6-2018

An Integrated Decision Support Framework for Life-Cycle Building Asset Management

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AN INTEGRATED DECISION SUPPORT FRAMEWORK FOR LIFE-CYCLE BUILDING ASSET MANAGEMENT

by

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A dissertation submitted to the Graduate College
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
Civil and Construction Engineering
Western Michigan University
June 2018

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Building assets are essential to the economic, cultural, and historical growth of any nation. Examples of buildings include shelters, entertainment facilities, living spaces, teaching facilities, civil offices, parking structures, police buildings, libraries, and service areas used to accommodate human activity. Deterioration of building assets, inadequate renewal budgets, climbing deficits, and increasing demand levels are difficulties that face owners when managing building assets. The role of asset management has recently become significant in municipal governments for strategic, operational, and financial reasons. The main functions of an asset management system include assessment of the current condition, prediction of future deterioration, asset prioritization, selection of maintenance and repair strategies, and fund allocation. Many research efforts have been mostly focused on managing a few infrastructure asset types such as bridges, pavements, and underground utilities while neglecting building assets. However, properly managing building assets cannot be ignored as they suffer over time serious problems including deterioration, premature failures, and possibly the need for replacement. Additionally, the scarcity of and increasing demand for building materials, shortages of land and energy, and limited resources add to the need for effective building asset management.

There are numerous types of assets that must be analyzed and categorized, presenting difficulties in the development of a universal management system for the different types of

buildings. Each building type is complex with unique characteristics and numerous components that have different maintenance needs and requirements. Additionally, existing standard building classification systems lack specific requirements for effective building asset management such as asset location and asset attributes including condition and deterioration rates. These standard systems have priorities that are mostly focused on estimating costs during the design and construction phases, and do not necessarily align well with the needs of asset management. Consequently, an effective data-driven decision-making process is critical for proactively maintaining and ensuring the long-term sustainability of building assets. Defining asset management requirements in the early project stages and facilitating the integration of asset data collected during design and construction with building asset information are critical issues that must be addressed. Early efforts in data integration have focused on the design and construction phases without considering asset management requirements and processes. Therefore, the goal of the research effort in this dissertation is to develop a comprehensive framework for building asset management that will facilitate the integration of all life cycle phases. An automated decision support system for building asset management using building information modeling (BIM) and relational database management systems (DBMS) was developed. The system consists of a new building asset inventory model that is based on the work breakdown structure (WBS) principles, a multi-phase condition rating method, and a building asset DBMS that is integrated with the BIM model.

The main contributions of this research include 1) developing a framework for asset management that integrates all life cycle phases of buildings; 2) eliminating duplicate data collection efforts and data redundancy, 3) improving the quality, integrity and timeliness of asset information; and 4) enhancing building asset performance through proactive maintenance or replacement decision making processes. The results and findings of this study could be the starting point for extensive work related to 1) as-built data that is needed for building asset management; 2) integrating the BIM-DBMS asset management with geographic information systems (GIS) to improve certain asset tracking such as underground utilities; and 3) examining the applicability of the proposed framework on other types of municipal assets such as roads, and bridges.

Dedicated to my beloved father Dr. Reda Alkasasbeh and mother Sabah Almani.

ACKNOWLEDGEMENTS

First of all, I sincerely thank my parents, sisters, and brothers. This journey would not have been possible without their support. Thank you for encouraging me in all of my pursuits and inspiring me to follow my dreams. I am especially grateful to my father Dr. Reda alkasasbeh who never let things get dull or boring he has made a tremendous contribution in helping me reach this stage in my life. I thank him for putting up with me in difficult moments where I felt stumped and for goading me on to follow my dream of getting this degree. This would not have been possible without his unwavering and unselfish love and support given to me at all times. I also would like to dedicate this work to my mother Mrs. Sabah Almani whose dreams for me have resulted in this achievement and without her loving upbringing and nurturing; I would not have been where I am today and what I am today. Many thanks my great mam.

There are no proper words to convey my deep gratitude and respect for my dissertation and research advisor professor Osama Abudayyeh. He has inspired me to become an independent researcher and has helped me realize the power of critical reasoning. He also demonstrated what a brilliant and hard-working scientist can accomplish. My sincere thanks also go to the members of my dissertation committee. They generously gave their time to offer me valuable comments toward improving my work.

To all my friends thank you for your understanding and encouragement, your friendship makes my life a wonderful experience. I cannot list names, but you are always on my mind. Also, I am so grateful to the Hashemite university for the scholarship opportunity and making it possible for me to complete my Ph.D.

Maha Reda Alkasisbeh

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CHAPTER I

INTRODUCTION

Buildings are essential to the economic, cultural, and historical growth of any nation some examples of buildings include shelters, entertainment facilities, living spaces, teaching facilities, civil offices, parking structures, police buildings, libraries, and service areas used to accommodate human activity. However, with age, exposure to severe conditions, and insufficient capacity to serve population growth, buildings deteriorate and become a source of pollution. Deterioration of building assets, inadequate renewal budgets, climbing deficits, and increasing demand levels are difficulties that face owners when managing building assets. Recently asset building management has become a significant area of focus in municipal governments for strategic, operational, and financial reasons. Building asset management is a strategic and systematic process for effectively operating, maintaining, upgrading, and expanding physical assets throughout their life-cycle. It is a proactive process that consists of maintaining a systematic record of individual assets that includes acquisition costs, original and remaining useful life, physical condition, and cost history of maintenance. However, effective asset management is more than maintenance as it also helps to achieve the required level of service while minimizing costs and reducing risk over an asset's life-cycle. Essentially, asset management can lead to better operational decisions, improved emergency response, greater ability to plan and pay for future repairs and replacements, increased knowledge of the location of the assets, and the ability to identify critical assets in a facility. Therefore, properly designed building asset management systems that enhance the methods of collecting and organizing data as well as improve asset management functions are needed to effectively plan and optimize the operation and maintenance of these assets.

Asset management as a concept has been around forever, and continues to evolve due to changes in attitudes, technology, and the needs of asset managers. Building asset management presents unique challenges defining what assets should be included and assessing condition and prediction the deterioration. Implementation of an asset management system is often confounded by the many schools of thought and priorities of the institution charged with managing the asset. Understanding the need for asset management and knowing the benefits that result from applying an asset management system are the main reasons behind the movement toward better asset management in the United States and around the world. In addition, asset management is already widely accepted in the private sector worldwide and has been practiced since the mid-1990s by transportation agencies in the United Kingdom, Australia, and New Zealand.

There is a strong need to increase efforts to develop a more holistic approach to asset management in different agencies, improving the techniques that are used to collect, store, analyze data, implement automation in asset management systems, develop intelligent management of assets, visualize assets for better management, and integrate asset management with building information modeling (BIM) (Flintsch 2006, Sarfi 2012, Pedicini 2014, Meng nd, Sowah 2014, Terreno 2015).

Problem Statement and Significance

A successful functioning society relies on infrastructure assets that are owned mainly by municipalities. These assets include basic facilities, services, and other necessary installations. These infrastructure management systems include a wide range of assets that touch almost every aspect of our daily lives. Such assets include buildings, utilities, pavement, bridges, communication systems, roads, tunnels, equipment, railroads, and distribution pipelines. However, there are many challenges facing the organizations charged with managing these assets. These issues arise from such factors as the large size of facilities, their complex nature, high costs, and other institutional factors such as inadequate management (Ahluwalia 2008).

Critical buildings are an essential part of the municipal infrastructure management system. These include shelters (including multi-use spaces), entertainment facilities, living spaces, civil offices, public work yards, civil service buildings including police and fire protection, libraries, and service areas to accommodate human activity. Many studies have emphasized the need for properly managing buildings to continue to operate in efficient and safe manner. In this regard, Eweda stated (Eweda 2010):

> "Building facilities are a major part of urban infrastructure, as they provide shelter, living space, and service areas to accommodate human activity. Despite their great economic, cultural and historical importance, many studies have shown that buildings are sick, deteriorating and considered to be a major source of pollution."

Many research efforts and approaches have mostly focused on managing few infrastructure asset types such as bridges, pavements, and underground utilities. However, there are many challenges in applying asset management methodologies to buildings. In this regards Grussing stated (Grussing 2014):

> "Although asset management methodologies and tools related to the civil infrastructure domain have existed for decades, there are many challenges in applying these same techniques to buildings."

On other hand, building asset management is necessary to increase the service life of buildings. This important function cannot be ignored because buildings will suffer serious problems including deterioration, premature failures and renewals, and possibly the need for replacement. Additionally, challenges from scarcity of and increasing demand for building materials, shortages of land and energy, and limited resources, add to the need for a consistent building asset management system. In this regard, Grussing stated **(**Grussing 2014):

> "Numerous influences, however, are creating greater awareness of the need for structured building life cycle management similar to other civil infrastructure classes. One such influence is the rapid expansion of developing world economies and infrastructure, which is raising the demand for basic commodities such as concrete, steel, wood, and copper."

Also, Eweda said (Eweda 2010):

> "Lack of funds and mismanagement are the principle reasons for the unsatisfactory performance of building facilities. Maintaining a building is essential to keep it performing and functioning for a longer period of time".

There is a serious need to implement more efficient, sustainable, and proactive asset management strategies to improve the management of buildings. Deterioration of building assets, inadequate renewal budgets and climbing deficits, and increasing demand levels are difficulties that municipalities face when managing building assets. The challenge in applying proper asset management methodologies for buildings mainly lies in their varied categories, types, complexities, and uses (Eweda 2010, Grussing 2014, Ahluwalia 2008, Pantelias 2005). In this regard, Ahluwalia stated (Ahluwalia 2010).:

> "Maintenance for buildings is a complex task largely due to the complexity of buildings in terms of their large number of components that have different maintenance requirements."

Also, one of the main challenges in applying asset management strategies to buildings is the timely availability of quality asset information, which partly comes from as-built data generated during the design and construction phases and partly relies on the condition assessment data collected throughout the operation and maintenance phase of a facility. This challenge is further complicated by the lack of integration between these phases of the life-cycle of a building, making information flow more difficult and ineffective. A second challenge lies in the fact that there are numerous types of assets that must be analyzed and categorized, which may present difficulties in the development of a consistent management system for the different types of building assets since each building type is complex with unique characteristics and has numerous components with different maintenance needs and requirements. A third challenge in existing building asset management systems is that they mostly use standard building classifications for categorizing and analyzing assets. However, these standard systems were designed without taking into consideration asset management needs such as asset location and asset attributes including condition and deterioration rate. In addition, existing standard building classification systems lack specific requirements for effective building asset management such as asset location and asset attributes including condition and deterioration rates. Additionally, these standard systems have priorities that are mostly focused on estimating costs during the design and construction phases, and do not necessarily align well with the needs of asset management.

Additionally, many of the previous building research efforts have focused on design/construction integration without consideration of the operation and maintenance phases (asset management). However, many other infrastructure assets research efforts have focused on life-cycle data to support decision making in asset management. In this regard Yuan stated (Yuan 2017):

> "State highway agencies (SHAs) typically wait to inventory their assets according to their locations, dimensions, and material types and properties after they are constructed and open to traffic. However, the construction phase is the best time to collect asset data because access is easier and safer, and more importantly, the data needed for operation and maintenance (O&M) inventory already are being collected during the construction inspection and documentation process."

Also, Yuan said (Yuan 2016):

> "Accurate and complete construction records and as-built data are key prerequisites to the effective management of transportation infrastructure assets throughout their life cycle. The construction phase is the best time to collect such data."

So, there is a serious need to implement a life cycle approach in building asset management to integrate the asset data collected during design and construction with building asset management information. There are other infrastructure asset management research efforts have discussed the integrating of life-cycle data while using diverse software applications. Since using diverse software applications led to inconsistencies of levels of detail, data syntax and semantic. These research goals is to develop an ontology that enables unification and interconnection between software applications to integrate the life cycle data. In this regard Le stated that (Le 2016).

> "The implementation of diverse software applications imposes big challenges for integrating life-cycle data to support decision making in highway asset management due to the potential inconsistencies of levels of detail, data syntax and semantics."

Some researchers have suggested using Building Information Modeling (BIM) for asset management functions. It is an information-rich model with large volumes of asset data that are a prerequisite for an effective operation and maintenance phase. Such data include materials and assemblies that were used in the building, construction means and methods, and location of building components. (Lee 2015). Also, BIM uses an Industry Foundation Classes (IFC) format which is an open source format and official international standard. In addition, IFC adds a common language for transferring that information between different BIM software applications while maintaining the meaning of different pieces of information in the transfer. This reduces the need of remodeling the same building in each different application. However, the use of BIM in asset management is relatively new and researchers have identified several challenges including the lack of technical alignment between BIM software tools and asset management processes and functions as well as the integration between project phases (Terreno 2015, Mehmet 2011, Yan 2008, Talebi 2014, Ghosh 2015). In this regard Terreno stated (Terreno 2015):

> "BIM Adaptation and implementation challenges include lack of technical alignment between BIM software tools and FM processes and lack of integration between project phases."

Also, Talebi stated that (Talebi 2014):

> "BIM software tools presently are not applicable or 'ready packed' to fit the asset management processes. In other words, number of BIM tools supporting asset management processes by far is fewer than tools supporting design stage. This issue causes ineffective administrative work routines and gives restricted support to the crew onsite. Lack of technology

> alignment also leads to a digital divide between the design and
> other stages."

Also, attempting to add the time factor to 3D models when developing a construction schedule in current BIM platforms can be a challenge as it creates a discrepancy between the standard built-in classification systems and the need for developing tasks on a work breakdown structure (WBS) (Park 2016).

However, there is a need to address the conceptual integration of all phases in the life-cycle, so the information can flow better during the lifecycle. Therefore, the purpose of this research effort is to develop a comprehensive framework for building asset management that will facilitate the integration of all life cycle phases and become the basis for the development of a decision support system for asset management using BIM and database management systems (DBMS).

Research Goals and Objectives

The main goals of this research are to develop a comprehensive framework for building asset management that facilitates the integration of all life cycle phases, and to develop an automated decision support system for asset management. To achieve these goals, the following objectives will be pursued:

- Investigate existing municipality assets and their categories.
- Investigate exiting standard building classification systems.
- Develop a building asset management model that allows information integration between the various phases in the lifecycle.
- Develop an automated decision support system that uses an integrated BIM-DBMS as a platform.
- Validate the model and its integration with BIM system using a case study.

CHAPTEER II

LITERATURE REVIEW

This chapter presents a review of efforts described in building asset management systems.

Identification of Municipal Assets

The most fundamental step in an asset management system is to identify every asset. If the mangers in municipalities do not know what the assets of the city are, it is very hard to manage the system effectively, same for universities. Although what the city owns is seemingly straightforward to know, the reality is much different. The difficulties come from several factors: some of the assets are underground or otherwise hidden; assets are usually installed at different time periods over a long time; sometimes asset records are old, inaccurate, or missing; and changes in management may cause problems in the historical knowledge of the asset system. It is important to improve the program that develops the asset database, collecting data and data inventory over long time periods. (Alex 2014, EFCNMT 2006)

Assets generally are divided into government service assets and commercial assets. Government service assets are the assets provided by the government to provide services to the city (for example). They can be managed directly or indirectly for the benefit of their constituents and in order to attain any local service goals. They can involve public parking areas, government administrative buildings, police stations, health centers, water provision, parks, roads, transport terminals, pavement, river margins, etc.

Commercial assets are the assets that are leased or sold for commercial works such as sports facilities buildings, commercial offices, market properties, parking properties, and commercial spaces in transport terminal buildings. These are a different municipality asset type that depends on many factors related to national and local regulations and requirements. (Alex 2014, RTI 2006).

> "The classification of property and use will depend on the practices, traditions, laws and regulations governing the particular municipal government jurisdiction" (RTI 2006).

Classification of Municipal Assets – Cases studies

Municipalities are custodians of huge amounts of public assets including land, buildings, infrastructure, plants, and equipment that have been procured through public resources. Most cities have similar assets; the following are some examples of cities and universities and the assets that they are responsible for managing along with their explanation.

Edmonton, AB, Canada

Managers of Edmonton, the capital of Alberta, Canada, realize the need for improving Edmonton assets spatially when they take into consideration population and economic growth. Many of Edmonton's assets were built between 1950 and 1970, so, the average age of Edmonton's assets is over 30 years with most assets having an average life of approximately 50 years. Because of these reasons a study of the city's assets was performed. This study classified Edmonton's assets as follows:

- Drainage class,
- Road right-of-way,
- Parkland,
- Transmitting facilities and equipment,
- Buildings,
- Fleet,
- Traffic control and lighting,
- Entertainment facilities,
- Affordable housing,
- Waste management facilities,
- Technology equipment and others.

The drainage class includes sanitary and storm sewers, along with wastewater treatment. Road right-of-way includes all arterial, collectors, and local roads, curbs and gutters, sidewalks, bridges, gates, and streetscapes. Parkland includes gardens, trails, hard surfaces, playgrounds, sports fields, parks and climbing gyms. Transmitting facilities and equipment includes transit centers, bus equipment and systems, and the trolley system. Buildings include civil offices, public work yards, emergency response, police buildings, and libraries. Fleet includes transit buses, city vehicles, and automotive shop equipment. Traffic control and lighting includes traffic signals, signs, street lighting, and parking meters. Entertainment facilities include arenas, leisure centers, swimming pools, Fort Edmonton Park (a living history museum), and zoos. Affordable housing includes non-profit housing, like community housing and senior living centers. Waste management facilities include administrative facilities, transfer stations, processing facilities, and landfill operations. Technology equipment is an intangible asset that includes servers, networks, and all communication equipment. In addition, there are other assets that include emergency response equipment, police equipment, and library contents (Edmonton 2006)

Minnesota (State), Hamilton, Ontario (city), Laredo, Texas (City), New Mexico (State)

The State of Minnesota, City of Hamilton, Ontario, Laredo, Texas, the State of New Mexico and many other cities and states provide their local governments with guides and policies to help them understand and implement systems for accounting and financial reporting of assets and to give them procedures to protect and maintenance the assets. In general, they categorized their asset classes in the same way; they are as follows**:**

- Land and land improvement,
- Building,
- Equipment, machinery, vehicles and furniture,
- Library holdings,
- Works of Art and historical treasures,

- Infrastructure, and
- Software

Land is considered any surface of the earth that is owned whether developed or undeveloped. It has a long useful life and can be used to support structures or trees, landscapes, agriculture, and grasses. Land improvements are permanent additions to the land that have limited useful life. Some municipalities consider land improvements as a separate category and give it its own individual record. The assets that are included in the land and improvement category are: landscaping, sprinkler systems, parking lots, driveways, parking barriers, roadways, entertainment, athletic areas, golf courses, swimming pools, tennis courts, fountains, plazas and pavilions, paths and trails, water internment and water supply systems, septic systems, water wells, lighting systems, retaining walls, fencing, and gates.

Buildings are structures that are always joined to the land; buildings must have a roof as one of its parts and be surrounded by walls, buildings cannot be transferred. Municipal buildings include:

- Town halls, storage buildings, libraries, schools, research facilities, classrooms, offices, clinics, and even cemeteries.
- Attached construction to buildings (such as yards, courts, sunrooms, garages, staircases, etc.).
- Entertainment facilities (such as museums, gymnasiums, soccer complexes, and theatres).
- Wall or floor covering (such as carpeting, tiles, paneling, and paints)
- Windows, doors, built-in closets and cabinets, baseboards, light fixtures, ceiling trim, siding, or other interior framing.
- Reinforcement of floors, beams, steel grids, walls, rafters, joists, roofing, and masonry.
- Heating and cooling systems, plumbing, electrical wiring, phone or closed-circuit television systems, networks, fiber optic cables.

- Equipment that will be fixed in a building, along with fixtures or machinery that cannot be removed without damaging some parts of the building.

Equipment, machinery, vehicles and furniture are defined as fixed or movable tangible assets to be used for operations, including automobiles, vans, trucks, trailers, motorcycles and all types of machinery or equipment, except machinery and equipment used in road construction (note: fixed equipment like building lifts or water pumps are part of the asset).

Library holdings are defined as gatherings of books and reference materials that provides information required in the learning process, research, and academic sector. The library holdings category includes: Journals, Periodicals, microforms, audio/visual media, computer-based information, and manuscripts. Works of art and historical treasures includes public research and education collections or items, where the local government does not receive any financial gain from these items. This category includes; rare books, manuscripts, maps, documents, recordings, paintings, sculptures, designs, artifacts, memorabilia, exhibits, and any artwork.

Infrastructure is defined as assets that have long useful lives and are immobile. They are generally retained far longer than other assets. Infrastructure consists of systems of assets, which include: highway roads, paved shoulders, streets, roads, gutters, sidewalks, airport runways, taxi areas, signage, bridges, railroads, trestles, canals, waterways, wharfs, docks, sea walls, bulkheads, boardwalks, dams, drainage facilities, transmitting towers, fire systems, power distribution stations, water and gas, fiber optic and telephone distribution systems, and light systems (traffic, outdoor, street, etc.).

Finally, the last asset class is software, including materials and services. When funds are distributed over capital assets by municipalities, there are other asset classes that are not mentioned but should be taken into consideration. These asset classes include assets under construction, leasehold improvements, and easements.

Assets under construction usually includes works that are incomplete or still in progress such as works in buildings, infrastructure (highways and energy distribution systems) then while these constructions are put into use they will be included in other asset classes, Leasehold Improvements, when a lessor makes improvements on the leased property, which will lead to returning the improvements to the property owner when the lease comes to an end. These improvements may include renovations on existing structures, and the building of new projects on leased property. Easements, which giving limited right to use land that owned by another (DFA 2001, APDOSASM 2002, NM State 2009, City of Laredo 2006, EC 2001, Yigitcanlar 2008).

University Assets

Many universities recognize that asset management is important for recording, inventorying, maintaining, disposing, understanding and adhering to the rules, regulations and procedures governing university assets. Asset management also increases the useful life of university assets, ensures the long-term sustainability of the utility, in addition to achieving better operational decisions, improved emergency response, and to increase the ability to plan and pay for future repairs and replacements. A University of Cincinnati asset management study classified assets that should be tracked in the University of Cincinnati's asset management system (UCAMS) as: Personal property and Real property. Personal property is defined as fixed or movable tangible assets to be used for operations, the benefits of which extend beyond one year from date of acquisition and rendered into service (University of Cincinnati 2013).

Real Property Capital Assets include:

- Land and land improvement
- Buildings
- Building structure
- Floor coverings

- Roof coverings
- Elevators
- Electrical and lighting
- Plumbing
- HVAC
- Exterior walls and construction
- Interior walls and finishing
- Free standing structures (i.e. Pole barns)
- Infrastructure – roads and driveways
- Infrastructure – sewers and tunnels
- Infrastructure - network
- Building equipment and lab fixtures

Personal Property includes:

- Audio-visual and multimedia equipment
- Musical instruments
- Copy equipment (office copiers)
- Office equipment (other than copiers)
- Lab equipment
- Automobiles and Motorcycles
- Trucks, vans, buses, and other licensed vehicles
- Marine boats
- Athletic, recreation equipment
- Telecom equipment
- Radio equipment
- Security equipment
- Printing equipment
- Money handling equipment
- Sewing equipment
- Software
- Furniture

Summary of Asset Classifications

Cities have a large number of tangible and intangible assets; the following is a summary of asset types (tangible and intangible asset) that resulted from this literature review. (Alkasisbeh 2018, DFA 2001, APDOSASM 2002, NM State 2009, City of Laredo 2006, EC 2001, Yigitcanlar 2008).

Table 1 Municipality Tangible Asset Types

Equipment, Machinery, Vehicles and Furniture	Building	Land and Land Improvements
• Automobiles • Snow clearing vehicles • Vans • Trucks • Boiler • Pumps • Lift • Trailers • Motorcycles • Loaders • Cabinets • Desk • Chairs	• All municipal buildings (town halls, storage buildings, symmetries, libraries, schools, office, Clinics, research area and classrooms. • Attachment construction to the building such as yards, courts, sunrooms, garages, staircases, etc • Entertainment facilities such as (museums, gymnasiums, soccer complexes, theatres) • Wall or floor covering such as carpeting, tiles, paneling, and paints • Windows, doors, built-in closets and cabinets • Baseboards, light fixtures, ceiling trim, etc. • Siding, roofing, masonry, etc. • Reinforcement of floors or walls, and beams, rafters, joists, steel grids, or other interior framing • Heating and cooling systems • plumbing and electrical wiring • Phone or closed-circuit television systems, networks, fiber optic cable, wiring needed in the Installation of equipment (that will be fixed in the building) • Fixtures or machinery that cannot be removed without damaging some parts of the building	• Landscaping and System of sprinkler • Parking lots, driveways, parking barriers and roadway, • Entertainment and athletic areas, Golf courts, Swimming pools, tennis courts • Fountains, • Plazas and pavilions • Paths and trails • Water internment and water supply systems, and septic systems • Water well • Lighting systems • Retaining walls • Fencing and gates

Table 2 Municipality Intangible Asset Types

Intelligence	Relational	Intellectual	Social	Symbolic	Organization
• Visualizing and understanding context of identity • Ability to strategies systems, procedures and competencies • Communication intelligence findings of citizens	• Social integration • Cultural integration and tolerance • Political dynamism	• Development of innovation systems • Design, patents, copyrights, intellectual property, commercialization of new knowledge • Strong focus on research and development	• Trust, cooperation, relationship, networks • Soft (social) infrastructure • Cultural heritage and social capacity to transmit knowledge • Civic and citizen participation in decision-making	• Image, identify, reputation, experience • Creativity and innovation capacity • Knowledge and creativity • Capacity to define and legitimize cultural, moral and artistic values, standards and styles	• Institutional capacity • Organization and management capacity • Human resources management capacity

Asset Management in Buildings

Elhakeem (2005) has developed in his research a simple visual approach to support less subjective assessment of the current severities of defects associated with various building components during field inspection. Also, he modified a Markov chain approach using optimization for component-dependent prediction of future severities. As well as he discussed a procedure for determining the least-cost strategy to repair component deficiencies.

Ahluwalia (2008) in his research has introduced a comprehensive building condition assessment framework. The framework has been utilized reactive-maintenance records to predict the condition of components and to prioritize inspection tasks among limited available resources. Also, it has been employed a unique visual guidance system that is based on surveys and field data collection to support uniform condition assessment of building components. Additionally, it has been introduced a location-based inspection process with a standardized building hierarchy.

Grussing (2014) in his paper discussed the goals for asset management including improved building asset performance, better risk management, and lower total ownership costs over the entire life cycle of the asset. The objectives of this paper are to identify the wide array of approaches to building life cycle management, review the benefits and challenges of the current state of practice, and propose a framework for achieving improved facility information for facility decision support. This paper has identified both methods involved in current building life cycle asset management practice, and the challenges and gaps that exist in an optimal investment strategy for existing buildings. In addition, the author has explained how new technologies such BIM are being used in different ways to improve the quality, focus, and efficiency of building information to support decisions, the integration of these diverse approaches and varying sources of disparate information. As well as how this technology will greatly help to improve the state of practice of asset management in the future.

Building Asset Hierarchy Systems

A five-level building hierarchy that includes system, subsystem, component, type or element, and instance levels was proposed by Elhakeem (2005) as shown in Figure 1. The system level includes aggregated systems such as architectural, structural, sitework and mechanical systems. The subsystem level includes components under each system such as the exterior closure under the architectural system and paved surfaces under the sitework system. The component level includes different items in the building under the each of the subsystems such as doors under architectural and boilers under mechanical. The type or element level includes various types of the same component, for example, wooden vs steel windows. Finally, the instance level identifies any various instances of the same component at different locations within the facility or identifies other criteria such as age, deterioration, or historical value.

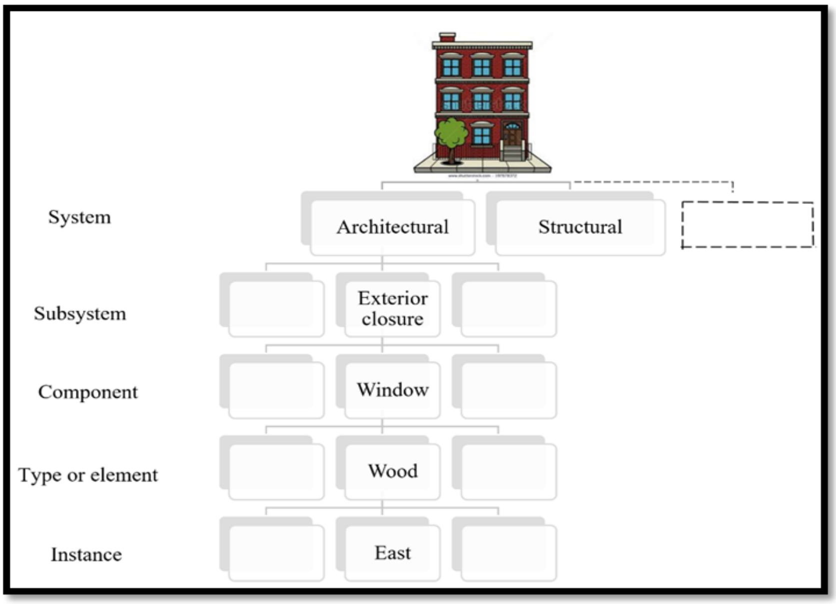

Figure 1. Asset management hierarchy developed by Elhakeem (2005)

Grussing (2014) proposed a hierarchical model that is based on the Uniformat element classification system. Figure 2 illustrates the hierarchy which consists of three levels.

The first level represents general building systems, such as the roofing system. The second level represents the building components, such as roof covering. The third level represents the building sections. The building sections level includes attributes that describe the characteristics of the components including material types and locations, for example, rubber single-3 ply type for roof covering.

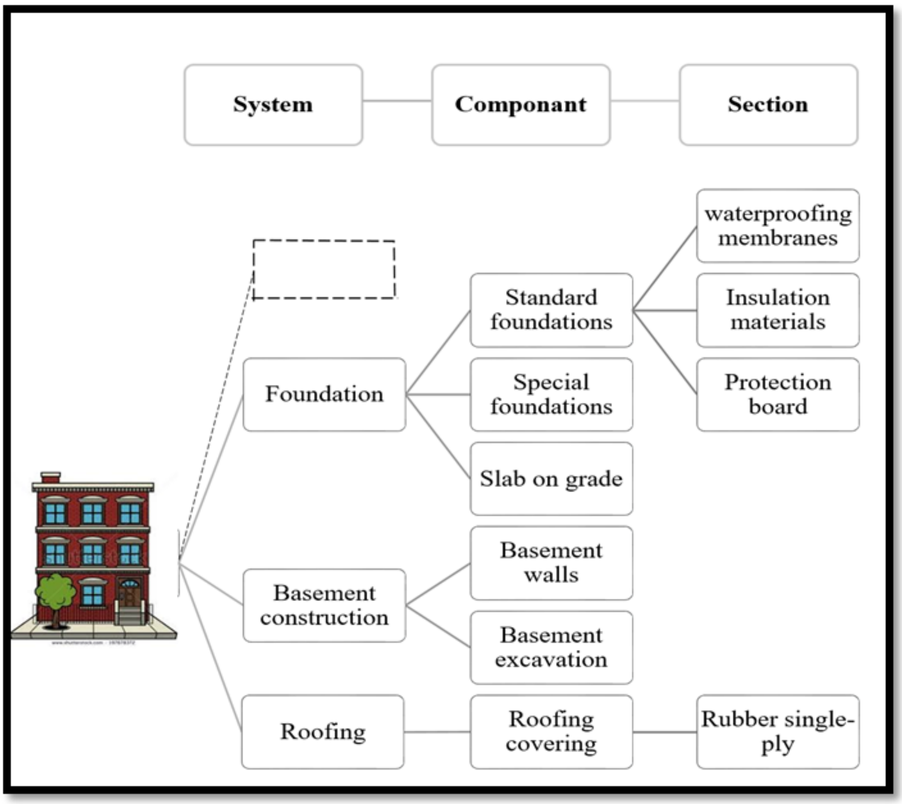

Figure 2. Asset management hierarchy developed by Grussing (2014)

Finally, Eweda (2015) developed a six-level building hierarchy as demonstrated in Figure 3. The first level is the building level that represents the building type. Level two is the space level that includes all the functions inside the building, such as offices or classrooms. Level three represents the category level, which includes the four main building disciplines represented inside the space, such as architectural, mechanical, electrical, and structural. Level four is the family level and includes all the components in the same category that have similar characteristics, such as column under the structural category, and ceiling under the architectural category. Level five is the family type level which includes the different types of components, such as sliding window in the windows family, and curtain wall under wall family. The last level is the family instance level, which includes the properties of individual components, such as white paint exterior wall 14-in. thickness inside the exterior wall family type.

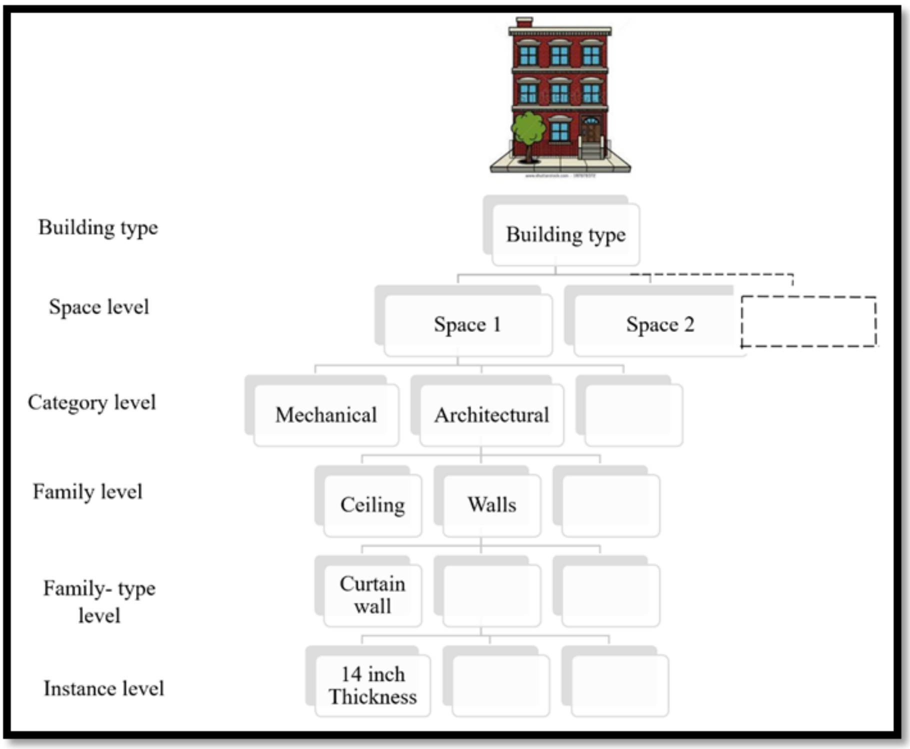

Figure 3. Asset management hierarchy developed by Eweda (2015)

Standard Building Classification Systems

Classification requires standardized and consistent terminology and semantics for the construction industry. Components of an asset can be organized into different classes. These classes have objects with certain properties. Basically, classification is about rearranging data to be converted into information, and after that, into knowledge. Specifications, cost estimation, and organizing building product libraries depend on building classification. In addition, building classification can help in the sharing of data across departments of a construction organization (Lou 2008, Afsari 2016).

The Library Classification System (LCS), is one of the earliest forms of information classification systems, designed to be a simple way for engineers to organize and access information. There are many types of LCS including the Dewey Decimal Classification (DDC), Universal Decimal Classification (UDC) and the Library of Congress Classification (LCC) (Lou 2008). Today, several countries and institutions have developed various classification systems such as the International Organization for Standardization (ISO/DIS) 12006-3, the United Nations Standard Products and Services Code (UNSPSC), the Norwegian Bygg Og Anlegg Referanseninliotek (BARBi), the Swedish Byggandets Samordning AB (BSAB) in Sweden, Uniclass in the UK, DBK in Denmark, and OmniClass and MasterFormat system in North America (Lou 2008, Afsari 2016).

There are main differences among building classification systems. Each system has its own way of classifying construction components. In addition, each classification system can categorize the same classes of objects in different manner. Configuring how the objects should be sorted into classes depend on the purpose of the classification (Afsari 2016).

This study will focus on major classification systems in North America that are used for classifying building objects in building information modeling. These classifications are CSI classifications i.e. OmniClass, MasterFormat, and UniFormat.

The OmniClass Construction Classification System (OCCS) is produced by CSI (Construction Specifications Institute) and CSC (Construction Specifications Canada). OmniClass has been widely used in North America for many years. The purpose of OmniClass is to help in managing project information, sorting and retrieving information, and providing classification for all components and processes within the building life cycle. The most important part of this classification is that it can be used within the national BIM standard in the United States. Many OmniClass tables are used as a basis for other systems such as UniFormat for the elements table, MasterFormat for the work results table, and Electronic Product Information Cooperation (EPIC) for structuring components (Afsari 2016).

OmniClass is a faceted classification that is suitable for control of project information. It has the capability to classify data from many points of view including organizing information and serving participants who work and sustain the built environment throughout the facility life cycle (Afsari 2016). OmniClass uses 15 ISO tables as shown in Figure 4 (CSI 2006).

Within 15 tables, there are tables 21, 22 and 23 used for classification of building products. Table 21 (Elements) is based on UniFormat, Table 22 (Work Results) is based on MasterFormat. Table 23 (Products) is based on EPIC. Each table demonstrates a different facet of building information. In addition, each of them classifies a particular type of information. Any table could be used independently or combined with other tables to classify building object. A combination of these tables in a faceted approach is perfect for classifying the components and their functions accurately.

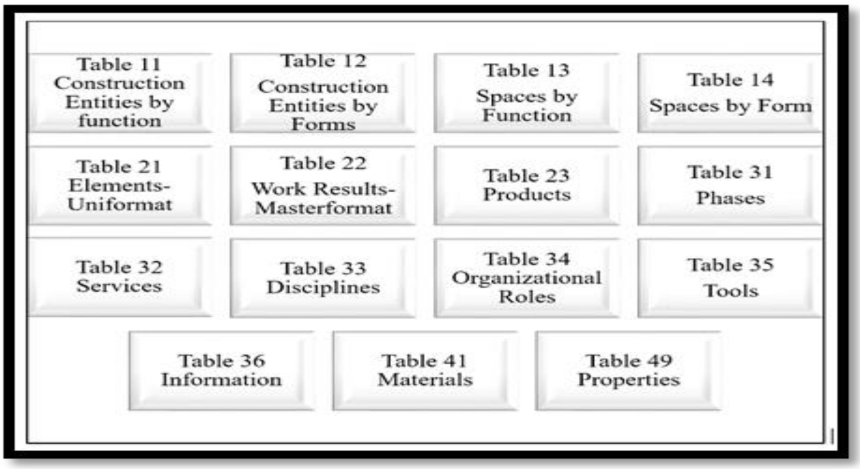

Figure 4. OmniClass tables (CSI 2006)

MasterFormat is a master list of numbers and titles supported by CSI and CSC. Since the 1960s most buildings in the United States and Canada have used this standard for managing building information. MasterFormat organizes construction information into procurement and contracting requirements, and technical divisions of activities and work practices. It is mainly used to organize project manuals, organize cost information, and relate drawing notations to specifications. It is also used to classify product models and other technical information (Afsari 2016).

MasterFormat is a hierarchical classification system. It is broken down into two groups and seven subgroups as shown in Figure 5. Each subgroup includes divisions, as shown in Figure 6. There are fifty divisions (00-49) with 15 of them reserved for future expansion.

Neither groups nor subgroups are numbered, while divisions include sets of numbered titles which are called sections. Sections identify work results which are permanent or temporary features of building projects achieved in any stage of the project life cycle (CSI 2004). The top level (level 1) in the hierarchy of the classification system is called divisions. Levels two through four are called sections. Moreover, the user may create any additional extensions at Level 5 as desired. MasterFormat was heavily updated and new sections were added to the latest version (CSI 2004).

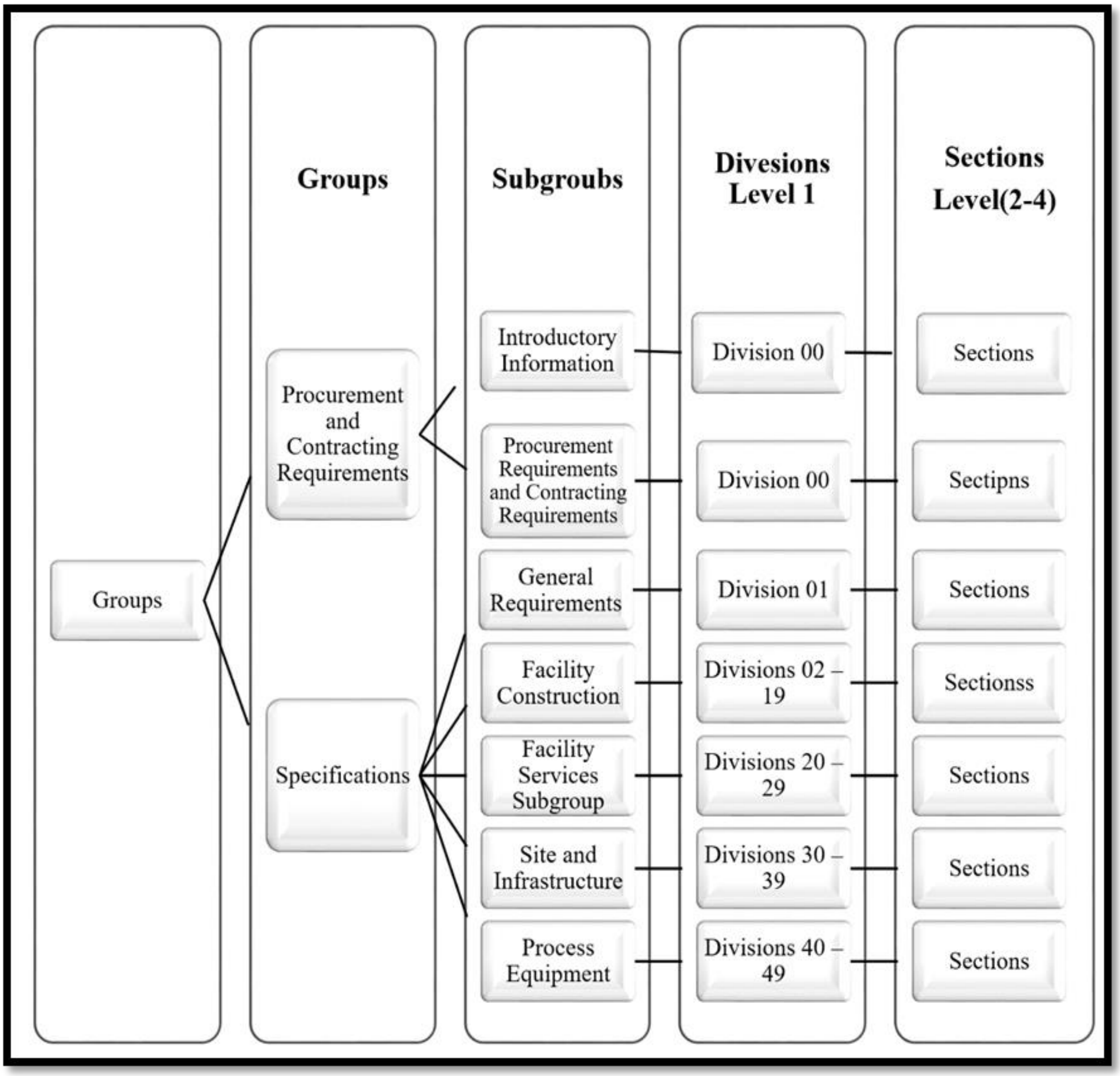

Figure 5. MasterFormat classification system (CSI 2004)

Introductory Information Procurement, Requirements Contracting Requirements	GENERAL REQUIREMENTS SUBGROUP	FACILITY CONSTRUCTION SUBGROUP	FACILITY SERVICES SUBGROUP	SITE AND INFRASTRUCTURE SUBGROUP	PROCESS EQUIPMENT SUBGROUP
• Division 00 – Procurement and Contracting Requirements	• Division 01 – General Requirements	• Division 02 – Existing Conditions • Division 03 – Concrete • Division 04 – Masonry • Division 05 – Metals • Division 06 – Wood, Plastics, and Composites • Division 07 – Thermal and Moisture Protection • Division 08 – Openings • Division 09 – Finishes • Division 10 – Specialties • Division 11 – Equipment • Division 12 – Furnishings • Division 13 – Special Construction • Division 14 – Conveying Equipment • Division 15 – Reserved for Future Expansion • Division 16 – Reserved for Future Expansion • Division 17 – Reserved for Future Expansion • Division 18 – Reserved for Future Expansion • Division 19 – Reserved for Future Expansion	• Division 20 – Reserved for Future Expansion • Division 21 – Fire Suppression • Division 22 – Plumbing • Division 23 – Heating, Ventilating, and Air-Conditioning (HVAC) • Division 24 – Reserved for Future Expansion • Division 25 – Integrated Automation • Division 26 – Electrical • Division 27 – Communications • Division 28 – Electronic Safety and Security • Division 29 – Reserved for Future Expansion	• Division 30 – Reserved for Future Expansion • Division 31 – Earthwork • Division 32 – Exterior Improvements • Division 33 – Utilities • Division 34 – Transportation • Division 35 – Waterway and Marine Construction • Division 36 – Reserved for Future Expansion • Division 37 – Reserved for Future Expansion • Division 38 – Reserved for Future Expansion • Division 39 – Reserved for Future Expansion	• Division 40 – Process Interconnections • Division 41 – Material Processing and Handling • Equipment • Division 42 – Process Heating, Cooling, and Drying • Equipment • Division 43 – Process Gas and Liquid Handling, • Purification, and Storage Equipment • Division 44 – Pollution and Waste Control Equipment • Division 45 – Industry-Specific Manufacturing • Equipment • Division 46 – Water and Wastewater Equipment • Division 47 – Reserved for Future Expansion • Division 48 – Electrical Power Generation • Division 49 – Reserved for Future Expansion

Figure 6. MasterFormat divisions (CSI 2004)

UniFormat is a publication of CSI and CSC. It is a standardized classification for organizing preliminary construction information into standard categories or on the basis of systems and assemblies. A revised version of UniFormat was adapted in developing table 21 of OmniClass to use in cost estimation during schematic design phase (CSI 1999).

UniFormat classifies elements that usually perform a given function regardless of the design specification and construction method. It is highly used in BIM to identify object families starting at early design stages. UniFormat framework is a hierarchical system. It comprises three major groups which are: elements for level 1 that rely on their special function, group elements for level 2, and individual elements for level 3. Figure7. shows the eight major groups and their subgroups (CSI 1999).

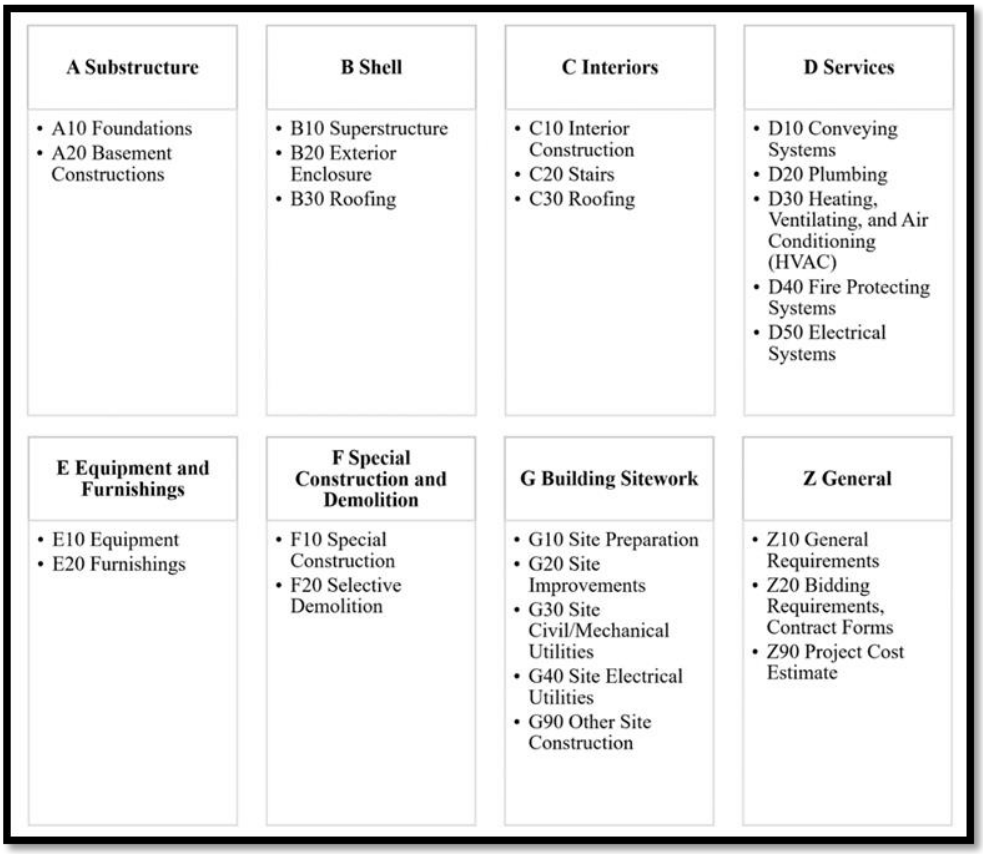

Figure 7. UniFormat classification system (CSI 1999).

Mechanisms of Evaluation Building Condition Aggregation

An example of the processes of an evaluation system proposed by Elhakeem (2005) are illustrated Figure 8. This evaluation used the distress survey approach. The first step is defining the deficiencies that affect each instance, which are determined by using a questionnaire. The second step is determining the weight of each deficiency identified in Step 1; again, this is determined by using a questionnaire. The third step is determining the severity of deficiencies by an inspector. Fourth step is calculating the deterioration Index (DI) for instance (the lowest level in his proposed hierarchy system). Since having the list of deficiencies along their weights, a single (DI) value can be calculated for any instance using Equation 1.

$$DI_j = \frac{\sum_{i=1}^{d} W_i \times S_{ij}}{100}$$

Equation 1

Where: DIj is Deterioration Index for instance (j), Wi, is the weight for deficiency (i) and Sij is the inspector's judgment of the extent of deficiency (i), that is, the severity, for instance (j). The fifth step is aggregating the condition from the instance to the component level by using Equation 2.

$$CDI_C = \frac{\sum_j (Z_{jc} \times DI_{jc})}{\sum_j Z_{jc}}$$

Equation 2

(CDIc) is the aggregated (DI) of parent component (c); (DIjc) is the deterioration index of instance (j); and (Zjc) is the percentage of instance (j).

Elhakeem illustrated how to roll up the condition or determine the condition at higher levels in the asset hierarchy from the calculated condition of each component at the lowest level (instance level in his proposed hierarchy mentioned elsewhere). Therefore, a mechanism for aggregating the DIs at a parent level from all its children becomes necessary. To accomplish this, weights are assigned to each child that reflect the child's relative contribution to the overall condition of the parent. The deterioration index at any level higher than the component level (i.e., subsystem, system, building) can be calculated from the Dis of the components underneath it, using Equation 3.

$$DI_{Parent} = \frac{\sum_{child} (RIF_{child} \times CDI_{child})}{\sum_{child} RIF_{child}}$$

Equation 3

(CDI_{child}) is (DI) of each component (only the component) that is a child to the desired parent, and (RIF_{child}) is the relative importance of each component, (CDI_{child}) values are determined from Equation 1.

It is important to note that, this approach can roll up the condition (DI) at any level in the hierarchy as a function of the condition and relative importance of each instance.

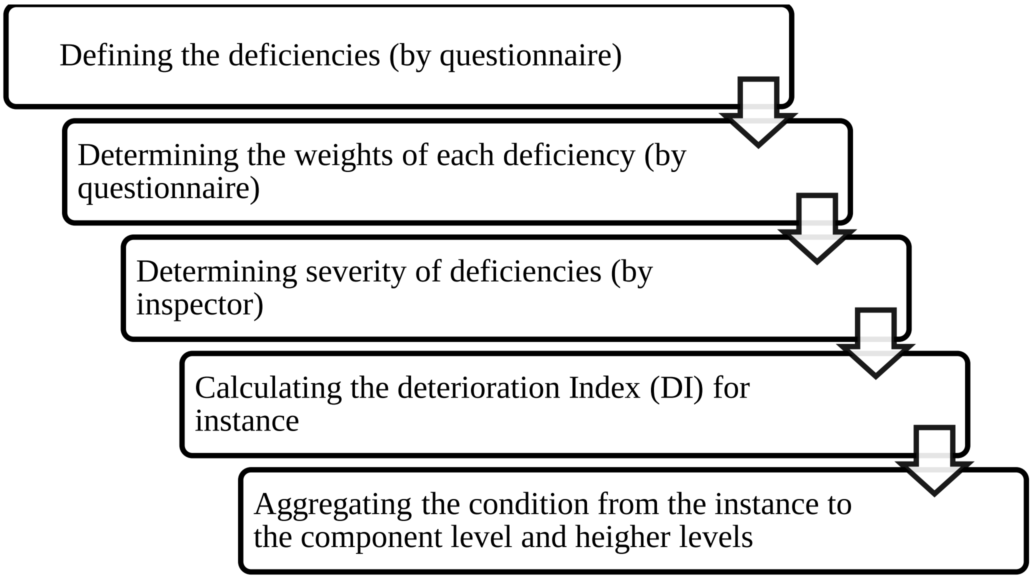

Figure 8. Evaluation mechanism developed by (Elhakem 2005)

Eweda (2015) proposed an evaluation mechanism, the processes are illustrated in Figure 9. The first step in this mechanism is to identify the relative weight of each building category (i.e. architectural, structural) inside each space type as well as relative weights of families inside each category. The relative weights are determined via a questionnaire that filled out by experts. Eweda chose the Analytical Network Process (ANP) in order to calculate the relative importance, that is, the weight, of each building category inside a space type (W:Catji) and the weight of families inside each category (W:famnj) using the ANP Super-matrix; since the ANP addresses the interrelationships between the different components, and the effect of one component's deterioration on the deterioration of other components. The second step is calculating the physical condition of each space. This step is done by calculating the utility value of the building category (U:Catji) inside each space by multiplying the utility value calculated for each family by the relative weight of the families inside each category (assigned by an inspector) by using Equation 4.

$$U.Cat_{ji} = \sum_{n=1}^{l} U.Fam_{nj} \times W.Fam_{nj}$$

Equation 4

Then the physical condition of the space PC (SPi) can be calculated by multiplying the utility value of the category (U:Catji) inside the space by its weight (assigned by the facility manager) using Equation 5.

$$PC(SP_i) = \sum_{j=1}^{m} U.Cat_{ji} \times W.Cat_{ji}$$

Equation 5

The third step is calculating the physical condition of entire building PC (B). This can be calculated by multiplying the physical condition of each space PC (SPi) by the relative weight of this particular space using Equation 6.

$$PC(B) = \sum_{i=1}^{n} PC(SP_i) \times W.SP_i$$

Equation 6

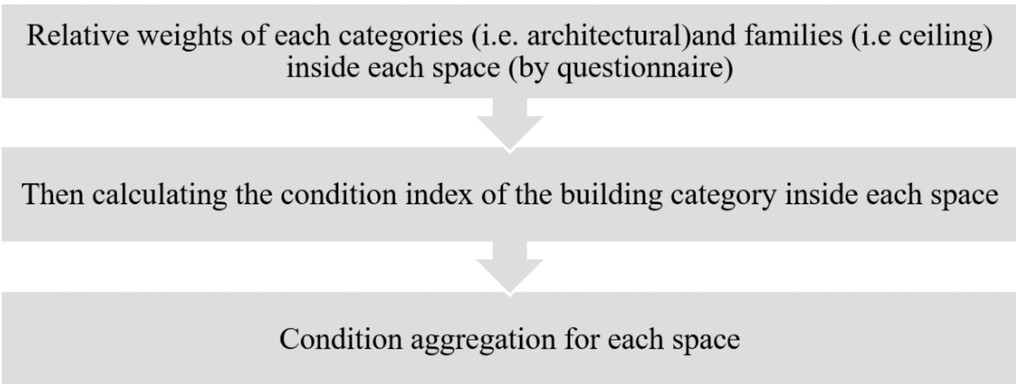

Figure 9. Evaluation mechanism developed by Eweda (2015)

BIM as an Automated Tool for Asset Management

Terreno (2015) illustrated how to optimize the benefits of BIM; the benefits of BIM are increased when it is used in both the design and construction phase of a project and beyond that. This means that BIM should be employed in the asset management phase of a constructed asset. This paper explained the benefits gained from the effective integration of BIM in asset management. Terreno case study depends on interviews with key employees on a major university building project, along with a review of project documents. The writer summarized qualitative descriptions of the benefits of BIM from these interviews. The paper concluded with a discussion of the vital benefits gained from the effective integration of BIM and asset management, in which it helps give a comprehensive determination of a project's life-cycle. This paper’s conclusion proposed the benefits through the all project phases, including those in the lifecycle stage, for a better assessment of the effectiveness of BIM implementation in asset management and how it is crucial challenge is the issue of interoperability with origins in the initial handover process from construction to operations in one instance, or from traditional FM data management software to BIM. Thabet developed steps for converting the spreadsheet-based methodology into a model-based approach allowing the asset management department to directly link to a building information modeling (BIM) system (Thabet 2017). He concluded that Integrating building life-cycle phases would better facilitate information flow and improve the availability, reliability, and consistency of asset information, resulting in saving time and cost. Also, Kiviniemi (2014) discussed a case study for adapting BIM for asset management and concluded that the main challenge in adapting BIM is the lack of interoperability of current systems and fragmentation of current information. Additionally, Bercerik mentioned that even though BIM would improve productivity, support proactive decision making, and reduce costs, the facility mangers had to recognize the challenges that should be overcome before fully realizing the vision of BIM and asset management (Bercerik-Gerber 2012).

To link BIM data to asset management there are some options that have been developed by researchers. For instance, Teicholz (2013) proposed data transfer strategies to integrate BIM with asset management that included the use of open standards, such as Construction Operations Building Information Exchange (COBie) that specifies the format and naming standards for asset data and can be imported directly into the asset management software. Also, Dimyadi (2014) mentioned other strategies for exchanging asset data between BIM and asset management systems including 1) the use of proprietary links between BIM software and asset management platforms such as EcoDomus, and OnumaSystems, 2) the use of industry foundation classes (IFC) format, and 3) direct links through application programming interfaces (APIs).

Discussion

Building asset management systems mostly tend to use standard building classification systems for asset inventory (Ahluwalia 2008, Grussing 2014). There are several standard building classification systems that have been developed to achieve consistent inventory across diverse building types, including Masterformat, Uniformat, and Omniclass construction classification system (OCCS) (CSI 2006, CSI 2004, CSI 1999). Most of the previous studies in asset management systems have suggested adopting one of these standard construction classification systems without properly analyzing their effectiveness in achieving the goals of asset management. These systems are comprehensive enough and can be employed as categorization criteria, but still lack the specific requirements of building asset management such as asset location and asset attributes including condition and deterioration rate. Additionally, these standard systems have priorities that may not align well with the needs of asset management. For example, the Uniformat standard classification focuses on functional components without regard to the material types used and without regard to the component location. For instance, stairs in this classification are mainly considered as building components without regard to the materials they are made of (i.e. concrete or steel) or their locations in the building. This type of classification system can only be useful for rough estimates in the early design stages but may not be useful for asset management. As another example, the Masterformat classification system is designed to focus on construction components and final work results such as cast-in-place concrete and steel structural framing. This classification is useful in organizing construction information such as procurement, contracting requirements, and managing construction costs, but cannot be used for maintenance and operation management since it does not support information about the current condition of assets. Additionally, assets information need to be defined by their locations including space functions and floors to facilitate the maintenance work which is cannot be done using this classification. Similar issues also exist with the third classification system, OCCS.

Other attempts to develop asset inventory systems seems to be very basic and generic, making them ineffective in physically locating building assets inside various types of buildings, for example, to facilitate maintenance work. Additionally, many systems did not include utilities as parts of a building or did not consider the whole life cycle of a building during the design phase. Furthermore, not all types of buildings were included and many of them only focused on educational buildings. Finally, none of the asset inventories presented in previous literature had comprehensive levels of detail that included all phases of building lifecycle.

The existing evaluation mechanisms of condition aggregation depend on determining relative weight for each level. A questionnaire was used to define these weights, which is subjective and time consuming. In addition, in order to roll up the condition through children to their parents, time consuming mathematical calculations are required. Calculating the condition at any level using the roll-up method is accomplished using a building hierarchy levels system that can already have drawbacks previously mentioned and can lose their cost-effectiveness. Also, the use of one number for any building level rating may conceal a deficiency (such as corrosion for steel windows, air or water penetration, clogged building drainage, or corroded wall reinforcement) in a critical component within the overall building system (Alkasisbeh 2018). So, the use of a single number can deform the visible condition of any building level by masking the existence of deteriorated critical building components. Also, it provides an incorrect sense of condition when using an averaging process. For instance, an HVAC system rating may be perceived as having a fair condition based on an average score, while it could be the case that the HVAC piping and pumps were in poor condition which could be problematic or indicative of impending failure.

Another challenge in applying asset management strategies to buildings is the timely availability of quality asset information, which partly comes from as-built data generated during the design and construction phases and partly relies on the condition assessment data collected throughout the operation and maintenance phase of a facility. This challenge is further complicated by the lack of integration between these phases of the life-cycle of a building, making information flow more difficult and ineffective. Additional complications include 1) coping with non-consistent terminologies and taxonomies used by different stakeholders, 2) designers and contractors do not have a full understanding of asset management operations and wait to the end of construction to turn over the as built information in a data dump, 3) the lack of methodology to document and collect appropriate data for asset management during the design and construction phases, and 4) designers and contractors do not have prior experience on how to deliver an as-built data with needed information to support asset management system. The need for integration has recently become recognized by researchers and some attempts have started to address this challenge (Alkasasisbeh 2018).

Previous building research efforts studies have not focused on the building asset database and timely access to asset information throughout the asset's life-cycle. However, database is integral across all project phases as complex data stores that facilitate sharing, maintaining, updating, and retrieving large amounts of data, as well as increasing the integration between project phases.

Also, there is lack of technical alignment between BIM software tools and asset management processes. Such an alignment provides more accurate information from a data-rich asset, automatically updates models, improves interoperability requiring no change from current data, as well as giving clearer asset management requirement definitions for design and construction, reducing response time in operations, and assisting proactive maintenance.

CHAPTER III

RESEARCH METHODOLOGY

The research plan consists of a five-major step process shown in Figure 10. The first step in the process is problem definition, which involves identifying and improvement of concepts, and identifying the data items and processes needed for managing building assets. Standard building classification systems were used as sources of information along with the procedures contained in building inspection forms, as built documentations, asset management reports, and building condition assessment literature. The outcomes of this step are the data items and processes that are required for the development of a proposed building asset management framework.

The second step, conceptual modeling, includes design of a building's inventory system, design entity relationships (E-R) that represents the design of the information system for building asset management. The outcome of this step is a conceptual data framework including developing WBS based framework for building asset inventory, developing multi-part condition rating model and creating a building asset relationship data model. The third step, computation modeling, involves transforming the E-R data model developed in the second step to a relational database schema. The fourth step, computer modeling, integrates BIM-DBMS to develop the automated building asset management decision support system. Finally, the fifth step, implementation and evaluation, validates the developed system and demonstrates its capabilities on a real-life project.

The problem definition step will include many tasks including:

- Conduct a comprehensive literature review on the municipality's asset management research, to clearly classify municipalities' assets.

- Study building systems, standard building classification systems, building inspection forms and reports, as built documentations, life cycle analysis, service life prediction, deterioration modeling, risk assessment, condition rating, existing condition assessment and asset management systems.

Conceptual modeling will contain the following tasks:

- Investigate municipalities asset types classification mainly focus on buildings as one type of these asset.
- Design a building inventory system by developing asset work breakdown structure.
- Develop a multi-part condition rating model.
- Develop E-R conceptual data model.

Computational modeling will include the following tasks:

- Develop relational database schema for building assets management.

Computer modeling and prototype implantation will include the following tasks:

- Develop a building decision support tools by using (BIM) and (DBMS).

Case study and evaluation step will include the following task:

- Implement the developed decision model on Western Michigan University building as a case study.

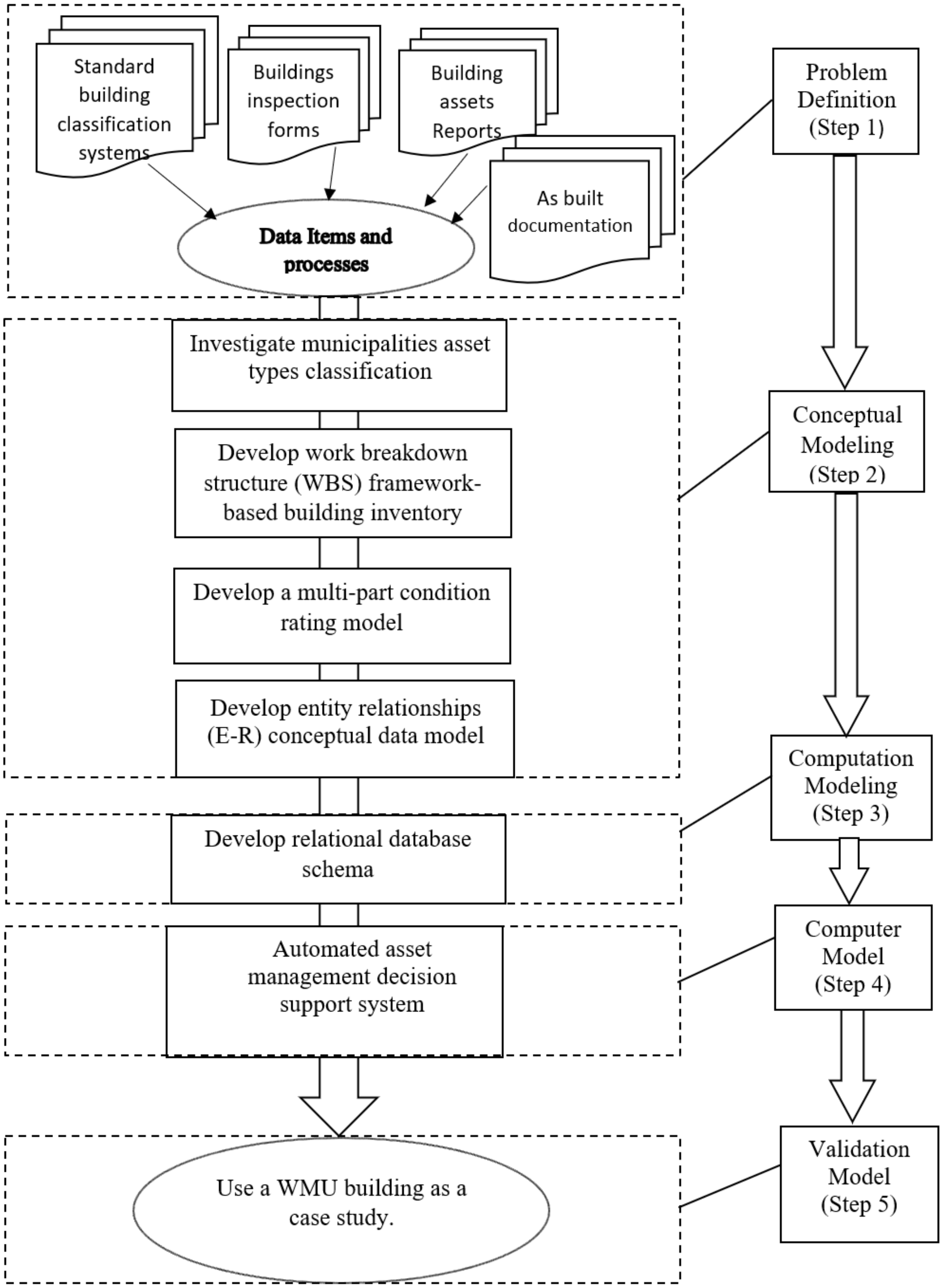

Figure 10 Research methodology

CHAPTER IV

BUILDING ASSET MANAGEMENT

This chapter presents a background to the research work by providing a description of the relevant knowledge areas in building asset management.

The Role of the Asset Management System

Any resource, either tangible or intangible, that can be owned and has an estimated life of more than one year is called an asset. Tangible or physical assets include land, buildings, building improvements, plant land and improvements to land, easements, vehicles, machinery, equipment, infrastructure and similar physical items. Intangible assets include human capital, and similar assets that cannot be seen. These assets can be assumed as capital assets when obtained by the city with a value greater than $5,000 (NT n.d.)

Asset management receives a lot of attention today not only in the United States but also globally. The term “asset management” can be interpreted and defined in many ways. There have been attempts to define asset management as "life-cycle cost management". The term has been used in the phrase "asset management reliability". The term has also been substituted for maintenance or reliability practices. Pantelias defines asset management as "a global management process through which we consistently make and execute the highest value decisions about the use and care of our assets" (Pantelias 2005).

Other researchers have defined asset management as a systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organized and flexible approach to making the decisions necessary to achieve the public’s expectations (OECD 2001).

According to the AASHTO Subcommittee, asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives (Sowah 2014). “Asset management system” has been defined as systems that serve defined communities where the system as a whole is intended to be maintained indefinitely to a specified level of service by the continuing replacement and refurbishment of its components (IPWEA 2015).

For the purposes of this report, asset management systems can be defined as management processes of operating, maintaining, monitoring, upgrading, and expanding physical assets for maintaining a desired level of service with the minimum and appropriate life cycle cost. Asset management can be used as a tool to guarantee that facility services are delivered in sustainable and effective ways.

Asset management may apply to both physical assets, such as buildings, infrastructure, and equipment, as well as nonphysical assets, such as intellectual property. Asset management can be used in many industries as diverse as transportation, electric power, manufacturing, public service companies and many others. Asset management is a proactive management of infrastructure assets, rather than reactive, it consists of processes and activities such as maintaining a systematic record of individual assets, called an inventory, which includes acquisition costs, original and remaining useful life, physical condition, and cost history for maintenance. The asset process also includes creating an optimization model, implementation of designed programs and many other activities (Pantelias 2005, Sowah 2014, OECD 2001).

Benefits and Importance of Asset Management

Effective asset management is more than maintenance. Asset management also helps to achieve a required level of service while minimizing cost. Additionally, asset management helps to reduce risk and ensure effective enhancement of capital over an asset’s life cycle (AAMCoG 2012).

In its research, New Mexico Environmental Finance Center concludes that asset management is also beneficial because it can lead to better operational decisions, improved emergency response, greater ability to plan and pay for future repairs and replacements, increased knowledge of the location of the assets, increased knowledge of what assets are critical to the utility and which ones are not, more efficient operation, better communication with customers, rates based on sound operational information, and increased acceptance of rates (Environmental 2006).

Effective asset management systems can assist municipal governments in providing local residents with enhanced services depending on the municipal's asset use (such as government buildings, health centers, water provision, parks, roads, and pavement). Generally, asset management allows utility managers to proactively rehabilitate or replace system components on a frequent basis instead of waiting to repair damaged assets when it is much more expensive and disruptive to system operations.

Utility asset managers in New Jersey conclude the benefits of asset management as follows: ensuring the long-term sustainability of the utility, identifying asset location, condition, and criticality, prolonging asset life through sound decision-making and focused operations and management, promoting system reliability, resilience and sustainability, and consistently meeting customer demands.

Researchers also suggest that asset management can be powerful in setting realistic rates based on sound operational and financial planning, budgeting focused on activities critical to sustained performance, meeting service expectations and regulatory requirements, reducing occurrences of and improving responses to emergencies, reducing energy needs and costs, and improving system security and the safety of assets (NJEIFP nd).

Buildings Asset Management Components

As is mentioned in previous section, buildings are a significant municipal asset class. However, there are many categories of building. Figure 11 illustrates the different categories of federal buildings in United States (Grussing 2014).

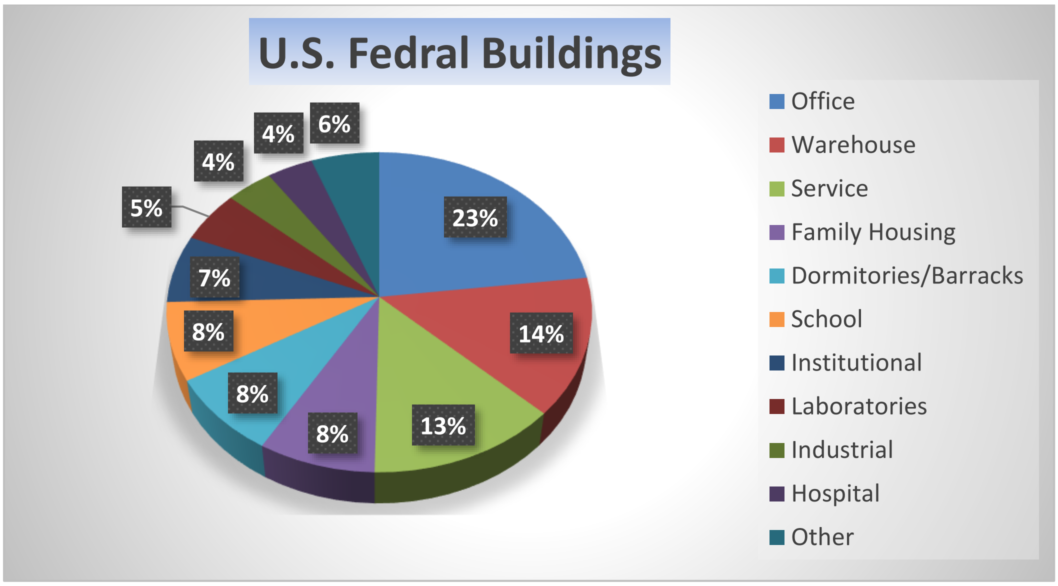

Figure 11 Uses for U.S. Federal Buildings (Grussing 2014)

Building asset management has become highly necessary. There are many factors that must be considered in building asset management including limited resources and challenges to reduce energy and materials usage. Significant demand for basic products that has resulted from the growth of world economies and infrastructure has led to scarcity of materials. Products such as concrete, steel, wood, copper, and other building materials need to be allocated wisely to avoid further future resource limitations. For example, renovation of existing buildings helps reduce the amount of material compared to a new construction project. Another factor is the shortage of land available in urban areas to build new facilities. Moreover, the preservation of historical buildings makes demolition of older buildings challenging. An additional factor is the role that asset management may play in reducing environmental effects and greenhouse emissions. (Grussing 2014).

However, the extreme complexity of building facilities presents challenges to the adoption and improvement of methodologies and tools of asset management systems, whereas asset management methodologies and tools have been widely adopted in several infrastructure domains that include roads and pavements, railroads, bridges, and distribution pipelines.

Pantelias (2005) mentioned that asset management systems involve different components, which are generally the same for all asset management systems (Pantelias 2005). These components can be easily modified to adapt to the needs of any management system. According to literature, the main components of an asset management system include: condition assessment, deterioration modeling, selection of maintenance and repair strategies, condition after-repair, and prioritization of building components for repair. The sequencing of asset management components is shown in the Figure 12. below (Elhakeem 2005).

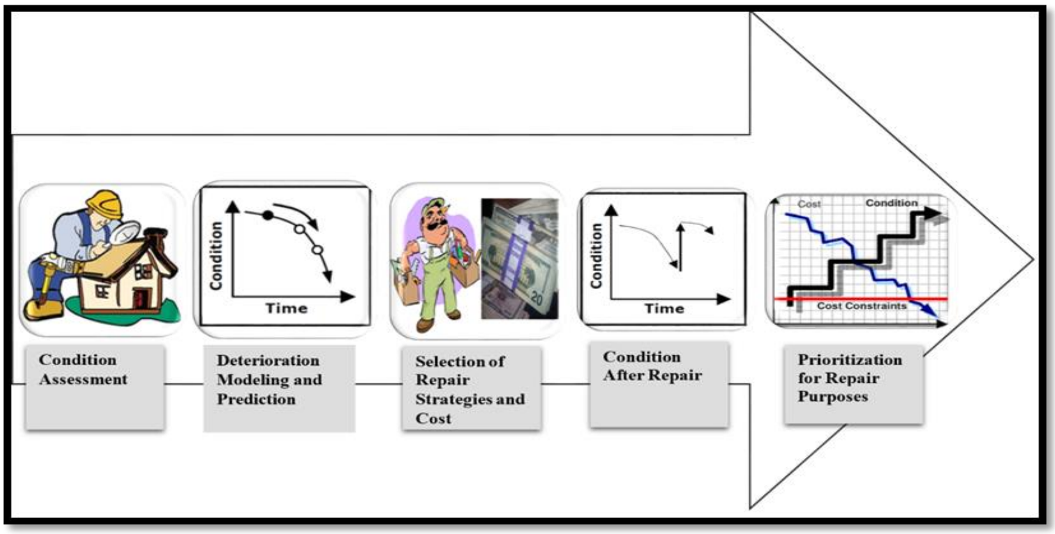

Figure 12 Asset Management Components

Building Condition Assessment

To make the asset's performance stronger, the asset's current condition should be assessed. Condition assessment is the most important component in the asset management process. The results represent the starting point for other components such as deterioration or repair selection. Rugless (1993) defined condition assessment as "a process of systematically evaluating an organization's capital assets in order to project repair, renewal, or replacement needs that will preserve their ability to support the mission or activities they were assigned to serve". Sadek (2003) defined condition assessment as "a system inventory and inspection to evaluate the current condition of the system based on established measures of the condition". Other literature defined condition assessment as the evaluation of the condition of the functional system that satisfies the required objectives. Condition assessment consists of converting inspection data into condition index, which are then used to support the infrastructure asset management decision-making process (Elhakeem 2012, Eweda 2015, Ahlluwalia 2008).

From an aggregated reading of available literature, it can be concluded that the main aspects of condition assessment are asset inventory, condition rating mechanism, data collection and building inspections, and analysis of inspection data. Figure 13. illustrates process of these assessment aspects (Elhakeem 2005, Eweda 2015, Ahlluwalia 2008).

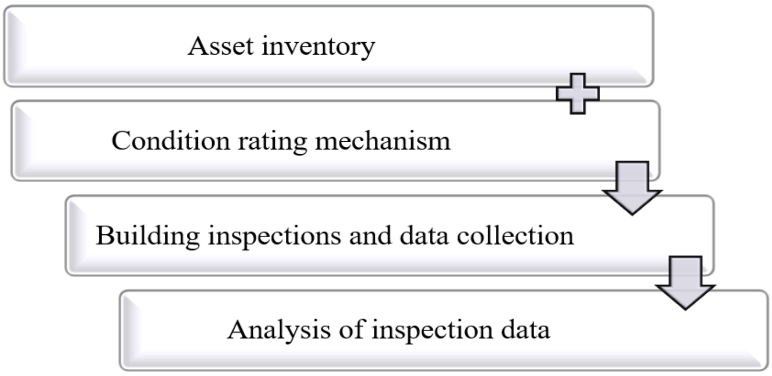

Figure 13 Process of Asset Condition Assessment

Assets Inventory

The first step in condition assessment is a data inventory system or asset hierarchy. It is the most important step because this becomes the foundation for all other aspects of asset management. During this step, it should be understood what assets the building has. In addition, an asset hierarchy is created to categorize the components in the building because a building has generally been divided into numerous systems and fixtures. In addition, this hierarchy will help in determining the inspection level. Therefore, this step consists of creating an accurate building inventory list, with attributes that define the characteristics of these assets, such as material type, equipment type, capacity, age, and location (Grussing 2014, Krugler 2006, EFCNMT 2006). However, to create a usable building hierarchy system, standard building classification systems should be taken into consideration. Standard building classification systems provide standardized and consistent formats for defining building components. Each system of classification is suitable for specific objectives.

The following is the municipalities building inventory list based on case studied mentioned in literature review:

- All municipal buildings (town halls, storage buildings, symmetries, libraries, schools, office, Clinics, research area and classrooms.
- Attachment construction to the building such as yards, courts, sunrooms, garages, staircases, etc.
- Entertainment facilities such as (museums, gymnasiums, soccer complexes, theatres)
- Wall or floor covering such as carpeting, tiles, paneling, and paints
- Windows, doors, built-in closets and cabinets.
- Baseboards, light fixtures, ceiling trim, etc.
- Siding, roofing, masonry, etc.
- Reinforcement of floors or walls, and beams, rafters, joists, steel grids, or other interior framing.
- Heating and cooling systems.
- plumbing and electrical wiring.
- Phone or closed-circuit television systems, networks, fiber optic cable, wiring needed in the Installation of equipment (that will be fixed in the building)
- Fixtures or machinery that cannot be removed without damaging some parts of the building.

Condition Rating Mechanism

There are two approaches to condition evaluation which are: a direct condition rating system, and a distress survey. The direct condition rating approach is a visual inspection for each asset and the process of evaluating this asset against a set of criteria. The inspector has to specify the condition of the asset based on a comparison of the current situation to the desired condition or performance of that particular asset. For the sole purpose of identifying the condition of the asset, the direct condition rating approach is appropriate. This approach is a less accurate but faster method for performing condition evaluation and requires an inspector with enough experience during the interior inspection process (Elhakeem 2005, Eweda 2015).

On the other hand, in the distress survey approach, the common deficiencies that may affect each type of an asset should be defined, then a condition index should be determined. There are many check lists and deficiency list for different types of asset inspection. In addition, this approach provides a record of what has been historically wrong with the inspected asset. This approach is appropriate when the purpose is to identify current problems or failures and more details are required. Also, it is the most accurate and reproducible procedure (Elhakeem 2005, Uzarski 2007) (See Figure 14).

Rating mechanism	Definition	Purpose	Accuracy	Progress
Direct condition rating	Visual inspection of each component and an evaluation of that item against a set of criteria	Identifying the condition of the asset	Less accurate	More faster
Distress survey	Visual inspection and it provides a record of what needs to be fixed in the inspected instance	Identifying current problems	More accurate	Less faster

Figure 14 Difference between approaches of condition evaluation

The condition assessment can be qualitative and generic, such as good or bad, or it can be in ranking approach such as 0 through 5, A through F, excellent through unacceptable, etc. The condition assessment can also be detailed and/or quantitative in accordance to established practices. However, depending on performance criteria, the data collected during condition assessment can be different from one asset class to another. Generally, the organization begins an assessment of their assets by assessing asset condition at a higher (top down) level, advancing to more detailed level inspections where appropriate. (EFCNMT 2006)

Approach for Grading Condition

According to the International Infrastructure Management Manual (IIMM), the approaches to condition assessment are: core or simple condition rating, intermediate condition rating, and advanced condition rating. A simple top-down approach is typical for agencies responsible for large groups of passive assets such as roads, pipes, and distribution assets. This approach is illustrated in Table 3.

Table 3 Simple Condition Rating

Rank	Description of conditions	Action Required
1	Very good condition	Normal maintenance required
2	Only minor defects	More maintenance required (5%)
3	Maintenance required to return to accepted level of service	Significant maintenance required (10-20%)
4	Renewal required	Significant renewal/upgrade required (20-40%)
5	Unserviceable assets	Over 50% of asset needs replacement

The Intermediate grading approach improves the capability to rank an asset that would present a significant problem at condition levels 3, 4, and 5 as illustrated in Table 4.

The advanced system approach typically employs nondestructive techniques in combination with visual assessment procedures. This approach is not applicable for all asset types, though it may applicable for critical assets. The advanced systems approach enables the condition to be assessed on up to ten variable parameters with condition scores between 0 and

1000. These advanced systems can still be banded into base scores of 1 to 5 if required as shown in Table 5 (IPWEA 2015).

Table 4 Intermediate Condition Rating

Rank	Description of conditions	Action Required
3	Level of Service Maintenance	Minor
3.4		Average
3.8		Significant
4	Requires Major Upgrade	Minor
4.2		Average
4.4		Medium
4.6		Substantial
4.8		Significant
5	Asset Basically Unserviceable	Minor
5.2		Average
5.4		Medium
5.6		Substantial
5.8		Significant

Table 5 Advanced Condition Rating

Base ranking	Roads (0-1000)	Drains, Sewers (0-200)	Water Mains (0-500)	Buildings (0-10)	Parks (0-125)	Plant (0-100)
1	0-200	0-40	0-100	0-2	0-25	0-20
2	200-400	40-80	100-150	2-4	25-50	20-40
3	400-600	80-120	150-200	4-6	50-75	40-60
4	600-800	120-160	200-300	6-8	75-100	60-80
5	800-1000	160-200	300-500	8-10	100-125	80-100

The Transportation Information Center (TIC) at the University of Wisconsin-Madison helps local highway officials in understanding and rating the surface condition of asphalt pavement. The Pavement Surface Evaluation and Rating manual (PASER) helps to identify types of defects and provides guidelines for rating pavement condition through a simple visual inspection system. The PASER manual gives an explanation of different surface distress that can help in the evaluation and rating of asphalt pavement surfaces. This rating scale ranges from 10, which is excellent condition, to 1, which is represents failure. The duration needed to go from excellent condition (10) to complete failure (1) depends on the quality of the original construction and the volume of heavy traffic loads. This PASER manual gives ratings that are related to required maintenance or repair as shown in the Table 6. Condition State of Pavement (1-10) (Walker 2002).

Table 6 Condition States of Pavement

Rating	Definition
9 & 10	No maintenance required
8	Little or no maintenance
7	Routine maintenance, crack sealing and minor patching
5 & 6	Preservative treatments (sealcoating)
3 & 4	Structural improvement and leveling (overlay or recycling)
1 & 2	Reconstruction

Elhakem (2005) proposed in his study to evaluate building components to a Deterioration Index (DI) of 100 points. The (DI) values indicate the level of component deterioration. The DI ranges from 0, indicating minimum deterioration (excellent condition) to 100 that indicates maximum deterioration or extremely critical condition. Table 7 shows the DI range which divided into 11 divisions with five linguistic expressions.

Table 7 Deterioration Index (DI) 1-100

Deterioration Index (DI)	Condition
0	Excellent
10	
20	
30	Good
40	
50	Fair
60	
70	Poor
80	
90	Critical
100	

Eweda (2015) proposed a condition index scale which is divided into six levels as shown in Table 8. This index was adapted from several scales and was finalized after several discussions with facility managers and experts in building condition assessment.

Table 8 Condition Index 1-100

Condition Index	Condition rating	Description of conditions
F	0-19	No longer function or complete failure **(Failure)**
E	20-39	Serious damages that affect the function **(Poor)**
D	40-59	Some defects are recorded but do not significantly affect the function **(Fair)**
C	60-74	Good condition with minor defects that do not significantly affect the function **(Good)**
B	75-89	Very good condition with very minor defects **(very good)**
A	90-100	Excellent condition, no defects **(Excellent)**

Data Collection, As-Built Data and Building Inspection

During this step, recorded data should include components and their attributes such as location to give an overall picture of the asset. This seems easy, but it isn't because record data is often inaccurate, and data can be missing. However, the components and their locations are not the only things that should be collected during this step. Component characteristics, component used life, asset cost, component asset condition, and remaining life of components and all useful information that can help the decision-making process must be captured, and these data collection requirements can be classified into the following categories (Krugler 2006, EFCNMT 2006, Pantelias 2005):

- Component location: the location of the asset as identified using a referencing system or Global Positioning System (GPS) coordinates.
- Component physical attributes: the description of the assets characteristics. For example, material type, volume, width, etc.
- Component condition: after the assets are determined and located, it is essential to know the condition of the assets.

However, in order to achieve an effective asset management system and make correct decisions, it is very important the data have the following characteristics when integrated in a database:

- Accuracy: inaccurate data is useless, and it is a waste of money and time. The data values should be considered accurate information.
- Integrity: the information should be the same whenever two elements represent the same piece of information.
- Validity: The data accurately reflects the concept it is intended to measure.
- Security: Keep the sensitive, confidential, and important data protected by limiting access to them and ensure back-up by other storage techniques.
- Appropriateness: The amount of collected data and the frequency of their modifications should depend on the organization requirements.
- Reliability: The data should have consistent measurements. The degree to which an instrument measures the same way each time it is used under the same condition with the same subjects is necessary. It can be said that the data is reliable when the same data would have been collected each time over repeated tests or observations.
- Affordability: When collecting data, resources and financial issues of the company should be taken into consideration (Pantelias 2005).

As Built Data

Design and construction phases have large volumes of asset data that are prerequisite for a successful and effective building management during the operation and maintenance phase(Le 2016, Yuan 2016). Such data include materials and assemblies that were used, construction means and methods, and location of building components. They can provide reliable information for life-cycle building assets performance prediction and decision-making functions. Additionally, the separation of the design and construction data from the asset data collection process in the current practice leads to many problems including information loss or inaccurate and incomplete asset data which may contribute to delays in building management tasks, and cost overruns, resulting in wasted time and money on nonvalue-added tasks such as searching and verifying as-built documentation during the asset management phase (Yuan 2017, Le 2016, Park 2017, Abdel-Monem 2013).

Building Inspection

The goal of the inspection process is to obtain required data to calculate the performance or to evaluate the condition by calculating a numeric value that represents a particular condition.

Full knowledge of the deficiencies that the component can suffer from is required when using a distress survey for evaluating the condition of building components. A standardized inspection approach is therefore vital to detect these distresses and measure them. In order to standardize the inspection process, many researchers have developed check lists and deficiency lists for inspection. A paper form or an electronic form could be used for these lists. In addition, other researchers have developed automated inspection processed using robots, images, satellite technology, automated devices, and smart sensors. Fiqures15,16,17,18 illustrate examples of inspection forms developed by U.S. Department of Housing and Urban (National Institute of Building Sciences 2000). Figure 19. Illustrates an example of deficiency list used for window inspection (Elhakeem 2005).

Building Name/Location

____

____

____

Lot size	Zoning classification
Year building built	Date of alterations
Total building area	
Applicable building codes	Height limitation
Setback requirements:	
Front yard	
Side yard	
Rear yard	
Other	

General comments:

____

Figure 15 Building information form developed by U.S. Department of Housing and Urban (National Institute of Building Sciences 2000)

Inspection checklist

1—Site

	Data	Condition/needed repairs
1.1 Drainage		
Window well sizes		
Basement stairwell size		
1.2 Site improvements		
Types of plantings		
Fence dimensions		
Lighting types		
Driveway dimensions		
Sidewalk widths		
Step dimensions		
Retaining walls		
1.3 Outbuildings		
Garage dimensions		
Shed dimensions		
Other		
1.4 Yards and Courts		
Areaway dimensions		
Lighting dimensions		
Access		
1.5 Flood Region		
❏ Flood risk zone (see local authorities)		

Figure 16 Site information form developed by U.S. Department of Housing and Urban (National Institute of Building Sciences 2000)

2—Building Exterior

	Data		Condition/needed repairs
2.1 Foundation Walls and Piers			
See Sections 4.1 and 4.2 for masonry			
See Section 4.7 for concrete			
See Section 4.5 for wood			
2.2 Exterior Wall Cladding			
Cladding material			
Thermal insulation			
2.3 Windows and Doors			
Door types		No.	
Window types		No.	
Storm window type		No.	
Storm door type		No.	
2.4 Decks, Porches, Balconies			
Size(s)			
Flooring material(s)			
Railing height(s)			
2.5 Pitched roofs	❏ Replace	❏ Retain	
Covering type			
Flashing type			
2.6 Flat Roofs	❏ Replace	❏ Retain	
Covering type			
Flashing type			
2.7 Skylights			
Size(s)			

Figure 17 Building exterior inspection form developed by U.S. Department of Housing and Urban (National Institute of Building Sciences 2000)

3—Building Interior

	Data	Condition/needed repairs
3.1 Basement/Crawl Space		
Floor height		
Floor material		
Wall material		
Insulating materials		
3.2 Interior Spaces		
Room		
Dimensions	Height	
Ceiling/wall material(s)		
Floor material		
Door size(s)		
Window size(s)		
Closet size(s)		
Trim		
No. 120V outlets	❑ 240V outlet	
Heat source		
Skylights		
Room		
Dimensions	Height	
Ceiling/wall material(s)		
Floor material		
Door size(s)		
Window size(s)		
Closet size(s)		
Trim		
No. 120V outlets	❑ 240V outlet	
Heat source		
Skylights		

Figure 18 Building interior inspection form developed by U.S. Department of Housing and Urban (National Institute of Building Sciences 2000)

Possible Deficiencies	Symptoms
Broken / Detached Seals	Air and water penetration, condensation
Frame Related Deficiencies	Broken, rot or rust, air and water penetration
Glazing Problems	Cracks, broken, lost transparency
Hardware Problems	Rusty, obsolete, inoperable
Finishing Problems	Need paint, wet / dirt surroundings

Figure 19 Deficiency list used for window inspection (Elhakeem 2005)

Analysis of Inspection Data

This is the last step in the condition assessment process. Since the inspection process provides measurements of the severity of each deficiency of a component, some analyses should be done to translate these measurements into condition values. Once the condition of a component is calculated, it is used to calculate the condition at any level in the building asset hierarchy. This procedure is called condition aggregation. After that, the building components contribute to the evaluation the overall building system performance. The same connection occurs between the building systems and the whole building (Elhakeem 2005, Ahluwalia 2008, Eweda 2015).

Deterioration Prediction of Building Assets

Deterioration prediction is a significant technique in the building lifecycle management process. Asset managers understand that strong asset management systems are needed to supply accurate performance models. A strong asset management system can be used to predict the future condition of an asset. Decisions can then be made to establish funding for the asset throughout the life cycle of the asset. (Krugler 2006).

Several models have been developed to predict the deterioration of municipal assets, including deterministic models, statistical or stochastic models, and artificial intelligence models. Determining which performance models are necessary depends on the types of assets that will be managed, and the data inventory needed to develop the models (Elhakeem 2005 Edirisinghe 2015). Deterministic Models present a mathematical relationship between input and output parameters of an asset to develop a good correlation from these parameters. These models could be a very simple straight-line extrapolation model or more complex regression analysis models. Regression is a statistical tool that used for investigating the relationships between variables. There are many types of regression including linear, non-linear, stepwise, and multiple regression. However, regression allows for more accurate predictions of future deterioration than simple straight-line extrapolation. It is worth to mention that for complex assets, the mathematical relationship with a good correlation cannot be derived on the basis of a highly variable data set, so a deterministic approach could not be applicable (Elhakeem 2005 Edirisinghe 2015).

Stochastic or statistical models depend on statistical theories which are more appropriate for modeling forecasting with data sets that have a high level of uncertainty, making these models more appropriate for deterioration modeling of infrastructure and structures in a time-dependent stochastic process. Statistical models are used to define measurement errors and certain probabilistic relationships between input data and output data. Markovian models are the most common stochastic techniques that have been used widely in modeling the deterioration of infrastructure facilities (Elhakeem 2005 Edirisinghe 2015).

Building Required Level of Service

Desired level of service is one of the objectives that asset management struggles to improve strategies to achieve. In other words, the service should be provided to the satisfaction of the customer. The asset management system's level of service can be evaluated by using performance measures, driven either by the customer, measuring the service level that agency receives, or by using technical performance measures which measure the level of service supplied by the organization (Krugler 2006).

Risk Assessment

According to AASHTO, risk management is a process of detecting risk sources, evaluating these sources, and integrating extenuation actions and strategies into the routine system functions of the agency (Rasdorf 2015). Risk is determined by taking into account both the probability (likelihood) and consequence (criticality) of asset failure. Condition is also an indicator of probability of failure, and it is possible to use the data from condition assessment to develop deterioration models for assessing the probability of asset failure.

The consequence of an asset failure generally remains quite constant over time while, whereas the probability of failure does not since as the asset deteriorates and ages, the probability of asset failure commonly increases. The primary focus of a condition assessment system should be on high-risk assets. It should start with critical (higher consequence of failure) assets and progressively move to lower criticality assets over time. In any case, risk assessment enables an agency to determine appropriate operational, capital maintenance, and other asset management strategies (Rasdorf 2015, Urquhart 2006). Table 9 shows the risk assessment matrix with the consequence of asset failure (COF) (criticality) as the vertical axis with five levels (1 being low and 5 being highly critical) and the probability of failure (POF) (likelihood) as the horizontal axis with five levels (1 being low and 5 being highly probability of failure). The risk of failure (ROF) is determined from the matrix and can be one of four possible outcomes: extremely high, high, moderate, and low.

Table 9 Risk of Failure (ROF) Rating Matrix

OF	Probability of Failure (POF)				
Consequence of Failure (COF)	1	2	3	4	5
1	Low	Low	Medium	Medium	Medium
2	Low	Low	Medium	Medium	Medium
3	Medium	Medium	High	High	High
4	Medium	Medium	High	Extreme	Extreme
5	Medium	Medium	High	Extreme	Extreme

BIM for Improving Building Asset Management Systems

Improved information control and database management strategies are reflected in the Architecture, Engineering, and Construction (AEC) Industry. In the past, there were many attempts to improve design tools in the AEC industry from 2D drawing to 3D modeling. For example, Autodesk Revit can be integrated with Building Information Modeling (Yan 2008).

Collaboration of numerous individuals is essential to the success of a construction project, especially when team members are separated geographically. Continuously sharing information on time and accurately among project participants is essential to keeping a project on time, on budget, and without conflicts or defects.

There are overhead costs in building industry estimated at $15.8 billion a year, or approximately 3-4% of the overall industry income, that result from poor interoperability and data management. BIM can help the building industry improve its productivity by producing 3D design visualization, enhancing coordination, and decreasing the conflicts between systems that can be easily seen and addressed early in the project timeline.

Although BIM has been in use for many years, the construction industry has not been using BIM to its full capacity. McGraw Hill stated that until 2009, nearly half of all industry agents had not adopted any BIM software on projects in the U.S. Becerik indicated that cost is the reason behind the poor adoption of new BIM technology within the AEC industry, requiring technology, process, and organizational investments to initiate BIM. In addition, adoption of BIM would require changes to the traditional ways of design and build projects (Gerber 2010).

What is Building Information Modeling

Building Information Modeling (BIM) refers to a digital combination of software applications intended to simplify coordination and project collaboration (Bloomberg 2012). It is also a way to create an automatic model for visualization, engineering analysis, conflict analysis, code criteria checking, cost estimating, as-built product, budgeting and many other objectives (Kreide 2013). BIM can also be understood as an advanced way to design and document the construction process by virtually constructing the project within a computer before actual construction begins, which saves a substantial amount of time during the design phase.

BIM is a multidimensional model; it can be primarily 3D, 4D with time, and 5D with cost; this allows a range of visual and non-visual project information to be tagged to each object in the model such as a structural material, size, manufacturer information, construction sequence cost, specifications and other attributes. It can be said that BIM is made up of intelligent building components, which contain the attributes and parametric rules for each element (Bloomberg 2012).

BIM gives consistent coordinated views and representations of the digital model and includes reliable data for each view. Moreover, the 3D nature of BIM streamlines communication between design professionals and allows the complexities of a building to be better understood. According to the National BIM Standard, BIM is "a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition" (KIA 2013). BIM is a collaborative tool used by the AEC industries based on a number of software solutions. It is a technology and a process to manage construction projects. BIM is a set of technology developments and processes that has transformed the way infrastructure is designed, analyzed, constructed and managed (Latiffi 2013).

BIM uses IFC format which is an open source format and official international standard. This IFC format gives a common language for transferring that information between different BIM software applications while maintaining the meaning of different pieces of information in the transfer. This reduces the need of remodeling the same building in each different application. (Love 2015).

Applications of Building Information Modeling

There are many applications for building information models in the construction industry. The most important and innovative usages of BIM technology are visualization, fabrication/shop drawings, code reviews, forensic analysis, facilities management, construction sequencing, cost estimating, and conflict, interference, and collision detection (Azhar nd).

Visualization: One of the most important benefits of BIM technology is the ability to see/visualize the structure before ground is even broken. It provides the chance for all project parties to understand and visualize the completed project, which can be difficult with only 2D drawings. Although this benefit saves money and time throughout the structure life cycle, it requires additional effort.

Fabrication/shop drawings: Creating shop drawings for building systems using BIM can be done quickly and easily once the model is complete. Shop drawings that are produced from BIM models are accurate, coordinated and reliable enough to direct the process of fabrication. Moreover, including digital design data within the BIM model allows for a more efficient and higher quality output during the fabrication and detailing processes. BIM contains vital information about all parts of the fabrication mechanisms such as measurements, specifications, installation, and connection details. Three-dimensional shop drawings also store huge amounts of information which can be used to select better construction methods. Furthermore, BIM produces integrated shop drawings from different construction parties which can assist architects and engineers to understand if the contractors, manufactures, and suppliers understood the design, avoiding future fundamental on-site changes.

Code reviews: fire departments and other officials may use these models for their review of building projects.

Forensic analysis: a building information model can easily be adapted to graphically illustrate potential failures, leaks, evacuation plans, etc.

Facilities management: facilities management can use BIM for, maintenance scheduling, building system analysis, asset management, space management and tracking, renovation, disaster planning, and record modeling. Record modeling can help maintain the building during its lifecycle. The building information molding software which controls and monitors the use of mechanical and electrical equipment can be linked to the record model to identify the location that requires maintenance (Mehmet 2011).

Construction sequencing: BIM can effectively integrate time components into the 3D model, allowing the addition of a schedule-related dimension. These 4D BIM models can produce a graphically rich and animated representation of the planned construction sequence set against time. 4D schedules are a powerful tool for coordinating and communicating planned work to all project participants. It can be used to create material ordering, fabrication, and delivery schedules for all building components. In addition, it can optimize the sequence of construction, manage project logistics, communicate the project plan to subcontractors, proactively make timely adjustments, and manage workflows. Good project scheduling leads to precise and timely delivery of materials and equipment and reduces the potential for damage.

Cost estimating: 5D BIM adds cost to the other four dimensions. It integrates the design with estimating, scheduling, and costing, generates bills of quantities, and preforms derivations of productivity rates and worker costs. By using BIM, the software can read the model geometry and propose quantity calculations. Cost data is accurately linked to each element resulting in a detailed cost schedule, after that the software can easily calculate the cost of the project. Moreover, in BIM software, the material quantities, bill of materials and project cost estimate are automatically extracted and changed when any changes are made in the model. BIM also provides precise cost estimation through all construction periods where it can simply identify key variables in order to make financial decisions and improve whole project performance.

Conflict, interference and collision detection: because BIM models are created to scale, in 3D space, all major systems can be visually checked for collisions. One of the best uses of BIM technology is to detect and fix these clashes ahead of time; for examples, identifying if pipes run into the heating, ventilation, and air-conditioning systems (HVAC), cut through a floor, or verify that piping does not intersect with steel beams, ducts or walls. Knowing about clashes ahead of time and using the clash detection system, conflicts in the project can easily identified and resolved saving project hundreds of thousands of dollars and months of wasted time.

Advantages of Building Information Modeling

Many mistakenly believe BIM is just new advanced software. Actually, BIM is not only software, it is a process that depends on information-rich models to assist owners and the architecture, engineering, and construction industry to plan, design, construct, and manage building and construction projects in a dynamic way. As companies decide to implement BIM, they will identify all the benefits that come from using BIM and they will see their organization, business, processes, and technology change (Mehmet 2011).

The most important advantage of BIM is that it helps provide an accurate geometrical representation of the parts of the construction process in an integrated data nature. In addition, it gives faster and more effective processes, the information is more easily shared, and better design and building proposals can be rigorously analyzed.

Since BIM simulations can be performed quickly and the performance of those systems benchmarked, it helps to enable improved and innovative solutions. BIM can be used to control the whole construction life, determine costs and store environmental data.

BIM allows for predicting lifecycle costs and provides a better understanding of automated assembly. Digital product data can be exploited in downstream processes and can be used for manufacturing and assembling of structural systems. The company's customer service proposals are better understood through accurate visualization. Lifecycle data requirements, design, construction and operational information can be used in asset management (KIA 2013). Improved productivity due to easy retrieval of information, increased coordination of construction documents, and embedding and linking of vital information such as vendors for specific materials, location of details and quantities are required for estimation and tendering (Love 2015).

Integration of BIM with Asset Management

The integration of BIM and asset management is a relatively new technique. This integration helps to provide greater possibilities for reducing costs and developing processes. The implementation of BIM in many aspects of building Operations and Maintenance (O&M) is intended to lead to more sustainable, efficient and well managed buildings.

The cost savings and improvements associated with BIM/AM integration depend on increasing the accuracy of the data model for AM. The automatic generation of AM data will lead to procedural expediency for daily operational requirements, increase management proficiencies, and improve long range planning. BIM/AM integration has encountered several challenges. These challenges as mentioned by Terreno are immaturity of users, lack of clear guidelines, ambiguity for integration into current processes, lack of newly structured contractual agreements for BIM-based projects, unaligned coordination between the social nature of BIM projects and technological functionality, interoperability constraints, lack of technical alignment between BIM software tools and AM processes, lack of integration between project phases, and increased associated costs, such as training and outsourcing.

On the other hand, there are many benefits for integration of BIM with AM that encourages participants to overcome these difficulties and apply BIM technology in their companies. Terreno (2015) in his paper identified the benefits of the integration of BIM and AM, these include: noted improvements in collaboration, more detailed strategic planning with holistic considerations, more detailed and extensive design reviews towards more seamless lifecycle integration, clearer AM requirements definition for design and construction, incorporation of requirements into contract documents, more accurate information from a data-rich asset, automatically updated models, improved interoperability requiring no change from the current data system, increased employee productivity and efficiency, easier data retrieval, shorter response time in operations, more proactive maintenance, and an increased level of emergency preparedness

CHAPTER V

AN INTEGRATED LIFE-CYCLE FRAMEWORK AND MODEL FOR BUILDING ASSET MANAGEMENT

Existing building asset management systems typically wait to build the asset information model until after they have been constructed and operated. Fiqure.20 illustrates the flow of information in existing building management systems and shows the lack of integration between the design and construction phases and the asset management process.

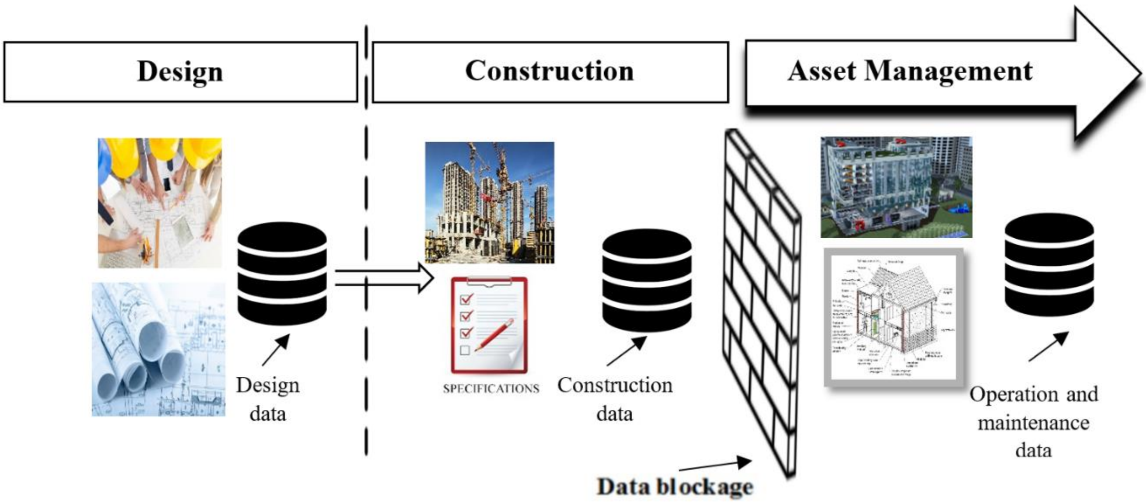

Figure 20 Asset data flow in current practice

As mentioned earlier, design and construction phases have large volumes of asset data that are prerequisite for a successful and effective building management during the operation and maintenance phase. Therefore, the goal of this chapter is to develop an integrated life-cycle framework and information model for building assets that will improve the asset management process and will address these challenges in current practice. The framework must consider appropriate building standards for classifying the inventory of assets and will facilitate asset data flow throughout building life-cycle phases.

Many organizations depend on the WBS concept for breaking down a project into manageable work packages that have well defined scopes and have used WBS as the basis for integrated design and construction project management (Rasdorf 1991, Ibrahim 2009). However, these efforts did not extend to the asset management phase of a facility. In this research effort, the same WBS framework is proposed for asset management during the operation and maintenance phase of a facility's life-cycle. There is only one framework that is needed to manage the building life-cycle phases, ultimately ensuring that all data gathered from design and construction phases effectively integrated with the asset management phase. Figure 21 schematically illustrates the proposed model that integrates all life-cycle phases and overcomes the data blockage in the current practice.

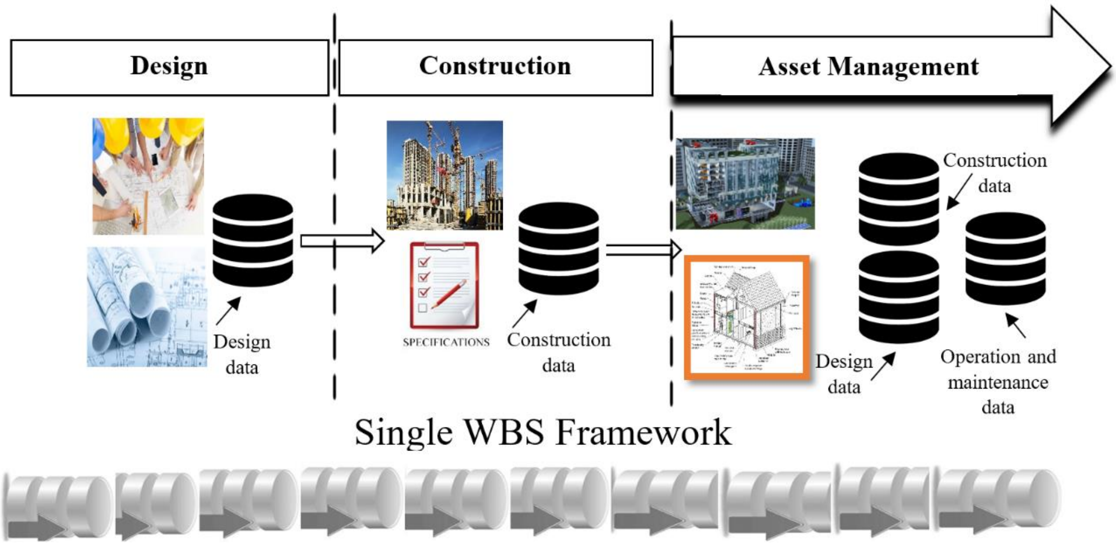

Figure 21 Suggested asset data flow

Life-Cycle Data Items for Building Assets

Building asset information system should cover all the building assets along with their information and attributes that define the characteristics of these assets, as well as all the activities and processes that result in the achievement of an effective building. However, all the project phases contribute to the data that must be included in the asset information system.

From previous comprehensive literature review it can be concluded that the building information can be divided into static, historical (As-built) and dynamic data. Historical data include the asset type, location, and configuration, while the dynamic data cover the condition of the building assets over time as well as the maintenance history of an asset and the static data that define the processes needed by the building asset management system. As shown in Figure. 22 the, historical data is assembled from design and construction phases and integrated with dynamic data that are defined at the asset management phase and static data which are definition of the process needed by the building asset management system. Depending on these data items, asset management decisions can be made and will include condition assessment, selection of maintenance and repair strategies, condition improvement after repair, asset prioritization, and fund allocation. The resulting final set of data items will be discussed in the following sections.

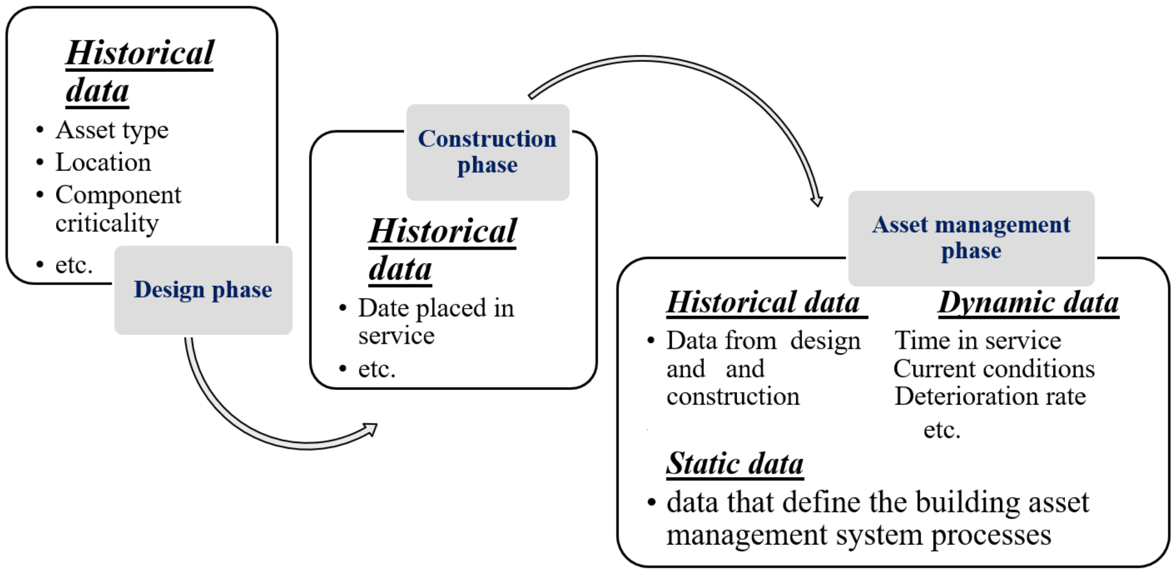

Figure 22 Data through the building life cycle

A Conceptual Data Model Design for Asset Management Framework

The following steps have been used to develop the life-cycle WBS framework for the building asset model.

1- Define asset management hierarchy:

- Identify breakdown criteria: The purpose of the WBS hierarchy is to define the elements and their properties that will be used in the building inventory system. This means that the breakdown logic (criteria) must be developed to configure how a facility will be classified and subdivided into the asset elements that will be monitored and managed.
- Construct WBS sequencing: This step breaks down a building into its subdivisions using the criteria above to develop the WBS hierarchy.
- Develop breakdown definition: This step defines each of the WBS components at all levels and establishes the control account and asset account levels.

2- Design a coding system: This step defines and organizes project work content through the creation of codes that will be used as identifiers throughout the life-cycle of a facility.

3- Determine control and asset accounts: A control account is used for managing the design and construction phases while an asset account is used for managing asset components after the facility is in operation. Since the ultimate goal of this research is the asset management phase, the focus will be on asset accounts that will be defined at an adequate level of details on the WBS to allow for effective decisions about condition assessment and asset maintenance. It is worth noting that the asset accounts will include data from the relevant completed control accounts in the form of as-built data. Such data are readily integrated since they both types of accounts (control and asset) reside on the same WBS.

4- Define life-cycle asset information: This asset information represents all the data items and attributes as well as the processes that will be used to manage these assets.

WBS-Based Asset Hierarchy

It is difficult to effectively use asset information if the asset components are not categorized in a unified framework (Alkasisbeh 2018, Lou 2008). The first challenging task in any hierarchical system is identifying the breakdown criteria for establishing the different levels of the hierarchy for the building asset management system, particularly when building components are complex. The proposed WBS hierarchy is designed to span the building life-cycle stages to ensure the effective and timely flow of quality data and information from the design and construction phases to the operation and maintenance phase. Since the goal is to develop a hierarchy that will ultimately be used for asset management, the WBS-based inventory system will take into consideration asset management requirements such as asset location, asset condition, asset criticality, deterioration prediction, selection of maintenance and repair strategies, condition improvement after repair, asset prioritization, and fund allocation (Uzarski 2007, Transit 2013).

Figure. 23 illustrates the proposed asset hierarchy that consists of eight levels. The criteria for the levels will include building categories to cover numerous types of buildings, building parts, building systems, building subsystems, floors, and space function to identify the accurate location, and assets. The order in which the criteria are applied across the hierarchy defines the structure. The highest level in the structure is the entire asset management system and the proposed sequence for subdivided levels takes into consideration the operation, work section, inspection, and location. The sequence of the structure is based on the notion that buildings can be subdivided into major parts such as substructure, superstructure, and sitework.

Each part includes a diverse set of systems that support the core operational functions. Many subsystems exist within each system. Each subsystem has an assigned floor; each floor is then further divided into spaces that are related to the different types of functions. Each space function is composed of numerous assets. Note that this WBS framework must be developed early in the design phase and used throughout the project phases to achieve the full life-cycle integration.

A common language for building inventory is essential to the success of a building asset management system. The lack of a common language impedes coordination and performance comparisons across buildings within the asset management system because significant variation exists between building types. Adapting consistent inventory definitions will give a common language through different building types. To reduce subjectivity and ensure clarity in terminology, the proposed framework adopts most of its definitions, when appropriate, from standardized construction classification systems. Therefore, it is vital to identify the standard definition to adopt for each of the criteria. The following are the breakdown levels and the definitions of each level: (CSI 2011, CSI 2004):

- **Level 1** is the asset management system level.
- **Level 2** is the building categories: In this model, the Spaces by Function table of OCCS is adapted to define the categories of building (CSI 2011). OCCS has been the most widely used system in North America for many years and defines and classifies building space functions as groups under spaces. The building categories based on the OCCS are as follows: service buildings, education and training buildings, recreation buildings, healthcare buildings, commerce activity buildings, storage buildings, residential buildings, laboratory buildings, government buildings, library buildings, museum buildings, production, fabrication, and maintenance buildings, protective buildings, parking buildings, and spiritual buildings (see appendix A).

- **Level 3** is the major building components and includes substructure, superstructure, and sitework. The superstructure is the part of a building that is located above the ground level and the substructure is the part of the building located below the ground level. Sitework is attached to the building and is considered in this inventory as part of the building. Sitework covers the utilities as well as parking lots and yards (see appendix A).
- **Level 4** is the building systems and includes a diverse set of systems that support core operational functions. This model uses the Masterformat to assign building systems as follows (CSI 2004): structural system, architectural system, mechanical system, electrical system, and conveyance system (see appendix A).
- **Level 5** is the building subsystems. This model uses the Masterformat to identify and define the building subsystems as follows (see appendix A):
  - Under the architectural systems, the subsystems include openings, finishes, furnishing, recreation equipment, exterior enclosure and landscape.
  - Under the mechanical system, the subsystems include fire suppression, plumbing, gas and vacuum systems, HVAC (heating, ventilating and air conditioning), water distribution, sanitary sewage, storm drainage, mechanical equipment, and fuel distribution.
  - Under the electrical system, the subsystems include power distribution, lighting, lighting, electrical equipment, integrated automation, communication, and security system.
  - Under the structural system, the subsystems include structural component such as beams, columns, walls, slabs, footings and stairs.
  - Under the conveying system, the subsystems include conveying equipment such as escalators, elevators, and lifts.

- **Level 6** is the floors of buildings and covers basement, ground floor, first floor, second floor, and so on.
- **Level 7** is the space function. This model adopts the Spaces by Function table of OCCS to extract a comprehensive list of space functions (see appendix A). Examples of space functions include classroom, laboratory, mechanical room, ultra sound room, electrical room, newborn nursery room, patient room and so on.

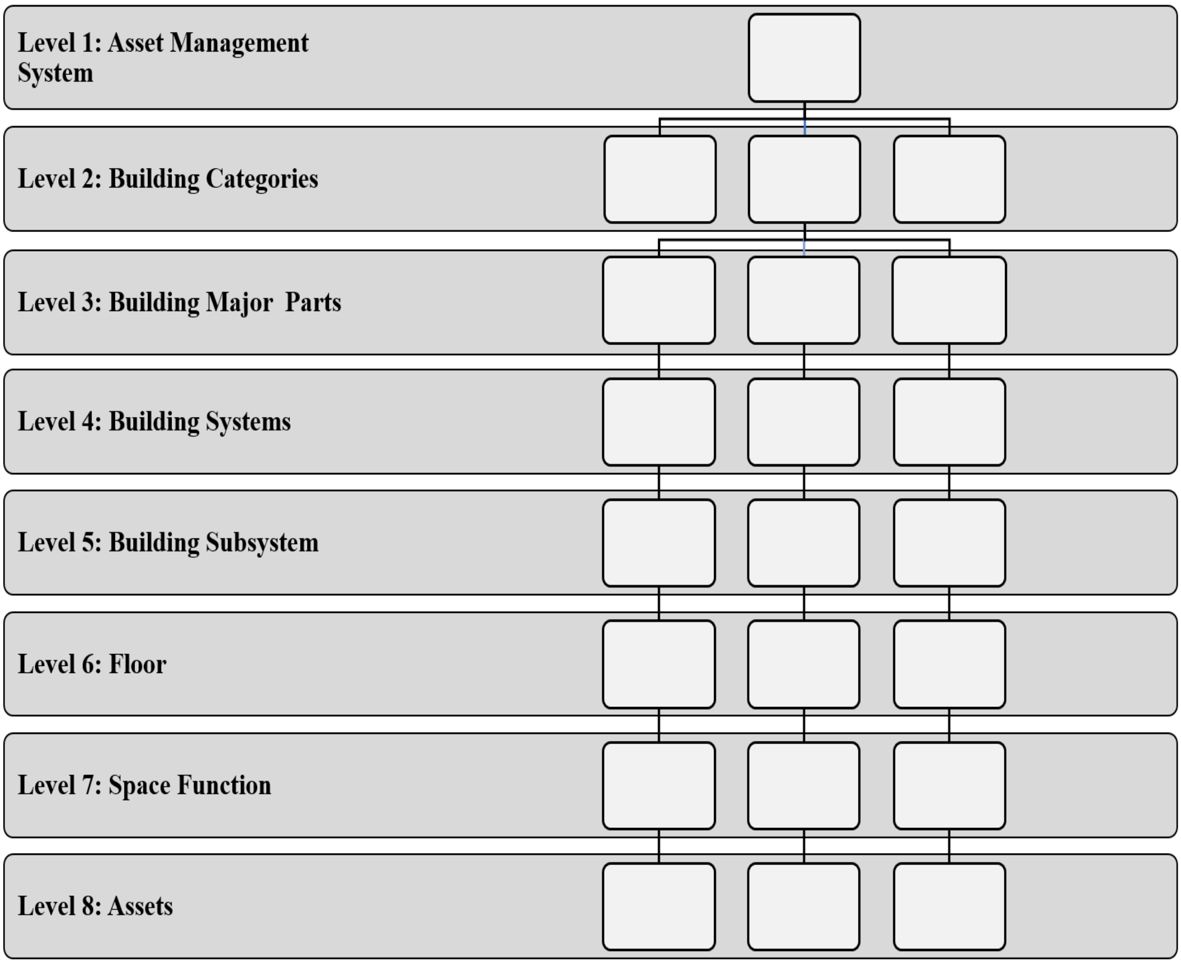

Figure 23 Proposed life cycle building asset management hierarchy

- **Level 8** is the assets. This model uses the Masterformat to extract a comprehensive list of assets that can be included in each subsystem (see Appendix A). The following are some examples of building assets: drainage piping, sewage piping and septic tank for sanitary sewage systems, windows for openings, aggregate paving for landscape systems, transformer and electrical power generator for power systems, and energy lightings for lighting systems.

Coding System

An identification system is developed to support the WBS framework. It is designed to provide an easy mechanism for addressing each task and asset so that they are uniquely identified, tracked, and correctly summarized. In the WBS, every level has a unique assigned number. Level 1 is designated by 1.0.0.0.0.0.0.0 and all remaining levels are subordinate to this level. For example, level 2 is designated by 1.X.0.0.0.0.0.0 (e.g., 1.1.0.0.0.0.0.0, 1.2.0.0.0.0.0.0), level 3 is designated by 1.X.X.0.0.0.0.0 (e.g., 1.1.1.0.0.0.0.0, 1.1.2.0.0.0.0.0), and so on. Since the proposed WBS has eight levels, then each code will have eight digits.

Asset Management Accounts and Life-Cycle Asset Information

As mentioned before, asset information must be acquired and maintained in asset accounts defined at an adequate level of detail on the asset management WBS. The proposed WBS has eight levels which include many details that are necessary for decisions to be carried out at any time in a building life-cycle. It is worth noting that asset accounts can be created at any level on the WBS depending on the desired details and available resources. For instance, the entire HVAC system can be the asset account in a facility when limited resources exist. In this case, the facility manger can assign the subsystem level to be asset account level. While another facility manger may have more resources to allow for breaking down the HVAC system into smaller asset accounts to monitor and manage with more details. The following are examples of asset accounts defined at different WBS levels:

- Asset account defined at floor level:
  - First floor openings for classrooms, halls, faculty and administrative office. The openings in this account include doors, windows, and curtains.

- Asset account defined at subsystem level:
  - Lighting system for all building floors. This account includes lighting fixtures, interior daylighting devices, emergency lighting ballasts, and lamps.
- Asset account defined at space function level:
  - Finishes in the first floor for bathroom. This includes ceiling, flooring and wall finishes.

However, at the asset account level, the integrated asset information that are needed for achieving an effective building management must be identified. In this research, the final life-cycle integrated building asset information that have resulted from the comprehensive literature review include the following data items:

- Categories description: Description of each building type.
- Categories ID: Identification number of each building type.
- Asset account description: All possible asset accounts, where the asset account is an adequate level of detail on the asset management WBS defined to be a management point.
- Asset account ID: Identification number of all asset account.
- Criticality: Value of criticality for each asset account.
- Design life: Estimated service life of the asset account.
- Replacement value: Expected value of the asset account if it need to be replaced.
- Installation or placed date: Date when the asset account is installed or placed in service.
- Building description: Name of the building.
- Building ID: Building identification number.
- Building Address: Address of the building.

- Building area: Area of the whole building.
- Building year built: Year when the building was built.
- Inspection method description: Description of inspection that used for inspecting the asset account (i.e. Direct rating method).
- Inspection method ID: Inspection method identification number.
- Employee name: Name of the inspector or the analyst.
- Employee ID: Inspector or analyst identification number.
- Employee experience: Inspector or analyst level of experience.
- Employee address: Inspector or analyst address.
- Inspection date: Date of inspection.
- Time in service: Age of asset at the time of inspection.
- Condition rating: Condition assessment rating (from 0 to 5).
- Condition rating description: Description of the 0–5 condition rating.
- Condition rating ID: Condition rating identification number.
- Action required: Level of maintenance required depend on the asset condition.
- Criticality rating: Criticality assessment rating (from 0 to 5).
- Criticality rating description: Description of the 0–5 criticality ratings.
- Criticality rating ID: Criticality rating identification number.
- Risk rating: Risk assessment rating (from low to extreme).
- Risk rating description: Description of the low–extreme risk ratings.
- Risk rating ID: Risk rating identification number.
- Prediction date: Date when the remaining service life is estimated.
- Prediction condition value: Condition index for the prediction date.
- Remaining service life: Estimated remaining asset life.
- Maintenance description: Description on maintenance required.

- Maintenance cost: Cost of the maintenance required.

Asset Performance Assessment and Condition Aggregation

It is proposed a multi-part condition rating model. Table 10 is an example that will be used to explain and demonstrate the efficacy of this approach. In this example several buildings are included in the asset management system. Based on the aforementioned WBS inventory framework, the space function level has been identified to be the asset account level for these buildings. The asset account level for the building bathrooms in the architectural systems will be used as the case study which include ceiling, flooring and wall finishes, doors, windows, sinks, sink faucet, toilet, toilet flush, urinals, hand dryers, mirrors, partitions, and showers (see Table 2).

Table 2 uses the component rating system (Table 3) to evaluate the conditions for each asset. The composite asset account score outcomes are calculated using the average of the rounded values closest to whole numbers. Considering the potential combinations of fourteen distinct asset account components and five condition states, each asset account has 1220703125 possible rating outcomes. Based on the composite score value, the asset accounts are as follows: 1.5> excellent condition, 1.5 to 2.4 good condition, 2.5 to 3.4 fair condition, 3.5 to 4,4 poor condition, 4.5-5.0 severe condition. The average value of the sum of each asset at asset account rating represents a composite score.

There is a concern that the values of composite scores and asset account component conditions can vary significantly. For example, in Ellsworth building (Table 10) the value of an average composite score (part 1) is 3.0 (fair condition) while asset account has a component rating of 5.0 (severe condition). Similar discrepancies are also observed in Waldo, Sindecuse, Dunbar, Moore and Knauss bathrooms (Table 10).

Table 10 Rating values in WMU buildings' Bathrooms

	WMU Buildings									
Bathrooms components	**Ellsworth**	**Waldo**	**Sindecuse**	**Floyd**	**Dunbar**	**Moore**	**Chemistry**	**Knauss**	**Physical Plant**	**Wood**
Flooring	4	3	4	1	4	4	3	4	3	3
Walls	4	3	3	2	3	4	2	3	3	3
Ceiling	2	2	3	1	2	2	2	2	2	2
Doors	3	3	3	1	5	3	2	4	2	2
sinks	3	3	2	1	3	3	2	2	2	2
Sink Faucet	2	3	2	1	3	3	3	2	2	2
Toilet	3	2	2	1	3	2	2	2	3	2
Toilet Flush	3	2	2	1	2	4	2	2	2	2
Urinals	4	2	2	1	2	2	2	2	2	2
Hand Dryers	2	2	2	1	2	2	2	2	2	2
Mirrors	3	2	2	1	2	2	2	2	2	2
Partitions	3	4	3	2	4	2	2	5	2	2
Showers	5	3	2	1	3	3	2	3	3	2
Part 1	**3**	**3**	**2**	**1**	**3**	**3**	**2**	**3**	**2**	**2**
Part 2	**5**	**4**	**4**	**2**	**5**	**4**	**3**	**5**	**3**	**3**
Part 3	**5**	**4**	**4**	**1**	**5**	**4**	**2**	**5**	**2**	**2**

To address the identified difference between the values of composite scores and asset account components conditions, this study proposes a new scoring system and a step-by-step (multi-part) model for calculating the rating scores more accurately. The first part will be the average of the asset account composite score. The second part uses the lowest composite score value (highest number) as a definite value for the overall rating score. The third part is designed as a step-by-step guide for choosing either model one or model two. This model uses the lowest composite score value as a definite value for the overall rating score in case this value exceeds four (severe condition). In case the obtained values do not exceed four, the total rating score is calculated as the average value of the sum of each asset rating at asset account (Alkasisbeh 2018).

An Entity-Relationship Conceptual Data Model

An entity-relationship (E-R) conceptual data model for the building asset management information system was developed using the final list of data items (see Figure. 24). In this figure, the E-R data model consists of eleven entities: Facilities categories, buildings, asset accounts definitions, risk rating, asset account inspection, asset account remaining life prediction, criticality rating, employee, inspection method, asset account maintenance, and condition rating. Each entity has data items called asset information or attributes. For example, the 'risk rating' entity has five attributes: 'Condition rating', 'Criticality rating', 'Risk rating ID', 'Risk rating description', and 'Risk rating.'

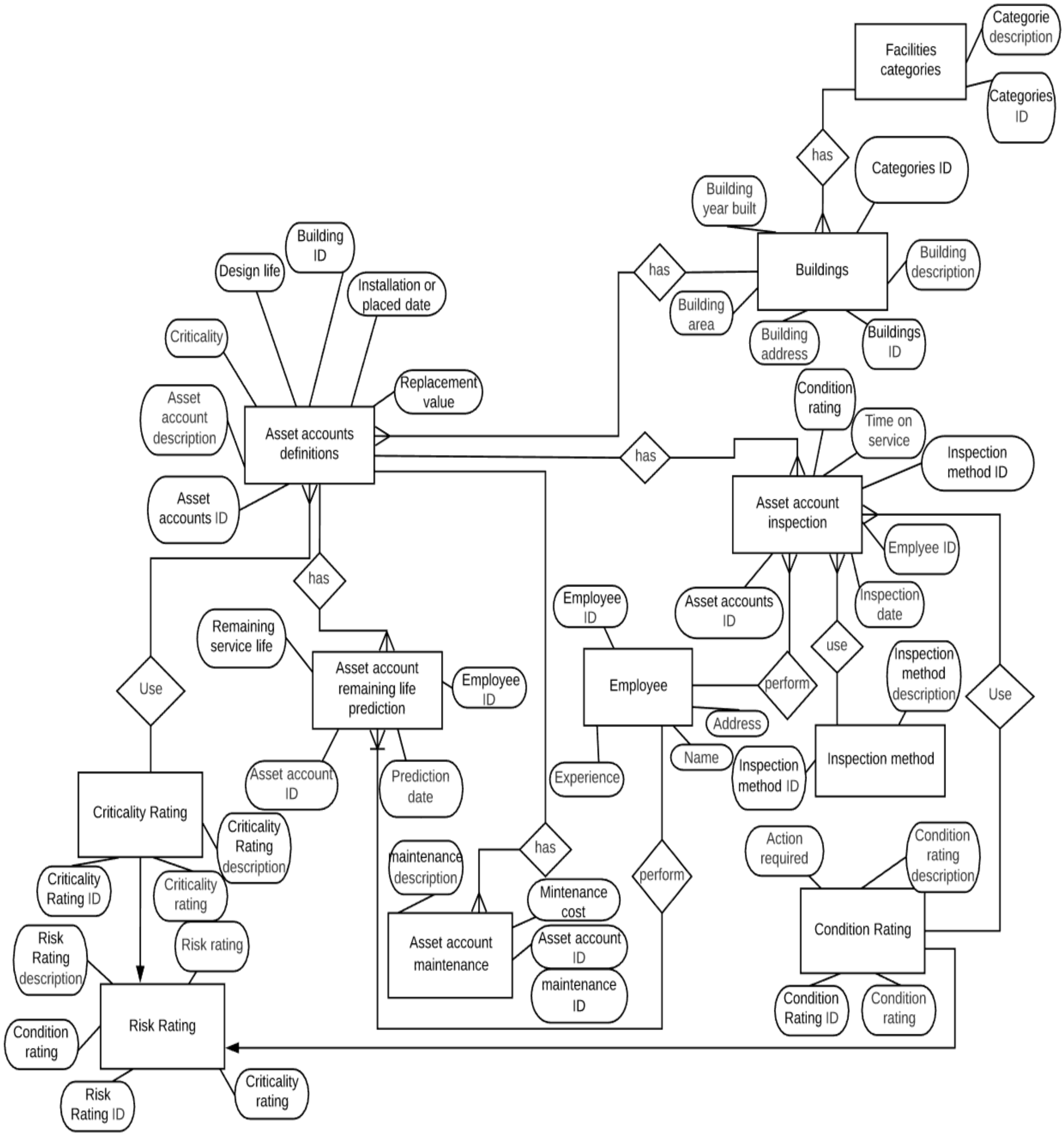

Figure 23 E-R diagram for the building asset information system

CHAPTER VI

ASSET MANAGEMENT MODELING USING THE RELATIONAL MODEL AND BIM

The development of an integrated building asset data management system requires designing a corresponding database schema that represents the various life-cycle phases of the building assets. The computational data model for the asset information system was created from the E-R conceptual data model as a relational database schema. Relations are expressed using the following format:

Relation-name (attribute 1, attribute 2, …. attribute n).

with the primary keys underlined. The relational model has been optimized to the third normal form (3NF) since 3NF eliminates insertion, update, and deletion anomalies (Abudayyeh 2004, Park 2017). The integrated life-cycle building asset management relational model consists of the three main databases: historical, static, and dynamic. The following subsections discuss these databases.

As Built Database and BIM Data (Historical data)

This database includes the tables that have historical as-built information that are generated from the design and construction phases and are potentially stored in BIM models. The tables in this database are:

1. Building (Building ID, Building description, Building address, Building area, Building year built, Categories ID).
2. Asset account definitions (Asset account ID, Building ID, Asset account description, Criticality value, Installation or placed date, Design life, Replacement value).

Static Database

This database includes the tables that define the asset management system components and processes. These tables are:

1. Facilities categories (Categories ID, Categories description).
2. Inspection method (Inspection method ID, Inspection method description).
3. Condition rating (Condition rating ID, Condition rating description, Condition rating, Action required).
4. Criticality rating (Criticality rating ID, Criticality rating description, Criticality rating).
5. Risk rating (Risk rating ID, Asset account ID, Rating description, Risk rating, Condition rating, Criticality value).
6. Employee (Employee ID, Name, Employee experience, Employee address).

Dynamic Database

This database includes the tables that will store and process asset condition assessment and prediction information over time. These tables are:

1. Asset account inspection (Asset account ID, Inspection date, Condition rating, Inspection method ID, Employee ID, Condition rating ID, Time on service,).
2. Asset account remaining life prediction (Asset account ID, Prediction date, Employee ID, Remaining service life,).
3. Asset account maintenance (Asset account ID, Maintenance Description, Maintenance Date, Maintenance cost).

CHAPTER VII

AUTOMATED ASSET MANAGEMENT DECISION SUPPORT SYSTEM

This chapter involves developing a life-cycle relational database model for asset management that is integrated with BIM and composed of historical, static, and dynamic databases. This chapter will involve the following tasks

1. This task involves developing the data acquisition module, which includes designing the required asset inspection and prediction and maintenance forms for the dynamic database along with the data entry forms for populating the static and historical databases.
2. This task involves developing the data storage module which includes creating the database tables from the relational data model and database schema.
3. This task is the data processing module, which includes integrating BIM with DBMS for extracting historical as-built asset information from BIM models as well as developing the asset management reports.
4. This task involves developing the web-based user interface, which involves two menu items including data entry forms and reports.

Data Acquisition Module

The data acquisition module consists of several forms that are developed to facilitate the data entry for populating the three databases. In static database, a data entry form for each static table. For the dynamic database, the information can be obtained directly from the user or extracted from the static or historical databases. The inspection and prediction and maintenance data acquisition forms have been designed to populate the dynamic database. In the inspection data entry form, information regarding the condition of assets include current condition, inspection date and other relevant static and historical information as shown in Figure. 25.

Inspection Data Entry Form			
Building ID:			
Asset account inspection Information			
Inspection date:			
Asset account description		Asset account ID	
Inspection method		Inspection method ID	
Time in service		Condition value	
Employee name:		Signature:	

Figure 24 Dynamic inspection data entry form

The prediction and maintenance form will be used for the prediction of asset remaining life and is based on user data entry as well as data from the static and historical databases. (see Figure. 26).

For the historical database, the information can be obtained from the design and construction phases which will be extracted from the BIM model. To populate the tables in this database, entry forms as well as automated extraction and populating scripts were developed. Figure. 27 shows the data entry form for the historical database, which includes building and the asset account definition tables. Please note that this form is directly invoked by the ETL interface to populate the relevant database tables and is not available to a user.

Prediction and Maintenance Data Entry Form			
Building ID:			
Asset account prediction condition Information			
Asset account description		Asset account ID	
Prediction date:		Prediction condition value	
Asset account maintenance information			
Date:			
Maintenance description		Maintenance cost	
Remaining service life			
Employee name:		Signature:	

Figure 25 Dynamic prediction and maintenance data entry form

Historical Data Entry Form			
Building information			
Building description		Building ID	
Building category		Building Address	
Building area		Building year built	
Asset account Information			
Asset account description		Asset account ID	
Installation or placed date		Design life	
Criticality value		Expected replacement value	

Figure 26 Historical data entry form

Data Storage Module

Figure. 28 schematically illustrates the proposed module that integrates all life-cycle data by using BIM and DBMS. While the dynamic data can be obtained from the asset management phase using inspection and prediction and maintenance forms, the as-built information can be obtained from BIM as a historical database. Note that the complete data storage module is an implementation of the DBMS schema discussed earlier and shown in Figure. 29.

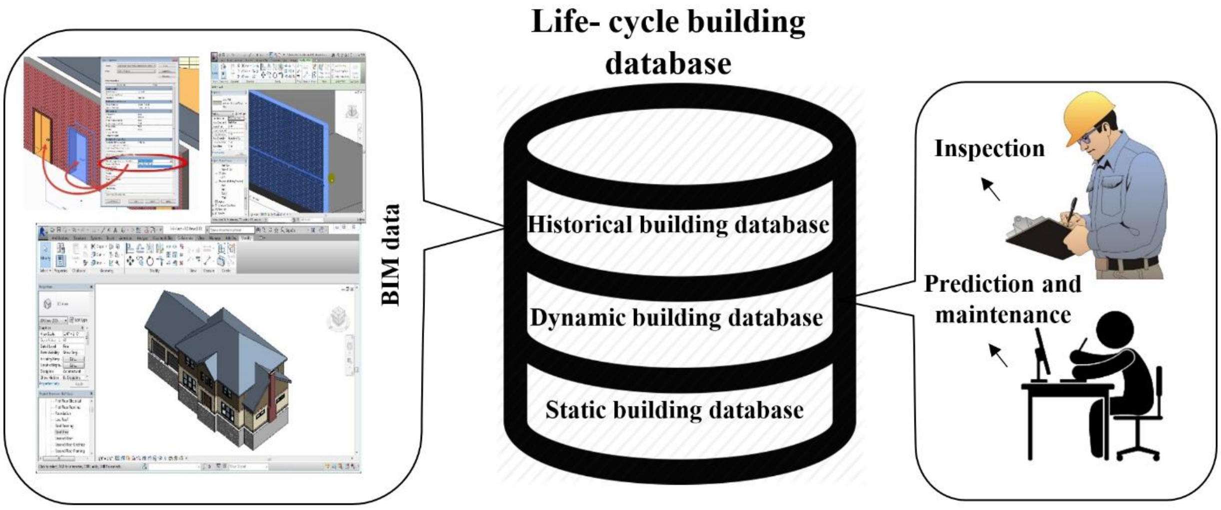

Figure 27 Suggested asset database storage module design

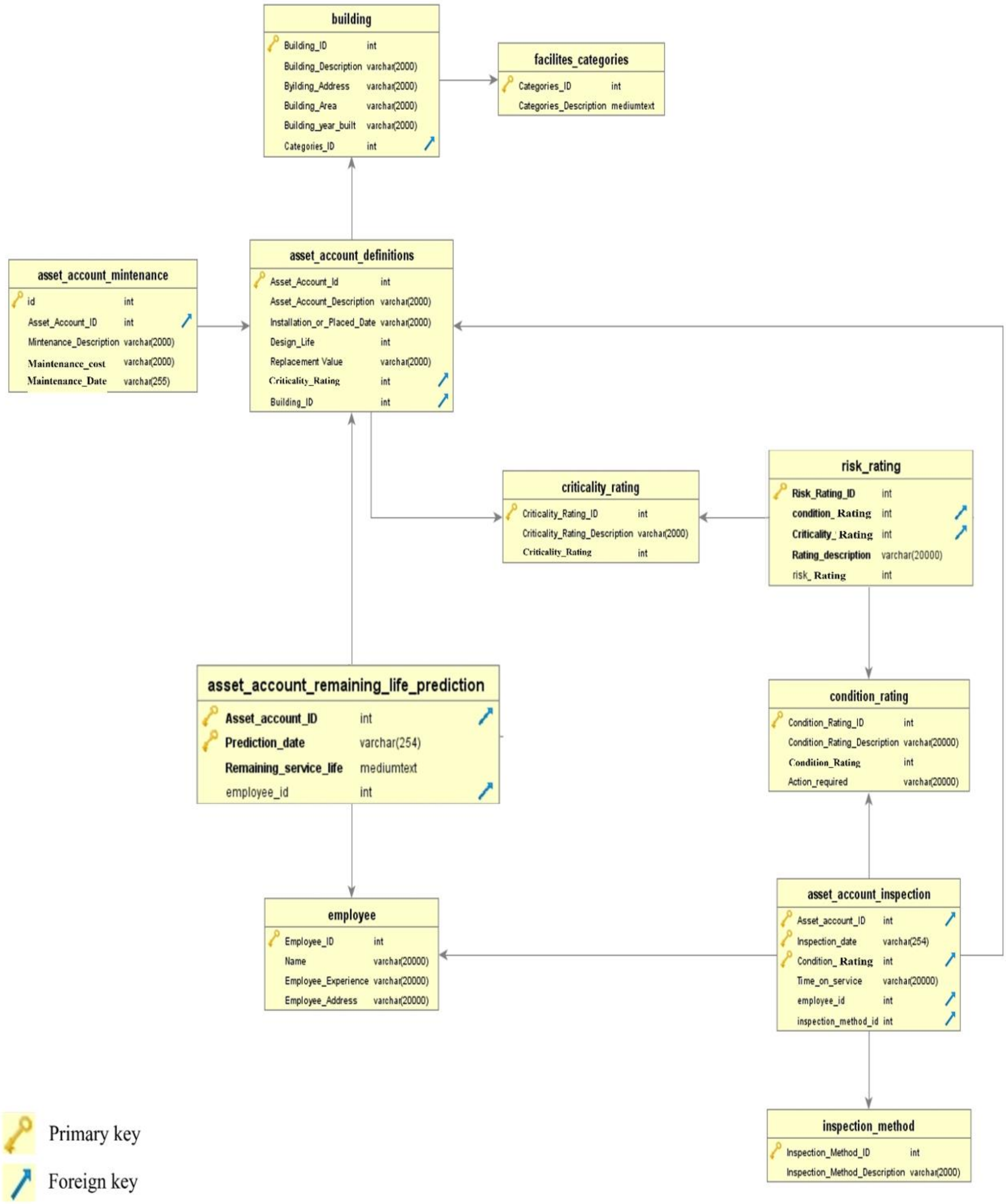

Figure 28 Building asset database schema design

Data Processing Module

To facilitate the extraction of as-built data from the design and construction phases to the asset management decision support system, an Extract, Transform, and Load (ETL) automated

technique was developed. Figure.30 schematically illustrates how this technique has been carried out by performing the three operations:

1. Extract the as-built data from BIM models using flat comma-separated values (CSV) files;
2. Transform the extracted data to a staging area for reformatting to fit the relational database schema; and
3. Load the data into the historical database tables.

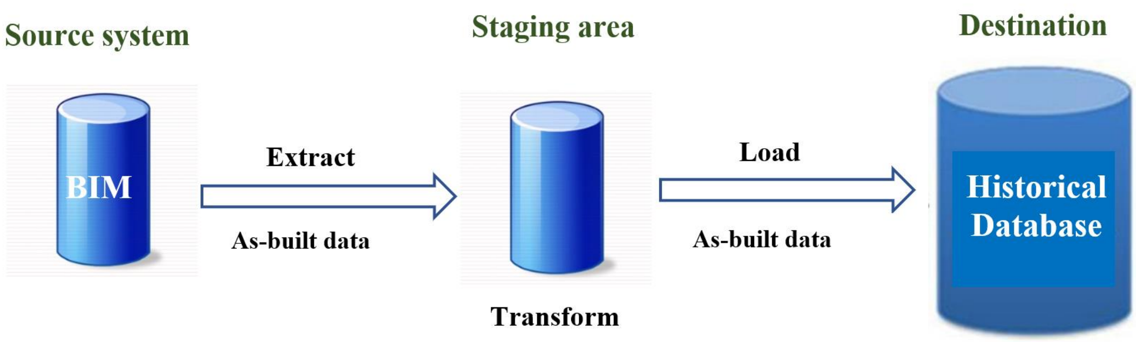

Figure 29 The ETL technique data flow diagram

To process the asset data and produce reports, four database views were designed and developed. Each view produces an asset management report that is used for decision making. The four reports that have been developed are:

- Asset account status report: This report is useful when the status of a certain asset is needed by the asset manager. In this report, the asset condition behavior can be identified for specified given time interval. Determining the condition behavior later will also help in prediction analysis for this asset,
- Asset accounts condition assessment report: This report includes condition information about all existing asset accounts for a given date range. It facilitates making decisions regarding maintenance needs and helps with fund allocation,
- Asset account remaining service life report. This report presents the prediction of the remaining life for all existing assets. It can be helpful for future planning of fund allocation as well as taking proactive maintenance actions,
- Asset account risk assessment report. This report shows the risk value for all existing assets for given date range. It is used when the criticality is important for the decision since the risk value is a function of both condition value and the criticality. Examples of these reports will be provided with the case study section.

User Interface

A web-based user interface has been developed for this system to facilitate access from any computer connected to the internet using a standard browser. The interface includes two menu items (see Figure.31):

1. Data entry forms: This component includes dynamic, static, and historical database entry options.

A. Dynamic database option: This includes three data entree screens including asset account inspection, asset account prediction, and asset account maintenance screens.

Figure 32 represents asset account inspection screen. Figure 33 represents the asset account prediction screen and Figure 34 shows the asset account maintenance screen. Note that some of the fields are populated automatically from the static database such as the asset account description once an ID is entered by the user, while other fields are entered by the user.

B. Static database option: This option has six screens that facilitate populating the tables in the static database.

C. Historical database option: This option facilitates populating the historical database using the ETL technique and the automated scripts that are developed for extracting as-built data.

2. Reports: Four user report options exist under the report menu item:

A. Asset account status report screen,

B. Building asset accounts condition assessment report screen,

C. Building asset accounts condition prediction report screen, and

D. Building asset accounts risk assessment report screen.

Examples of these reports will be discussed in the case study section.

Figure 30 Developed integrated lifecycle asset management web interface

Figure 31 Asset account inspection screen

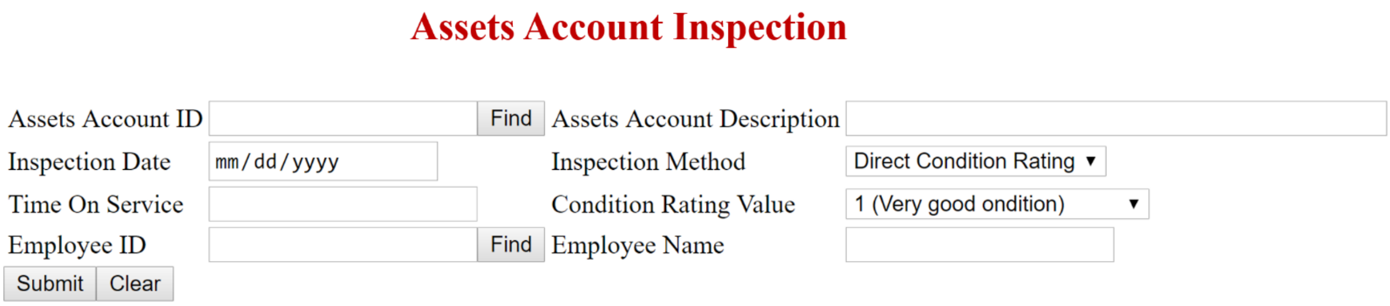

Figure 32 Asset account prediction screen

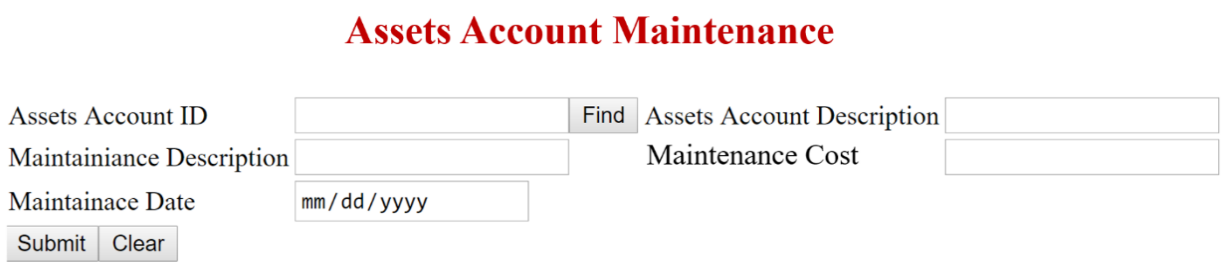

Figure 33 Asset account maintenance screen

CHAPTER VIII

CASE STUDY

Background - WMU College of Engineering and Applied Sciences (CEAS)

The College of Engineering and Applied Sciences (CEAS) building at Western Michigan University (WMU) will be used as a case study in this paper to demonstrate how to use the proposed automated WBS-based asset management framework and decision support system. CEAS was built in 2003 with a total space of 323,000 square feet on 2 floors that are dedicated for teaching and research. It includes seven computer teaching labs, 75 research and teaching laboratories, and several classrooms, offices, study lounges, and breakout rooms. The building also has a penthouse that houses all its mechanical and electrical systems. The layout of the building is divided into two 600-foot wings (east and west) that are joined by a central glass hub. In addition to the entire engineering complex there are two attached parking garages and a basement. Figure. 35 shows the layout of CEAS building.

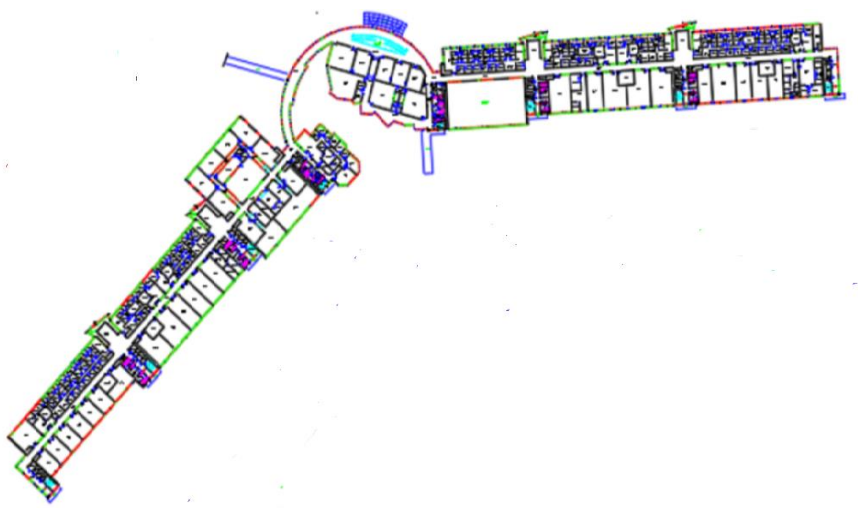

Figure 34 Western Michigan University's College of Engineering and Applied Sciences layout

WBS and Asset Accounts for CEAS

A WBS asset management inventory has been developed for CEAS to be used with the automated asset management decision support system. Portion of the WBS is shown in Figure. 36 which illustrates the CEAS substructure and superstructure. From this figure, the first level is the entire asset management system followed by the educational building type as the second level. The third level is for the building components which includes substructure and superstructure. The forth level is the system level and includes the CEAS architectural, electrical, mechanical, structural, and conveyor system systems.

The fifth level is for the subsystems including finishes and openings for the architectural system; HVAC for the mechanical system; lighting and power for electrical system; and walls and stairs for structural system. The sixth level is for the floors and includes the CEAS first, second, and penthouse levels for the superstructure, and the basement under the substructure. The seventh level is the space function and includes such spaces as faculty and administrative offices, stair area and bathrooms in the first floor, classroom in the second floor, electrical rooms in basement and mechanical room in the penthouse. The eighth level includes such assets as ceiling for faculty and administrative offices, electrical power generator for electrical room and wood single-flush door size: 36" x 84" for classroom E- 241.

As mentioned before the proposed WBS framework has flexible asset accounts at different levels of details. In this case study, the asset accounts are marked with an asterisk as shown in the Figure.36. As demonstrated in this figure, the asset account level represents the depth of the asset management breakdown for each subdivision.

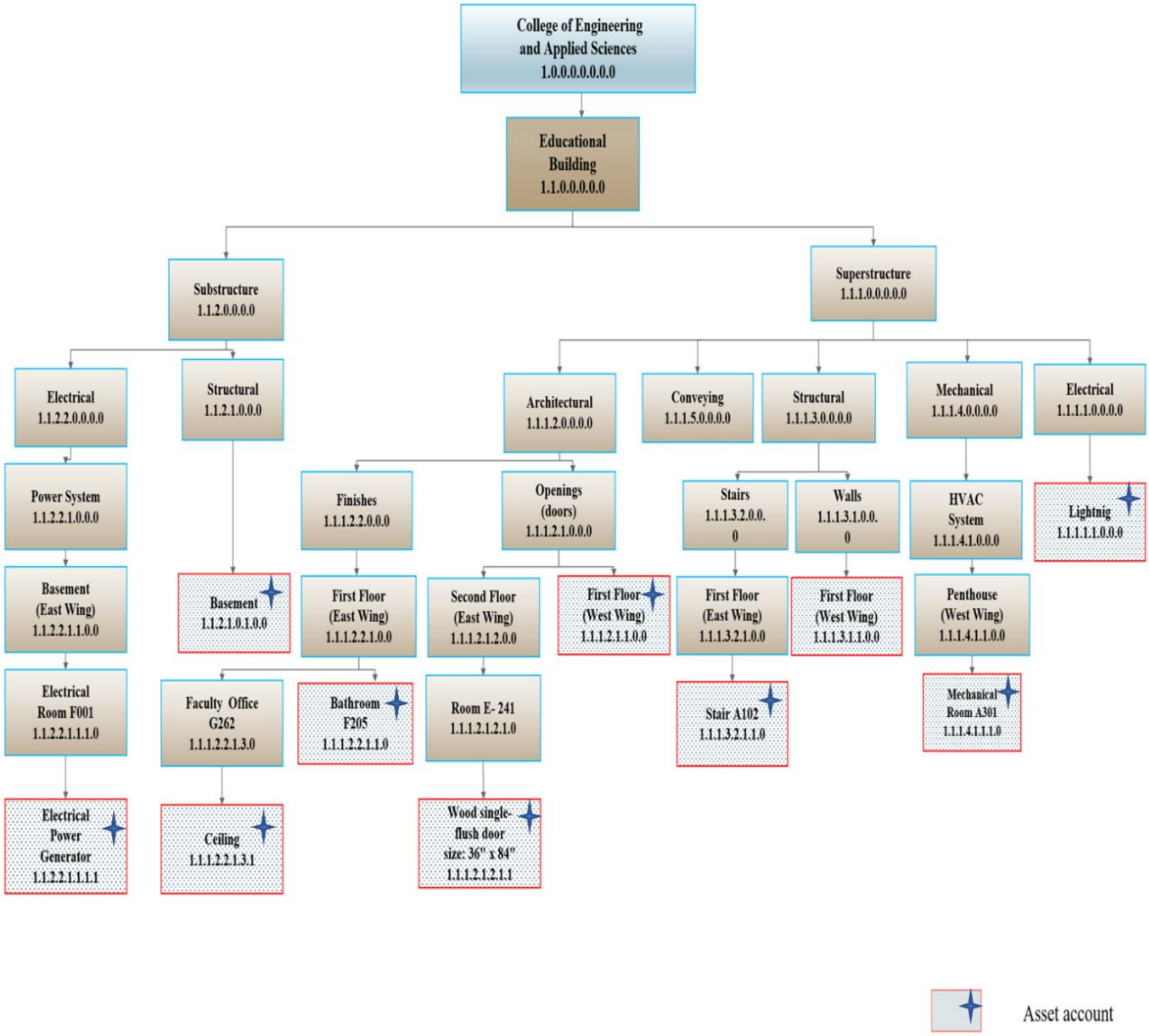

Figure 35 Developed WBS for Western Michigan University's College of Engineering and Applied Sciences

The following are examples of asset accounts defined at different WBS levels along with their descriptions:

- Asset account defined at the floor level (level 6):
  - West and east wings of first floor doors for classrooms, halls, faculty and administrative office.

– Structural system in west and east wings for basement floor which includes beams, columns, walls, slabs, and stairs.

- Asset account defined at subsystem level (level 5):
  – Lighting system for all building floors (first floor, second floor, and penthouse).
- Asset account defined at space function level (level 7):
  – Mechanical equipment in west wing of penthouse for mechanical room A-3001.
  – Finishes in east wing of first floor for bathroom F205. This includes ceiling, flooring and wall finishes.
  – Stair for space function A102. The base level for this stair is first floor and the top level is second floor.
- Asset account defined at asset level (level 8):
  – Celling for faculty office G262 in east wing of first floor.
  – Electrical power generator for electrical room F001 in east wing of basement.
  – Wood single-flush door size: 36" x 84" for room E- 241 in east wing of second floor.

DBMS Tables and Data Entry

For static database storage module that has been identified in DBMS, each table has fixed data (static) as shown in Figures. 37,38,39,40,41 and 42.

Categories_ID	Categories_Description
1	Education and training buildings
2	Service buildings
3	Recreation buildings
4	Healthcare buildings
5	Commerce activity buildings
6	Residential Buildings
7	Storage Buildings
8	Laboratory Buildings
9	Government buildings
10	Library buildings
11	Museum buildings
12	Production, Fabrication, and maintenance buildings
13	Protective buildings
14	Parking buildings
15	Spiritual Buildings

Figure 36 Facility Categories table in the static storage module

These figures represent the data entry for facilities categories table, inspection method, condition rating table, criticality rating table, employee table and risk rating table respectively.

Inspection_Method_ID	Inspection_Method_Description
1	Direct Condition Ratina
2	Distress Survev

Figure 37 Inspection Methods table in the static storage module

Condition_Rating_ID	Condition_Rating_Description	Rating	Action_required
1	Verv aood ondition	1	No maintenance needed
2	Onlv minoe defects	2	Routine maintenance reauired
3	Maintenance reauired to	3	Sianificant maintenance reauired
4	Renewal reauired	4	Renewal and/or uparade reauired
5	Unserviceable assets	5	Replacement is needed

Figure 38 Condition Rating table in the static storage module

Criticality_Rating_ID	Criticality_Rating_Description	Rating
1	Verv minor	1
2	Minor	2
3	Moderate	3
4	Sianificant	4
5	Maior	5

Figure 39 Criticality Rating table in the static storage module

Employee_ID	Name	Employee_Experience	Employee_Address
30	Maha	10 years	1022 w main Dr MI 4009
40	Nancv	5 years	1326 clavmmor Dr MI 4980
50	Matt	15 years	1342 Kl ave MI 4808

Figure 40 Employee table in the static storage module

Risk_Rating_ID	Prediction_condition_value	Criticality_value	Rating_description
1	1	1	Low
2	1	2	Low
3	1	3	Medium
4	1	4	Medium
5	1	5	Medium
6	2	1	Low
7	2	2	Low
8	2	3	Medium
9	2	4	Medium
10	2	5	Medium
11	3	1	Medium
12	3	2	Medium
13	3	3	High
14	3	4	High
15	3	5	High
16	4	1	Medium
17	4	2	Medium
18	4	3	High
19	4	4	Extreme
20	4	5	Extreme
21	5	1	Medium
22	5	2	Medium
23	5	3	High
24	5	4	Extreme
25	5	5	Extreme

Figure 41 Risk Rating table in the static storage module

The historical (as-built) database has been extracted from BIM models. This database includes the building table and asset account definition table as shown in Figures. 43 and 44. Figure 43 represents historical information regarding the CEAS building included in this database. Figure 44 represents historical database for the selected asset accounts for CEAS. For populating the dynamic database, inspection, prediction and maintenance information for these asset accounts have been collected. The inspection data covers the period from 2015 to 2018, the prediction information covers the period from 2014 to 2018, and the maintenance database table year from 2015 to 2018. Examples of these databases are shown in Figures. 45, 46, and 47, respectively.

Building_ID	Building_Description	Byilding_Address	Building_Area	Building_year_built	Categories_ID
10000000	College of Engineering and Applied Sciences (CEAS)	4601 Campus Dr. Kalamazoo, MI 49008	323.000 square feet	2003	1

Figure 42 Western Michigan University's buildings table in the historical BIM database

Asset_Account_Id	Asset_Account_Description	Installation_or_Placed_Date	Design_Life	Replacement Value	Criticality	Building_ID
11111000	Lighting system for all building floors (first floor, ground floor, and penthouse)	2003	20	130.000	5	10000000
11121100	West and east wings of first floor doors for classrooms, halls, faculty and administra...	2003	100	150.000	3	10000000
11121211	Wood single-Flush door size: 36" x 84" for room E- 241 in east wing of second floor	2003	60	1.000	3	10000000
11122110	Finishes in east wing of first floor for bathroom F205	2003	15	80.000	3	10000000
11122131	Ceiling for faculty office G262 in east wing of first floor	2003	15	5.000	2	10000000
11131100	West and east wings of first floor walls	2003	50	300.000	5	10000000
11132110	Stair for space function A102		80	100.000	5	10000000
11141110	Mechanical equipment in west wing of penthouse for mechanical room A-3001	2003	50	200.000	5	10000000
11210100	Structural system in west and east wings for basement floor	2003	100	500.000	5	10000000
11221111	Electrical power generator for electrical room F001 in east wing of basement	2003	25	20.000	5	10000000

Figure 43 College of Engineering and Applied Sciences building's asset account definition table in the historical BIM database

id	Asset_Account_ID	Mintenance_Description	Maintainance_Cost	Maintainace_Date
45	11111000	Routine maintenance	10.000	2015-02-19
46	11111000	Routine maintenance	2.000	2015-10-09
47	11121100	Significant maintenance	20.000	2015-02-09
48	11121100	Routine maintenance	4.000	2016-07-16
49	11122110	Routine maintenance	10.000	2015-03-09
51	11122110	Routine maintenance	1.000	2016-03-16
52	11122110	Routine maintenance	3.000	2018-03-09
53	11221111	Routine maintenance	3.000	2015-05-09
54	11221111	Routine maintenance	500	2017-04-15
56	11221111	Routine maintenance	1000	2018-03-24
57	11121211	Routine maintenance	100	2018-03-18
58	11210100	Routine maintenance	10.000	2015-04-21
59	11210100	Routine maintenance	8.000	2016-07-17
61	11210100	No maintenance	0.00	2018-03-19
4	11121100	Significant maintenance	25.000	2018-03-22

Figure 44 College of Engineering and Applied Sciences building's asset account inspection table

Asset_account_ID	Prediction_date	Remaining_service_life	employee_id
11111000	2014-03-01	4	30
11111000	2015-03-01	4	40
11111000	2016-03-01	4	50
11111000	2017-03-01	4	40
11111000	2018-03-01	3	30
11121100	2014-03-01	4	30
11121100	2015-03-01	4	30
11121100	2016-03-01	4	50
11121100	2017-03-01	4	40
11121100	2018-03-01	3	30
11121211	2014-03-01	5	50
11121211	2015-03-01	5	50
11121211	2016-03-01	5	40
11121211	2017-03-01	5	40
11121211	2018-03-01	5	50

Figure 45 College of Engineering and Applied Sciences building's asset account remaining life prediction table

id	Asset_Account_ID	Mintenance_Description	Rehabilitation_Cost	maintainace_Date
48	11121100	Routine maintenance required	N/D	2016-07-16
49	11122110	Routine maintenance required	N/D	2015-03-09
50	11122110	Routine maintenance required	N/D	2015-09-09
51	11122110	Routine maintenance required	N/D	2016-03-16
52	11122110	Routine maintenance required	N/D	2018-03-09
53	11221111	Routine maintenance required	N/D	2015-05-09
54	11221111	Routine maintenance required	N/D	2017-04-15
55	11221111	Routine maintenance required	N/D	2017-10-27
56	11221111	Routine maintenance required	N/D	2018-03-24
57	11121211	Routine maintenance required	N/D	2018-03-18
58	11210100	Routine maintenance required	N/D	2015-04-21
59	11210100	Routine maintenance required	N/D	2016-07-17
60	11210100	Routine maintenance required	N/D	2017-05-11
61	11210100	Routine maintenance required	N/D	2018-03-19
62	11111000	No maintenance needed	N/D	2018-03-09

Figure 46 College of Engineering and Applied Sciences building's asset account maintenance table

Asset Management Reporting

The following reports are examples from the CEAS asset management decision support system:

- Asset Account Status Report (see Figure. 48): This report presents an example of the status of a specific asset over a specified period of time. For example, Figure. 48 is the *Celling for Faculty Office G262 in East Wing of First Floor* asset account report and shows that the ceiling of this room was in a good condition (Rated as 2) in 2015 and began to deteriorate in 2016 and 2017 with ratings of 3 and 4, respectively. In 2018, this asset has reached a rating of 5 that requires a total replacement. (see appendix B for this report view).

Assets Account Status Report

From 01/01/2015 To 03/20/2018
Building ID 10000000 Asset Account ID '11122131' Submit

Asset Account Description: **Celling for faculty office G262 in east wing of first floor**
Building Name: **College of Engineering and Applied Sciences (CEAS)**

Date	Condition Value	Condtion rating Description
2015-01-09	2	Only minor defects
2015-09-09	2	Only minor defects
2016-03-16	3	Maintenance required
2016-09-29	3	Maintenance required
2017-05-15	4	Renewal required
2017-10-23	4	Renewal required
2018-03-09	5	Unserviceable assets

Figure 47 An example of an asset account status report

- Building Asset Accounts Condition Assessment Report (see Figure 49): This report presents condition ratings during the month of March 2018 for all CEAS assets. This report indicates that some assets (i.e. celling for faculty office G262 in east wing of first floor) need to be replaced while others (i.e. lighting system for all building floors (first floor, ground floor, and penthouse)) do not need any maintenance. (see appendix C for this report view).

Building Assets Accounts Condition Assessment Report

From 03/01/2018 To 03/30/2018 Building ID 10000000 Submit

Building Name: **College of Engineering and Applied Sciences (CEAS)**

Asset Account ID	Asset Condition Description	Condition Value	Condtion rating Description
11111000	Lighting system for all building floors (first floor, ground floor, and penthouse)	1	Very good ondition
11121211	Wood single-Flush door size: 36" x 84" for room E- 241 in east wing of second floor	2	Only minor defects
11122110	Finishes in east wing of first floor for bathroom F205	2	Only minor defects
11210100	Structural system in west and east wings for basement floor	2	Only minor defects
11221111	Electrical power generator for electrical room F001 in east wing of basement	2	Only minor defects
11121100	West and east wings of first floor doors for classrooms, halls, faculty and administrative office	3	Maintenance required
11132110	Stair for space function A102	3	Maintenance required
11141110	Mechanical equipment in west wing of penthouse for mechanical room A-3001	3	Maintenance required
11121100	West and east wings of first floor doors for classrooms, halls, faculty and administrative office	5	Unserviceable assets
11122131	Celling for faculty office G262 in east wing of first floor	5	Unserviceable assets

Figure 48 An example of a building assets accounts condition assessment report

- Building Assets Account Remaining Service Life Report (see Figure 50): This report presents the prediction of the remaining service life for all CEAS asset from year 2016 to 2018. From this report the asset manager must conclude that the *Celling for Faculty Office G262 in East Wing of First Floor asset* is a priority. (see appendix D for this report view).
- Building Asset Accounts Risk Assessment Report (see Figure 51): In this report all the risk values for the CEAS assets in 2018 has been presented. This report shows that the asset including lighting system for all building floors (first floor, ground floor, and penthouse), stair for space function A102, and mechanical equipment in west wing of penthouse for mechanical room A-3001 have more risk value so it should be the focus of the asset manager. (see appendix E for this report view).

Building Assets Accounts Remaining Service Life Report

From 01/01/2016 To 03/01/2018 Building ID 10000000 Submit

Building Name: **College of Engineering and Applied Sciences (CEAS)**

Asset Account ID	Asset Condition Description	Remaining service life	Year
11111000	Lighting system for all building floors (first floor, ground floor, and penthouse)	9	2016
11111000	Lighting system for all building floors (first floor, ground floor, and penthouse)	8	2017
11111000	Lighting system for all building floors (first floor, ground floor, and penthouse)	7	2018
11121100	West and east wings of first floor doors for classrooms, halls, faculty and administrative office	24	2016
11121100	West and east wings of first floor doors for classrooms, halls, faculty and administrative office	24	2017
11121100	West and east wings of first floor doors for classrooms, halls, faculty and administrative office	24	2018
11121211	Wood single-Flush door size: 36" x 84" for room E- 241 in east wing of second floor	44	2016
11121211	Wood single-Flush door size: 36" x 84" for room E- 241 in east wing of second floor	43	2017
11121211	Wood single-Flush door size: 36" x 84" for room E- 241 in east wing of second floor	42	2018
11122110	Finishes in east wing of first floor for bathroom F205	6	2016
11122110	Finishes in east wing of first floor for bathroom F205	5	2017
11122110	Finishes in east wing of first floor for bathroom F205	5	2018
11122131	Celling for faculty office G262 in east wing of first floor	5	2016
11122131	Celling for faculty office G262 in east wing of first floor	5	2017
11122131	Celling for faculty office G262 in east wing of first floor	4	2018
11131100	West and east wings of first floor walls	84	2016
11131100	West and east wings of first floor walls	84	2017
11131100	West and east wings of first floor walls	83	2018
11132110	Stair for space function A102	64	2016
11132110	Stair for space function A102	64	2017
11132110	Stair for space function A102	63	2018
11141110	Mechanical equipment in west wing of penthouse for mechanical room A-3001	33	2016
11141110	Mechanical equipment in west wing of penthouse for mechanical room A-3001	32	2017
11141110	Mechanical equipment in west wing of penthouse for mechanical room A-3001	32	2018
11210100	Structural system in west and east wings for basement floor	84	2016
11210100	Structural system in west and east wings for basement floor	84	2017
11210100	Structural system in west and east wings for basement floor	84	2018
11221111	Electrical power generator for electrical room F001 in east wing of basement	9	2016
11221111	Electrical power generator for electrical room F001 in east wing of basement	9	2017
11221111	Electrical power generator for electrical room F001 in east wing of basement	8	2018

Figure 49An example of building assets accounts remaining service life report

Building Assets Accounts Risk Assessment Report

From 01/01/2018 To 03/30/2018 Building ID 10000000 Submit

Building Name: **College of Engineering and Applied Sciences (CEAS)**

Asset Account ID	Asset Condition Description	Risk Value	Risk Rating Desc
11111000	Lighting system for all building floors (first floor, ground floor, and penthouse)	4	Extreme
11121100	West and east wings of first floor doors for classrooms, halls, faculty and administrative office	3	High
11121211	Wood single-Flush door size: 36" x 84" for room E- 241 in east wing of second floor	3	High
11122110	Finishes in east wing of first floor for bathroom F205	3	High
11122131	Celling for faculty office G262 in east wing of first floor	2	Medium
11131100	West and east wings of first floor walls	2	Medium
11132110	Stair for space function A102	4	Extreme
11141110	Mechanical equipment in west wing of penthouse for mechanical room A-3001	4	Extreme
11210100	Structural system in west and east wings for basement floor	3	High
11221111	Electrical power generator for electrical room F001 in east wing of basement	3	High

Figure 50 An example building assets accounts risk assessment report

CHAPTER IX

CONCLUSION

Summary

Building asset management is an integrated data-driven decision-making process that is needed for proactively maintaining and ensuring the long-term sustainability of building assets. This research effort presented a building asset management system that was developed using on the WBS hierarchy as the sole model for managing all phases of a building life-cycle. A life-cycle asset management system has been developed based on an integrated relational DBMS-BIM model. The integrated approach addresses the challenges discussed in the literature by creating one conceptual model that can be used throughout the life-cycle of a building and by facilitating the integration of BIM with asset management, resulting in more sustainable, efficient and well managed buildings, as well as in eliminating the costly and time-consuming duplicate efforts caused by the separation of the life-cycle processes. The proposed framework provides an inventory system that covers all types of buildings along with their life-cycle information. The framework provides an accurate location for each asset in a building, hence facilitating maintenance work assignments and allowing information integration between the various phases of the life-cycle. It also allows for creating flexible asset accounts that can be defined at any WBS level depending on the desired details and the availability of resources. An automated decision support system for building asset management using BIM and DBMS was then developed. This included developing the data acquisition, data storage, and data processing modules. Furthermore, this research has illustrated how using a single number to generate a composite rating of a building asset condition assessment can lead to inaccurate results and increase the possibility of faulty conclusions about the buildings. To improve the condition rating, a new scoring system and a step-by-step guideline model to calculate the performance assessment was developed.

Conclusions

While there are several existing systems in use for building asset management, they all suffer from the challenges that are discussed in the paper. This research has tried to address and improve on these challenges. What is being proposed in this work is a fundamental shift from fragmented approaches to an integrated life-cycle approach that addresses these challenges. Also using BIM-based solution is desired, but several incremental steps before adopting a BIM for the asset management process are need, since effective building asset data management requires the development of an integrated data model so that information can flow better during the lifecycle.

Therefore, this research addressed the conceptual integration framework of all phases in the life-cycle, so the information can flow better during the lifecycle and then this integrated become the basis for the development of a decision support system for asset management using BIM and DBMS. However, the large inventory of old facilities that lack design and/or construction information will continue to be a challenge and limitation for this study. More research will be needed to address this challenge.

Contributions

The contributions of the work presented in this dissertation include:

- Proposing the use of the WBS model as the sole approach for integrating all life-cycle phases of a building. This integration facilitates maintenance work assignments and allows information integration between the various phases of the life-cycle, hence reducing the costly and time-consuming duplicate efforts caused by the separation of the life-cycle processes.
- Increasing the efficiency of building asset management by facilitating a wide range of functionalities including enabling the accurate acquisition, storage, processing, and reporting of asset information in a timely manner by using the

proposed automated BIM-DBMS decision support system that integrates all life cycle phases of buildings.

- Developing a multi-phase condition rating method that will help decision-makers have a more accurate condition assessment for their assets to identify critical assets and more effectively allocate resources for repairs and/or replacements.

Recommendations for Future Research Directions

There are several potential improvements to the developed asset management system that can be further researched. These include:

- The integrated framework can be the starting point for extensive analysis and modeling of as-built data that are needed for building asset management.
- Integrating the BIM-DBMS asset management with geographic information systems (GIS) to improve certain asset tracking such as underground utilities.
- Expanding BIM platforms to include full relational DBMS functionalities.
- Examining the applicability of the proposed framework on other types of municipal assets such as roads, and bridges.
- Developing asset condition prediction models so that long-term funding and resource plans can be developed for the building asset management.
- Developing risk assessment models that incorporate probability of failure and criticality of asset for evaluating significant building assets.

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Appendix A: Standard classifications of decomposition criteria

Building Categories	Building parts	Floor/Altitude	Asset' s Tasks	Building Systems	Subsystems
• Service buildings • Education and training buildings • Recreation buildings • Healthcare buildings • Commerce activity buildings • Storage Buildings • Residential Buildings • Laboratory Buildings • Government buildings • Library building • Museum buildings • Production, Fabrication, and maintenance buildings • Protective buildings • Parking buildings • Spiritual Buildings	• Superstructure • Substructure • Sitework	• Foundation • Basement • Ground floor • First floor • Second floor • Third floor • Fourth floor • Successive floor •	• Define component criticality • Determine the time in service • Compute remaining service life • Inspect current condition • Predict deterioration rate • Determine costs of rehabilitation • Determine asset performance standards thresholds • Specify the asset nameplate (type, make, model, serial) • Determine the quantity • Determine purchasing information • Determine date placed in service • Determine expected useful life • Determine expected replacement value	• Structural • Architectural • Mechanical • Electrical • Conveying	• Openings • Finishes • furnishing • equipment • fire suppression • plumbing • Gas and Vacuum Systems • Heating, ventilating and air conditioning system (HVAC system) • Water distribution • sanitary sewerage • storm drainage • Fuel distribution • Integrated automation • Power distribution • lightening • Lighting • communication, • safety and security • Landscape

Appendix A -Continued

Space Function

- **Planned work space**
- **Planned building service space**
- **Planned Circulation Space**
- **Planned Parking Space**
- **Light Well**
- **Air Shaft**
- **Occupant Void Area**
- **Exterior Wall Space**
- **Interior Wall Space**
- **Perimeter Encroachment**
- **Exterior Parking Spaces**
- Exterior Parking Circulation
- Exterior Parking Access Control Point
- Exterior Parking Stall
- **Interior Parking Spaces**
- Interior Parking Ramp and Circulation
- Interior Parking Access Control Point
- Interior Parking Stall
- Interior Vehicle Service Space
- **Vertical Penetration**
- Mechanical Circulation
- Elevator Shaft
- Elevator Pit
- Elevator Cab
- Elevator Machine Room
- Dumbwaiter
- Escalator
- Freight Elevator
- Stairway
- Egress Stairway
- Tenant Stairway
- Monumental Stair
- Ramp
- Chimney
- Chute
- Service Riser Space
- Power Distribution Riser
- Information Signal Distribution Riser
- Gas Distribution Riser
- Liquid Distribution Riser
- **Horizontal Infrastructure/Service Space, Non-Occupied**
- Power Distribution Network
- Information Signal Network
- Gas Distribution Network
- Liquid Distribution Spaces
- **Control Room**
- Fire Command Center
- Guard Stations
- **Loading Dock**
- **Restroom**
- Men's Restroom
- Women's Restroom
- Unisex Restroom
- **Utility Equipment Room**
- Refrigerant Machinery Room
- Furnace Room
- Incinerator Room
- Fuel Room
- Gas Room
- Liquid Storage Room
- Liquid Use, Dispensing and Mixing Room
- Hydrogen Cutoff Room
- Electrical Room
- Switch Room
- Telecommunications Room
- Transformer Vault
- **Waste and Recycling Spaces**
- Hazardous Waste Storage
- **Building Service Support Spaces**
- Building Manager Office
- Custodial Space
- Shop Area
- Access Chamber
- Areaway
- Service Space
- Furred Space
- Crawl Space
- Attic Space
- Plenum
- **Equipment Platform**
- **Interstitial Space**
- Unimproved Shell
- Alteration or Conversion Space
- Circulation Spaces
- **Primary Circulation Spaces**
- Corridor
- Aisle
- Mall
- Concourse
- Concourse
- Breezeway
- Moving Walkway
- **Transitional Circulation Spaces**
- Entry Vestibule
- Entry Lobby
- Box Lobby
- Vestibule
- Elevator Lobby
- Freight Elevator Vestibule
- Landing
- Anteroom
- Air Lock
- Sally Port
- Jet Way
- Secondary Circulation Spaces
- Door Set-Back
- Restricted Spaces
- Refuge Spaces
- Transitional Circulation Spaces
- **Connector**
- **External Circulation Spaces**
- **Secondary Circulation Spaces**
- Door Set-Back
- **Restricted Spaces**
- **Refuge Spaces**
- **Breakout Space**
- **Lecture and Classroom Spaces**
- Lecture Classroom
- Classrooms (age 9 plus
- Classrooms (ages 5–8)
- Lecture Hall (Fixed Seats
- Assembly Hall
- Seminar Room
- **Class Laboratories**
- Open Class Laboratory
- Physics Teaching Laboratory
- Astronomy Teaching Laboratory
- Research/non-class Class Laboratory
- Laboratory Service Space
- **Training Spaces**
- Computer Lab
- Woodshop/Metal shop
- Training Support Space
- Religious Education Space
- **Study Spaces**
- Study Room
- Study Service
- **Athletic Recreation Spaces**
- Athletic Spectator Seating
- Bleacher
- **Team Athletic Recreation Spaces**

Appendix A -Continued

Space Function

- **Outdoor Swimming Pool**
- **Indoor Swimming Pool**
- Diving Tank
- **Non-Athletic Recreation Spaces**
- **Park**
- **Pleasure Garden**
- **Indoor Firing Range**
- **Outdoor Shooting Range**
- **Recreational Deck**
- **Playground**
- **Game Room**
- **Gambling Table**
- **Amusement Ride**
- **Parade Grounds**
- **Computer-Aided Visual Environment**
- **Hobby and Craft Center**
- **Dance Floors**
- **Wellness Spaces**
- **Fitness Center**
- Exercise Room
- Weight Room
- **Judicial Spaces**
- **Courtroom**
- Jury Box
- Jury Room
- Judge' s Bench
- Evidence Room
- Jury Assembly Space
- Witness Stand
- **Judge' s Chambers**
- **JCC–Judicial Chambers**
- **Law Clerk Space**
- **Robing Area/Room**
- **Hearing Room**
- JHR–Judicial Hearing Room
- **Legislative Spaces**
- **Council Chambers**
- **Legislative Hearing Room**
- **Military Spaces**

- **Military Spaces**
- **Performance Spaces**
- **Outdoor Theater**
- **General Performance Spaces**
- Acting Stage
- Orchestra Pit
- Performance Rehearsal Space
- Soundstage
- Performance Hall
- Band Training Space
- **Audience Spaces**
- Pre-Function Lobby
- Audience Seating Space
- **Supporting Performance Spaces**
- Projection Booth
- Catwalk
- Stage Wings
- Motion Picture Screen Space
- **Display Spaces**
- **Art Gallery**
- **Exhibit Gallery**
- **Sculpture Garden**
- **Ornamental Garden**
- **Observation Deck**
- **Creative Spaces**
- **Recording Studio**
- **Artist' s Studio**
- **Photo Lab**
- Motion Picture Exchange
- **Media Production**
- Media Production Support
- Sound Lock
- **Zen Garden**
- **Museum Gallery**
- **Library**
- **Library Stack**
- **Worship spaces**
- **Meditation Chapel**
- **Altar**
- **Reflection Space**

- **Chapel**
- **Mihrab**
- **Shrine**
- **Sanctuary**
- **Confessional Space**
- **Ark**
- **Bimah**
- **Tabernacle**
- **Pulpit**
- **Choir Loft**
- **Ceremonial Spaces**
- **Marriage Sanctuary**
- **Baptistery**
- **Circumcision Space**
- **Cathedra**
- **Procession Spaces**
- **Death Spaces**
- **Crypt**
- **Morgue**
- Morgue Compartment
- **Grave Space**
- **Anechoic Chamber**
- **Hazard Containment**
- **Clean Room**
- Clean Room Class 1
- Clean Room Class 2
- Clean Room Class 3
- Clean Room Class 4
- Clean Room Class 5
- Clean Room Class 6
- Clean Room Class 7
- Clean Room Class 8
- Clean Room Class 9
- Clean Room Support Space
- **Temperature and Pressure Chamber**
- Data Center
- Data Center Tier I
- Data Center Tier II
- Data Center Tier III

- Data Center Support Space
- **Controlled Space Support**
- **Miscellaneous Environmentally Controlled Spaces**
- Film Storage Vault
- Computer Server Room
- **General Examination Spaces**
- Exam Room
- Exam Room, Airborne Infection Isolation
- Exam Room, Isolation
- Exam Room, OB/Gyn
- Exam Room, Pediatric
- Exam Room, Protective Environment Isolation
- Exam Room, Podiatry
- Exam Room, Security
- Height/Weight Screening Space
- Holding Room, Secured
- **Inpatient Care Spaces**
- Anteroom, Inpatient Airborne Infection Isolation
- Anteroom, Inpatient Protective Environment Isolation
- Anteroom, Inpatient Isolation/Seclusion
- Labor, Delivery, Recovery, Postpartum Room
- Medical Information Computer System Room
- Newborn Nursery
- NICU Nursery
- Nursery Transport Unit Alcove
- Nursery, Airborne Infection Isolation
- Nursery, Observation
- Nursery, Special Care

Appendix A -Continued

Space Function

- Patient Room
- Patient Room, Airborne Infection Isolation
- Patient Room, Bariatric
- Patient Room, Intensive Care
- Patient Room, Intensive Care, Airborne Infection Isolation
- Patient Room, Intensive Care, Protective Environment Isolation
- Patient Room, Isolation
- Patient Room, Monitored
- Patient Room, One-Bed
- Patient Room, Protective Environment Isolation
- Patient Room, Seclusion
- Patient Room, Transitional, One-Bed
- Patient Room, Two-Bed
- **<u>Multi-Medical Service Support Spaces</u>**
- Clean Linen Storage Room, Healthcare
- Clean Supply Room, Healthcare
- Clean Utility Room, Healthcare
- Consultation Room, Patient
- Mental Health Interview/Counseling Room
- Equipment Storage Room, Healthcare
- Medical Records Storage Room
- Nurse Workspaces
- Nurse Station
- Nurse Station/Communication Center
- Nurse Sub-Station
- Nurse Triage Space
- Soiled Utility Room, Healthcare
- Soiled Utility/Supply Room, Healthcare
- Mental Health Multipurpose Room w/Control Room
- Resuscitation Cart Alcove
- Mental Health Quiet Room
- **<u>Diagnostic Imaging Spaces</u>**
- Angiographic Procedure Room
- Bone Densitometry Room
- CT Scanning Room
- CT Simulator Room
- Cystoscopy Radiology Room
- Head Radiographic Room
- Mammography Room
- Mobile Imaging System Alcove
- MRI Scanning Room
- MRI System Component Room
- PET/CT Scanning Room
- PET/CT Simulator Room
- Radiographic Chest Room
- Radiographic Room
- Radiographic/Fluoroscopic Room
- Radiographic/Tomographic Room
- Radiology Computer Systems Room
- Stereotactic Mammography Room
- Ultrasound Room
- Ultrasound/Optical Coherence Tomography Room
- Whole Body Scanning Room
- **<u>Diagnostic Imaging Support Spaces</u>**
- Angiographic Control Room
- Angiographic Instrument Room
- Angiographic Procedure Control Area
- Angiographic System Component Room
- Silver Collection Area, Diagnostic Imaging
- Computed Radiology Reader Area
- Computer Image Processing Area, Diagnostic Imaging
- X-Ray, Digital Image Storage Space
- CT Control Area
- CT Power and Equipment Room
- Image Quality Control Room
- Image Reading Room
- X-Ray, Plane Film Storage Space
- Mammography Processing Room
- X-Ray Film, Daylight Processing Space
- MRI Control Room
- MRI Viewing Room
- PET/CT Control Room
- Radiographic Control Room
- Radiographic Darkroom
- Tele-Radiology/Tele-Medicine Room
- Viewing/Consultation Room, Diagnostic Imaging
- X-Ray, Mobile C-Arm Alcove
- **<u>Radiation Diagnostic and Therapy Spaces</u>**
- Equipment Calibration Space, Radiation Diagnostic and Therapy
- Health Physics Laboratory
- Linear Accelerator Component Room, Healthcare
- Linear Accelerator Entrance Maze, Healthcare
- Linear Accelerator Room, Healthcare
- Linear Accelerator Control Room, Healthcare
- Radioactive Waste Storage Room, Healthcare
- Nuclear Medicine Dose Calibration Space
- Nuclear Medicine Scanning Room
- Nuclear Medicine Patient "Hot" Waiting Room
- Patient Dose/Thyroid Uptake Room
- Radiation Dosimetry Planning Room
- Radio pharmacy
- Radium Cart Holding Space
- Radiation Therapy, Mold Fabrication Shop
- Sealed Source Room
- **<u>Heart and Lung Diagnostic and Treatment Spaces</u>**
- Brachytherapy Room
- Cardiac Catheter Instrument Room
- Cardiac Catheter System Component Room
- Cardiac Catheterization Control Room
- Cardiac Catheterization Laboratory
- Cardiac Testing Room
- Echocardiograph Room
- EKG Testing Room
- Extended Pulmonary Function Testing Laboratory
- Microvascular Laboratory
- Pacemaker ICD Interrogation Room
- Pacemaker/Holter Monitor Room
- Procedure Viewing Area
- Pulmonary Function Testing Laboratory
- Pulmonary Function Treadmill Room
- Pulmonary Screening Room
- Respiratory Inhalation Cubicle
- Respiratory Therapy Clean-up Room
- Spirometry Test Room
- Stress Echocardiograph Room
- Stress Testing Treadmill Room
- Transesophageal Echocardiography Room
- **<u>General Diagnostic Procedure and Treatment Spaces</u>**
- **<u>General Diagnostic Procedure and Treatment Spaces</u>**
- Allergen Preparation Space
- Allergy Injection Room
- Allergy Skin Testing
- Antepartum Testing (NST) Room
- Biofeedback Treatment Control/Office
- Biofeedback Treatment Room
- Cast and Splint Room
- Chemotherapy Treatment Room
- Dermatology Cryotherapy Space

Appendix A -Continued

Space Function

- Dialysis Clean Equipment Preparation Room
- Dialysis Soiled Equipment Processing
- Dialysis Training Room
- EEG Exam Room
- EEG Instrument and Work Room
- EEG/Sleep Study Monitoring Room
- Electromyography Room
- ENT Procedure Room
- Evoked Potential Response Room
- General Purpose Dirty Treatment Room
- Immunization Room
- Infectious Disease Decontamination Shower
- Infectious Disease Decontamination Suite
- Life Support Unit Room
- OB/GYN Treatment Room
- Patient Observation and Treatment Room
- Pentamidine Treatment Room
- Peritoneal Dialysis Exam Room
- Peritoneal Dialysis Procedure Room
- Phototherapy Treatment Room
- Renal Dialysis Bed Station, Private
- Renal Dialysis Room, Negative Pressure
- Renal Dialysis, Chair Station, Cubicle
- Renal Dialysis, Water Treatment Room
- Sleep Study Room
- Provider Trainee Observation Area, Healthcare
- Treatment Cubicle, Healthcare
- Treatment Room, Healthcare
- Neuropsychology Testing Laboratory
- **Eye and Ear Healthcare Spaces**
- Audiology Immittance Room
- Audiometric Exam Booth
- Audiometric Exam Suite
- Audiometric Multi-Exam Suite
- Audiology Electrophysiology Exam Room
- Hearing Aid Testing Laboratory
- Electroretinography Room
- ENT Exam Room
- Exam/Training Room, Low Vision
- Eye Lane
- Laser Treatment Room
- Ophthalmology Procedure Room
- Ophthalmology/Optometry Exam Room
- Photography Room, Ophthalmology/Optometry
- PRK/LASIK Treatment Room
- Sinusoidal Vertical Axis Rotational Rest Room
- Tilt Table Testing Room
- Training Room, Low Vision, Polytrauma
- Ultrasound/Optical Coherence Tomography Room
- Ventriculography Room
- Vision/Hearing Screening Room
- Vision Screening Room
- Vision Testing Station
- Visual Fields Room
- Eye, Contact Lens Fitting/Dispensing Space
- Eyeglass Fitting and Dispensing Space
- **Endoscopy/Gastroenterology Spaces**
- Bronchoscopy Equipment Preparation Room
- Bronchoscopy Procedure Room
- Endoscope Clean-up, Sterilization, and Storage Room
- Endoscopy Room
- Gastroenterology Laboratory
- Proctoscopy/Sigmoidoscopy Room
- Urodynamics Treatment Room
- **Surgical Spaces**
- Anesthesia Workroom and Equipment Storage
- Cardiac Operating Room
- Cardiac Pump Room
- Cesarean Birth Room
- Cystoscopy Room
- Equipment Storage Room, Surgical
- Frozen Section Laboratory
- General Operating Room
- Nerve Block Induction Room
- Neurosurgery Operating Room
- Orthopedic Operating Room
- Patient Holding Area, Surgical
- Post anesthesia Recovery Cubicle
- Post anesthesia Recovery Isolation Room
- Postoperative Recovery Lounge
- Preparation/Recovery Spaces, Surgical
- Preparation/Recovery Cubicle, Surgical
- Preparation/Recovery Room, Surgical
- Procedure/Minor Operating Room
- Scrub/Gowning Area
- Sub-Sterile Room
- Operating Room, Sterile Storage
- Surgical Laser Treatment Room
- Recovery Room, Surgical
- Surgical Suite, Workroom and Supply Space
- **Clinical Laboratory Spaces**
- Automated Clinical Laboratory
- Bioassay (Radioimmunoassay) Room
- Blood Gas Laboratory
- Blood Chemotherapeutics Room
- Bone Dissection Laboratory
- Clinical Chemistry Laboratory
- Clinical Microbiology Laboratory
- Cytology Laboratory
- Cytology Screening and Histology Space
- Dermatology Laboratory
- Electron Microscope Suite
- Electron Microscope System Room
- Entomology Laboratory
- Flow Cytometer Space
- Fluorescence Microscope Room
- General Clinical Laboratory Area
- Hematology Laboratory, Coagulation
- Hematology Laboratory, Routine
- Histology Laboratory
- Immunopathology Laboratory
- Microbiology Biosafety Laboratory
- Microbiology Mycology Laboratory
- Microbiology Mycobacteriology Laboratory
- Moth's Laboratory
- Mycology Laboratory
- Nephrology Renal Study Space
- Renal Studies Laboratory
- Urine Testing Alcove
- Urinalysis Laboratory
- Urology Laboratory
- Medical Autopsy Room
- **Clinical Laboratory Support Spaces**
- Blood Bank Donor Station
- Blood Bank Preparation Rom
- Blood Bank Blood Product Storage Space
- Blood Bank Storage and Transfusion Room
- Blood Specimen Collection Room
- Cell Bank Freezer, Ultra Low
- Electron Microscope Automated Data Processing Room
- Electron Microscope Cutting Room
- Electron Microscope Dark Room
- Electron Microscope Developing, Printing and Enlarging Room
- Electron Microscope Finishing Room
- Electron Microscope Preparation Room
- Glassware Washing and Decontamination Room, Clinical Laboratory
- Glassware Washing Room, Clinical Laboratory
- Slides and Blocks Storage Room, Clinical Laboratory
- Sterilization and Solution Preparation Room, Clinical Laboratory
- Tissue Storage Area, Clinical Laboratory
- Microbiology Media Preparation Laboratory
- Specimen Accessioning, Processing and Distribution Room
- Laboratory, Water
- **Pharmacy Spaces**
- Chemotherapy Agent Medication Preparation Room
- Compound Sterile Preparation Space - High Risk
- Compound Sterile Preparation Space - Low Risk
- Compounding Area
- Dialysate Preparation Room

Appendix A -Continued

Space Function

- IV Admixture Anteroom
- IV Admixture Room
- Medication Preparation Room
- Methadone Dispensing Station
- Oncology Drug Preparation Area
- Pharmacy
- Pharmacy, Dispensing Space
- Pharmacy Manufacturing & Prepack Space
- Prescription Receiving Station
- Pharmacy, Bulk, Breakdown and Verification Area
- Pharmacy, Controlled Substances and Secured Dispensing
- **<u>Medical Services Logistic Spaces</u>**
- Automatic Cart Wash Area, Healthcare
- BSL3 Infectious Disease Suite, Autoclave Room
- BSL3 Suite, Autoclave Room
- Cart Assembly/Queue Area, Healthcare
- Clean Cart Holding Area, Healthcare
- Medical Material Cart Restocking Area
- Clean Linen Preparation and Storage Area, Healthcare
- Clean Supply Preparation and Assembly Area, Healthcare
- Clean Supply Preparation Area, Healthcare
- Equipment Processing and Clean Storage Room, Healthcare
- Ethylene Oxide Gas Sterilizer Room
- Instrument Sterilization Room
- Central Sterile, Receiving and Decontamination
- Manual Cart Wash Area, Healthcare
- Soiled Cart Holding Area, Healthcare
- Soiled Cart Receiving Area, Healthcare
- Soiled Instrument and Equipment Receiving and Decontamination Room, Healthcare
- Sterile Supply Preparation and Assembly Area, Healthcare
- Biomedical Electronic Repair

- **<u>Rehabilitation Spaces</u>**
- Amputee Training Area
- Brace Shop Fitting Shop
- Brace Shop Adjustment/Modification Area
- Brace Shop Welding Area
- Computer Activities Room, Rehabilitation
- Prosthesis Design and Manufacturing Room, Rehabilitation
- Dynamic Alignment Room
- Therapeutic Exercise Spaces
- Therapeutic Exercise Area
- Exercise/Therapy Gymnasium
- Individual Therapeutic Exercise Area
- Treatment/Exercise Area
- Eye Fitting Studio
- Facial/Body Fitting Studio
- Fitting Room, Custom Fabrication
- Fitting Room, Soft Goods Fabrication
- Gait Lane
- Gait Study Track
- Hearing Aid Fabrication and Modification Room
- Hubbard Tank - Full Immersion
- Hubbard Tank - Partial Immersion
- Hydrotherapy Area
- Neurophysiology Rehabilitation Room
- Occupational Therapy Room
- Occupational Therapy, Daily Living Skills Training and Evaluation Room
- Pediatric Developmental Therapy Space
- Physical Therapy/Kinesiology Therapy Room
- Post urography Exam Room
- Prosthetic and Orthotic Dust Room
- Prosthetic and Orthotic Fume Room
- Prosthetic and Orthotic Work Station
- Prosthetic and Orthotic, Maintenance Support Room

- Rehabilitation Therapy Gym
- Speech Pathology Individual Therapy Room
- Speech Therapist, Exam and Treatment Space
- Therapeutic Pool
- Wheelchair Repair Workspace
- Whirlpool
- Rehabilitation Living Skills Training Apartment
- **<u>Dental Spaces</u>**
- Dental CS Suite
- Dental Hygiene and Operatory Room
- Dental Hygiene Room
- Dental Porcelain Room
- Dental Prosthetics Laboratory
- Dental Screening Room
- Dental Self Preparation Area
- Dental Treatment t Room, Mini Laboratory
- Dental Treatment Room
- Dental Treatment Room, Conscious Sedation Support
- Dental Treatment Room, Endodontics
- Dental Treatment Room, Orthodontics
- Dental Treatment Room, Pediatrics
- Dental Treatment Room, Periodontics
- Dental Treatment Room, Prosthodontics
- Dental X-Ray Room
- Instrument Preparation and Sterilization Room
- Maxillo-Facial Laboratory
- Maxillo-Facial Treatment Room
- Oral Pathology Laboratory
- Oral Surgery Residency Room
- Oral Surgery Room
- Panoramic Dental X-Ray Room
- Dental X-Ray Support Room
- **<u>Medical Research and Development Spaces</u>**
- Research Animal Recovery Area
- Barrier Suite, Procedure Laboratory
- Biomedical Research BSL3 Suite Tissue Culture Room
- Biomedical Research Tissue Culture Room
- Laboratory, Research, Biochemistry

- Biosafety Level 3 Laboratory
- BSL3 Infectious Disease Suite, Procedure Laboratory
- BSL3 Procedure Room
- Environmental Suite Infectious Disease Procedure Laboratory
- Research Infectious Disease Animal Holding Area
- Research Veterinary Radiography Control Room
- Research and Development Machine Shop
- Research Veterinary Radiography Procedure Room
- Research Diagnostic Laboratory
- Research NMR Room
- Research Procedure Laboratory
- Research Veterinary Surgical Suite, Animal Preparation Room
- Research Veterinary BSL3 Infectious Disease Suite Holding Room
- Research Veterinary Barrier Suite Holding Room
- Research Veterinary Chemical/Radioisotope Suite Holding Room
- Research Veterinary Environmental Suite Holding Room
- Research Veterinary Quarantine Holding Room
- Research Veterinary Surgery Room
- Veterinary Spaces
- Hospitalization Kennel
- Infectious Disease Animal Holding Area
- Veterinary Radiography Control Room
- Veterinary Radiography Procedure Room
- Veterinary Surgical Suite, Animal Preparation Room
- Veterinary BSL3 Infectious Disease Suite Holding Room
- Veterinary Barrier Suite Holding Room
- Veterinary Examination and Treatment Room
- Veterinary Quarantine Holding Room
- Veterinary Surgery Room
- Cage Wash Area
- Veterinary Food Preparation Room
- **Chemistry Laboratories**
- **Biosciences Laboratories**

Appendix A -Continued

Space Function

- Physical Sciences Laboratories
- Optical Physics Laboratory
- Physics Research Laboratory
- Astronomy Laboratories
- Astronomy Research Laboratory
- Earth and Environmental Sciences Laboratories
- Geology Laboratory
- Earth Sciences Research Laboratory
- Forensics Laboratories
- Psychology Laboratories
- Bench Laboratories
- Dry Laboratories
- Integration Laboratories
- Wet Laboratories
- Laboratory Storage Spaces
- Laboratory Support Spaces
- Office Spaces
- Office Service
- Dedicated Enclosed Workstation
- Shared Enclosed Workstation
- Dedicated Open Workstation
- Shared Open Workstation
- Open Team Setting
- General File and Storage
- Shared Workstation File and Storage
- Shared Equipment Station
- Lookout Gallery
- Banking Spaces
- Bank Teller Space
- Automatic Teller Machine Space
- Vault
- Trading Spaces
- Trading Floor

- **Demonstration Spaces**
- **Sales Spaces**
- Checkout Space
- Display Space
- Fitting Space
- Vending Machine Area
- Auction Room
- Pet Shop Animal Space
- **Commercial Service and Repair Spaces**
- **Commercial Support Spaces**
- **Hotel, Motel, Hostel, and Dormitory Service Spaces**
- Dormitory
- Hotel Residence Room
- **Commerce Activity Support Areas**
- Information Counter
- Lobby Non-Circulation Space
- Post Office Space
- Mail Room Space
- Box Lobby
- Meeting Spaces
- Conference Room
- Press Conference Room
- Community Room
- War Room
- Meeting Equipment Room
- Waiting Space
- Reception Space
- Waiting Room
- Queuing Space
- Business Support Space
- Grooming Activity Spaces
- Makeup Space
- Haircutting Space
- Food Service
- Cooking Spaces
- Kitchen Space
- Food Preparation Space
- Cooking Space
- Dishwashing Station

- Dining and Drinking Spaces
- Dining Room
- Banquet Hall
- Food Court
- Snack Bar
- Salad Bar
- Liquor Bar
- Beverage Station
- Table Bussing Station
- Serving Station
- Vending Perishable Product Space
- Cafeteria Vending Space
- Tray Return Space
- Food Discard Station
- Coffee stations
- **Child Care Spaces**
- Daycare sickroom
- Child Day Care Space
- Play Room
- CLD–Child Care
- **Resting Spaces**
- Rest Area
- Break Room
- **Laundry/Dry Cleaning Space**
- **Smoking Space**
- **Material Handling Area**
- **Batching Space**
- **Production Process**
- Workbench
- Workbench
- **Printing and Reproduction Spaces**
- **Quality Control and Test Spaces**
- Product Inspection Space
- Production Observation Space
- **Production Service and Repair Spaces**
- **Production and In-Process Storage Spaces**
- **Production Support Spaces**

- **Greenhouse Spaces**
- Greenhouse Support Space
- **Animal Securing Spaces**
- Cage
- Animal Stall
- Kennel
- Aquarium
- **Detention Spaces**
- Detention Cell
- Holding Cell
- Impound Lot
- Dayroom
- **Spaces for Protection from the Elements**
- Park Shelter
- Entry Porch
- Covered Walkway
- Canopy
- Shielded Room
- Containment Room
- **Spaces for Protection from Violence**
- Safe Room
- Bunker
- Bomb Shelter
- **Warehouse Spaces**
- High Bay Warehouse Space
- General Warehouse Space
- Warehouse Support Space
- **Non-Warehouse Storage Spaces**
- Storage Room
- GNS–General Storage
- Closet
- Coat Check
- Locker Room
- Vehicle Storage Compartment
- Portable Bin
- Vessel Hold

Appendix A -Continued

Space Function		Assets	
• Filing Space • Supply Room • Unit Storage • Consolidation/Containerization Point • Self-Storage Space • Operational Storage (Misc) • Operational Hazardous/Flammable Storage • <u>Moveable Storage Spaces</u> • Vehicle Storage Compartment • Portable Bin • Vessel Hold • <u>Environmentally Controlled Storage Spaces</u> • Refrigeration Compartment • Freezing Compartment • Humidity Controlled Storage Space • Vacuum Sealed Storage Compartment • <u>Specialty Storage Spaces</u> • Sanitary Storage Room • Soiled Storage Room Space • Sacristy • Vestry • Hazardous Material Storage Space • Book Stacks • Baggage Claim • Evidence Room • Vehicle Impound Lot • Operating Fuel Storage • <u>On-call Room</u> • <u>Bathroom</u> • Shower Space • Toilet Space • Ablution Room • Combination Toilet and Bathing Space • <u>Mud Room</u> • <u>Laundry Room</u> • <u>Bedroom</u> • Mental Health Resident Bedroom • Mental Health Resident • Bedroom, Bariatric	• <u>Nursery</u> • <u>Kitchen</u> • <u>Customer Site</u> • <u>Home Office</u> • <u>Rent-An-Office</u> • <u>No Fixed Location</u> • <u>Supplier Site</u> • <u>Roof</u> • <u>Roof Terrace</u> • <u>Penthouse</u> • <u>Antenna Farm</u> • <u>Heliport</u> • <u>Balcony</u> • <u>Deck</u> • <u>Pedestrian Travel Spaces</u> • Sidewalk • Pedestrian Way • Pedestrian Bridge • Footpath • Trail • Gangway	• Doors and Frames • Curtain • Walls • Floors • Windows • Skylights • Plaster and Gypsum Board • Tiling • Ceilings • Cladding • Flooring • Wall Finishes • Painting and Coating • Retail and Service Equipment • Banking Equipment • Hospitality Equipment • Office Equipment • Postal, Packaging, and Shipping Equipment • Unit Kitchens equipment • Foodservice Equipment • Educational and Scientific Equipment • Partitions • Toilet, Bath, and Laundry Accessories • Fireplaces and Stoves • Lockers • Wardrobe and Closet • Library Equipment • Audio-Visual Equipment • Laboratory Equipment • Planetarium Equipment • Observatory Equipment • Vocational Shop Equipment • Exhibit Equipment	• Entertainment and Recreation equipment • Broadcast, Theater, and Stage Equipment • Musical Equipment • Athletic Equipment • Recreational Equipment • Play Field Equipment • Healthcare Equipment • Medical Sterilizing Equipment • Examination and Treatment Equipment • Patient Care Equipment • Dental Equipment • Optical Equipment • Operating Room Equipment • Radiology Equipment • Mortuary Equipment • Facility Maintenance Equipment • Facility Solid Waste Handling Equipment • FReligious Equipment • Agricultural Equipment • Horticultural Equipment • Veterinary Equipment •

Appendix A -Continued

Assets			
• Arts and Crafts Equipment • Security Equipment • Detention Equipment • Office Accessories • Table Accessories • Portable Lamps • Bath Furnishings • Bedroom Furnishings • Furnishing Accessories • Rugs and Mats • Office Furniture • Hospitality Furniture • Detention Furniture • Institutional Furniture • Industrial Furniture • Residential Furniture • Amusement Park Equipment • Convening equipment • Dumbwaiters • Elevators • Escalators and Moving Walks • Lifts • Turntables • Fire Pumps • Storage Tanks for Fire-Suppression Water • Plumbing Piping • Facility Potable-Water Storage Tanks • Plumbing Equipment • Domestic Water Softeners	• Domestic Water Filtration Equipment • Electric Domestic Water Heaters • Fuel-Fired Domestic Water Heaters • Domestic Water Heat Exchangers • Domestic Water Preheaters • Plumbing Fixtures • Facility Fuel Piping • Facility Fuel Pumps • Facility Fuel-Storage Tanks • HVAC Piping and Pumps • Hydronic Piping and Pumps • Steam and Condensate Piping and umps • Refrigerant Piping • Internal-Combustion Engine Piping • HVAC Ducts and Casings • Air Plenums and Chases • Air Duct Accessories • HVAC Fans • Special Exhaust Systems • Air Terminal Units • Air Outlets and Inlets • Ventilation Hoods •	• Particulate Air Filtration • Gas-Phase Air Filtration • Electronic Air Cleaners • Breechings, Chimneys, and Stacks • Heating Boilers • Heating Boiler Feedwater Equipment • Furnaces • Fuel-Fired Heaters • Solar Energy Heating • Equipment • Heat Exchangers for HVAC • Central Cooling Equipment • Refrigerant Compressors • Packaged Compressor • Refrigerant Condensers • Packaged Water Chillers • Cooling Towers • Central HVAC • Equipment • Thermal Storage • Air-to-Air Energy Recovery Equipment • Packaged Outdoor HVAC Equipment • Custom-Packaged Outdoor HVAC Equipment • Evaporative Air-Cooling Equipment • Decentralized HVAC Equipment • Decentralized Unitary HVAC Equipment • Humidity Control Equipment	• Integrated Automation Network Equipment • Integrated Automation Network Devices • Integrated Automation Network Gateways • Integrated Automation Terminal Devices • Integrated Automation Instrumentation and Terminal Devices • Devices for Fire-Suppression Systems • Integrated Automation Instrumentation and Terminal Devices for Plumbing • Integrated Automation Instrumentation and Terminal Devices for HVAC • Integrated Automation Instrumentation and Terminal Devices for Electrical Systems • Integrated Automation Instrumentation and Terminal Devices for Communications Systems • Integrated Automation Instrumentation and Terminal Devices for Electronic Safety and Security Systems

Appendix A -Continued

Assets			
• Medium-Voltage Utility Switchgear and Protection • Devices • Waterway and Marine Signaling and • Control Equipment • Signaling and Control Equipment for Waterways • Marine Signaling and Control EquipmentSignaling and Control • Equipment for Dams • Waterway and Marine Equipment • Shoreline Protection • Artificial Reefs • Levees • Waterway Bank Protection • Waterway Scour Protection • Dam Equipment • Gas and Vapor Process Piping and • Ductwork • Steam Process Piping • Compressed Air Process Piping • Combustion System Gas Piping • Specialty and High-Purity Gases Piping	• Liquids Process Piping • Liquid Fuel Process Piping • Petroleum Products Piping • Water and Wastewater Process Piping • Specialty Liquid Chemicals Piping • Liquid Acids and Bases Piping • Liquid Polymer Piping • Bulk Materials Piping and Chutes • Bulk Materials Valves • Welding and Cutting Gases Piping • Vacuum Systems Process Piping • Boilers • Heaters • Industrial Heat Exchangers and Recuperators • Industrial Furnaces • Industrial Ovens • Cooling Towers • Chillers and Coolers • Condensers and Evaporators • Gas Dryers and Dehumidifiers • Material Dryers • Gas Fans, Blowers, Pumps and Boosters	• Gas Compressors • Gas Process Equipment • Process Air and Gas Filters • Liquid Process Equipment • Location Liquid Pumps • Suspended Liquid Pumps • Submersible/Immersible Liquid Pumps • Specialized Liquid Pumps • Process Liquid Filters • Gas and Liquid Purification Filtration Equipment • Gas and Liquid Purification Process Equipment • Non-pressurized Tanks and Vessels • Pressurized Tanks and Vessels • Particulate Control Equipment • Gaseous Air Pollution Control Equipment • Noise Pollution Control Equipment • Odor Treatment Equipment • Odor Dispersing and Masking/Counteracting Equipment	• Water Pollution Containment and Cleanup • Equipment • Solid Waste Collection, Transfer, and Hauling Equipment • Solid Waste Processing Equipment • Composting Equipment • Waste-to-Energy Plants • Fluidized Bed Combustion Equipment • Rotary Kiln Incinerators • Gasification Equipment • Pyrolysis Equipment • Hazardous Waste and Medical Waste Incinerators • Heat Recovery Equipment for Waste Thermal • Processing • Synthesis Gas Cleanup and Handling Equipment • Concrete Accessories • Reinforcement Bars • Decks • Grouting • Paneling • Stairs and Railings • Screens and Exterior Shutters • Joists • Gratings

Appendix A -Continued

Assets			
• Medium-Voltage Utility Switchgear and Protection • Devices • Waterway and Marine Signaling and • Control Equipment • Signaling and Control Equipment for Waterways • Marine Signaling and Control Equipment Signaling and Control • Equipment for Dams • Waterway and Marine Equipment • Shoreline Protection • Artificial Reefs • Levees • Waterway Bank Protection • Waterway Scour Protection • Dam Equipment • Gas and Vapor Process Piping and • Ductwork • Steam Process Piping • Compressed Air Process Piping • Combustion System Gas Piping • Specialty and High-Purity Gases Piping	• Liquids Process Piping • Liquid Fuel Process Piping • Petroleum Products Piping • Water and Wastewater Process Piping • Specialty Liquid Chemicals Piping • Liquid Acids and Bases Piping • Liquid Polymer Piping • Bulk Materials Piping and Chutes • Bulk Materials Valves • Welding and Cutting Gases Piping • Vacuum Systems Process Piping • Boilers • Heaters • Industrial Heat Exchangers and Recuperators • Industrial Furnaces • Industrial Ovens • Cooling Towers • Chillers and Coolers • Condensers and Evaporators • Gas Dryers and Dehumidifiers • Material Dryers • Gas Fans, Blowers, Pumps and Boosters •	• Gas Compressors • Gas Process Equipment • Process Air and Gas Filters • Liquid Process Equipment • Location Liquid Pumps • Suspended Liquid Pumps • Submersible/Immersible Liquid Pumps • Specialized Liquid Pumps • Process Liquid Filters • Gas and Liquid Purification Filtration Equipment • Gas and Liquid Purification Process Equipment • Non-pressurized Tanks and Vessels • Pressurized Tanks and Vessels • Particulate Control Equipment • Gaseous Air Pollution Control Equipment • Noise Pollution Control Equipment • Odor Treatment Equipment • Odor Dispersing and Masking/Counteracting Equipment	• Water Pollution Containment and Cleanup • Equipment • Solid Waste Collection, Transfer, and Hauling Equipment • Solid Waste Processing Equipment • Composting Equipment • Waste-to-Energy Plants • Fluidized Bed Combustion Equipment • Rotary Kiln Incinerators • Gasification Equipment • Pyrolysis Equipment • Hazardous Waste and Medical Waste Incinerators • Heat Recovery Equipment for Waste Thermal • Processing • Synthesis Gas Cleanup and Handling Equipment • Concrete Accessories • Reinforcement Bars • Decks • Grouting • Paneling • Stairs and Railings • Screens and Exterior Shutters • Joists • Gratings • Thermal Protection • Moisture protection • Protection • Damp proofing and Waterproofing • Water Repellents • Weather Barriers

Appendix B: Building Asset Account Status View

```
SELECT     asset_account_inspection.Inspection_date,
      asset_account_inspection.Condition_value,
      condition_rating.Condition_Rating_Description
   FROM asset_account_inspection asset_account_inspection
   INNER JOIN condition_rating condition_rating
      ON asset_account_inspection.Condition_value = condition_rating.Rating
   INNER JOIN asset_account_definitions asset_account_definitions
      ON asset_account_definitions.Asset_account_ID =
asset_account_inspection.Asset_account_ID
   WHERE (Inspection_date BETWEEN 'inspectionDateFrom' AND 'inspectionDateTo')
   AND asset_account_definitions.Asset_account_ID = assetAccountId
   and asset_account_definitions.Building_ID = buildingId
```

Appendix C: Building Asset Account Conditions Assessment View

```
SELECT aai.Asset_account_ID Asset_account_ID,
  aad.Asset_Account_Description Asset_Account_Description,
  aai.Condition_value Condition_value,
  cr.Condition_Rating_Description Condition_Rating_Description
FROM asset_account_inspection aai
INNER JOIN condition_rating cr
  ON cr.Rating = aai.Condition_value
INNER JOIN asset_account_definitions aad
  ON aad.Asset_Account_Id = aai.Asset_Account_Id
where (
 aai.Inspection_date between 'inspectionDateFrom' and 'inspectionDateTo')
and aad.building_id=buildingId
```

Appendix D: Building Asset Account Remaining Service Life View

```
SELECT asset_account_definitions.asset_account_id,
    asset_account_definitions.asset_account_description,
    asset_account_remaining_life_prediction.remaining_service_life,
    Substr(asset_account_remaining_life_prediction.prediction_date, 1, 4)
    year
FROM   asset_account_remaining_life_prediction
    asset_account_remaining_life_prediction
    INNER JOIN asset_account_definitions asset_account_definitions
        ON asset_account_definitions.asset_account_id =
          asset_account_remaining_life_prediction.asset_account_id
WHERE  ( asset_account_remaining_life_prediction.prediction_date BETWEEN
         'inspectionDateFrom' AND 'inspectionDateTo' )
    AND asset_account_definitions.building_id = buildingid
```

Appendix E: Building Asset Account Risk Assessment View

```
SELECT asset_account_inspection.asset_account_id,
      asset_account_definitions.asset_account_description,
      (SELECT rating_description
       FROM   risk_rating
       WHERE  condition_value = asset_account_inspection.condition_value
             AND criticality_value = asset_account_definitions.criticality)
      Rating_description,
      (SELECT risk_value
       FROM   risk_rating
       WHERE  condition_value = asset_account_inspection.condition_value
             AND criticality_value = asset_account_definitions.criticality)
      risk_value
FROM   asset_account_remaining_life_prediction
      asset_account_remaining_life_prediction
      INNER JOIN asset_account_definitions asset_account_definitions
             ON asset_account_definitions.asset_account_id =
               asset_account_remaining_life_prediction.asset_account_id
      INNER JOIN asset_account_inspection asset_account_inspection
             ON asset_account_inspection.asset_account_id =
               asset_account_definitions.asset_account_id
   WHERE (asset_account_remaining_life_prediction.Prediction_date between
'inspectionDateFrom' and 'inspectionDateTo')
   AND asset_account_definitions.Building_ID = buildingId
```