ENVIRONMENTAL INFORMATION MODELING: AN INTEGRATION OF BUILDING INFORMATION MODELING AND GEOGRAPHIC INFORMATION SYSTEMS FOR LEAN AND GREEN DEVELOPMENTS

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Kenechukwu Chigozie Ezekwem

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department
Construction Management and Engineering

April 2016

Fargo, North Dakota

North Dakota State University
Graduate School

Title

ENVIRONMENTAL INFORMATION MODELING: AN INTEGRATION OF BUILDING INFORMATION MODELING AND GEOGRAPHIC INFORMATION SYSTEMS FOR LEAN AND GREEN DEVELOPMENTS

By

Kenechukwu Ezekwem

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Jerry Gao

Chair

Dr. Eric Asa

Dr. Achintya Bezbaruah

Approved:

04/12/ 2016

Date

Dr. Young Bai

Department Chair

ABSTRACT

Building Information Modeling (BIM), used by many for building design and construction, and Geographic Information GIS System (GIS), used for city planning, contain large spatial and attribute data which could be used for Lean and green city planning and development. However, there exist a systematic gap and interoperability challenge between BIM and GIS that creates a disjointed workflow between city planning data in GIS and building data in BIM. This hinders the seamless analysis of data between BIM and GIS for lean and green developments. This study targets the creation of a system which integrates BIM and GIS system data. The methods involve the establishment of a novel Environmental Information Modeling (EIM) framework to bridge the gap using Microsoft Visual C#. The application of this framework shows the potential of this concept. The research results provide an opportunity for more analysis for lean and green construction planning, development and management.

ACKNOWLEDGEMENTS

I would like to show my gratitude to my thesis committee chairman, Dr. Jerry Gao PE, CPC, for supporting and guiding me throughout my graduate studies. Also, I would like to thank my thesis committee members Dr. Eric Asa and Dr. Achintya Bezbaruah for taking out time from their busy schedules to evaluate my thesis and provide constructive comments. I would also like to thank Ingrid Scarski and Ann Denney for their great care during my program. . Every interaction with them left me more encouraged and optimistic, and their interest in my progress was very supportive.

Lastly, I offer my regards and blessings to all those who supported me in any respect during the completion of this thesis, words are not enough to express my gratitude.

DEDICATION

With complete gratitude, I dedicate this thesis to my mother:

Mrs. Angelina Ezekwem

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF DEFINITIONS

Environmental Information Modeling (EIM)...........	simply put, this is the big data of the construction industry. It is the digital representation of, integration, integration, interpretation, analysis, and management of all types of data for the buildings, infrastructures and their host environment.
Building Information Modeling (BIM)...............	a process involving the generation and management of digital representations of physical and functional characteristics of places.
Geographic Information System (GIS)...............	a computer system for capturing, storing, checking, interpreting, analyzing and displaying data which are spatially referenced to earth.
Big Data (BD)..	the use of predictive analytics or other certain advanced methods to extract value from data, and seldom to a particular size of data set.
Lean Construction	a combination of operational research and practical development in design and construction with an adoption of lean manufacturing principles and practices to the end-to-end design and construction process.
Green Construction	refers to both a structure and the using of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle.
Information Technology (IT)............................	the application of computers to store, retrieve, transmit and manipulate data, often in the context of a business or other enterprise.

LIST OF APPENDIX TABLES

LIST OF APPENDIX FIGURES

1. INTRODUCTION

The US construction industry, valued at about 652 billion USD *[~3.74% of the GDP]* (U.S. Department of Commerce, 2015) is facing the challenge of inefficient coordination of information for the planning and execution of construction processes in sustainable ways. This challenge has been identified as a key factor behind the negative impacts of urban infrastructure projects on their environment (Sebastian, Claeson-Jonsson, & Giulio, 2013). This stems from inefficient communication caused by poor information exchange across different industry participants and different Information Technology (IT) systems. This poor information exchange results in avoidable project cost overruns and waste (Jr., Farrington, & Ledbetter, 1992). Through the rapid adoption of IT in the industry, Building Information Modeling (BIM) has become quite common in the practice of the US construction Industry (Johnny & Ka-Lin, 2014) and GIS has gained increasing adoption in the industry for numerous geospatial-related activities (Li, Chen, Yong, & Kong, 2005). These two IT systems have brought notable improvements to industry processes. Due to the increasing demands and policies, aimed at improving the environmental, social and economic responsibilities of the industry (Akintola, Jack S., & Girma, 2012), there now exists a need for the integration of these systems for the analysis of structures and their surrounding environments (Rizal, Michel, & Helm, 2013).

This thesis focuses on the poor and inefficient integration of information from both BIM and GIS software systems for lean and green construction developments. Through literature review, the thesis explores the possibility of integrating digital BIM and GIS data for lean and green planning and design. This is important because most BIM and GIS users face either great redundancy or crucial loss of information when attempting to integrate information across both IT systems, and this is also seen in the difficulty faced by architecture, engineering, construction and city planning participants in the integration of software applications and data for the analysis and management of their business data (António & Ricardo, 2010). Although there is an increasing awareness of the responsibility of the industry in increasing and sustaining the environment through improvements within their diverse and considerably fragmented industry (Horman, Riley, Lapinski, Korkmaz, & Pulaski, 2006), there is still insufficient research for the development of platforms that provide seamless and efficient integration of BIM and GIS data for the analysis of building and environmental information for lean and green construction. Considering the industries increasing awareness that their products and services have social, economic and environmental impacts, the need to find better ways of managing, analyzing and communicating construction related information now exist (Olah, 2011). The methods employed in this thesis involves the establishment of a unique system - Environmental Information Modeling (EIM) framework to bridge the interoperability gap between the systems for lean and green construction. This was achieved using Microsoft Visual C# programming language to integrate BIM and GIS system data through the development of a software application for this framework which shows the potential of the EIM concept. The research results provide an opportunity for more analysis for Lean and green city planning, development and management.

1.1. Statement of the Problem

The lack of seamless interoperability of BIM and GIS data for lean and green construction development is a challenge facing the industry today. Even with the effort made by the International Alliance for Interoperability (IAI) through the establishment of: Industry Foundation Classes for the AEC community, and the effort made by Open Geospatial Consortium (OGC) through the establishment of Geographic Markup Language (GML) for the geospatial community (Hassan A. & Burcu, 2009), this challenge still exists. Prior research has studied ways of integrating both systems for multiple construction-related activities. In a study for the integration and management of BIM and GIS - (El Meouche, Rezoug, & Hijazi, 2012), it was observed that although both systems have their strengths, weaknesses, and purpose of use, the existing tools for leveraging on both systems are not straightforward and results in information loss. In another study on its integration for low disturbance construction (Sebastian, Böhms, & Helm, 2013), the authors sort to develop a solution for the integration of BIM and GIS, however, it was observed that this requires "Open BIM and GIS software standards" and that these systems have developed their standards differently which makes the integration inefficient. In another study on the software architecture for BIM and GIS integration for facility management (Tae Wook & Chang Hee, 2015), it was observed that during information exchange between heterogeneous systems, information is lost or altered. In all these efforts, information loss was observed and the processes for the integration was not seamless due to the heterogeneous nature of both systems.

Other researchers have looked at issues like: tower crane location optimization (Javier & Ebrahim, 2012), asset management (Zhang, Arayici, Wu, & Aouad, 2009), site selection and fire response (Isikdag, Underwood, & Aouad, 2008) with another study which discussed similar attempts at the integration of both systems (Irizarry, Karan, & Jalaei, 2013) for construction where BIM data is exported into GIS-based system for analysis, however, information loss posed a challenge. While there exist some research, as stated above, for the integration of the systems, these research attempts are yet to through sufficient light on the use of these IT systems for lean and green construction developments (Ritu, Anil, & Mohammed, 2014). This focus of BIM-GIS integration for lean and green construction development is crucial because there is a relationship between buildings/infrastructure - represented in BIM, and their host environments – represented in GIS (Eduardo & Simos, 1998). This relationship has significant impacts, worthy of investigation due to (Ignacio, Antonio, & Alfonso, 2011). It is also important to note that most designers and contractors in the US, now use BIM for building design and construction (McGraw Hill Construction, 2014) and most cities now use GIS for their overall city infrastructure planning and control (Qing, Xue, Xiulan, & Jiansheng, 2011). While these two systems have heavy/rich graphical data and attributes (Sam, Abbas, Priyan, & Tuan, 2014), which are useful for lean and green construction analysis (U.S. Green Building Council - North Ohio Council , 2016), the lack of interoperability between them creates a disjointed flow of information across both IT platforms and this hinders the seamless and efficient analysis of information for lean and green construction development. The motivation and focus for this study are the development of a framework to solve this interoperability challenge and to create a platform that offers increased efficiency in lean and green construction development processes.

1.2. Purpose of Study

The purpose of this study is to develop a demo application and a framework where BIM and GIS can be seamlessly integrated for lean and green construction development.

The specific study goals/objectives are:

- Determination of the barriers to BIM and GIS integration for lean and green construction from literature review
- Development of a proposed Environmental Information Modeling [EIM] framework for BIM and GIS integration
- Development of a demo EIM software application for lean and green construction developments.

1.3. Significance of Study

The significance of this study can be seen in three ways. First, through the proposed EIM framework, the study result provides a demo software application for the integration of BIM and GIS data for lean and green developments, which shows the potential of the EIM concept. The Second is the expected reduction of construction waste through increased awareness and analysis during the design phase. Lastly, it can be expected to improve sustainability efforts in construction through the examination of the relationship that exists between buildings/infrastructure and their environment.

1.4. Limitations and Assumptions

The theoretical assumption taken from this study is that every information stored in both the GIS and BIM systems have been entered correctly, free of errors and represents in full, the virtual prototypes of buildings, infrastructures, and their immediate host environment. It assumes that the BIM and GIS data are up to date. The size of data used is appropriate for this proposed framework.

1.5. Organization of Thesis

This thesis is organized in the following sequence: This thesis research began with the review of existing literature and theory on BIM, GIS, BIM-GIS integration, lean construction and green construction. After the review, there was an analysis of the reviewed information and an identification of the problem. The next step was data collection, where some editable copies of publicly city GIS data were collected and recorded. Information was collected and organized using mind maps and Microsoft access database files to simplify information and keep track. Then, the next step involved the creation of the EIM framework which shows the flow and integration of static and dynamic data from both BIM and GIS for lean and green construction development. The framework shows the various types of data, pre and post loaded that the demo EIM application uses for its analysis of information. Then, an analysis was conducted using the sample application, which crosschecks information from Autodesk Revit Architecture's BIM application and ESRI's ArcGIS GIS data. The developed application is limited to Autodesk and ESRI software applications and handles only a few aspects of the potential lean and green processes for construction development. The results show the potential for increased efficiency and better decision making for lean and green construction developments using information from both systems. It suggests that data should be free for use at all times, from the chained, Interoperable and defragmented IT systems that are commercially available.

2. RESEARCH METHODS

This chapter provides information on the research methods used in this thesis. As shown in figure 1, the research method begins with an initial study done in the preliminary literature review stage. This stage provided the foundation of the EIM study, and through the provision of clarity, it helped in the determination of the aim, objectives and hypothesis for this topic of study. It was essential in the determination of what has been researched, what remains to be researched and what is evolving for investigation. This initial stage also helped in the avoidance of repetition for research efforts related to this thesis.

In order to conduct this study, several key published papers on BIM and GIS were studied, in order to understand their concepts and applications within the construction processes. While conducting this study, various mind maps were created as a graphical way to represent ideas and concepts. They were used as visual thinking tools for structuring BIM and GIS information gathered from publications for better analysis, comprehension, and synthesis. MindMeister, a cloud-based collaborative mind mapping software, developed by MeisterLabs GmbH (AppAppeal, 2016), was used for its: task-management ability, presentation creation tools, and connective API's for web services like Wikipedia and Google.

As shown in figure 2, it shows the relationships between ideas in tree diagram methods. The diagram shows the sub-topics studied during the study of BIM modeling.

During this initial/preliminary study, other IT tools, such as Microsoft OneNote and Microsoft Access were fairly used as database management systems. Through the use of these tools, information was collected and organized to create reports, proposals, and presentations.

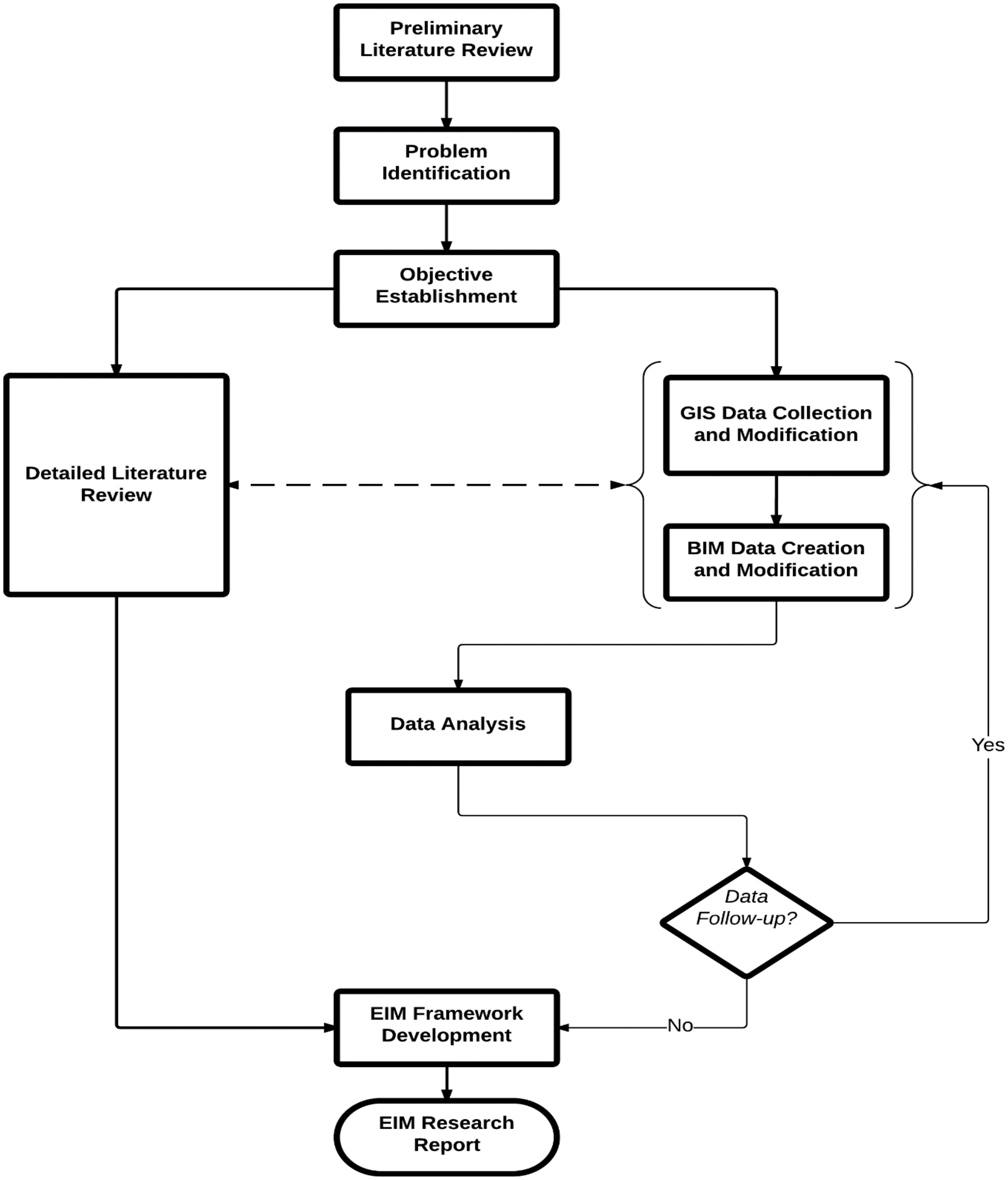

Figure 1. Research Methodology

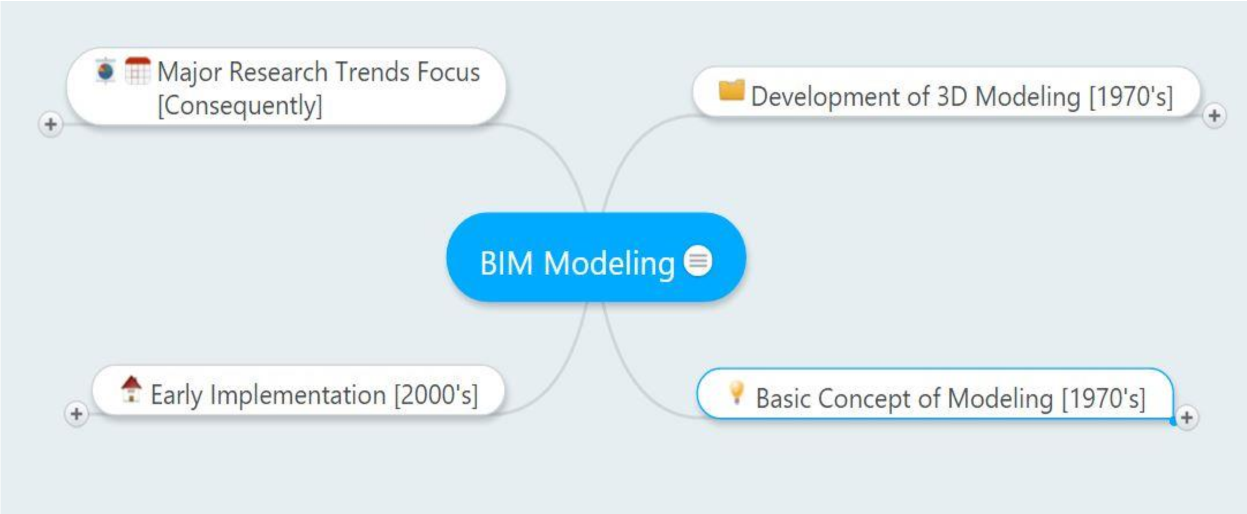

Figure 2. MindMeister Map Snippet

OneNote's application User interface, was efficient in providing support in the following ways:

- Gathering and organizing research with sections and pages
- Keeping track of important pages
- Organization of information in an outline with note flags
- Using audio and video to view recorded studies
- Using the research task pane to find information
- Sharing the research with my advisor and collaborating

The outcome from this preliminary literature review stage led to the next research stages/phases described in the following subsections.

2.1. Problem Identification and Objective Establishment

During the preliminary or initial studies, an analysis was conducted using the information gathered at this stage for the identification of the thesis problem. The problem identified was the interoperability or systematic gap between BIM and GIS for lean and green construction developments. Inquiries were made into this challenge and it was observed that this challenge creates a fragmented workflow between city or spatial planning data systems in GIS platforms and building design data in BIM platforms. The aim of this research is to close the gap between BIM and GIS for some aspects of lean and green construction developments, through the development of a framework and a sample software application. In order to close this gap, objectives were set through the careful evaluation of the purpose/aim of the thesis, the analysis of the both BIM and GIS systems, and a combination of ideas to form both BIM and GIS literature reviews. At the end of this step, the stage was set for next steps in the research methodology.

2.2. Detailed Literature Review

At this stage, the literature review became more detailed. Additional papers, discussing attempts to integrate BIM and GIS, were studied. A more robust literature database was created for BIM, GIS, and their integration attempts. A numerous concept/mind maps were developed for the study. The development of the maps and database was categorized into:

- BIM Studies
- GIS Studies
- BIM and GIS Integration
- Lean and Green Construction

This set the stage for the collection, creation and modification of GIS and BIM data. The collected data was analyzed and necessary follow-up made to ensure the required information for the scope of this research was available through data collection and literature review.

2.2.1. GIS Data Collection and Modification

From preliminary considerations, the data requirement for GIS data, proposed for the EIM framework is Esri's ArcMap data file formats with the file extensions shown in Table 1.

This requirement was after the selection of the BIM application used in this thesis. The BIM application can export and import data in the require file extensions for the GIS data collection. The data required in GIS formats is simply the map of the city of Fargo, with attributes information like zoning, addresses, and assumed LEED design criteria for specific areas.

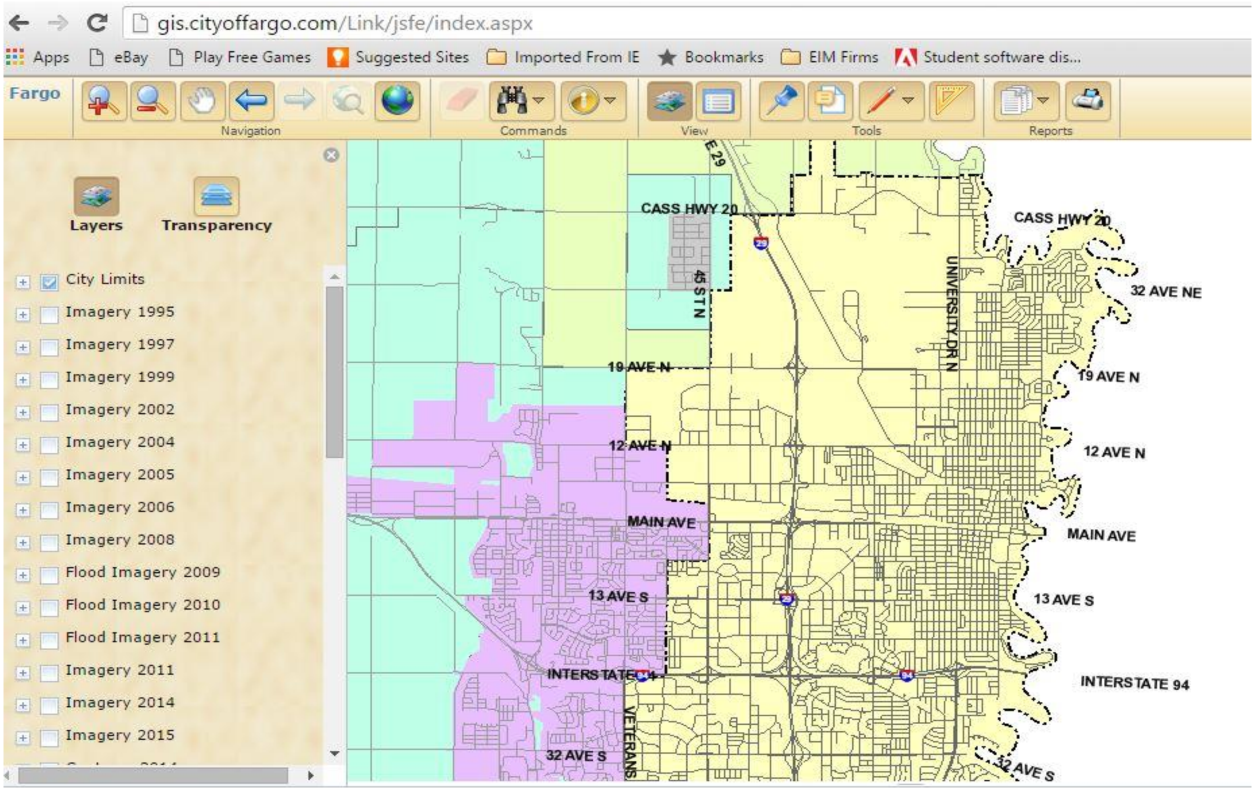

Figure 3. City of Fargo's Online Interactive Map

This data is available online in the city of Fargo website (City of Fargo, 2016) for the public viewing and analysis (See Figure 3 for the websites interactive user interface). For the purpose of this research, the editable copy of this map was collected from the city of Fargo, in order to access the required file formats and extensions for data collection. With this collected version of the interactive map, the required attribute data for this thesis could be arranged in tables and accessed through Microsoft access database application, which is used for the sample software development.

2.2.2. BIM Data Creation and Modification

Also, from preliminary considerations, the data requirements for the BIM model proposed for the EIM framework is Autodesk's Revit Design Suite which has import and export functionality that can work with the file extensions shown in table one. The data required for the BIM model is simple enough data for a sample virtual construction project that can be used to test the proposed framework.

Table 1. Required GIS and BIM Data File Extensions

Type	Description
.mdb	Personal geodatabase Microsoft Access file.
.xls	File for opening Microsoft Office Excel tables directly in ArcGIS and working with them like other tabular data sources.

2.2.3. Data Analysis

To determine the data collected for both BIM and GIS, information from the BIM and GIS data was processed using a simple information system as shown in figure 4. The established data requirements in Table 1 and the converted or processed information was either saved as output information of used for updating the literature review through a feedback process as shown in Figure 4. During the conversion process, all information from BIM and GIS was passed through the following steps (see Figure 4 for the visual description of this listed steps):

- Sorting of Information
- Filtering of Information

- Storing of Relevant Information
- Analysis of all information
- Synthesizing
- Conversion
- Hypothesis testing

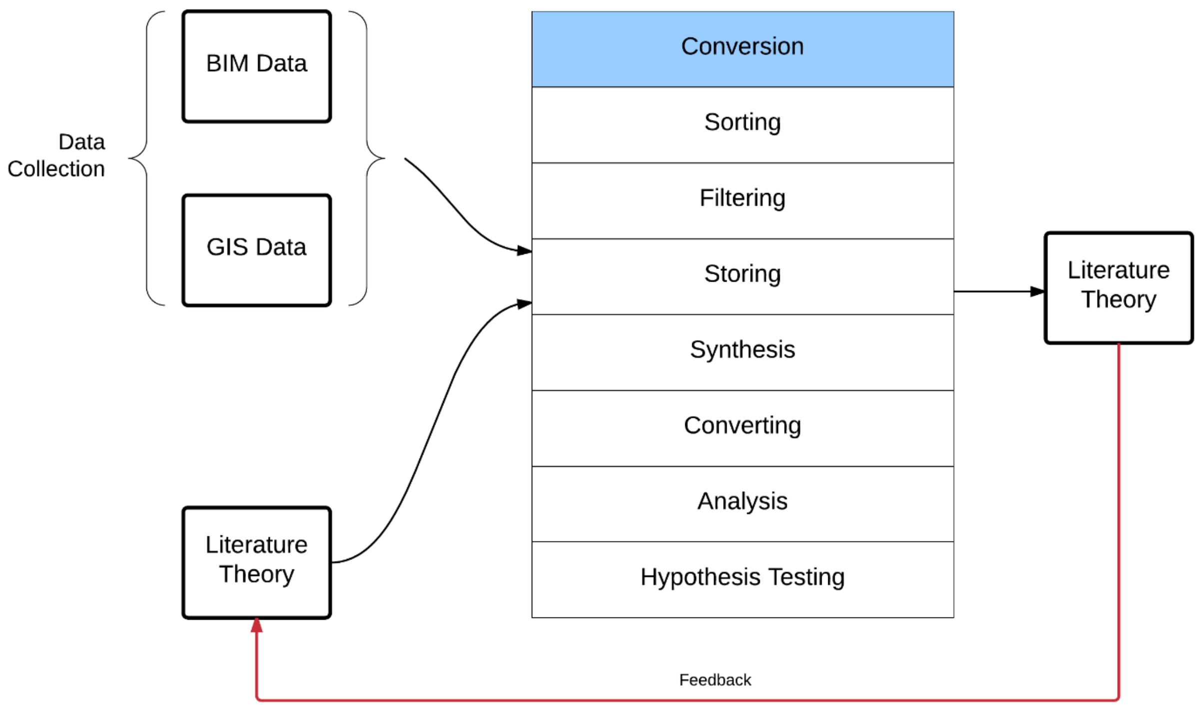

Figure 4. Simple Information System Model

2.3. EIM Framework Establishment

A framework was developed for the integration of BIM and GIS for lean and green construction developments. This framework was designed to integrate both BIM and GIS data at a database file level, using the Microsoft database file system which is a common file extension of both BIM and GIS systems. This set the stage for the development of a software system for this analysis.

2.3.1. EIM Platform Development

Prior to the development of the sample software application, an additional literature review was carried out into the methods used in the development of software applications using Microsoft C#.NET. During this process, the researcher got trained in the management of software development using Agile Project management methodology and got certified by International Scrum Institute as a Certified Scrum Master (See Figure 5). Scrum is an Agile Project Management Framework to develop great products that customers love (International Scrum Institute, 2016).

The additional skills acquired from this training, improved the research process through the approach undertaken for the application development, which involved the development of activity diagrams and user interface mockups shown in chapters 4. After the creation and review of these diagrams and user interface mockups, a sample application database was developed in the required file formats shown in table 1, for use by the proposed sample EIM application. In this development, the multi-paradigm programming language C# was used because of the researcher's familiarity with the development language and its features: portability, simplicity and the fact that the Application Programming Interface of Revit Architecture and Esri's ArcGIS can be done with C#.

Figure 5. Copy of the Researcher's Scrum Certificate

2.4. Scope of Study

The GIS scope of this study was limited to the city of Fargo, North Dakota, USA as shown in Figures 6. The city’s proximity to North Dakota State University made data collection and verification convenient and based on the 2010 census numbers, Fargo is the largest city in the State of North Dakota, accounting for nearly 16% of the state population (United States Census Bureau, 2015). Its relevance, convenience, and proximity made the city a manageable scope for this research. The BIM scope was two sample construction projects.

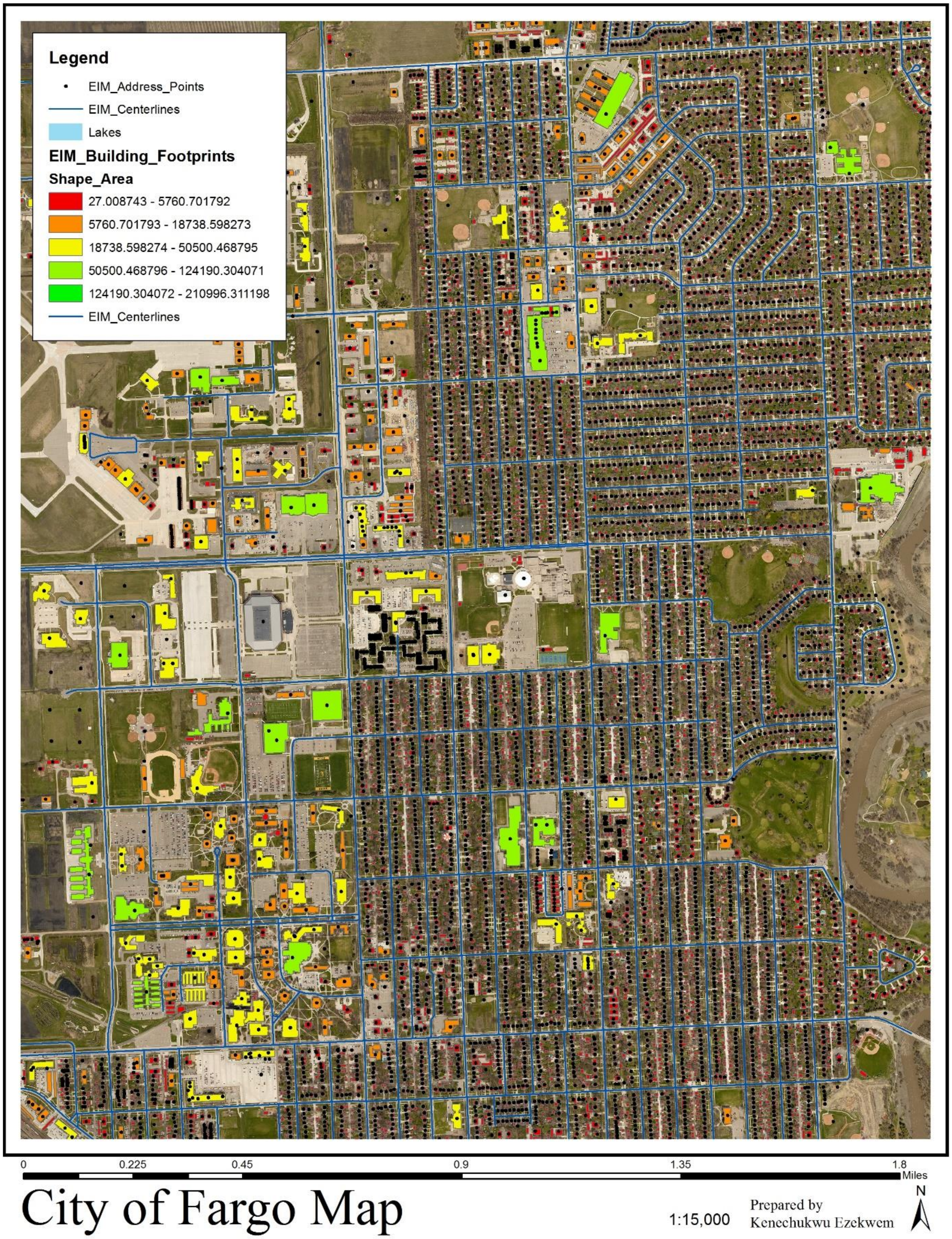

Figure 6. City of Fargo with Building Footprints and Areas - (City of Fargo, 2016)

3. LITERATURE REVIEW

3.1. Background

Chapter one outlined the needs and aims of integrating BIM and GIS for lean and green construction. Chapter two discussed the research methodology of this thesis research topic and in this chapter, the literature review for the research topic is discussed. It will cover the current state of the research and the viewpoints of other researchers regarding the integration of BIM and GIS. Before the discussion of the literature review specific to the research problem, which is the interoperability or systematic gap between BIM and GIS for lean and green construction developments, the concepts of BIM, GIS, lean construction and green construction will be discussed to provide a background knowledge.

3.2. BIM Concepts

As shown in figure 7, the BIM journey started in the 1970s, based on the early computer-aided design efforts in several industries (Rebekka, Julian, & Frank, Building Information Modeling (BIM) for existing buildings — Literature review and future needs, 2014). In September 1974, a 23-page report proposing the concept of BIM as a solution to the challenges faced by the Architectural, Engineering, Construction and Operations Industry was published. Then, it was term the “Building Description System - BDS” and stated its importance in reducing the cost of deviation that usually occurs in the design, construction and operation of buildings. BDS was proposed as a combination of both software and hardware that would be useful for storing and manipulating building design information at a detail allowing design, construction, and operational analysis (Charles, et al., 1974).

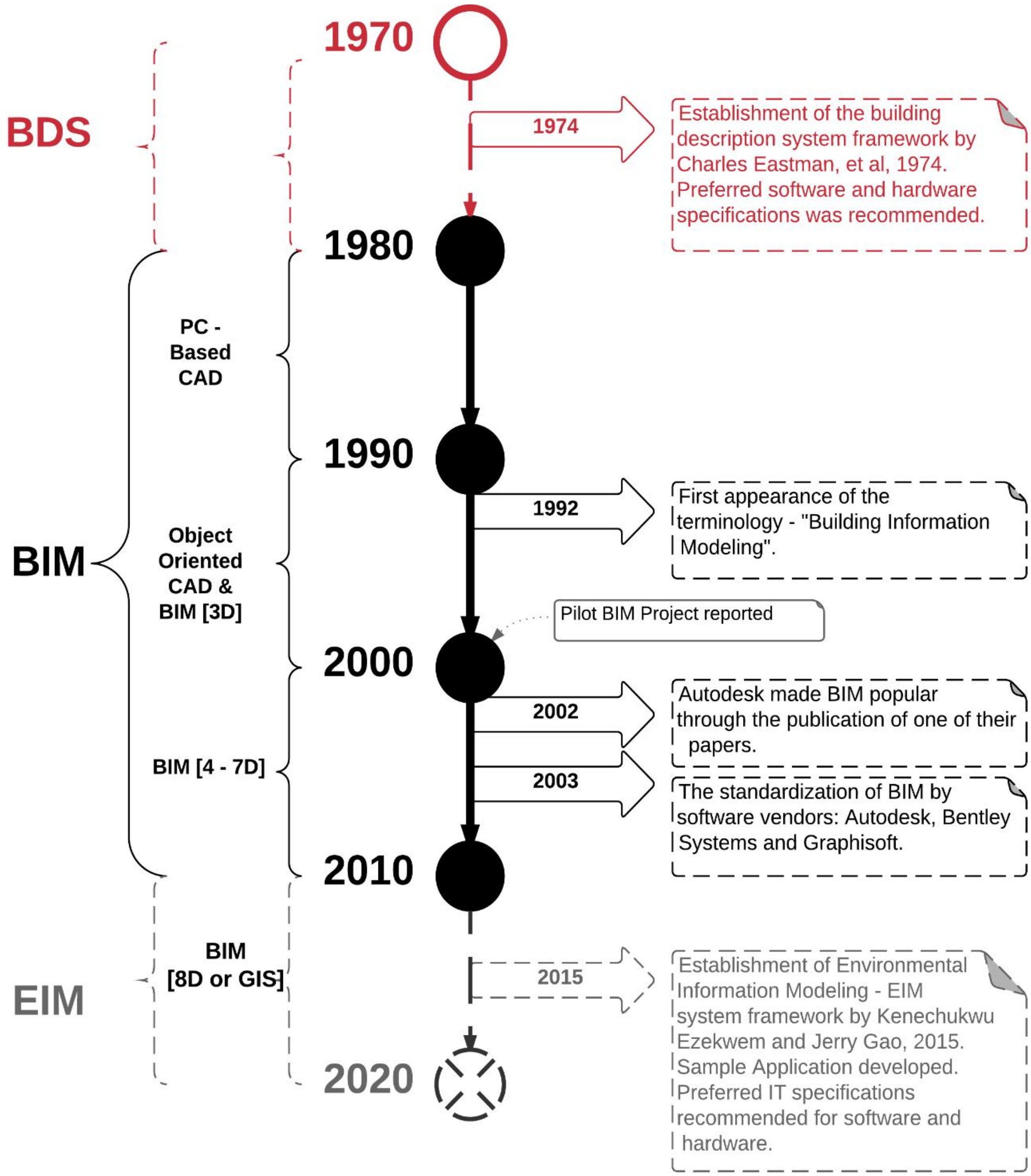

Figure 7. The Journey and Prospects of BIM

This system was proposed to replace the traditional system of relying on two-dimensional drawings which were described as having the following inherent problems:

- Redundancy: [2D drawings can be highly redundant]
- Drawings are 2D and buildings are 3D [Poor Visualization]
- Design Change leads to changes in a whole set of drawings [Not Parametric]
- Large effort is usually directed into keeping the information in the set of two-dimensional drawings for building projects currently
- Descriptions of the same part of a building are usually found in several different scales

During this period, many industries developed integrated analysis tools and object-based parametric modeling. However, the construction sector put its foot down on its traditional 2D design methods (Rebekka, Julian, & Frank, Building Information Modeling (BIM) for existing buildings — Literature review and future needs, 2014). Besides the inherent problems associated with 2D drawings, they always had augmented, accompanying notes and written specifications. This made the process of information extraction or analysis very tedious. In addition to all this, the traditional system had a high tendency to mix up current work with past work making it difficult for builders to distinguish. However, with BDS [now BIM] there was potential for the proposed IT system to provide a platform for:

- Automated Drawing Generation [Views]
- Drawing Consistency Quantitative Analysis
- Qualitative Analysis
- Building Code Checks
- Quantity Take-Offs or Parts Lists [Facility Management]

- BDS to reduce the direct costs of design, as now carried out, by more than fifty percent.
- Greater Design Flexibility
- Broader Variety of Design Philosophy
- Required Operations with Prevailing Design Philosophy
- Easy graphic entering of arbitrarily complex element shapes.
- Interactive graphic language for editing and composing element arrangements
- Hardcopy graphic capabilities
- A sort and format capability allowing sorting of the database by attributes.

In retrospect, the concept of BIM has been in existence for 41 years and was considered a database that would provide a single description of all building elements or space, relative to others (See Figure 7). The first appearance of the terminology – BIM was in a 1992 paper by G.A. van Nederveen and F.P. Tolman. It was made popular by an Autodesk report, "White Paper", where BIM was explained as Autodesk's Strategy for the application of IT to the building industry (Autodesk, 2002). The evolution of BIM progressed to the 1980's when the use of PC-Based CAD was introduced. Later on, during the 1990's, object-oriented CAD was introduced and the use of the internet for sharing data became a current practice. The first recorded implementation of BIM as an IT system was in 1987, and it was termed "Virtual Building Concept" (Cinti, Garagnani, & Mingucci, 2012). It was implemented by Graphisoft's software package – ArchiCAD. The terminology has been adopted by the major vendors of CAD software and it is now widely accepted as referring to a category of leading-edge software for building design and related applications (Watson, 2010). BIM modeling was introduced in pilot projects in the early 2000s to support building design of architects and engineers. Consequently, major research trends focused on the improvement of preplanning and design, clash detection, visualization, quantification, costing and data management. For the first BIM hardware, Charles Eastman proposed a system, as shown in figure 8, which runs on a Digital Equipment PDP-11/20 with extended disc memory and graphics which can support an interactive graphic language for editing and composing element arrangements. The proposed system was designed for the easy graphic entering of arbitrarily complex element shapes with hardcopy graphic capabilities that can produce perspective or orthographic drawings of high quality (Charles, et al., 1974).

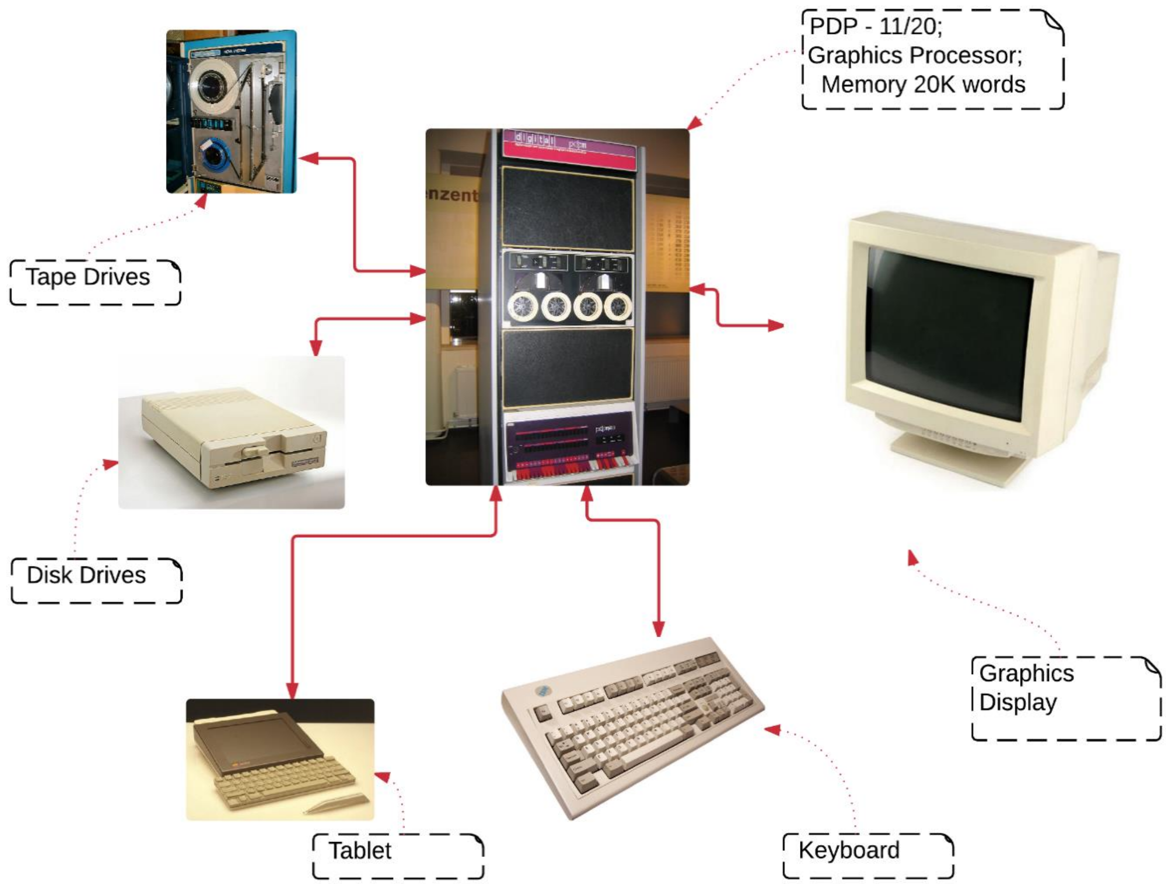

Figure 8. An Early BIM Hardware System (Charles, et al., 1974)

3.2.1. The Setting for BIM

Buildings and structures differ in type *[e.g. residential, commercial, municipal, infrastructural]*, in age *[e.g. new, existing, heritage]* and in *ownership [e.g. private owner, housing association, authorities, universities]*. These differing framework conditions are influencing the application of BIM, it's setting, it's level of detail *[LOD]* and it's supporting functionalities regarding design, construction, maintenance and deconstruction processes due to stakeholders' requirements (Rebekka, Julian, & Frank, Building Information Modeling (BIM) for existing buildings — Literature review and future needs, 2014). The three initial tasks related to buildings and structures are planning, design, and construction. These tasks are often considered together because they all occur in a relatively short time just before the occupancy of a facility during which operations and facility management sets in (Kymmell, 2008).

3.2.2. The Nature of BIM

BIM is very much talked about in the building industry these days by different industry personnel who usually have different ideas about its concepts, its Nature of BIM -what BIM is, what it should be used for and who should use it. One of the most common misconceptions about BIM is that BIM is a type of software. Another common misconception is that BIM is any 3D representation of any AEC design. BIM has so many definitions proposed by different people with different ideas of what BIM is. In an attempt to define BIM, many scholars and groups have looked at it in the following different ways:

- BIM as a Process
- BIM as a Simulation
- BIM as a Method
- BIM as an Evolution

- BIM as a Technology or Tool

The truth is that BIM is all the above and more. One of the shortest definitions of BIM is the one proposed by M.A. Mortenson Company, it defines BIM as "an intelligent simulation of architecture" (Chuck Eastman, Paul Teicholz, Rafeal Sacks & Kathleen Liston, 2008) (Modeling Rules, 2006). This definition views BIM as a simulation. There are other definitions of BIM that view it as a simulation and there are:

- A project simulation consisting of the 3D models of project components with links to all required information connected with the project's planning, construction or operation, and decommissioning (Kymmell, 2008).
- A digital representation of physical and functional characteristics of a facility (National BIM Standard - United States, 2014)
- A shared digital representation of physical and functional characteristics of any built object which forms a reliable basis for decisions (Rebekka, Julian, & Frank, Building Information Modeling (BIM) for existing buildings — Literature review and future needs, 2014) (ISO Standard, ISO 29481-1:2010(E), 2010).

The next set of BIM definitions (Below) view BIM as a tool or a technology:

- An emerging technology in which digital information models are employed in a virtual space to achieve high-quality and efficient construction and management throughout the life cycle of a facility (Kuo-Feng Chiena, 2014).
- As Building Information Model (BIM) is a tool to manage accurate building information over the whole LC (Rebekka, Julian, & Frank, Building Information Modeling (BIM) for existing buildings — Literature review and future needs, 2014).

- An emerging technology for building modeling, collaborative design, and integrated project delivery (Wei Yan, 2011).
- A tool for visualizing and coordinating AEC (architecture, engineering, and construction) work, avoiding errors and omissions, improving productivity, and supporting scheduling, safety, cost and quality management on construction projects (LiJuan Chen, 2014).

The Next set of BIM definitions (Below) view BIM as a process or a method:

- A set of interacting policies, processes, and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle (David Bryde, 2013).
- A method for creating, sharing, exchanging and managing information throughout the lifecycle of a building between all the stakeholders (Ali Motamedi, 2013)[19].
- A process involving the generation and management of digital representations of physical and functional characteristics of places.

The final definition of BIM that I state is the one that views as an evolution from the previously known methods. It defines BIM as an advanced evolution of Computer-Aided Design [CAD] (Darius Migilinskas, 2013). It is important to note that these definitions, whether viewed from a process, simulation, method, evolution or technological point, are all correct and addresses the quest of different roles of the building industry – project management, facility management, architectural design, engineering design, etc. However, models that have multiple 2D CAD references which must be combined to define them, contain only 3D data, lack support behavior or that are not parametric do not pass as BIM (Chuck Eastman, Paul Teicholz, Rafeal Sacks & Kathleen Liston, 2008). Figure 9 shows the misconceptions that shouldn’t be held about

BIM in a mind map. There are always misconceptions of what BIM means in the industry today. However, as shown in the figure, BIM should have a simulation which should exhibit the following characteristics: Digital, Spatial (3D), Measurable, Comprehensive, Accessible and durable (Chuck Eastman, Paul Teicholz, Rafeal Sacks & Kathleen Liston, 2008). It should be adequate to support data for design, construction, maintenance and deconstruction – Project Life Cycle (Rebekka, Julian, & Frank, Building Information Modeling (BIM) for existing buildings — Literature review and future needs, 2014).

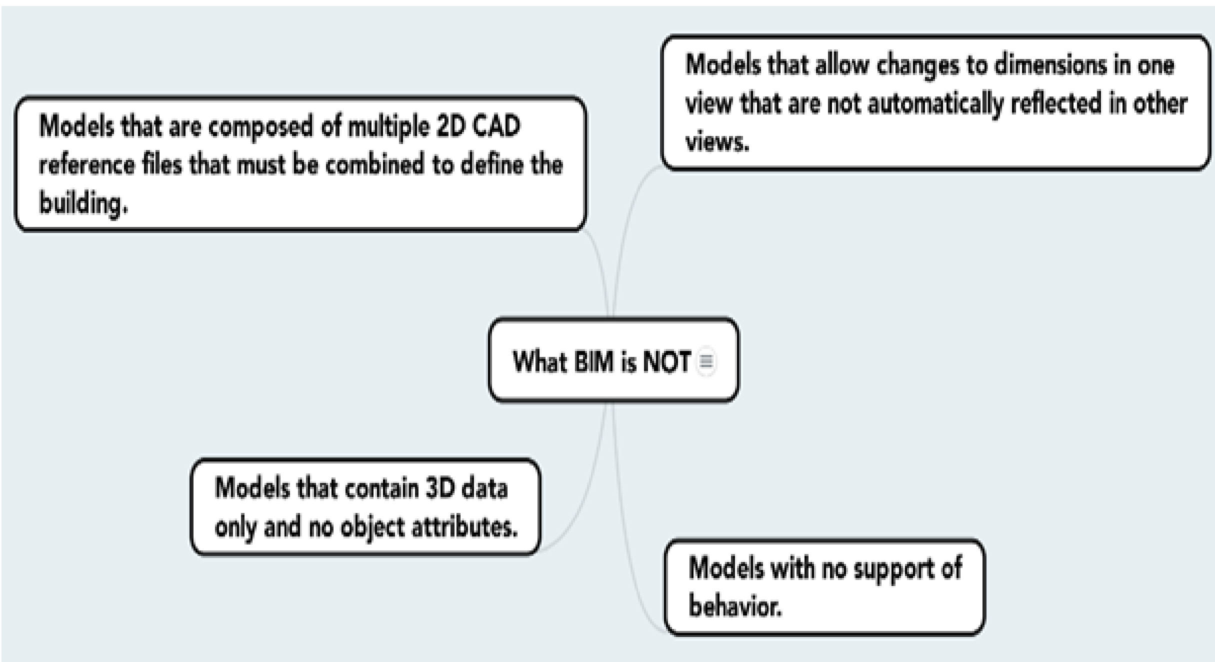

Figure 9. Common BIM Misconceptions

3.2.3. Why Use BIM?

Using BIM tremendously benefits construction projects in various aspects. It yields numerous benefits, including about 40% elimination of unbudgeted change, cost estimation accuracy within 3%, about 80% reduction in cost estimate generation time, savings of up to 10% of the contract value through clash detection, and an up to 7% reduction in project time (Kuo-

Feng Chiena, 2014)[13]. The benefits of BIM can be categorized in numerous ways. Each categorization highlights some aspects of the benefits that other ones don't. Some of the ways BIM can be categorized are listed below:

- Direct and Indirect Benefits *[Type 1]*
- Benefits by BIM Function *[Type 2]*
- Benefits by Development Phase *[Type 3]*
- Existing and Potential Benefits *[Type 4]*

In direct and indirect benefits *[Type 1]*, BIM benefits are split into two groups just as the name implies. Under the direct benefits, you find BIM benefits like Visualization *[Improved Visualization]* and Centralization of Project Information *[Improved Documentation]*. Under indirect benefits, which account for the largest benefits of BIM, they are benefits like Elimination *[BIM's most primary benefit]* and Collaboration *[Necessity for collaboration]*. When BIM benefits are categorized by function *[Type 2]*, the BIM benefits are grouped into three: Visualization benefits, Collaboration benefits, and Elimination benefits. Visualization Benefits deals with all individual benefits and the improved perception that comes with it. Collaboration benefits deal with the corporative action of several team members which is a result of the BIM process that always facilitates and encourages this interdisciplinary teamwork. The last group is the Elimination benefit which deals with project-related benefits like reduced waste, risk, and conflicts (Kymmell, 2008).

In type 3 *[Benefits by Development Phase]*, BIM benefits are split into four benefits groups: Pre-construction benefits, Design benefits, Construction benefits, Construction and Fabrication benefits and Post-construction benefits. Pre-construction benefits deal with the concept, feasibility, early design benefits and building performance/Quality benefits. [It is important to know that the use of BIM provides a means of increasing total project quality by improving design quality]. Design benefits deal with:

- Early and more accurate visualization of design
- Automatic low-level corrections when changes are made to design
- Generation of accurate and consistent 2D drawings at any stage of the design
- Early collaboration of multiple design disciplines
- Easy check against design intent
- Extraction of cost estimates during the design stage
- Improved energy efficiency and sustainability.

The construction and fabrication benefits deal with a whole set of differently grouped benefits like:

- Synchronization of Design and Construction Planning
- Discovery of design errors and omission before construction
- Quick reaction to design or site problems
- Use of BIM model as a basis for fabrication components
- Better implementation of Lean construction techniques
- Synchronization of procurement with design and construction

The post-construction benefits focus on better management and operation of facilities and BIM's integration with facility operation and management systems (LiJuan Chen, 2014) (Chuck Eastman, Paul Teicholz, Rafeal Sacks & Kathleen Liston, 2008) (Ali Motamedi, 2013) (Johnny Kwok-Wai Wonga, 2014) (Kuo-Feng Chiena, 2014). In retrospect, the use of BIM has provided a means of increasing total project quality and it accomplishes this in the following ways:

- Increases efficiency and precision and improves design evaluation and communication.
- Reduces errors due to better coordination between documents and the entire team, thus minimizes conflicts.
- Simulation and optimization can be conducted for better performance, lower costs, and shorter lead times.
- Automatic generation of engineering documents produces precise and consistent information.
- Reduces maintenance costs and time by providing timely and relevant information to facility management (FM) as early as the design stage.

Increased total project quality comes with decreased or eliminated deviations [errors and omissions] which lead to an increased ROI ultimately (LiJuan Chen, 2014). The digitized and parameterized characteristics of BIM enable project designers to fully analyze the influences of the environment and energy, and the parametric design facilitates the production of highly accurate results and instant feedback to changing variables when construction personnel encounters complex geometric designs (Kuo-Feng Chiena, 2014). The last type of BIM benefits categorization *[Type 4]* groups the benefits of BIM into Existing and proposed. Existing benefits cover all the known benefits already aforementioned while the potential benefit covers all the anticipated benefits of BIM. One anticipated benefits of BIM is in Building Regulation – Checking Planning Compliance. Another anticipated use is in the supply chain management of reinforced concrete works. Some research groups are looking into this (Darius Migilinskas, 2013) (David Bryde, 2013) (Jungsik Choi, 2014).

3.3. GIS Concepts

The first known use of GIS was by Roger Tomlinson in the year 1968 in his paper "A Geographic Information System for Regional Planning" (ESRI, 2013). Tomlinson is also acknowledged as the "father of GIS" (UCGIS, 2013). However, modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a CAD program, and geo-referencing capabilities.

The term GIS describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information. GIS applications are tools that allow users to create interactive queries, analyze spatial information, edit data in maps, and present the results of all these operations (K.C., 1986) (Vida Maliene, 2011) Geographic information science is the science underlying geographic concepts, applications, and systems (Goodchild, 2010).

3.3.1. Why Use GIS?

GIS has many benefits in project construction and operations. GIS plays a crucial role in the management of the environment and allocation of resources in many application domains. (Michels, 2001). The potential benefits of GIS are listed below:

- Improved Building Cost Estimation
- Visualization
- Reduction in Construction Waste
- Site Material Layout
- Traffic control of one site machinery
- Automated Schedule Monitoring system for precast building construction

- Housing Market Supply and Information
- Numerical simulation for slope stability
- Movement of compaction equipment

GIS has the potential to contribute to the development of smarter and safer infrastructures through its powerful toolkits, used for the management of field operations, office operations, human resources and physical assets. Through the use of the location power of GIS data, it can aid in decision making, centered on the determination of capacity enhancements, improvement of operations, and identification of investments. For instance, in transportation, GIS has been used to predict pothole occurrence. An innovative, new GIS model, developed by the UK's Cranfield University, has been used successfully by Lincolnshire County Council to predict where potholes will frequently reoccur in roads, thereby saving money on expensive resurfacing. Funded by the Engineering and Physical Sciences Research Council (EPSRC), the UK's main agency for funding research in engineering and the physical sciences, Cranfield's work was part of the Infrastructure Transitions Research Consortium (ITRC) (UK Infrastructure Transportation Research Consortium, 2015). GIS can be used to store digital data, which can easily be updated, and enhanced for design and construction analysis. It supports automated acquisition and storage of data in GIS environment to support construction project information management and analysis. This digital data can be used for the management of the entire lifecycle of an institution. Through geospatial intelligence, it helps in the management of existing buildings and provides information, required for decision making in proposed buildings. Before putting a shovel to dirt, GIS provides analysis for better decisions in the construction industry.

3.4. Lean Construction Concept

The term “lean” was coined by the research team working on international auto production to reflect both the waste reduction nature of the Toyota production system and to contrast it with craft and mass forms of production (Womack, Jones, & Roos, 1990). Lean construction is a “way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value," (Lauri, Pekka, & Jarkko, 2002). The application of new forms of production management in construction leads to lean construction which improves the productivity of the construction industry. The industry needs this production management style because of the decline that it experienced on productivity globally, for over 40years now- see figure 11. However, lean-based tools have emerged and have been successfully applied to simple and complex construction projects, improving their productivity (Remon Fayek & Sherif Mohamed, 2013) which is much needed as shown in figure 11, which shows the deviation in labor productivity, with the non-farm productivity surpassing the construction industry’s productivity since 1964. The unique challenge facing the construction industry is its project-based nature. Unlike manufacturing, construction is a project based-production process, involving various risk with impacts that affect the project constraints: time, cost and scope. However, lean construction has the potential for reducing the effects of risk on projects. In retrospect, lean construction is concerned with the alignment and holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, salvaging, and recycling (Abdelhamid 2007, Abdelhamid et al. 2008). Typically, lean begins with a pilot start within an organization with management approval and support. It is then demonstrated through projects. At this time, lean processes, unique and effective to organizational processes are standardized and then integrated into the supply chains of the organization. Then, through the constant aim for ideal lean implementation within organizations, lean processes are improved drastically.

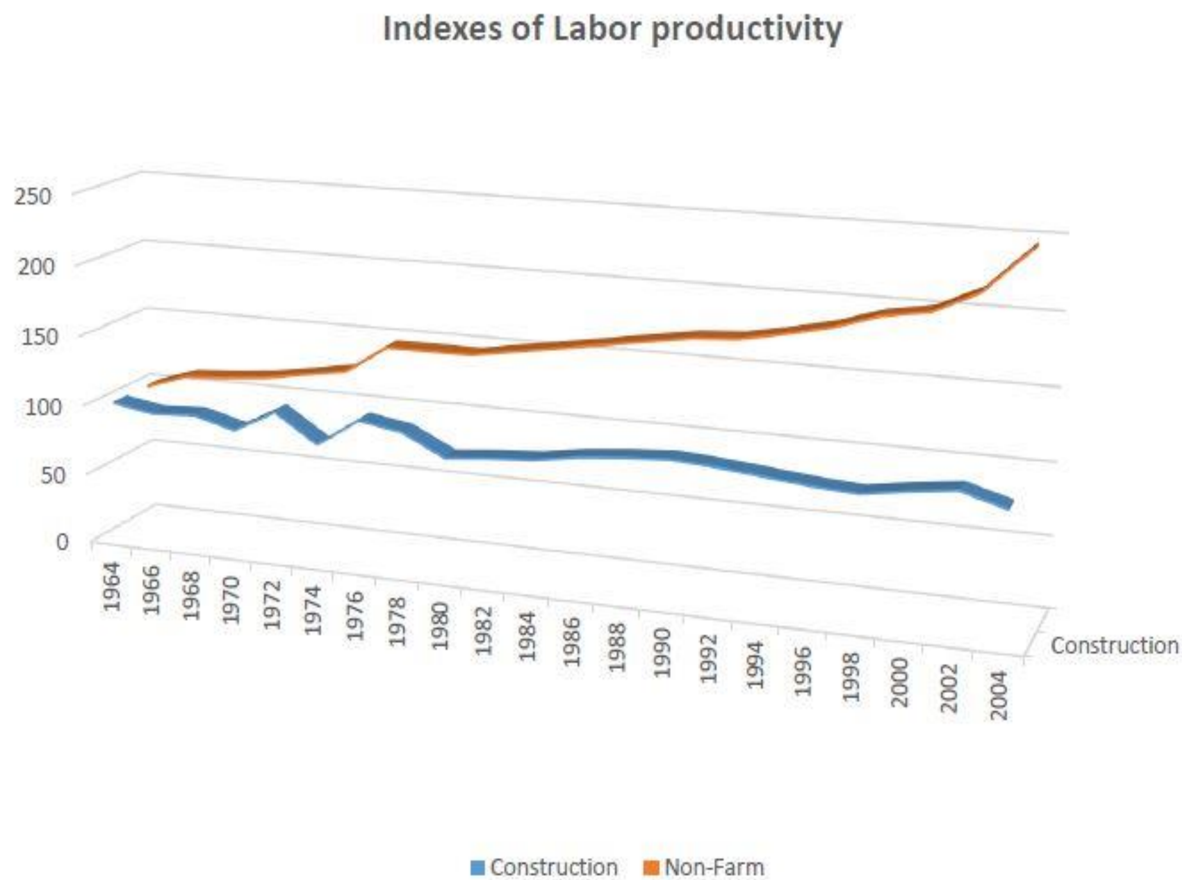

Figure 10. Labor Productivity Index - U.S. Bureau of Labor Statistics

One of the channels of lean implementation is through the Lean Project Development System (LPDS). It involves the following processes:

- Project Definition
- Lean Design
- Lean Supply
- Lean Assembly

- Production Control

With Integrated Project Delivery (IPD), project participants can overcome key organizational problems. The IPD approach to contracting aligns project objectives with the interest of key participants. It relies on clear communication which is one of the key benefits of BIM. BIM is also considered part of the toolkit for assisting the fulfillments of lean construction aims. One of the important aspects that lean focuses on is performance improvement. To do this, some factors are considered: Time Spent of Improvement, Performance Improvement Skills and mechanisms, Improvement perspective and goals, Operational Improvements, Problem complexity, and Improvement results and feedback loops.

The fundamental principles of lean construction are:

- Specification of Value [Customers cost for project production and installation]
- Identification of Value Stream
- Flow [Smooth and uninterrupted movement: Flow of work from crew to customer]
- Pull
- Perfection

Lean aims to reduce construction waste. Waste is defined as anything different from the absolute minimum amount of resources of materials, equipment and manpower, necessary to add value to the product (Remon Fayek & Sherif Mohamed, 2013). Waste is measured in terms of cost and can be classified into the following types: Overproduction, Substitution, Waiting Time, Transportation, Processing, Inventory, Movement, and Production of defective products. There are types of waste that are difficult to measure.

Table 2. Causes of Waste

Causes of Waste	**Flows**	**Resources**: *Materials, Equipment or labor*.
		Information: *Lack of information, poor information quality and timing of delivery*.
	Conversion	**Method**: *Deficient design, poor information quality and timing of delivery*.
		Planning: *Lack of work space, too many people in a workplace and poor working conditions.*
		Quality*: Poor execution and damages to finished work.*
	Management	**Decision making***: Poor allocation of work to labor and poor distribution of personnel.*
		Supervision/Control

They are usually related to the efficiency of the processes, equipment or personnel. Some of the controllable causes of waste can be categorized into flows, conversion, and management as shown in table 2.

In an effort to reduce waste, the last planner system is employed. This system measures the percentage planned completed and percentage expected time-overrun which is determined at the start of the project. The last planner system involves daily huddle meetings, the Kanban system, quality management tools, visual inspection techniques and plan/work environments. The objectives of this system are improved workflow production units in the best achievable sequence/rate and improved delegation of work to direct workers. Another technique for implementing concurrent engineering.

One of the ways lean is achieved in the industry is through performance improvements. This is achieved through time spent on production, management support, employee motivation and perceived need for employment. It can also be improved through performance improvement skills and mechanisms, perspective and goals, operational improvements, problem complexity, improvement results and feedback. Quick feedback helps a lot. The interaction between project and production management is necessary for construction project success. Lean guarantees this success through the flawless alignment of the entire supply chain involved in each project, as unique as the project may be, in other to minimize waste and maximize value.

The main tool, used by lean construction for making design and construction processes is the “Last Planner System” - LPS. This ensures that construction work is carried out in such a manner that leads to seamless workflow and reduced resources. The LPS measures percentage expected time-overrun [PET] or Percentage Planned Completed [PPC]. It integrates the master plan, phase plan, look-ahead plan, weekly planning and percentage of promises completed on time.

3.5. Green Construction Concept

Green construction involves the balance between construction and the sustainable environment. In this type of construction, processes that are environmentally responsible and resource-efficient are put into consideration throughout the life-cycle of construction projects. When discussing sustainability, reference is made to economic growth that meets the current generation without compromising the opportunity and the potential for future generation needs. The construction industry is urged to move from traditional wet construction method towards environmentally friendly, energy efficient and less waste generation methods of construction (Abdullah et al., 2009). This requires close cooperation of the design team, the architects, the engineers, and the client at all project stages. Green construction brings together a vast array of practices, techniques, and skills. It aims at the following:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution, and environmental degradation

U.S. General Services Administration found out that sustainably designed buildings cost less to operate and have excellent energy performance. Over a 20-year life period, some green buildings have yielded $53 to $71 per square foot back on investment.

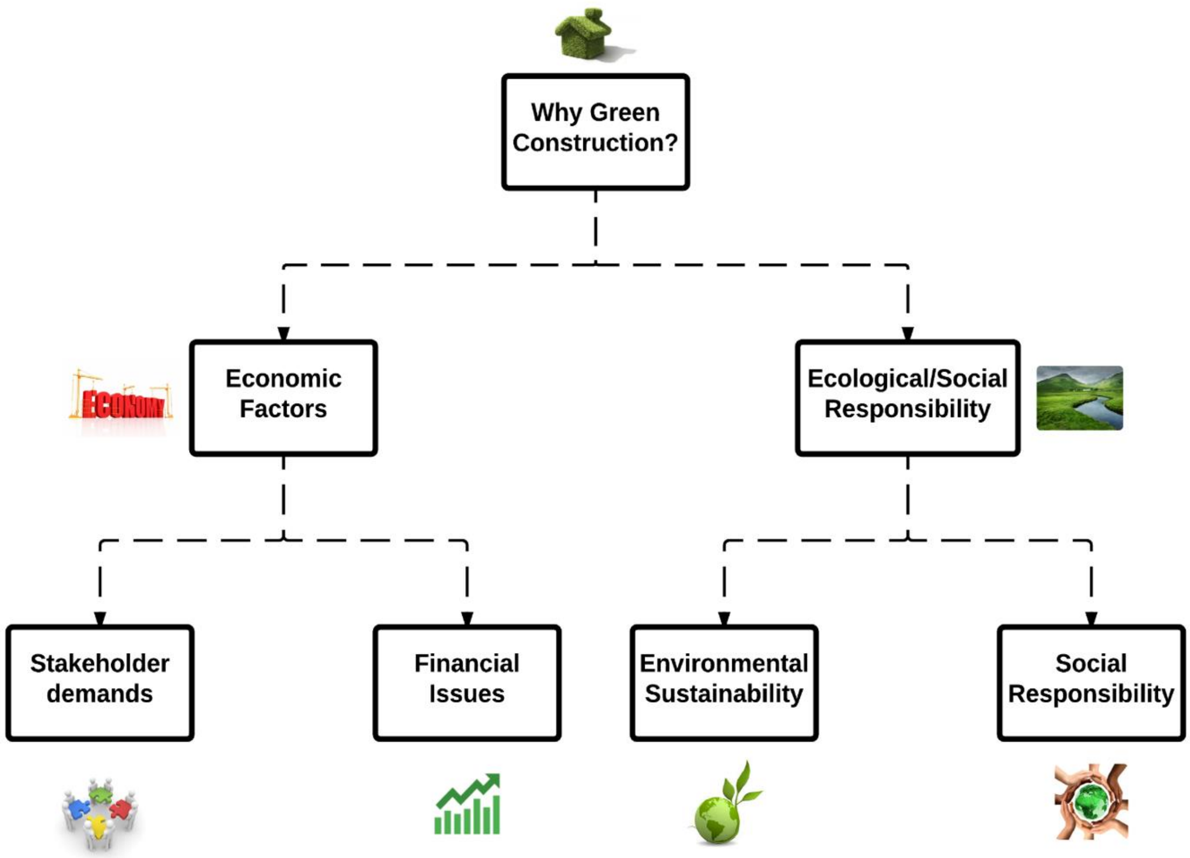

Figure 11. The Need for Green Construction

The goals or the fundamental principles of green construction are bordered on life cycle assessment, water efficiency, siting and structure design efficiency, energy efficiency, materials efficiency, indoor environmental quality enhancement, operations and maintenance optimization and waste and toxic reduction. Green construction can be rated with the Leadership in Energy and Environmental Design (LEED) system, developed by the U.S. Green Building Council. LEED helps building owners and operators be environmentally responsible and use resources efficiently. Green construction can also be assessed or rated through other international frameworks and tools. Some of these tools are IPCC Fourth Assessment Report, UNEP and Climate change, GHG Indicator, Agenda 21, FIDIC's PSM and IPD Environment Code. As shown in figure 11, the need for green construction stems from economic, social and ecological factors. It is influenced by stakeholder demands, financial issues, environmental sustainability, and social responsibility. Although there is no magic formula, success comes in the form of leaving a lighter footprint on the environment through conservation of resources, while at the same time balancing energy-efficient, cost-effective, low-maintenance products for our construction needs.

3.6. Literature Review: Previous BIM and GIS Integration

With all the efforts made so far to support the integration of BIM and GIS, the interoperability between these systems still exist. This becomes for challenging in the topic focus of this thesis: BIM and GIS integration for lean and green construction. The persistence of this challenge in the industry has not been completely solved, even with the attempts from various researchers. In this section, the review of some of the research works done on the integration of BIM and GIS is discussed.

Prior research has studied ways of using both BIM and GIS for multiple construction-related activities. In a study focused on the integration of BIM and GIS for historical purposes, the authors stated that due to the increasing use of laser scanning and photogrammetry for cultural heritage site records and the evolution of digital information systems, there has been a great interest for the generation of 3D cultural heritage models. This has inspired some research with a focus on bridging the gap between parametric CAD modeling and 3D GIS. This paper presents the research of the authors which aimed at building a new concept – Historical Building Information Modeling (HBIM). They focused on the integration of HBIM and 3D GIS for the modeling of cultural heritage sites. They carried out a case study with involved a three-step process. The process starts with laser scanning (Photogrammetric Survey), passes through a stage where the HBIM is made and ends with the integration of the HBIM and the 3D GIS for records and analysis. They stated that the integration of both systems the advantages of both CAD and GIS can be utilized. This brings the detail and accuracy of CAD to work with the complex and spatial query capabilities of GIS in one system. However, unlike CAD, BIM has more interoperability with GIS and was used by the authors for this research work. To do this, they used a two-stage approach which started with an integration of site survey which was produced together with parametric libraries in the BIM environment and then both details are used for the modeling of the HBIM. From there the HBIM now gets integrated into the 3D GIS using the CityGML framework. Conversions are made to this framework from the HBIM format and data is linked for new capabilities to be added to the model. The authors applied this methodology to their case study – "Henrietta Street". They authors chose to combine the BIM system with the GIS system for numerous reasons. Existing work has shown that the integration of both systems can be used for planning, 3D cadaster, environmental simulations and disaster management. All this is possible because of the capability of BIM to produce digital documentations; design schedules with its objects representing parametrically. They also highlighted the capability of GIS to store visualize and analyze geographical data. As a result of technological advances, GIS has gone 3D which has enabled more complex analysis, visualization, and documentation of data which was used in the implementation of the authors. The authors had a successful implementation of their framework with their methodology. However, they encountered minor challenges with lead them to state two recommendations for the system: the development of a CityGML extension for HBIM library objects and a database management system for storing, managing and querying CityGML models

Other researchers have looked at issues like: tower crane location optimization (Javier & Ebrahim, 2012), asset management (Zhang, Arayici, Wu, & Aouad, 2009), site selection and fire response (Isikdag, Underwood, & Aouad, 2008) and other studies discussed similar combinations of both systems, like in a research were BIM and GIS was integrated for supply chain management (Irizarry, Karan, & Jalaei, 2013), The authors conducted a literature review of several studies that describe the use of IT-based tools for CSCM. This existing IT-based tools are limited and have a heavy reliance on bar charts and histograms for their visual representations. They highlighted the chances enhancing the process of CSCM by taking advantage of the data richness and visualization capabilities of Building Information Modeling (BIM) and Geographic Information Systems (GIS) in a single system. They stated the importance of bringing these two systems (BIM and GIS) into one single system, which is to maximize both values from both systems. This integration of these two systems is presented as an effective tool for the monitoring of resources in CSCM with a visual representation better than the bar charts and histograms. From the case study conducted by the authors, it was observed that the integration of BIM and GIS enables tracking of the Supply Chain (SC) status. The integration also provides warning signals to ensure the delivery of materials in construction projects. In the study, the status of the materials within the SC can be vividly demonstrated in the BIM model. The time required for the provision of the materials list was largely reduced and scheduling functionality was also added to the integrated system from BIM. This integration was successful because of the various functionalities of both systems which were all present in the proposed system. This includes GIS functions with helped in the support of a wide range of spatial analysis for construction logistics (Warehousing and transportation). This helped in mapping the entire SC process and in the provision of cost management for the SC logistics. These all adds in the cost reduction of logistics. The BIM system provided data for the building product manufacturers or online sources and it also provides an accurate and detailed takeoff in an early stage of the procurement process. It also provides a great visualization capability for the generation of graphical reports and alerts. One major challenge noted by the authors is the manual input of quantities that can't be extracted from the BIM. They highlighted the importance of ensuring data integrity for both BIM and GIS for a proper implementation.

In similar studies exploring the potential of BIM and GIS in emergency management (Consulting Specifying Engineer, 2013), it was clear that fire protection and response is an essential public service in urban areas – It is the most costly, non-trivial public service (Murray, 2013), which is known to be time-sensitive service. The ability to locate people quickly and accurately is critical to the success of fire protection and response services (Li, Becerik-Gerber, Krishnamachari, & Soibelman, 2014). This public service can be provided by both public and private organizations. In the United States, this service is provided by the fire department which also provides *[Proactive]* fire prevention services through enforcement roles and other roles (Cote, 2003). The fire department can also be responsible for providing emergency medical services. Fire department services span back as far as 24 BCE *[more than 2000 years ago - in Ancient Rome]* when the first known fire service was founded by Emperor Augustus (Coe, 2009). Today, fire protection and response services have been improved through innovation. They stated that BIM and GIS are innovative industry tool has the potential to improve and support the services of the fire department and comes in handy with building specific tasks during fire protection and response. However, as BIM technology improves and moves outward from structural and architectural models, the fire protection industry as a whole reaps the benefits of using all the graphic and attribute information that can be found in a BIM project to plan for the overall life safety of buildings and the occupants through life safety integration during all stages of the development process (Consulting Specifying Engineer, 2013). With a few modifications to the functionality of BIM, using compatible programming languages, algorithms can be scripted to efficiently search for a solution. BIM provides a graphical interface for users to interact with in addition to all the attribute data that it can store. With some integration with geometric sensing technology, BIM can yield a promising indoor localization solution for fire emergency response operation through the use of Environment information which can be stored in GIS. However, this requires advanced programming to modify the functionalities of existing BIM applications.

In another study for integrating and managing BIM and GIS - (El Meouche, Rezoug, & Hijazi, 2012), it was observed that although both systems have their strengths, weaknesses, and purpose of use, the existing tools for leveraging on both systems are not straightforward and results in information loss. In another study on its integration for low disturbance construction (Rebekka, Julian, & Frank, Building Information Modeling (BIM) for existing buildings — Literature review and future needs, 2014), the authors sort to develop a solution for the integration of BIM and GIS, however, it was observed that this requires “Open BIM and GIS software standards” and that these systems have developed their standards differently. In another study on the software architecture for BIM and GIS integration for facility management (Tae Wook & Chang Hee, 2015), it was observed that during information exchange between heterogeneous systems, information is lost or altered.

However, there still exist a research gap for the integration of BIM and GIS for lean and green construction and as a result, there is a need for a study for this integration which is the focus of this thesis research.

3.7. Summary

Although some efforts have been made in both the academic and professional domains to support the integration of BIM and GIS, the interoperability between these systems still exist, and the software architecture of both systems contributes to this challenge. When it comes to the integration of this systems for lean and green construction, the systematic and research gap that exist acts as a barrier to solving this problem. In conclusion, the need to bridge this interoperability gap between BIM and GIS, for lean and green construction, still exist and this thesis focuses and creating a framework to bridge this gap.

4. DATA COLLECTION AND ANALYSIS

All data collected for GIS was in ESRI's ArcGIS software formats and those for BIM, was collected in Autodesk's Revit format. Revit, which is built upon the Modeling strategy of full integration in one place, allows users to simply choose what portion of building design information to work with. It is a fully "parametric system". When a single change is made anywhere, it updates all corresponding views/schedules within the model itself, and can update its extension database which was used for this project.

Table 3. BIM Wall Extract from the BIM Database

Id	Type Id	Volume	Area	Length	Unconnected Height	Top Constraint
198694	SIP 202mm Wall - conc clad	4.52	22.35	6,202.00	3,300.00	196,629.00

All Revit's data used in this project was in its primary file format, *.rvt format, and with an "add in" functionality, it can produce an EIM friendly database file format through an export system. This exported information is stored in an attribute file structures, with rows and columns, as shown in Table 3.

A fuller version of this can be found in Table B1 in appendix B of this thesis document. This extract from the appendix is a truncated version of the BIM wall data exported to the EIM friendly database file format from the sample BIM project 01 (see figure 12) used in the proposed framework application.

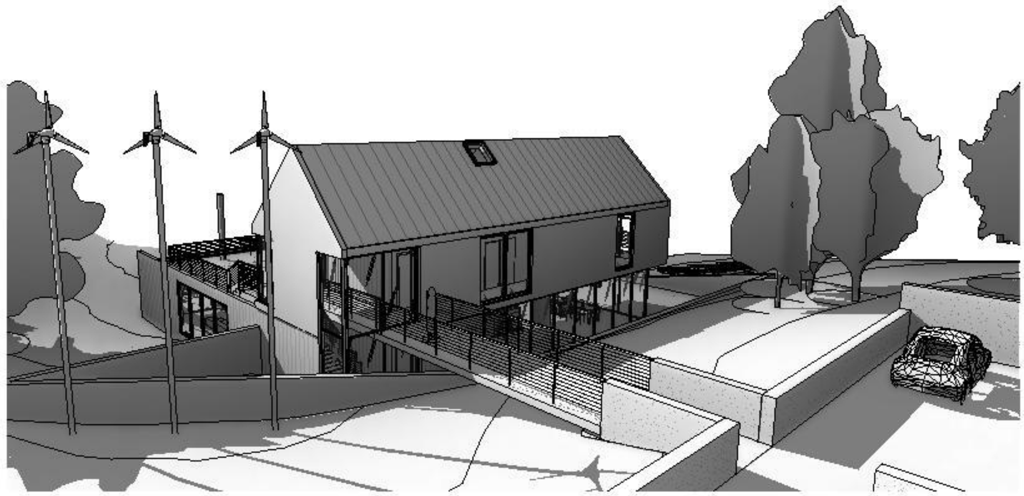

Figure 12. BIM Sample Project 01

A more detailed description of this sample data is shown in Appendix B with Table B1 showing an extract from its wall information from the BIM database, Table B2 showing the level information for the project and Figures B1 through B5, showing the sample projects sheets:

- Title Sheet
- Site Plan
- Floor Plans
- Elevations and Sections
- Elevations, Sections, and Details

Some of the information stored in the BIM database is used for the sample application analysis. The BIM database is stored with the file extension *.accdb which is the file extension for Microsoft Access, windows based Database Management System from Microsoft Corporation.

The collection of the editable version of the required city of Fargo GIS data was done at the city of Fargo office. The collected file contained the graphic and attribute data for the following types of information in ESRI's ArcMap file formats:

- Street Lights
- Street Names
- Rivers
- Neighborhoods
- Parks
- Pavement Management
- Ponds
- Metro Shields
- Limited Disturbance Zone Setback
- Lakes
- Garbage Routes
- Fargo Tax Parcels
- Contours
- Building Footprints
- Airport Polygon
- Address Points
- Fargo Image Base map

For the sample application, the address point, building footprint data and street line data was used in the GIS map (See Figure 7) for the application development.

4.1. Description of Data Collected for GIS and BIM

A “view/read-only” copy of the collected GIS data used for this research can be found in the city of Fargo website (City of Fargo, 2016). Three sample BIM models were used for this research and only one residential sample design was used for the EIM sample application demonstration. A diagrammatic description of EIM data, showing all this, is shown in figure 13, in a mind map diagram. The breakdown of the data source, data analyzer, and data management application is built around the single concept – EIM data. Most of the GIS information collected from the city of Fargo are pre-programmed into the proposed EIM application. This makes them a part of the application. However, this pre-programmed GIS information can, in some cases, be modified or updated. That way they remain relevant and up-to-date.

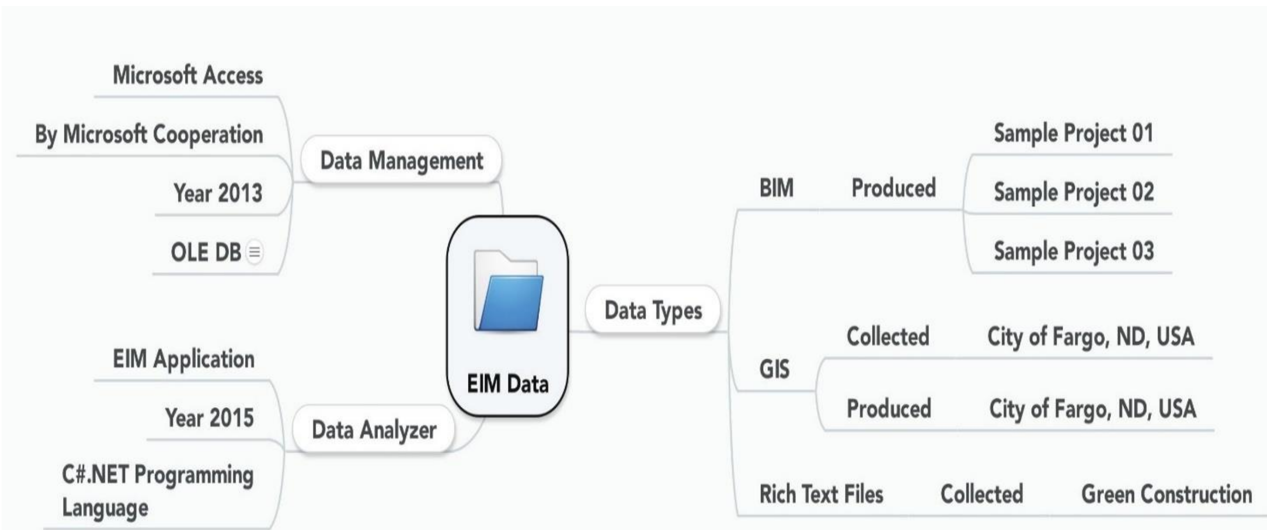

Figure 13. Diagrammatic Description of EIM data

5. DEVELOPMENT OF EIM FRAMEWORK

This thesis research is focused on the study of the integration of BIM and GIS for lean and green construction, the establishment of a framework for this integration and the development of a sample software application for this integration. The researcher's interest in this topic results from experience in the industry, both on an academic and an industry level. On a micro scale and in the author's career in construction, many events of interoperability have occurred between different IT systems and platforms within the BIM, CAD, and GIS platforms. On a macro scale, the industry is also faced with this challenge and is becoming increasingly aware of the need to solve this problem, especially now that the industry under pressure to analyze the relationship between buildings and their environments through lean and green construction processes. Yet, there are few clear solutions to mitigate the existing interoperability challenges and because of the industry's awareness of this problem and the lack of a clear solution to mitigate the issue, a pressing need exists to examine the topic and provide relevant insight and solutions to the construction industry.

The researcher's background in the design, construction, and computer programming brought strength to the research study in the way of insight and understanding into the topic, the IT systems and the experiences of the industry. It placed the researcher as an insider in relationship to the topic and culture of construction. Having experienced the topic first hand and viewed others as they experienced it combined with an experiential understanding of the construction industry has provided a background from which to examine the topic. At the same time, this experiential background can potentially weaken the objectivity of the researcher due to familiarity with the topic and culture of construction. To help maintain objectivity during the process of data gathering and analysis, a continual effort was made to guard against assumptions based on experience and an effort was made to treat the data with a fresh and clear perspective.

5.1. The Framework

As shown in Figure 14, the EIM framework begins with the development of a software system, where BIM data from Autodesk Revit Architecture and GIS data from ESRI's ArcGIS application can be integrated for data analysis focused on lean and green construction. At the stage, the main tool used is Microsoft C#.NET programming language which is one of the programming languages provided by default in the chosen BIM software, which works well the chosen GIS application as well through the use of Software Development KIT, downloadable on ESRI's website (ESRI, 2013).

Based on this framework, the application is developed with the required GIS data, preloaded, through programming, into the system by default. City development constraints from the international building code is also preloaded, through programming, into the system. At this stage, green building information is also preloaded into the system, through programming. This now leads to the integration of the application into the BIM software system – Revit Architecture. When launched, the EIM application obtains data from the BIM software and integrates them with the all the preloaded information. This now draws references from BIM application for the analysis of the chosen information for lean and green construction. The EIM software application now saves the information into the EIM database which will also contain all the preloaded information. This then sets the stage for an analysis that takes advantage of computer hardware speed and internet connectivity to instantly analyze building design in a Lean way for the chosen sustainability requirements.

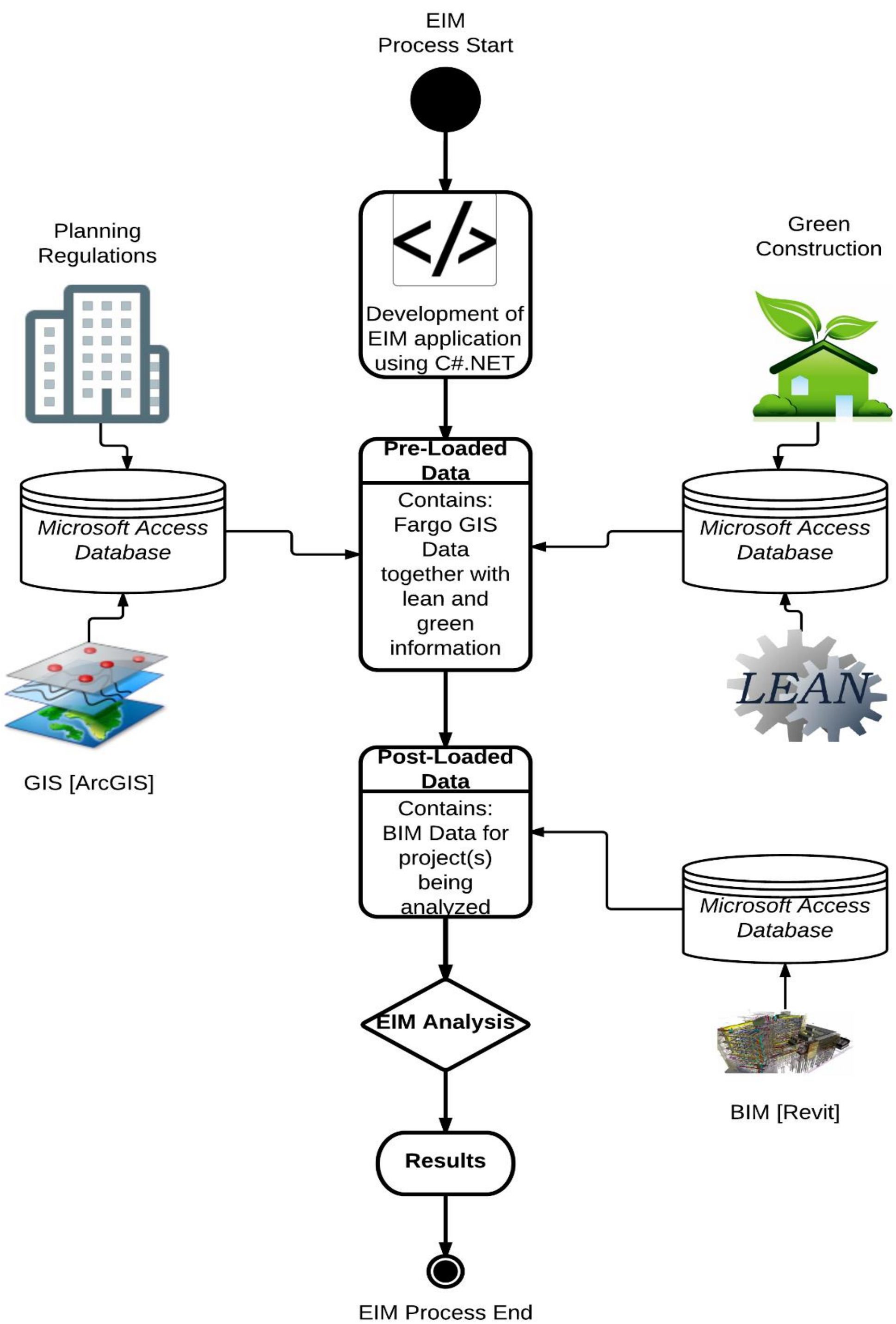

Figure 14. The EIM Framework

5.2. Application Development

For the proposed EIM development, the author aimed at creating a solution that can enable change in the construction industry through the definition of needs and the recommendation of solutions that deliver value to all stakeholders in the industry in a Lean and sustainable way. To achieve this, the author went through the following processes:

- Definition of needs
    - This was done through the determination of the research problem. At this stage, the problem was identified and the direction was set for the development of a solution.
- Elicitation of requirements
    - This was achieved at the literature review stage in order to determine the system and coding requirements needed for the software development.
- Analysis of software requirements
    - At this stage, the application requirements for the application development was analyzed. This includes case use diagrams and use cases for the application development.
- Communication of requirements
    - Here, the collected documents and analysis results are documented for use. Also, codes are developed for the proposed processes.
- Identification and proposal of solutions
    - Through software programming, solutions are developed and proposed for the proposed framework application. This is done carefully with all the information elicited at the beginning of the development process.

- Validation of Solutions
    - Here, any existing problems are found and fixed using Microsoft Visual Studio’s debugger. The debugger can guide the program through corrections in some cases.

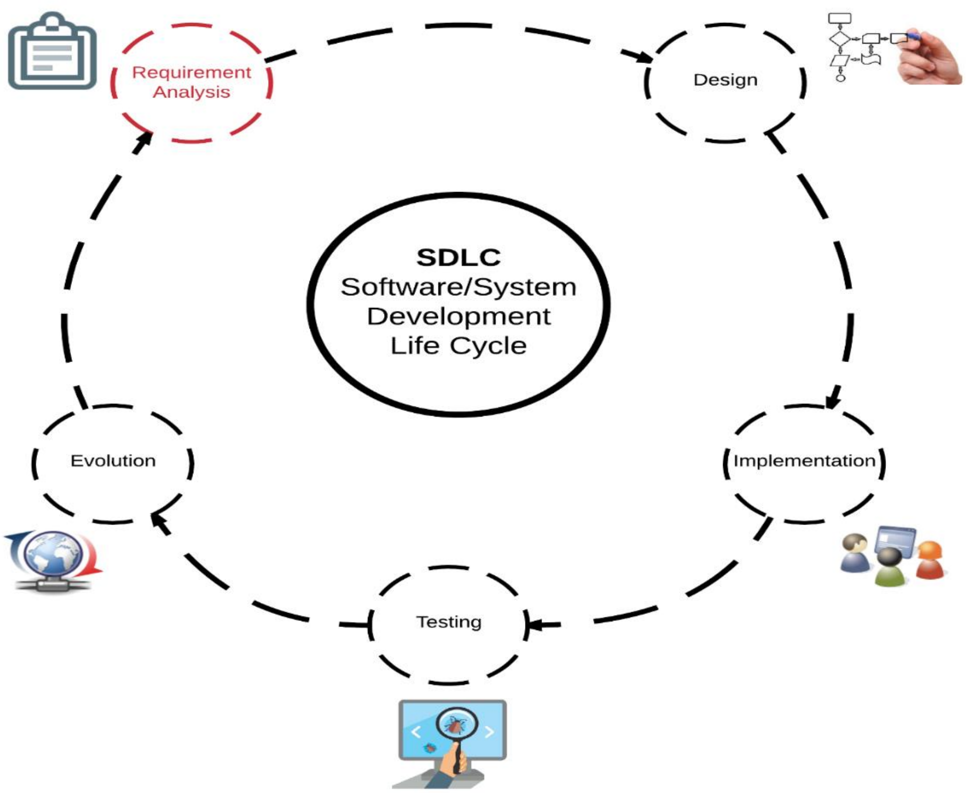

Figure 15. Software/System Development Life Cycle

The EIM Software Development Lifecycle (SDLC) used for the EIM application development has four vital phases as shown in Figure 15. The first phase is the “requirements and analysis phase”. Here the problem is identified, together with the scope or project boundary. Here the project management plan and other planning documents are developed. An analysis of the expected user needs is developed together with user requirements. The basis for acquiring the required resources needed to achieve a solution is considered. Then created a detailed functional requirements document *[Check appendix for an abstract of the requirement document]*. The second phase is the “design phase”. Here, the detailed requirements are compiled into a complete, detailed systems design document which focuses on how to deliver the required functionality. The third phase is the “implementation phase”. Then the transformation of designs stored in the system design document is done to convert it into a complete information system *[Using Visual Studio: C#.NET]*. This includes acquiring and installing systems environments.

As shown in figure 14 and 15, the database is created, tested, prepared and coded into the application using mainly C# language. Microsoft Visual basic was used to compile the EIM program, and perform test readiness reviews. The fourth phase is the “testing phase”. Here, the author demonstrates that the EIM system conforms to requirements needed for the EIM software development. The final phase is the “evolution phase”. Here, the EIM application is reviewed for an update to both front and back end designs. This is the stage for changes and enhancements that may be required based on testing, analysis or feedback from users.

The software development methodology used is the agile methodology, which promotes adaptive planning, evolutionary development, early delivery, continuous improvement, and encourages rapid and flexible response to change (Agile Alliance, 2013). This method of development ensured that the researcher was always ready to respond to any required changes that might be needed for the EIM project. Using the agile methodology, the EIM software can be seen as a living organism, which actively changes due to environmental change.

5.3. EIM Access Management Process

A profiled system with an EIM registration and login window was developed. Here, the potential users of this proposed system can register with the EIM system before using the system and existing users can log in using information saved in the EIM database. The account setup is designed to be free, however, the option of making purchases related to planning approval or other city of Fargo premium services can be provided in this framework. In addition to this, if any EIM user chooses to use the application with the internet while communicating with the database, the user would be responsible for any fees associated with internet usage as determined by the internet service provider used – e.g. mobile carrier or internet providers.

To be eligible to sign up for the EIM application, you must be 16 years or older, have a social security number and an email address. The application was designed not to permit joint accounts. You can only sign up for one EIM account per email address and social security number. In an effort to authenticate and secure digital identities, the proposed EIM software does not permit more than one personal account. However, you can open corporate or administrative accounts if you already have a personal account. In such cases, the social security number of the corporate account administrator can be used for a personal account also.

In order to register for EIM use, the user has to provide the following information on the signup window [See Figure 16, showing the sign-up section of the login program boxed in red]:

- First Name
- Last Name
- *Email
- *Password
- Gender

- Address
- State and City
- Zip Code and Unit No
- *Date of birth
- *Social Security Number

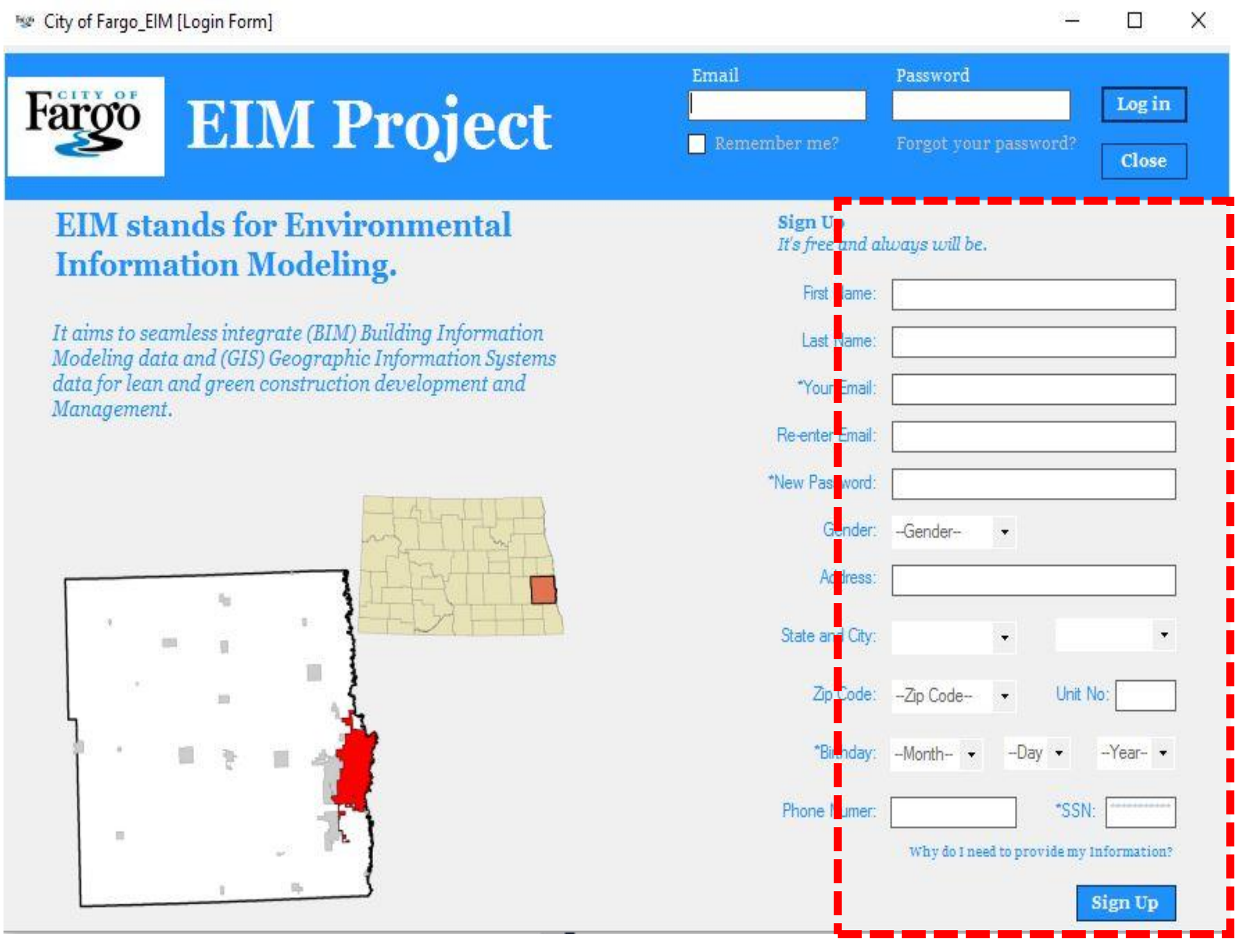

Figure 16. Windows Form with the Signup Section of the Login Program Boxed in Red

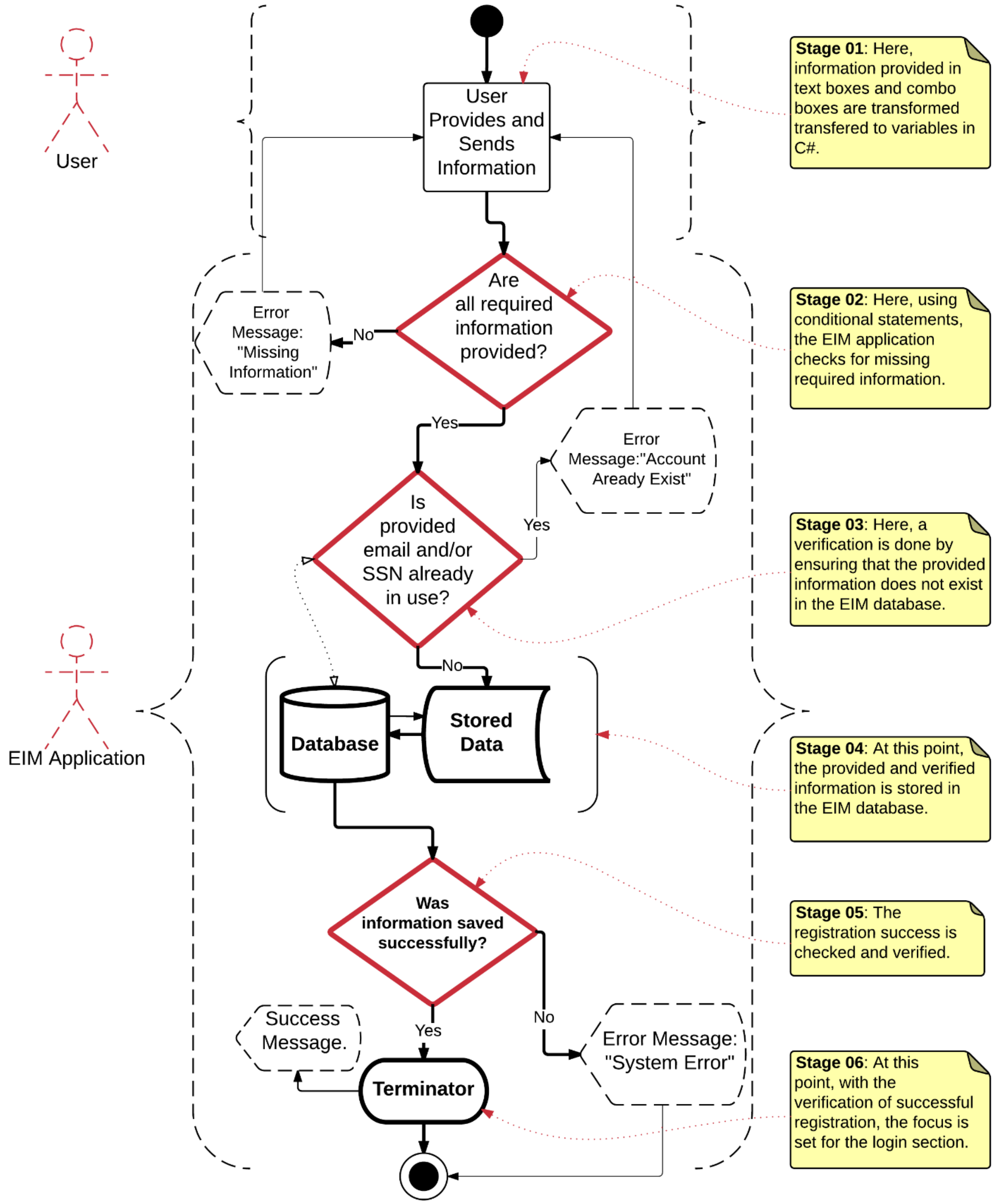

Figure 17. EIM Registration Process

The registration process which involves six stages or processes are shown in the use case diagram shown in figure 17 and are explained below. The first stage [Stage 01], as described in the figure above, is done by the user. Here, the user provides the requested information by typing into the text boxes and selecting the options in the combo boxes. Once the user is done, the click on the “Sign Up” button where the preceding stages [Stage 02 to Stage 06] are automatically done by the EIM application using the c# codes provided below.

Table 4. EIM User Access Management Process Codes in C#

EIM User Access Management: [Registration Process C# Codes shown below]	

1	private void buttonSignUp_Click(object sender, EventArgs e)
	{
	//Add registration data to the Data Base
	//Here we write the C# code for the whole registration process.
	//These codes begin to process immediately after the user is done inputting and clicks the “Sign //Up” button.
	
	//String variables are declared and loaded with the email address for verification
	string emailSpellCheck01 = txtboxYourEmail.Text.ToString();
	string emailSpellCheck02 = txtboxReEnterEmail.Text.ToString();
	
	//Validate the registration input information provided by the user
	if (emailSpellCheck01 == emailSpellCheck02 & txtboxFirstName.Text != "" & txtboxLastName.Text != "" & txtboxYourEmail.Text != "" & txtboxNewPassword.Text != "")
	try
	{
	//Connect and open the data base.
	string constring = @"Provider=Microsoft.ACE.OLEDB.12.0;Data Source= G:\C# Projects\01_EIM_03 23 2016\01 DATABASE\EIM_Thesis_NDSU_CME_03 23 2016.accdb";
	OleDbConnection conDataBase = new OleDbConnection(constring);
	
	//Open connection to the EIM database
	conDataBase.Open();

Table 4. EIM User Access Management Process Codes in C# (continued)

2	//Add string information to the open EIM database: Specifically at the Login table
	OleDbCommand cmdDataBase = new OleDbCommand("INSERT INTO EIM_login (FirstName, LastName, YourEmail, Gender, Address, State, City, Zip, UnitNo, [Password]) VALUES ('" + txtboxFirstName.Text + "','" + txtboxLastName.Text + "','" + txtboxYourEmail.Text + "','" + comboBoxGender.SelectedText + "','" + textBoxAddress.Text + "','" + comboBoxState.SelectedText + "', '" + comboBoxCity.SelectedText + "','" + comboBoxZipCode.SelectedText + "', '" + textBoxUnitNumber.Text + "','" + txtboxNewPassword.Text + "')", conDataBase);
	cmdDataBase.ExecuteNonQuery();
	MessageBox.Show("Welcome to the EIM world" + Environment.UserName + "... You can now login to start!", "Your registration, using" + textBoxEmail.Text + " as your email was successful...!");
	conDataBase.Close();

3	//Clear the Sign up text boxes and comboboxes
	txtboxFirstName.Text = "";
	txtboxLastName.Text = "";
	txtboxYourEmail.Text = "";
	txtboxReEnterEmail.Text = "";
	txtboxNewPassword.Text = "";
	comboBoxGender.SelectedText = "";
	textBoxAddress.Text = "";
	textBoxUnitNumber.Text = "";
	textBoxPhoneNumber.Text = "";
	textBoxSSN.Text = "";
	comboBoxCity.Text = "";
	comboBoxState.Text = "";
	comboBoxGender.Text = "";
	comboBoxDay.Text = "";
	comboBoxMonth.Text = "";
	comboBoxYear.Text = "";
	comboBoxZipCode.Text = "";

Table 4. EIM User Access Management Process Codes in C# (continued)

4	<pre> }
	            catch (Exception ex)
	            {
	                MessageBox.Show("Your sign up failed due to" + ex.Message);
	            }
	
	        else
	        {</pre>

5	MessageBox.Show(Environment.UserName + " one or more of the information required for registration has not been accurately or completely provided", "Inconsistent email address or registration information");
	txtboxFirstName.Focus();
	txtboxYourEmail.SelectAll();
	txtboxReEnterEmail.SelectAll();

6	//Clear the Sign up text boxes and comboboxes
	txtboxFirstName.Text = "";
	txtboxLastName.Text = "";
	txtboxYourEmail.Text = "";
	txtboxReEnterEmail.Text = "";
	txtboxNewPassword.Text = "";
	comboBoxGender.SelectedText = "";
	textBoxAddress.Text = "";
	textBoxUnitNumber.Text = "";
	textBoxPhoneNumber.Text = "";
	textBoxSSN.Text = "";
	comboBoxCity.Text = "";
	comboBoxState.Text = "";
	comboBoxGender.Text = "";
	comboBoxDay.Text = "";
	comboBoxMonth.Text = "";
	comboBoxYear.Text = "";
	comboBoxZipCode.Text = "";
	
	    }
	}</pre>

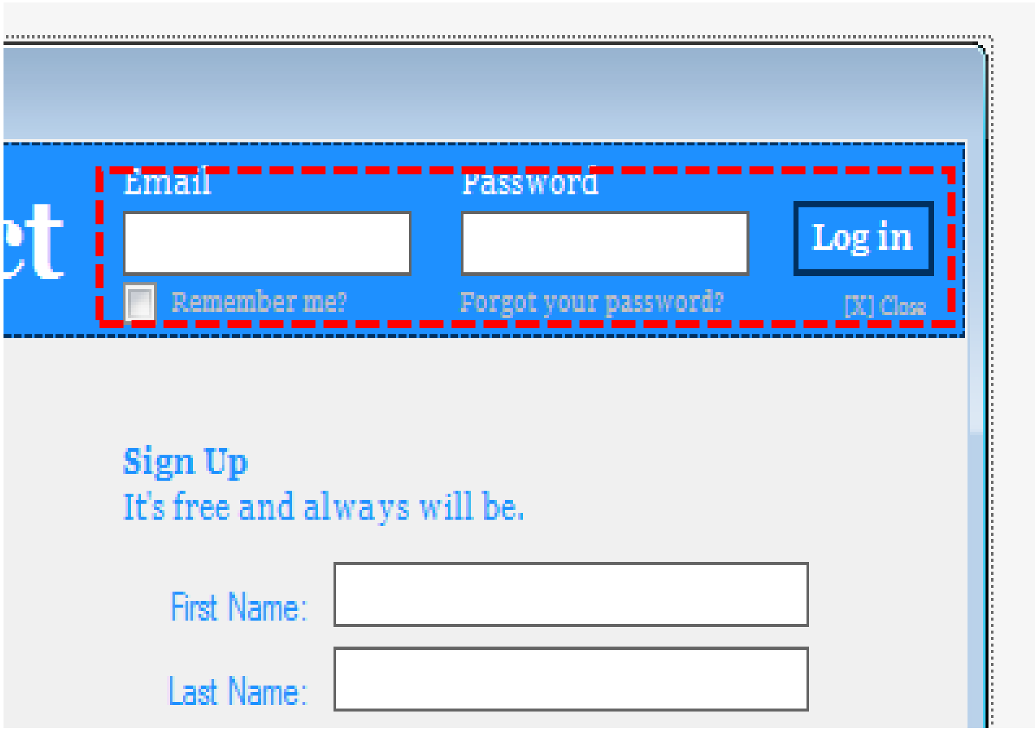

Figure 18. Login Section of the Window Form

Once a user is verified and registered, the user can login by entering the required and registered email address and password. To do that, the user has to input the required information using the provided "Email" and "Password" text boxes. Once the information is typed in, the user can then click the "log in" button as shown in figure 18. Also, the login process which involves five stages or processes are shown in the use case diagram shown in figure 21 below and are explained in detail below the figure. At the first stage [Stage 01], as described in figure 19, the user provides the requested information by typing into the text boxes provided. Once the user is done, the click on the "Sign in" button ushers an automated EIM process, where the preceding stages [Stage 02 to Stage 05] are automatically done by the EIM application using the C# codes provided below.

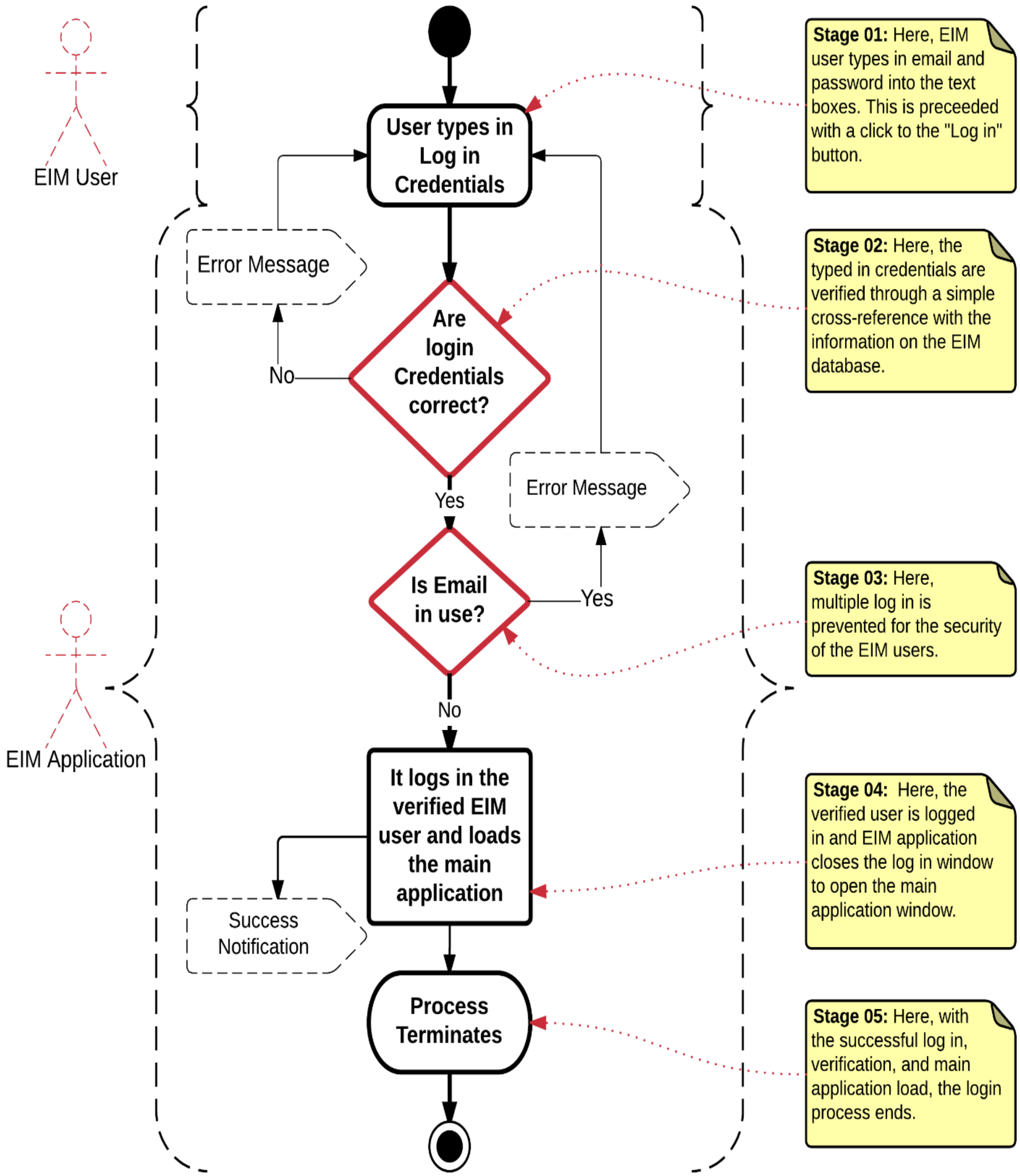

Figure 19. EIM Login Process Flow Chart

Table 5. EIM Login Process C# Codes

EIM User Access Management: [Login Process C# Codes shown below]	

C# Codes for process A	if (textBoxEmail != null & textBoxPassword != null)
	try
	{
	string constring = @"Provider=Microsoft.ACE.OLEDB.12.0;Data Source= G:\C# Projects\Data Base\EIM_Thesis_NDSU_CME_10 14 20151.accdb";
	OleDbConnection conDataBase = new OleDbConnection(constring);
	OleDbCommand cmdDataBase = new OleDbCommand("SELECT * FROM [EIM_login] WHERE YourEmail = '" + this.textBoxEmail.Text + "' AND Password = '" + this.textBoxPassword.Text + "';", conDataBase);
	OleDbDataReader myReader;
	
	conDataBase.Open();
	myReader = cmdDataBase.ExecuteReader();
	int count = 0;
	while (myReader.Read())
	{
	count = count + 1;
	
	}
	if (count == 1)
	try
	{
	// Declaration of variable
	string loginSuccess = "";

Table 5. EIM Login Process C# Codes (continued)

C# Codes for process B	//Load next window while making first one disappear
	this.Hide();
	Form2 f2 = new Form2();
	f2.ShowDialog();
	this.Close();
	}
	catch (Exception ex)
	{
	MessageBox.Show(ex.Message);
	}
	else
	{
	MessageBox.Show("Your EIM Username or Password did not match, please enter your correct login information or register if you are a new user");
	textBoxPassword.Text = "";
	}
	}
	catch (Exception ex)
	{
	MessageBox.Show(ex.Message);
	}
	else
	MessageBox.Show("Please enter your EIM email and password", "Incomplete Login Information");
	textBoxPassword.Text = "";
	}

C# Codes for process C	//Load string message
	loginSuccess = "Welcome! Your login was successful. You are logged in using " + textBoxEmail.Text + " as your email. This will be your unique identifier and username. Please proceed by clicking the 'Ok Botton' which loads the main app";
	
	//Display Message
	MessageBox.Show(loginSuccess, "Successful Login with: " + textBoxEmail.Text + " as EIM email and ID");
	conDataBase.Close();

5.4. EIM Analysis Process

Once the EIM application executes the access verification and login codes shown in table 5, it loads the main application user interface – "EIM Analysis Centre". On this form, the researcher explored the possibility of using the EIM application to access information from the datasets of both BIM and GIS for pre and post -development process analysis. It automates processes that aid in the assessment of green design and construction through lean processes.The EIM analysis center has the following four tabs listed below for diverse pre- and post-development processes.

- LEED v4 Building Design and Construction Project Checklist
- Planning Approval (See figure 22)
- Emergency Management Information (See figure 23)
- EIM Graphical Displays

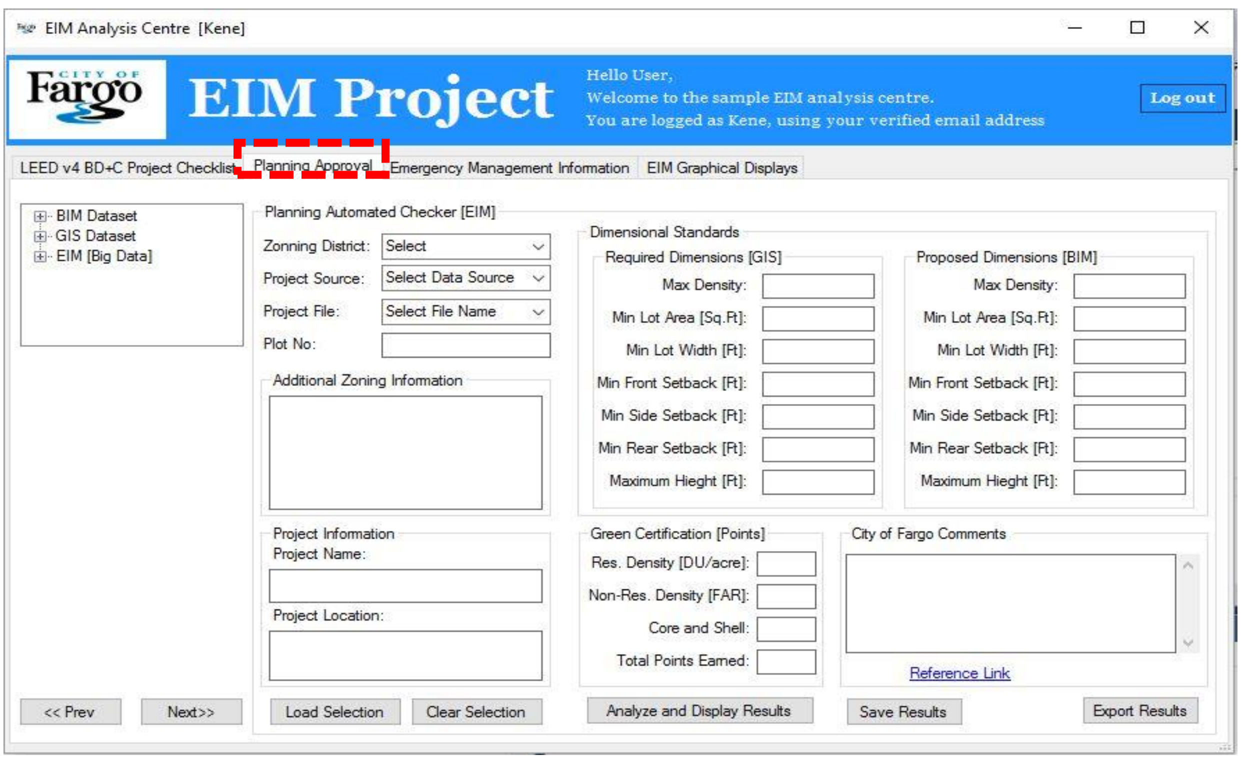

Figure 20. EIM Main Application – Planning Approval Tab

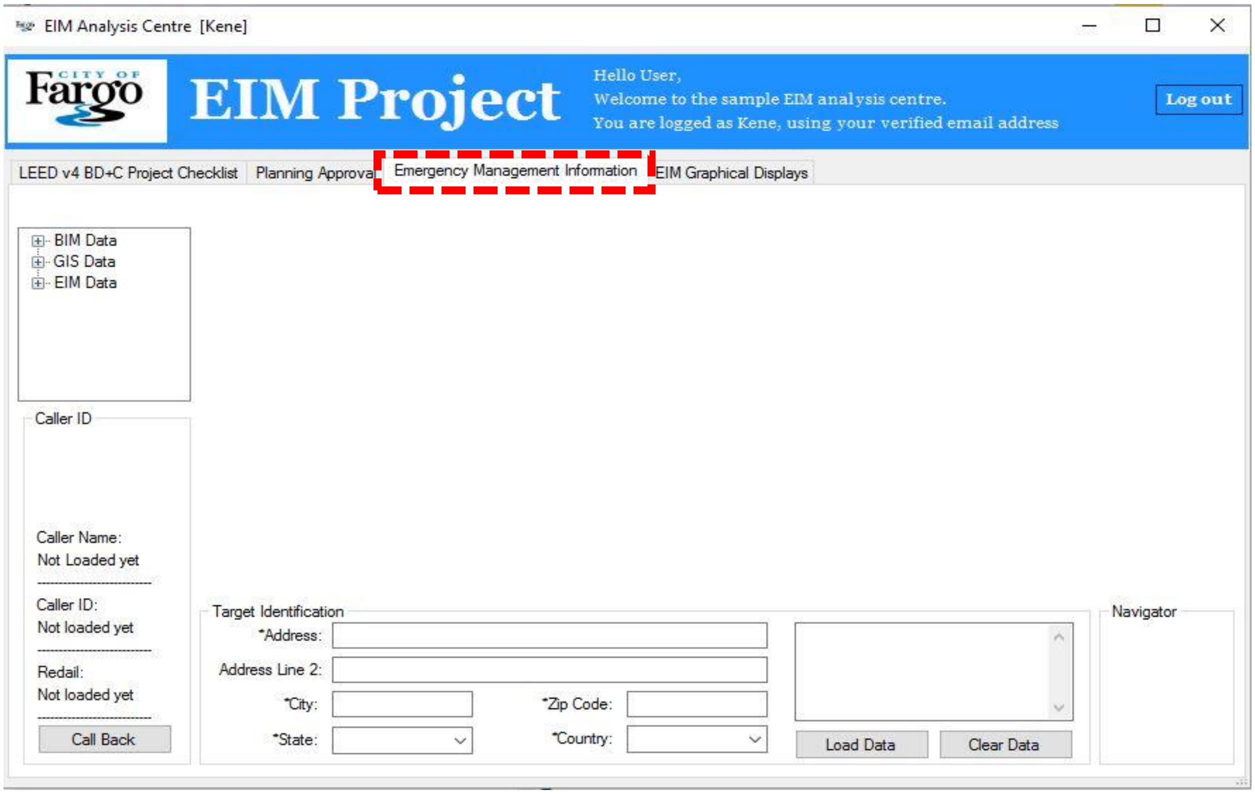

Figure 21. EIM Main Application - Emergency Management Information Tab

Within the planning approval tab, the EIM application is programmed to analyze and display results for planning approval. It compares some vital proposed dimensions from the BIM file and checks them against the required dimensions, based on the selected zoning district. It also uses some information contained in the BIM dataset – e.g. Floor Area Ratio – FAR against some information contained in the GIS dataset to calculate some Green Certification Points that must have been earned with the proposed design. In doing all these, it shows potential for green design and construction analysis through lean, automated planning approval process and the calculation of possible green points earned from the building data. It provides Just in Time [JIT] delivery for some quantitative/dimensional evaluations which are required in the planning approval process while increasing awareness of the relationship between buildings and their environments with its Green certification calculations. The analysis and display process flow chart is shown in figure 22.

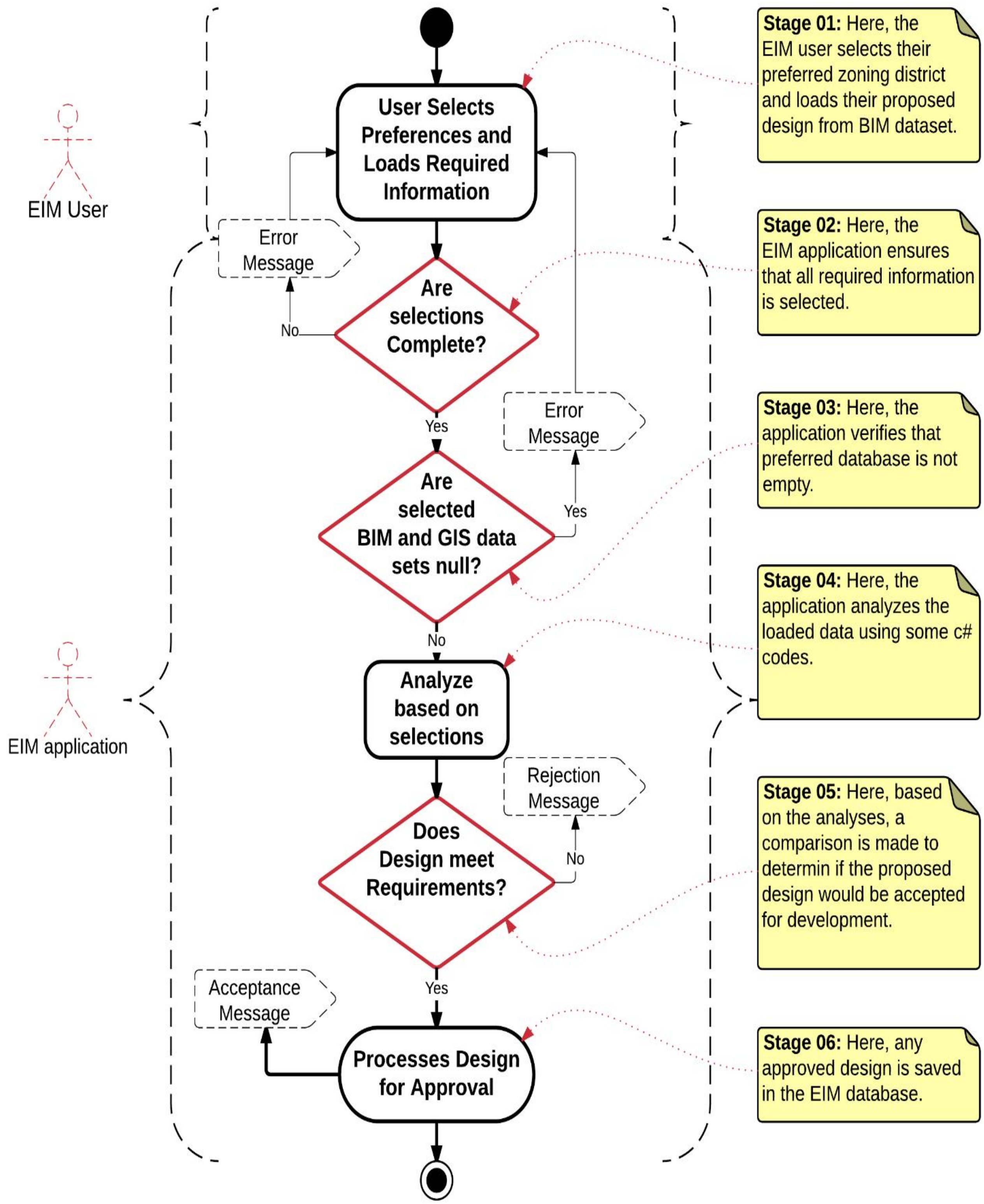

Figure 22. EIM Analysis and Display Process Flow Chart

Table 6. EIM Analysis and Display C# Codes.

EIM User Access Management: [Analysis and display process C# Codes shown below]	

1	//Assign database values to the integer.
	required1 = textBoxMaxDensityReq.Text;
	required2 = textBoxMinLotAreaReq.Text;
	required3 = textBoxMinLotWidthReq.Text;
	required4 = textBoxMinFrontSetbackReq.Text;
	required5 = textBoxMinSideSetbackReq.Text;
	required6 = textBoxMinRearSetbackReq.Text;
	required7 = textBoxMaximumHeightReq.Text;
	
	proposed1 = textBoxMaxDensityProp.Text;
	proposed2 = textBoxMinLotAreaProp.Text;
	proposed3 = textBoxMinLotWidthProp.Text;
	proposed4 = textBoxMinFrontSetbackProp.Text;
	proposed5 = textBoxMinSideSetbackProp.Text;
	proposed6 = textBoxMinRearSetbackProp.Text;
	proposed7 = textBoxMaximumHeightProp.Text;
	
	int issueCountInteger = 0;
	string issueCountString = "";

2	//Analyze for equality
	//Maximum Density
	if (required1 == proposed1)
	{
	textBoxMaxDensityProp.ForeColor = Color.Green;
	one = "Your proposed [BIM] maximum density is equivalent to the requirements. ";
	}
	else
	{
	textBoxMaxDensityProp.ForeColor = Color.Red;
	one = "Please check your maximum density. ";
	issueCountInteger += 1;
	}
	//Minimum Lot Area
	if (required2 == proposed2)

Table 6. EIM Analysis and Display C# Codes (continued)

3	<pre>{
	    textBoxMinLotAreaProp.ForeColor = Color.Green;
	    two = "Your proposed [BIM] lot size is equivalent to the requirements. ";
	}
	else
	{
	    textBoxMinLotAreaProp.ForeColor = Color.Red;
	    two = "Check your [BIM] lot size. ";
	    issueCountInteger += 1;
	}
	//Min Lot width
	if (required3 == proposed3)
	{
	    textBoxMinLotWidthProp.ForeColor = Color.Green;
	    three = "Your proposed [BIM] lot width is equivalent to the requirements. ";
	}
	else
	{
	    textBoxMinLotWidthProp.ForeColor = Color.Red;
	    three = "[Issue:3] Check your [BIM] Lot width size. ";
	    issueCountInteger += 1;</pre>

4	<pre>}
	//Min front setback
	if (required4 == proposed4)
	{
	    textBoxMinFrontSetbackProp.ForeColor = Color.Green;
	    four = "Your proposed [BIM] front setback is equivalent to the requirements. ";
	}
	else
	{
	    textBoxMinFrontSetbackProp.ForeColor = Color.Red;
	    four = "[Issue:4] Check your [BIM] front setback. ";
	    issueCountInteger += 1;
	}</pre>

Table 6. EIM Analysis and Display C# Codes (continued)

5	//Min side setback
	if (required5 == proposed5)
	{
	textBoxMinSideSetbackProp.ForeColor = Color.Green;
	five = "Your proposed [BIM] side setback is equivalent to the requirements. ";
	}
	else
	{
	textBoxMinSideSetbackProp.ForeColor = Color.Red;
	five = "[Issue:5] Check your [BIM] side setback. ";
	issueCountInteger += 1;
	}
	//Min side setback
	if (required6 == proposed6)
	{
	textBoxMinRearSetbackProp.ForeColor = Color.Green;
	six = "Your proposed [BIM] side setback is equivalent to the requirements. ";
	}
	else
	{
	textBoxMinRearSetbackProp.ForeColor = Color.Red;
	six = "[Issue:6] Check your [BIM] side setback. ";
	issueCountInteger += 1;

6	}
	//Min side setback
	if (required7 == proposed7)
	{
	textBoxMaximumHeightProp.ForeColor = Color.Green;
	seven = "Your proposed [BIM] side setback is equivalent to the requirements. ";
	}
	else
	{
	textBoxMaximumHeightProp.ForeColor = Color.Red;
	seven = "[Issue:7] Check your [BIM] side setback. ";

Table 6. EIM Analysis and Display C# Codes (continued)

7	issueCountInteger += 1;
	}
	
	//Put all the observed comments here
	textBoxCityOfFargoComments.Text = one + ". " + two + ". " + three + ". " + four + ". " + five + ". " + six + ". " + seven;
	issueCountString = issueCountInteger.ToString();
	if (issueCountInteger == 0)
	{
	MessageBox.Show("No issus were seen in your imported BIM project. Please proceed to pay for your planning approval [Use the reference link below]. Your approval number and details has been emailed to you.", "Congratulations! " + comboBoxProjectFile.Text + " can now be approved for District: " + comboBoxZoningDistricts.Text);
	}
	else
	{
	MessageBox.Show("The City of Fargo, through this EIM application, has found " + issueCountString + " concern(s) with your proposed BIM project: " + comboBoxProjectFile.Text + ", Submitted for the selected District: " + comboBoxZoningDistricts.Text + ". Check 'City of Fargo' comment box for details. All dimensions that don't match required dimensions have been highlighted in red. Our suggestions has been emailed to you.", issueCountString + " Concern(s) detected.");
	}
	}

The next function the researcher designed for is the emergency management information system. This is a potential post-construction application of the EIM system. On the emergency management tab, in the “target identification” group box, boxed in red in figure 23, the EIM user inputs the response target address and clicks the “load data” button. Using some C# codes, the EIM application automatically performs and cross-reference of its database to find the address inputted. Once the address is found, it displays a route map from the responder’s location to the target location and then pulls up static BIM views of the building for the EIM user which can be sent to the crew or the first response team. It also displays building material information from the BIM database – e.g. fire rating.

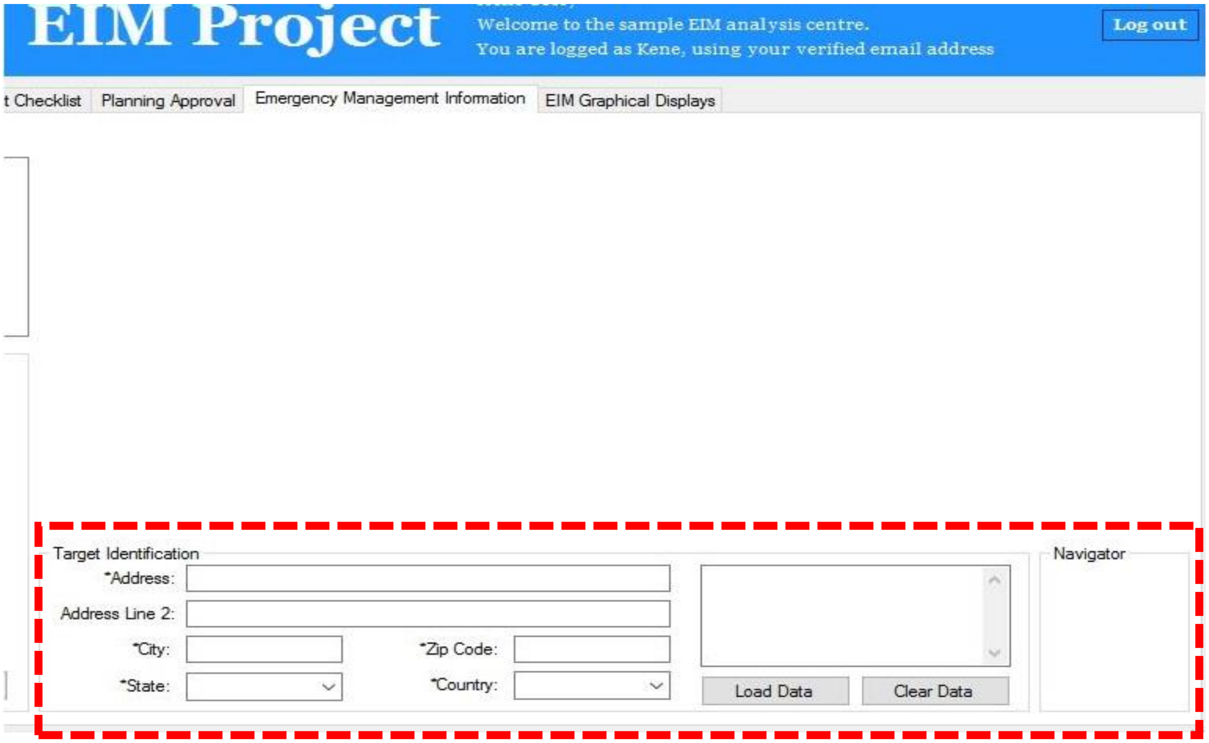

Figure 23. EIM: Emergency Response Information

5.5. Summary

The development of the sample EIM application, based on the proposed EIM framework showed some potential in lean and green construction processes. It showed potential in the analysis of proposed BIM building designs data against existing environmental design constraints which can be stored GIS systems. Leveraging on computer hardware speed and computer programming, EIM can increase efficiency in the analysis of buildings and the environments which ultimately improves decision making before, and after construction. It provides support in the project checklist form green construction by LEED for building design and construction. It supports the services of planning approval in a lean way and gives insight into the LEED green assessment for building design and construction.

6. EIM APPLICATION USE

In this section, the application's access management system is tested and verified for use. Firstly, the author registered with an email address and a password to use the application. Then, to verify that access was secure, a wrong email address and password was inputted and the following message box shown in figure 24 was displayed. Although the EIM application knows the computer software user profile, which it addresses the user with, it denies access and prompts the user with helpful information.

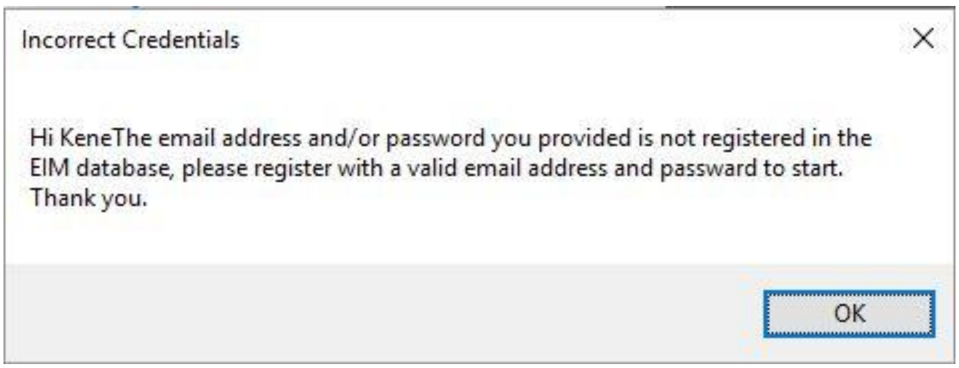

Figure 24. Wrong Login Information

Once the right login email and password is typed in and entered, access is granted with a message box shown in figure 25 below.

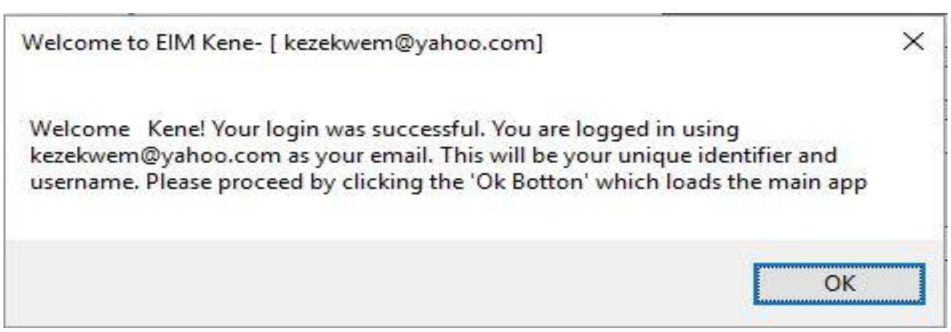

Figure 25. Welcome Message Box

6.1. Discussions and Findings

The EIM application quickly accesses both BIM and GIS information from their various database tables. It the search through all tables and records for any required information required for analysis during this process. The application integrated both BIM and GIS data for LEED project assessesment which checks for the following aspects of building design and construction:

- Location and Transportation
- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Material and Resources
- Indoor Environmental Quality
- Innovation
- Regional Priority

The total points that can be earned through the LEED assessment program is 110 points with different point ranges having the following certification types:

- 40 to 49 points (Certified)
- 50 to 59 points (Silver)
- 60 to 79 points (Gold)
- 80 to 110 points (Platinum)

The application also showed potential for lean processes in the planning approval processes and emergency management process, using information collected from the integration of BIM and GIS.

7. CONCLUSIONS AND SUMMARY

The purpose of this chapter is to discuss and interpret, the results of the study found in the application developed in the previous chapter. The research findings will be used in conjunction with the theoretical framework of EIM to explain and interpret the processes involved in the seamless integration of BIM and GIS for lean and green developments. The purpose will be to provide more understanding and insight for the construction industry and add to the body of knowledge in the scholarly literature. In addition, limitations of the study will be discussed and recommendations for further research will be given. The sections for this chapter will consist of, a summary of results, discussion of results, implications of the study results, recommendations for further study, and a conclusion.

The research studied both BIM and GIS, prior attempts on their integration, together with the basic principles of lean and green construction. After this literature review, the researcher using Microsoft C# programming language, together with a basic EIM framework, developed an application that leveraged on the speed of modern computer hardware and advanced computer programming to integrate and analyze data from both BIM and GIS data sets which were mined and stored in the EIM database. This new database was developed with Microsoft Access – A database management software. The results show potential for more integration of both systems for lean and green construction.

The construction industry is large, complex and fragmented due to the systematic gap that exists in its processes and the lack of interoperability between its IT systems. This results in a disjointed flow of information across industry participants and usually requires multiple IT platforms for the analysis of the same information. With the increase in stored digital data, across multiple IT systems like BIM and GIS, datasets have become so large and complex that the traditional applications and platforms are yet to become adequate for accesses data across both BIM and GIS platforms. This creates a challenge that makes it inconvenient to study the relationships between buildings and their environment. It makes it difficult to capture, analyze, share, transfer and visualize all the data related to buildings and their environment. However, in this report, the examination of the integration of BIM and GIS data for lean and green construction was conducted. The EIM framework developed, alongside the sample EIM application, show potential for increased efficiency and better decision making for lean and green construction developments. It shows the convenience of free data which can be free for use at all times, places and in all ways. It highlights that information should be freed from the chained, interoperable and defragmented IT systems. It ushers a platform where time is spent on informed decision making, rather than data mining and system exports and imports. In retrospect, EIM shows how the construction industry can leverage on BIG data for lean and green construction developments through the integration of BIM and GIS data.

7.1. Recommendations for Further Research

For further research, I would recommend not just dynamic attribute data binding for BIM and GIS, but graphical data binding for both systems. This would require additional programming for both systems. It is also recommended that both BIM and GIS application vendors adopt a standard database structure for exporting information from their unique platforms which would reduce the required c# codes necessary to find ant data across both systems. Considering the type of sensitive information contained in the EIM database, a stronger, more secure database and application is required to provide data security.

REFERENCES

Agile Alliance. (2013, June 8). *What is Agile?* Retrieved from Agile Alliance: http://www.agilealliance.org/the-alliance/what-is-agile/

Akintola, A., Jack S., G., & Girma, Z. (2012). Construction innovation and process improvement. In A. Akintoye, J. Goulding, & G. Zawdie (Eds.), *Construction Innovation and Process Improvement.* (1st ed., pp. 3-17). Wiley-Blackwell. 10.1002/9781118280294.ch1

Ali Motamedi, A. H. (2013). Knowledge-Assisted BIM-Based Visual Analytics For Failure Root Cause Detection In Facilities Management. *Automation in Construction*, 73-83.

António, G., & Ricardo, J.-G. (2010). Value proposition on interoperability of BIM and collaborative working environments. *Automation in Construction*, 522-530.

AppAppeal. (2016, Febuary). *MindMeister*. Retrieved from AppAppeal: http://mindmeister.appappeal.com/

Autodesk. (2002). *White Paper - Building Information Modeling in Practice.* [White Paper on BIM] Retrieved from http://usa.autodesk.com/company/building-information-modeling

Charles, E., David, F., Gilles, L., Joseph, L., Douglas, S., & Christos, Y. (1974). *An Outline of the Building Description System.*

Chuck Eastman, Paul Teicholz, Rafeal Sacks & Kathleen Liston. (2008). *BIM Handbook.* John Wiley & Sons, Inc.

Cinti, L., Garagnani, S., & Mingucci, R. (2012). BIM tools and design intent. Limitations and opportunities. *Practical BIM 2012 - Management, Implementation, Coordination and Evaluation.* Los Angeles.

City of Fargo. (2016). *Interactive GIS Map*. Retrieved from City of Fargo: http://gis.cityoffargo.com/Link/jsfe/index.aspx

Coe, C. K. (2009). *Handbook of Urban Services: A Basic Guide for Local Governments.*

Consulting Specifying Engineer. (2013, 04 22). *Bim and Fire protection*. Retrieved from http://www.csemag.com/single-article/bim-and-fire-protection-engineering/22fcd71622fbf3046ca5d9908d46fddc.html

Cote, A. E. (2003). *Fire protection handbook / Arthur E. Cote, editor-in-chief ; John R. Hall, Jr., associate editor ; Pamela A. Powell, managing editor ; Casey C. Grant, consulting editor*. Quincy: National Fire Protection Association, 2003.

Darius Migilinskas, V. P. (2013). The Benefits, Obstacles and Problems of Practical BIM Implementation. *Procedia Engineering*, 767-774.

David Bryde, M. B. (2013). The Project Benefits of Building Information Modelling (BIM). *INternational Journal of Project Management*, 971-980.

Eduardo, M., & Simos, Y. (1998). Proceedings of Plea 1998, Passive and Low Energy Architecture. *Environmentally Friendly Cities.*

El Meouche, R., Rezoug, M., & Hijazi, I. (2012). Integrating And Managing Bim In Gis, Software Review. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, 31-34.

ESRI. (2013, April 18). *ArcNews Fall 2013*. Retrieved from esri: http://www.esri.com/news/arcnews/fall12articles/the-fiftieth-anniversary-of-gis.html

Goodchild, M. F. (2010). Twenty years of progress: GIScience in 2010. *Journal of Spatial Information Science*, 3-20.

Hassan A., K., & Burcu, A. (2009). *CAD and GIS Integration.* CRC Press.

Horman, M. J., Riley, D. R., Lapinski, A. R., Korkmaz, S., & Pulaski, M. H. (2006). Delivering Green Buildings: Process Improvements for Sustainable Construction. *Journal of Green Building*, 123-140.

Ignacio, Z. B., Antonio, V. C., & Alfonso, A. U. (2011). Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Building and Environment*, 1133-1140.

International Scrum Institute. (2016). *Accredited Scrum Certifications for Agile Software Practitioners*. Retrieved from Scrum Institute: http://www.scrum-institute.org/

Irizarry, J., Karan, E. P., & Jalaei, F. (2013). Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction*, 241-254.

Isikdag, U., Underwood, J., & Aouad, G. (2008). An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes. *Advanced Engineering Informatics*, 504-519.

ISO Standard, ISO 29481-1:2010(E). (2010). Building Information Modeling - Information Delivery Manual.

Javier, I., & Ebrahim, P. K. (2012). Optimizing Location of Tower Cranes on Construction. *Journal of Information Technology in Construction*, 351-366.

Johnny Kwok-Wai Wonga, K.-L. K. (2014). Implementing ‘BEAM Plus’ for BIM-based sustainability analysis. *Automation in Construction*, 163-175.

Johnny, K.-W. W., & Ka-Lin, K. (2014). Implementing ‘BEAM Plus’ for BIM-based sustainability analysis. *Automation in Construction*, 163-175.

Jr., J. L., Farrington, J. J., & Ledbetter, W. B. (1992, March 01). Causes Of Quality Deviations In Design And Construction. *Journal of Construction Engineering and Management*, 34-49.

Jungsik Choi, J. C. (2014). Development of BIM-based evacuation regulation checking system for high-rise and complex buildings. *Automation in Construction*.

K.C., C. (1986). Advances in geographic information systems, computers, environment and urban systems. In C. K.C., *Advances in geographic information systems, computers, environment and urban systems* (pp. 175-184).

Kuo-Feng Chiena, Z.-H. W. (2014). Identifying and assessing critical risk factors for BIM projects: Empirical study. *Automation in Construction*, 1 - 15.

Kymmell, W. (2008). *Building Information Modelling.* McGraw-Hill Books.

Lauri, K., Pekka, H., & Jarkko, L. (2002). Design Management in Building Construction: From Theory to Practice. *Journal of Construction Research*.

Li, H., Chen, Z., Yong, L., & Kong, S. C. (2005). Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency. *Automation in Construction*, 323-331.

Li, N., Becerik-Gerber, B., Krishnamachari, B., & Soibelman, L. (2014). A BIM centered indoor localization algorithm to support building fire emergency response operations. *Automation in Construction*, 78-89.

LiJuan Chen, H. L. (2014). A BIM-based construction quality management model and its applications. *Automation in Construction*.

McGraw Hill Construction. (2014). *The Business Value of BIM for Construction in Major Global Markets.* Bedford: McGraw Hill Construction.

Michels, R. B. (2001). The global GIS: a case study. *Automation in Construction*, 597-606.

Modeling Rules. (2006). Retrieved from Architecture Week: http://www.architectureweek.com/2006/1011/tools_1-1.html

Murray, A. T. (2013). Optimising the spatial location of urban fire stations. *Fire Safety Journal*, 64-71.

National BIM Standard - United States. (2014). *FAQ on the NBIMS-US™*. Retrieved February Tuesday 11th, 2014, from National BIM Standard-United States website: http://www.nationalbimstandard.org/copyright.php

Olah, A. B. (2011). The Green Building and Sustainability: Sustainable Construction of Ecological Green Living Buildings. *The International Journal of the Constructed Environment*, 39-50.

Qing, C., Xue, L., Xiulan, H., & Jiansheng, W. (2011). A GIS-based Green Infrastructure Planning for Sustainable Urban Land Use and Spatial Development. *Procedia Environmental Sciences*, 491-498.

Rebekka, V., Julian, S., & Frank, S. (2014). Building Information Modeling (BIM) for existing buildings — Literature review and future needs. *Automation in COnstruction*, 109-127.

Rebekka, V., Julian, S., & Frank, S. (2014). Building Information Modeling (BIM) for existing buildings — Literature review and future needs. *Automation in Construction*, 109-127.

Remon Fayek, A., & Sherif Mohamed, H. (2013). Applying lean thinking in construction and performance improvement. *Alexandria Engineering Journal*, 679-695.

Ritu, A., Anil, S., & Mohammed, A. (2014). BIM Based Conceptual Framework For Lean And Green Integration . *Proceedings IGLC-22 Sustainability, Green and Lean* , (pp. 123-132). Oslo, Norway .

Rizal, S., Michel, B., & Helm, P. v. (2013). BIM and GIS for Low-Disturbance Construction. *International Conference on Construction Applications of Virtual Reality*. London, UK.

Sam, A., Abbas, R., Priyan, M., & Tuan, N. (2014, December). A Data Model for Integrating GIS and BIM for assessment and 3D visualisation of flood damage to building.

Sebastian, Claeson-Jonsson, & Giulio, D. (2013). Implementation of MEAT for. *Construction innovation: information, process, management*.

Sebastian, R., Böhms, H., & Helm, P. v. (2013). BIM and GIS for low-disturbance construction.

Tae Wook, K., & Chang Hee, H. (2015). A study on software architecture for effective BIM/GIS-based facility management data integration. *Automation in Construction*, 25-38.

U.S. Department of Commerce. (2015, October 19). *Gross Domestic Product - (GDP) - by - Industry Data*. Retrieved from Bureau of Economic Analysis: http://www.bea.gov/industry/gdpbyind_data.htm

U.S. Green Building Council - North Ohio Council . (2016, Febuary). *BIM-Lean and Green*. Retrieved from USGBC.

UCGIS. (2013). *Roger Tomlinson*. Retrieved from ucgis: http://ucgis.org/ucgis-fellow/roger-tomlinson

UK Infrastructure Transportation Research Consortium. (2015, Novermber 11). *ITRC*. Retrieved from UK Infrastructure Transportation Research Consortium: http://www.itrc.org.uk/

Vida Maliene, V. G. (2011). Geographic information system: Old principles with new capabilities. *Urban Design International*, 1-6.

Watson, A. (2010). BIM - a driver for change. *Nottingham University Press*, (p. 137).

Wei Yan, C. C. (2011). Integrating BIM and gaming for real-time interactive architectural visualization. *Automation in Construction*, 446 - 458.

Womack, J. P., Jones, D. T., & Roos, D. (1990). *The Machine That Changed the World.* New York, NY 10020: Free Press.

Zhang, X., Arayici, Y., Wu, S. A., & Aouad. (2009). Integrating BIM and GIS for large-scale facilities asset management: a critical review. *The Twelfth International Conference on Civil, Structural and Environmental Engineering Computing.*

APPENDIX A. EIM ACCESS MANAGEMENT PROCESS

The code for the designed a profiled system which protects unwanted access to the proposed EIM registration and login process is shown in Table A1 and its user interface is shown in Figure A1.

Table A1. Access Management User Interface Design Codes

The C# Codes for the Access Management User Interface is Shown in this Table	

1	namespace EIM_UPDATE_03_24_2016
	{
	partial class Form1
	{
	/// <summary>
	/// Required designer variable.
	/// </summary>
	private System.ComponentModel.IContainer components = null;
	
	/// <summary>
	/// Clean up any resources being used.
	/// </summary>
	/// <param name="disposing">true if managed resources should be disposed; otherwise, false.</param>
	protected override void Dispose(bool disposing)
	{
	if (disposing && (components != null))
	{
	components.Dispose();
	}
	base.Dispose(disposing);
	}

2	#region Windows Form Designer generated code /// <summary> /// Required method for Designer support - do not modify /// the contents of this method with the code editor. /// </summary>

Table A1. Access Management User Interface Design Codes (continued)

3	private void InitializeComponent()
	{
	System.ComponentModel.ComponentResourceManager resources = new System.ComponentModel.ComponentResourceManager(typeof(Form1));
	
	}
	}

These codes control the graphic and property values of the access management user interface which is shown in Figure A1.

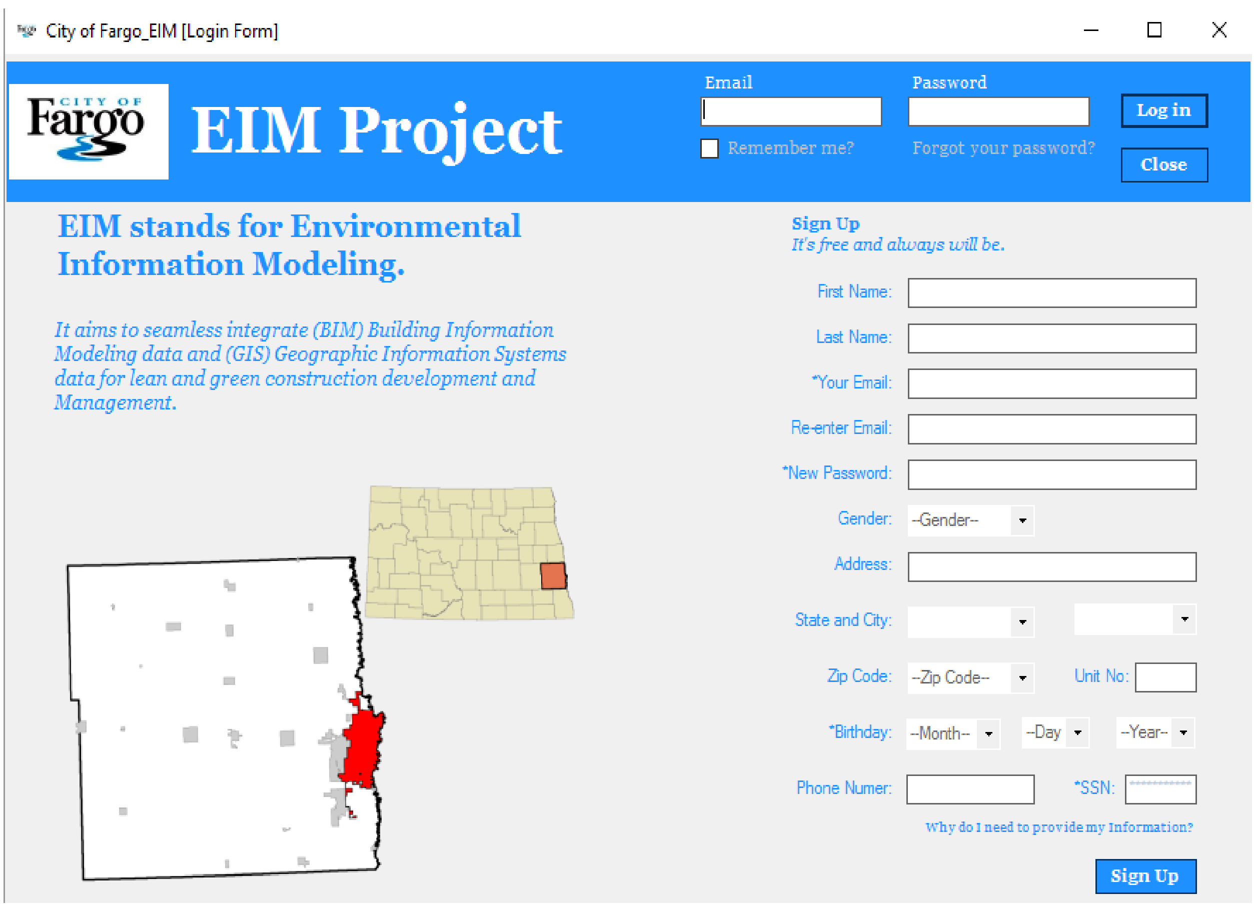

Figure A1. Access Management User Interface Design

This interface is designed with windows form common controls like textboxes, buttons, combo boxes, picture boxes, and labels.

The code for the registration and login process is shown below. The process is designed to guide the user through the processes with descriptive information displayed with message prompts when needed.

Table A2. User Registration and Login Codes

The C# Codes for User Registration and Login are Shown in this Table	

1	}
	
	private void label3_Click(object sender, EventArgs e)
	
	{
	MessageBox.Show("Your email reset link has been emailed to you", "Email and Password Reset");
	}

2	private void checkBoxRememberMe_CheckedChanged(object sender, EventArgs e)
	{
	if (textBoxEmail.Text != "")
	if (checkBoxRememberMe.Checked)
	
	{
	MessageBox.Show("Hi " + Environment.UserName + ", your login credential (" + textBoxEmail.Text + ") will be saved for future reference", "Frequent user prompt");
	}
	
	Else

Table A2. User Registration and Login Codes (continued)

3	{ MessageBox.Show("Hi " + Environment.UserName + ", your login credentials will no longer be saved for future reference, thank you", "Non-frequent user prompt"); textBoxEmail.Clear(); textBoxEmail.Focus(); } Else
4	{ MessageBox.Show("Hi " + Environment.UserName + ", please enter your email address first. Thanks.", "Missing email prompt"); } }
5	private void label17_Click(object sender, EventArgs e) { MessageBox.Show("The EIM framework is a secure system deserved to serve and protect you with the information you provide", "Why Register?"); } } }

These codes control the graphic and property values of the access management user interface which is shown in Figure A1.

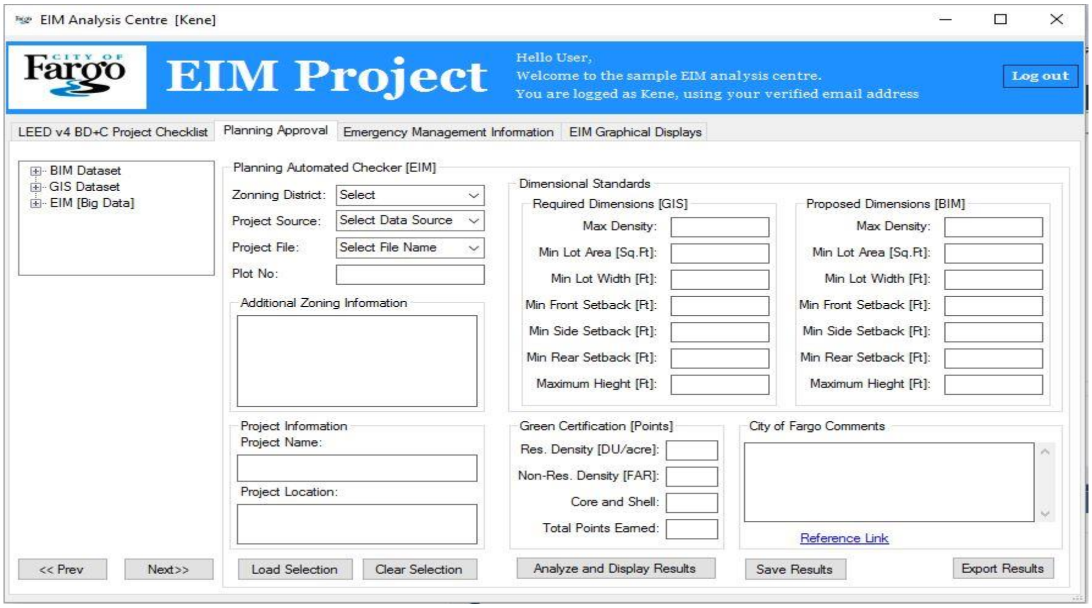

Figure A2. Analysis Form: Planning Approval Tab

This interface is designed for the analysis of buildings based on the city of Fargo's planning document. Figure A3 is designed for assisting emergency management officials with information.

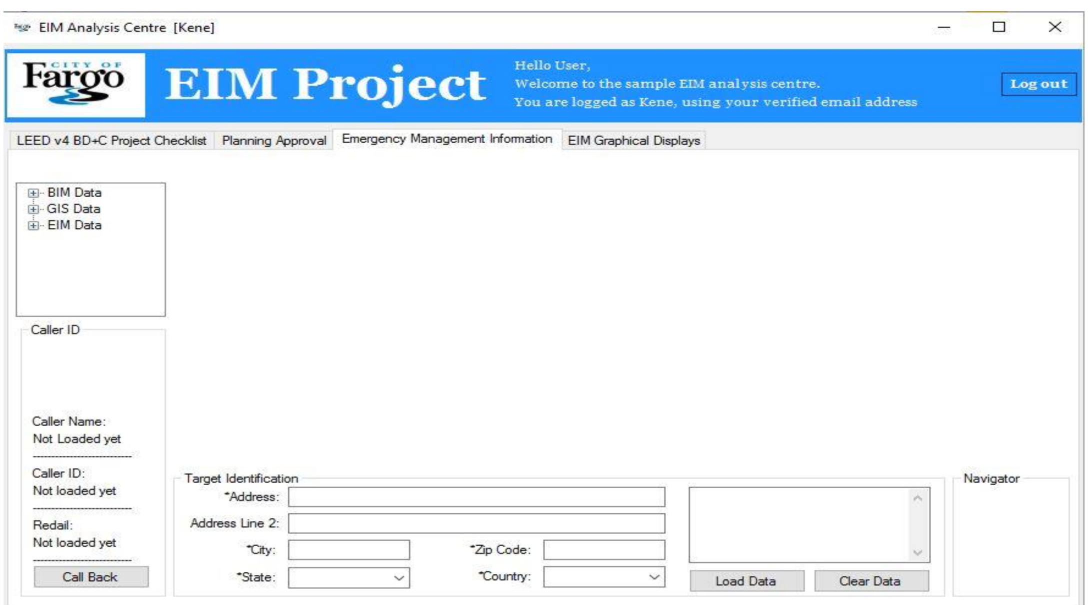

Figure A3. Analysis Form: Emergency Management Information

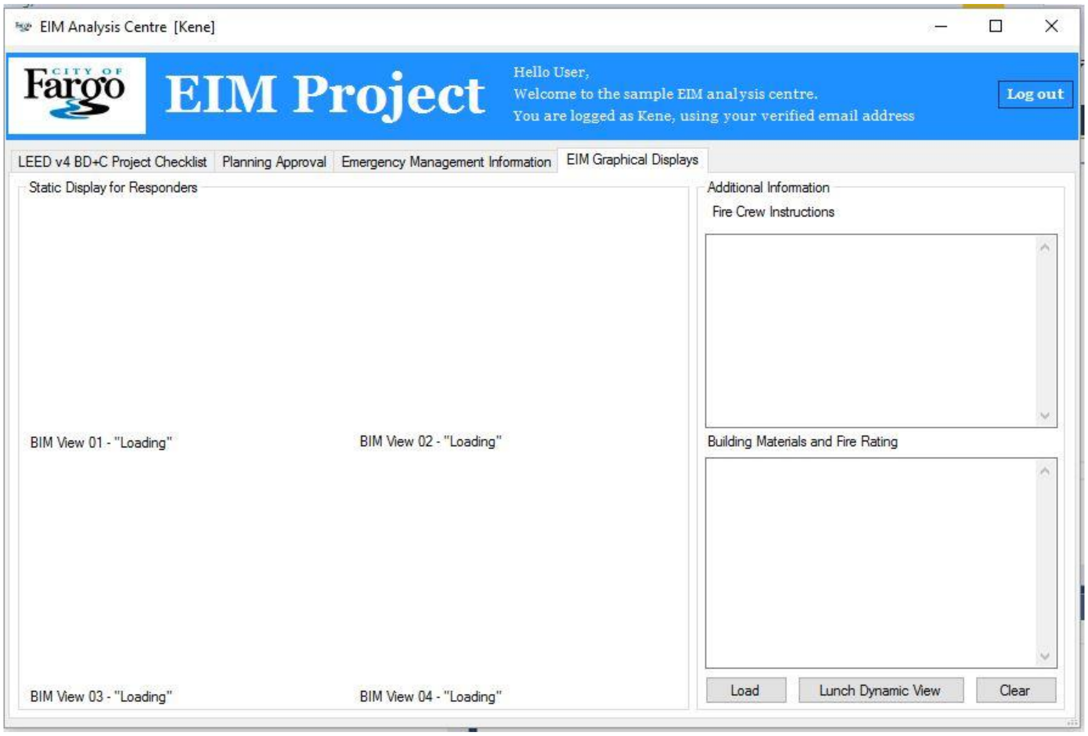

Figure A4. Analysis Form: EIM Graphics Display for Emergency Management

This interface is designed to provide the graphical representation of buildings, structures or their environment for emergency response.

Table A3. Code for Analysis Windows Form Interface

The C# Codes for Code for Analysis Windows Form Interface are Shown in this Table	

1	namespace EIM_UPDATE_03_24_2016
	{
	    partial class Form2
	    {
	        /// Required designer variable.
	        /// </summary>
	        private System.ComponentModel.IContainer components = null;
	        /// <summary>
	        /// Clean up any resources being used.
	        /// </summary>
	        /// <param name="disposing">true if managed resources should be disposed; otherwise, false.</param>

Table A3. Code for Analysis Windows Form Interface (continued)

2	`protected override void Dispose(bool disposing)`
	
	`{`
	`        if (disposing && (components != null))`
	`        {`
	`            components.Dispose();`
	`        }`
	`        base.Dispose(disposing);`

3	`        }`
	
	`        #region Windows Form Designer generated code`
	`        /// <summary>`
	`        /// Required method for Designer support - do not modify`
	`        /// the contents of this method with the code editor.`
	`        /// </summary>`
	`    }`
	`}`

APPENDIX B. GIS AND BIM DATA COLLECTED

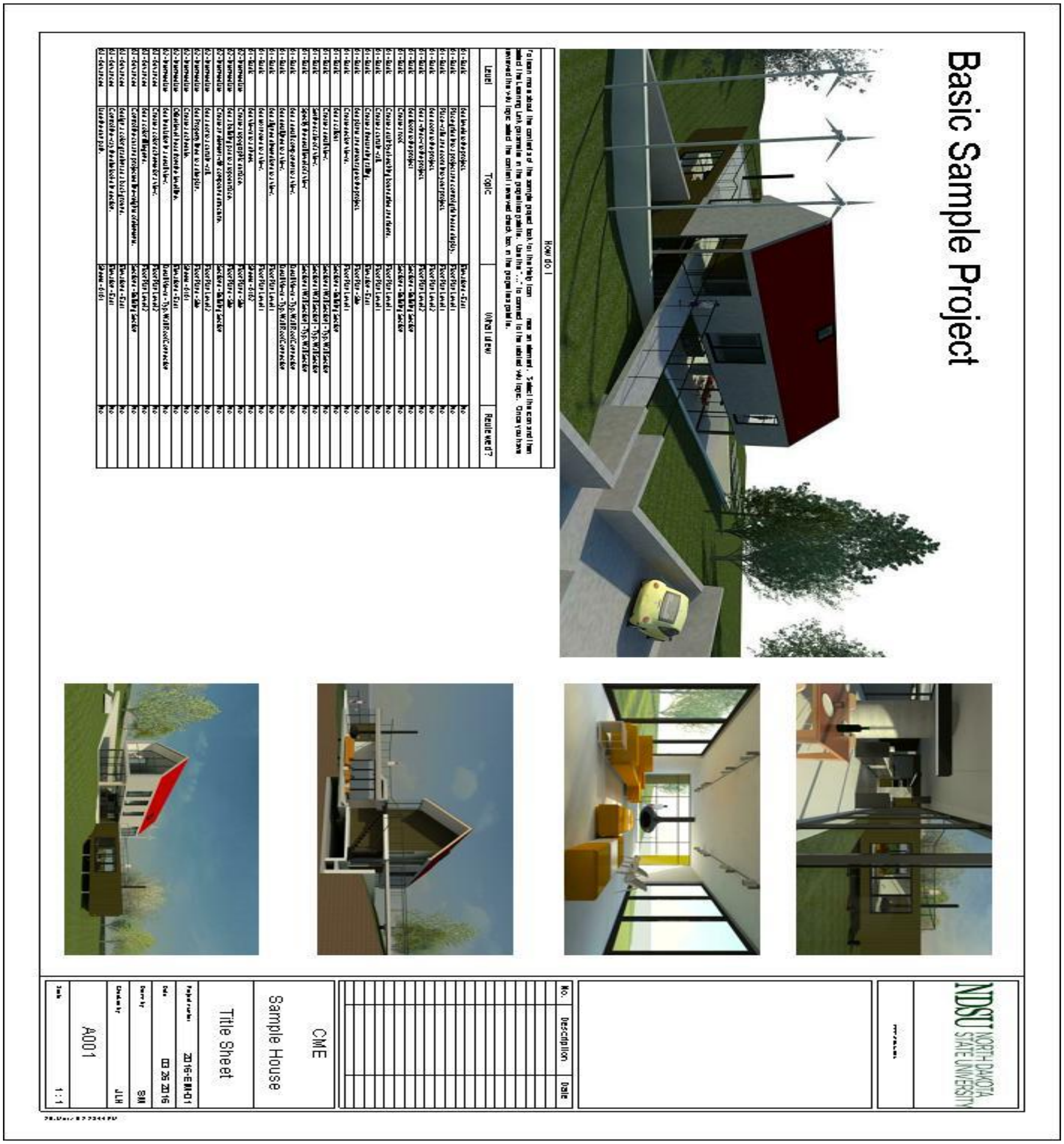

Figure B1. Sample BIM: Title Sheet [Landscape]

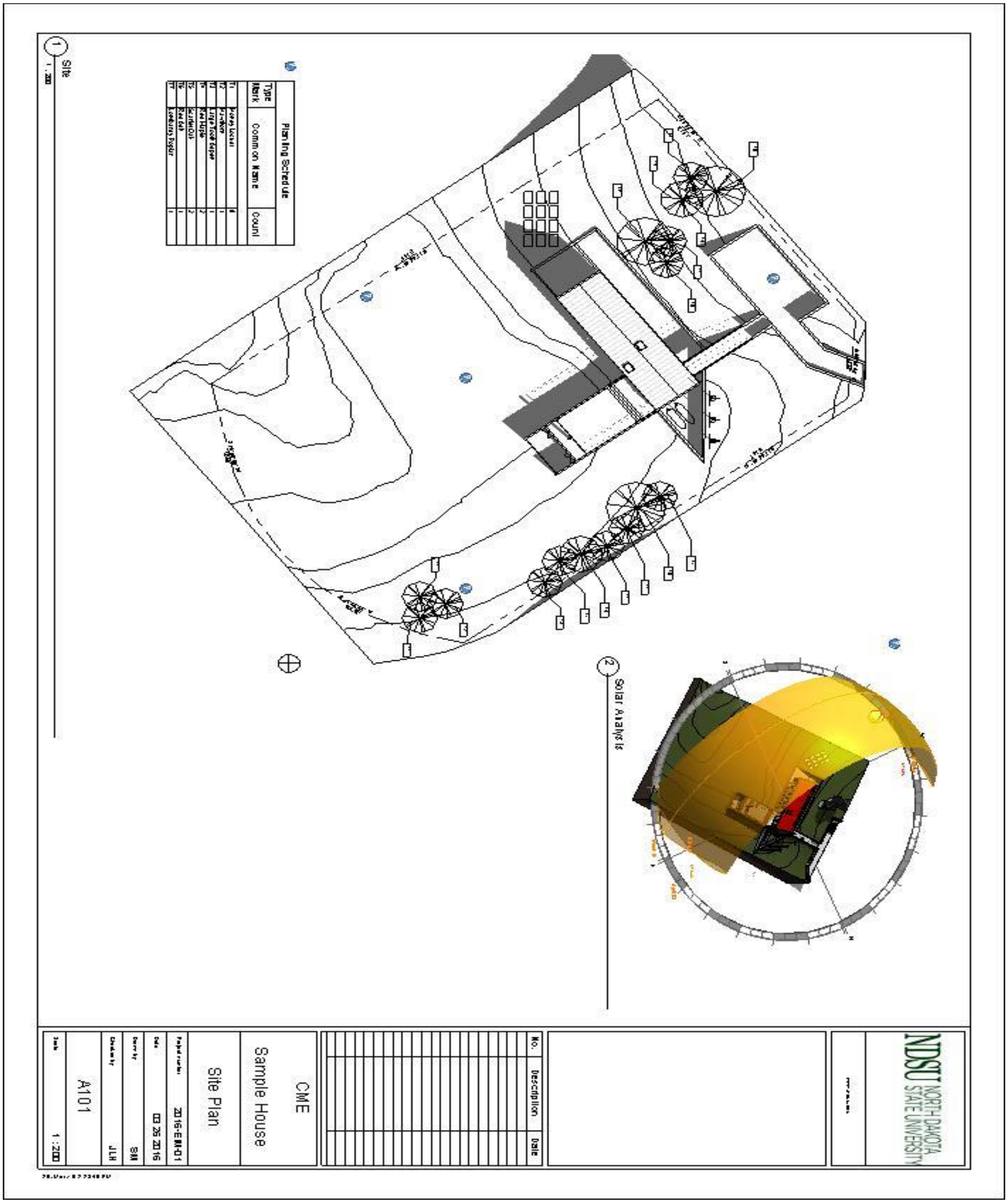

Figure B2. Sample BIM: Site Plan [Landscape]

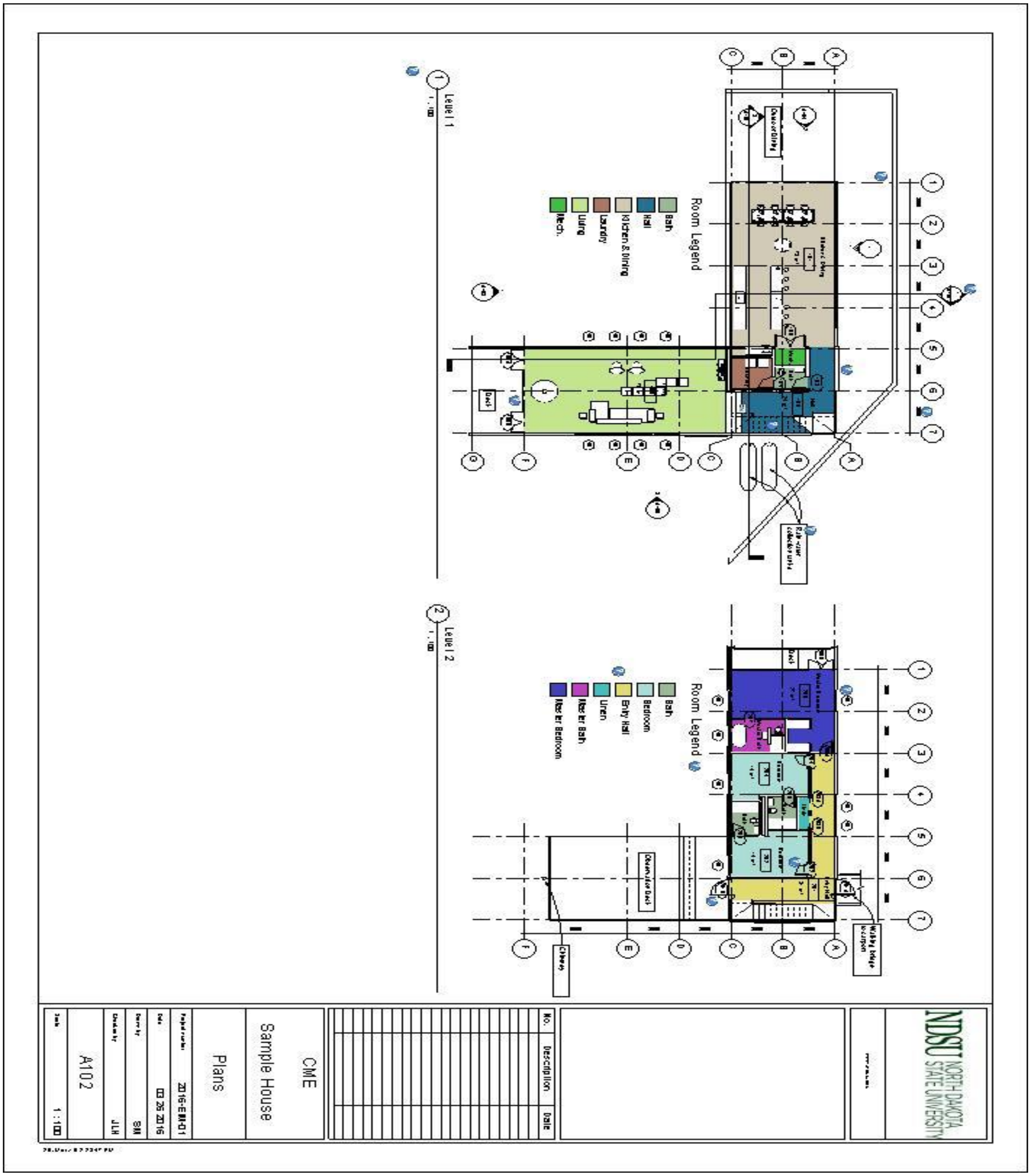

Figure B3. Sample BIM: Floor Plans [Landscape]

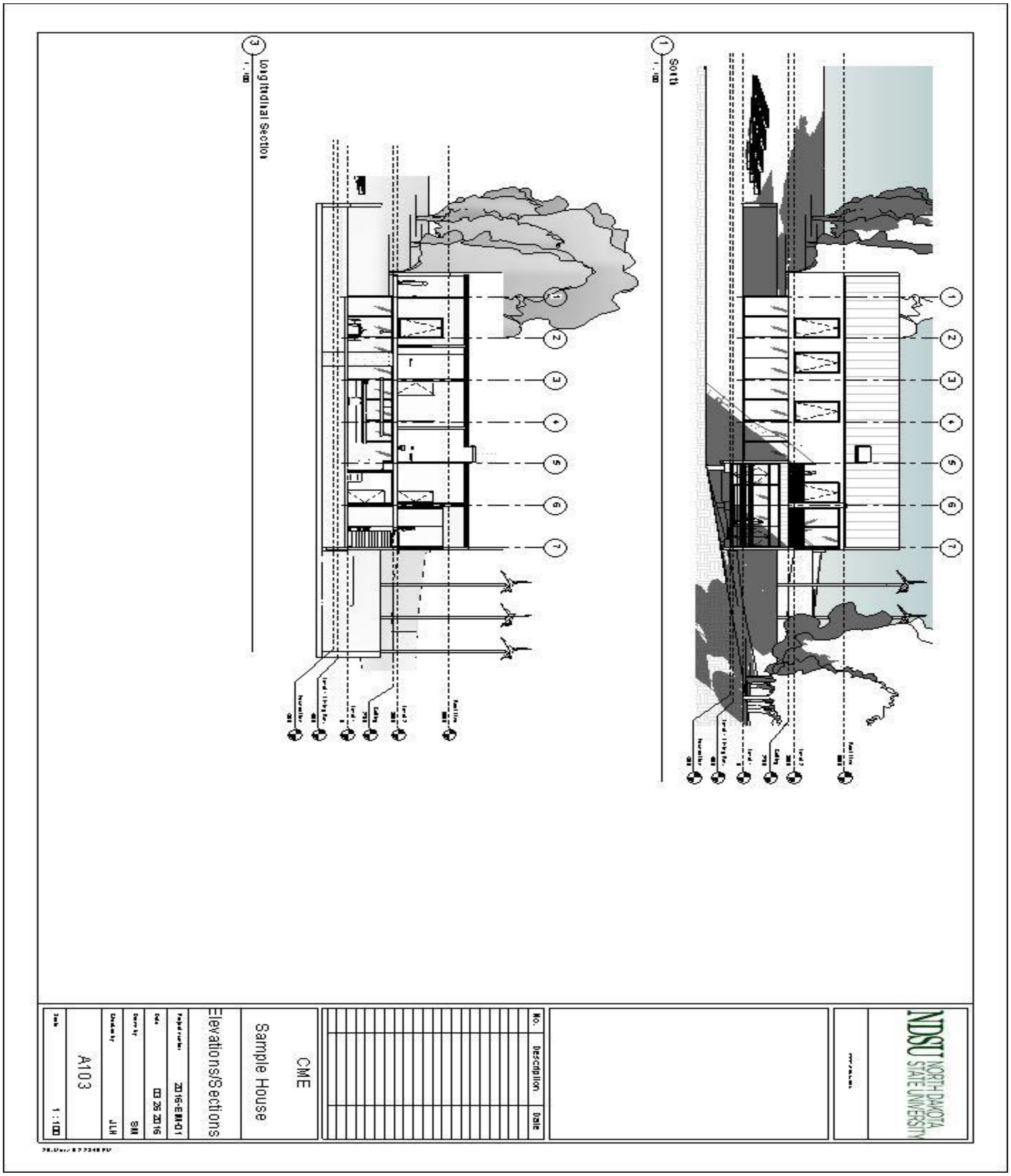

Figure B4. Sample BIM: Elevations & Sections [Landscape]

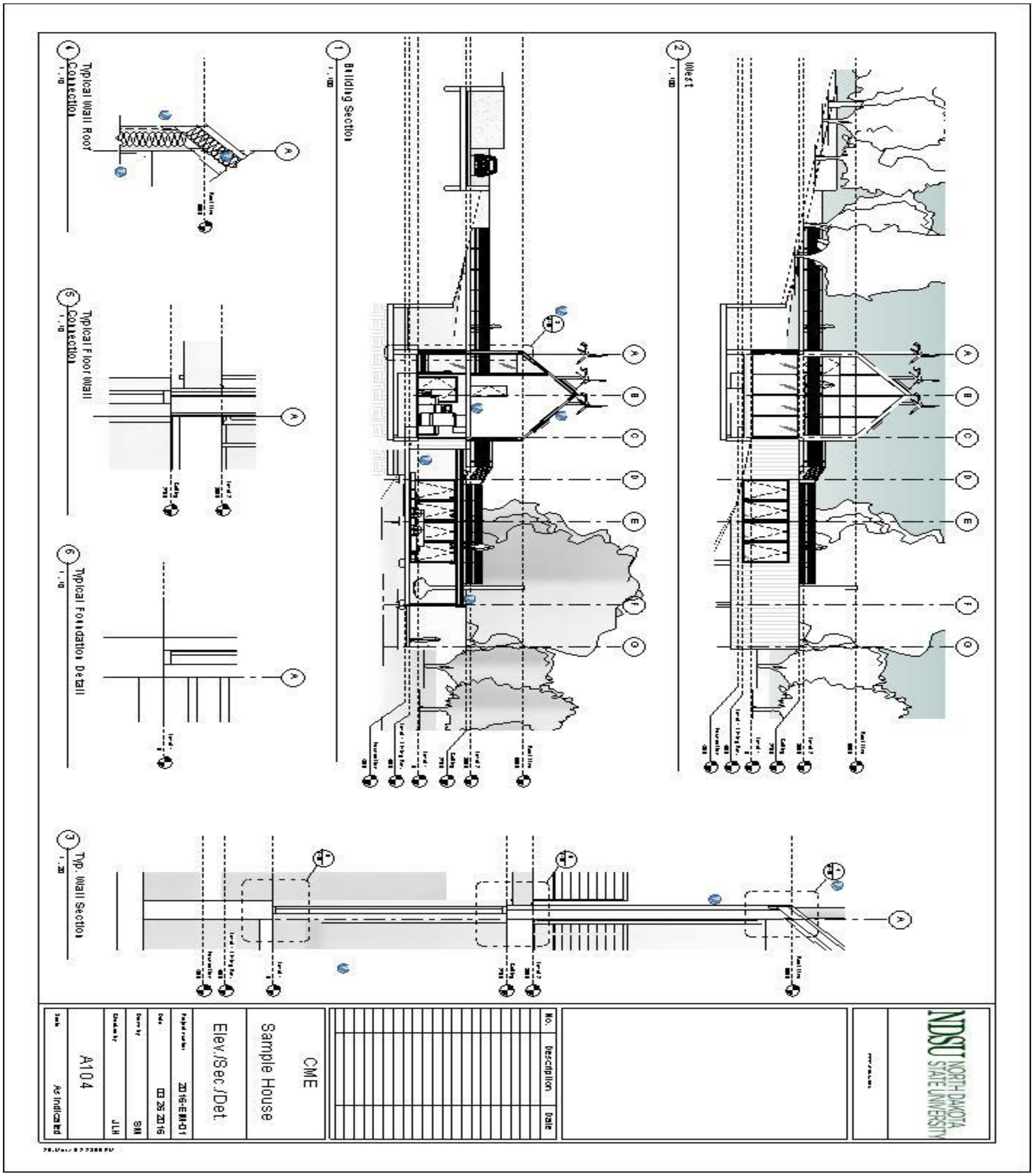

Figure B5. Sample BIM: Elevations, Sections & Details [Landscape]

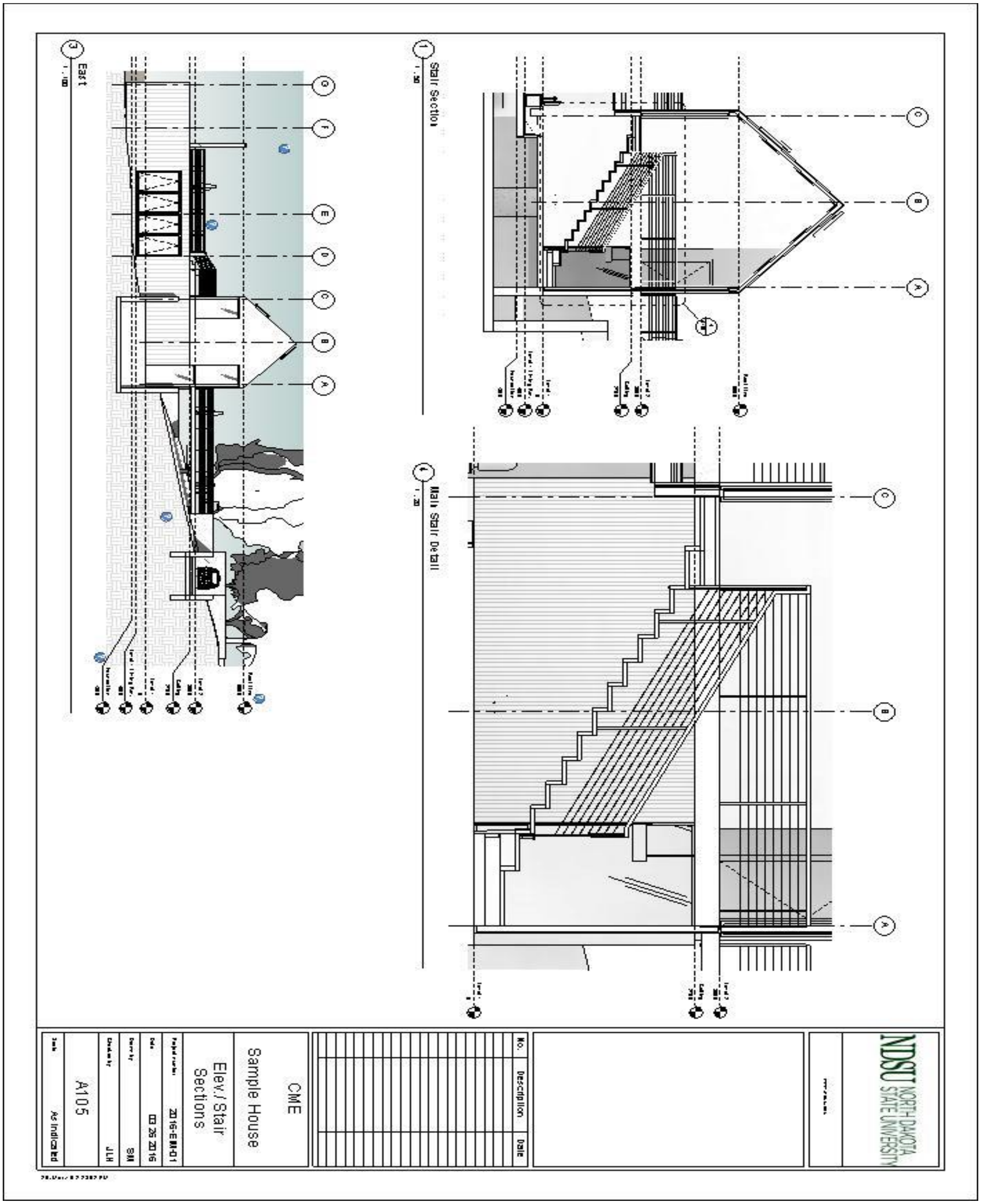

Figure B6. Sample BIM: Sections

Table B1. BIM Wall Extract from BIM Database

Id	Type Id	Volume	Area	Length	Unconnected Height	Top Constraint
198694	SIP 202mm Wall - conc clad	4.52	22.35	6,202.00	3,300.00	196,629.00
198749	Wall - Timber Clad	1.21	6.01	4,580.00	3,000.00	245,423.00
234869	Wall - Timber Clad	4.34	21.47	4,661.00	3,446.22	694.00
418079	Wall - Timber Clad	1.75	8.64	3,200.00	2,700.00	245,423.00
422243	Wall - Timber Clad	1.21	5.99	3,041.00	2,700.00	694.00
423099	SH_Curtain wall		17.10	3,000.00	5,700.00	196,629.00
424922	Interior - 165 Partition (1-hr)	0.99	5.99	3,041.00	2,700.00	694.00
425745	Interior - 165 Partition (1-hr)	1.06	6.41	2,558.45	2,700.00	694.00
427092	Wall - Timber Clad	12.34	61.11	19,822.00	3,900.00	694.00
428588	SIP 202mm Wall - conc clad	8.09	43.20	19,702.00	3,300.00	196,629.00
428745	SIP 202mm Wall - conc clad	8.15	43.30	19,702.00	3,500.00	196,629.00
428797	SH_Curtain wall		26.49	6,202.00	3,000.00	196,629.00
429964	Interior - Partition	2.98	24.81	6,202.00	3,000.00	196,629.00
430064	Interior - Partition	4.47	40.01	11,380.00	3,000.00	196,629.00
430318	Interior - Partition	1.56	13.03	2,824.00	3,000.00	196,629.00
430361	Interior - Partition	1.52	12.82	2,880.00	3,000.00	196,629.00

Table B1. BIM Wall Extract from BIM Database (continued)

430412	Interior - Partition	0.80	6.65	2,157.00	3,000.00	196,629.00
430859	Interior - Partition	2.22	19.56	4,661.00	3,000.00	196,629.00
493612	CL_W1	6.80	24.78	9,628.06	3,500.00	245,423.00
493697	CL_W1	20.83	74.56	21,026.02	3,500.00	245,423.00
493790	CL_W1	15.45	55.18	15,750.14	3,500.00	245,423.00
493879	Foundation - 300mm Concrete	9.06	30.90	8,946.55	3,500.00	245,423.00
497540	Interior - Partition	1.61	13.56	2,440.00	3,000.00	196,629.00
506386	Interior - Partition	0.73	6.13	1,200.00	3,000.00	196,629.00
506797	Interior - Partition	0.60	4.98	1,020.00	3,000.00	196,629.00
530178	SIP 202mm Wall - conc clad	1.19	5.91	6,202.00	3,300.00	196,629.00
599841	Retaining - 300mm Concrete	7.60	25.33	7,150.00	3,400.00	
599906	Retaining - 300mm Concrete	13.98	46.59	13,702.00	3,400.00	
599951	Retaining - 300mm Concrete	4.23	14.11	4,150.00	3,400.00	
627064	CL_W1	10.25	36.62	24,690.00	1,500.00	311.00
627729	CL_W1	2.69	9.75	6,722.76	1,500.00	311.00
628523	CL_W1	7.73	27.62	18,449.00	1,500.00	311.00
655533	Wall - Timber Clad	0.67	3.30	6,202.00	550.00	245,423.00
704275	SH_Curtain wall		16.20	6,202.00	2,700.00	694.00
707722	SH_Curtain wall		7.87	1,481.00	5,700.00	196,629.00
708088	SH_Curtain wall		3.73	1,481.00	2,700.00	196,629.00

Table B1. BIM Wall Extract from BIM Database (continued)

709245	SH_Curtain wall		7.85	3,010.00	2,700.00	196,629.00
745997	Retaining - 300mm Concrete	7.99	26.62	10,240.00	2,600.00	
746235	Retaining - 300mm Concrete	5.99	20.63	7,225.85	2,600.00	
746589	Retaining - 300mm Concrete	4.02	14.07	5,000.00	2,600.00	
746634	Retaining - 300mm Concrete	3.82	13.42	5,200.00	2,600.00	
746766	Retaining - 300mm Concrete	5.30	18.34	7,095.76	2,600.00	
765523	Retaining - 300mm Concrete	2.50	8.34	2,840.00	3,100.00	245,423.00
765620	Retaining - 300mm Concrete	2.50	8.34	2,840.00	3,100.00	245,423.00
768442	Interior - Partition	1.62	13.67	2,880.00	3,000.00	196,629.00
845266	Wall - Timber Clad	2.76	13.64	4,700.00	2,700.00	311.00
846939	SH_Curtain wall		31.85	11,899.00	2,700.00	694.00
847436	SH_Curtain wall		16.47	6,101.00	2,700.00	694.00
849032	Wall - Timber Clad	8.64	42.75	15,202.00	3,900.00	245,423.00
906885	Interior - 165 Partition (1-hr)	0.80	4.86	1,982.55	2,700.00	694.00
937935	Interior - Partition	0.75	6.24	1,837.00	3,000.00	196,629.00
938974	Interior - Partition	1.51	12.62	2,504.00	3,000.00	196,629.00

Table B1. BIM Wall Extract from BIM Database (continued)

939084	Interior - Partition	1.20	10.10	2,494.90	3,000.00	196,629.00
976752	Interior - Partition	0.28	2.37	3,161.00	800.00	311.00
977133	Cavity wall_sliders	2.62	9.37	2,940.00	3,300.00	245,423.00
977377	SH_Curtain wall		31.86	11,800.00	2,700.00	245,423.00

Table B2. BIM Level Extract from BIM Database

Id	TypeId	Design Option	Name	Elevation
311	305		Level 1	0
694	305		Ceiling	2700
196629	305		Roof Line	6000
245423	305		Level 2	3000
511122	305		Foundation	-800
515270	305		Level 1 Living Rm.	-550