAI) in their projects to define Industry Foundation Classes (IFCs) (IAI 1998). The aim in developing IFCs is to be able to describe or conceptually model the industry project under study, which in this case, is the development of a prototype for a roofing maintenance management integrated system. The development methodology comprises of the following steps:

3.1 Usage scenarios

Usage scenarios are descriptions of situations that show the use of IFCs to carry out the selected process, i.e. developing a roofing maintenance management system. In usage scenarios, a set of assertions is made. The objective of developing assertions is to: identify classes, identify relationships, identify cardinality of relationships, and identify attributes (Liebich and Wix 1998). These assertions then can be modeled and implemented. e.g. "**A roof section can leak".** The knowledge of the roof section that leaks involves identifying the building for which a complaint about the leaky roof was made.

Example assertion:

A roof section can leak

- A **building** *contains* <u>one or more</u> **roof sections**
- A **roof section** *is characterized by* ***Section name, area and perimeter***

Legend: **Class**|*Relationship*|<u>Cardinality</u>|***Attribute***

Fig. 2: Assertion example in a usage scenario

3.2 Process definition

A process definition includes a description of the tasks involved to carry out the selected process. Fig. 3 through 7 are process diagrams that outline the tasks involved in carrying out each of the five steps (processes) in roofing maintenance management. It can be observed that the ending task in one step (process) is the beginning task in the following step (process). The figures provide the logical sequence of the tasks within each step and associated information requirements.

Step 1 - Identify roofing system components requiring assessment

Process Definition: The purpose of this process is to identify the components within the roofing system assembly that may require maintenance operations within their service life.

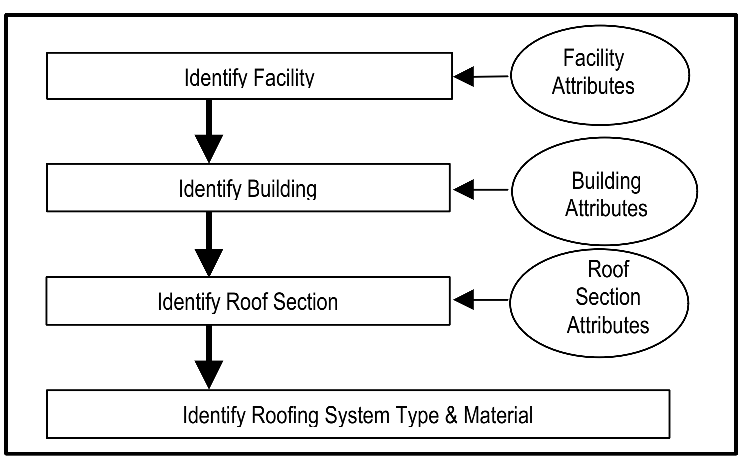

Fig. 3: Process diagram for the first step within the framework

Step 2 - Identify roofing system performance requirements

Process Definition: The tasks within this process involve identifying the performance requirements of both the roofing system as a unified entity, and the components that make-up the assembly of the roofing system.

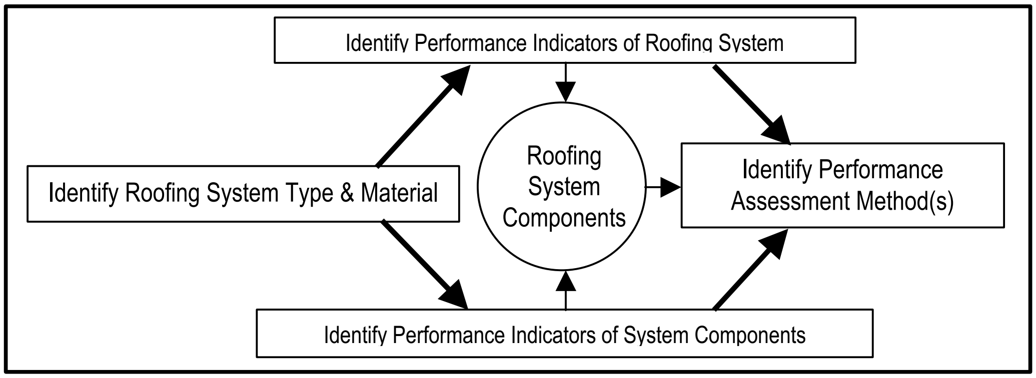

Fig. 4: Process diagram for the second step within the framework

Step 3 - Identify roofing system performance assessment methods

Process Definition: The purpose of this process is to identify the performance assessment method(s) to be able to catalog the system components that cease to meet the performance requirements and, hence, require maintenance actions.

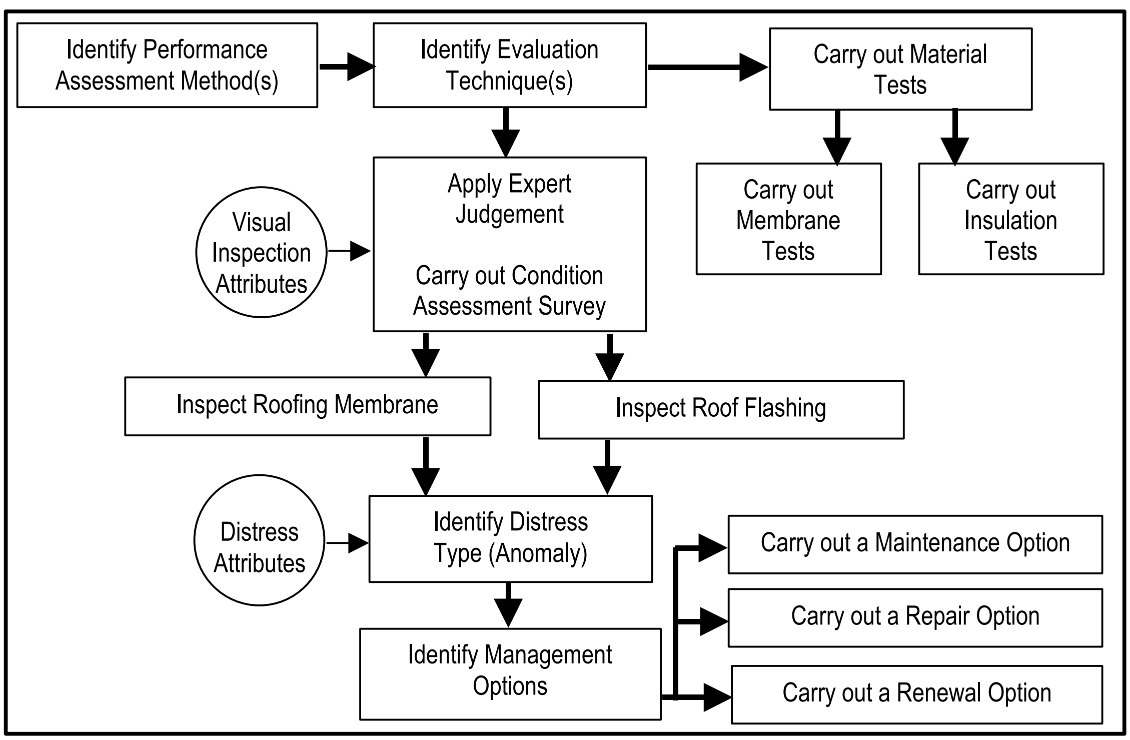

Fig. 5: Process diagram for the third step within the framework

Step 4 – Roofing system maintenance planning

Process Definition: The purpose of this process is to determine maintenance priorities based on four main analyses: performance and service life prediction analysis, life cycle costing analysis, analysis of conflicting management objectives and value engineering analysis, hence recommending the most feasible maintenance action

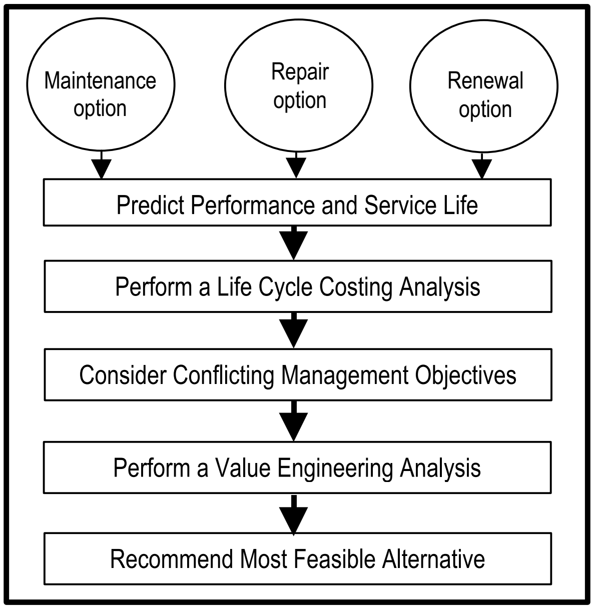

Fig. 6: Process diagram for the fourth step within the framework

Step 5 – Roofing system maintenance operations management

Process Definition: The purpose of this process is to identify the activities involved when carrying out a roofing system renewal option. The other two options include: general maintenance (which can be carried out during the visual inspection) and localized repairs.

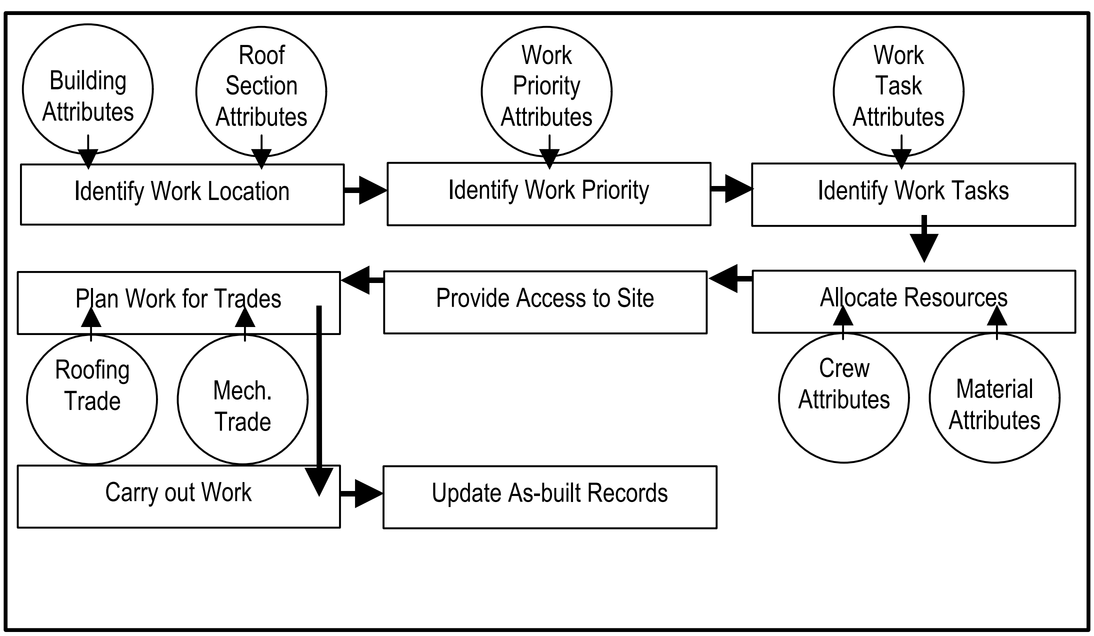

Fig. 7: Process diagram for the fifth step within the framework

3.3 Information analysis

The high level information input and output requirements of each process step (as obtained from the process definition phase) are used to define detailed data elements (e.g. classes or entities and their attributes).

3.4 Information modeling and validation

In this stage, the results from the information analysis are transferred into a conceptual model, illustrated with simplified diagrams using an informal Express-G graphical notation. Information elements are represented as classes (entities), attributes, and entity relationships.

Vanier (1998) in a paper addressing the issues of how to handle the archival and retrieval of historic information; and how to ensure the upwards compatibility of data, systems and models for the purpose of exchange of data, presented a product model for roofing maintenance. This product model is developed with the purpose of storing data on visual inspections during the life cycle of the roofing system.

Fig. 8 illustrates a portion of the product model (under development) for the proposed framework of roofing maintenance management outlined earlier. The intended product model aims at integrating the five steps (processes) which form the structure of the framework. The figure only shows the classes (entities) as gleaned from the process definition stage.

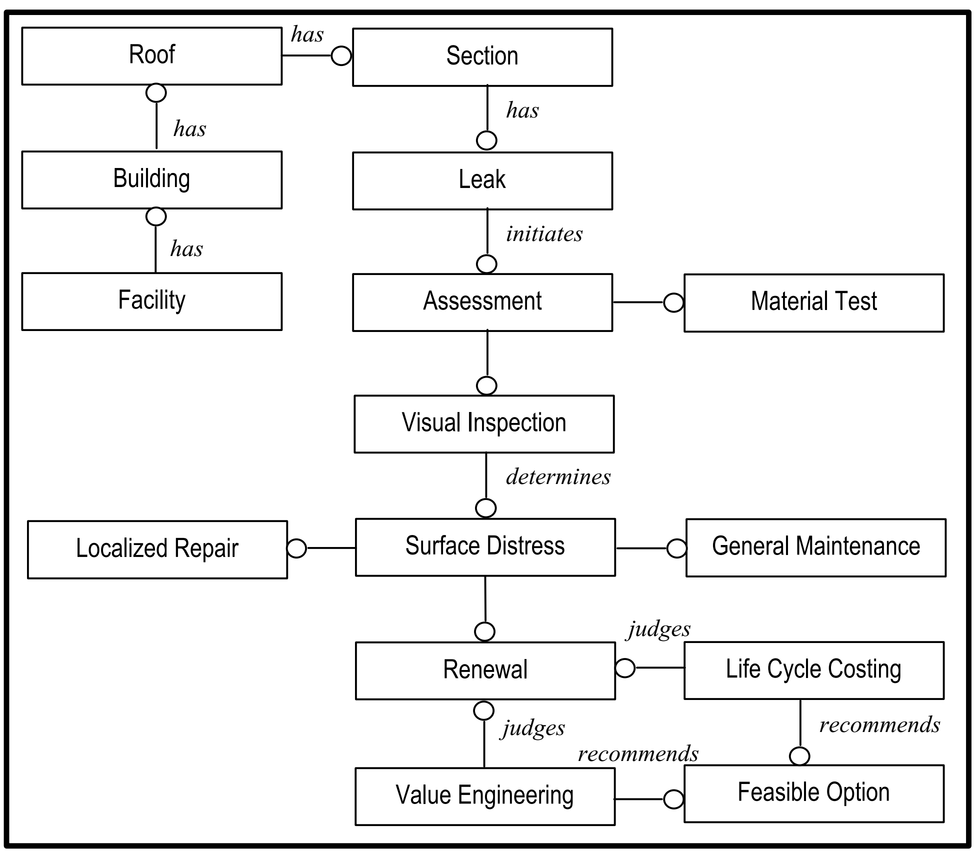

Fig. 8: Portion of the integrated framework of roofing maintenance management product model

4 Conclusions

This paper has introduced the development of a framework for integrating the steps involved in managing maintenance operations of flat or low-sloped roofing systems. The framework is built on five main steps, starting with the current condition of a roofing system in hand, and ending with updating as-built records. Currently, the development of the integrated framework is at its information modeling and validation stage. An implementation phase will follow the design stage of the prototype model. Data for the purpose of testing the prototype will be obtained in collaboration with the BELCAM project. This will serve as quantitative validation for the developed model. Results from complete prototype implementation and validation will be made available in future publications.

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