An Information Model to Support Maintenance and Operation Management of Building Mechanical Systems

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ABSTRACT

AN INFORMATION MODEL TO SUPPORT MAINTENANCE AND OPERATION MANAGEMENT OF BUILDING MECHANICAL SYSTEMS

MARIA AL-HUSSEIN

This thesis presents an information model developed to represent, organize, and link information essential to maintenance and operation management, a facility management function. It first describes the facility management domain and identifies facility information as a primary element to sustain the decision-making process. Then it discusses the need for open communication channels to allow information exchange throughout facility's life-cycle phases, reviews several models addressing information integration, and introduces a framework, which ensures interoperability within different facility management functions. The proposed information model focuses on the information describing building mechanical systems and utilizes object-oriented modeling language. To validate the information model, a prototype is implemented and a real case-study is investigated to provide data and to demonstrate how the research relates to practice.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Large building projects are unique in nature, involve hundreds of participants, thousands of decisions, a huge volume of data, and evolve through different time-phases starting with an idea about a building, followed by feasibility, design, construction, and operations and maintenance phases. The Operations and Maintenance phase accounts for approximately 80% of the total life-cycle costs and lasts during the longest portion of the facility's life [Christian and Pandeya 1997]. Recent construction statistics reveal that Canada spends $52 billion on building construction yearly, $8.5 billion of this amount being spent on repairs and maintenance of buildings [Vanier 1998]. ***Facility Management*** (FM) is the domain responsible for the operations and maintenance of buildings.

Although, FM is concerned with facility use and maintenance, its mission is viewed by facility owners as to add value to an enterprise by continually improving the quality of the operating environment [Majahalme 1995]. Furthermore, facility managers are under increasing pressure to operate at low cost and within shorter time frames. Downsizing, outsourcing, globalization, and accountability characterize the business environment in which they operate. Like the other management-related domains, appropriate, well structured, and timely data are critical to the decision maker. For the facility manager this means accessing a broad range of facility data in order to achieve cost-effective decisions [Teicholz and Takehiko 1995].

Most of the information regarding buildings is created during the design and construction phases (see Figure 1-1) and the rate of information accumulation reaches a maximum prior to the facility commissioning [Yu et al.1999, Svensson 1998].

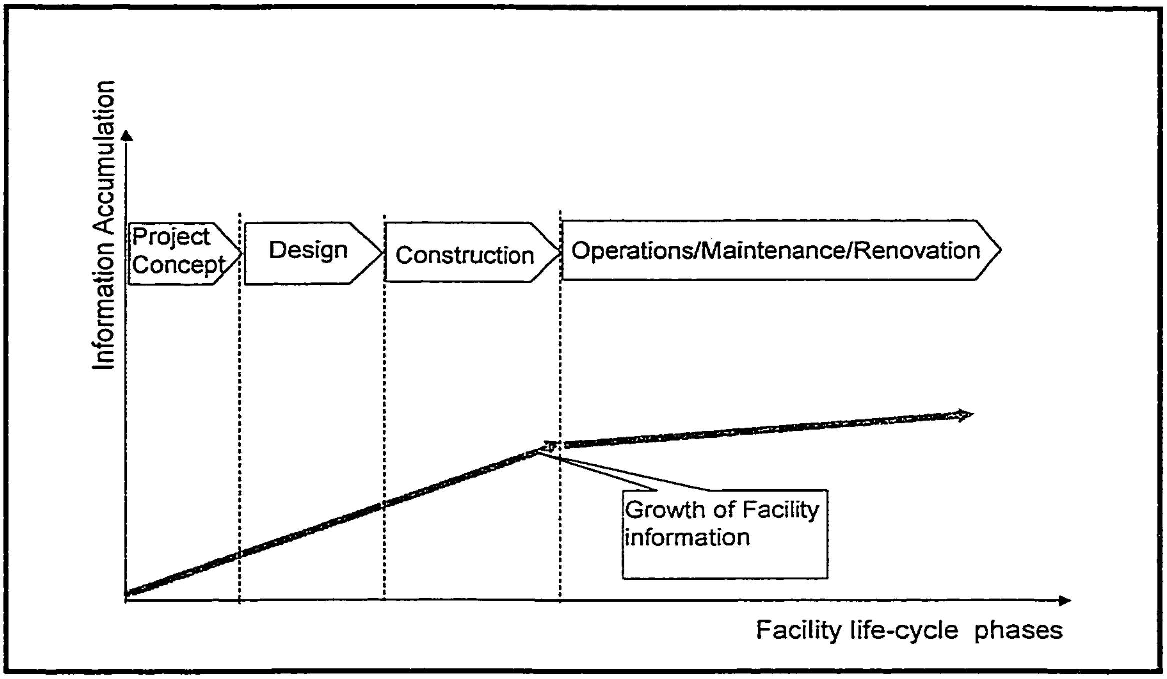


Figure 1-1 Building Project Information Life-Cycle [after Yu et al. 1999]

Despite the fact that much of this information is useful for facility operations and maintenance, the current practice is that building owners and managers acquire the constructed facility with incomplete and sometimes inaccurate, "as-built" information (the actual information describing the facility after commissioning). Information Technology (IT) has been proven to manipulate, store, and structure large amounts of data effectively in other domains, thus utilizing it could be useful for FM as well. The main factors contributing to this lack of as-built facility information are summarized as follows:

- the lack of established standards and coordination efforts to effectively capture the data as construction progresses,
- the increasing scale and sophistication of buildings and their systems contribute to the complexity of the information required to manage facilities,
- the lack of established practice to overview the building project and to produce accurate information at commissioning,
- the way in which Information Technology has been adopted by the Architectural, Engineering and Construction (AEC) industry has created "islands of information" and further reinforced the existing industry fragmentation [Hannus and Pietiläinen 1995].

Facilitating the structuring, sharing and exchange of information throughout the building's life-cycle and among various professional domains would enable facility managers to operate efficiently. This research addresses the needs and perspectives of FM.

1.2 Research Objectives and Domain

1.2.1 Research Objectives

The scope of this research is to develop an information model, i.e. a collection of information regarding a specific object [Fisher and Froese 1996], to support facility maintenance management and to promote information integration spanning the facility's life-cycle. Maintenance and Operation of the building systems (M/O), one of the FM functions, is the focus of this thesis. The research project is based on information requirement analysis and modeling to develop a comprehensive data structure for efficient and consistent information handling. Key data is described as part of an object repository, which is a set of objects facilitating information exchange. To reflect the dynamic nature of the facility, the M/O function is decomposed into processes and sub-processes, which are described as an integral part of the data. Thus, the main research objectives are:

- to identify the key information elements associated with the operations of building mechanical systems, which are essential to maintenance management from the FM perspective,
- to propose an information framework to organize, store, manage, and retrieve that information.,
- to validate the information model by implementing a prototype.

1.2.2 Defining the Research Domain

This research addresses and investigates the facility management domain. To outline the research area, a multidimensional model of buildings ("3P-Model") [Bedard and Gowri 1989] has been employed. The 3P-Model expresses the complex reality of buildings by presenting the phases through which a facility evolves, the participants involved, and the facility components in a 3-dimension model. It encompasses three axes, namely, the "Physical" x-axis, the "Time or life-cycle Phases" y-axis, and the "Participants" z-axis. Figure 1-2 depicts the 3P-Model space where this research is situated.

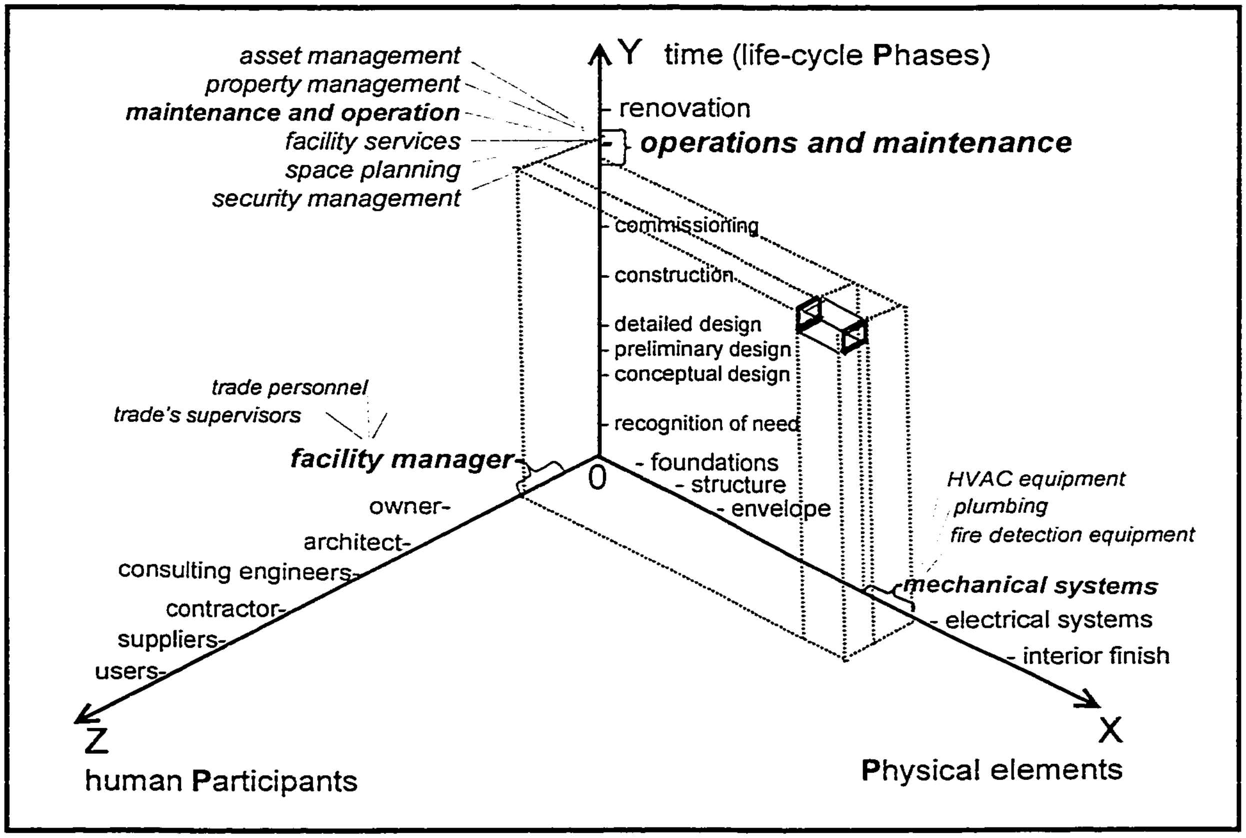


Figure 1-2 Multidimensional (3P- Model) representation of the research domain

The First Axis (X) represents the facility as a system composed of many sub-systems and components. Most buildings are composed of the following main systems: foundation, structure, envelope, mechanical systems, electrical systems, and interior finish. With respect to this axis, the research focuses on the *mechanical systems*, which in turns are decomposed into HVAC equipment, plumbing, fire protection equipment, motors, conduits and various equipment. One of the main functions of the mechanical systems is to provide and maintain constant comfort indoors. They form part of the environmental control systems within a facility.

The Second Axis (Y) represents the dynamic nature of the facility and details the phases or primary processes throughout the facility's life, namely feasibility, design, construction, operation and maintenance. Life-cycle phases encompass various processes through which a facility develops, and each of the phases, in turn, can be broken down into numerous sub-processes and activities. With respect to the Y-axis, this research work focuses on the operation/maintenance (use) phase and, furthermore, investigates in detail the maintenance management process.

The Third Axis (Z) describes the participants involved throughout the facility's life, or the human intervention. The architect, engineers, contractors, suppliers are the main participants in the design/construction phases. However, the facility managers, along with the owner, are concerned with the lengthiest phase. The role of the facility manager is usually performed by a team of a managers, supervisors, and trade personnel. Regarding the Z-axis, this research addresses the facility manager's needs and represents their perspective. Their role and functions are discussed in detail in Chapter Two.

To provide clarity, the terms "building" and "facility" (used interchangeably throughout this thesis) are defined as follows:

- building - "a physical structure comprising partially or totally enclosed spaces and providing shelter"
- facility - "a physical structure, including related site works, serving one or more main purposes" [ISO 1993].

1.3 Thesis Methodology and Structure

To achieve the objectives, this research has followed three major steps shown in Figure 1-3, namely literature review, information model development, and research results validation.

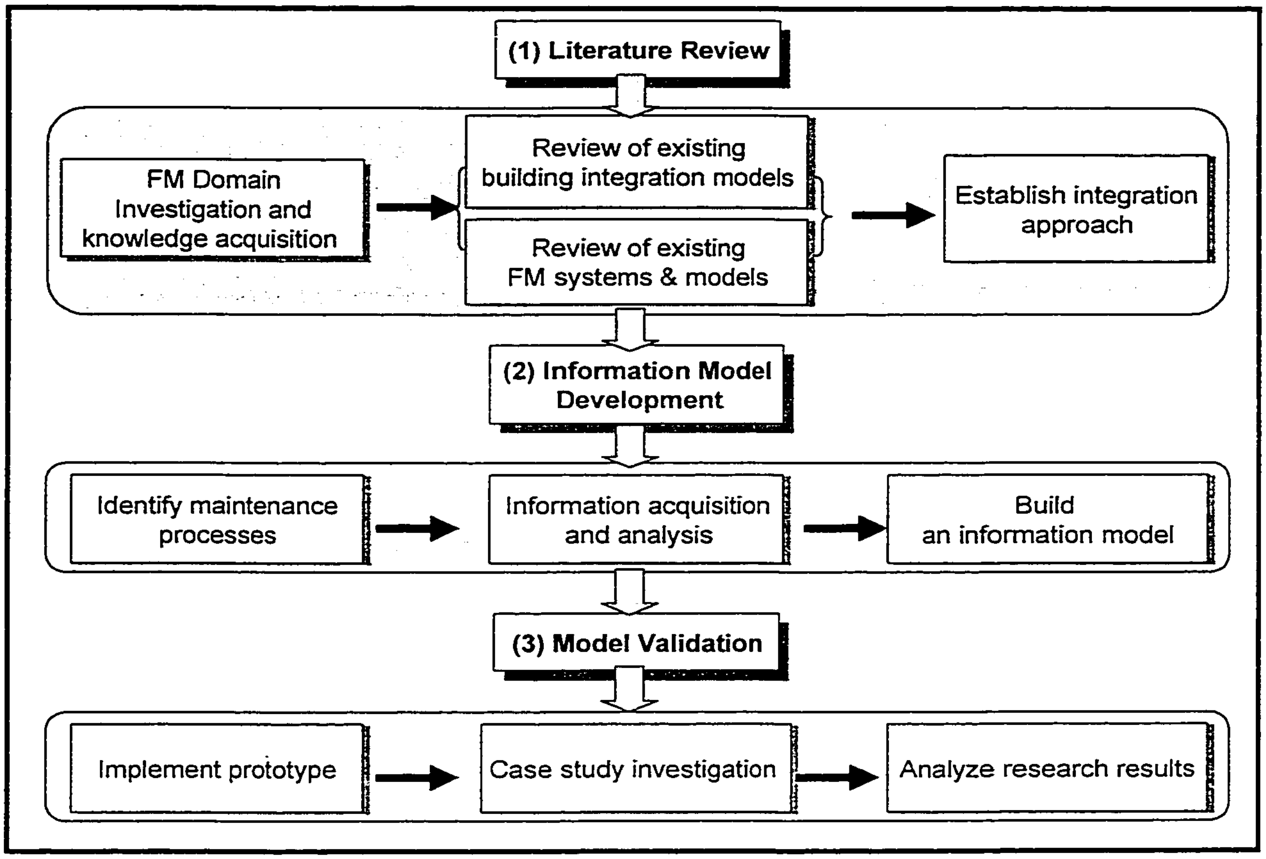


Figure 1-3 Research Methodology

Although the **first step** involves literature review, it strives to accomplish three goals:

- to gain a comprehensive understanding of the FM domain with regards to maintenance management,
- to investigate research works on information integration throughout facility life and research addressing FM needs specifically, and
- to select an integration platform to sustain building an information model which satisfies the research objectives stated above .

The findings of the literature review, along with current FM practice and domain are discussed in *Chapter Two*.

The **second step** entails the development of an information model, which is documented in *Chapter Three*. Furthermore, Chapter Three details the activities that are necessary to accomplish maintenance management, explains the conceptual perspective for the proposed model and data gathering process, and outlines the structure of the information model.

The **third step** is comprised of validation of the research work, which is discussed in *Chapter Four*. Chapter Four presents the implementation of a prototype and the investigation of a case study to illustrate how the concepts are realized in practice, and furthermore presents model evaluation. *Chapter Five* summarizes this research, identifies its original contributions, and formulates some recommendations for future research.

CHAPTER TWO

FACILITY MANAGEMENT: LITERATURE REVIEW

This chapter defines the facility management (FM) domain and its dependence on building life-cycle phases from an information handling perspective. Current practice and IT applications in FM are also discussed. Different integration approaches in construction are presented and related studies are summarized.

2.1 Facility Management Domain

2.1.1 Definition and Functions

Traditionally, facility management (FM) has been considered primarily as facility maintenance and operation tasks. However, changes in the business environment, such as downsizing and globalization, increasing technical complexity of contemporary building, and the escalation of facility maintenance/operation costs all have contributed to facility management being defined as a significant business area, by building owners and operators. Consequently the FM mission has been recognized as to add value to a business by continually improving the quality of the operating environment, and to ensure the organization's primary business functions [Teicholz and Takehiko 1995, Hamer 1988].

Due to its diverse technical background the FM domain has grown out of, the definition of FM, as well as the role of facility managers, differs from one organization to another. The following is the most widely accepted definition of FM in the industry: "The practice of coordinating the physical workplace with the people and the work of the organization, integrating the principles of administration, architecture, and the behavioral and engineering science" [from US Library of Congress 1983 in Svensson 1998]. Although, the definition above includes a diverse range of activities, three main types of activities can be distinguished:

- property management or real estate related activities,
- property operations and maintenance to sustain building systems and elements, and
- office administration.

The primary FM functions constitute the foundation for the various efforts to establish comprehensive FM functions' categorization and description, notable are the International Facility Management Association (IFMA) [Svensson 1998], the Building Owners Managers Association (BOMA) [BOMA], and the North American Facilities Domain Committee of the International Alliance for Interoperability (IAI) [Yu et al.1999]. This research work follows the FM function's classification developed by IAI, shown in Figure 2-1.

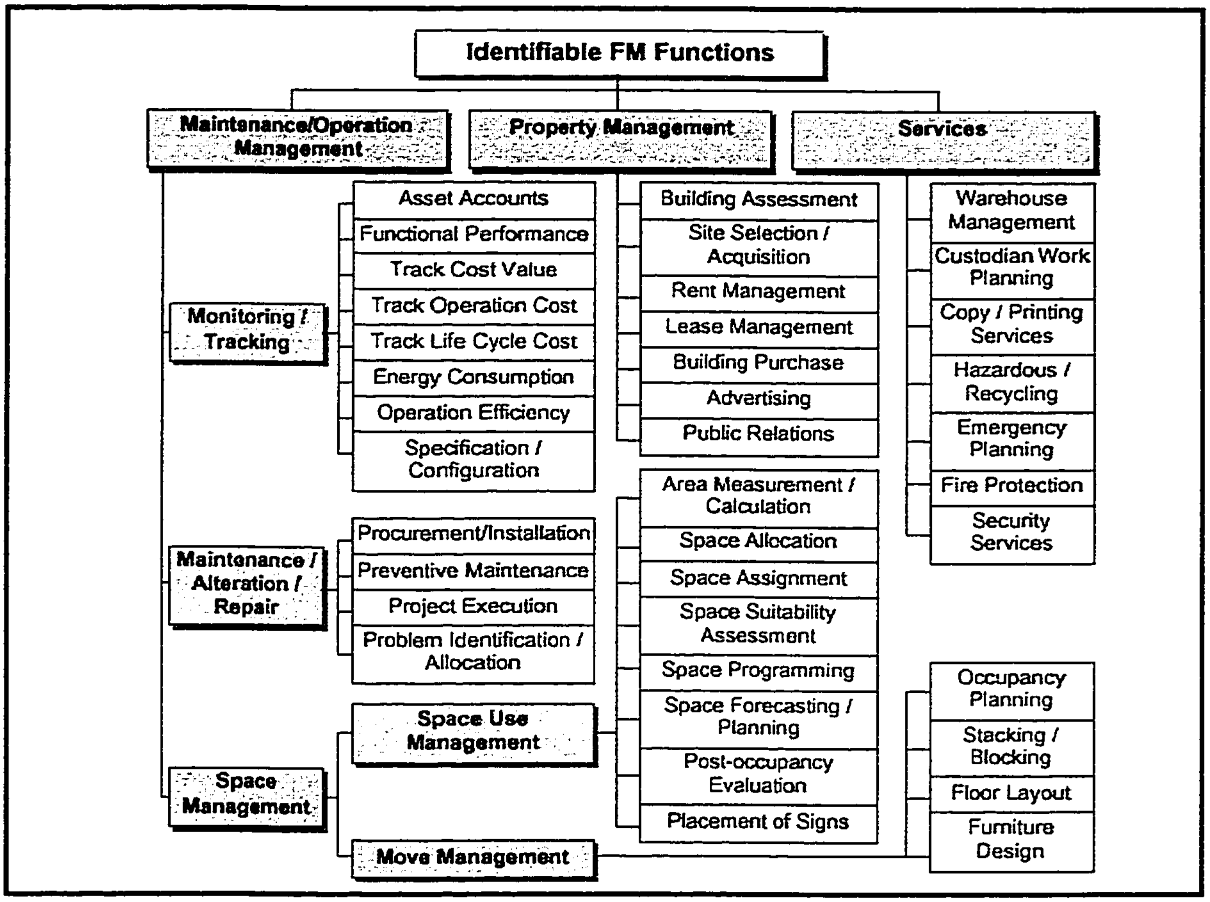


Figure 2-1 Identifiable FM Functions [Yu et al. 1999]

As shown in Figure 2-1 the primary functions, in the Hierarchy chart, are Maintenance/Operation Management (M/OM) function, Property Management function, and Services function. Each function is decomposed into sub-functions and further into atomic activities. For instance, the Maintenance and Operation Management function is decomposed into sub-functions: Monitoring/Tracking Assets, Maintenance/Alteration/ Repair, and finally Space Management. Moreover, the Maintenance/Alteration/ Repair sub-function is further detailed into: Procurement/Installation, Preventive Maintenance, Project Execution, and Problem Identification/Allocation activities.

The FM functions are carried out with respect to the FM elements, which are grouped by the IAI FM domain committee, into two major groups: Building System Elements and Non-building System Elements, as shown in Figure 2-2 [Yu et al. 1999]. In turn, the Building System Elements are further decomposed into: Building Shell, Environment, Mechanical, and Electrical Elements, which are decomposed into atomic elements.

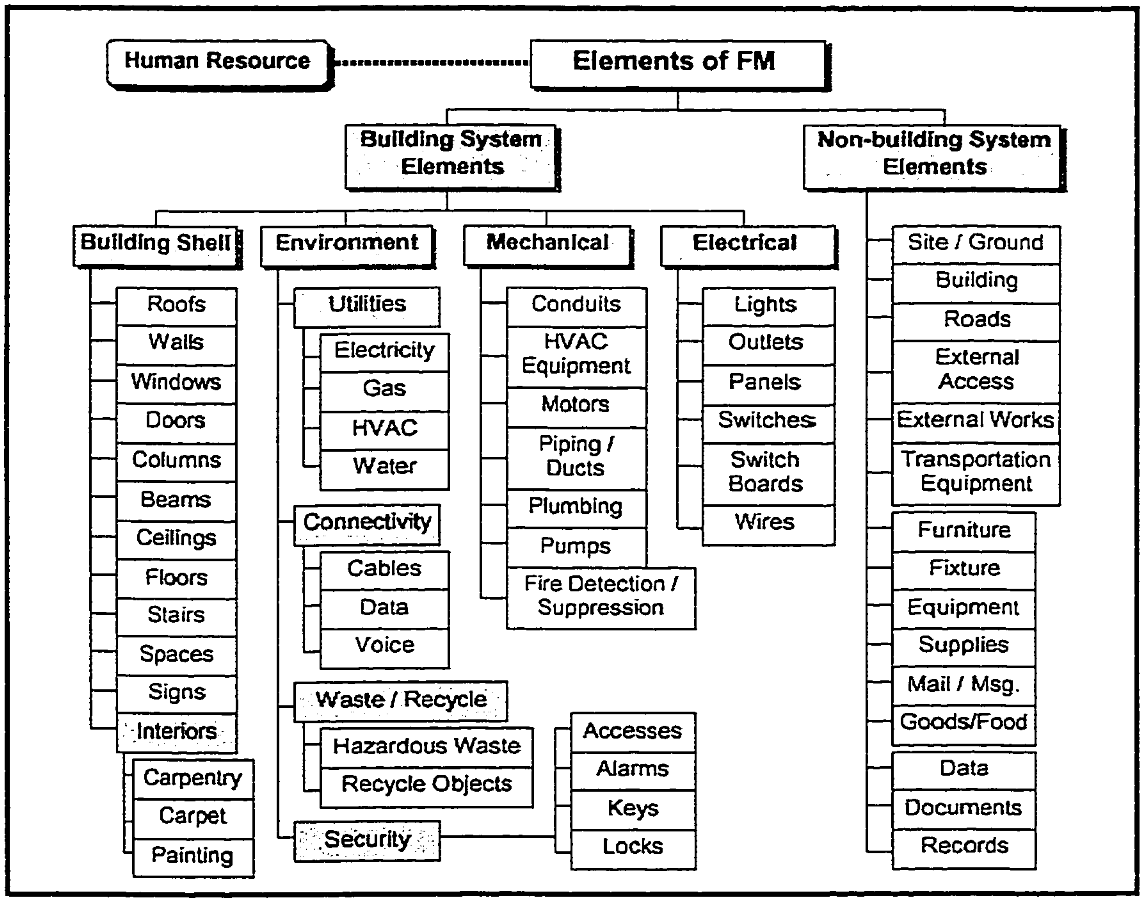


Figure 2-2 FM Elements Chart [Yu et al. 1999]

Despite the diverse nature of the performed activities, some FM functions are perceived to be critical to the industry. A survey conducted in the U.S.A. concluded that the Maintenance and Operation Management function is the most strategic in facility management [Teicholz and Takehiko 1995]. In this research, the *Maintenance and Operation Management* group of functions, with respect to *building mechanical systems*, is established as the problem domain.

2.1.2 Maintenance and Operation Management Group of Functions

Maintenance and Operation Management (M/OM) is the FM group of functions accounted for providing a management structure for the periodic servicing of equipment, preventive maintenance of equipment, and scheduling of routine building services such as replacing light bulbs, paint, and so on. The primary M/OM objective is to keep the facility systems in the best possible condition at the lowest possible cost. Striving to achieve cost-effective maintenance, facility managers tackle the following issues in their daily activities [Hammer 1988]:

- reducing unscheduled maintenance through employing predictive maintenance schedules and monitoring the equipment performance towards eliminating costly equipment failures,

- evaluating the most appropriate timing for maintenance operations to be performed in order to keep low equipment downtime and operation interruptions ,
- analyzing various strategies to follow with regard to facility systems rehabilitation,
- estimating the amount to spend on maintenance within a given budget, while satisfying the expected equipment performance,
- utilizing accurate forecasts of future equipment replacement and maintenance towards reduced operating costs.

The types of maintenance recognized by the practitioners are defined as [Headley and Griffith 1997]:

- preventive maintenance - taking corrective or preventive action in order to avoid expected or avoidable failure,
- corrective maintenance - the day to day repair or replacement of defective items.

Note that the different types of maintenance are further detailed in section 3.3.2.

2.1.3 Information as paramount decision support element

Similarly to any other management domain, FM and M/OM (in particular) efficiency is critically dependant on timely, accurate, and complete information and feedback. Therefore, comprehensive and reliable information is vital to the decision making process and to long-term decision effectiveness. There are two major aspects of facility data required to support every day maintenance management: facility data accumulated during the building design and construction phases of the building life-cycle, and the data created during the O/M phase of the building life-cycle.

First aspect: The architecture, engineering, and construction industry (A/E/C) is engaged primary with the first three building life-cycle phases, namely inception/planning, design, and construction. Due to the project environment, information is exchanged through drawings and reports. Presently, different computer-aided drafting (CAD) tools and domain-specific computer applications are used increasingly in the A/E/C industry in Canada [Rivard 1999]. Due to computer applications, which focus and automate particular processes with proprietary data structures, and to the fragmented nature of the A/E/C industry, there is no analytical and systematic approach for data collection and exchange among different parties and phases. Consequently, the facility owners and managers acquire a completed facility with information limited to CAD drawings, operation instructions, maintenance manuals and schedules, equipment test certificates, which are largely in paper format and supplied in an erratic manner (illustrated in Figure 2-3).

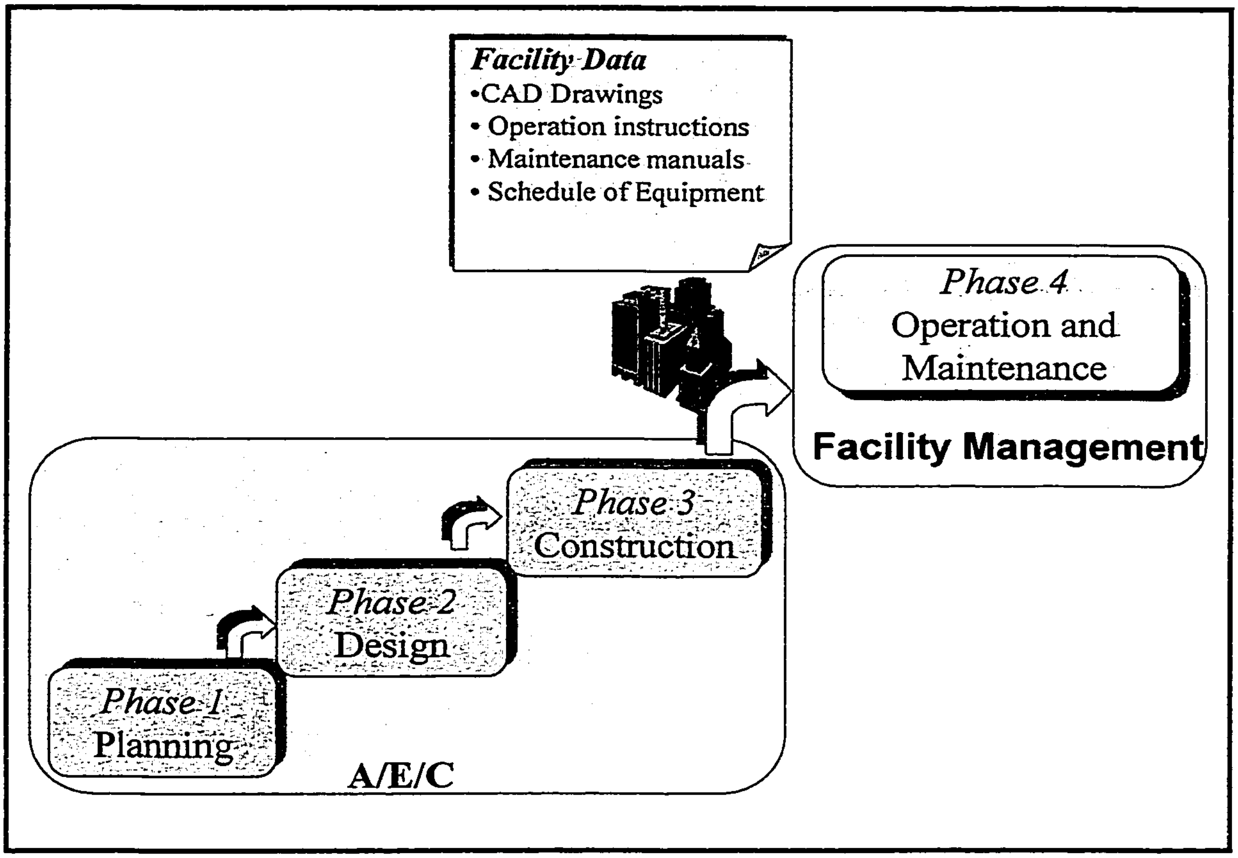


Figure 2-3 The Building Life-Cycle Phases

Conversely, useful information available from the design and installation stages of the building project is not available to facility owners and managers. Therefore, the problem encountered is twofold:

- lack of data acquisition concerning facility's mechanical systems during design and construction,
- acquired data, like documents and drawings, in non-electronic media which require re-entering.

Second aspect: During the facility's operation and maintenance phase, a large amount of diverse data is required and created to effectively maintain the facility's mechanical systems. Furthermore, the data is stored in a wide variety of media, with about 94% on paper [Attinger 1994]. Information Technology (IT), with its capability to store and manipulate large quantities of data, is considered a remedy for information management for operational efficiency and lowering maintenance costs. However, IT is employed in a discrete manner and different CAD systems and computer applications, which automate particular FM processes (e.g. space management, operations control), are utilized to support different FM functions. This approach, rooted in the multi-disciplinary characteristics of the FM functions themselves, perpetuates information fragmentation and creates a deficiency of structured and controlled information flow. Furthermore, the manual data input from one computer application to another introduces errors and hampers the efficiency of the decision making process. Adding to the problem are the building control systems, such as security, lighting, and HVAC, which incorporate Direct Digital Control (DDC) components that are manufacturer-dependant and use non-compliant communication protocols [Teicholz and Takehiko 1995]. Figure 2-4 illustrates the existing stand-alone computer applications deployed to support FM functions.

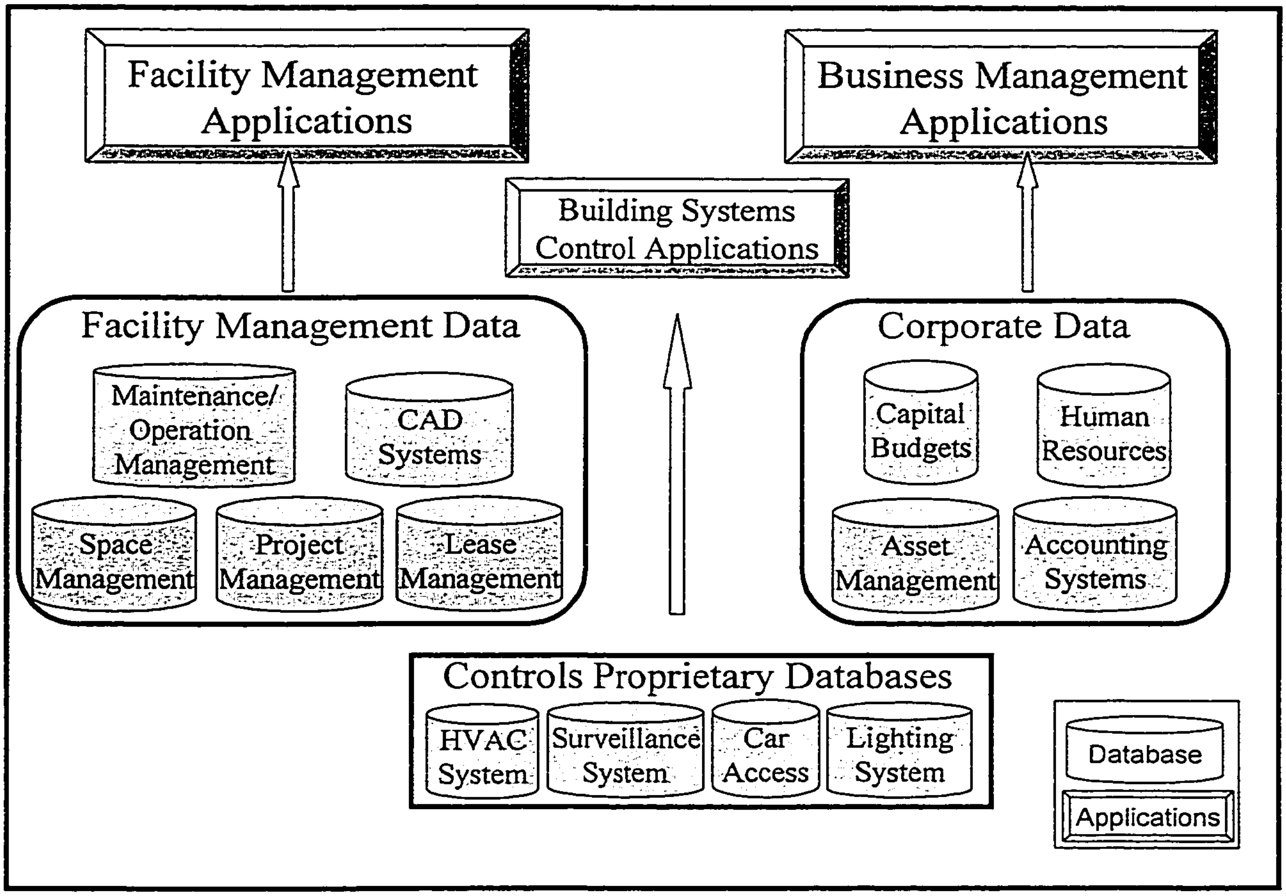


Figure 2-4 Current utilization of computer applications and data exchange in FM

2.2 Information Integration across the facility life-cycle: Literature Review

A literature review of available research works, concerned with information integration and standardization from an FM perspective, is presented in the following section. Accounting for the facility as a product developed through stages, the literature survey is presented in a coherent way and organized in the following sections:

- the first section focuses on different information integration strategies to establish robust data structures for storing and exchange of facility information . Although some of the investigated research tackles the A/E/C domain, the results are discussed as the foundation for facility data integration,
- the second section is concerned with the available standards for information interoperability, and the capability to communicate information between various applications and system parts,
- the third section discusses integrated models developed to fulfill FM functions and information requirements.

2.2.1 Integration Approaches

A number of research projects have attempted to develop coherent and exhaustive models to facilitate continuous and interdisciplinary data sharing.

Three distinct approaches are presented, namely *product models*, *process models*, and *project models*.

2.2.1.1. Product Models (or Product Data Models)

Product models form a distinct category of research efforts, and are based on the concept that a model holds data about a product in an integrated way over its life. The term Product Data is defined by the International Organization for Standardization (ISO) [ISO 1989] as "the totality of data elements, which completely define a product for all applications over its expected life cycle. Product data includes the geometry, topology, tolerances, relationships, attributes and features necessary to completely define a component part or an assembly of parts for the purposes of design, analysis, manufacture, test, inspection and product support". Due to the potential of product models to structure information describing an engineering product throughout its life, researchers have adopted the concept to represent the building as product, as a remedy for information sharing. However, there is no standard definition that is agreed upon for a product model. Stumpf et al. (1996) define it as a structure to organize the building information in order to exchange data among project participants. Eastman and Augenbroe (1998), as well Björk (1997), describe product models in a broader manner as information modeling of products and associated processes, facilitating information sharing between engineering disciplines and between life-cycle stages. Oxman 1995 and Hazlehurst et al. 1997 identified the following common elements of the product models:

- product models are a conceptual description of buildings,
- they are capable of coherently structuring all the information describing buildings, necessary for design and construction,
- these structures hold the data throughout the building life-cycle,
- the primary aim of the product models is to automate the data transfer between different applications used in different disciplines, and the information exchange across the building life-cycle phases.

2.2.1.2 Process Models

The product model, presented in section 2.2.1.1, promotes a product- centric approach towards facility information integration. However, the need to model the diverse and complex processes undertaken during facility life were recognized and a process-centered approach has been proposed by the research community. Process models are defined as a representation of the important steps undertaken throughout a project's life cycle [Stumpf et al. 1996]. Wix (1997) further details the process model as a description of required tasks within an activity with the aim of promoting activities' scope standardization. Furthermore, a process model is perceived as a definition of different procedures that assists in defining the information flow through the various activities and tasks [Betts 1997]. Based on these definitions it can be concluded that process models are used to:

- identify and describe the activities required to carry out a procedure in a specified domain,

- define the information flows in the activities.

Several research projects using process models have been reported [Froese 1996]. A few examples of these are the construction-process-related models developed within the ICON project [Aouad 1994], the AEC core process model for AEC [Froese 1996], and the Generic FM process model [Svensson 1998]. A sample of FM process models is shown in Figure 2-5. The FM process model determines the FM generic activities, namely Core process (1), FM Configuration Process (2), Fm Execution Process (3), and FM Control Process (4) and the information flows represented by the activity's input/output.

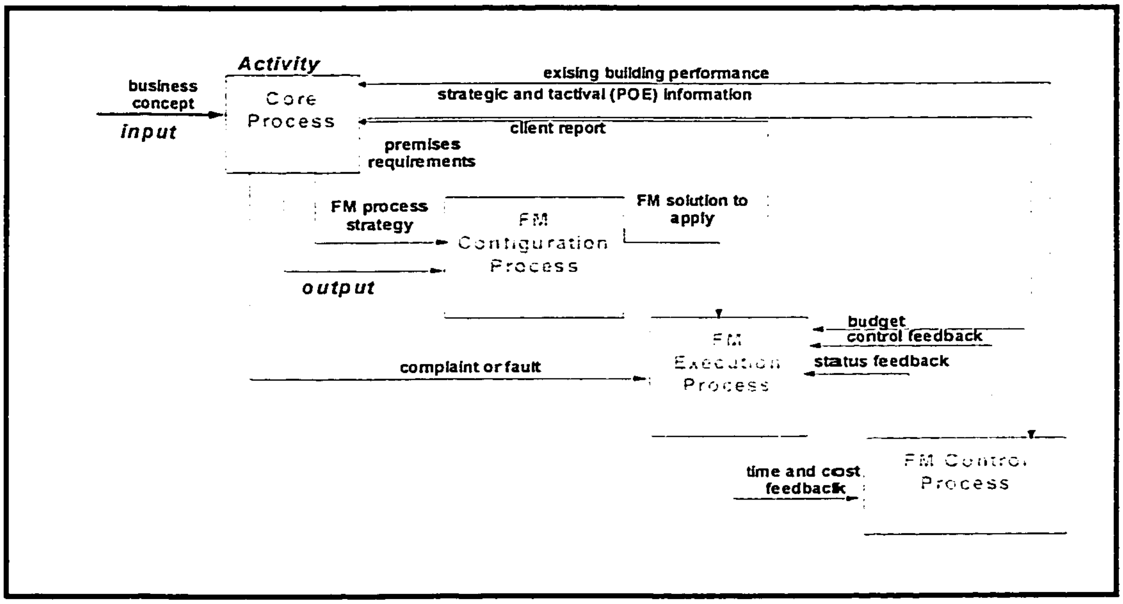


Figure 2-5 The generic FM Process Model [Svensson 1998]

2.2.1.3 Project Models

Luiten in 1994 proposed a building project model (BPM) to integrate product, activity, and resource information by relating products, activities, and time throughout the building project [Froese 1996]. As shown in Figure 2-6, the BPM model captures the relationships between product (its progression from one state to another), required activities (transform, transport, store and verify activities) and resources (labor, material, equipment, and constructor).

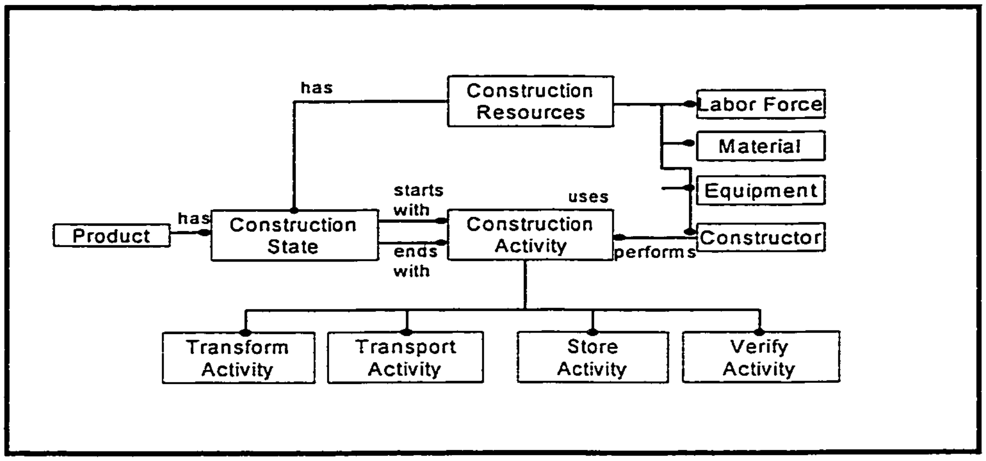


Figure 2-6 Building Project Model [Luiten 1994 in Froese 1996]

Stumpf et al. (1996) identify the project model, in a generic manner, as a framework to integrate product, process, and organizational aspects of A/E/C projects, in order to support project management. Based on these models, it can be concluded that project models represent a structured approach for managing building project information, which focuses on the design and construction life-cycle phases.

2.2.1.4 Integration approaches summary

Three types of models have been developed in the area of A/E/C with the aim to represent the building as an integral object and to enable information sharing, namely the product model, process model, and project model. However, the different models tend to focus on a particular viewpoint of a common object, a building. Product models address information required to identify buildings. Process models identify industry activities necessary to carry out building projects. Project models depict products, processes, and resources involved in building projects. Although the objective of the three model types is to provide a framework for information integration, only product models aim to support information exchange spanning the entire life of a building. Furthermore, process models can be viewed as enhanced product models, which include an additional dimension, the necessary activities. Project models address the need for a foundation to manage building projects, thereby attempting to support the construction management domain.

2.2.2 Standardization efforts for information interoperability and exchange

Integration strategies, presented in section 2.2.1, strive to provide a complete unification of an overall system regarding the sharing of information and functions, leading to reduction in duplication of procedures and resources. In this context, interoperability denotes the capability to communicate information between various applications and different parts of a system. Presently, due to the fragmentation in the A/E/C industry, communication among participants in the facility life-cycle is "**Node to Node**" as illustrated in Figure 2-7 a).

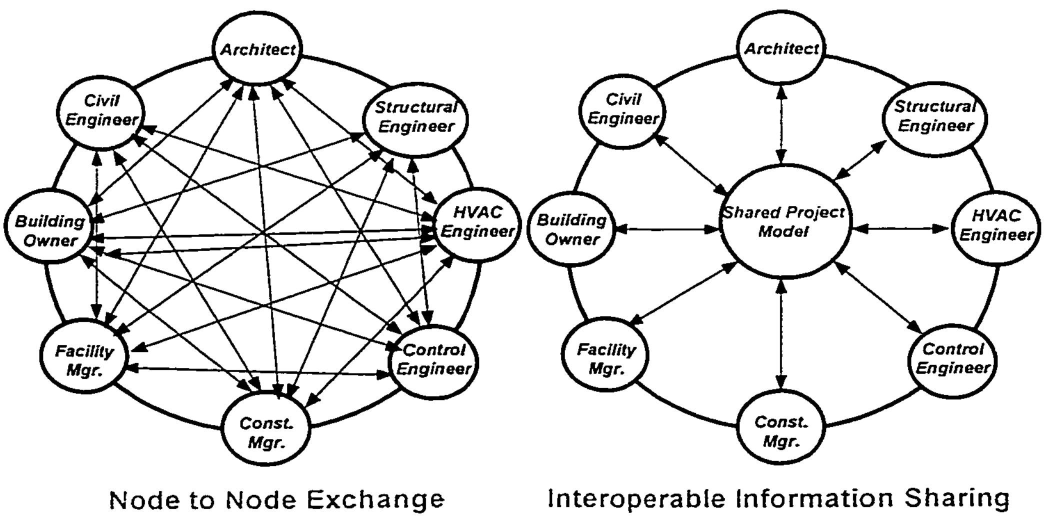


Figure 2-7 Interdisciplinary Data Exchange

a) Node to Node exchange b) Interoperable Information Sharing [Teicholz 1996]

Moreover, the computer applications, automating particular processes, produce data in incompatible formats, which requires data re-entry, introduces errors, and hampers information verification. The apparent solution is to develop standards for representing information and a vendor independent interchange format that enables interoperability and allows computer tools to share information. Therefore, establishing data standards provides the common frame through which various participants can communicate, thus enabling interoperable information sharing as shown in Figure 2-7 b) [Teicholz 1996].

There are two main efforts in developing standards for building data representation and exchange are ISO-10303 [1993] referred to as *STEP* (Standard for the Exchange of Product data model) and *International Alliance for Interoperability* (IAI) [Wix and Liebich 1997]. Both focus on an explicit building product description and a deployment of channels for information sharing. The main concepts underlying STEP and IAI development are discussed next.

2.2.2.1 STEP (ISO 10303) – objectives and architecture

STandard for the Exchange of Product model data is the informal name of the ISO standard 10303 [1993], and is defined as an international standard for computer-interpretable representation and exchange of product data. STEP's objective is to provide a neutral mechanism to describe product data throughout the life-cycle of a product and to facilitate data sharing and archiving. The development of STEP comprises the following elements:

- methodology development - e.g. EXPRESS language,
- integrated resources (IR) development – basis for product data,
- application protocols (AP) – a suit of APs defines an industry standard.

Furthermore, APs are data standards that enable information exchange and represent data models to describe specific application. Four works are in progress within the building construction group:

- **AP 225** – Building Elements Using Explicit Shape Representation. Focuses on representing buildings as assemblies of elements e.g. beams, columns [ISO 1996a]
- **AP 228** – Building Services HVAC. Concentrates on the heating, ventilation, and air conditioning building system [ISO 1996b]
- **AP230** - Building Structural Frame: Steelworks. It covers construction steelwork frame design, analysis, detailing, and manufacturing [ISO 1996c]
- **STEP Part106**, Building Construction Core Model (BCCM), a model initiated in 1994 and intended to serve as a unifying reference for building construction APs [ISO 1996d].

Special attention is given to the BCCM due to its concept of defining a generic part that is shared by other models. The BCCM aims to establish a common structure of building concepts, thus enabling information consistency among computer applications within a specific construction area (e.g. estimating) and between applications utilized in different construction areas (e.g. scheduling and estimating) [Froese 1996].

2.2.2.2 Industry Foundation Classes (IFC) –objectives and architecture

IAI is a global, industry-based consortium, with AEC/FM industry collaboration, that aims to identify the required information for exchange (or *what*), to develop the methods of communicating the defined information (or *how*), and to provide a holistic approach regarding facility life-cycle information. The organizational structure is formed by several international chapters embodying industry domain committees, e.g. facility management, architecture [IAI]. IAI develops a building product model definition, or *Industry Foundation Classes* (IFC) as a mechanism for information sharing throughout facility life, across involved disciplines, and for enabling interoperability between AEC/FM computer applications [Froese et al.1998]. Furthermore, the IFCs assemble a model that describes building objects and their components. The model adopts the BCCM (STEP), presented in section 2.2.2.1, layered architecture through integrating IFC Core Model with BCCM. Each layer encompasses a number of grouped modules. The four-layered conceptual IFC structure is shown in Figure 2-8 and presented below [Wix and Liebich 1997].

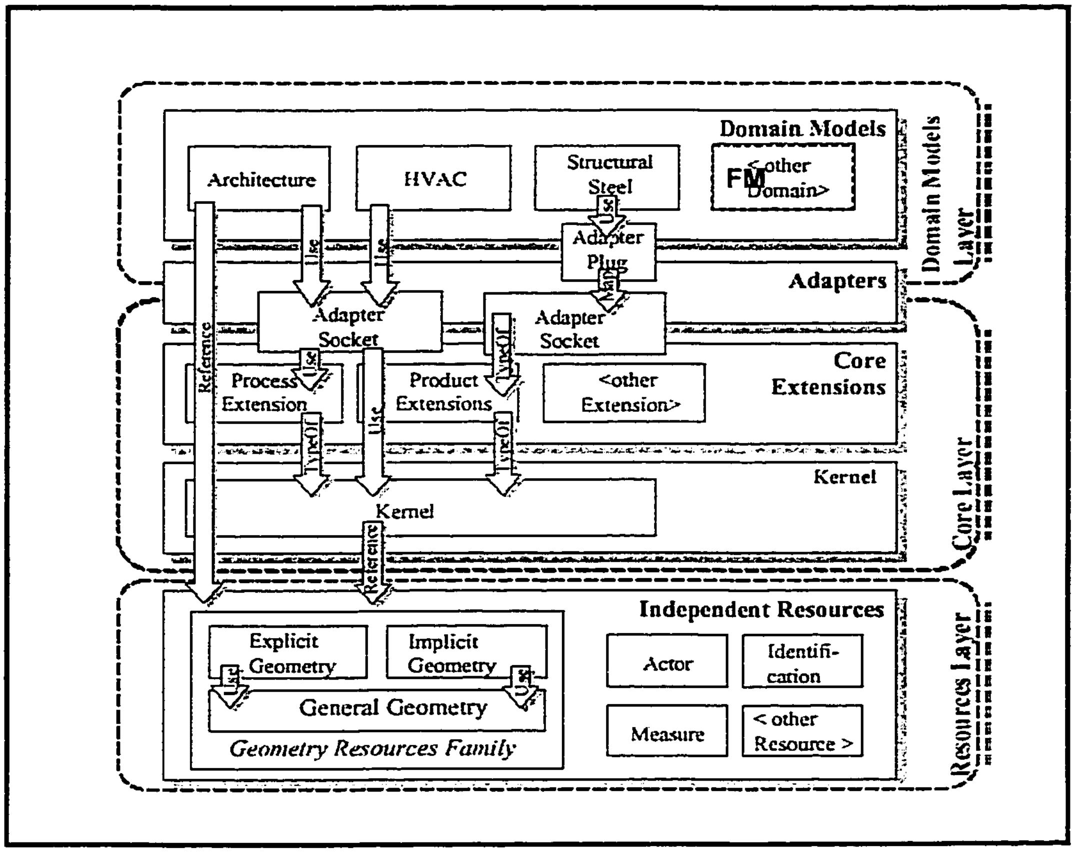


Figure 2-8 IFC Object Model Architecture [Wix and Liebich 1997]

- The *Resource Layer* is the bottom layer and describes fundamental data definitions used by all of the higher layers. It consists of independent resources (identification, units and measures, etc.), and geometry (explicit, implicit). Thus, measurements created in the Resource layer can be used to describe an object space, which is defined in the Domain Layer.
- The *Core Layer* is the foundation for the IFC model and contains two parts, namely Kernel and Core Extensions. In the Kernel are identified all the basic concepts related to buildings (e.g. object, attributes) that are common in AEC/FM industries. The Core Extensions support concepts encountered in

different groups of the AEC/FM, which are specific to the concepts of the Kernel (e.g. product extension, process extension).

- The *Interoperability Layer* (Adapters) defines modules that provide interface with the Domain Layer to ensure communication channels among different groups.
- The *Domain Models Layer* is the level visible to practitioners working in various professional domains (e.g. FM, Architecture). It details the domain specific processes and types of applications. Each module in the Domain Layer may refer to and use objects defined in the Resource and Core Layers.

2.2.2.3 Standardization approaches summary

With the growing number of computer applications for architecture, engineering, construction, and facility management, and the increasing complexity and globalization of building projects, the need for standard models facilitating interapplication information sharing has been recognized by the AEC/FM industry and the research community. Two main efforts towards standardization are STEP (ISO) and IFCs (IAI), which were introduced in sections 2.2.2.1 and 2.2.2.2. The approaches share a common feature: both focuses on product information and product models as a means of providing interoperability. The scope of STEP standards within the AEC/FM is limited to information describing building elements (e.g. columns, beams geometry, material properties), construction steelwork (e.g. frame design, fabrication), and HVAC building services. It appears complex to develop and use, and fails to address FM information needs. The IFCs model seems to propose a holistic approach to buildings in order to ensure interoperability between the design/construction phases and the operation/maintenance phase. However, it is an ongoing research project and IFCs definitions are not publicly available. Therefore, there are no existing standards, or common building model to support information exchange and integration for the AEC/FM.

2.2.3 Integrated FM Models

The following is a review of some of the major research projects, which focus on FM information integration.

2.2.3.1 Information System for Facility Management (ISFM)

The research defines a conceptual model to support computer-based information system for FM [Majahalme 1995]. The ISFM consists of four sub-models, namely, Business Activities model for facility management (BAfm), Management Activities model for facility management (MAfm), Concepts model for facility management (COfm), and Document System model for facility management (DSfm) (Figure 2-9).

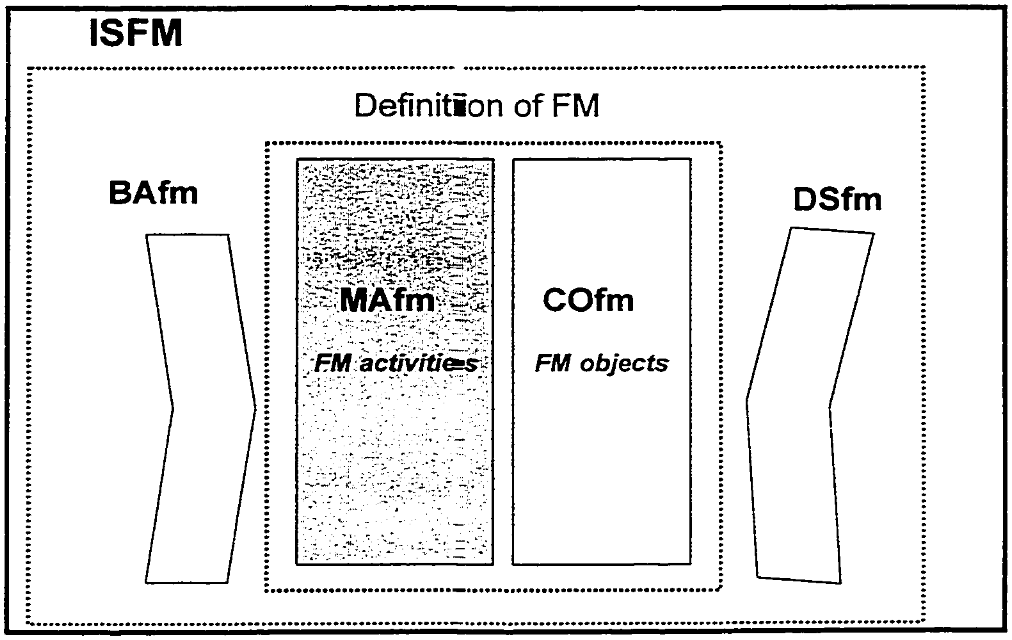


Figure 2-9 The ISFM model components [Majahalme 1995]

The sub-model COfm uses product model concepts to develop a hierarchical structure for classification of FM related information and decomposes into a space system (data about spaces), a building technical system (data about structural, mechanical, electrical systems), and an environmental system (data about infrastructure, support services). The MAfm sub-model focuses on formulating and modeling FM processes and required input/output. BAfm describes FM business activities such as an organization's mission and strategy. DSfm proposes a document management system for processing FM documentation. ISFM model defines FM objects and activities on a general level and represents an overall view of FM, however, it is not capable of identifying the specific information required by the different FM functions.

2.2.3.2 Facility Management System

The Facility Management System (FMS) [Bos 1995] focuses on the information needs of FM decision-makers, accounting for the management- oriented nature of FM processes. The FMS's architecture consists of an object management system and existing FM computer applications (shown in Figure 2-10). The object management system (1) is the kernel of the FMS, providing for integration of the data generated by FM applications (2), and includes databases and a knowledge base. An object model and a functional model form the core of the object management system. In the object model spaces, furniture, appliances, and apparatus (e.g. copier) are structured. On the other hand, the functional model describes activities involved in different decision-making processes (e.g. determining the total cost of painting).

The research work also examines the requirements for an FM information system capable of storing, managing, and retrieving a large volume of facility data in order to assist FM decision-makers. Bos [1995] outlines some of the critical system requirements as:

- flexibility to support scalability and changes in requirements,
- capability to provide uniform language,
- capability to support the abstraction, complexity, and multimedia format of facility information.

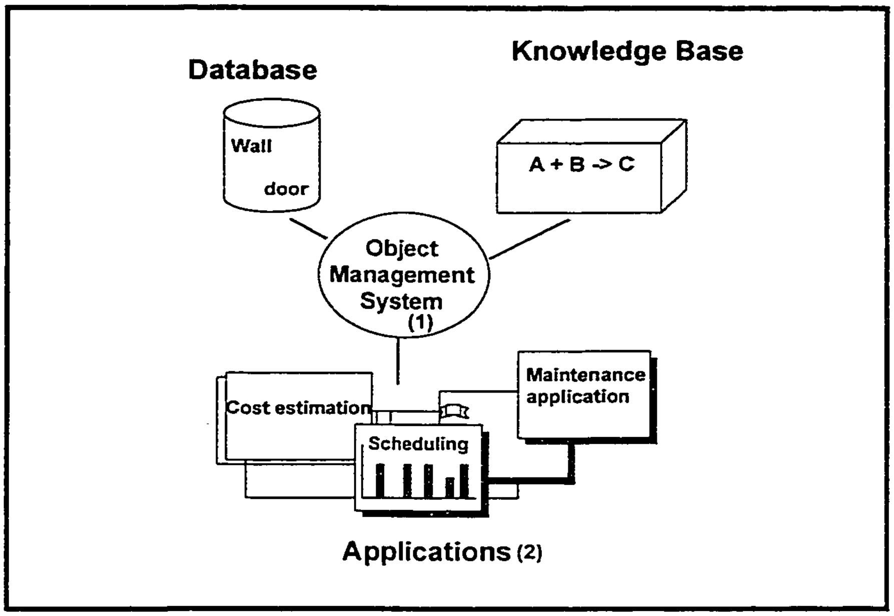


Figure 2-10 FMS system architecture [Bos 1995]

Bos defines FM as management activities concerned with space, energy management, and maintenance planning of buildings and their interiors. Due to this definition, the space is modeled as a primary concept and machinery, furniture, appliances are determined as elements to space.

2.2.3.3 Integrated Facility Management Information System

The Integrated Facility Management Information System (IFMIS) [Cheng et al. 1996] is a STEP compliant integrated system adopting a product models approach. The system includes a Control Data Repository (CDR), which holds facility information and an Exchange Control Mechanism (ECM), enabling data exchange between CDR and FM existing applications (CAD system, Asset and Maintenance Management System, Building Energy Management System).

Figure 2-11 illustrates the IFMIS components. The CDR implementation is based on a developed product model. STEP physical file is the data exchange media utilized in ECM. Furthermore, the CDR can be populated via an enhanced CAD system. Thus objects in drawings are associated with specific object data within the CDR. The system integrates CAD system and asset/maintenance/energy maintenance applications through a central database. Further, it automates the process of converting CAD drawings' objects and their properties into information stored in a database.

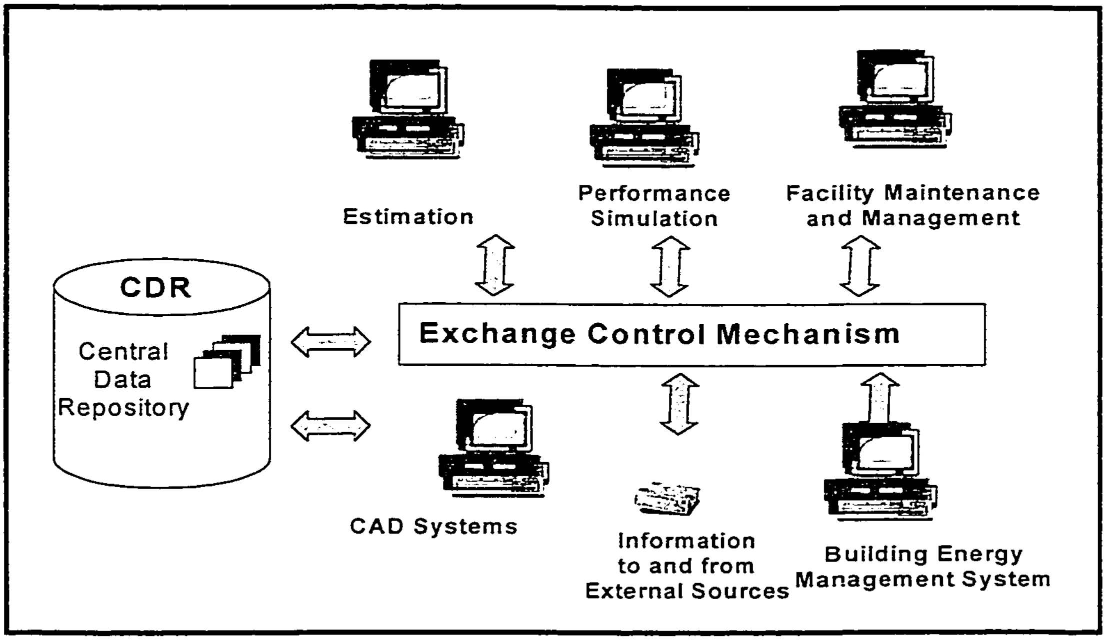


Figure 2-11 IFMIS Architecture [Cheng 1996]

2.2.3.4 KBS Model

The KBS model [Svensson 1998] is a notable research project applying the approaches of both product and process models to develop an information structure that is capable of supporting FM functions. The KBS model describes the structure of a building product model that adopts the Swedish building product classification tables (BSAB) and STEP standards. The KBS scope focuses on a spatial system (e.g. building spaces), a technical system (e.g. structural, electrical, HVAC and sanitation, transport, and control/monitoring systems), and construction sections and parts (e.g. frame, plate, opening, connection, and installation elements). These systems, along with the KBS_Core, form the model architecture depicted on Figure 2-12.

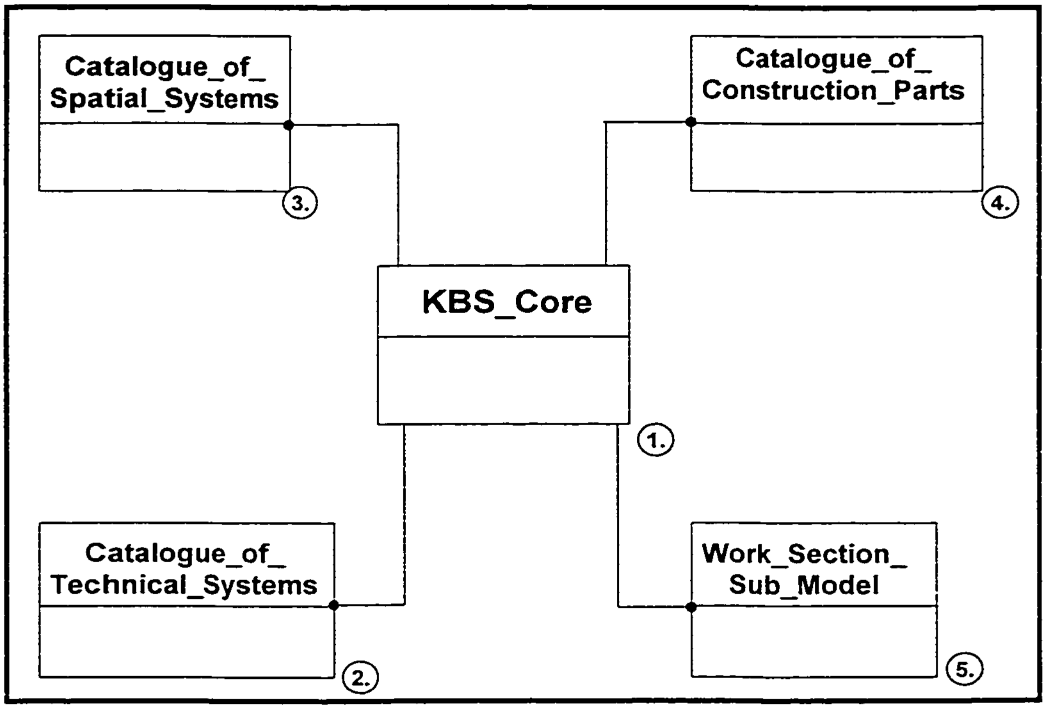


Figure 2-12 KBS model components [Svensson 1998]

The Core part represented by (1) in the model is designed to handle information regarding specific entities and has relationships with three systems (2,3,4) and with Work_Section sub-model (5). Furthermore, the KBS_Core is determined by a classification hierarchy, established to define the KBS model structure. Figure 2-13 shows the four levels of the hierarchy and illustrates how it can be applied to structure information about building components.

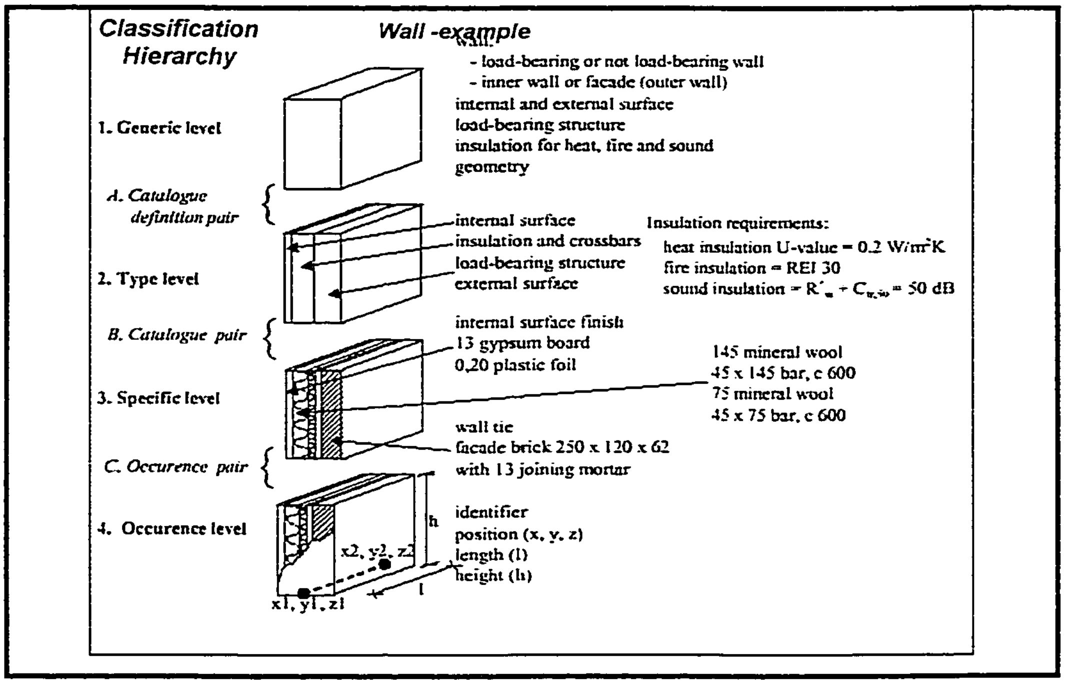


Figure 2-13 The classification hierarchy applied to a construction part [Svensson 1998]

The generic wall properties, which depend on the type of wall, its thickness and layer data, are stored in the type level, while the specific data identifying a specific wall (e.g. position, height, length), is stored in the specific and occurrence levels. The example demonstrates how different levels of details, required by different processes, undertaken in facility management, are accommodated. The KBS model is validated by implementing three prototypes whose scope is defined by identifying a range of supported FM functions. The KBS model structure reflects a specific building classification. The component that describes technical systems structures information around three main concepts: technical_system, space_room, and tenant. The technical_system concept is described broadly through system_part, operation budget, operation statistics, zone, energy consumption, and function entities. These entities are not further decomposed and detailed.

2.2.3.5 Development Framework for Data Models for Computer-Integrated Facilities Management

Yu et al. [1999] are involved in an ongoing research aiming to develop an information framework to facilitate information integration and sharing among FM computer applications throughout the entire facility's life. The system components are shown in Figure 2-14.

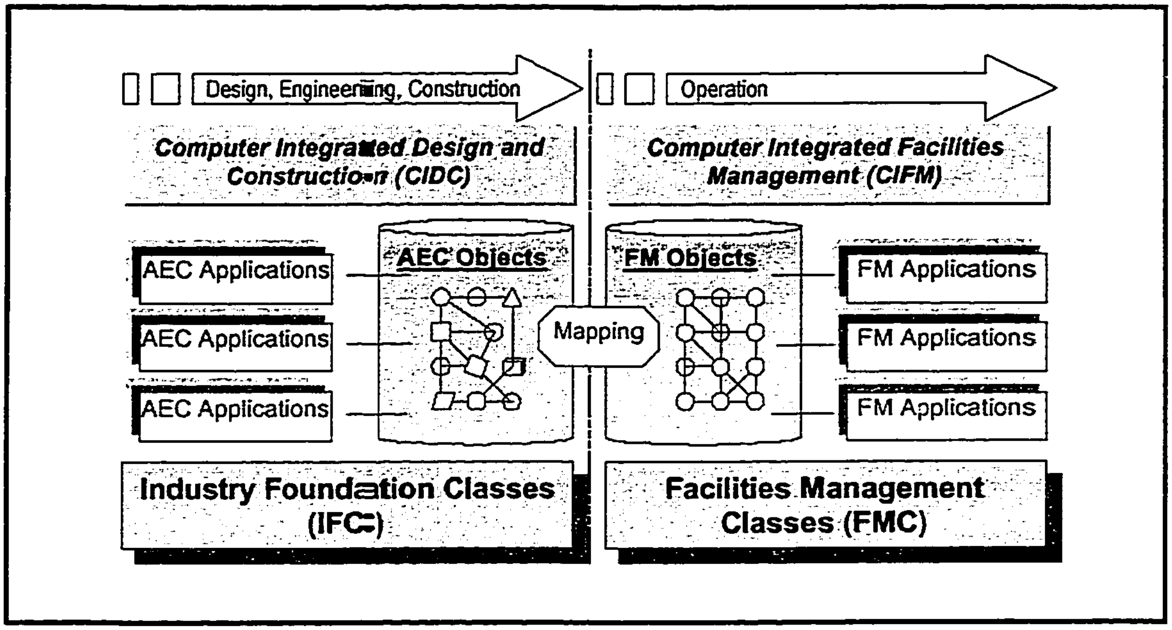


Figure 2-14 Information Framework Supported by IFCs and FMC's [Yu 1999]

The project builds on IFCs (IAI), as a mechanism to capture building project information spanning from design to commissioning. However, to reflect the dynamic and complex FM nature, Facilities Management Classes (FMCs) are defined. The research project strives to implement the FMCs with compliance to the IFCs in order to ensure information integration and interoperability. Figure 2-15 shows the system architecture outlining the main components.

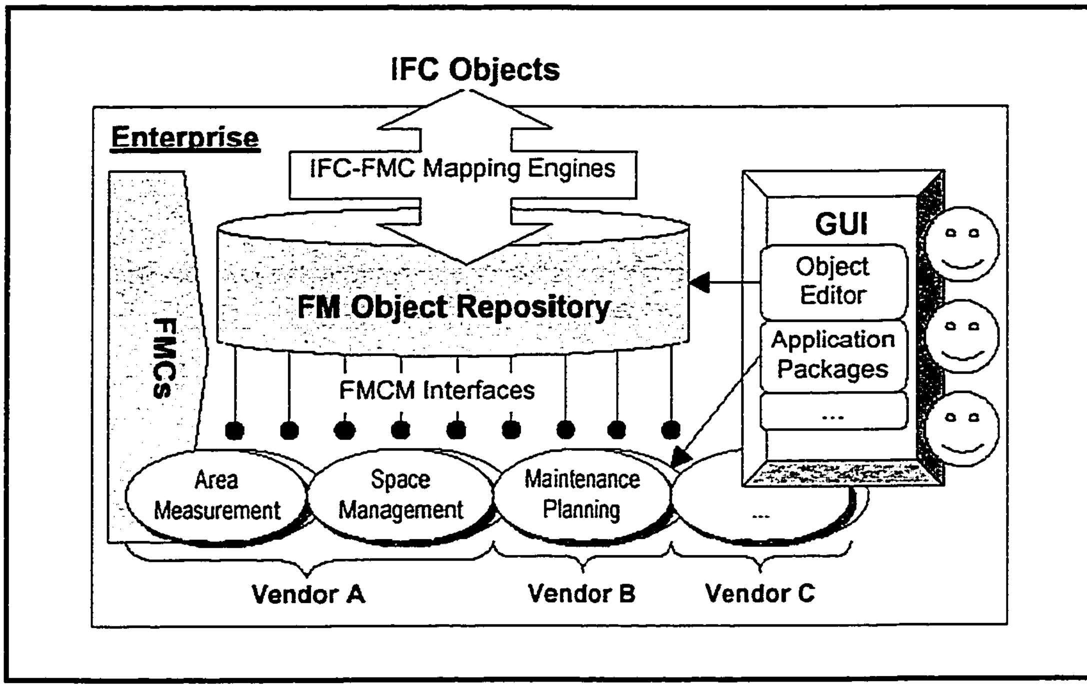


Figure 2-15 CIFM System Architecture Supported by FMCs [Yu et al. 1999]

An Object Repository, including the FMCs, is the core of the system and contains the information used by FM applications. The FMCs are comprised of a set of models, core and shared, containing general definitions that represent facility information required to carry out FM activities and common to all FM applications. To ensure interoperability between FM and AEC applications, the FMCs are required to be compliant with the IFCs. The Object Repository represents a database that includes FM object information. The IFC-FMC Mapping Engine is a mechanism to map IFCs objects into FMCs objects and further to enable the acquisition of captured information during the design/construction building phases. The FMC Object Interface defines a means of interaction between the Object Repository and FM applications. The research project outlines only the conceptual framework for the development of FMCs, thus, no detailed structures of the classes to support FM information needs are yet available.

2.2.3.6 Other Models

Another product model developed as a conceptual structure to store, manage, and retrieve FM information, is the Facility Programming Product Model (FPPM) [Perkinson et al.1992]. The FPPM defines different categories of facility information as "cells", which are described by address elements and by utility elements. The FPPM objective is to establish a framework capable of supporting evaluation and decision-making processes during the life of a building project. A notable effort towards integrating spatial with non-spatial facility data is the Facility Information Model [Zamanian 1993]. The project proposes an object-based structure for accommodating both geometric modeling and databases technologies, in order to manage spatial and non-spatial facility information in a cohesive manner.

Wix et al. [1999] present a process model developed within IAI and utilizing IFCs, that defines the primary maintenance processes and required information. The model describes the following key processes when performing maintenance management: Identify Asset, Plan Maintenance, Do maintenance, Record Account, Use Maintenance Libraries, Purchase Equipment for Maintenance, and Account for Maintenance Cost and associated concepts (e.g. asset, work order). The model identifies the information flows on a general level and lacks further detailed investigation and classification of the facility information required for carrying out maintenance management.

2.2.3.7 FM Models Findings

The literature review of available research works reveals the significant efforts towards developing a standard approach for handling information throughout the design, construction, and operation and management phases of a facility. Moreover, the projects tackling FM information needs indicate the AEC/FM industry requirements for efficient information management. Although the projects suggest integrated systems encompassing product models to structure facility information, the following shortcomings have been noticed:

- research efforts focus on the semantics of the models themselves,
- models are developed at a very general level, with no detailed descriptions of the entities and their attributes,
- representation and structure of the facility information vary considerably from one model to another and, as a result, there is no established and recognized building product model,
- proposed models and systems are not developed at the level of detail considered for a practical application in the FM domain and demonstrate limited capabilities,
- None of the research works address maintenance management and the information required to carry out its processes.

2.3 Summary

Throughout the literature review, a common strategy for enabling data exchange and sharing is evident. This is the concept of a central, unified data repository implemented as a single data source during the entire life of the facility. Comprehensive data structures are regarded as the most promising route to facilitate information integration and sharing. However, there is no established building product model for structuring facility information. Furthermore, none of the reviewed research works studied the information requirements for maintenance management. From the literature survey, an integration strategy appeared useful. The IFCs (IAI) framework is adopted as a base in developing the proposed information model in this research work.

The following chapter details an information model to structure and describe the information needed to assist in maintenance management.

CHAPTER THREE

PROPOSED INFORMATION MODEL

In this chapter an information model to overcome the problems identified in Chapter Two is proposed. A set of activities required to carry out equipment maintenance management are identified and decomposed. A framework to enable information integration and to provide a basis for model building is also discussed. Furthermore, information to support maintenance activities is detailed and structured using an object-oriented modeling language.

3.1 Identifying the Processes to carry out Maintenance Management

Maintenance and operation management (or maintenance management , these terms are used interchangeably throughout this thesis), as described in section 2.1.2, is the FM function responsible for keeping building mechanical systems (facility element identified in section 2.1.1) in working condition at economical cost. Further, maintenance is defined as all actions necessary for retaining an item in, or restoring it to, a specified condition. Maintenance management is a complex function, which encompasses many activities and tasks to fulfill its specific objectives. To capture the overall management activities, a process model is developed using $IDEF_0$ notation [Whitten et al.

1998], taking advantage of the clear task and data flow presentations that this notation provides. The $IDEF_0$, is the most common methodology for activity modeling and consists of processes with input, output, controls, and mechanisms represented as flows among processes. The $IDEF_0$, notation is illustrated by the legend of Figure 3-1. This research work focuses on activities modeling, identifying processes and input/output flows. Therefore, the control and mechanism flows are not considered.

The involved activities and required information flows are described through a process model which strives to fulfill the two following goals:

- to provide a mechanism to formulate and categorize activities in line with FM procedures,
- to assist in identifying necessary information to support maintenance management function.

Note that the activities are grouped to reveal different levels of detail.

An asset, a focal concept in FM, is defined as a valued object to manage, and on which maintenance work is to be performed [Wix et al. 1999]. It highlights the two principal activities performed on building mechanical systems (viewed as assets from FM perspective), namely, managing and maintaining. These two processes along with "Manage Resources", "Emergency Operations", "Control Quality", "Control Productivity", and "Control Safety" are identified as key processes as shown in Figure 3-1.

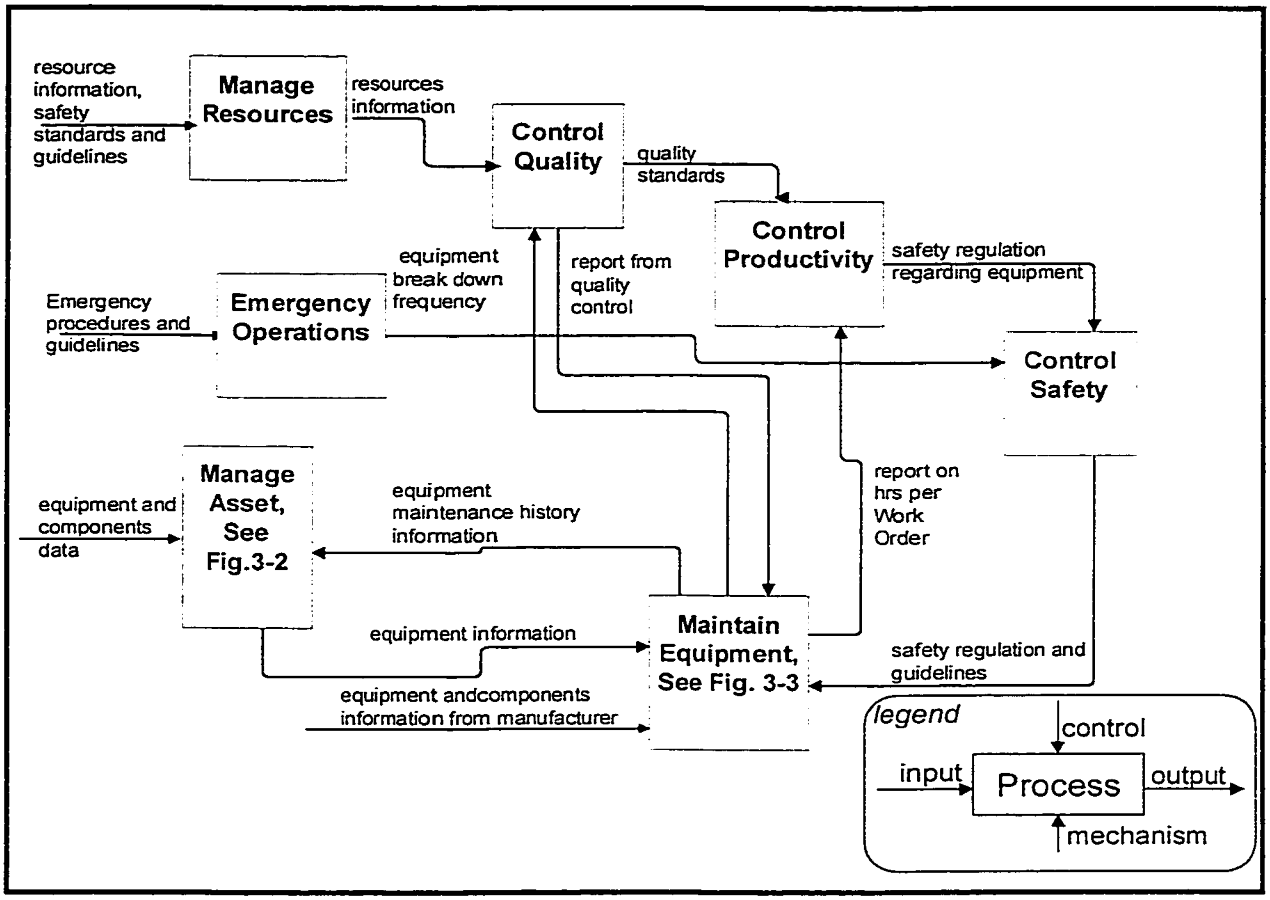


Figure 3-1 The Key Maintenance Management Processes

The analysis of the main maintenance management activities showed that the processes "Manage Asset" and "Maintain Equipment" are fundamental to building mechanical system maintenance management. Further, these processes are decomposed into their sub-processes and are presented below.

3.1.1 Manage Asset

The process "Manage Asset" is decomposed into the following activities, as depicted in Figure 3-2:

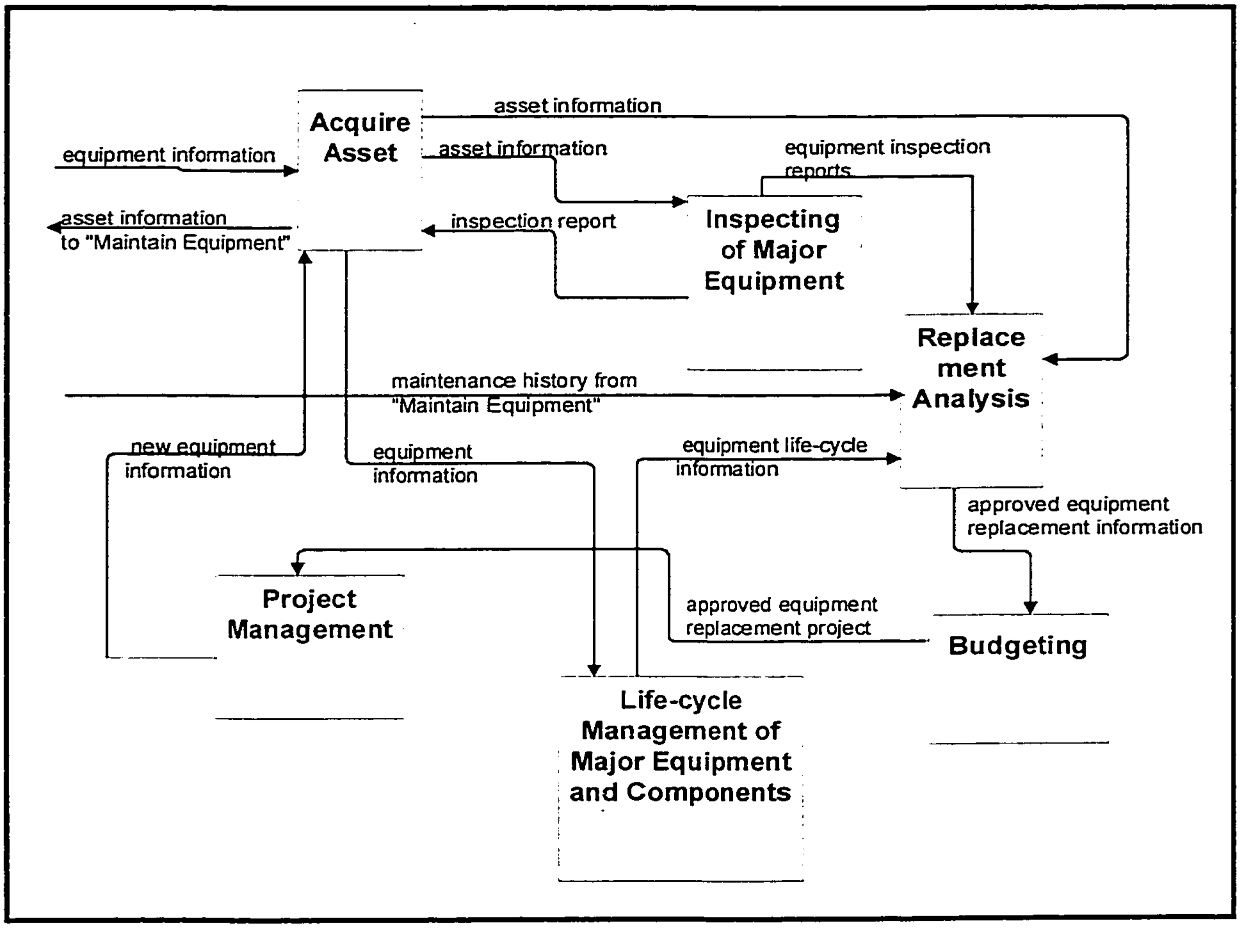


Figure 3-2 "Manage Asset" process - decomposition diagram

- "Acquire Asset" sub-process consists of the tasks involved with identifying and registering equipment as an asset. Once the facility is acquired, all major pieces of equipment (regarding mechanical system) are identified and registered, and a management plan is established. The information accumulated during these activities is a principal source for the “Manage Equipment” process and, furthermore, is essential for asset valuation, depreciation, and life-cycle costing. The sub-process is further decomposed into tasks in Appendix 1.

- "Inspection of Major Equipment" (Figure 3-2) encompasses activities pertaining to the annual building inspection of major system components (e.g. cooling tower). The annual inspection report can be used as input information for the “Maintain Equipment” process, with regard to “Corrective Maintenance” activities, which are discussed in section 3.1.2. The sub-process is further decomposed into tasks, which are reported in Appendix 1.

- “Replacement Analysis” is a very significant sub-process in maintenance management (Figure 3-2). The activity is carried out whenever a major piece of equipment requires replacement, such as in the following cases:
  - new requirements are issued for the offices served by the equipment (e.g. capacity changes with time),
  - new standards or regulations to comply with (e.g. chiller’s refrigerant type),
  - increasing maintenance cost or deterioration of equipment performance .

- The information required to sustain the replacement analysis sub-process includes reports about service calls and maintenance work performed, along with the associated costs. The next step is to acquire professional services to conduct a technical evaluation of the equipment identified for replacement.

The evaluation report, along with the life-cycle consideration, are the basis to determine whether to continue maintenance is a cost-effective approach or not. Once the replacement is approved, it is budgeted and the replacement project is scheduled and executed. Therefore, the replacement approval triggers an information flow for the budgeting process. The sub-process is further decomposed into tasks in Appendix 1.

- "Project Management" and "Budgeting" are identified as general management activities and are not analyzed in this research work.

3.1.2 Maintain Equipment

The "Maintain Equipment" process shown in Fig. 3-1 is a core process in FM. As discussed in section 2.1.2, there are three types of maintenance, namely corrective, preventive, and predictive. The major distinction between them lies in the way the actions are initiated and their objectives. Service calls or requests for work refer to corrective maintenance. The equipment manufacturer's recommendations regarding frequency of equipment inspections and periodic checks, initiate the preventive maintenance. Scheduling periodic tests to determine the condition of specific equipment components are the basis for predictive maintenance. A work order, defined as "a contract, agreement, or request for execution of the work" [Wix et al., 1999], is another focal concept in

FM like an asset (defined in section 3.1) and is an integral part of all types of maintenance. Work orders are a primary information source for facility managers.

The information necessary for equipment maintenance originates from the "Acquire Asset" process, which is shown in Fig. 3-1. Other information sources to sustain equipment maintenance can be obtained from the followings:

- operation and maintenance manuals, maintenance check lists, replacement parts lists originating from the equipment manufacturer,
- recommended maintenance procedures and required completion time from various government bodies.

The "Maintain Equipment" process is further decomposed into sub-processes, as shown in Figure 3-3, and as described in sections 3.1.2.1 and 3.1.2.2.

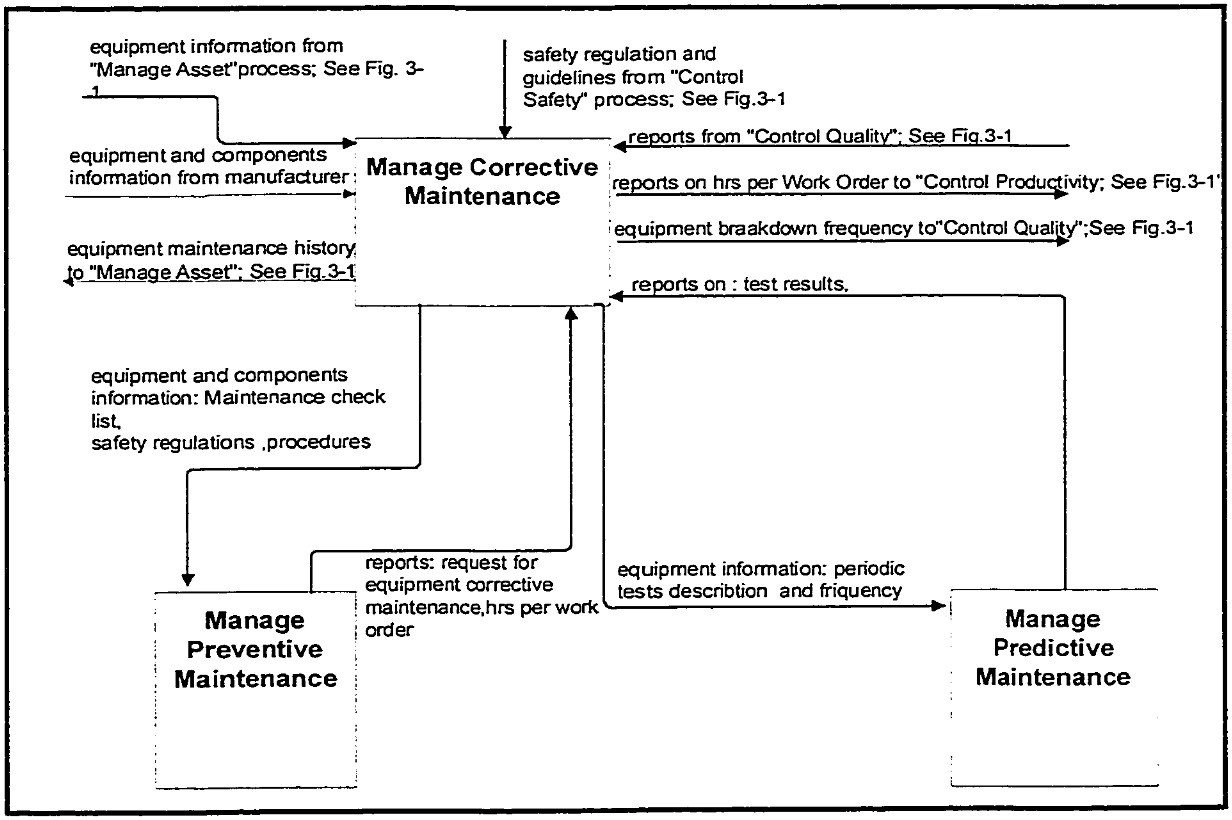


Figure 3-3 FM Maintain Equipment Process decomposition diagram

3.1.2.1 Manage Corrective Maintenance sub-process

"Manage Corrective Maintenance", or unplanned maintenance, includes activities performed due to the failure of an equipment or a component. The process' objective is to restore the failed equipment or component to a specified, optimal level of performance. This sub-process is primary initialized by a request from the facility users in case of:

- malfunctioning equipment that is apparent to the facility user (e.g. tap leaking, baseboard heater not functioning properly),
- a minor alteration required (e.g. to add extra lighting fixtures in an office),
- a complaint regarding a facility operation is reported (e.g. too warm climate in the office during a summer day).

The user request is reported and registered as a maintenance demand through a Call Center (or Helpdesk). In the Call Center, the request is logged as a demand for tracking purposes, a priority status is assigned, the trades needed to carry out the job are determined, and, finally, work orders are issued to complete the action. The number of work orders issued depends on the trades required to ensure the proper maintenance action. Currently, in most facilities, corrective maintenance is the major type of work that is performed. The sub-process is further decomposed (as reported in Appendix 1) into the following actions, which are self-explanatory: Register Request, Assign Priority, Create

Work Order, Perform Maintenance Work, Submit Time/Material/Cost Sheet, Close Work Order, Record Maintenance Work, Analyze Equipment Breakdown.

3.1.2.2 Manage Preventive Maintenance sub-process

"Manage Preventive Maintenance", or planned maintenance, seeks to identify and schedule activities in order to sustain the equipment's optimal performance and economic value. It also aims to minimize equipment failure and a system's unsatisfactory performance. Maintenance activities are performed on a periodic basis. Task descriptions and required frequencies for each piece of equipment, are specified by the equipment manufacturer in the maintenance checklists. Having accounted for the lists, facility managers set up procedures and schedules to avoid equipment failure. Furthermore, if a problem is encountered, corrective action may be required. The information accumulated during the maintenance procedure becomes part of equipment maintenance history. This information is used for the " Replacement Analysis" shown in Fig. 3-2. The process is further decomposed and reported in Appendix 1. The activities involved are Define Maintenance Procedures, Schedule Preventive Maintenance, Update Maintenance Calendar, Perform Preventive Maintenance, Update Maintenance History.

3.1.2.3 Manage Predictive Maintenance sub-process

"Manage Predictive Maintenance" is a process similar to preventive maintenance, its objective being to prevent equipment failure. However, maintenance actions are executed only when certain conditions are reached. Therefore, predictive tests (e.g. oil test, or vibration analysis on bearings) are scheduled and if the test results indicate that a particular equipment condition is reached, then corrective maintenance actions are scheduled. The process is further decomposed in Appendix 1 and the involved activities are: Identify Predictive Test Procedures, Schedule Predictive Tests, Perform Predictive Tests, Record Results, Analyze Test Results, Require Corrective Maintenance Action.

3.2 Building the Information Model

Maintenance management function has been discussed and analyzed in section 3.1 through the description of a process model encompassing identified processes and information flows necessary to carry out the equipment maintenance management. However, the information, determined as inputs/output flows to perform the different activities, is captured in general terms. A process of acquiring the detailed information is required to support the identified processes in maintenance management. Thus an information gathering strategy is presented in section 3.2.1. Next, section 3.2.2 defines information model characteristics needed to overcome the information deficiency in maintenance management, as identified in section 2.1.3, and to serves as a guidance during model development (section 3.3). Section 3.3.3 discusses a framework for integrating the proposed information model within FM.

3.2.1 Information Gathering

The activities involved in carrying out equipment maintenance have been outlined in section 3.1. Furthermore, the general information needs, in terms of data flows among the different maintenance processes, have been modeled. However, to build an information model, detailed data regarding the maintenance processes needs to be collected. To acquire this data, an information gathering strategy has been established, which included interviews, sampling, and observations of the work environment.

- *Interviews* - Critical to the information gathering process is the selection of experts from the FM domain to interview. Experts have been selected on the basis of their knowledge of two main areas: expertise in maintenance management of building systems and knowledge in FM in general, to justify that the information acquired is common to the industry domain. Based on this criteria, total of eight experts were interviewed ,the list includes:

1. representatives from BOMA and IFMA, the two recognized FM bodies

2. representatives from the FM departments at Concordia University, McGill University, ETS (Ecole de Technologie Superieure), Alexix Nihon (an office building complex), and the Molson Center.

- *Sampling of existing documentation*- this is the process of collecting sample documents, forms, records and supportive decision process reports. Most of the samples have been collected from the Maintenance group at Concordia University, Physical Plan department. The gathered documentation assisted in detailing the input and output of the processes and further refined the information to support the FM maintenance activities.

- *Observation* – Observation of the work environment was conducted at the Call Center and Maintenance division of Concordia University in order to observe the activities that were performed to complete a task.

The required data was collected through the interviews, the observation and the close examination of the sampled documentation. In addition, this process led to a comprehensive understanding of maintenance management procedures. This proved to be helpful in identifying characteristics of an information model capable of supporting decisions relevant to the maintenance of a facility.

3.2.2 Model Characteristics

The acquired knowledge regarding current maintenance management practice revealed the significance of timely, consistent, and electronically accessed information in assisting FM managers in their decisions. In addition, the necessity of addressing information integration and interoperability problems with respect to FM applications and facility life-cycle phases was discussed in section 2.1.3. Despite the availability of product models and classification systems, as reviewed in section 2.2, there is no established data structure capable of presenting, organizing, and linking the information required to operate and manage a facility.

To address this deficiency, an information model has been developed. The model focuses on the information needed for the maintenance management of buildings' mechanical systems, particularly for office buildings. The analysis of the maintenance activity information flows discussed in the section 3.1, and study of current maintenance practices assisted in determining the characteristics of the information model, which are illustrated in Figure 3-4.

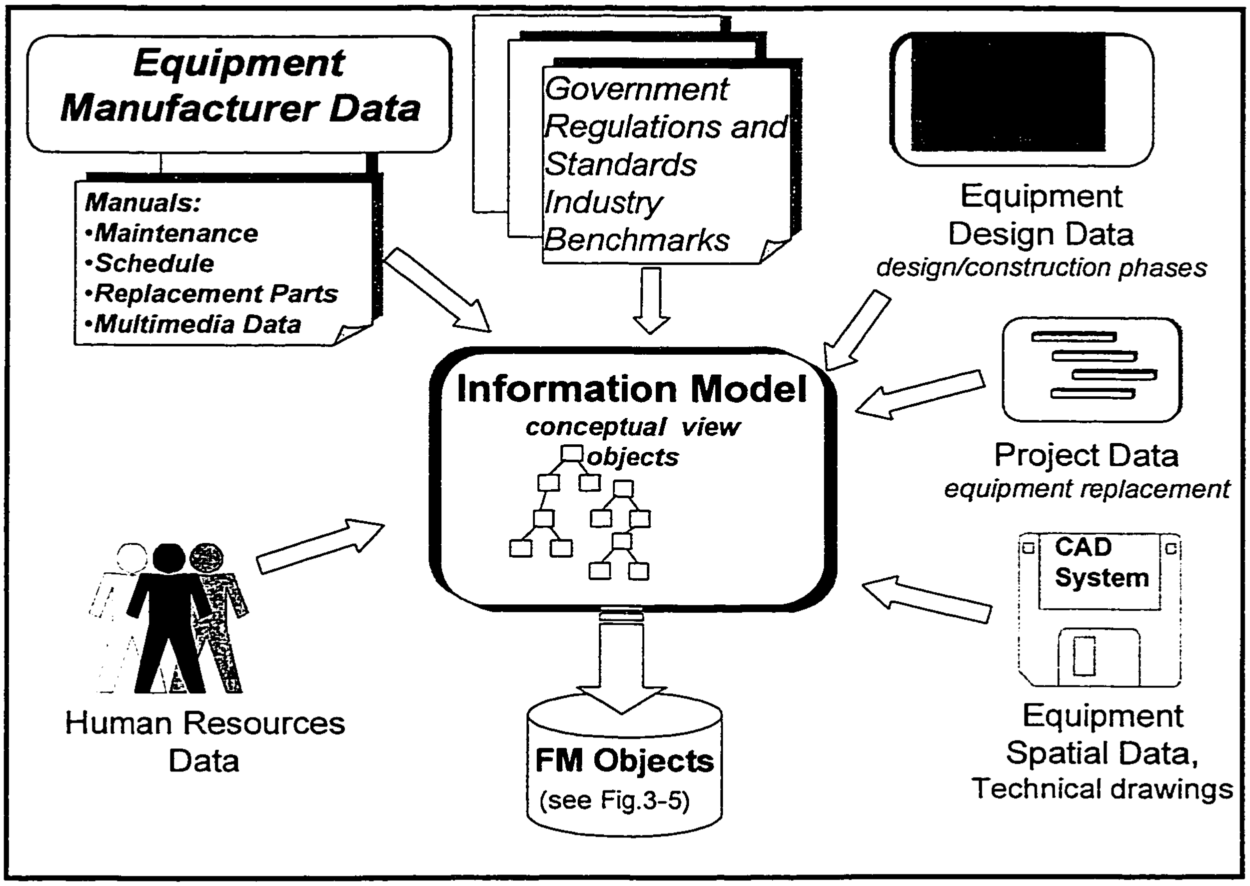


Figure 3-4 Information structured in the proposed information model

The information model characteristics are identified as follows:

- defines the categories of information required to support maintenance management of building mechanical systems,
- is comprised of a consistent and comprehensive data structure for storing, managing and retrieving building mechanical systems related information, in order to establish controlled information flow,
- is capable of associating text data (e.g. operation/maintenance manuals, equipment technical data) with spatial data (e.g. equipment geometrical attributes, equipment location in a facility) and multimedia

data (e.g. equipment images and videos) pertaining to building mechanical systems as illustrated in Figure 3-3,

- integrates information originating from heterogeneous sources to sustain an efficient decision-making process, namely data from:
    1. equipment manufacturers,
    2. government regulations,
    3. project data,
    4. equipment textual and spatial data generated during design/construction facility phases,
    5. other sources, e.g. human resources, essential for the management of the building systems, as shown in Figure 3-3.
- part of a framework, as described in the next section 3.2.3, to enable information exchange among different FM applications like CAD systems, maintenance, inventory and financial applications. Furthermore, it lays the foundation to promote a holistic information management approach spanning the facility's life from a FM perspective.

3.2.3 Framework to Support Information integration

The analysis of the current utilization of computer applications and data exchange in the FM industry, discussed in section 2.1.3, revealed that different applications are not capable of exchanging information due to the lack of a common data representation. The various computer application generate data in different formats, data types, levels of detail and scope. To overcome this problem and to ensure that the proposed information model is capable of supporting information integration, a framework was developed, as shown in Figure 3-5, and presented below.

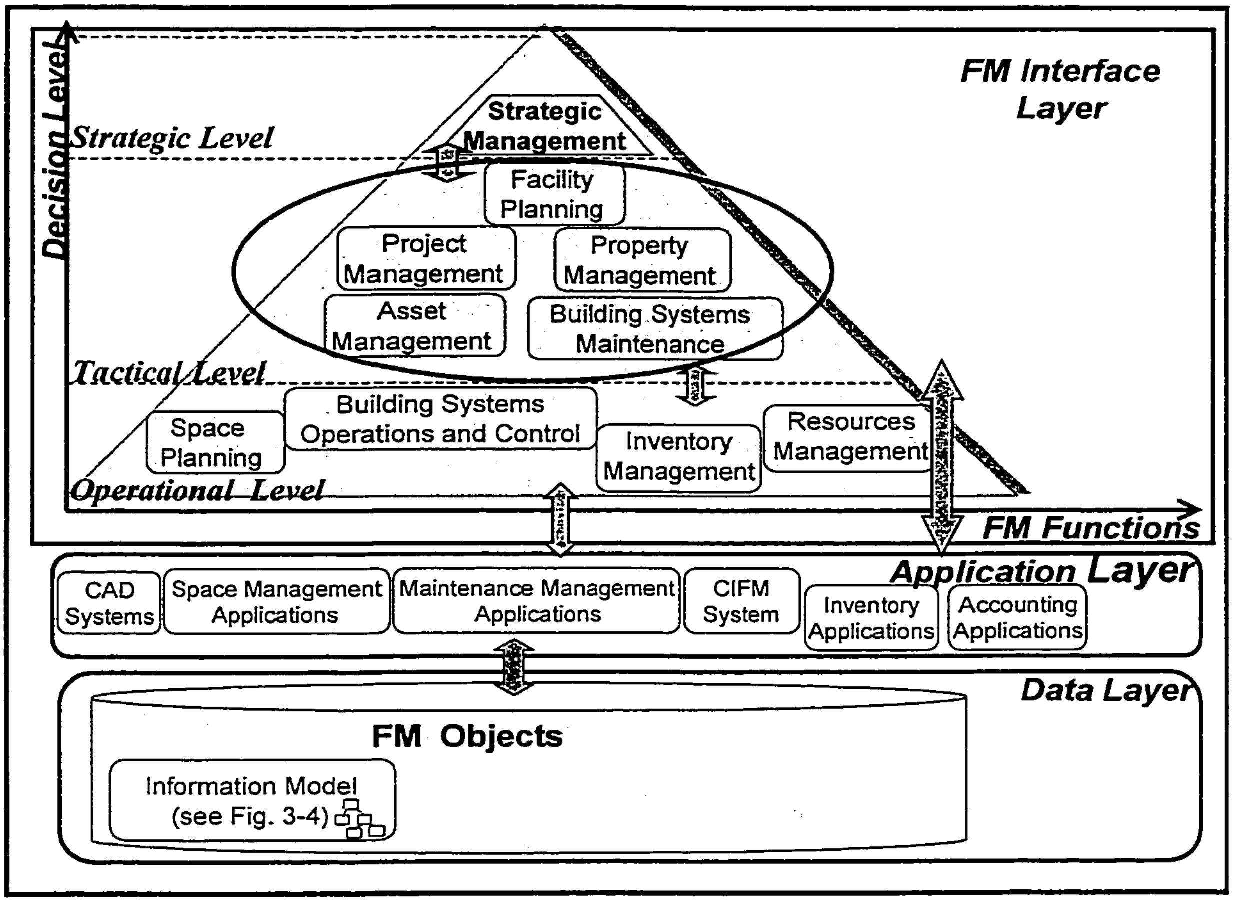


Figure 3-5 FM Framework to Support Information Exchange

As discussed earlier, (section 2.2.2.2) this research follows the IFCs (IAI) integration approach and builds on the layered architecture of IFCs as a structure enabling information sharing and exchange. The FM framework consists of three layers: Data layer, Application layer, and FM Functions Interface layer. The Data layer includes a FM Objects repository, which consists of information about facility components, systems and other data required to support the various FM activities. This information is structured in terms of objects and represents a common data store for facility information. The advantages of such a concept, which is similar to the IFCs Resource and Core Layers and to the FMCs layer, overviewed in section 2.2.3.5, are summarized as:

- storing data in a structure, that is independent of any FM applications. Therefore different FM applications access consistent data and share data,
- promoting data reusability by eliminating data reentry and redundancy (e.g. location information is required by a space management system and by a maintenance system),
- not constraining the data structure to a specific type of database, it can be implemented in a relational database or in an object-oriented database,
- allowing for the data structure to be scalable, in terms of adding new objects or new attributes to created objects.

The proposed information model identifies and structures part of the FM Objects repository, which is related to the information necessary to sustain equipment maintenance management activities.

The Application layer is comprised of various FM applications and tools deployed to automate and perform specific FM activities (e.g. MS Project, accounting application, space and maintenance management). The FM

Functions layer represents FM practitioners in terms of different FM functions, as discussed in section 2.1.1, and is detailed to reflect the FM business decision levels. The x-axis represents the FM, the y-axis depicts the FM business decision levels [Svensson 1998], namely, operational level, tactical level, and strategic level. Until now, most of the FM developed applications have targeted the operational level processes (e.g. HVAC control systems, space planning). FM efficiency, however, is highly dependent on the effective information utilization and exchange between operational, tactical and strategic levels, as illustrated in Fig.3-5. The model strives to provide information support primarily for the building systems maintenance processes and activities occurring on the **tactical decision level**.

3.3 Defining Modeling Language and Detailing the Information Model Structure

The maintenance management function has been decomposed into processes and related activities, and the information requirements have been identified as information flows among these activities (in section 3.1). Thereafter, in order to detail the information flows, a data-collecting strategy was determined (in section 3.2.1). To build a basis for modeling the data, the information model characteristics were identified (in section 3.2.2) and the framework to promote integration and encompass the data structure was presented. Next, the proposed information model is outlined through a description of the modeling language utilized in the development (in section 3.3.1) and the data structure (in section 3.3.2) that conceptually describes the information organization.

3.3.1 Describing the Modeling Language

3.3.1.1 Object-Oriented Modeling Concepts and Advantages

Information modeling is a challenging task, especially while fulfilling two competing goals: an accurate representation of a complex engineering reality and simple utilization. Therefore, it was opted to achieve internal content-richness while targeting external simplicity of models. To account for the modeling factors and the dynamic nature of a facility, the information modeling process was carried out by utilizing the Object-Oriented Modeling (OOM) approach [Rumbaugh et al.1991].

The fundamentals of the object-oriented approach are based on the synthesis of the Data and the Process concepts into a new concept called Object, which is comprised of both data (attributes) and methods (the processes that act on the data). Other major characteristics of the OOM include data abstraction, encapsulation, and inheritance. Furthermore, the object-oriented abstraction appears to naturally exhibit the real-life objects with their characteristics, behavior, and communication with each other. It offers a set of conceptual and physical models to reason and represent different aspects of complex engineering systems. Objects with similar attributes and methods are grouped in classes.

The advantages of using OOM summarized as follows [Stumpf et al. 1996, Svensson 1998];

- Provides a semantically rich information framework towards integrating product and process models, where multiple viewpoints can be modeled to facilitate facility information generated from different disciplines and participants throughout the entire facility life.
- Enables a description of the problem domain in terms of real world objects and supports complex data structures (e.g. associating multimedia with text data).
- Encourages the reuse of the objects and holds better as requirements evolve because it is based on the underlying framework of the problem domain itself.
- Focuses on the high-level representation of the model rather than on computer-oriented structures, thus incorporating the meaning of the real system.

The Unified Modeling Language (UML) [Rumbaugh et al. 1999] is used to develop the information model and is described in the following section.

3.3.1.2 Object-Oriented Modeling Language

In an object-oriented modeling, objects, classes, and their relationships are the primary modeling elements. The objects represent what need to be described in the problem domain, and the relationships reveal how the objects are related to each other. The properties of an object are represented by attributes. The functions that can be applied to an object are behavior or methods. A class is a description of an object type or a set of objects that share same properties and behaviors, specified by operations. Therefore, a class is an abstraction, which describes the data structure in terms of attributes and behaviors. An object is an instance of a class [Rumbaugh et al. 1999].

The types of relationships, essential to the proposed model, are association, generalization, and dependency.

- *Association relationship* captures the discrete connection among individual objects of a given class. Any constraints holding on a relationship are revealed through multiplicity (one-to-many, many-to-many), a mechanism, which distinguishes how many objects (instances) from one class, can be related to one object from the other class. To depict the different connection semantics, there are normal, recursive, and aggregation association. The **aggregation association** is a special type illustrating "whole-part" relationship (e.g. a component is a part of a piece of equipment) and is essential to model complex engineering systems like mechanical systems. Note the association types are listed only with regards to the associations applied in this research work.

- *Generalization relationship* is "the taxonomic relationship between a more general description and a more specific description that builds on it and extends it" [Rumbaugh et al., 1999]. This relationship addresses inheritance (OO feature providing meant of reusing information) and is fundamental to the classification demands of the modeled domain. An example of generalization is the relationships among different types of Work Orders (Preventive WO, Corrective WO) which are semantically defined by a general object Work Order (see section 3.3.2.3).
- *Dependency relationship* is the connection between two objects, one independent and one dependent. Any changes in the independent element will affect the dependent. For instance, maintenance work performed on a fan should be registered in the maintenance history of the cooling tower as well, given that the fan is a component of the cooling tower.

The objects and their relationships, in the information model, are described using the notation of the adopted modeling language Unified Modeling Language [Rumbaugh et al., 1999] illustrated in Figure 3-6. Furthermore, a CASE tool that supports the UML notation is utilized in this research work. The tool, Rational Rose [Rational Software Corporation] provides a graphical environment for the development of the information model, and generates textual description.

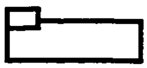
Notation	Function
◇	Aggregation relationship – *utilized in the decomposition hierarchy*
Δ	Generalization relationship –*utilized in the generalization structures described in section 3.3.3*
——	Association relationship
	Class –set of objects
	Subsystem- a package treated as a unit in terms of specifications and identity.

Figure 3-6 UML Notation

3.3.2 The Proposed Information Model Structure

3.3.2.1 Classifying maintenance information

The two main object-oriented modeling concepts, as introduced in section 3.3.1.2, are objects and the relationships among them. Therefore, the acquired data has been examined with the following objectives:

- to identify different objects that represent and describe the data handled throughout maintenance activities,
- to reveal any natural dependencies among the identified objects.

During the analysis, it was apparent that few of the objects relate closely and have a similar origin, which led to identifying the following types of information related to the maintenance activities:

1. technical information regarding building mechanical systems, such as data about equipment and their components,
2. information pertaining to maintenance activities, e.g. data from a work order to replace burned light,
3. information describing various projects taking place in maintenance management e.g. replacement projects,
4. data that has not been classified into the previous groups, however is required in maintenance management, e.g. facility location drawings.

The four groups are illustrated in Figure 3-7, using the UML package concept (shown in Figure 3-6) and namely are: Building System, Maintenance, Project, and Facility packages.

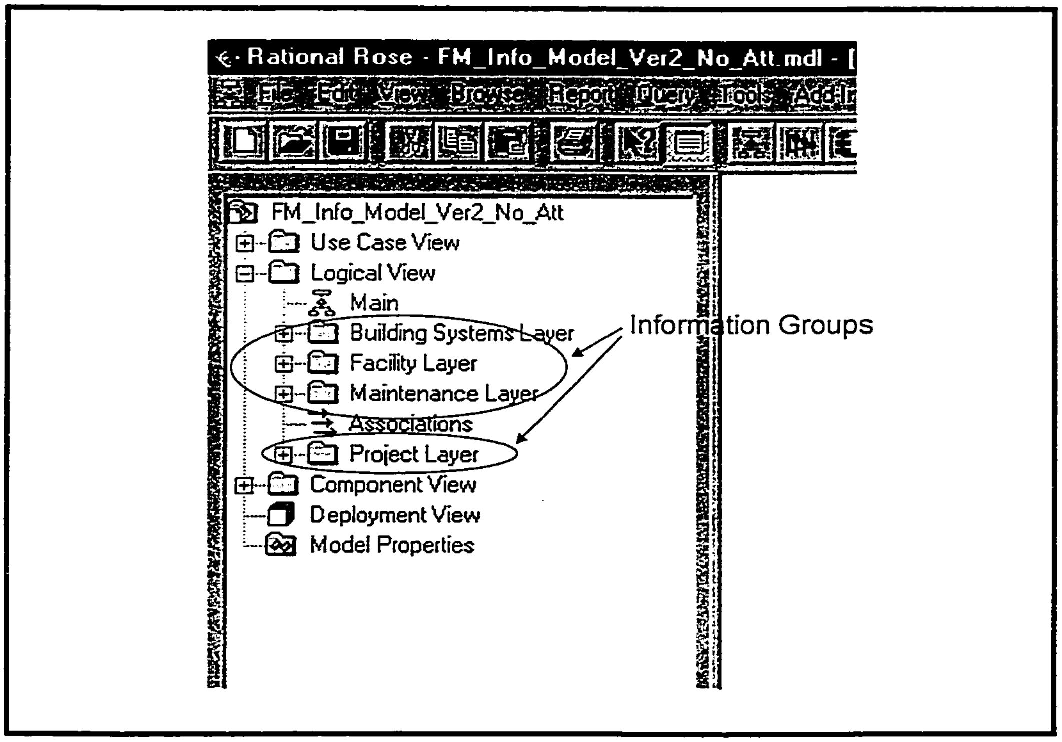


Figure 3-7 The Identified Information Groups

The created information groups (packages) identify the types of information required to support equipment maintenance activities and provide a basis for the classification of equipment maintenance information. Furthermore, examining the data within each group demonstrated that it mainly consists of information revealing different levels of detail pertaining to one generic object. Therefore, the information describing those objects can be organized into hierarchies or specially defined structures that denote various levels of decomposition and that are used to model the data within the four groups, as proposed next.

3.3.2.2 Defining Mechanical Systems Hierarchy

Within the Building Systems group, which contains data pertaining to the mechanical systems (section 3.3.2.1), a hierarchy is defined to conceptually describe a type of mechanical system. The hierarchy is created using the UML notation and is formed of four levels of decomposition, as shown in Figure 3-8.

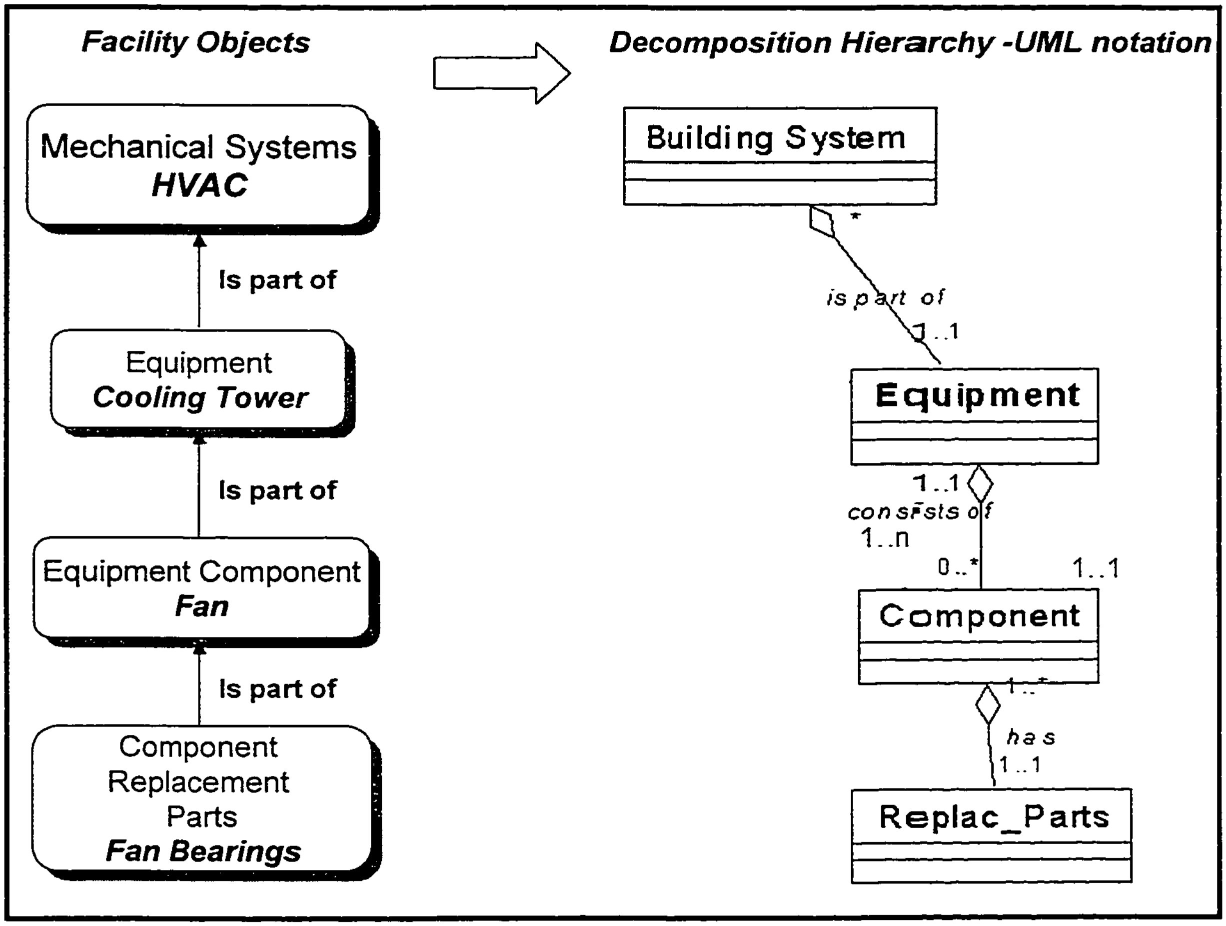


Figure 3-8 Decomposition Hierarchy to structure Mechanical Systems Information

The hierarchy consists of Building System class, Equipment class, Component class, and Replacement Parts class. An example of a type of mechanical system, illustrated in Figure 3-8, is applied to demonstrate how equipment information is structured using the decomposition hierarchy. HVAC system encompasses numerous major pieces of equipment, such as cooling tower and chillers. Further each equipment consists of different components (e.g. a fan is component of a cooling tower), and in turn, every component is formed of parts (e.g. fan bearings are part of a fan). It is important to note that each hierarchy level adds new details of information to the previous one.

The decomposition hierarchy is defined to organize the data pertaining to the mechanical systems, however, part of the information classified as Building Systems group data was identified as independent objects, and represented by Asset, Maintenance History, Task, Specification and Manufacturer classes. The Asset class is created to capture the FM perspective of a major equipment or group of similar equipments (as discussed in section 3.1) and to contain economical data pertaining to equipment (e.g. economical life). In addition, the information classified in the Asset class is essential to enable information flow from the maintenance system to FM accounting systems as part of the framework defined in section 3.2.3. The Manufacturer class is a class developed to contain data on the equipment manufacturer such as name and communication data. It is assumed that equipment components are produced by the same manufacturer as the equipment itself. The Maintenance History class organizes data regarding equipment preventive and corrective maintenance schedules such as the last maintenance date and frequency. Description of the maintenance tasks is modeled in a Task class. The various equipment specifications defining installation, operation, maintenance, and inspection procedures, which are provided by the manufacturer, are defined as Specification class.

The relations among the decomposition hierarchy and the described classes are defined in the class diagram shown in Figure 3-9.

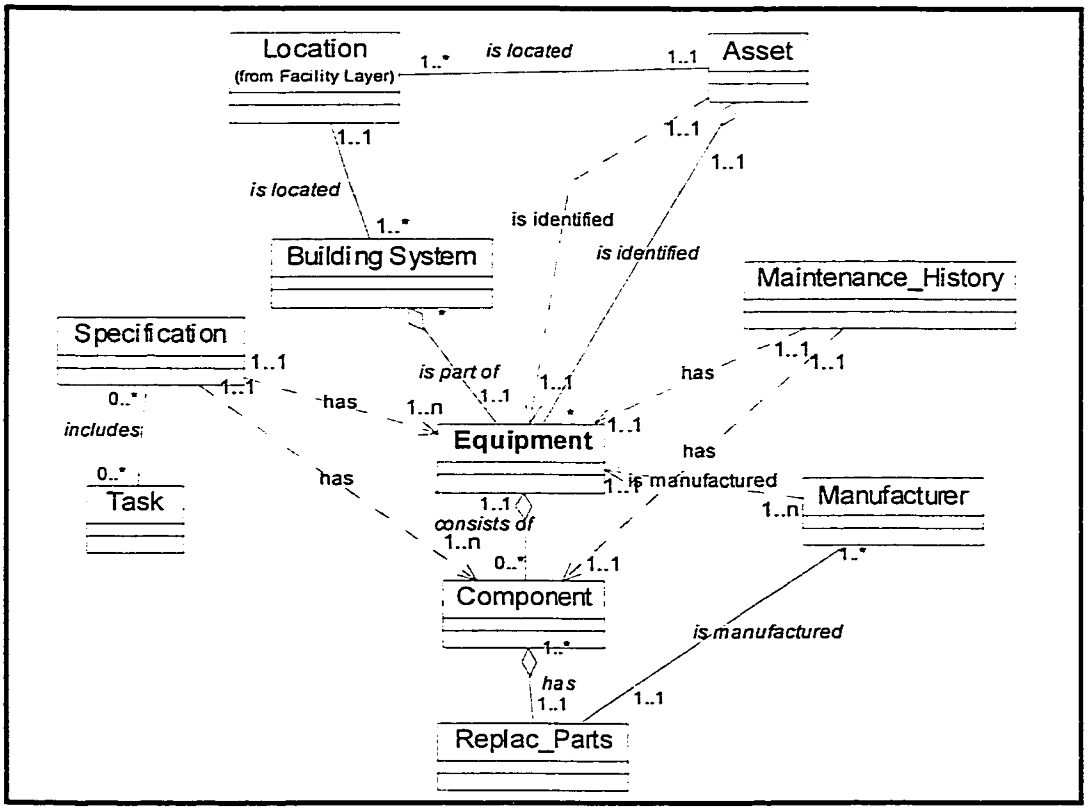


Figure 3-9 Class Diagram structure to organize Building Systems information

The class diagram (Figure 3-9) represents a structure developed to organize building systems information to support maintenance activities. The Location class (section 3.3.2.5), although not part of the Building Systems data, is shown to allow for the accounting of the physical location of building systems and assets and to demonstrate the existing relation between the corresponding classes. There are two types of relationship between Equipment class and Asset class. The first one is a dependency relationship to satisfy the requirement that a major equipment is identified as an asset, and the second is aggregation association to represent the fact that a group of objects can be defined as one asset. The following sections describe a decomposition hierarchy, and additional classes defined to structure the information classified in the Building Systems group. A structure developed to support information defined in the Maintenance group is also presented.

3.3.2.3 Describing a Structure to organize the Maintenance group Data

The required information to respond to a maintenance request from a facility user or to execute a scheduled maintenance action, and any information pertaining to equipment maintenance, that was identified in section 3.1.2, is classified in the Maintenance group. Work order (introduced in section 3.2.1) is a focal concept in maintenance group and primary source of information. Furthermore, with respect to the types of maintenance work (section 3.1.2) three types of work orders are distinguished, namely corrective work orders, preventive work orders, and inspection work orders. In addition, request work orders have been identified to indicate any work requested by a facility user that is not defined as corrective or preventive maintenance. To model the work orders' information, a specialization structure is proposed employing generalization relations, and is depicted in Figure 3-10. In object-oriented modeling, specifically in UML, generalization relations are used to denote an existing dependency between a general element and a specific element and, further, to apply the object-oriented inheritance concept.

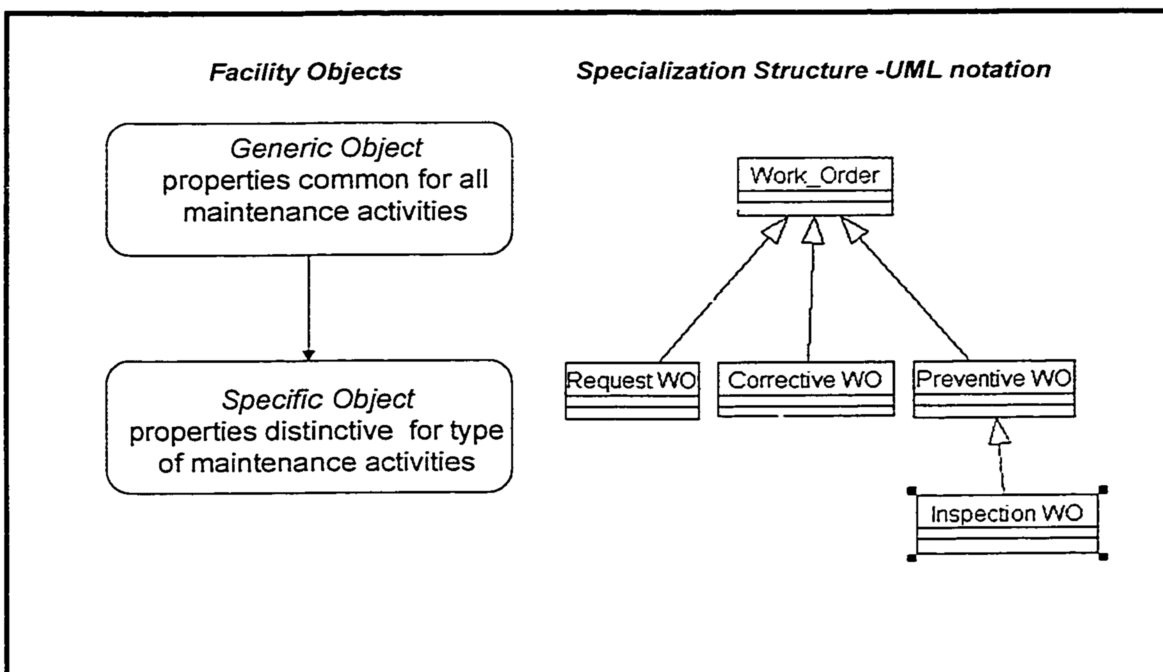


Figure 3-10 Proposed Specialization Structure to organize Work Order maintenance information

A Work Order class is defined to contain general data that is common to any types of work order, such as work order date issued, closed date, location. Any information specific to the type of maintenance work is classified into classes corresponding to the specific maintenance activities, namely Corrective Work Order, Preventive Work Order, Request Work Order. For instance, a description of tasks to be performed on specific equipment is determined as information describing a Preventive Work Order. Thus, the Preventive Work Order, Corrective Work Order, and Request Work Order classes are classified as more specific elements that are fully consistent with the general class work order, while containing additional information distinctive to each type of maintenance activities. Accounting for the similar nature of the predictive and preventive maintenance activities (discussed in section 3.1.2), in terms of work scope and objectives, and analyzing collected data related to these activities, only Preventive Work Order class was defined. Due to the difference in scope of preventive maintenance work and inspection work (described in section 3.1.1), Inspection Work Order class was created as a sub-class of Preventive Work Order class.

To model the other information grouped in the Maintenance group, Request Work and Material List classes were developed. The Request Work class is structured to contain information that describes facility users' requests or complaints registered through a Call Center (or Helpdesk). The Material List class is a structure to organize data such as required material and parts to perform maintenance work. Figure 3-11 shows all the classes developed to structure the Maintenance group information. In addition, the relations between the specialization structure and classes request work and material list are defined. The Equipment class, identified in the Building Systems group, is presented in the diagram as well, in order to provide information pertaining to the equipment through the relationship between class equipment and class work order. The Location class (described in section 3.3.2.5) serves as a physical locator for registration of work request.

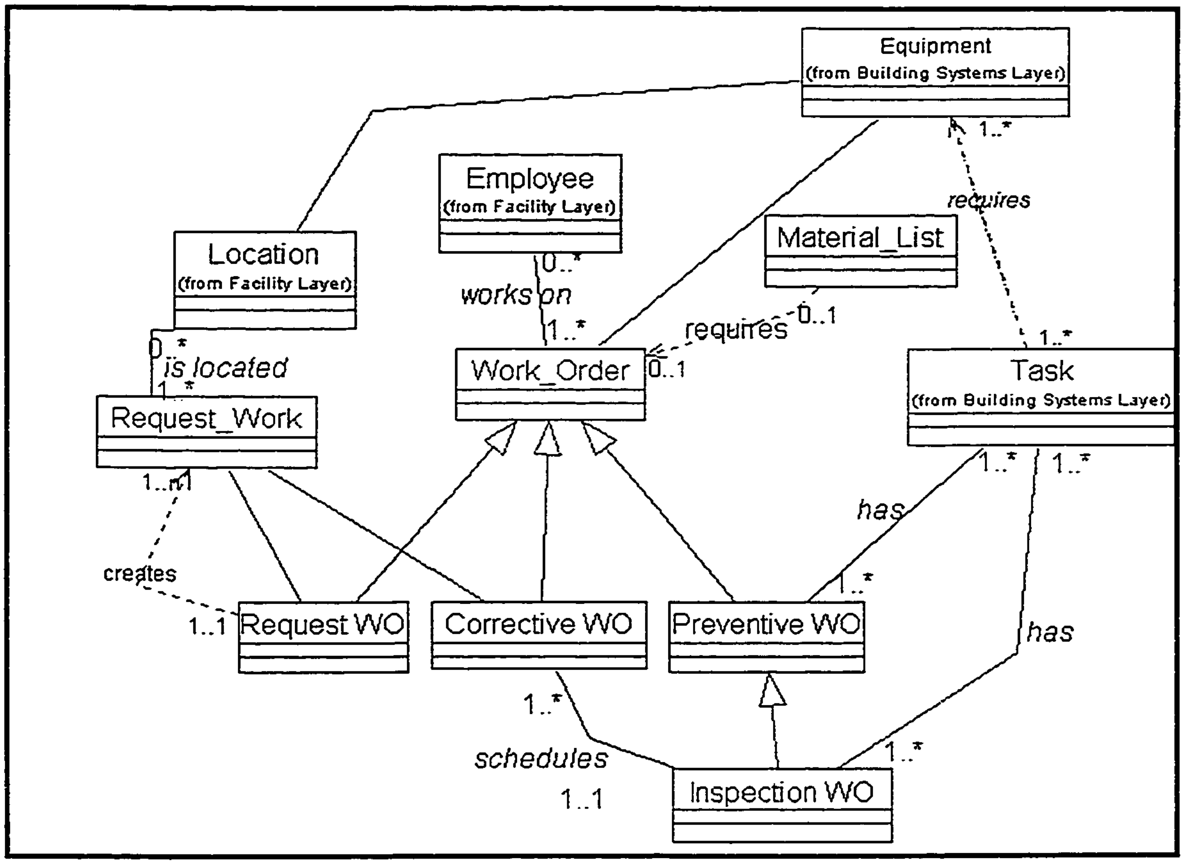


Figure 3-11 Class Diagram to structure Maintenance group Information

Finally, the Task class, from the Building Systems group, describes the previously stored information about standard maintenance tasks pertaining to equipment preventive maintenance actions. This information, as work description, is required whenever a preventive work order is issued.

3.3.2.4 Defining a structure to organize the Project group data

The Project group includes information on the various projects undertaken within FM. Equipment replacement is a primary kind of project undertaken in maintenance management. Having analyzed the acquired data, it appeared that the acquired information describes two objects: project and documentation. The two defined objects are developed into Project class and Documentation class, respectively, as shown in Figure 3-12.

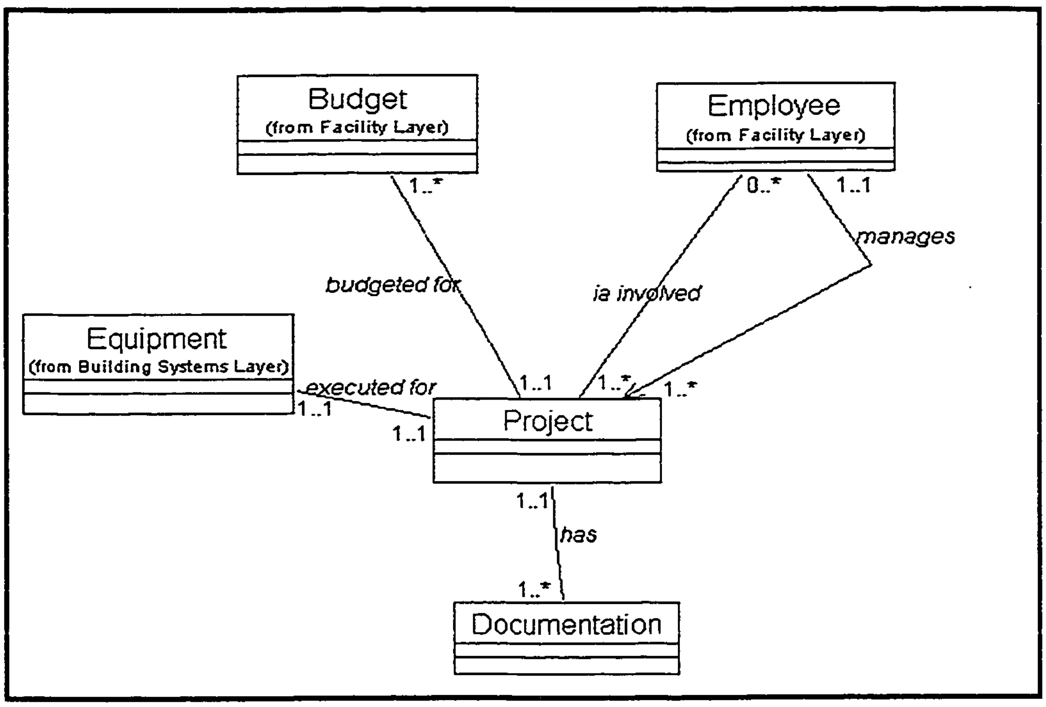


Figure 3-12 Class diagram to structure Project group data

The Project class is a structure to organize data pertaining to any executed FM project and, in particular, to hold information required to support the equipment replacement analysis process, which is a triggering point for a replacement project. Project supporting documentation is modeled as a separate class (Documentation class) due to its data intensive contents. Note that project documentation is addressed with regards to maintenance management and document management is not a focus of this research work. Due to the high dependency of the documentation's contents, and of project itself on FM internal procedures, the properties are identified in general terms, e.g. document date, type, description, project description and so on. In the class diagram, Figure 3-12, the Equipment class, Employee class, and Budget class are represented in order to illustrate the existing relations between Project group classes and listed ones. Employee class and Budget class are presented next.

3.3.2.5 Organizing Facility group Information

The Facility group includes data that has not been classified into the previous groups. Although, the information appears to be part of information requirements of other FM functions, it is grouped here for the following reasons:

- it provides important details to support maintenance management activities, such as facility location, manpower data,

- it establishes a channel for information exchange between the other FM functions and maintenance management as an integral part of the framework (discussed in section 3.2.3).

Analyzing the collected data, three information groups are distinguished:

- information describing facilities location,
- information regarding human resources involved in maintenance activities,
- financial information pertaining to project budgeting.

Therefore, three classes are developed to structure the outlined information Location class, Employee class, and Budget class. The classes are supportive of the main structures defined in sections 3.3.2.2-3.3.2.4 and are depicted in Figures 3- 9,11, and 12.

3.3.2.6 Defining Types of Attributes

The identified structures developed to organize and store maintenance data encompass numerous classes, as depicted in Figures 3-9 to 11. Essential elements of these classes are their attributes, which describe object characteristics.

Facility information, describing mechanical systems and maintenance activities, can be categorized into two distinct, nevertheless related data types: spatial and non-spatial. The facility's spatial type of information pertains to the topological relations of physical objects in a facility (e.g. pump located in a particular floor of the building), and to the geometric attributes of mechanical systems objects (e.g. equipment drawings in CAD format). The facility's non-spatial information describes all the other characteristics of facility objects, such as object properties and functionality (e.g. equipment technical characteristics, and supporting manuals). Having the information model built on object-oriented concepts, the classes attributes type can be defined as spatial or non-spatial type of data in order to reflect the FM information diversity.

In addition, the defined classes' attributes serve the following purposes:

- to integrate the various types of data (e.g. text, drawings, and pictures) originating from different sources, however pertaining to one object,
- to provide a structure for the existing paper-based operation/ maintenance manuals supplied by the manufacturers, thus promoting information accessibility.

To illustrate the latter, the attributes of the Equipment class and Specification class are listed in Figure 3-13. The Equipment class attributes that need attention are:

- *picture* is an image type of data to capture the object's images,
- *drawing* can be a drawing, originating from a CAD system to present details pertaining to the equipment and its components,
- *design parameters* is an attribute that captures a summary of the design information generated during the design phase of the facility,
- *technical data* is an attribute to hold the equipment's technical specifications information originating from the equipment manufacturer

and supplied during construction phase when equipment is installed, or in case of equipment replacement.

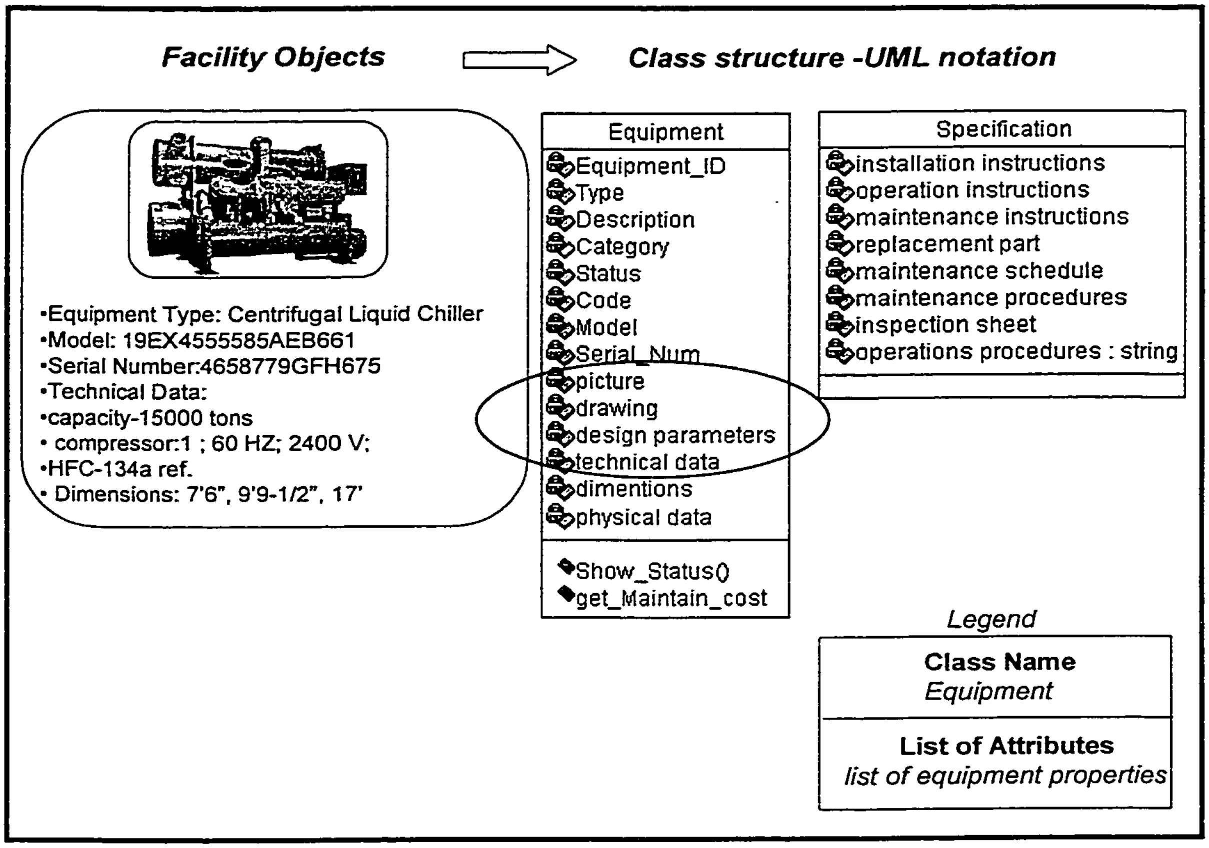


Figure 3-13 Illustrating Attributes Data Types

The Specification class, as defined in section3.3.2.2, is developed to structure information originating from the operation, maintenance, and installation manuals, regarding equipment provided by the manufacturers. Currently, the information is supplied in a paper format and some is manually entered in maintenance computer applications. The class attributes represent the various equipment manuals' data.

The proposed class diagrams are detailed in Appendix 1.

3.4 Summary

In this chapter an information model developed to represent, store, process, and retrieve information essential to equipment maintenance management has been presented. In addition, maintenance activities and the information to support them, has been defined and modeled. A framework, conforming to the IAI approach, has been developed to promote information integration among various FM functions and throughout facility life-cycle phases, in particular the design/construction and operate/maintain phases. The utilization of the IAI/IFC development methodology and the use of Object-Oriented modeling language have enabled the structuring of the information. The proposed information model integrates various types of data, originating from heterogeneous sources that pertain to mechanical systems and are vital to the maintenance decision making process. Therefore, it serves as a conceptual platform to structure FM information and can be implemented in any computer environment.

A prototype implementation is described in the next chapter in order to validate the proposed information model. Furthermore, a case study is used to test the prototype with data in a practical environment.

CHAPTER FOUR

INFORMATION MODEL VALIDATION

This chapter presents a validation technique for the proposed information model. A prototype is described, and a practical case-study is investigated as a testing environment to demonstrate the value gained by organizing the information in a coherent data structure. Finally, the development results are discussed.

4.1 Defining Evaluation Criteria for the Proposed Information Model

As mentioned earlier, the primary objective of this research is to develop a coherent data framework to hold information related to building systems, in order to support maintenance management. The proposed information model describes the data structure, strives to provide a formal manner for data capturing throughout the facility's life and to promote integration among various sources of data from FM perspective. As discussed in sections 1.3, the research methodology consists of step (1) literature review, step (2) model development, and step (3) model validation. The validation step aims to test and determine the effectiveness of the proposed information model.

It is imperative to select a legitimate testing strategy in order to achieve valid and conclusive results. Presently, there is no established methodology to prove a research work's credibility, particularly when IT advancements are applied [Clayton et al. 1997]. This research employs the Charrette Testing Method, proposed by Clayton et al. [1997] as a formal testing platform to determine the effectiveness of the information model. Clayton organizes the arguments, provided to quantify a computer-assisted process into four categories, in an increasing scale manner. The four categories are logical arguments, worked example, demonstration and trial. Note that the first one provides the minimal proof.

a) *"Logical Arguments"* - These are the theoretical arguments, which are fundamental to any research, however they lack experimental and practical proofs.

b) *"Worked Example"* - This is a functional prototype with the intention to support the logical arguments and to disclose how the research relates to practice. A functional prototype is one, based on a practical case, implemented to map the proposed concepts and emulate the functionality.

c) *Demonstration* – The demonstration arguments are a higher level of evidence, and are based on working prototype. Although, the prototype is demonstrated to experts from the researched domain for consideration, it still lacks evidence that the research can be utilized in a practical environment.

d) *Trial* - The trial arguments are the evidences concluded from the results of an application deployment. This kind of reason requires implementation of the proposed concepts into an application (software) and deployment into the field of research. The participants, using the application to perform the tasks, are observed, and the results compared with the contemporary process efficiency.

This research utilizes prototyping as a validation technique, which corresponds to the "worked example" of the second category of Charrette's testing method, and aims to fulfill the followings:

- to demonstrate that the proposed model can achieve the stated objectives,
- to illustrate how the conceptual model can be implemented in a practical environment.

The prototype is detailed in the next section.

4.2 Prototype Scope

Maintenance management of building mechanical systems is a FM function that encompasses a broad range of processes (described in section 3.1). Due to the lack of available data to sustain the implementation of the information model, the prototype addresses only one process, namely

Replacement Analysis, as part of the Manage Asset key-process detailed in section 3.1.1. Replacement Analysis is one of the key activities in maintenance management, one which provides an answer to the questions "How much money is to be spent yearly on a building's equipment maintenance, and when is it cost effective to replace equipment?" Facility managers determine the on-going costs of equipment maintenance and the future costs of a major equipment replacement. Some of the primary reasons for considering equipment replacement are declining efficiency, expensive maintenance, heavy energy consumption, and complying with new environmental standards. From an economic perspective, Replacement Analysis, which is commonly used in practice, is a process of comparing alternatives. One of the alternatives is generally to maintain or keep the existing equipment, while the remaining alternatives provide various replacement options [White et al. 1998].

The scope of the prototype, as shown in Figure 4-1, is defined in terms of the information used in the activities required to carry out the replacement of major equipment.

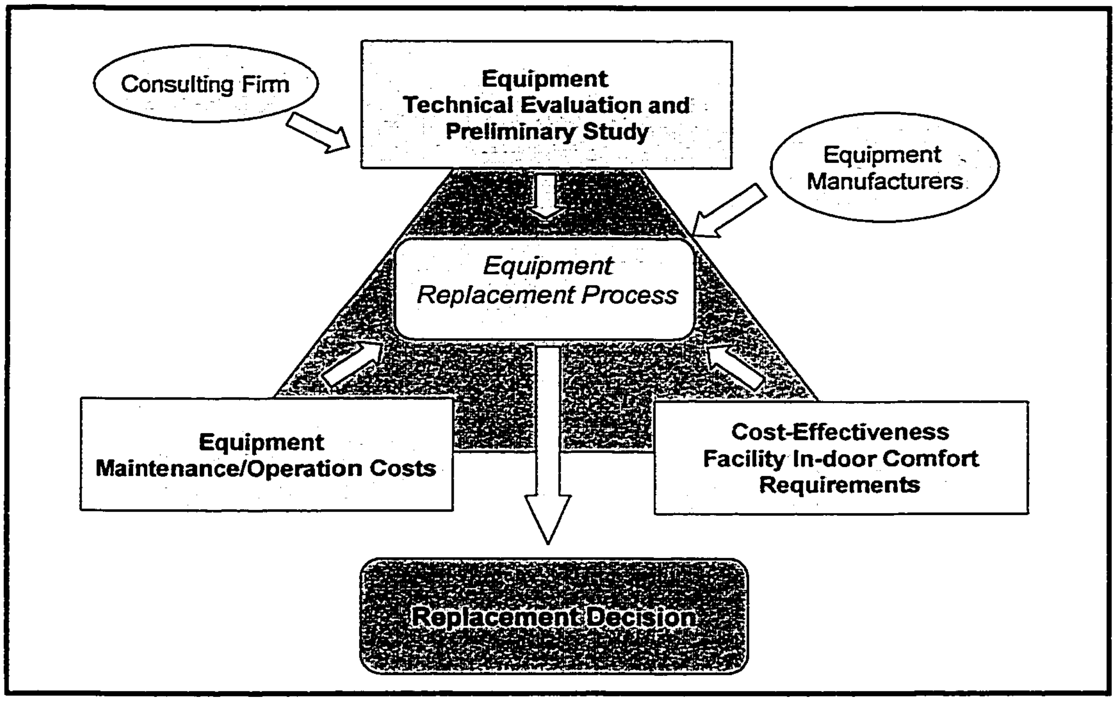


Figure 4-1 The Prototype scope for Replacement Analysis

The prototype integrates the data outlined below:

- *Equipment maintenance/operation costs* – the information pertaining to the maintenance history of equipment, including total cost of maintenance, and details regarding the equipment's failure and work demands. The data is generated using a maintenance computer system.
- *Equipment technical evaluation and preliminary study* - the information generated from a consulting firm that evaluates the existing equipment and proposes replacement alternatives.
- *Cost-effectiveness and indoor comfort requirements*- the information includes: a) The facility user's comfort requirements (e.g. history log of complains: hot during summer); b) Change of space assignment (e.g.

an office space to a computer lab); c) Budget and replacement alternative analysis data.

- *Data from equipment manufacturer* – technical specifications and installation data regarding the replacement equipment, as well as technical data pertaining to the removal of existing equipment.

4.3 Prototype Implementation

The prototype is implemented utilizing the programming environment of MS Access -97 and consists of the following two components, as illustrated in Figure 4-2:

a) *Database* - encompasses the part of the information model defined by the prototype's scope, and implemented in a relational database,

b) *FM Analyzer* –the main module, incorporating interfaces designed to serve as a tool for information searching, retrievals, and analysis.

The components are detailed in sections 4.3.1 and 4.3.2.

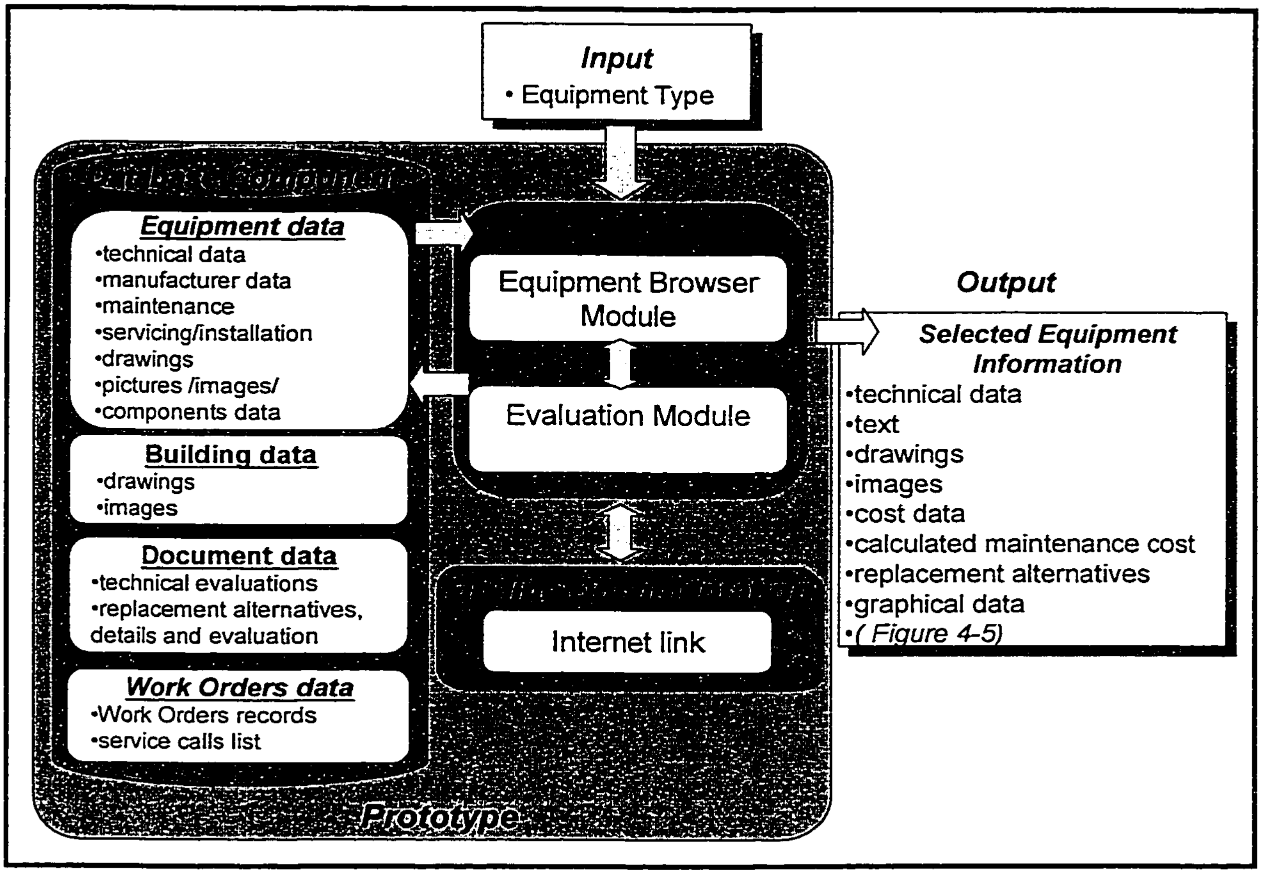


Figure 4-2 Prototype Architecture

The user accesses the information stored in the database through the FM Analyzer by selecting the type of equipment. The Equipment Browser module queries the database for complete information pertaining to the identified equipment and the user is presented with the following:

- equipment technical specifications,
- manufacturer's manuals, drawings, and images,
- equipment replacement parts and their maintenance history,
- equipment maintenance cost ,
- related documents and projects,
- building drawings and images related to equipment location.

Furthermore, the Browser is linked to a spreadsheet module (Evaluation module). The Evaluation module assists the user in analyzing replacement alternatives for the selected equipment. The module makes use of the preliminary study data to calculate the maintenance costs of different replacement alternatives and graphically presents the costs associated with the alternatives.

The Browser is linked with the particular equipment manufacturer as well. This allows for fast information updates.

4.3.1 The Database Component

The database component is implemented in a relational database. To achieve efficient mapping between the class diagram and the relational concepts, a conceptual entity-relationship (ER) diagram is developed. The ER diagram approach is a well-established data modeling technique [Elmasri et al. 1994] with two main concepts, entities and relationships. An entity, similarly to the object concept, represents a real life object and its characteristics; a relationship depicts how different entities relate to each other. The prototype ER diagram consists of the entities that hold information pertaining to Replacement Analysis, as discussed in section 4.1.1, and reflects the corresponding classes in the proposed information model, as detailed below. Figure 4-3 shows the ER Diagram where, for simplicity, only the entities and the relationships are shown.

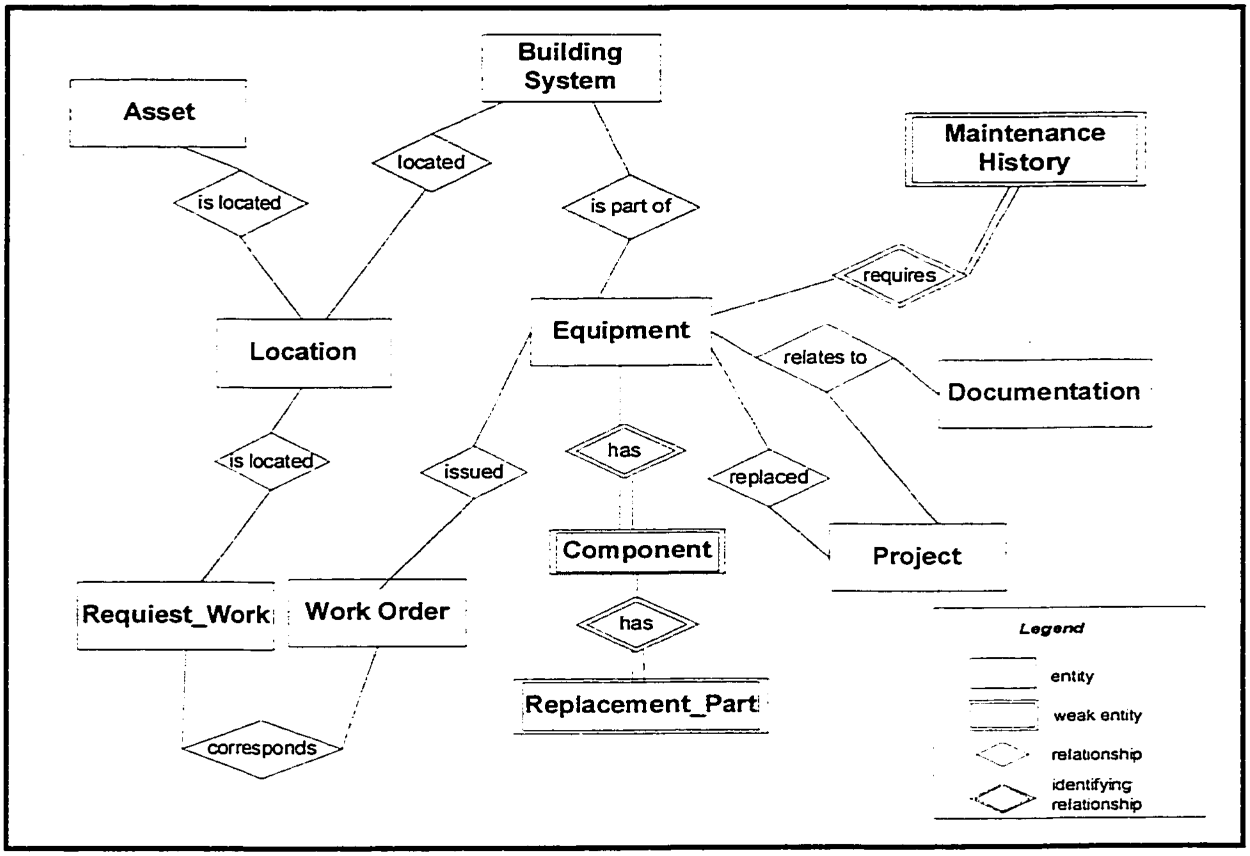


Figure 4-3 Prototype ER diagram

The entities Asset, Location, Maintenance History, Building System, Equipment, Component, Replacement Part correspond to the identical classes shown in Figure 3-9 (section 3.3.2.2), the entities Request Work, Work Order correspond to the classes shown in Figure 3-11 (section 3.3.2.3), and the entities Documentation, Project correspond to the classes identified in section 3.3.2.4 (Figure 3-12).

Next the data relational schema is derived from the conceptual entity-relationship diagram by means of an algorithm [Elmasri et al. 1994]. The resulting schema is implemented in MS Access and is illustrated in Figure 4-4. Moreover, the tables are detailed in Appendix 2.

The tables have been populated with data acquired from the case-study discussed in section 4.4.

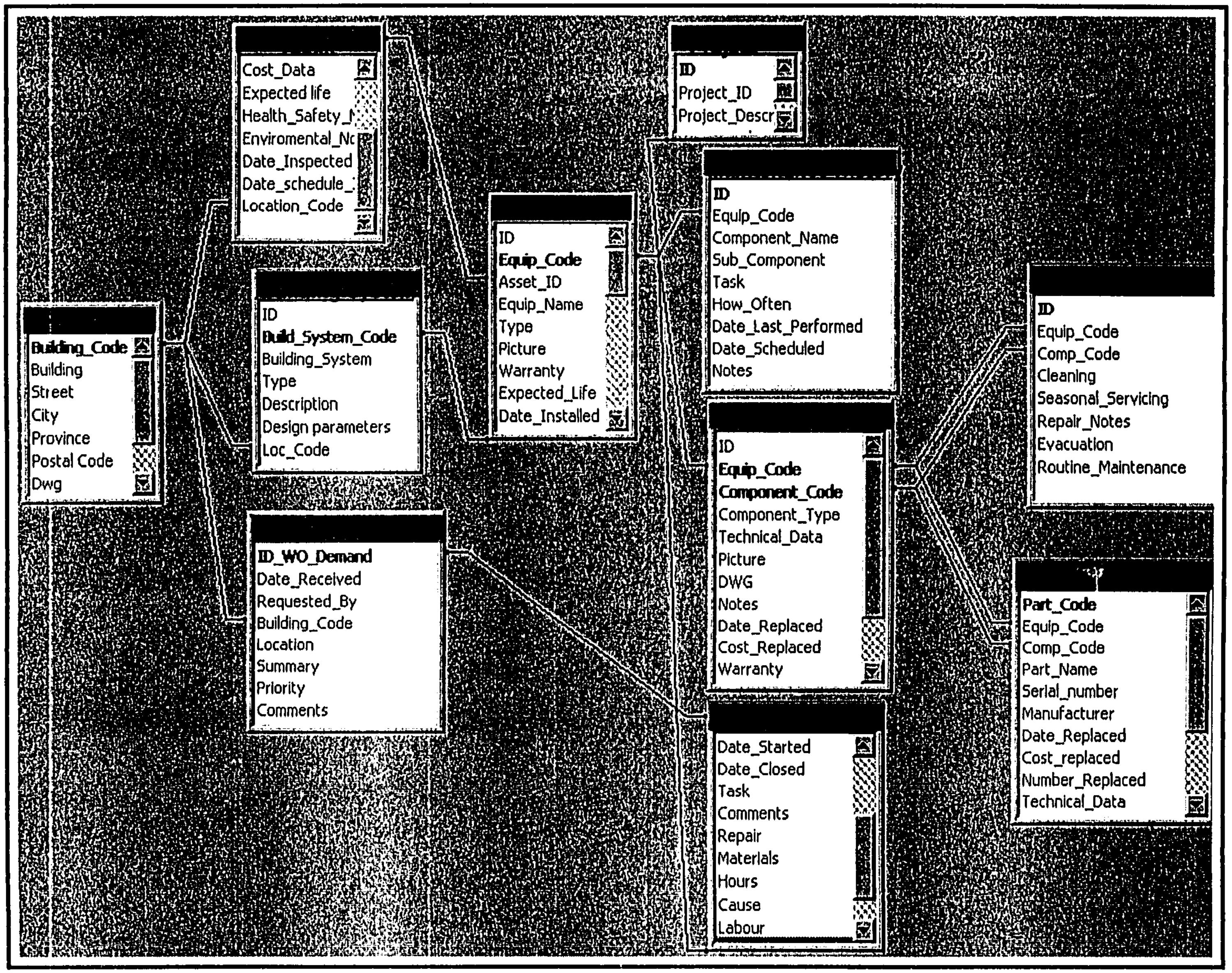


Figure 4-4 The Database Schema

4.3.2 The FM Analyzer Component

The FM Analyzer is a module developed to retrieve data based on a selected piece of equipment, hence to convert the structured data into useful information. The module has the following capabilities:

- queries the database in order to provide the user with data on selected equipment and reduces the manual effort in data gathering ,
- associates spatial with non-spatial data concerning an object,
- allows for "if-then" analysis,
- encompasses user-friendly screens which are simple to use.

The FM Analyzer is comprised of two modules (see Figure 4-2), namely the Equipment Browser Module and the Evaluation Module. The Browser module is the search engine of the prototype and is developed in MS Access, encompassing numerous queries, which are detailed in Appendix 2. The Browser retrieves the information pertaining to equipment selected by the user and displays it on the screen. The Evaluation module is implemented utilizing MS Excel, and developed to assist the user in comparing replacement alternatives, in case a preliminary study is necessary. The Evaluation module calculates maintenance costs and displays data in a graphical format to assist the user during the decision-making process. Data generated during the preliminary study is used in the analysis of alternatives. The discussed modules are illustrated in Figure 4-2, which shows the input-output. The output of the FM Analyzer is detailed next.

This output includes technical specifications, information on previously performed corrective and preventive work, location information, and completed preliminary study pertaining to the selected equipment. The data is in diversified formats (e.g. CAD drawings, equipment images, and equipment technical/maintenance details in text format). However it is organized and linked to provide the decision-maker with complete information pertaining to a piece of equipment. The output of the Browser Module is shown in Figure 4-5. The captured screen provides access to the data described below:

a) *Equipment location*: The information includes facility images and building (room) CAD drawings to help in locating the equipment.

b) *Technical data*: This section is comprised of equipment specifications, charts, and various drawings (equipment and its components) as supplied by the manufacturer. Clicking on the icons invokes files associated with particular equipment. These files are executed within their original environment (e.g. a component drawing will be executed in a CAD environment).

c) *Manuals data*: This section contains links to the manufacturer's numerous manuals provided for equipment installation. The following types of manufacturer manuals were identified: Operating and Maintenance Instruction manual, Replacement Parts manual, Routine Maintenance, Seasonal Servicing, and Inspection Notes.

d) *Preliminary Study Report:* Selecting this option will execute a query in order to retrieve data pertaining to the preliminary study performed to evaluate the equipment and to propose replacement alternatives. Figure 4-6 shows a screen printout that illustrates details from the preliminary study. Furthermore, the facility manager can analyze the different replacement alternatives, using the Evaluation module (depicted in Figure 4-7), by clicking on the Compare Alternatives window of Figure 4-6. The module presents the investment, operation, and maintenance costs pertaining to the alternatives in a graphical format. The capital investment and the operation costs of the different alternatives are determined from the preliminary study, however the maintenance costs for the alternatives are not yet identified. To calculate the maintenance costs for the alternatives proposed in the preliminary study, the Straight-line Depreciation (SLD) method is utilized [Peurifoy et al., 1998]. This method is selected to carry out the calculations due to its simplicity and common use for accounting purposes.

The method is based on accounting for investment, depreciation, and maintenance and operation costs, to determine the cost of acquiring and operating an equipment unit. The cost of depreciation (defined as the loss in value of equipment resulting from use and age) determined by the SLD method is assumed to decrease in value at a uniform rate from its original cost. Employing this concept, the maintenance cost of each replacement alternative is calculated as a percentage of the average annual value of the equipment's accumulative depreciation. The percentage is entered by the user. The time frame used in the module calculations is the equipment's useful life, as specified by the equipment manufacturer. The equipment's salvage value is assumed to be obsolete.

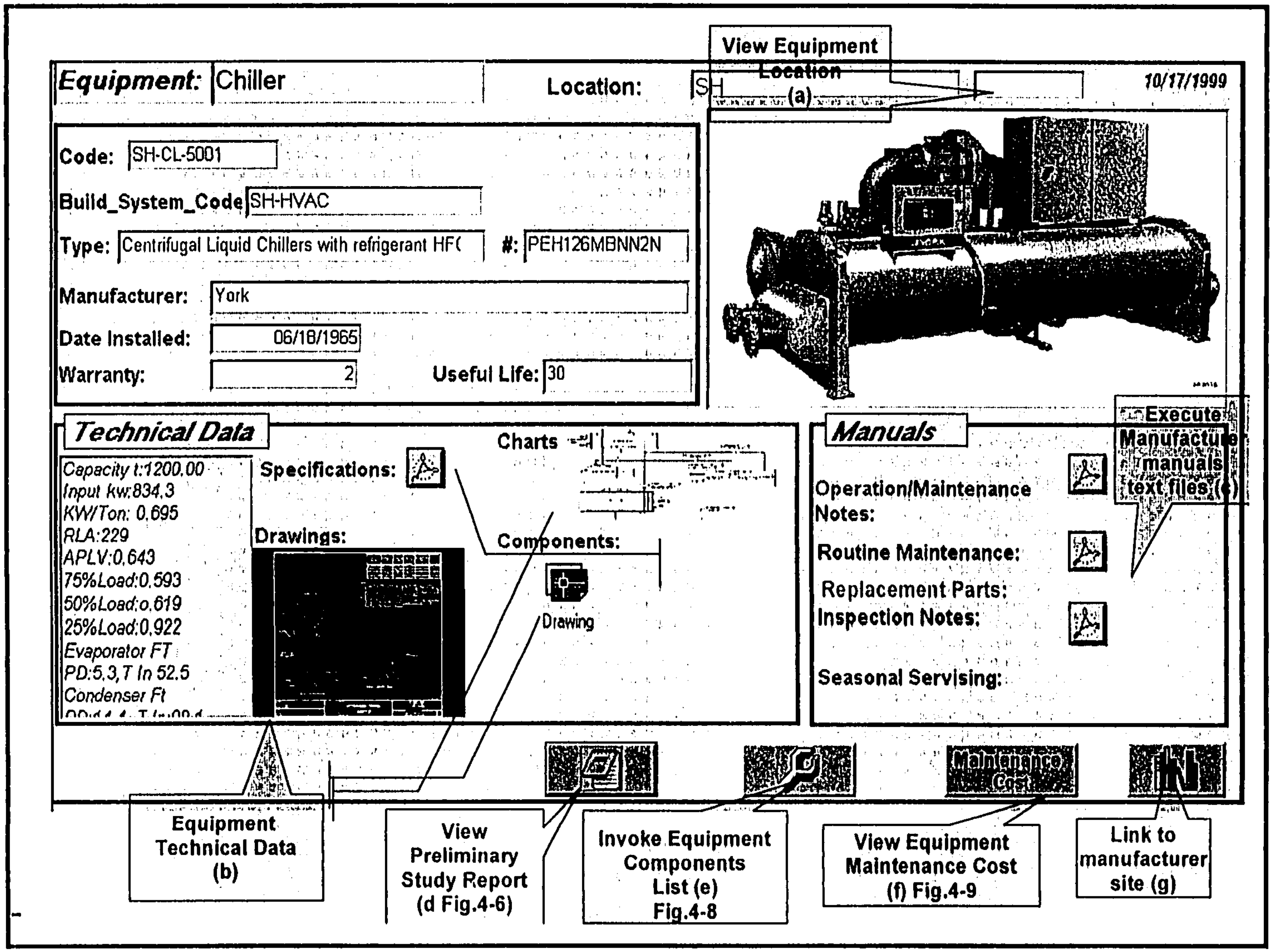
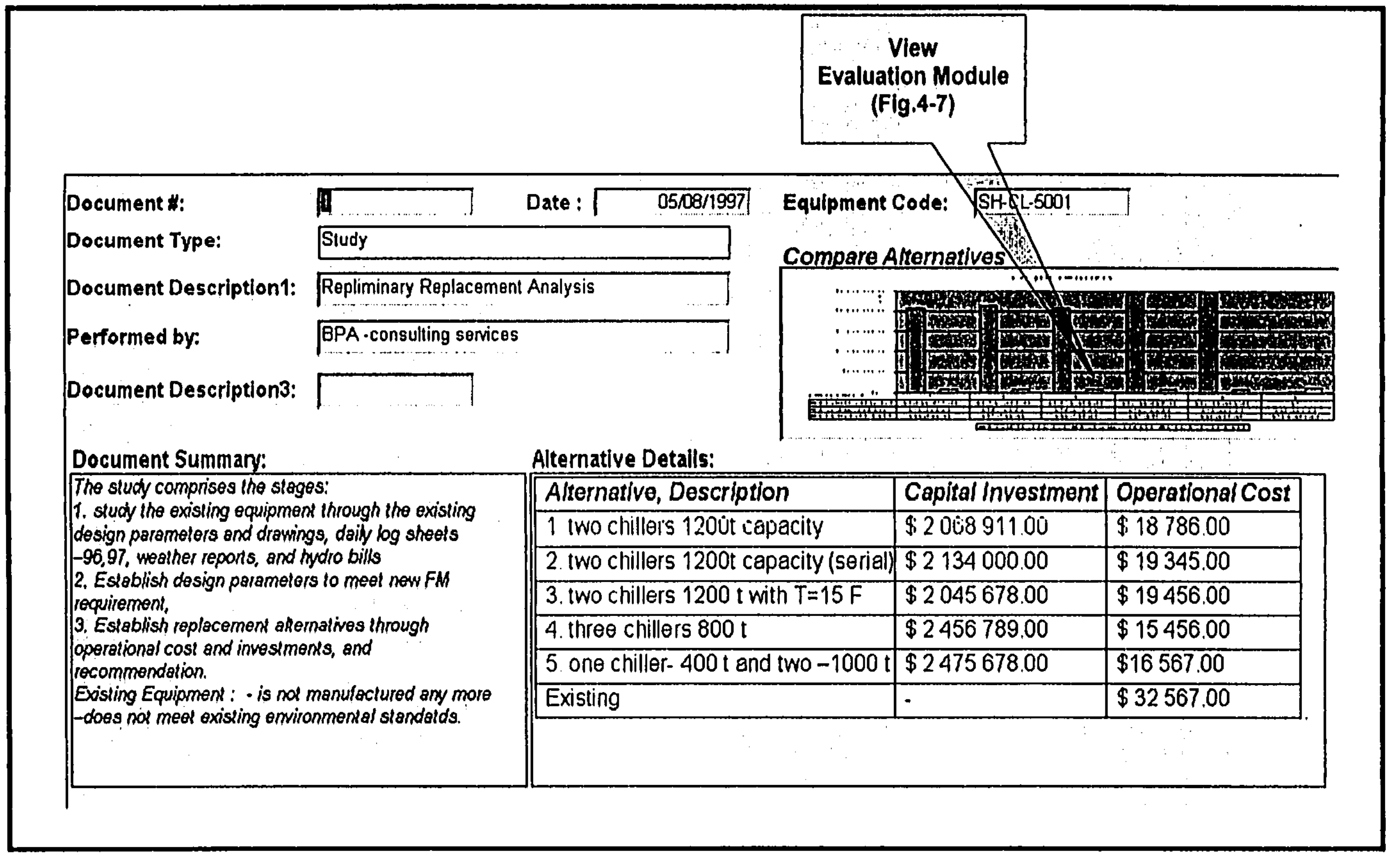


Figure 4-5 Browser View Screen



Alternative, Description	Capital Investment	Operational Cost
1 two chillers 1200t capacity	$ 2 068 911.00	$ 18 786.00
2. two chillers 1200t capacity (serial)	$ 2 134 000.00	$ 19 345.00
3. two chillers 1200 t with T=15 F	$ 2 045 678.00	$ 19 456.00
4. three chillers 800 t	$ 2 456 789.00	$ 15 456.00
5. one chiller- 400 t and two -1000 t	$ 2 475 678.00	$16 567.00
Existing	-	$ 32 567.00

Figure 4-6 Preliminary Study View Screen

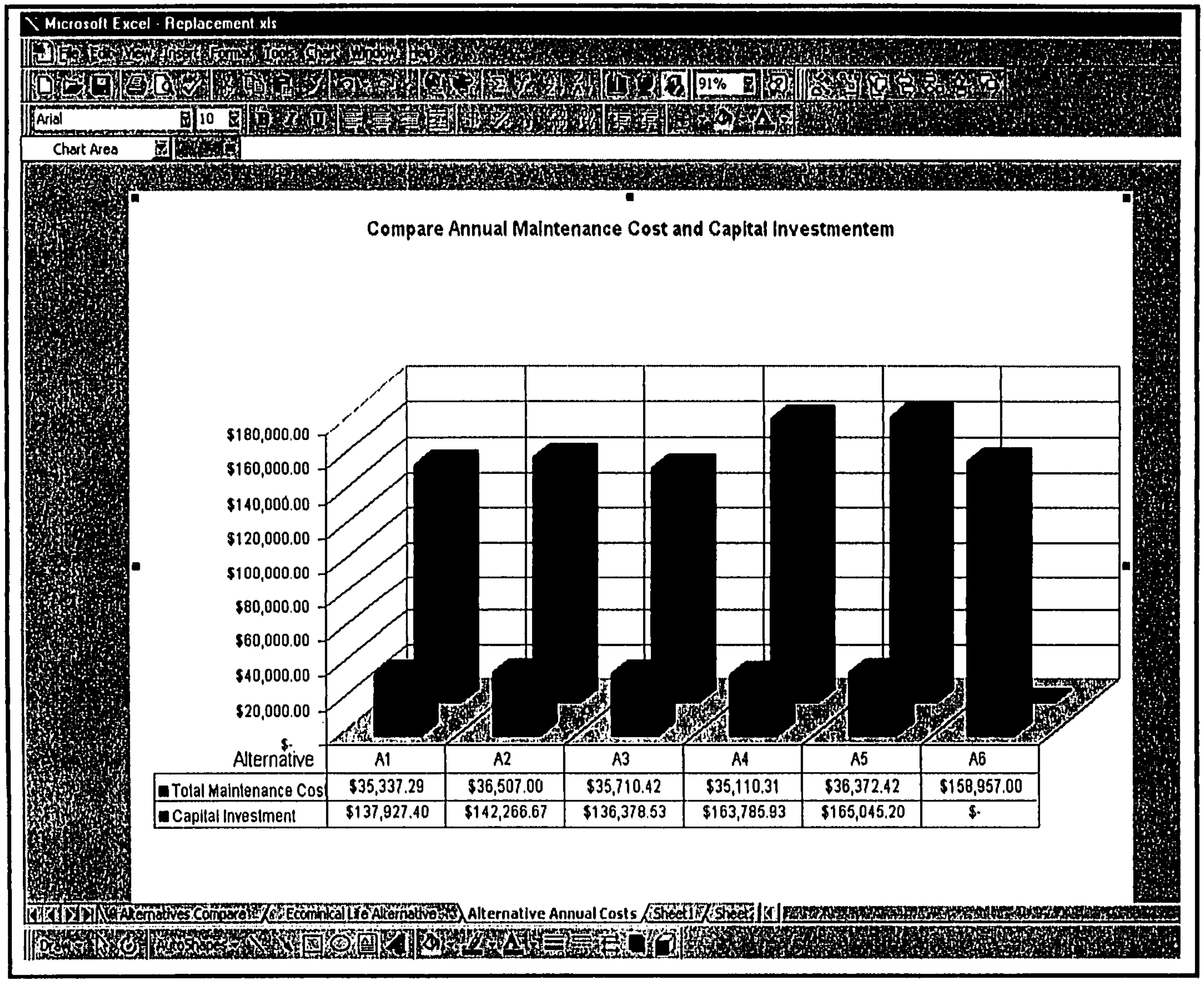


Figure 4-7 Evaluation Module - Cost Chart Screen

e) *Equipment components*: This is a list of the equipment components, as specified by the manufacturer in the Installation and Maintenance Data manual. The button executes a query to retrieve the information from tables containing component data. The results depicted in Figure 4-8, include part names, manufacturer, image, date last replaced, cost of replacement and number of replacements.

f) *Maintenance Cost:* The equipment 's maintenance cost information is generated through a query, which retrieves the cost accrued in the Work Orders created in case of corrective or preventive maintenance. In addition, the query calculates the total maintenance cost corresponding to the particular equipment. The results are presented in Figure 4-9.

g) *Connect to the Manufacturer's Site:* This link provides direct connection to the latest information published on the Internet site of the equipment manufacturer.

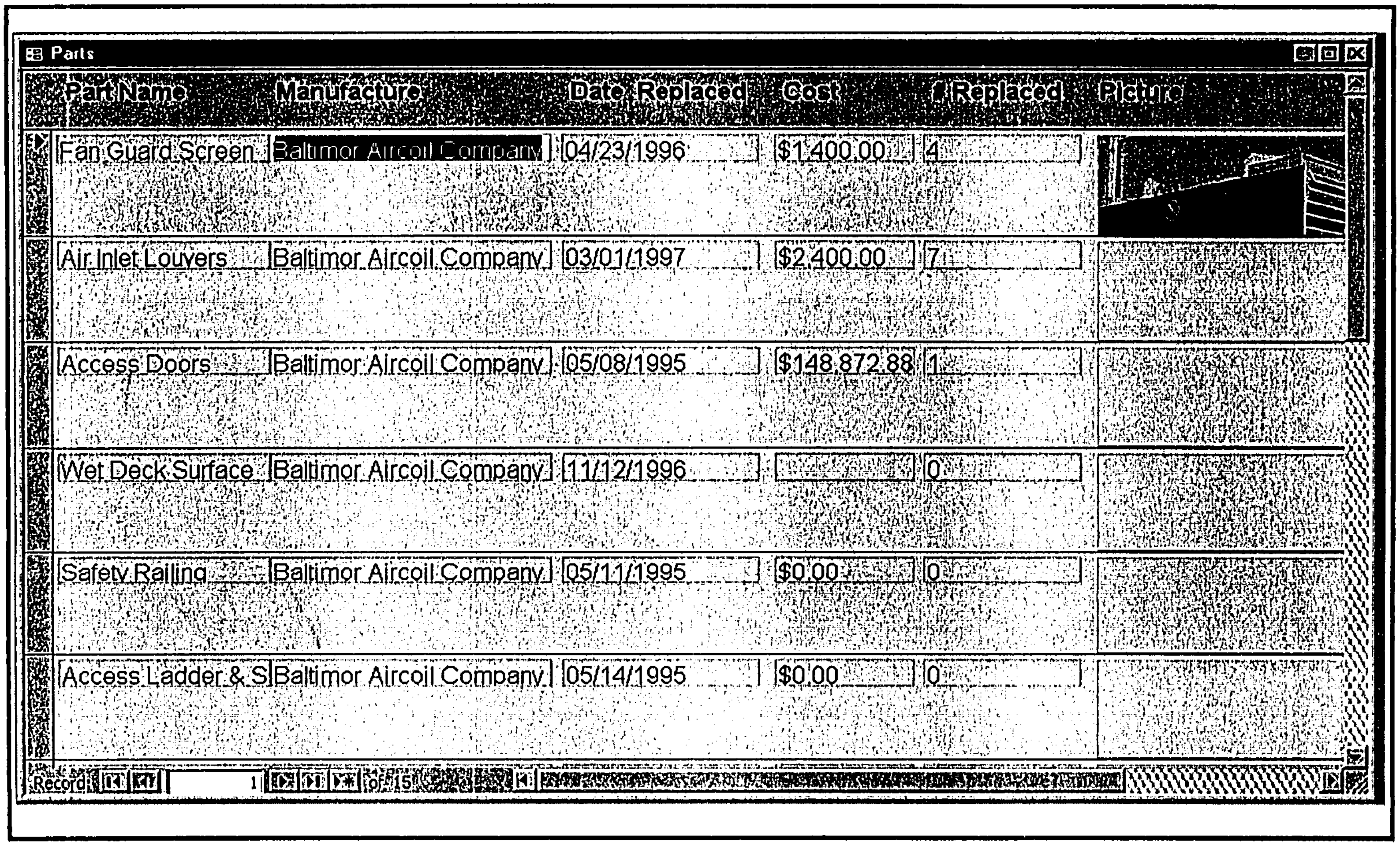


Figure 4-8 Equipment Components List Screen

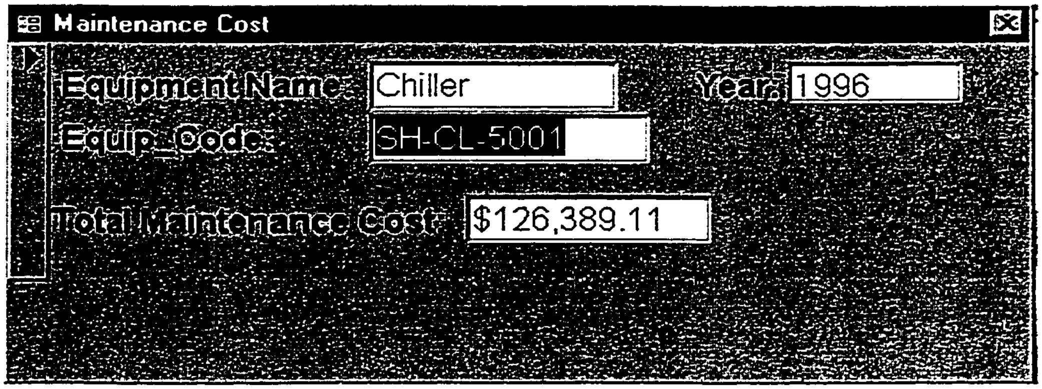


Figure 4-9 Equipment Maintenance Cost Screen

4.4 Implementation of a Real Case-Study

In order to evaluate the research development, an actual case-study has been investigated. The case-study involves a project to replace chillers for the Hall Building at Concordia University, Montreal, during 1997. Several interviews were conducted with the capital projects manager from the Facility Planning and Development department, at Concordia University, and the personnel involved in the project in order to gather required data. The archived documentation was closely examined to collect the available data. The case-study can be summarized in the following steps:

Step 1- The initial installation of the chillers took place in 1965. The original design parameters and criteria are not longer available.

Step 2- Numerous complains were received over the years from users regarding the indoor comfort. In addition the cost to maintain these chillers exceeded $ 80,000 annually for both 1995 and 1996.

Step 3- A preliminary study was performed in 1997 by BPA consultants, hired to technically evaluate the existing chillers, which included the following:

1. Chillers Evaluation:

- chillers are not compliant with the environmental standards regarding the type of refrigerant used,
- chillers are not manufactured any longer, therefore replacement parts can not be purchased,
- their useful life is about to expire.

2. Replacement Alternatives:

- establish design parameters to meet the existing demands in terms of cooling load for the Hall building,
- recommend different replacement alternatives (see Table 4-1) and detail the investment and operation costs for each alternative.

Table 4-1 –Replacement Alternatives

Alternative	Description	Capital Investment	Annual Operation Cost
1.	Two chillers with 1200 ton capacity	$ 2 068 911.00	$ 18 786.00
2.	Two chillers with 1200 ton capacity in parallel	$2 134 000.00	$ 19 345.00
3.	Two chillers with 1200 ton capacity with $\Delta T=15^0$ F (condensation)	$ 2 045 678.00	$ 19 456.00
4.	Three chillers with capacity 800 ton	$ 2 456 789.00	$ 19 456.00
5.	One chillers with 400 ton capacity and two chillers with 1000 ton capacity	$ 2475 678.00	$ 16 567.00
6.	Existing chillers	---	$ 32 567.00

Step 4- Alternative 1 was selected and suggested for budget approval.

The case-study analysis helped in identifying the actions taken by the facility manager and the data input throughout the decision-making process. Figure 4-10 depicts the tasks and information flows, which are detailed next.

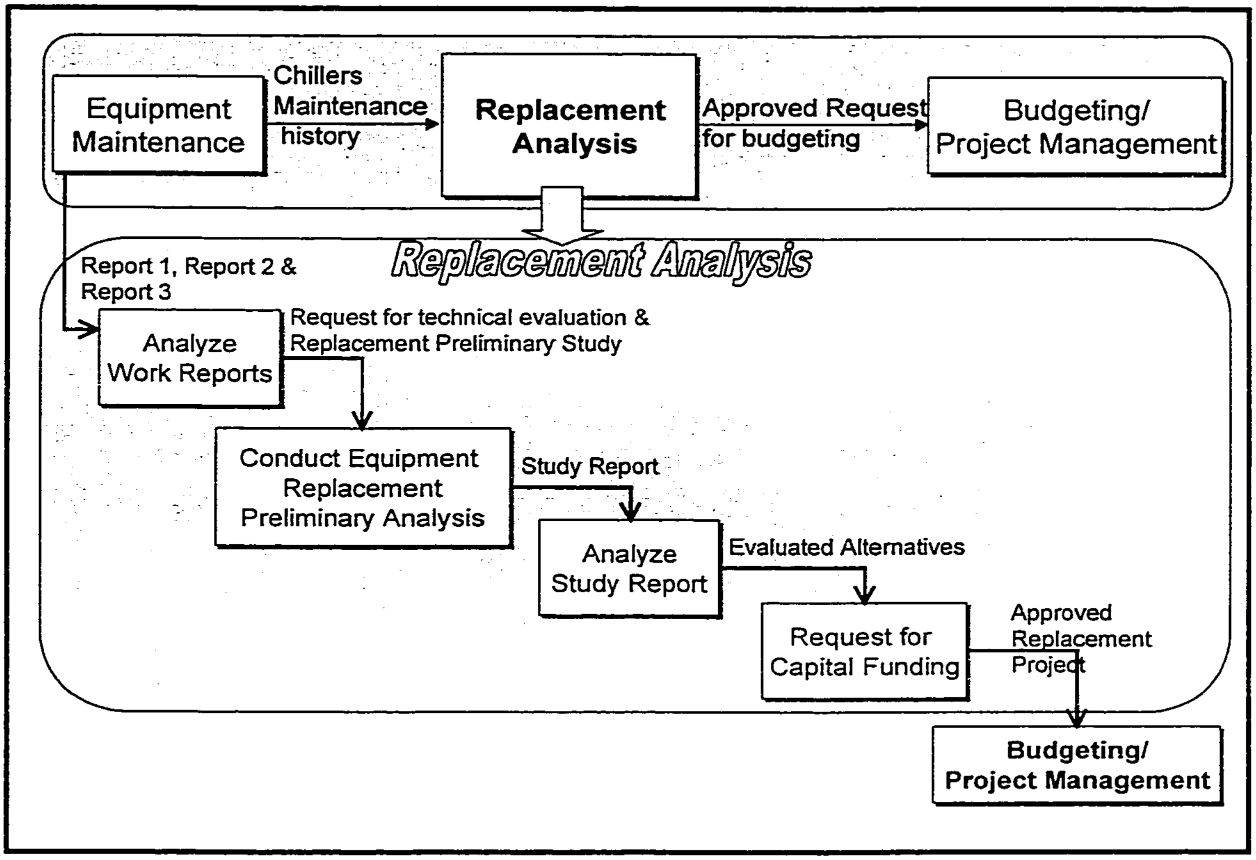


Figure 4-10 Chillers Replacement Analysis -task and information flow analysis

The task "Analyze Work Reports" uses for input Reports 1 to 3 which are outlined in Table 4-2. These reports are generated from computer maintenance application (EPIX) and can be obtained in digital format. The next task is to hire a technical consulting firm to technically evaluate the chillers and propose replacement alternatives (see Table 4-1). The study report is analyzed and the most desirable replacement alternative (#1, in this case) is selected. The relative cost of replacement against maintenance provides paramount evidence to support the request for replacement. Once the request is approved, the project is budgeted and scheduled for execution. The information exchanged during the performance of the tasks is mainly in paper format.

Table 4-2 Report Details

Report #	Information Source / Generated	Detailed Information
Report 1 Cost and Repair	Work Orders / Weekly	Date, Location, Description, Cost, References (Purchase Order)
Report 2 Maintenance Operations	Work Orders and Service Calls/ Weekly, Monthly	Date, Campus, Equipment, WO number, Equipment problem description, Date Repaired
Report 3 Daily Issued WO by Trades	Work Orders/ Daily	WO, Status, Equipment, Trade, Brief problem description, Location (Building)

The data acquired from the case-study has been entered into the database component of the prototype, presented in section 4.3.1. Once the user selects the type of equipment, in this case the chiller, the Browser component (detailed in section 4.3.2) retrieves the relevant information that is depicted in Figure 4-5. Buttons "maintenance cost" and "view preliminary study" (on the Browser interface in Figure 4-5) provide links to different queries in order to retrieve chillers' maintenance cost and preliminary study data (shown in Figures

4-6 and 4-9). Furthermore, from the preliminary study screen (Figure 4-9), the Evaluation module can be activated (Figure 4-7), which provides the user with required data to compare different replacement alternatives. The data includes capital investment, annual maintenance and operational costs of the replacement alternatives. Therefore the information regarding the case (chillers replacement) is available in a timely manner, and thereby promoting process efficiency.

The equipment data serves a twofold purpose: firstly to support the decision making process, and as an artifact in case of a similar replacement project. Having stored all information pertaining to the chillers' replacement project can be helpful when replacement is required again.

4.5 Prototype Findings

Having identified the overall purpose of the prototype, which is to evaluate the proposed information model, the findings of the implemented case-study are summarized as follows:

- The prototype and the implemented case-study effectively demonstrate how the information model can be implemented and used in practice. Furthermore, it shows that the information framework met the information requirements to carry out maintenance management activities with regard to equipment replacement, as described in section 3.1.1. The implemented case-study provides the arguments to conclude that the proposed information model achieved the main objective of the research, to provide a coherent data structure to hold the information needed for maintenance management.

- It enabled integration of heterogeneous data. The information, pertaining to the equipment, is available on-line regardless of the system that generated it. Therefore, an information exchange among different applications, promoting open communication channels, is achieved as well (e.g. CAD for the drawings, Work Orders records, manuals files from the manufacturer, economical data – Excel application). In addition, the robust data structure overcomes the existing problems associated with data redundancy and inconsistency (as discussed in section 2.1.3). For instance, any changes in the equipment location drawing (CAD system) will be evident for the facility manager accessing the file whilst viewing the equipment information.
- The implementation of the case-study reveals how the proposed model can assist in the decision making process; consequently, the facility manager can manage in a cost-effective and timely environment with access to the massive amount of data.
- The prototype demonstrates the advantages of the electronic data format over the traditional hardcopy manual, currently used in practice.

4.6 Summary

The proposed information model is validated through the development of a prototype and the utilization of a real case-study. The prototype, derived from the developed data structure, encompasses relational database and application, which provides a tool for viewing and retrieving information. It addresses the information needs of the Replacement Analysis process. Furthermore, the prototype achieves the following:

- reveals how a conceptual model relates to practice by implementing a prototype and a case-study, thus providing higher evidence to support the practicality of the proposed model,
- demonstrates the gained productivity and efficiency from properly structuring facility data, thus allowing proactive maintenance management, the ultimate goal of the FM,
- shows that integration of heterogeneous data generated from various applications and spanning facility life is attainable objective,
- utilizes available tools (MS Access and Excel), largely used in the industry, to show that the concept of data exchange and interoperability is achievable if a coherent and robust data structure is employed.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the final conclusions and contributions of this research work. Recommendations for future research in FM domain are also discussed.

5.1 Conclusions

Facility Management is under increasing pressure to improve the quality and reduce the costs of its services, to increase the efficiency and effectiveness of its processes and to promote accountability of its decision-makers. Contemporary facilities are getting more sophisticated with increasingly complex technology, while being subject to errors in specifications, installations and maintenance. Therefore, the availability of a complete, timely and well-organized facility information is critical for the facility manager. Since much of the information is generated during the design/construction phases, a holistic approach of the facility and its accumulated data are required to promote information sharing. More specifically, vast amounts of data are generated from various computer applications, in different formats, level of detail, and semantics.

The concept of utilizing a unified database used as a repository or data integrator among heterogeneous systems and spanning across the facility life is investigated. A repository of that kind can be utilized as a common information source, allowing data capturing and eliminating data re-entering, redundancy and errors. In addition it can function as a communication channel for information exchange among different FM applications.

Based on the repository concept an information model is developed and proposed in this thesis. The model focuses on the information needs with respect to one of the FM functions, namely Maintenance and Operations management, and identifies the information requirements associated with facility mechanical systems, as a building system element. Furthermore, it details a framework to structure, store, manage, and retrieve the defined information.

To validate the proposed information model, a prototype with a focal point on the Replacement Analysis process was implemented to map the proposed concepts and emulate the process (replacement analysis). The prototype not only disclosed how the research relates to practice, but also ensured that the proposed model accomplishes (provides) the identified characteristics. Furthermore, a real case-study (chillers replacement project at Hall building, Concordia University) was investigated to provide the data necessary to test the prototype efficiency.

5.2 Contributions

This research has proposed an information framework for maintenance management utilizing the central database concept through object-oriented development aiming to allow access to the vast amount of information describing mechanical systems. It attempts to demonstrate the feasibility of integrating the diverse data required for FM. The information model makes existing data available to support decision-making process without providing particular decisions. The main contributions are summarized as follows:

- Review of research work in the area of information integration and standardization throughout the facility's life-cycle. The different approaches were analyzed and their capabilities and limitations were evaluated.
- The framework, presented in section 3.2.3, is established to provide the conceptual basis for an open data sharing and exchange environment that facilitates maintenance management. Furthermore, the framework ensures that the proposed information model is capable of supporting information integration among the different FM applications.
- The thorough analysis of the maintenance management function identifies the required processes and the information flows among activities, which results in a process model. The process analysis is decomposed into activities and defines the information needs (data flows) associated with the process.

- Development of an information model which organizes heterogeneous data and represents a conceptual structure to store, manage, and retrieve the information required to support mechanical systems maintenance management. The model, implemented through object-oriented modeling, is capable of integrating and managing the large quantities of complex data needed for the decision-making process.
- Validation of the proposed information model is not only achieved through developing a prototype, but also by testing it using a real case study. The prototype focuses on the replacement analysis process and demonstrates how the information model relates to practice. The investigated case study provides data to test the model and shows that the information model can assist in providing appropriate and complete information to the decision-maker.

5.3 Recommendations for Future Research

Despite the fact that this research work builds on integration and interoperability, several issues still need to be addressed before the ultimate goal of integrated facility systems spanning facility life is achieved.

- Explore an integration mechanism between FM information model and IFCs (IAI) model to enable data exchange throughout a building's life-cycle phases.

- Facility management covers a broad range of functions (e.g. space management, communication management, facility planning) which can be investigated through applying the concepts discussed in this thesis. Therefore, further analysis is necessary to identify the information requirements and structure them as part of the developed information model in order to sustain FM's various activities.
- Further investigation is required into how equipment maintenance management activities relate to financial management systems in terms of equipment purchasing and inventory.
- This research work has included a prototype, which focuses on the replacement analysis process, to validate the proposed model. Hence, the model requires further testing and full implementation in an object-oriented database in order to validate the proposed data structure.

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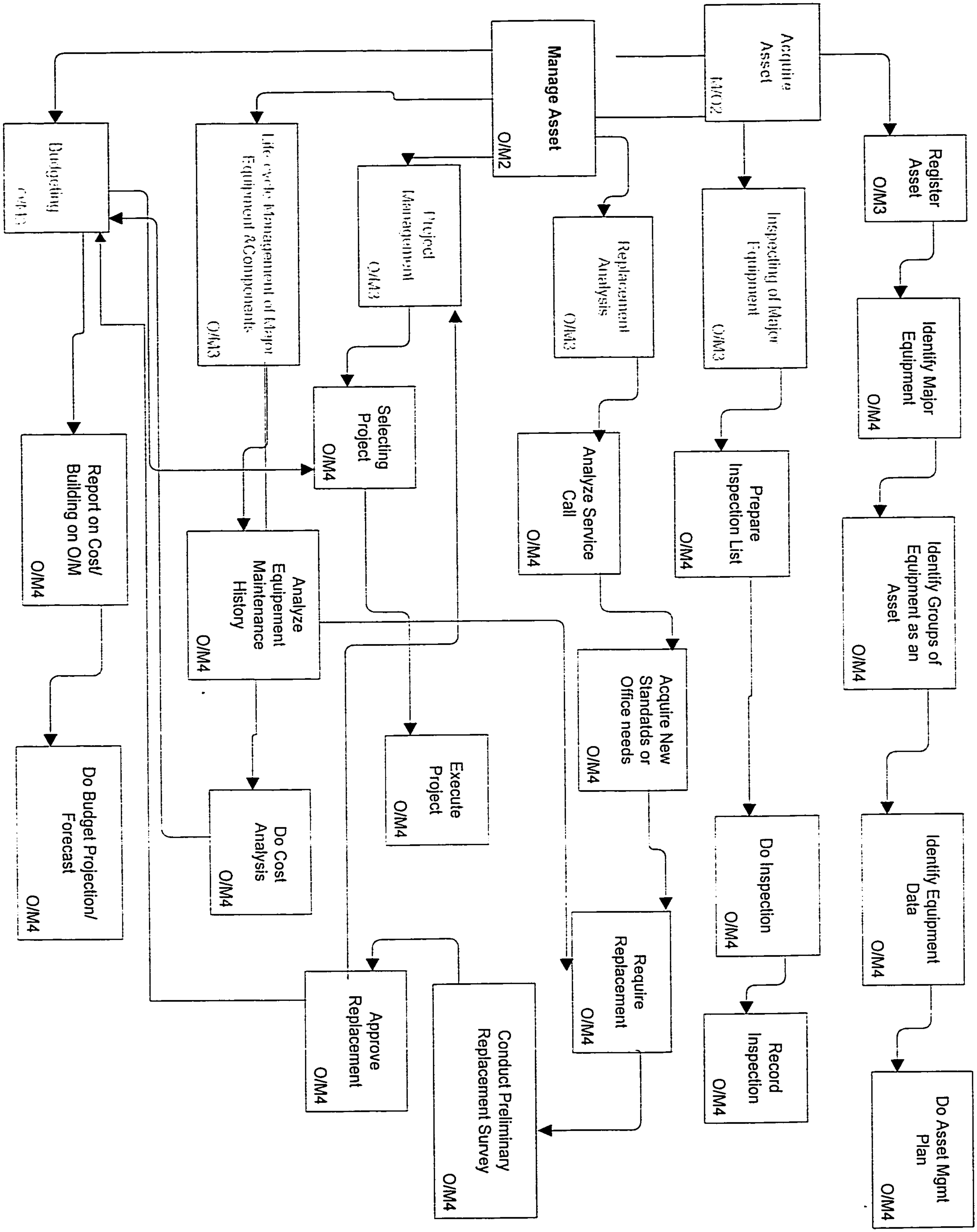
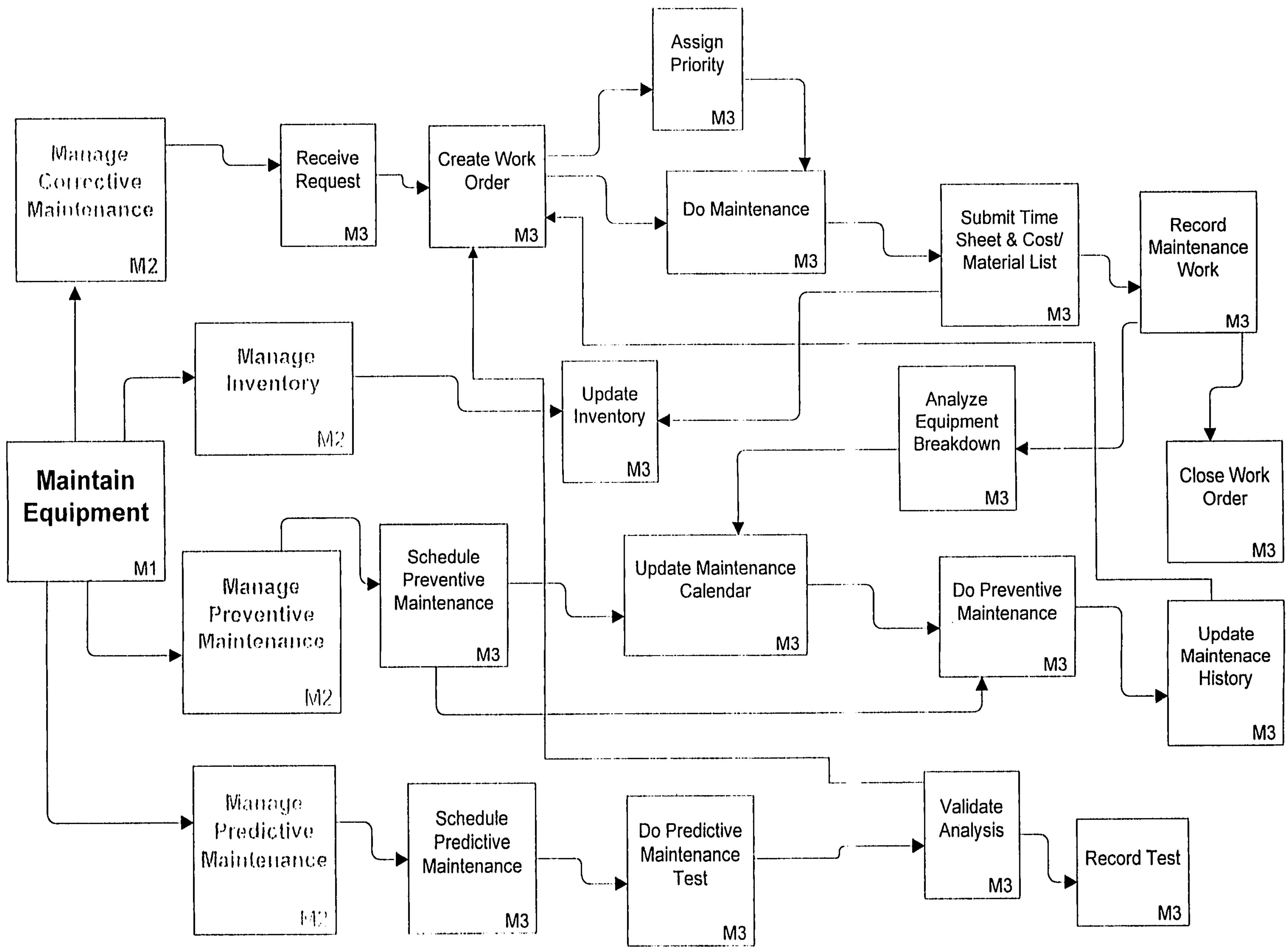
APPENDIX 1

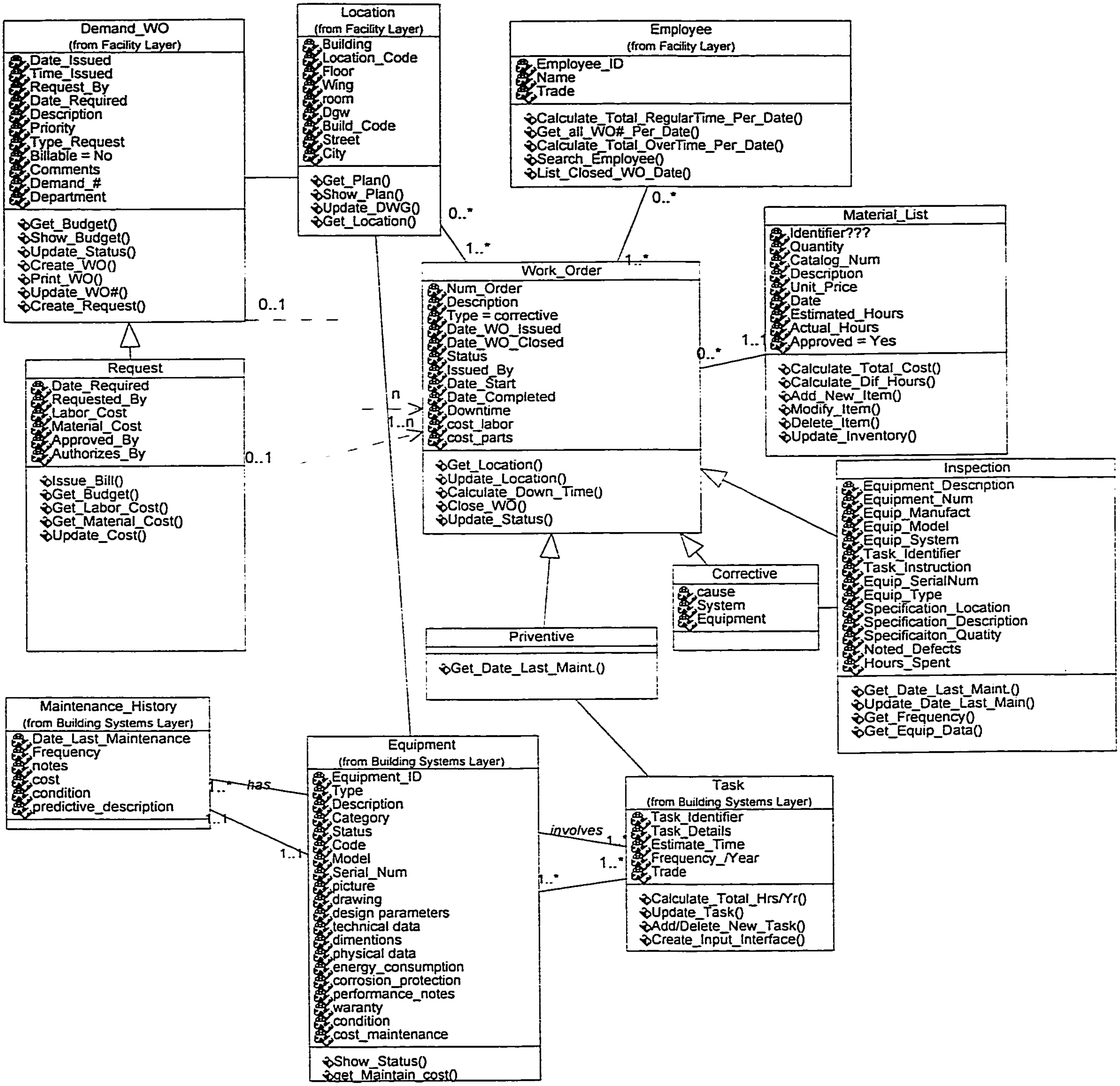
- ***"Manage Asset"*** *– sub-processes decomposition diagram*
- ***"Maintain Equipment"*** *– sub-processes decomposition diagram*

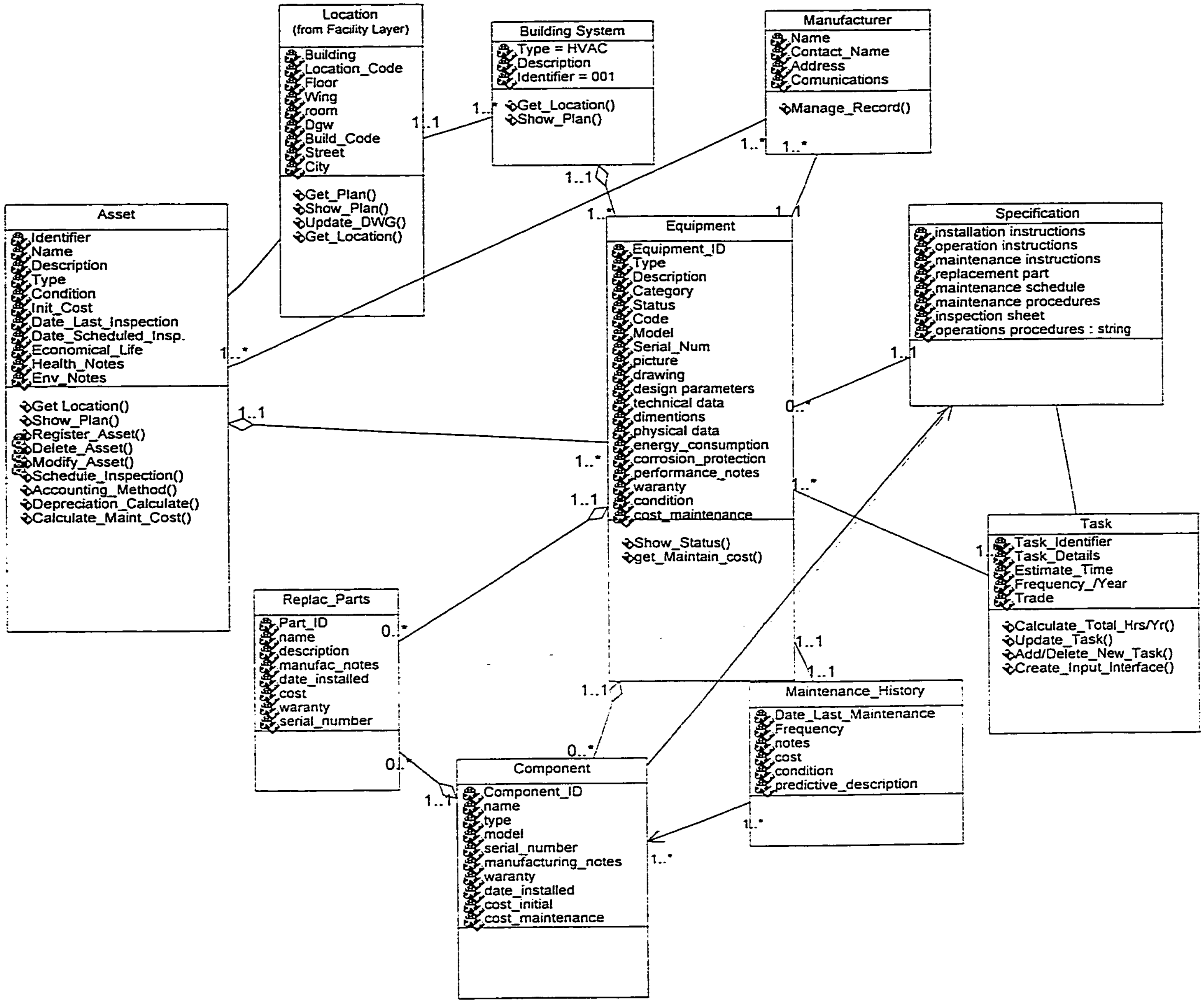
- ***Information Model*** *– Class Diagram and Class structure Examples*



Acquire Asset
Manage Asset O/M2
Register Asset O/M3
Identify Major Equipment O/M4
Identify Groups of Equipment as an Asset O/M4
Identify Equipment Data O/M4
Do Asset Mgmt Plan O/M4
Inspecting of Major Equipment O/M3
Prepare Inspection List O/M4
Do Inspection O/M4
Record Inspection O/M4
Replacement Analysis O/M3
Analyze Service Call O/M4
Acquire New Standards or Office needs O/M4
Require Replacement O/M4
Conduct Preliminary Replacement Survey O/M4
Project Management O/M3
Selecting Project O/M4
Execute Project O/M4
Approve Replacement O/M4
Life-cycle Management of Major Equipment &Components O/M3
Analyze Equipement Maintenance History O/M4
Do Cost Analysis O/M4
Budgeting
Report on Cost/ Building on O/M O/M4
Do Budget Projection/ Forecast O/M4


Manage Corrective Maintenance M2
Receive Request M3
Create Work Order M3
Assign Priority M3
Do Maintenance M3
Submit Time Sheet & Cost/ Material List M3
Record Maintenance Work M3
Manage Inventory M2
Update Inventory M3
Analyze Equipment Breakdown M3
Close Work Order M3
Maintain Equipment M1
Manage Preventive Maintenance M2
Schedule Preventive Maintenance M3
Update Maintenance Calendar M3
Do Preventive Maintenance M3
Update Maintenace History M3
Manage Predictive Maintenance
Schedule Predictive Maintenance M3
Do Predictive Maintenance Test M3
Validate Analysis M3
Record Test M3


Demand_WO
(from Facility Layer)
Date_Issued
Time_Issued
Request_By
Date_Required
Description
Priority
Type_Request
Billable = No
Comments
Demand_#
Department
Get_Budget()
Show_Budget()
Update_Status()
Create_WO()
Print_WO()
Update_WO#()
Create_Request()
Location
(from Facility Layer)
Building
Location_Code
Floor
Wing
room
Dgw
Build_Code
Street
City
Get_Plan()
Show_Plan()
Update_DWG()
Get_Location()
Employee
(from Facility Layer)
Employee_ID
Name
Trade
Calculate_Total_RegularTime_Per_Date()
Get_all_WO#_Per_Date()
Calculate_Total_OverTime_Per_Date()
Search_Employee()
List_Closed_WO_Date()
0..*
0..*
1..*
1..*
Material_List
Identifier???
Quantity
Catalog_Num
Description
Unit_Price
Date
Estimated_Hours
Actual_Hours
Approved = Yes
Calculate_Total_Cost()
Calculate_Dif_Hours()
Add_New_Item()
Modify_Item()
Delete_Item()
Update_Inventory()
Work_Order
Num_Order
Description
Type = corrective
Date_WO_Issued
Date_WO_Closed
Status
Issued_By
Date_Start
Date_Completed
Downtime
cost_labor
cost_parts
Get_Location()
Update_Location()
Calculate_Down_Time()
Close_WO()
Update_Status()
0..1
0..*
1..1
n
1..n
0..1
Request
Date_Required
Requested_By
Labor_Cost
Material_Cost
Approved_By
Authorizes_By
Issue_Bill()
Get_Budget()
Get_Labor_Cost()
Get_Material_Cost()
Update_Cost()
Inspection
Equipment_Description
Equipment_Num
Equip_Manufact
Equip_Model
Equip_System
Task_Identifier
Task_Instruction
Equip_SerialNum
Equip_Type
Specification_Location
Specification_Description
Specificaiton_Quatity
Noted_Defects
Hours_Spent
Get_Date_Last_Maint.()
Update_Date_Last_Main()
Get_Frequency()
Get_Equip_Data()
Corrective
cause
System
Equipment
Priventive
Get_Date_Last_Maint.()
Maintenance_History
(from Building Systems Layer)
Date_Last_Maintenance
Frequency
notes
cost
condition
predictive_description
1..*
has
1..1
1..1
Equipment
(from Building Systems Layer)
Equipment_ID
Type
Description
Category
Status
Code
Model
Serial_Num
picture
drawing
design parameters
technical data
dimentions
physical data
energy_consumption
corrosion_protection
performance_notes
waranty
condition
cost_maintenance
Show_Status()
get_Maintain_cost()
involves
1..*
1..*
1..*
Task
(from Building Systems Layer)
Task_Identifier
Task_Details
Estimate_Time
Frequency_/Year
Trade
Calculate_Total_Hrs/Yr()
Update_Task()
Add/Delete_New_Task()
Create_Input_Interface()


Location
(from Facility Layer)
Building
Location_Code
Floor
Wing
room
Dgw
Build_Code
Street
City
Get_Plan()
Show_Plan()
Update_DWG()
Get_Location()
Building System
Type = HVAC
Description
Identifier = 001
Get_Location()
Show_Plan()
Manufacturer
Name
Contact_Name
Address
Comunications
Manage_Record()
Asset
Identifier
Name
Description
Type
Condition
Init_Cost
Date_Last_Inspection
Date_Scheduled_Insp.
Economical_Life
Health_Notes
Env_Notes
Get Location()
Show_Plan()
Register_Asset()
Delete_Asset()
Modify_Asset()
Schedule_Inspection()
Accounting_Method()
Depreciation_Calculate()
Calculate_Maint_Cost()
Equipment
Equipment_ID
Type
Description
Category
Status
Code
Model
Serial_Num
picture
drawing
design parameters
technical data
dimentions
physical data
energy_consumption
corrosion_protection
performance_notes
waranty
condition
cost_maintenance
Show_Status()
get_Maintain_cost()
Specification
installation instructions
operation instructions
maintenance instructions
replacement part
maintenance schedule
maintenance procedures
inspection sheet
operations procedures : string
Task
Task_Identifier
Task_Details
Estimate_Time
Frequency_/Year
Trade
Calculate_Total_Hrs/Yr()
Update_Task()
Add/Delete_New_Task()
Create_Input_Interface()
Replac_Parts
Part_ID
name
description
manufac_notes
date_installed
cost
waranty
serial_number
Maintenance_History
Date_Last_Maintenance
Frequency
notes
cost
condition
predictive_description
Component
Component_ID
name
type
model
serial_number
manufacturing_notes
waranty
date_installed
cost_initial
cost_maintenance
1..1
1..*
1..*
1..*
1..1
1..*
1..1
1..*
1..1
1..1
0..*
1..*
1..1
1..*
1..1
0..*
1..1
1..1
1..1
0..*
0..*
1..1
1..*
1..*

Class name:

Location

Category: Facility Layer
External Documents:
Export Control: Public
Cardinality: n
Hierarchy:
Superclasses: none
Associations:

<no rolename> : Building System in association is located
<no rolename> : Asset in association <unnamed>
<no rolename> : Equipment in association <unnamed>
<no rolename> : Replac_Parts in association <unnamed>
<no rolename> : Work_Order in association Is Located
<no rolename> : Demand_WO in association <unnamed>

Public Interface:
Operations:

Get_Plan
Show_Plan
Update_DWG
Get_Location

Private Interface:
Attributes:

Building
Location_Code
Floor
Wing
room
Dgw
Build_Code
Street
City

State machine: No
Concurrency: Sequential
Persistence: Transient

Class name:
Building System

Category: Building Systems Layer
Documentation:
A Building System Class is a representation of the building engineering systems (like HVAC, plumbing).

External Documents:
Export Control: Public
Cardinality: n
Hierarchy:
Superclasses: none
Associations:

<no rolename> : Location in association is located
<no rolename> : Equipment in association <unnamed>

Public Interface:
Operations:

Get_Location
Show_Plan

Private Interface:
Attributes:

Type = HVAC
To discribe the building system name like HVAC, electrical, plumbing, ...

Description
Identifier = 001
To uniquelly identify the building system. Could be composed of the facility ID + system genereted number.

State machine: No
Concurrency: Sequential
Persistence: Persistent

Class name:

Class name:
Replac_Parts

Category: Building Systems Layer
External Documents:
Export Control: Public
Cardinality: n
Hierarchy:
Superclasses: none
Associations:

<no rolename> : Location in association <unnamed>
<no rolename> : (Register Part) in association <unnamed>
<no rolename> : Component in association <unnamed>
<no rolename> : Equipment in association <unnamed>

Public Uses:

Specification

Private Interface:
Attributes:

Part_ID
name
description
manufac_notes
date_installed
cost
waranty
serial_number

State machine: No
Concurrency: Sequential
Persistence: Transient

Class name:
Maintenance_History

Category: Building Systems Layer
External Documents:

<no rolename> : Specification in association <unnamed>
<no rolename> : Priventive in association <unnamed>

Public Interface:
Operations:

Calculate_Total_Hrs/Yr
Update_Task
Add/Delete_New_Task
Create_Input_Interface

Private Interface:
Attributes:

Task_Identifier
Task_Details
Estimate_Time
Frequency_/Year
Trade

State machine: No
Concurrency: Sequential
Persistence: Transient

Class name:

Equipment

Category: Building Systems Layer
External Documents:
Export Control: Public
Cardinality: n
Hierarchy:
Superclasses: none
Associations:

<no rolename> : Location in association <unnamed>
<no rolename> : (Register_Asset) in association <unnamed>
<no rolename> : Component in association <unnamed>
<no rolename> : Replac_Parts in association <unnamed>
<no rolename> : Building System in association <unnamed>
<no rolename> : Asset in association <unnamed>
<no rolename> : Maintenance_History in association has

<no rolename> : Task in association involves
<no rolename> : Manufacturer in association is manufactured
<no rolename> : Specification in association <unnamed>

Public Interface:
Operations:

Show_Status
get_Maintain_cost

Private Interface:
Attributes:

Equipment_ID
or Equipment Code.

Type
Description
Category
like mechanical, electrical, plumbing, architectural
.

Status
Code
or Abbreviations

Model
Serial_Num
picture
drawing
design parameters
technical data
dimentions
physical data
energy_consumption
corrosion_protection
performance_notes
waranty
condition
cost_maintenance

State machine: No
Concurrency: Sequential
Persistence: Transient

Class name:

Component

Category: Building Systems Layer
External Documents:
Export Control: Public
Cardinality: n
Hierarchy:
Superclasses: none
Associations:

<no rolename> : Equipment in association <unnamed>
<no rolename> : Replac_Parts in association <unnamed>
<no rolename> : Maintenance_History in association <unnamed>
<no rolename> : Specification in association <unnamed>

Private Interface:
Attributes:

Component_ID
name
type
model
serial_number
manufacturing_notes
waranty
date_installed
cost_initial
cost_maintenance

State machine: No
Concurrency: Sequential
Persistence: Transient

Class name:

Specification

Category: Building Systems Layer
Documentation:
Every piece of equipment when aquired (installed in the construction phase or purchased/replaces in the O/M phase) has specifications with listed spare parts, intallation, maintenance , and safety(trial run procedures) manuals.

External Documents:
Export Control: Public
Cardinality: n
Hierarchy:
Superclasses: none
Associations:

<no rolename> : Task in association <unnamed>
<no rolename> : Equipment in association <unnamed>
<no rolename> : Component in association <unnamed>

Public Uses:

Replac_Parts
Component

Private Interface:
Attributes:

installation instructions
operation instructions
maintenance instructions
replacement part
maintenance schedule
maintenance procedures
inspection sheet
operations procedures : string

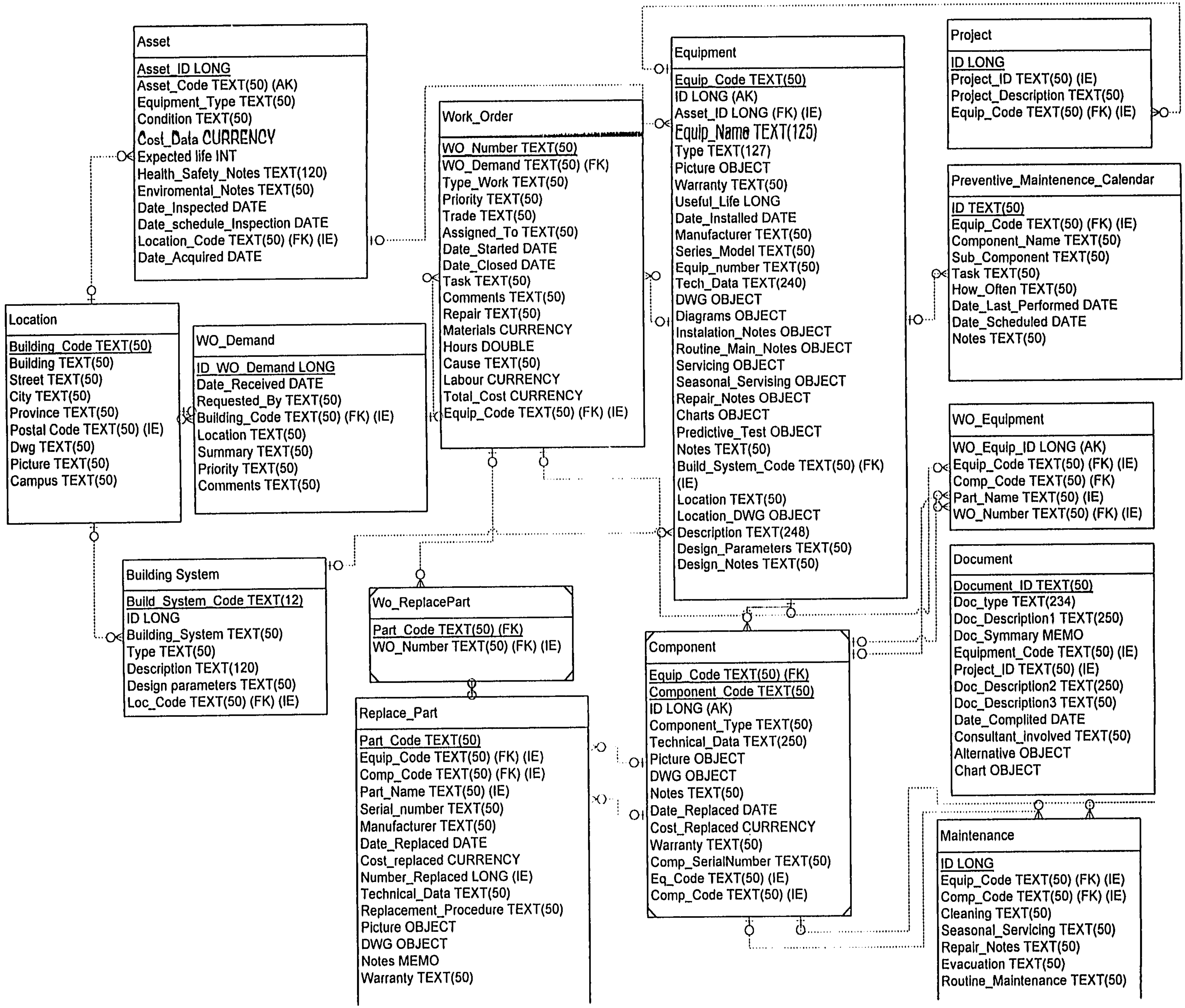
State machine: No
Concurrency: Sequential
Persistence: Transient

Association:
is located

Derived: No

APPENDIX 2

- ***Database Component*** – *database schema*
- ***Equipment Browser Module*** – *query example*


Asset
Asset_ID LONG
Asset_Code TEXT(50) (AK)
Equipment_Type TEXT(50)
Condition TEXT(50)
Cost_Data CURRENCY
Expected life INT
Health_Safety_Notes TEXT(120)
Enviromental_Notes TEXT(50)
Date_Inspected DATE
Date_schedule_Inspection DATE
Location_Code TEXT(50) (FK) (IE)
Date_Acquired DATE
Work_Order
WO_Number TEXT(50)
WO_Demand TEXT(50) (FK)
Type_Work TEXT(50)
Priority TEXT(50)
Trade TEXT(50)
Assigned_To TEXT(50)
Date_Started DATE
Date_Closed DATE
Task TEXT(50)
Comments TEXT(50)
Repair TEXT(50)
Materials CURRENCY
Hours DOUBLE
Cause TEXT(50)
Labour CURRENCY
Total_Cost CURRENCY
Equip_Code TEXT(50) (FK) (IE)
Equipment
Equip_Code TEXT(50)
ID LONG (AK)
Asset_ID LONG (FK) (IE)
Equip_Name TEXT(125)
Type TEXT(127)
Picture OBJECT
Warranty TEXT(50)
Useful_Life LONG
Date_Installed DATE
Manufacturer TEXT(50)
Series_Model TEXT(50)
Equip_number TEXT(50)
Tech_Data TEXT(240)
DWG OBJECT
Diagrams OBJECT
Instalation_Notes OBJECT
Routine_Main_Notes OBJECT
Servicing OBJECT
Seasonal_Servising OBJECT
Repair_Notes OBJECT
Charts OBJECT
Predictive_Test OBJECT
Notes TEXT(50)
Build_System_Code TEXT(50) (FK) (IE)
Location TEXT(50)
Location_DWG OBJECT
Description TEXT(248)
Design_Parameters TEXT(50)
Design_Notes TEXT(50)
Project
ID LONG
Project_ID TEXT(50) (IE)
Project_Description TEXT(50)
Equip_Code TEXT(50) (FK) (IE)
Preventive_Maintenence_Calendar
ID TEXT(50)
Equip_Code TEXT(50) (FK) (IE)
Component_Name TEXT(50)
Sub_Component TEXT(50)
Task TEXT(50)
How_Often TEXT(50)
Date_Last_Performed DATE
Date_Scheduled DATE
Notes TEXT(50)
Location
Building_Code TEXT(50)
Building TEXT(50)
Street TEXT(50)
City TEXT(50)
Province TEXT(50)
Postal Code TEXT(50) (IE)
Dwg TEXT(50)
Picture TEXT(50)
Campus TEXT(50)
WO_Demand
ID_WO_Demand LONG
Date_Received DATE
Requested_By TEXT(50)
Building_Code TEXT(50) (FK) (IE)
Location TEXT(50)
Summary TEXT(50)
Priority TEXT(50)
Comments TEXT(50)
WO_Equipment
WO_Equip_ID LONG (AK)
Equip_Code TEXT(50) (FK) (IE)
Comp_Code TEXT(50) (FK)
Part_Name TEXT(50) (IE)
WO_Number TEXT(50) (FK) (IE)
Building System
Build_System_Code TEXT(12)
ID LONG
Building_System TEXT(50)
Type TEXT(50)
Description TEXT(120)
Design parameters TEXT(50)
Loc_Code TEXT(50) (FK) (IE)
Wo_ReplacePart
Part_Code TEXT(50) (FK)
WO_Number TEXT(50) (FK) (IE)
Document
Document_ID TEXT(50)
Doc_type TEXT(234)
Doc_Description1 TEXT(250)
Doc_Symmary MEMO
Equipment_Code TEXT(50) (IE)
Project_ID TEXT(50) (IE)
Doc_Description2 TEXT(250)
Doc_Description3 TEXT(50)
Date_Complited DATE
Consultant_involved TEXT(50)
Alternative OBJECT
Chart OBJECT
Component
Equip_Code TEXT(50) (FK)
Component_Code TEXT(50)
ID LONG (AK)
Component_Type TEXT(50)
Technical_Data TEXT(250)
Picture OBJECT
DWG OBJECT
Notes TEXT(50)
Date_Replaced DATE
Cost_Replaced CURRENCY
Warranty TEXT(50)
Comp_SerialNumber TEXT(50)
Eq_Code TEXT(50) (IE)
Comp_Code TEXT(50) (IE)
Replace_Part
Part_Code TEXT(50)
Equip_Code TEXT(50) (FK) (IE)
Comp_Code TEXT(50) (FK) (IE)
Part_Name TEXT(50) (IE)
Serial_number TEXT(50)
Manufacturer TEXT(50)
Date_Replaced DATE
Cost_replaced CURRENCY
Number_Replaced LONG (IE)
Technical_Data TEXT(50)
Replacement_Procedure TEXT(50)
Picture OBJECT
DWG OBJECT
Notes MEMO
Warranty TEXT(50)
Maintenance
ID LONG
Equip_Code TEXT(50) (FK) (IE)
Comp_Code TEXT(50) (FK) (IE)
Cleaning TEXT(50)
Seasonal_Servicing TEXT(50)
Repair_Notes TEXT(50)
Evacuation TEXT(50)
Routine_Maintenance TEXT(50)

Properties

Date Created	10/15/99 2:20:15 AM	Def. Updatab	True
Last Updated	10/4/99 11:17:26 AM	OrderByOn:	False
RecordCount:	3		

Columns

Name	Type	Size
ID	Number (Long)	4

AllowZeroLength:	False
Attributes:	Fixed Size, Auto-Increment
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	1
ColumnWidth:	Default
Description:	building system number
Ordinal Position:	1
Required:	False
Source Field:	ID
Source Table:	Building System

Name	Type	Size
Build_System_Code	Text	12

AllowZeroLength:	False
Attributes:	Variable Length
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	2580
Description:	system code e.g. SH-CT-5001: Campus,Building, System Specific Number identifier
DisplayControl:	Text Box
Ordinal Position:	2

	Required:	True	
	Source Field:	Build_System_Code	
	Source Table:	Building System	
Building_System		Text	50
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	2430	
	Description:	name of the system: Electrical, plumbing, HVAC	
	DisplayControl:	Text Box	
	Ordinal Position:	3	
	Required:	True	
	Source Field:	Building_System	
	Source Table:	Building System	
Type		Text	50
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	1950	
	Description:	elec, mechanical	
	DisplayControl:	Text Box	
	Ordinal Position:	4	
	Required:	True	
	Source Field:	Type	
	Source Table:	Building System	
Description		Text	120
	AllowZeroLengt	False	

	h:		
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	2190	
	Description:	description of the system	
	DisplayControl:	Text Box	
	Ordinal Position:	5	
	Required:	False	
	Source Field:	Description	
	Source Table:	Building System	
Design parameters		Text	50
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	2010	
	Description:	desing paramenters	
	DisplayControl:	Text Box	
	Ordinal Position:	6	
	Required:	False	
	Source Field:	Design parameters	
	Source Table:	Building System	
Loc_Code		Text	50
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	

Description:	location code
DisplayControl:	Text Box
Ordinal Position:	7
Required:	False
Source Field:	Loc_Code
Source Table:	Building System

Relationships

Building SystemEquipment

uilding System		Equipment
Build_System_	—	Build_System_ Code

Attributes:	Not Enforced
Attributes:	One-To-Many

LocationBuilding System

Location		uilding System
Building_Code	—	Loc_Code

Attributes:	Not Enforced
Attributes:	One-To-Many

Table Indexes

Name	Number of
Build_System_Code	1
Clustered:	False
Distinct Count	3
Foreign:	False
Ignore Nulls:	False
Name:	Build_System_Code
Primary:	False
Required:	False
Unique:	True
Fields:	Build_System_Code, Ascending
Loc_Code	1
Clustered:	False

Distinct Count	2
Foreign:	False
Ignore Nulls:	False
Name:	Loc_Code
Primary:	False
Required:	False
Unique:	False
Fields:	Loc_Code, Ascending

PrimaryKey	1
Clustered:	False
Distinct Count	3
Foreign:	False
Ignore Nulls:	False
Name:	PrimaryKey
Primary:	True
Required:	True
Unique:	True
Fields:	Build_System_Code, Ascending

User Permissions

add
admin

Group Permissions

Admins
Users

Properties

Date Created	10/26/99 11:20:28 AM	Def. Updatab	True
Last Updated	10/16/99 9:01:58 PM	OrderByOn:	True
RecordCount:	2		

Columns

Name	Type	Size
ID	Number (Long)	4

AllowZeroLength:	False
Attributes:	Fixed Size, Auto-Increment
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
Ordinal Position:	1
Required:	False
Source Field:	ID
Source Table:	Equipment

Name	Type	Size
Equip_Code	Text	50

AllowZeroLength:	False
Attributes:	Variable Length
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
DisplayControl:	Text Box
Ordinal Position:	2
Required:	False
Source Field:	Equip_Code
Source Table:	Equipment

Asset_ID		Number (Long)	4
	AllowZeroLength:	False	
	Attributes:	Fixed Size	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Decimal Places:	Auto	
	Default Value:	0	
	Description:	FK from Asset table	
	DisplayControl:	Text Box	
	Ordinal Position:	3	
	Required:	False	
	Source Field:	Asset_ID	
	Source Table:	Equipment	
Equip_Name		Text	125
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	DisplayControl:	Text Box	
	Ordinal Position:	4	
	Required:	False	
	Source Field:	Equip_Name	
	Source Table:	Equipment	
Type		Text	127
	AllowZeroLength:	False	
	Attributes:	Variable Length	

	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	3930	
	DisplayControl:	Text Box	
	Ordinal Position:	5	
	Required:	False	
	Source Field:	Type	
	Source Table:	Equipment	
Picture		OLE Object	-
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Ordinal Position:	6	
	Required:	False	
	Source Field:	Picture	
	Source Table:	Equipment	
Warranty		Text	50
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	DisplayControl:	Text Box	
	Ordinal Position:	7	
	Required:	False	
	Source Field:	Warranty	

Source Table:	Equipment

Useful_Life	Number (Long)	4

AllowZeroLength:	False
Attributes:	Fixed Size
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
Decimal Places:	Auto
Default Value:	0
Description:	manufacturer expected useful life
DisplayControl:	Text Box
Ordinal Position:	8
Required:	False
Source Field:	Useful_Life
Source Table:	Equipment

Date_Installed	Date/Time	8

AllowZeroLength:	False
Attributes:	Fixed Size
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
Description:	date installed or replaced
Ordinal Position:	9
Required:	False
Source Field:	Date_Installed
Source Table:	Equipment

Manufacturer	Text	50

AllowZeroLength:	False

Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		
ColumnWidth:	Default		
DisplayControl:	Text Box		
Ordinal Position:	10		
Required:	False		
Source Field:	Manufacturer		
Source Table:	Equipment		

Series_Model		Text	50
AllowZeroLength:	False		
Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		
ColumnWidth:	Default		
Description:	Model /series escription;PEH/Phh 050		
DisplayControl:	Text Box		
Ordinal Position:	11		
Required:	False		
Source Field:	Series_Model		
Source Table:	Equipment		

Equip_number		Text	50
AllowZeroLength:	False		
Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		
ColumnWidth:	Default		
Description:	Manufac. Equipment serial number		

DisplayControl:	Text Box		
Ordinal Position:	12		
Required:	False		
Source Field:	Equip_number		
Source Table:	Equipment		
Tech_Data		Text	240
AllowZeroLength:	False		
Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		
ColumnWidth:	3630		
DisplayControl:	Text Box		
Ordinal Position:	13		
Required:	False		
Source Field:	Tech_Data		
Source Table:	Equipment		
DWG		OLE Object	-
AllowZeroLength:	False		
Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		
ColumnWidth:	Default		
Ordinal Position:	14		
Required:	False		
Source Field:	DWG		
Source Table:	Equipment		
Diagrams		OLE Object	-
AllowZeroLengt	False		

h:	
Attributes:	Variable Length
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
Ordinal Position:	15
Required:	False
Source Field:	Diagrams
Source Table:	Equipment

Instalation_Notes OLE Object -

AllowZeroLength:	False
Attributes:	Variable Length
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
Ordinal Position:	16
Required:	False
Source Field:	Instalation_Notes
Source Table:	Equipment

Routine_Main_Notes OLE Object -

AllowZeroLength:	False
Attributes:	Variable Length
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
Ordinal Position:	17
Required:	False
Source Field:	Routine_Main_Notes
Source Table:	Equipment

Servicing		OLE Object	-
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Description:	cleaning procedures	
	Ordinal Position:	18	
	Required:	False	
	Source Field:	Servicing	
	Source Table:	Equipment	
Seasonal_Servising		OLE Object	-
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Description:	annual shutdown procedures	
	Ordinal Position:	19	
	Required:	False	
	Source Field:	Seasonal_Servising	
	Source Table:	Equipment	
Repair_Notes		OLE Object	-
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Ordinal Position:	20	

Required:	False		
Source Field:	Repair_Notes		
Source Table:	Equipment		

Charts		OLE Object	-
AllowZeroLength:	False		
Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		
ColumnWidth:	Default		
Ordinal Position:	21		
Required:	False		
Source Field:	Charts		
Source Table:	Equipment		

Predictive_Test		OLE Object	-
AllowZeroLength:	False		
Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		
ColumnWidth:	Default		
Description:	predictive test task descriptopn		
Ordinal Position:	22		
Required:	False		
Source Field:	Predictive_Test		
Source Table:	Equipment		

Notes		Text	50
AllowZeroLength:	False		
Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		

	ColumnWidth:	Default	
	DisplayControl:	Text Box	
	Ordinal Position:	23	
	Required:	False	
	Source Field:	Notes	
	Source Table:	Equipment	
Build_System_Code		Text	50
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	DisplayControl:	Text Box	
	Ordinal Position:	24	
	Required:	True	
	Source Field:	Build_System_Code	
	Source Table:	Equipment	
Location		Text	50
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Description:	equipment location, floor, room#, wing	
	DisplayControl:	Text Box	
	Ordinal Position:	25	
	Required:	False	
	Source Field:	Location	

	Source Table:	Equipment	
Location_DWG		OLE Object	-
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Description:	dwg regarding equipment room placement.	
	Ordinal Position:	26	
	Required:	False	
	Source Field:	Location_DWG	
	Source Table:	Equipment	
Description		Text	248
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Description:	description notes	
	DisplayControl:	Text Box	
	Ordinal Position:	27	
	Required:	False	
	Source Field:	Description	
	Source Table:	Equipment	
Design_Parameters		Text	50
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	

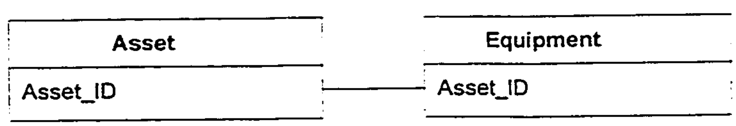
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	2100
Description:	equipment design data
DisplayControl:	Text Box
Ordinal Position:	28
Required:	False
Source Field:	Design_Parameters
Source Table:	Equipment

Design_Notes Text 50

AllowZeroLength:	False
Attributes:	Variable Length
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
Description:	equipment design notes
DisplayControl:	Text Box
Ordinal Position:	29
Required:	False
Source Field:	Design_Notes
Source Table:	Equipment

<u>Relationships</u>

AssetEquipment



Attributes:	Not Enforced
Attributes:	One-To-Many

Building SystemEquipment

uilding System		Equipment
Build_System_	—	Build_System_ Code

Attributes: Not Enforced
Attributes: One-To-Many

EquipmentComponent

Equipment		Component
Equip_Code	—	Equip_Code

Attributes: Not Enforced
Attributes: One-To-Many

EquipmentPreventive_Maintenence_Calendar

Equipment		tenence_Calendar
Equip_Code	—	Equip_Code

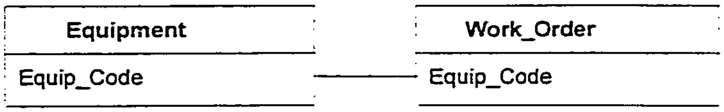
Attributes: Not Enforced
Attributes: One-To-Many

EquipmentProject

Equipment		Project
Equip_Code	—	Equip_Code

Attributes: Not Enforced
Attributes: One-To-Many

EquipmentWork_Order



Attributes:	Not Enforced
Attributes:	One-To-Many

Table Indexes

Name		Number of
Asset_ID		1
Clustered:	False	
Distinct Count	1	
Foreign:	False	
Ignore Nulls:	False	
Name:	Asset_ID	
Primary:	False	
Required:	False	
Unique:	False	
Fields:	Asset_ID, Ascending	
Buil_System_Code		1
Clustered:	False	
Distinct Count	1	
Foreign:	False	
Ignore Nulls:	False	
Name:	Buil_System_Code	
Primary:	False	
Required:	False	
Unique:	False	
Fields:	Build_System_Code, Ascending	
Equip_Code		1
Clustered:	False	
Distinct Count	5	
Foreign:	False	
Ignore Nulls:	False	
Name:	Equip_Code	
Primary:	False	
Required:	False	
Unique:	False	
Fields:	Equip_Code, Ascending	
ID		1
Clustered:	False	
Distinct Count	2	
Foreign:	False	
Ignore Nulls:	False	

Name:	ID
Primary:	False
Required:	False
Unique:	True
Fields:	ID, Ascending
PrimaryKey	1
Clustered:	False
Distinct Count	2
Foreign:	False
Ignore Nulls:	False
Name:	PrimaryKey
Primary:	True
Required:	True
Unique:	True
Fields:	Equip_Code, Ascending

User Permissions

add
admin

Group Permissions

Admins
Users

Properties

Date Created	10/16/99 10:03:26 PM	Def. Updatab	True
Last Updated	10/16/99 10:45:34 PM	MaxRecords:	0
ODBCTimeout:	60	OrderByOn:	False
Record Locks	No Locks	Records Affe	0
RecordsetTyp	All Records	ReturnsRecor	True
Type:	Select		

SQL

```
SELECT Equipment.Equip_Code, Equipment.Equip_Name,
Equipment.Picture, WO_Report.SumOfTotal_Cost,
WO_Report.Expr1
FROM Equipment INNER JOIN WO_Report ON
Equipment.Equip_Code = WO_Report.Equip_Code
WHERE (((WO_Report.Expr1)=1996));
```

Columns

Name		Type	Size
Equip_Code		Text	50
AllowZeroLength:	False		
Attributes:	Variable Length		
Collating Order:	General		
ColumnHidden:	False		
ColumnOrder:	Default		
ColumnWidth:	Default		
DisplayControl:	Text Box		
Ordinal Position:	0		
Required:	False		
Source Field:	Equip_Code		
Source Table:	Equipment		
Equip_Name		Text	125
AllowZeroLength:	False		
Attributes:	Variable Length		

	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	DisplayControl:	Text Box	
	Ordinal Position:	1	
	Required:	False	
	Source Field:	Equip_Name	
	Source Table:	Equipment	
Picture		OLE Object	N/A
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	Default	
	Ordinal Position:	2	
	Required:	False	
	Source Field:	Picture	
	Source Table:	Equipment	
SumOfTotal_Cost		Currency	8
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnWidth:	3210	
	Ordinal Position:	3	
	Required:	False	
Expr1		Number (Intege	2
	AllowZeroLengt	False	

h:	
Attributes:	Variable Length
Collating Order:	General
Ordinal Position:	4
Required:	False

Table Indexes

Name	Number of
Asset_ID	1
Clustered:	False
Distinct Count	1
Foreign:	False
Ignore Nulls:	False
Name:	Asset_ID
Primary:	False
Required:	False
Unique:	False
Fields:	Asset_ID, Ascending
Buil_System_Code	1
Clustered:	False
Distinct Count	1
Foreign:	False
Ignore Nulls:	False
Name:	Buil_System_Code
Primary:	False
Required:	False
Unique:	False
Fields:	Build_System_Code, Ascending
Equip_Code	1
Clustered:	False
Distinct Count	5
Foreign:	False
Ignore Nulls:	False
Name:	Equip_Code
Primary:	False
Required:	False
Unique:	False
Fields:	Equip_Code, Ascending
ID	1
Clustered:	False
Distinct Count	2
Foreign:	False
Ignore Nulls:	False
Name:	ID
Primary:	False

Required:	False
Unique:	True
Fields:	ID, Ascending
PrimaryKey	1
Clustered:	False
Distinct Count	2
Foreign:	False
Ignore Nulls:	False
Name:	PrimaryKey
Primary:	True
Required:	True
Unique:	True
Fields:	Equip_Code, Ascending

User Permissions

add

admin

Group Permissions

Admins

Users