GEOGRAPHICAL AND BUILDING INFORMATION SYSTEMS INTEGRATION

By

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To my family for their love and support

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LIST OF ABBREVIATIONS

BIM	Building Information Modeling
BRep	Boundary Representation
CAD	Computer Aided Drafting
CSG	Constructive Solid Geometry
DWF	Design Web Format
DWG	Drawing
DXF	Drawing Exchange Format
GIS	Geographical information
GML	Geography Markup Language
GUID	Globally Unique Identifier
IAI	International Alliance for Interoperability
IFC	Industry Foundation Class
KML	Keyhole Mark Up Language
Mxd	Arc Map File Extension
TIN	Triangulated Irregular Network
VRML	Virtual Reality Modeling Language
3D	Three Dimensional
2D	Two Dimensional

Abstract of Thesis Presented to the Graduate School
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Building Information Models (BIM) models compile extensive information about buildings, including object information, quantities, and cost information. Geographical Information Systems (GIS), process and present information about the sub terrain, terrain, demographics, and infrastructure. Information processed by GIS and BIM affect buildings in the preconstruction phase, the construction phase and during the life cycle of the building.

Currently, BIM and GIS systems are utilized separately. Viewing GIS and BIM together can help developers and designers answer questions about the location and orientation of the building and how the building will assimilate into the environment. Queries can be made in GIS regarding traffic patterns or demographics and the effect of the building on a proposed area can be scrutinized. Using BIM and GIS together can be, for example, beneficial for fire safety or disaster management allowing disaster management teams to analyze possible safety hazards. The benefits and the opportunities that can be achieved from interoperability of GIS and BIM software are infinite and depend on the end users needs.

The literature reviewed assessed the needs for BIM and GIS integration and the current methods used to integrate BIM and GIS. The literature review, concluded that 3 D models are being viewed in ArcScene™ software, but the models being viewed in ArcScene™ software are not BIM models (as BIM models are data rich). It was also determined that other software, such as Sketch Up™, was being used to visualize buildings in their built environment, which do not allow for analysis of the model.

The methodology used includes a series of tests to join BIM and GIS utilizing Keyhole markup language (KML) files and Industry Foundation Class (IFC) files, in an effort to analyze the benefits of visualization and analysis capabilities that each file had. The research concluded that KML files provide visualization of the building in the surrounding environment, and the files are best viewed in Google Earth™. It was concluded that to be most effective for the purpose of visualization the 3D KML files need to be created for the surrounding environment. IFC files provide opportunity for analysis of the building and its surrounding environment within GIS, but the file does not provide a seamless transition. When IFC files are transferred the coordinates are lost in transition and the scale / geo referencing of the building is not transferred. The research concluded that KML files are best used for visualization purposes, but limited for analysis. IFC files offer analysis and visualization in ERSI®, although geo-referencing is limited in ArcScene® software.

CHAPTER 1
INTRODUCTION

Statement of Problem

The scale of construction projects continue to increase and factors influencing their success are becoming more important. Factors having influences on construction projects can range from unknown site conditions, environmental impacts, government restrictions, building design, and so forth. Due to the wide range of factors that can affect the construction of projects, designers seek to obtain information about the unknown factors and make predictions prior to the construction phase.

Building Information Models (BIM) models compile extensive information about the building, including object information, quantities, and cost information. Geographical Information Systems (GIS), process and present information about the sub terrain, terrain, demographics, and infrastructure. Information processed by GIS and BIM about buildings in the preconstruction phase, the construction phase and during the life cycle of the building is important to owners in life safety planning and in facilities management.

Currently, BIM and GIS systems are utilized separately. Viewing GIS and BIM together can help developers and designers answer questions about the location and orientation of the building and how the building will assimilate into the environment. Queries can be made in GIS regarding traffic patterns or demographics and the impact of the building in a proposed area can be scrutinized. Using BIM and GIS together can be beneficial for fire safety or disaster management planning. The benefits and the opportunities that can be achieved from interoperability of GIS and BIM software are boundless and depend on the end users' needs. There is an ever increasing need for

viewing BIM and GIS in harmony as materials, methods, regulations, and unknown factors continue to increase and affect the outcome of a project.

Purpose of Study

The current methods of viewing 3D building models with their topology include, CityGML ®, Sketch Up™ and Google Earth™, and Virtual Reality Modeling Language (VRML). The methods are beneficial for visualization, but lack supporting information about the BIM model and the surrounding environment. These systems are neither smart, nor true BIM models as defined by the literature review. The purpose of this research is to review past research projects involving BIM and GIS integration and explore current methods and their limitations for currently available GIS and BIM software. The two specific methods explored include Keyhole Markup Language (KML) and Industry Foundation Class (IFC) models. The literature reviewed, revealed few past works incorporating these particular formats.

Scope and Limitations

This research examined methods for viewing BIM models with GIS information. There are many methods to view a 3D building within its built environment, but for the purpose of this research KML and IFC files were the focus. KML files are widely used with Google Earth™, herein after referred to as Google Earth, and have increasing functionality within Autodesk® Revit® (hereinafter Revit) Architecture software (the BIM software used) and ESRI® software. IFC files were also a focus as IFC is becoming a widely used format for viewing 3D models.

The methods explored utilizing IFC and KML files were neither extensive nor comprehensive as there are numerous standards bodies that are responsible for the definition of each file type.

Organization of Study

Chapter 2 presents a literature review of background information on BIM, GIS, IFC and case studies of 3D models in GIS. Chapter 3 presents the methods and procedures used during a series of tests that allowed a building to be viewed with its surrounding topology. Chapter 4 discusses the results of the various test combinations. Chapter 5 presents the analysis of Chapter 4 results. Chapter 6 presents the conclusions of the research and suggestions for future research.

CHAPTER 2
LITERATURE REVIEW

Introduction

Interoperability among different software packages has been receiving more attention as the number and diversity of software available increase. As the availability of software increases the need for software to work together becomes a necessity. Interoperability is the ability for different software to work together. Software interoperability within construction industry software is not customary. Software used in the construction industry is highly fragmented and it is common to use a different software package for each construction activity. Software common to the industry include: Primavera and SureTrak which are used for scheduling, Timberline and On Screen Take Off for estimating, Autodesk® AutoCAD® for drafting, Revit Architecture software for 3D modeling, and ESRI® GIS software for site selection. Most construction software is designed for specific individual processes and does not take into consideration that information that is captured by one construction function may be needed to make a decision for another construction process.

Construction projects are built concurrently and a majority of the information about the project is unknown or hypothetical in nature, therefore the most optimal situation is to have all information regarding the construction project stored in a single software package or within two software packages that are interoperable. Interoperable software allows for information in two separate systems to be captured together, allowing accurate decisions to be made.

Geographical Information Systems (GIS) and Building Information Modeling (BIM) are two systems that can benefit from interoperability. Integration of topology and

3D building models allows for a seamless transition between the sub terrain, the terrain and to the vertical built environment. Interoperability between the software allows for endless opportunities to be made by different decision makers ranging from urban planners, disaster management teams, developers, asset management, and sustainable designers. All parties can make better decisions by understanding all of the factors in the built environment that will affect their decision.

This literature review defines for the reader both GIS and BIM, allowing the reader to have an overview of each system and current interfaces of GIS and BIM. The literature review also provides benefits that the public could receive from a seamless interface between BIM and GIS. A brief overview of interoperability and current interfaces, such as IFC and Revit Architecture software extensions is included in this literature review. Finally, a review of case studies of current representations of 3D models in GIS and IFC interfaces is presented.

Definition of GIS

GIS is often used in site selection, as the software stores a tremendous amount of data regarding the soil, current ecological system, demographics, traffic patterns, and surrounding building information. GIS is classically defined as a database management tool with three basic categories: a spatially referenced database that links data to an area, a visualization tool that represents the database in map format to users, and an analytical tool that queries the data and returns responses about the spatial environment (Franklin et al. 2006). A GIS map is comprised of layers that collectively make a map (Figure 2-1).

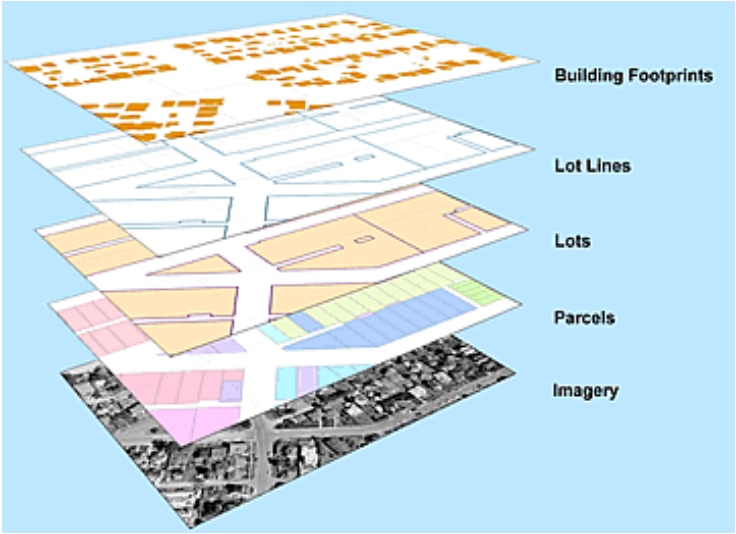


Figure 2-1. GIS layers

The layers, as shown in Figure 2-2, are supported by an attribute table which is essentially a database. GIS allows for queries to be made to the attribute table allowing

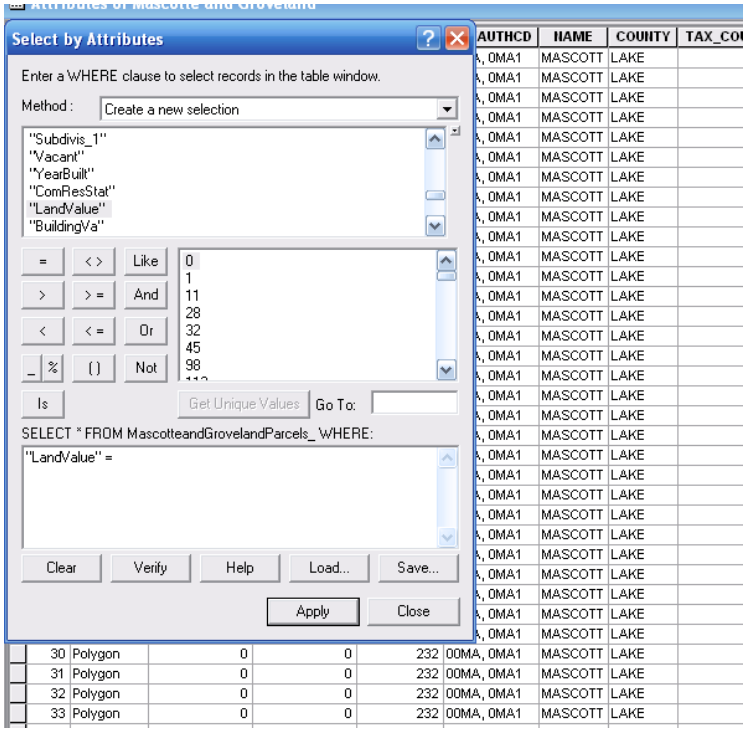


Figure 2-2. GIS attribute table and query

questions to be asked and the answers to be exported to a new layer. An example of a query that could be run in GIS is one where the developer would like to know what parcels are valued at $40,000 or less. The question would be run as "Value <= $40,000." All parcels that are valued at $40,000 or less will be highlighted in the attribute table and then exported as a layer in the map.

The GIS software marketed by ESRI consists of the following:

- ArcMap™ software (here after referred to as ArcMap) – topology
- ArcGlobe™ software (here after referred to as ArcGlobe) – 3D
- ArcScene™ software (here after referred to as ArcScene) – topology and 3D
- ArcReader™ software (here after referred to as ArcReader) – Viewing data
- ArcCatalog™ software (here after referred to as ArcCatalog) – creating shape files, geo databases, and viewing metadata

Definition of BIM

BIM, data rich 3D software, is gaining in popularity within the construction industry, but BIM is still somewhat new to the industry and does not have an absolute definition. What one may consider a BIM model may not truly be a BIM model. "The Associated General Contractors Guide defined BIM as a data rich, object-oriented, intelligent and parametric digital representation of the facility from which views and data appropriate to various users' needs can be extracted and analyzed to generate information, which can be used to make decisions and improve the process of delivering the facility. On the other hand, NBIMS defined BIM as "a computable representation of all the physical and functional characteristics of a building and its related project (life-cycle) information, which is intended to be a repository of information for the building owner (and operator) to use and maintain throughout the life-cycle of a building (Isikdag et al. 2008)." It is important to distinguish that a BIM is a data rich model that provides information about the building not only now, but also for future planning. This distinction

is essential for the purpose of this research, as the objective is join a data rich model i.e. an Revit Architecture software model to GIS. Often 3D models are wrongly referred to as BIM even though there is no supporting data associated with it. Visual representations of buildings are sometimes considered BIM in case studies reviewed, even though the model lacks a supporting database.

A BIM model provides information about the drawings, visualization of the building in 3D, cost, estimation and scheduling, energy simulation, and supporting information about the specification, and soon code checking (Jeong et al. 2009). The supporting information about the objects and geometry and analysis of the building make BIM models distinct from other VRML files or Sketch Up ™, here after referred to as Sketch Up, files. The fact that a BIM model has “smart” information makes the model more valuable than a simple 3D visual representation of a building.

Current BIM and GIS Interfaces

Web based formats are the most widely used to display 3D buildings and topology. Google Earth has quickly come to the forefront as a provider displaying 3D buildings. Google Earth displays KML files in both 3D and 2D format. Sketch Up files (skp) can also be displayed in Google Earth and are compatible with ESRI® software. 3D laser scanning that was once used for surveys is now used to capture points of buildings creating realistic replications of the building in 3D (Arayici 2007). Early efforts displaying 3D cities were commonly executed in VRML format, and include the Bath model, Glasgow directory, the Virtual Dublin project, Model City Philadelphia, and Virtual Los Angeles (Peng et al. 2002). The opportunity to display a data rich BIM and with topology has previously been limited by the lack of interoperability.

Benefits of GIS and BIM Interoperability

Integrating BIM and GIS software together allows a building to be shown in its built environment with all conditions, materials, and spatial relationships within the building and the sub terrain topology represented and available for query within the GIS system. Interoperability allows a developer to quickly visualize how the building assimilates to the surrounding environment and assist in site planning and design. GIS takes into consideration the terrain, surrounding features, roads, utilities and environmental hazards when selecting a site and designing a building (Lapierre and Cote 2008). A possible scenario where interoperability would assist in the design phase, would be analyzing traffic patterns to assess where a parking garage entrance should be located.

GIS and BIM allow for the visual impact of the landscape to be assessed (Isikdag et al. 2005). For example, if the terrain is higher than the front door of the building it would be revealed that storm water runoff may occur. If an entire city is created in 3D model urban planners can see how the removal of an existing building and its replacement with new developments will impact the environment and the database can be queried to see information on the building. Linking a BIM model to GIS software will allow for an array of information about the city demographics, local economy, and movements within the city and the building presented (Franklin et al. 2006).

The most powerful advantage of BIM and GIS integration is geospatial query and analysis. The original BIM model has information about the rooms, the area, the occupancy, the materials used to construct the building, and the intended use of the room (Lapierre and Cote 2008). GIS is often in used urban planning to manage public

utilities such as electric, gas, water, roads, and hazards analysis (Franklin et al. 2006). There are many scenarios where BIM and GIS could be queried and analyzed.

The benefit to analyzing the building data and the terrain data is apparent in disaster management. The information in one building affects another building in disaster management. In the case of disaster management, an emergency operation team will need architectural and engineering details of the building that is the scene of the emergency as well as the surrounding buildings interior, electric and water supply. If the building information is geospatially indexed and available to the city via web services real time decisions can be made in relation to shutting off the appropriate valves or using neighboring buildings to house victims, or quickly evacuating neighboring buildings and directing them on a safe path (Lapierre and Cote 2008).

Interoperability

Lack of interoperability among software is a problem that has persisted for many years, as the information from one software is needed to work in conjunction with another software. Lack of interoperability has become a critical problem as the use of BIM becomes more widely used. Inadequate interoperability is suspected to cost the AEC industries over $15 billion per year (Eastman et al. 2010). The lack of interoperability continues to grow as the need for comprehensive data increases.

A clarification should be made to the Associated General Contractors Guide definition regarding BIM. The data from BIM is extractable, but it is only extractable in limited formats. Revit Architecture software, the BIM modeling software, used in this research could easily be considered a closed loop system prior to the introduction of the IFC model and cooperation with OGC (Open Geospatial Consortium). The introduction

of the IFC and cooperation with the OGC has opened up greater export options for Revit Architecture software models.

ESRI and Autodesk, Inc. have both joined the Open Geospatial Consortium (OGC). The OGC has been established to provide international standards for geospatial interoperability (OGC 2010). Membership by both organizations displays the commitment by both firms to interoperability. Interoperability allows the two software systems to seamlessly transfer data between the systems. ESRI has published a document "ArcGIS® Data Interoperability". Autodesk ® software, design web format (DWF), drawing (DWG) / drawing exchange format (DXF), and Mapguide ® all provide direct read, data import, and data export into ArcGIS® software (hereinafter ArcGIS software) (ESRI 2009). Additional 3D file formats that allow direct read, data import, and data export into ArcGIS software include: Bentley ®, CityGML, Geography Markup Language (GML), and KML.

Industry Foundation Class

IFC files can be read directly and imported into ESRI® software. VRML files can be directly exported from ArcGIS® software (ESRI 2009). IFC files can be viewed in both ArcMap software and ArcScene software. ArcMap software displays 2D files and ArcScene software displays 3D files. IFC is a standardized data set developed by the International Alliance for Interoperability (IAI) (Kim and Seo 2008). There are many major software developers that have adopted IFC, including AutoDesk, Nemetschek IFC Viewer®, Graphisoft®, and MS Visio® (Karola et al. 2002).

IFC 2x2 and IFC 2x3 are both currently being used by developers and Revit Architecture files can be exported as IFC 2x2 and IFC 2x3. The adoption of IFC is very recent and the range of coverage is very broad, thus there are limitations within IFC

(Jeong et al. 2009). There are limitations within the IFC 2x3 with the geographic location. The IAI has addressed this with IFC 2x3G the G is for geographical information supports geo referencing building information (Espedokken 2007). IFC 2x3G has been rolled into IFC 2x4. IFC 2x4 will include the following:

- extensions in the building service and electrical design domain
- general improvements of the definition of building structures and elements
- references to external libraries
- linking to GIS models
- improvements on general resource definitions such as geometry (Liebich 2009).

Revit Architecture Extensions

An extension can be used to add functionality to a program giving two software packages the capability of working together in a common language format. AutoDesk, Inc. provides a variety of extensions that extend the capabilities ofRevit Architecture software. The extensions are either free for download or available with a subscription (Mangon and Piechnik 2007). The Globe Link extension and the Microsoft Excel extension both have the capacity to enhance the viewing of the information with the information associated with a building and the topology.

Globe Link Extension

The Globe Link extension allows a file to be published and acquired from Google Earth. KML files can be opened in Revit Architecture software or saved in Revit Architecture software as shown in Chapter 3, Section 8, Test Six . Importing KML files extends the capacity of Revit Architecture software and integrates GIS in an indirect manner, as maps can be created in ArcMap software, exported as a KML file, and the KML can be imported into Revit Architecture software. Publishing the building to Google Earth allows for a building to be shown in a scene with the surrounding imagery

provided by Google Earth. Furthermore, maps can be created in GIS and exported to Google Earth allowing for GIS information, 3D building models and Google Earth imagery all to be displayed in one location.

MS Excel Extension

Included in the Revit Architecture extension package is the MS Excel extension. MS Excel extensions allow buildings to be built from the excel model. (Figure 2-3) The file built in Revit Architecture software has the capability of being saved, and because the file is saved as an MS Excel file it can be imported into GIS and joined. The GIS file may need to be manipulated prior to import. Manipulations would include a Z value that is used to extrude the building.

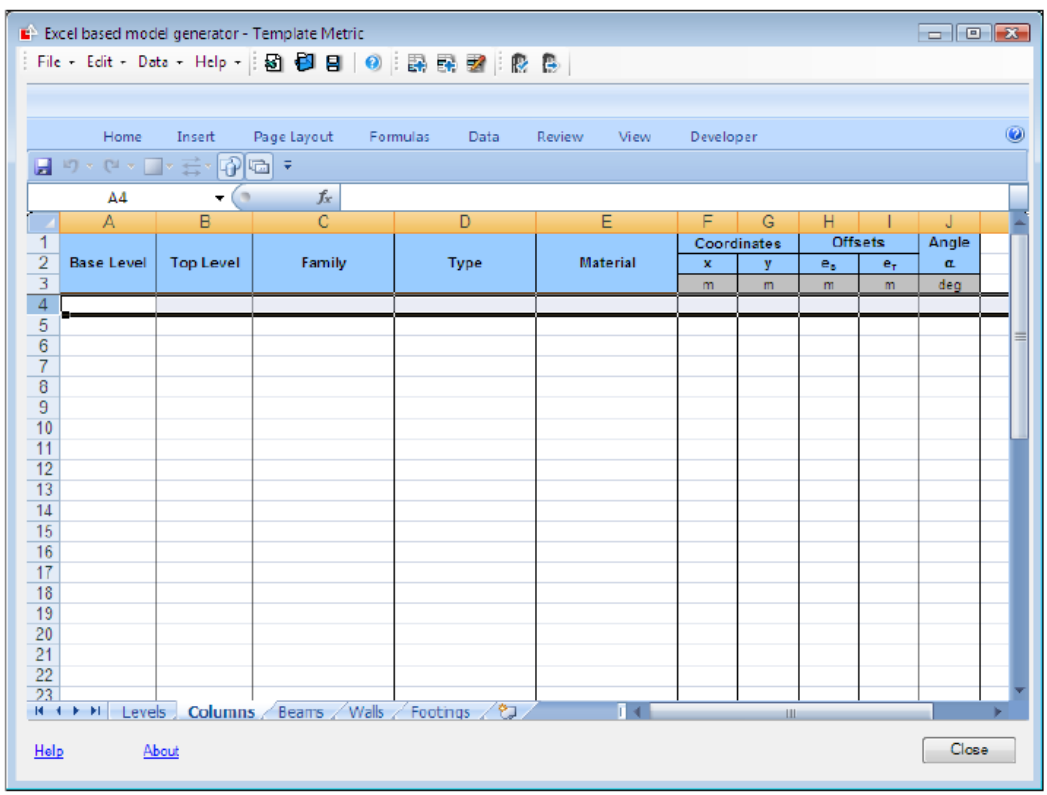


Figure 2-3. Excel extension, Mangon and Piechnik 2007

Case Studies

Case Study – ArcScene™ Software

The Greater Municipality of Istanbul Department of Development had the goal of developing BIM models of their City. For the purpose of disaster management the Municipality of Istanbul wanted to explore the possibility of exporting the BIM data and importing it into GIS. The BIM was transferred to IFC format and modeled in a schema level model view. An undisclosed input processing package was used for the mapping of the Model View. The Model view was then queried using an API model server database. The buildings geometry was then defined as a boundary representation (BRep) and the coordinates of the buildings elements were transferred from its local position to its global position, the final step defined the geometry to Constructive Solid Geometry (CSG) and transfers the CSG to BRep. The model was displayed by using ArcScene software. The screen shots revealed that there were tables supporting the following geospatial objects: column, beam, slab, window, door, wall elements (Isikdag et al. 2008).

The case study concluded that it was "difficult to transfer information from building models into geospatial environments and to represent buildings within geospatial information models (Isikdag et al 2008)."

Case Study - City of Vancouver

Vancouver, Canada; Incheon, Korea; and Salzburg, Austria are three cities that have been selected to partner with Autodesk to develop tools and software for 3D urban modeling. The goal of a 3D urban model is to create a virtual model that includes mapping data, building information, civil, and utilities information that is easily

assessable to the city, public, designers, developers, and utilities department for visualization, simulation, and analysis.

The City of Vancouver began digitizing maps in the 1980s and has continued towards the objective of a photo realistic city. The City of Vancouver has used a combination of software to execute their objective including: AutoCAD® software, ESRI® software, AutoMap 3D® software, Sketch Up on a limited basis, and Google Earth. The objective for the City of Vancouver was to have a 3D city that contains intelligent information about the mapping, buildings, civil, and utilities that can be utilized by the city, public, designers, utility departments, and development departments. The model created is photo realistic and provides the viewer with accurate perception of the city (Figure 2-4). The 3D model is viewed by staff from all over the city, and used to aid in making decisions regarding the City of Vancouver.

Figure 2-4. Vancouver 3D city

The City of Vancouver has executed a realistic 3D model of the built environment. The commitment of the city is to move towards intelligent models that have

infrastructure data and that are scalable. A consistent modeling approach is being explored. The models created by the City of Vancouver are visually robust.

Case Study - City of Sheffield

The City of Sheffield in the United Kingdom is modeled in 3D which is used by planners and urban designers to assess proposed developments. The preferred format currently being used is Sketch Up or AutoCAD ® (.dwg or .dxf) (Hanson 2009). Rudimentary applications include the use of VRML (Cheng et al. 2002).

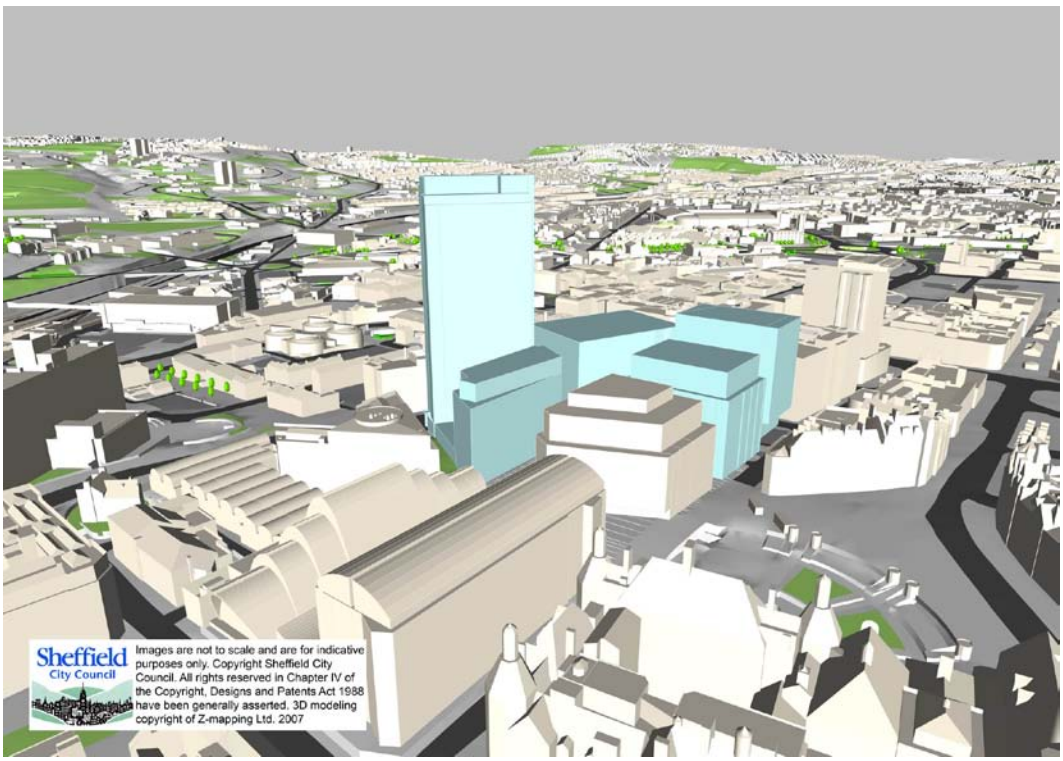


Figure 2-5. City of Sheffield, (Hanson 2009)

Case Study - Combinatorial Data

A 3D model which had no supporting data, meaning it is not data rich, was modeled in ArcScene software with ERDAS Imagine 3D virtual extension. A method known as combinatorial data model (CDM) was utilized. The combinatorial model is abstracted using the property of Poincare´ duality. The 3D model of the MSU-Mankato

campus, (see Figure 2-6), was developed with each node having a unique reference number (Node_ID) that is linked to a 3D polygon (PolygonZ_ID) (see Figure 2-7) defined in 3D Shape file format. In this manner, the 3D representation of a room shown in the 3D visualization module has the same ID as its corresponding node in the dual graph, and the node set of the CDM can be joined with the attribute data of the 3D shape files for use in thematic or attribute queries (Lee and Kwan 2005). The supporting imagery is added as a layer, and the 3D trees and the building are represented in ERDAS Imagine 3D virtual extension loaded into ArcScene software. The building is built from a combination of nodes that are linked to each other within the attribute table. This method is effective in representing the shell of the building, although there are not objects such as doors and windows represented in the model.

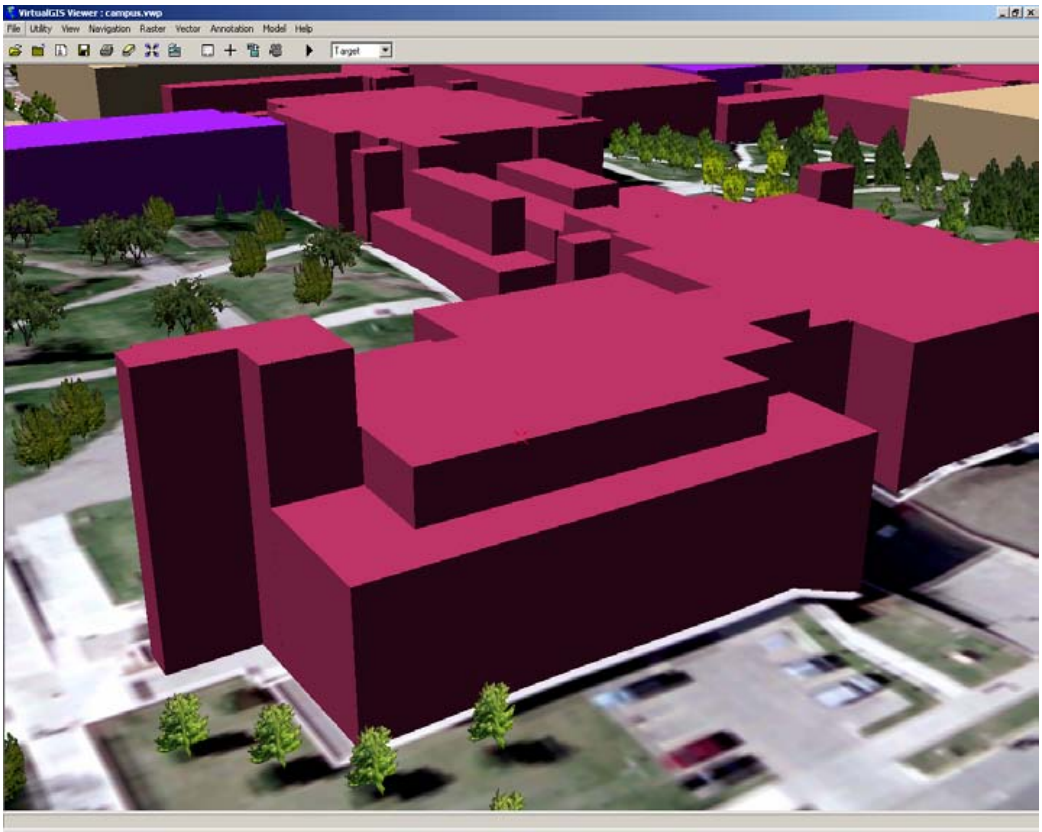


Figure 2-6. 3D model of the MSU-Mankato campus (Lee and Kwan 2005)

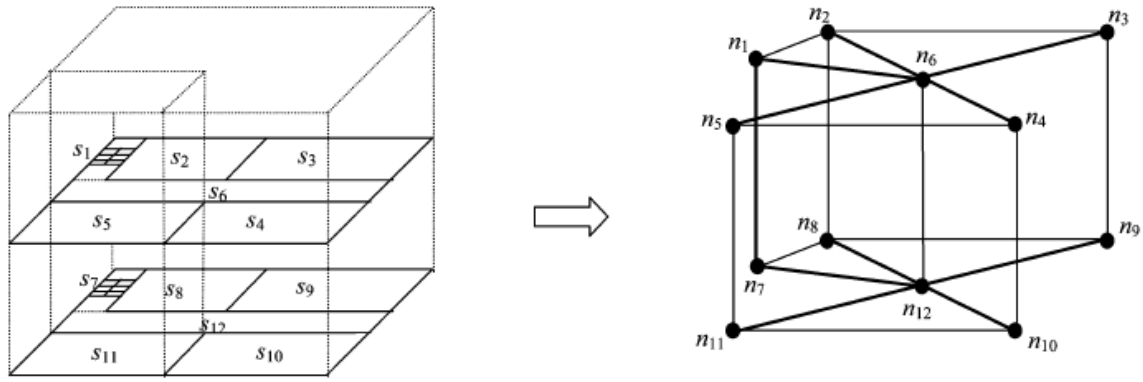


Figure 2-7. Node representation of MSU – Mankato campus (Lee and Kwan 2005)

Case Study – IFC and Auto CAD

The IFC export options adopted by developers are limited. Data is lost in transmission. A case study by Amor et al. (2007) revealed that data is lost in the transmission of CAD and IFC files. A file was exported from AutoCAD into an IFC model, opened in an IFC viewer, and opened again in CAD. The data revealed that that objects lost their globally unique identifier (GUID) or did not keep their original GUID. The represented accuracy of the model into the IFC view was 4.154093800000022 and the represented accuracy out was 4.1540938, meaning that the ending decimal places were deleted when it was exported out (Amor et al. 2007).

Case Study – IFC and Precast Concrete Pieces

The case study developed detailed structural precast concrete in the following software: Graphisoft® ArchiCad®, Bentley® Architecture V.8, Digital Project V1, R3, and Autodesk® Revit ® Building V. 9.1. All the models were exported to IFC and then imported into Tekla Structures. The Revit model had limitations when it was exported to the IFC model and when it was imported back into Revit. The case study concluded that none of the geometry was exchanged in its entirety and that there was a lack in

uniformity in the manner that internal objects were mapped to the IFC model (Jeong et al. 2009). This case study revealed that the IFC model is the present method for transferring data from BIM into other software, but it is not seamless resulting in a loss of detail.

Conclusion

There are many software applications being used to model the 3D world with its surrounding topology. The systems range from complex models created by individual authors such as the Istanbul or Mankato campus model or simple applications such as Sketch Up or VRML used to view 3D buildings and the terrain. The simple to complex models all fall short of the definition of being a true BIM, as they are not data rich often representing a shell of the building and a photo of the topology.

Visualizing buildings and topology in 3D benefits governments, the public, developers, planners, and disaster management team the method for achieving the objective is not yet effective. The literature review, while not comprehensive, did not uncover case studies involving IFC and GIS interoperability. The research purpose of this research is to join 3D BIM models with topology utilizing IFC and KML formats.

CHAPTER 3
METHODOLOGY

Revit Architecture software exports files in many formats such as AutoCAD® files, IFC files, 3D Max® files, and KML files. GIS has a data interoperability command that allows the import of these files. Revit software and GIS both have export and import options, although it is often unclear to the end user which system works the best and what is retained when exports and imports are performed. This methodology attempts a series of file combinations that allow a 3D building to be displayed with its surrounding topology.

A simple structure was created in Revit Architecture software for the purpose of this study. The principle behind the simple structure was to have basic geometry and basic components of a building represented. The test model represents shapes, openings, and materials common to most buildings. A simplified model is used for preliminary experimentation because of the unknown factors that may arise when exporting the model from Revit Architecture software into GIS software.

The test model constructed was exported from Revit Architecture software in DWF, KML, and IFC format and then imported into different ESRI® software and the results were analyzed. Table 3-1 outlines the software used in the research and the results achieved in each series of tests. ESRI® software claims to be interoperable with all DWF, KML, and IFC format. The extent of the interoperability is still unknown to this end user. This research explored the extent of Revit Architecture software and GIS interoperability, the results achieved by using different model integration approaches.

Table 3-1. Software test sequences

	Software test sequence					
	Test 1A	Test 1B	Test 2	Test 3	Test 4	Test 5A
Sequence	Test model Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®
	Navisworks®	Navisworks®	Navisworks®	Navisworks®	Navisworks®	Globe Link extension
	KML file	KML file	KML file	KML file	KML file	KML file export
	ArcScene software: direct import	ArcScene software: quick import	ERSI KML2SHP version 2.3	ArcScene software: data interoperability and custom formats	ArcGlobe software	Google Earth

	Software test sequence					
	Test 5B	Test 5C	Test 6	Test 7	Test 8A	Test 8B
Sequence	ArcMap software	Google Earth image	Test model Revit Architecture® with and without coordinates	Test model 20' x 20' Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®
	KML file	KML file	IFC file export	IFC file export	IFC file export	IFC file export
	Revit Architecture®	Revit Architecture®	ArcScene software – quick import	Notepad binary code modification	ArcMap software-editor – move building	ArcMap software-editor – scale button
	Globe Link import	Globe Link import		Nemetschek®	ArcScene	ArcScene software – building straight line
				ArcMap software		

CHAPTER 4
RESULTS

Autodesk® Revit Architecture® Test Model

The model is a two story building with a total area of 3,440 SF with each floor consisting 1,720 SF. The height of the building is 30 feet, and the building volume is 51,600 CF. Table 4-1 lists the material used in the building. Various views of the building are shown in Figures 4-1, 4-2, and 4-3. The model is referred to as demo_project in the remainder of the document. The file extension of the model will change as it is imported and exported into each software package.

Table 4-1. Building components

Building component	Material used
exterior walls	concrete masonry units
level 1 slab	concrete with vapor barrier
level 2 slab	light weight metal deck with concrete
roof	steel truss with EPDM membrane
outside doors	36"x 84" cold room
windows	36"x48" fixed
interior walls	6 1/8" partition
interior doors	36"x84" single flush

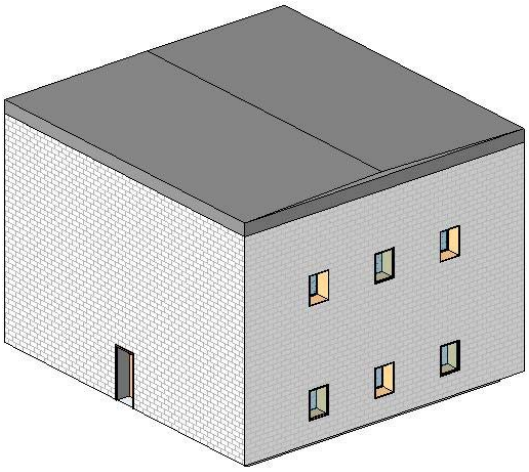


Figure 4 -1. Exterior 3D view

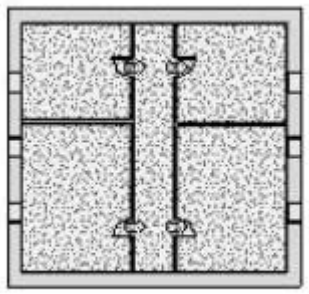


Figure 4-2. Plan view

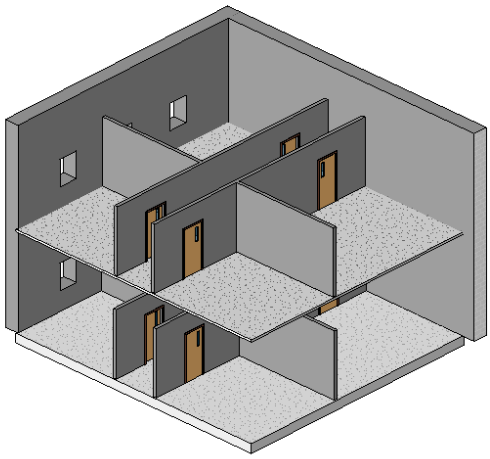


Figure 4-3. 3D interior view

Tests 1A and 1B: Navisworks® Software and ArcScene™ Software

The Tests 1A and 1B utilize Autodesk® Navisworks® Manage (hereinafter referred to as Navisworks) 2009, Revit Architecture 2009 software, Google Earth, and ArcScene software. Tests 1A &1B use Navisworks as a medium to export the file establishing the project location and then exporting the file to a common KML file medium. A direct import was performed to observe how the KML file interacted with ArcScene software, and then later the KML file was imported into ArcScene software using the quick import option.

Export

The demo_project.rvt file was exported from Revit Architecture software as a 3D DWF file and opened in Navisworks. The file was then exported from Navisworks as a KML file, establishing the latitude and longitude for the building (see Figure 4-4). (The KML file was saved as a KMZ file. A KMZ file extension is interchangeable with a KML file extension, as a KMZ file is a compressed KML.)

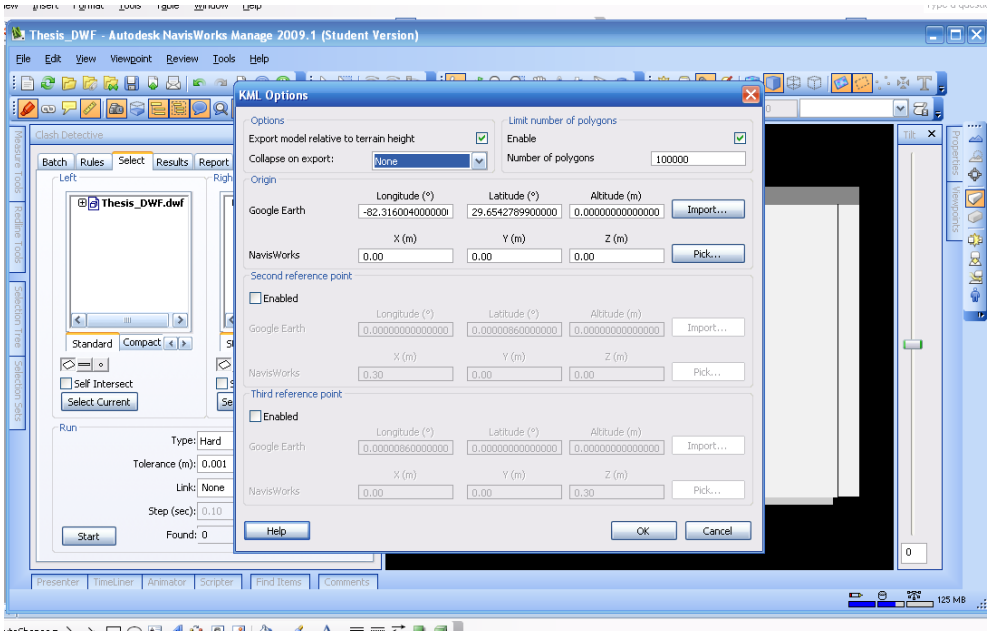


Figure 4-4. Navisworks KML export

Direct Import

The GIS software used to perform the import was ArcScene software. ArcMap software is the most commonly used GIS software, but it only has the capability to display data in 2D. ArcScene software was developed by ESRI for the purpose of 3D display. The demo_project.kmz file was added as a layer into the ArcScene software. ArcScene software offers the option to load the KML/KMZ file as a supported layer, therefore the appearance is that the file will be added similar to other files supported by

ArcScene software. The impression is that ArcScene software is compatible with KML files without necessary data conversion. The result of demo_project.kmz is shown in Figure 4-5. The file did not convert and the result was a solid line in the center. The line is made from the layer name “Placemark Collection”, which is highlighted in blue. The attribute table of this layer is comprised of Z (axis) values but there are no values assigned to the Z value (Figure 4-6).

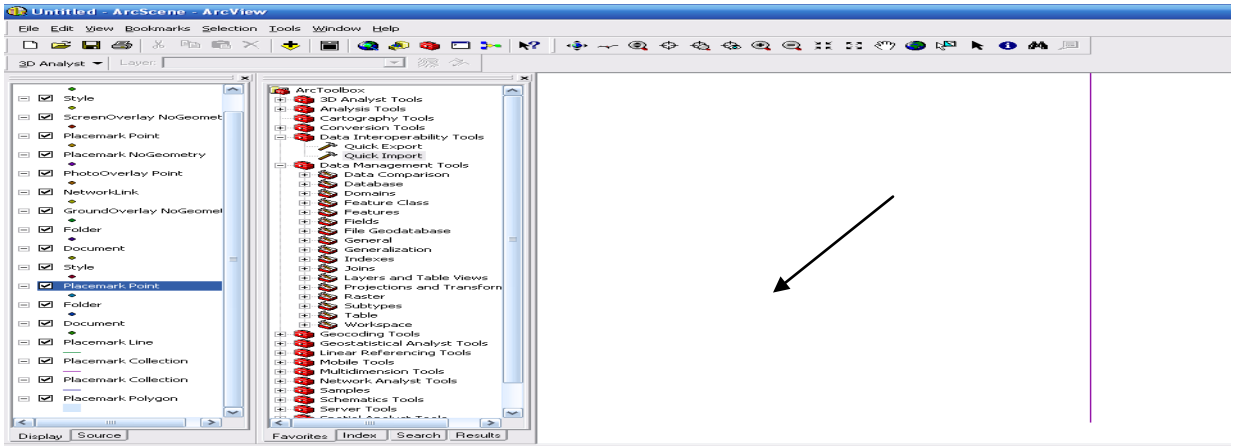


Figure 4-5. Direct KML import

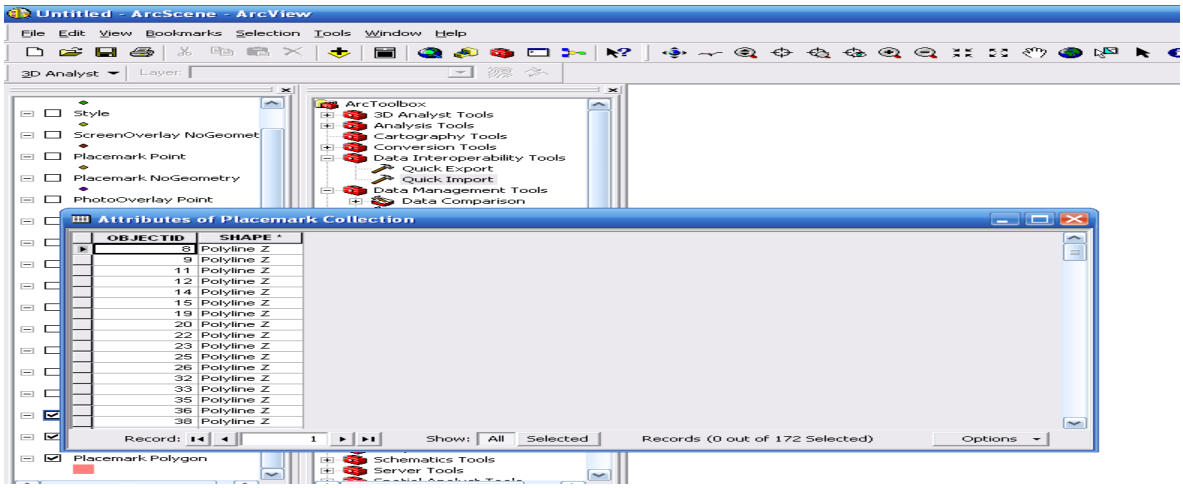


Figure 4-6. Direct KML import attribute table

The Z value assigns the height to a building for extrusion in ArcScene software. The absence of the Z value prevents the building from being extruded. The information

regarding the Z value is no longer available when the file is opened directly as a KML / KMZ file in ArcScene software.

Quick Import Option

As a part of the data interoperability package ArcScene software has a quick import option that allows data to be converted into formats that are interoperable with ESRI® software. The data types include KML and KMZ files.

The tool is located in ArcScene® software in ArcToolbox® software / Data Interoperability Tools / Quick Import. The data format for the file must be selected (see Figure 4-7), as there are many data interoperability formats and GIS does not automatically read the file. The file demo_project.kml was imported into the data interoperability tool and a geo database was created (Figure 4-7). A geo database was created, because this is the acceptable file format that loads in ArcScene software.

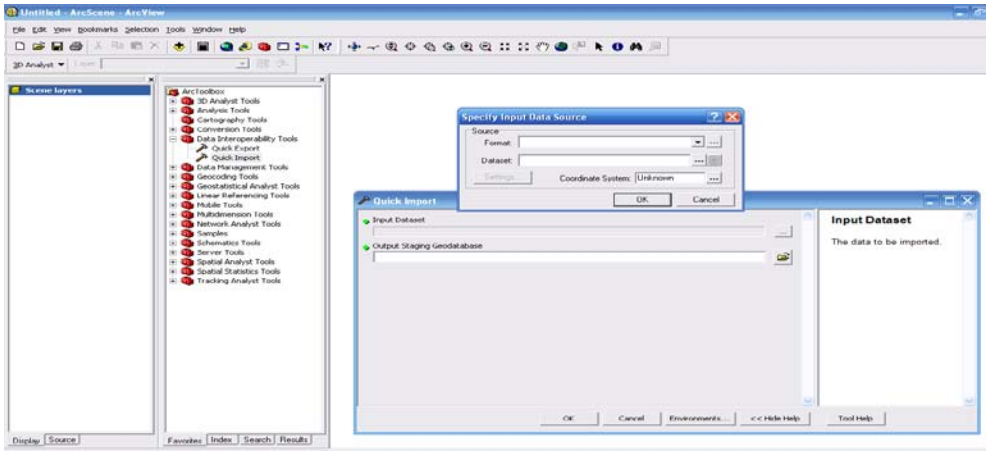


Figure 4-7. Quick import data interoperability

The geo database created by the data interoperability conversion was added into ArcScene software. The result (see Figure 4-8) shows that once again a straight line was created. The difference between the geo database that was created when the file was loaded directly and the KML/KMZ file is that only one layer that was created in the

geo database is the placemark_point layer versus many layers created when the KML/KMZ file was added directly. The placemark_point layer created a straight line in the direct import option. In the quick import option, placemark_point layer is no longer a straight line but two points.

The placemark_point layer was then converted to a raster file. The raster was then converted to a triangulated irregular network (tin) file. The tin file creates a straight line that is not 3D (Figure 4-8).

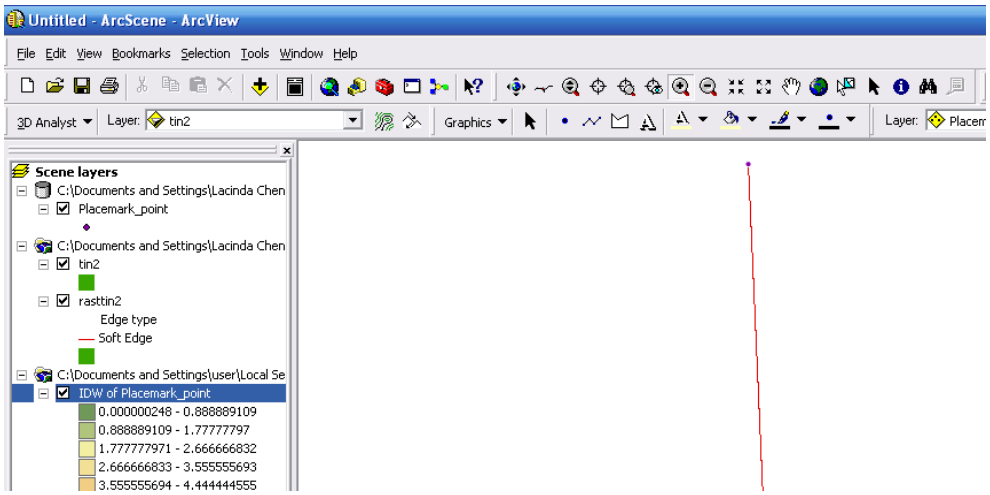


Figure 4-8. Raster results

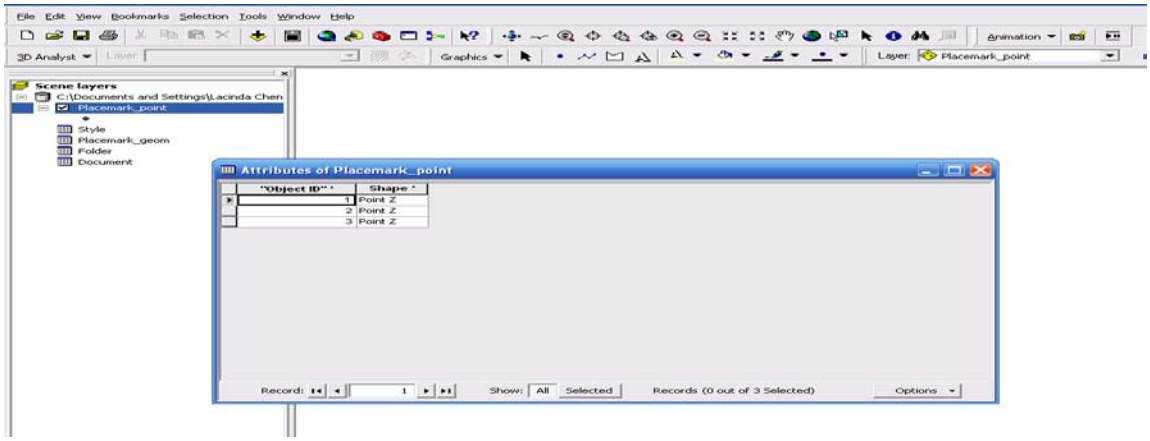


Figure 4-9. Raster attribute table

The attribute table for the two points is a series of z values (Figure 4-9). Points can be extruded in ArcScene software if there are heights or elevations assigned. The file created in the quick import option lacks both x, y, and z data. Therefore, the points can-not be extruded in ArcScene software because there are not distances assigned to the z value.

Test 2: KML to Shape file Conversion

File converters are often solutions used to convert data. The quick import option is a data interoperability converter written by ESRI®, but due to the results obtained in Tests 1A and 1B this research attempted to find another converter that would convert the KML data to a compatible shape file format. ESRI® software provides two KML to shape file converters on their website. The first is a KML2SHP version 2.3 converter, but after reviewing the technical specifications, the converter is only applicable for ArcView® 3.x software. The system that is being utilized in this research is ArcView 9.x software (Almeid 2009).

Test 3: KML Custom Formats Converter

The results produced in Tests 1 A and 1B indicated that teher was a need to retain more data when the KML file was converted to a geo database. As shown in Figures 4-6 and 4-9, the only information retained was objects defined as z shapes in the placemark_point layer. Creating a custom format allows more information to be retained in the attribute table when the file is converted from a KML to a geo database. Appendix A outlines the steps provided by the ESRI® help desk to create a custom format data interoperability converter. Figure 4-10 displays step two of the custom formats and Figure 4-11 displays step three of the custom formats.

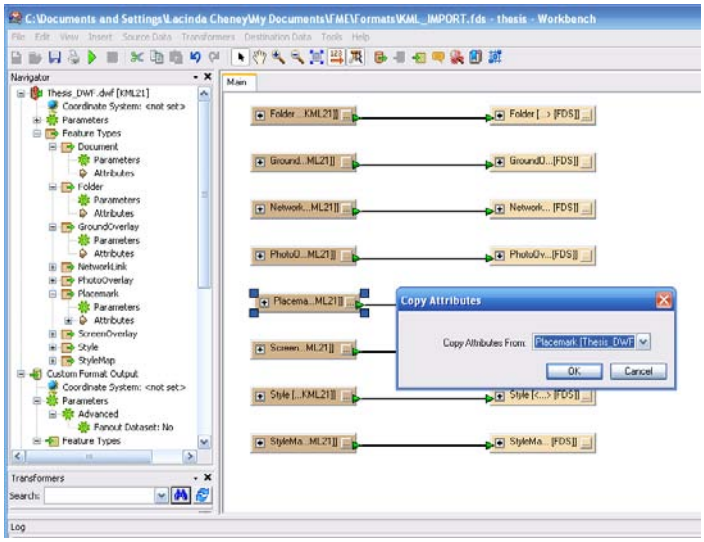


Figure 4-10. Step two of custom formats

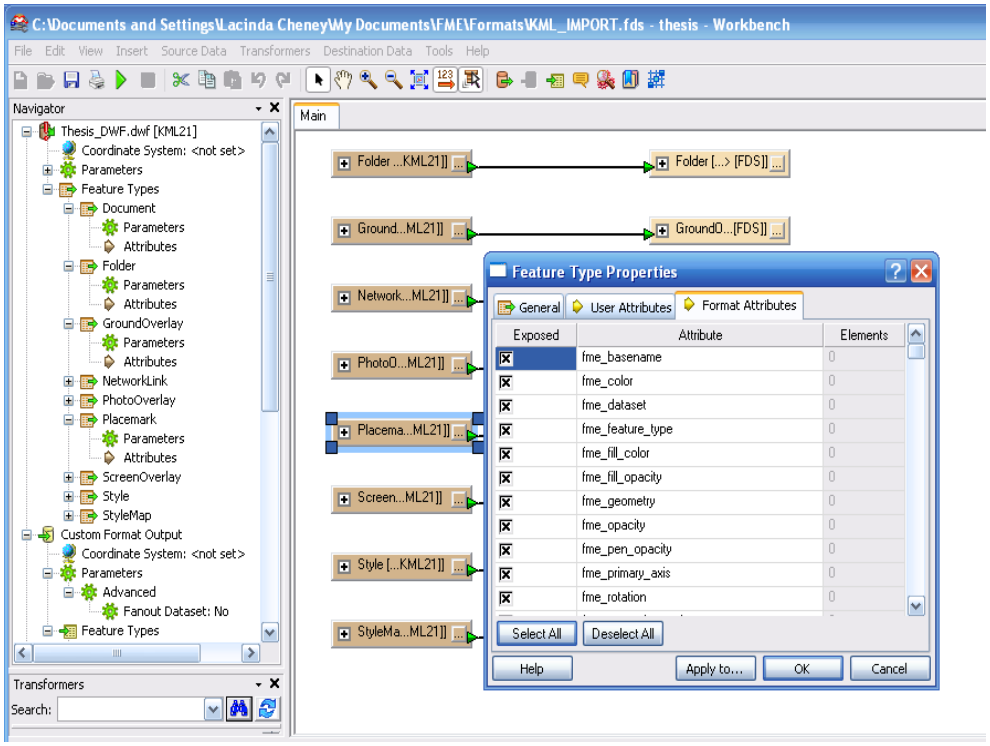


Figure 4-11. Step 3 of custom formats

Loading the custom formats converter is launched from the data interoperability quick imports tool in ArcScene software. A geo database was created from the demo_project.kml file custom format converter. The geo database created by the

custom formats converter created a layer called placemarks_points, which is the same layer that was created in the Series One quick import. The placemarks_points layer contains the latitude and longitude of the building. The placemark_point layer attribute table is more detailed than the attribute table produced in Series One. The columns in the attribute table are exactly the same columns that were specified in step three, Appendix A specified in the workbench. The attribute table contained more columns than the attribute table of Tests 1A and 1B, but the results are still null values, meaning that there is no supporting data for the cell (Figure 4-12).

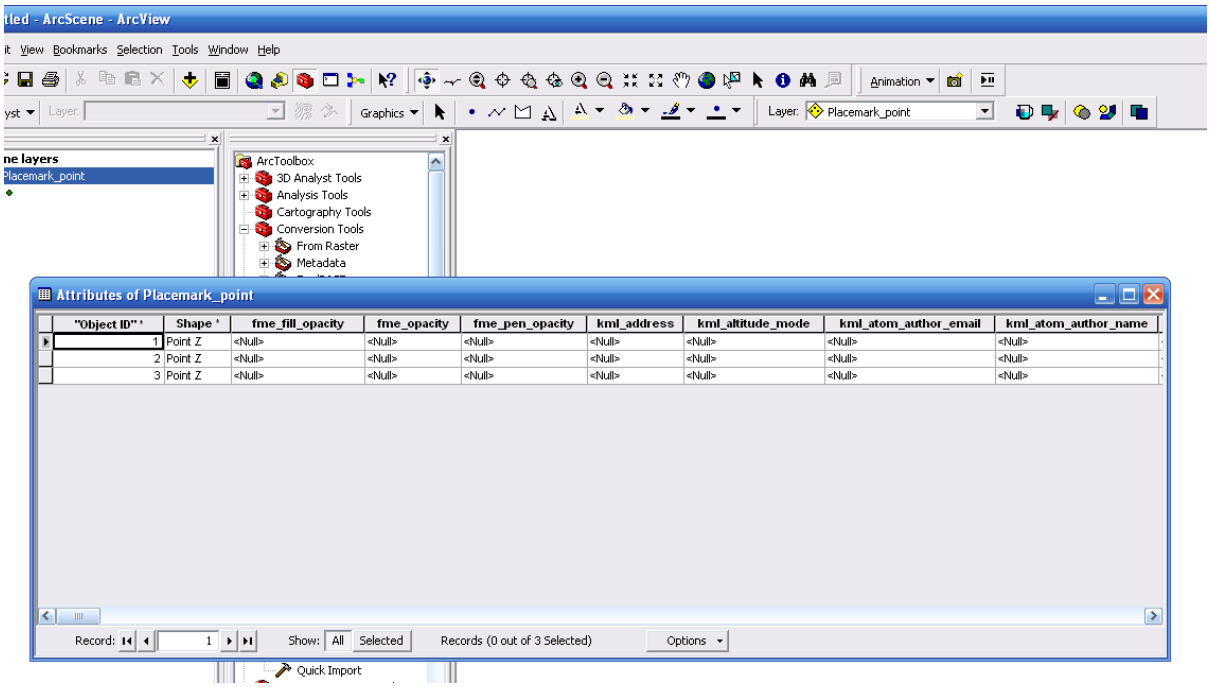


Figure 4-12. Custom formats attribute table

The geo database created from the custom formats converter was loaded into ArcGlobe software. The result was a balloon placemark placed on the globe (Figure 3-13). The geo database was loaded into ArcGlobe software because the results in Tests 1A and 1B indicated that ArcScene software does not view KML files correctly.

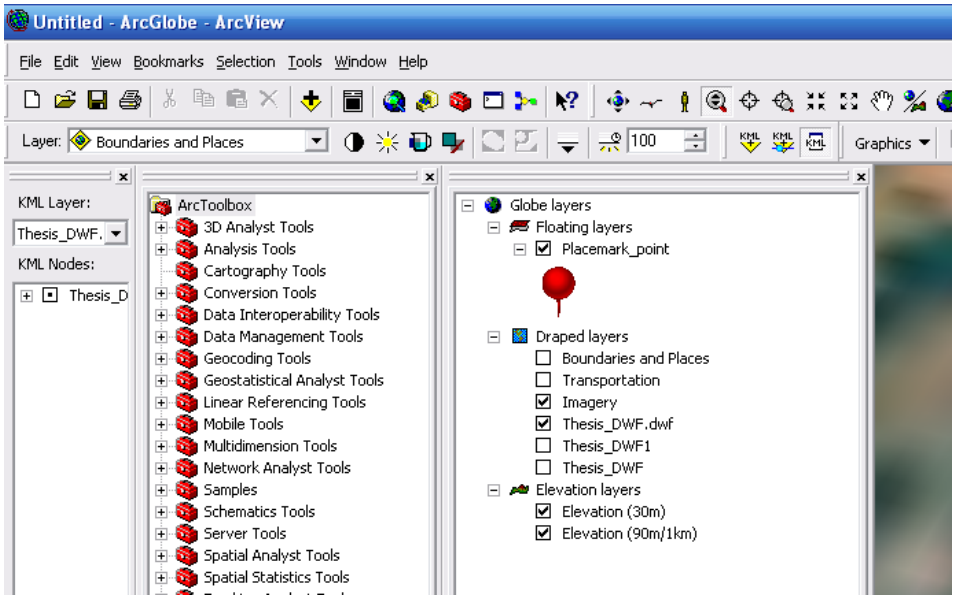


Figure 4-13. Custom KML format in ArcGlobe™ software

Test 4: KML to ArcGlobe Software

ArcGlobe software is produced by ESRI, and is capable of viewing KML files. When ArcGlobe software is opened, the Earth is displayed as an image draped on the globe (Figure 4-14). At a distance the resolution of the globe is clear, but when a map is created the resolution of the Earth's image is distorted as shown in Figure 4-17, because there is low resolution image. The imagery layer on the globe can be turned off and on depending on the end users needs.

Figure 4-14. ArcGlobe software

Maps created in ArcMap software can be loaded into ArcGlobe software and used for the surrounding topology replacing the low resolution imagery. Due to the poor resolution of the imagery on the globe, it s recommended to turn the image off and load supporting shape files, KML files, or imagery to create the surrounding topology (Figure 4-15).

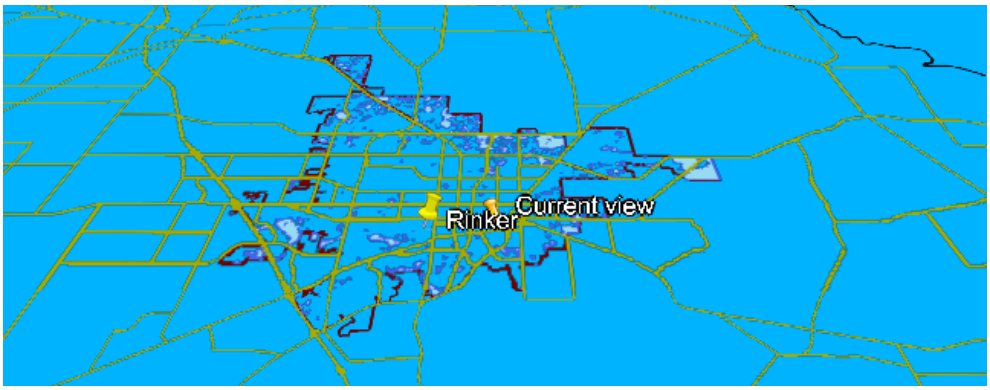


Figure 4-15. ArcGlobe software without imagery

The capability to add KML files in ArcGlobe software is initiated with the KML toolbar (Figure 4-16). The KML toolbar must be loaded, as it is not an automatic tool in ArcGlobe software. The command for the toolbar is located in view, toolbars, and KML. Once the toolbar is loaded, select the first button +kml. The tool bar +kml button must be used to load the KML file correctly into ArcGlobe software. This function allows for the file to be viewed in 3D in ArcGlobe software.

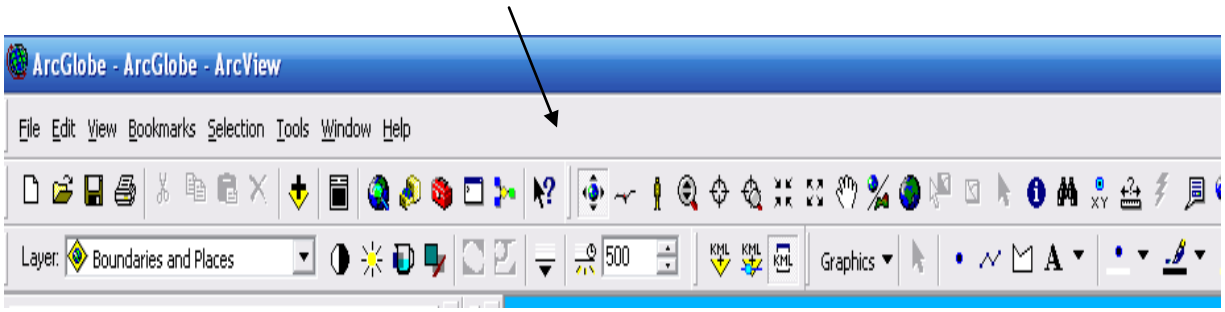


Figure 4-16. KML toolbar

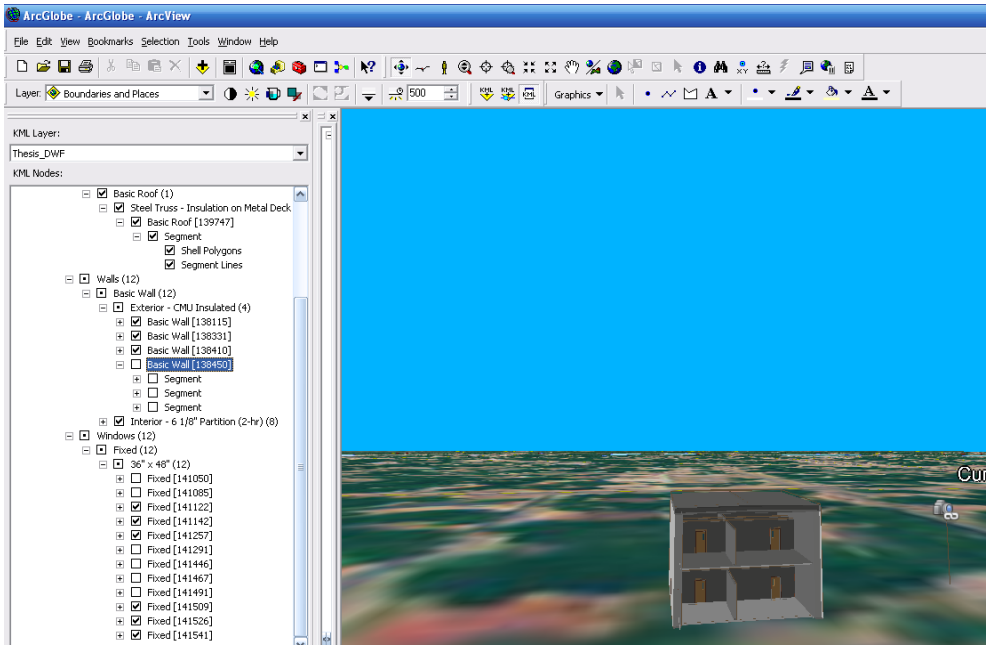


Figure 4-17. KML file in ArcGlobe software

The building is loaded into ArcGlobe software as a direct KML file, meaning that there is not data conversion necessary within the quick import option. The building is depicted accurately in ArcGlobe software with the doors, window, interior doors, exterior doors, slabs and wall all displayed as designed in 3D. The dimensions of the building objects are all to scale. The objects of the building are brought in as individual layers and the objects are grouped together. Individual objects can be turned on and off with a mouse click. This functionality is beneficial if the imported building is being used for disaster management purposes.

The resolution of the image layer is low. A proposed solution is to remove the image layer and add shape files maps created by the user. ArcGlobe software does not create maps similar to ArcMap software or ArcScene software. The images in ArcGlobe software can be exported as pdf files, but they do not create maps (Appendix B). This is a negative from a cartography perspective.

Tests 5 A, B and C: Autodesk® Revit ® Extensions

Globe Link

The Globe Link extension must be loaded into Revit Architecture software, and is obtainable by subscription only from AutoDesk. The option is located in Tools / External links. The objects can be exported as separate nodes or the nodes can be exported together. Both options were tried, and neither produced a noticeable result in the shape of the geometry. Figure 4-18 displays the first attempt at exporting the demo_project.rvt file to a KML file and publishing it to Google Earth. The building was published to an arbitrary place because latitude and longitude was not assigned to the building in Revit Architecture software. The results are shown in Figure 4-18 (south view) and Figure 4-19 (west view). The geometry of the roof and the front door did not stay aligned. The shapes of the windows were distorted, although the brown outline is evidence that the windows were still placed in the openings.

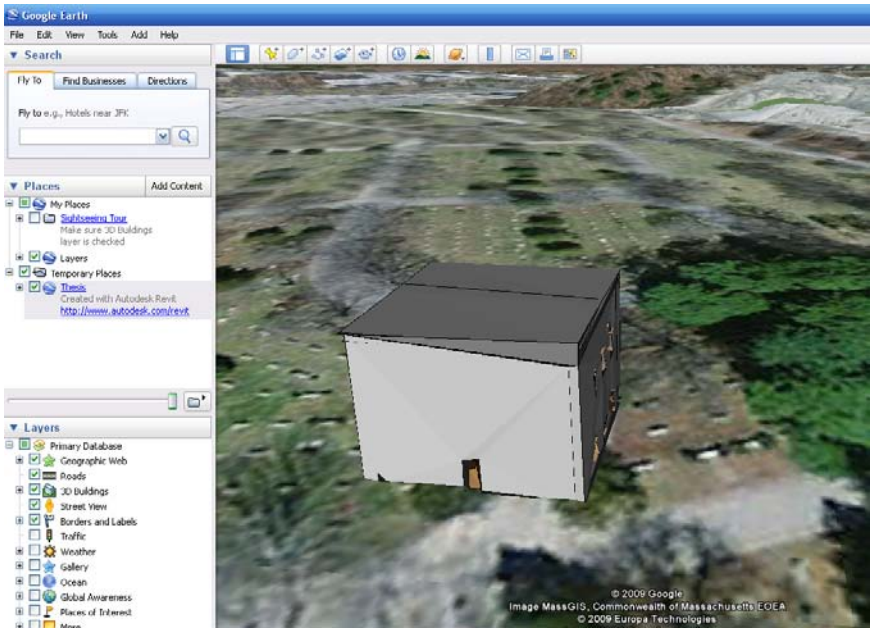


Figure 4-18. Globe Link extension south view in Google Earth

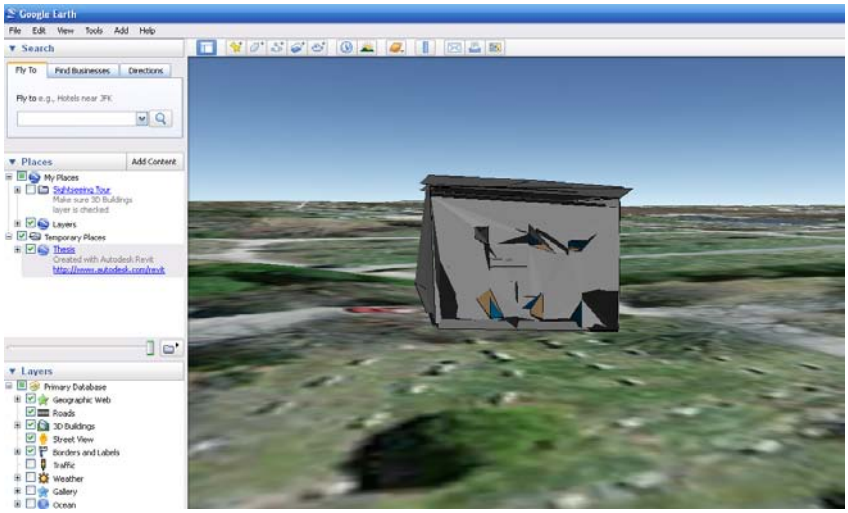


Figure 4-19. Globe Link extension south view in Google Earth

The next attempt to export demo_projected.rvt assigned the latitude and longitude in the Revit Architecture software. The file was exported as a KML file and opened in Google Earth. The result (Figure 4-20) shows that the building landed at the exact coordinates specified to the building in Revit Architecture software. The geometry of windows did not export true to the design in the Revit Architecture software.

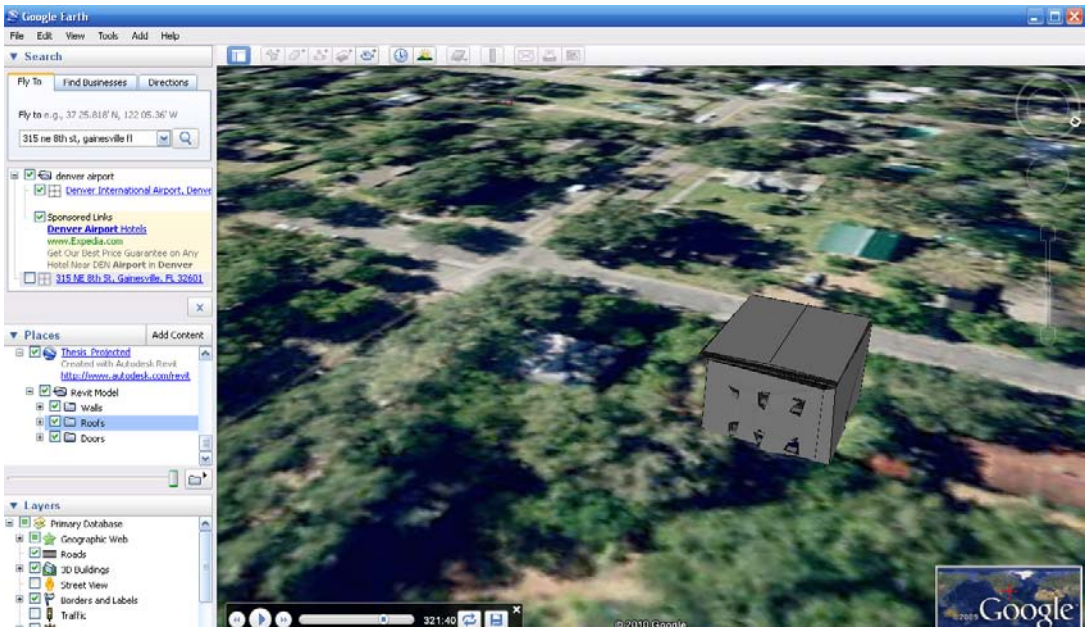


Figure 4-20. Globe Link extension with latitude and longitude assigned

Globe Link: KML File Import

The Globe link extension allows KML files to be imported into Revit Architecture software. The benefit of importing KML files into Revit Architecture software is that visual topography can be imported into Revit Architecture software, which can aid in decision making. For the purpose of this research, a map of Gainesville, Florida was created in ArcMap software. There are three different types of shape files in GIS: points, lines, and polygons. Two of the three file types were used in the creation of this map. The map created contained the following:

- Soils polygon shape file
- County Major Roads polyline shape file
- County Boundary polygon shape file
- Major City Roads polyline shape file
- Gainesville City Limit polygon shape file
- Gainesville City Limit Bodies of water polygon shape file

The intent of the map was to include different shape files to observe how they convert into KML files and can be viewed in Revit Architecture software. The tool to convert the MXD file into a KML was found in ArcTool® Box software under conversion tools, to KML (Figure 4-21). This tool converts shape files into KML files that can be loaded into Revit Architecture software or other compatible programs.

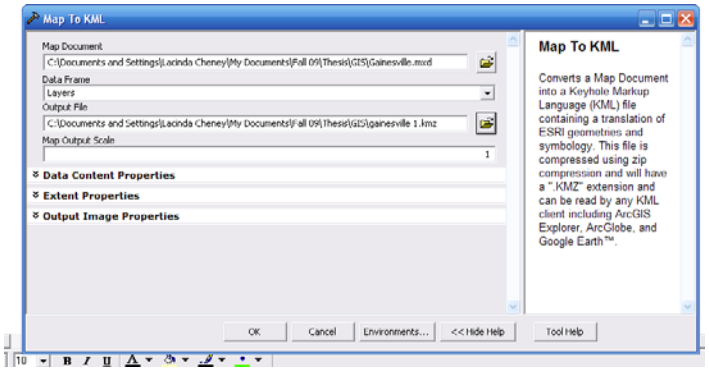


Figure 4-21. Map to KML conversion pop up

Appendix C shows the map that was created in GIS and saved as a MXD file. Figure 4-22 displays the KML map imported into Revit Architecture software. The map is large in comparison to the building size.

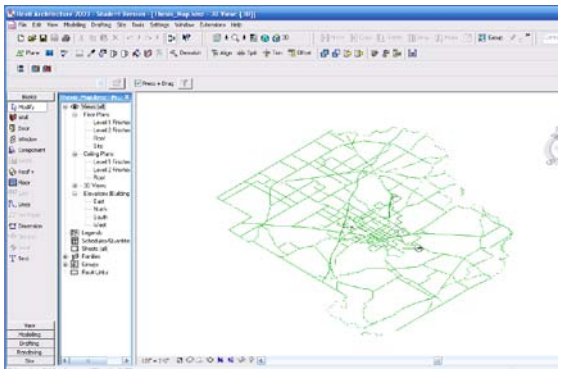


Figure 4-22. KML File imported into Autodesk® Revit Architecture® software

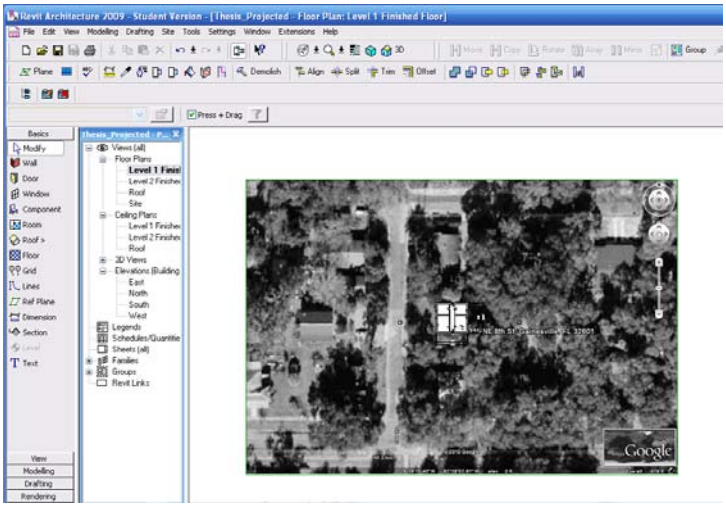


Figure 4-23. Google Earth KML file imported into Autodesk® Revit Architecture® software

Due the large scale (see Figure 4-22), the KML file created in ArcMap software was opened in Google Earth and zoomed into the region where the building was located. The zoomed in location was saved as a KML file and opened Revit Architecture software. Figure 4-23 shows a clear photo imagery of the KML file. The building and the KML were displayed in plan view. When the building was viewed in

3D, the imagery was no longer visible. The results shown in Figure 4-22 allow visibility of the building in plan view and 3D.

Test 6: IFC – ArcScene Software

The Industry Foundation Class (IFC) is a common format language for BIM models. The demo.rvt file was exported out of Revit Architecture software in IFC format. The demo.ifc file was then imported into ArcScene software utilizing the quick import function and selecting IFC as the import option. A geo database was created, and all layers were added including the supporting databases. The geometry of the model imported accurately, but the color was gray scale. The colors of the layers of the model were changed to allow for color differentiation of the model (Figure 4-24).

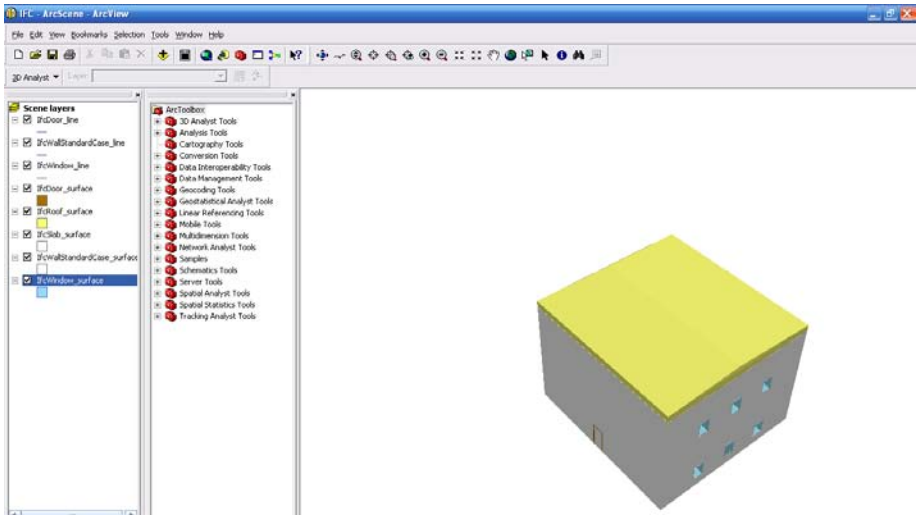


Figure 4-24. IFC file imported into ArcScene software

The objects in the building are imported as layers. For example, both interior and exterior doors are grouped together, windows, walls; slabs and the roof are all represented as individual layers. The layers can be turned on and off. Figure 4-25 represents the building with the roof layer turned off. Turning layers on and off is beneficial to end users who need to see the interior of building

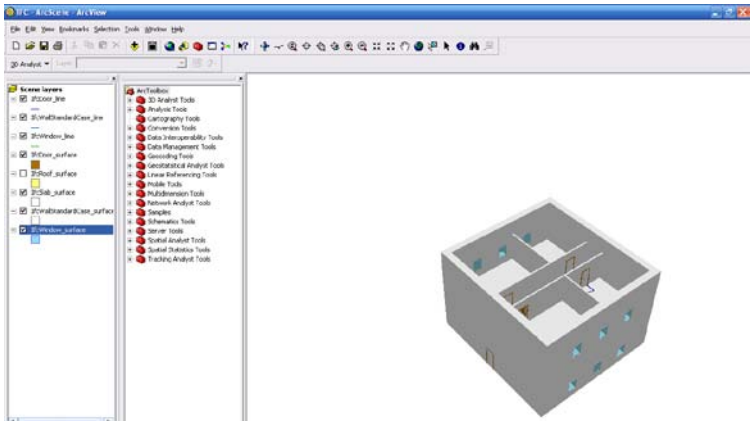


Figure 4-25. Interior view of IFC model in ArcScene software

The attribute tables of the individual layers contain specific data about the model, including the name and description of the material, the GUID, the height, and the width (Figure 4-26). The information about each layer can be queried. Querying the layers is an essential functionality of GIS.

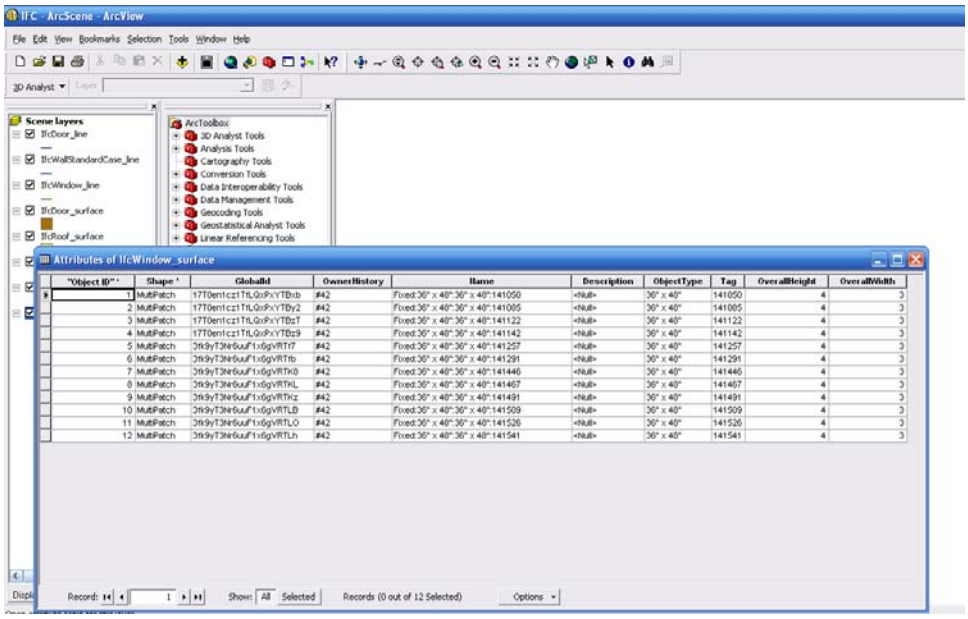


Figure 4-26. IFC attribute table

The goal of the research is to view the building and its components in conjunction with its topology and its infrastructure. The State of Florida county boundaries shape

file was added to ArcScene software. The county boundary shape file provided by the Florida Geographical Data Library was added to the demo_project.ifc map in ArcScene software (FGDL 2010). The county boundary was projected to the WCS GCS 1984 coordinate system, to establish a common projection. The county boundaries shape file was distorted and the polylines outlining the county boundary did not depict accurately.

Figure 4-27 shows the oversized representation of the building in comparison to the State of Florida. The size of the building when it is displayed next to the State of Florida indicates that the scale that was used to import the IFC model into ArcScene software was not as the same scale that was used to export the model from Revit Architecture software to IFC. Additionally, the building's coordinates are not within the latitudes and longitudes assigned to the State of Florida.

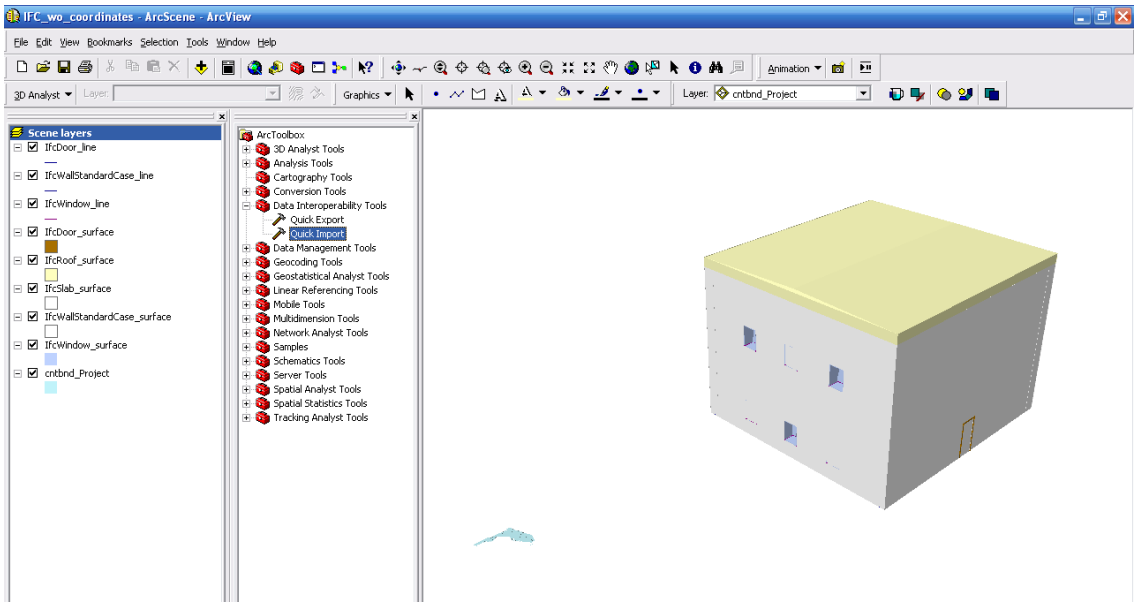


Figure 4-27. IFC model with State of Florida

When the IFC model was imported into GIS with the quick import option there was not an option that allowed for the coordinates or the scale to be set. This indicated

that the scale and the shared coordinates needed to be established in Revit Architecture software.

Test 7: IFC Model Coordinates and Scale

Coordinates

Revit Architecture software has an option located in tools / shared coordinates which allows coordinates to be assigned. The north east corner of the model was assigned shared coordinates of 29.65 and -82.31. The model was then exported out of Revit Architecture software as an IFC and loaded into ArcScene software with the data interoperability converter. The result (see Figure 4-28) displays that the location of the building is the same location as the mode without shared coordinates assigned.

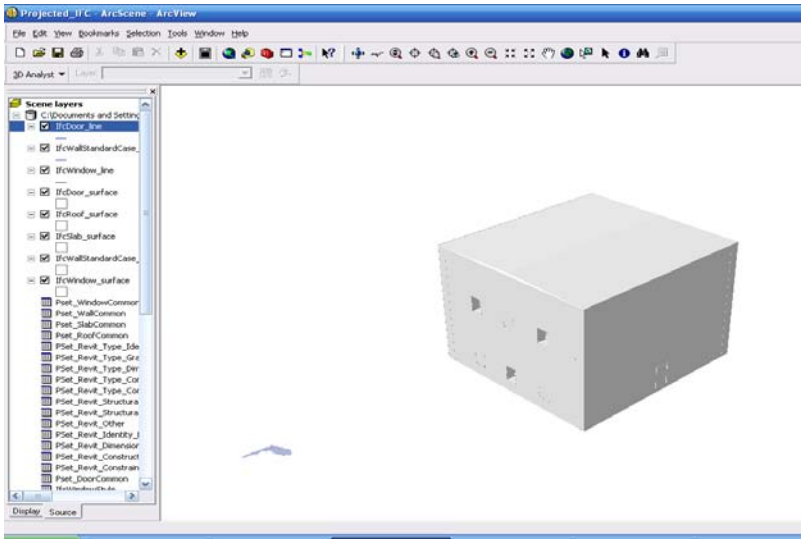


Figure 4-28. IFC import with shared coordinates assigned

The original demo.ifc file was opened in Nemetschek IFC Viewer® software. The properties of the demo.ifc file revealed that the local X, Y, Z coordinates were assigned to zero (Figure 4-29). This is the local placement and it was difficult to determine whether the local coordinates were the same as the global coordinates. The local placement is the central axis of the building.

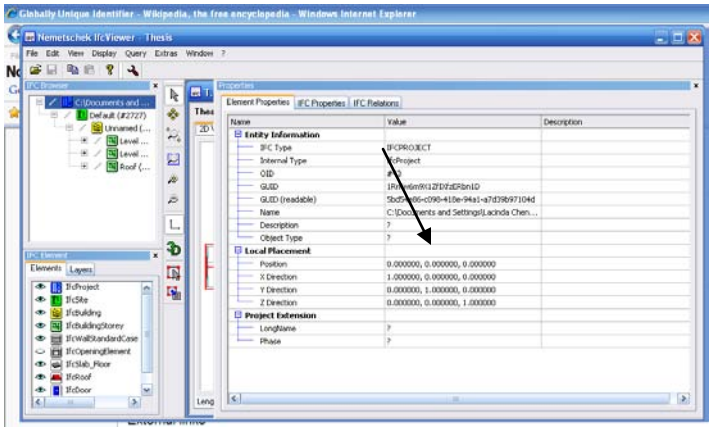


Figure 4-29. Coordinates in Nemetschek IFC Viewer®

The demo.ifc file was then opened in note pad and a search was made for the numbers 29.65 and -82.31, which were the shared coordinates assigned in Revit Architecture software. The entire number was not found, but a portion of the numbers was located on code line #2727. Line #2727 is the following:

#2727=IFCSITE('2t3jOKOPz9rQkZA4HJdqJn',#42,'Default',$,'',#2726,$,$,.ELEMENT.,(29,39,15,170399),(-82,-18,-57,-394800),-0.,$,$);.

The number 2t3jOKOPz9rQkZA4HJdqJn is the GUID for the site of the model. This GUID did not appear in any of the attribute tables in the map. The absence of the GUID indicated that another point was used to assign the latitude and longitude of the building.

Three models drawn in the following dimensions: 20’x 20’, 40‘x 40’, and 60’ x 60, were drawn to determine how the IFC models coordinates were being placed in ArcScene software, and what scale was used to transfer the models from IFC to ArcScene software. The models were made of four walls. The purpose of this approach was to reduce the number of lines of IFC information viewed in notepad.

A search was made for the east wall's GUID in notepad. Code line 131 contained the GUID and referenced information back to code line 116. Code line 116 is the Cartesian point, which is a spatial reference point, (#116=IFCCARTESIANPOINT((-26.80511635612962,33.49736737642829,0.)). The identity button was then used in ArcMap software and it was determined the numeric value assigned in code line 116 was the placement of the East wall's latitude and longitude and that the basis for placement was the top North East corner. The Cartesian Point for the east wall was changed to #116=IFCCARTESIANPOINT((-0.60511635612962,35.49736737642829,0.));, and the result as displayed in Figure 4-30 shows that the East wall moved.

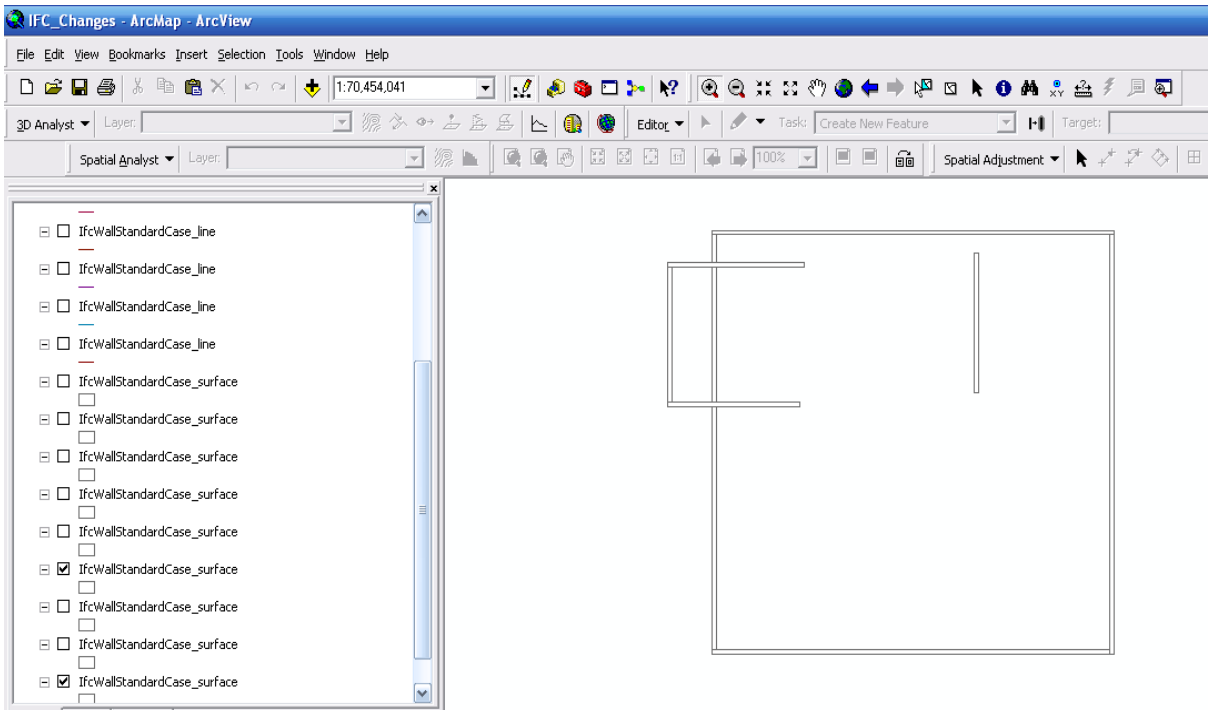


Figure 4-30. East wall moved

A search was then made for the south wall's GUID, and it was located on code line 161, which lead back to the Cartesian point on code line 146.

(#161=IFCWALLSTANDARDCASE('2H2oNAxmT66uRlRu1ahUv9',#42,'Basic Wall:Generic - 8":137485',$,'Basic Wall:Generic - 8":249',#148,#160,'137485'); #146=IFCCARTESIANPOINT((-27.13844968946295,13.83070070976161,0.))). The Cartesian Point on code line 146 was changed to the following: #146=IFCCARTESIANPOINT((-0.93844968946295,15.83070070976161,0.)); the result is shown in Figure 4-31.

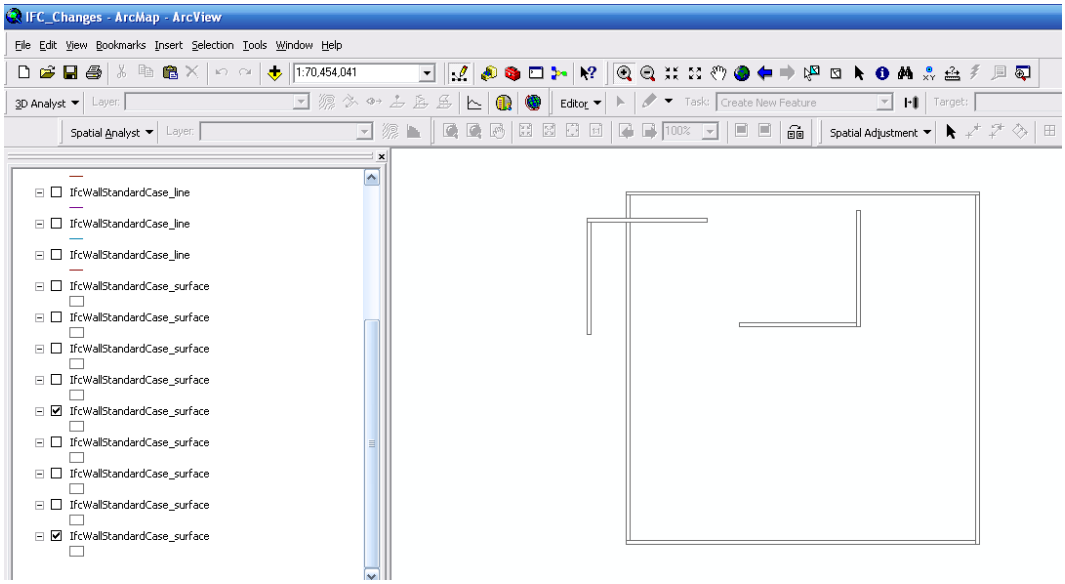


Figure 4-31. South wall moved

Scale

The original demo_ifc geo database was opened in ArcMap software and the identity function displayed the coordinates on the NW corner slab as -36.136489, 33.840905 decimal degrees in the ArcMap software. The SW Corner slab coordinates were -36.136489, -8.000656 decimal degrees in the ArcMap software. The walls of the demo_ifc geo database were scaled in feet and the results ranged from 14 million to 16 million feet (Table 4-2). It is important to note that the tape measure scale returned

different dimensions when all dimensions in this research were re-measured, with the discrepancy in the last four places.

The extremely high values provide evidence that the building, which was drawn in feet in Revit Architecture software, with the dimensions of 40’6 x 43’ from center line to center line of the concrete masonry units, was not being converted correctly. The question then arose as to where the conversion error was occurring. Did the error occur when the file was exported from Revit Architecture software to IFC, or did the error occur when the model was converted to a geo database in ArcScene software?

The file was opened in Nemetschek IFC Viewer® software and the model scaled correctly. Next, the units of the file were changed in Revit Architecture software to meters and centimeters as shown in Table 4-3. Finally, the units of the file were changed in Revit Architecture software to millimeters. The files were opened in Nemetschek IFC Viewer® and the files scaled according to their assigned scale, such as feet, meters, and centimeters.

After changing the scale in Revit Architecture software, exporting to an IFC, and converting to a geo database, it became apparent that GIS was not converting the IFC file using a metric or imperial scale. The data interoperability converter was converting the feet to decimal degrees when the file was converted into the geo database.

Table 4-2. Test model exported in feet

Revit Architecture® export in feet	
Wall	ArcScene software scale in feet
North wall	14,309,302
East wall	15,503,305
South wall	16,043,507
West wall	15,503,305

Table 4-3. Measurement of building in meters

Revit Architecture® export in meters	
Wall	ArcScene software scale in feet
North wall	4,981,849
East wall	4,745,568
South wall	5,046,632
West wall	4,745,568

The question then arose as to whether the walls were being placed in the ESRI® software with only the latitude and longitude Cartesian points. The north wall was selected, and it was identified that the length of the wall was IFC code line 56 and 61, note that the code lines that identify the length are also labeled Cartesian points. This is important because all of the information converted in the data interoperability tool is code lines that have Cartesian point references.

#56=IFCCARTESIANPOINT((20.66666666666664,0.));

#61=IFCRECTANGLEPROFILEDEF(.AREA.,$,#60,20.66666666666664,0.6666666666666714)

The wall was originally 20 feet long, so the value in code line 56 and 61 was doubled to 40 feet, see code lines below.

#56=IFCCARTESIANPOINT((40.66666666666664,0.));

#61=IFCRECTANGLEPROFILEDEF(.AREA.,$,#60,40.66666666666664,0.6666666666666714). The result shown in Figure 4-32, which shows that the length was extended both to the east and to the west. Code line 59 was then identified as a Cartesian point, and as the mid-point of the code line. The original value of line 59 is as follows: #59=IFCCARTESIANPOINT((10.33333333333332,0.));. The mid-point was doubled to 20 as follows: #59=IFCCARTESIANPOINT((20.33333333333332,0.)).

The results shown in Figure 4-33 displays the wall moved to the east.

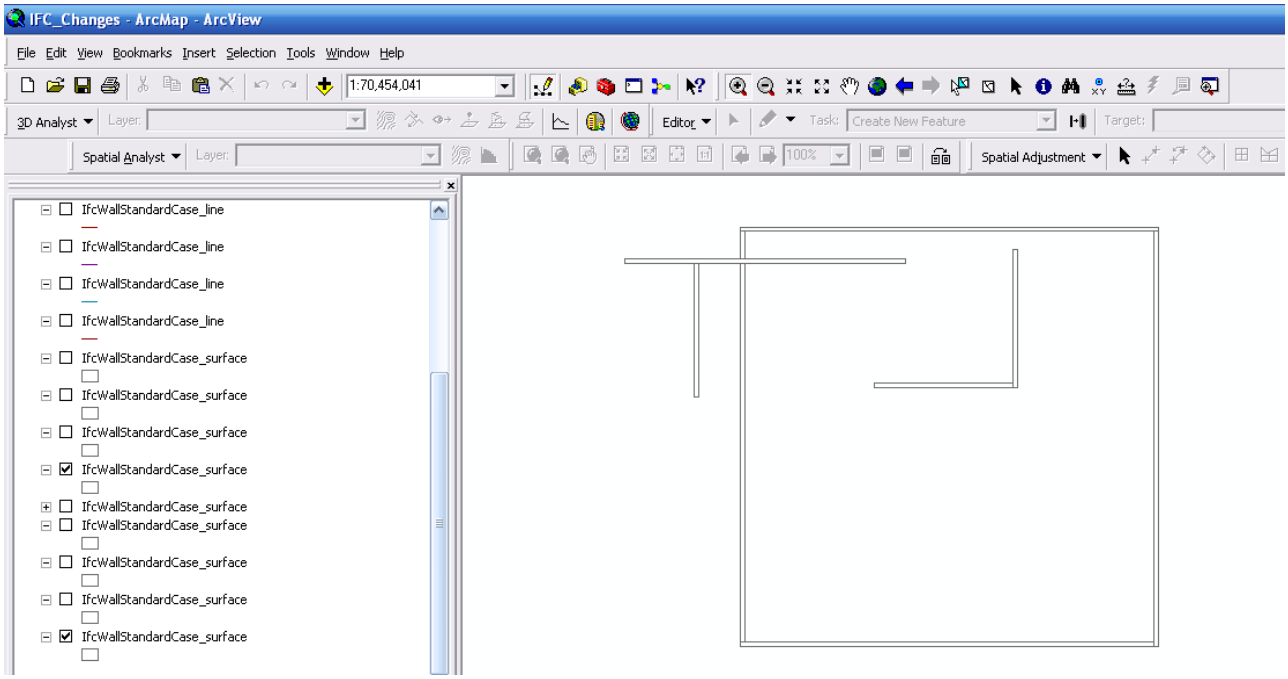


Figure 4-32. North wall distance increased to 40 feet

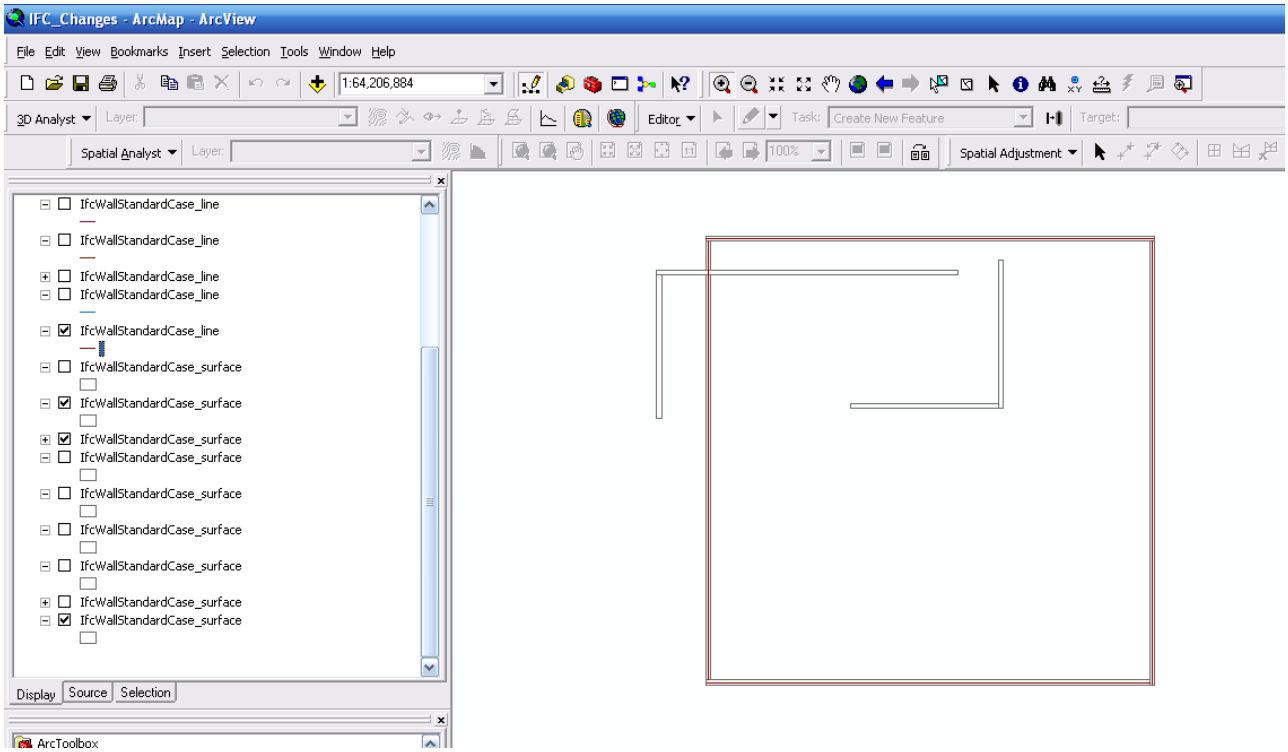


Figure 4-33. Mid-point adjusted

Tests 8A and 8B: Adjusting Coordinates and Scale in GIS

When it became apparent that the problem of geographic location and building scale was occurring when the IFC file was converted into a geo database, and an attempt was made to adjust both the coordinates and the scale with in ESRI® software. Figure 4-34 shows the building and the State of Florida in plan view. The image was taken in ArcMap software, as all edits to a project have to been done in ArcMap software (ArcScene software does not allow edits to be performed). The entire building was selected by area, and the building was then picked up with the “X” in the center of the plan view and moved to the appropriate geographic location. Due to the size of the building it was located directly over the state of Florida (see Figure 4-5). The geo database that was modified in ArcMap software was then opened in ArcScene software. The result, (see Figure 4-36), shows the building in 3D located directly over the State of Florida.

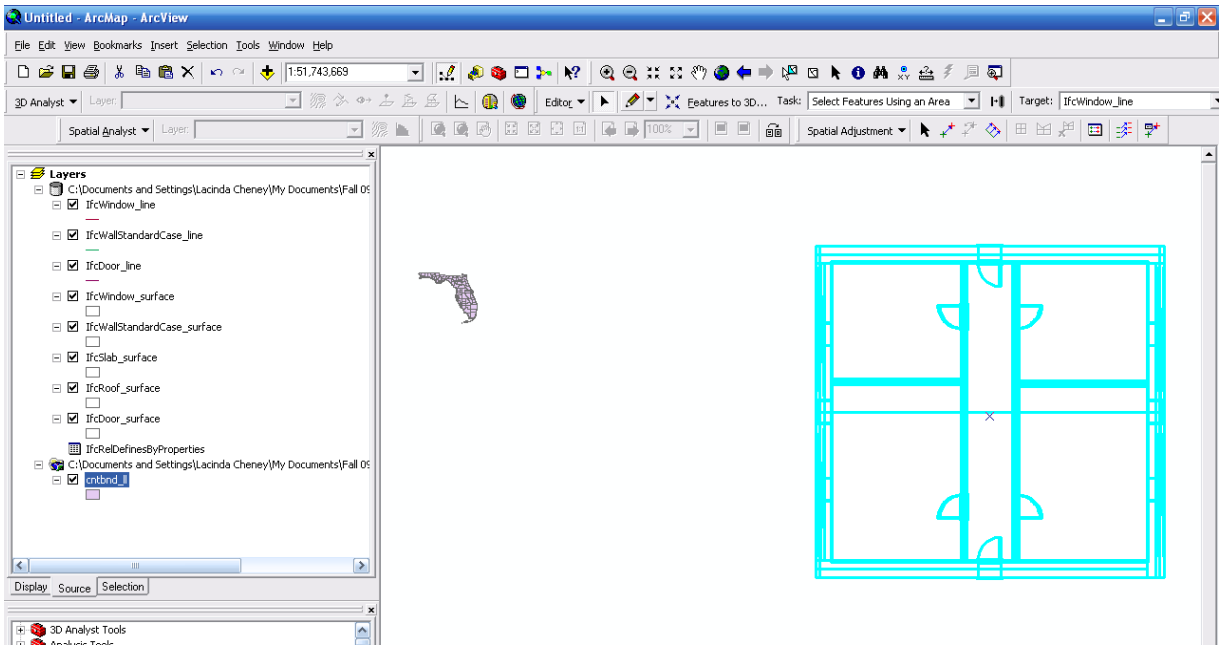


Figure 4-34. Building selected by area in ArcMap software

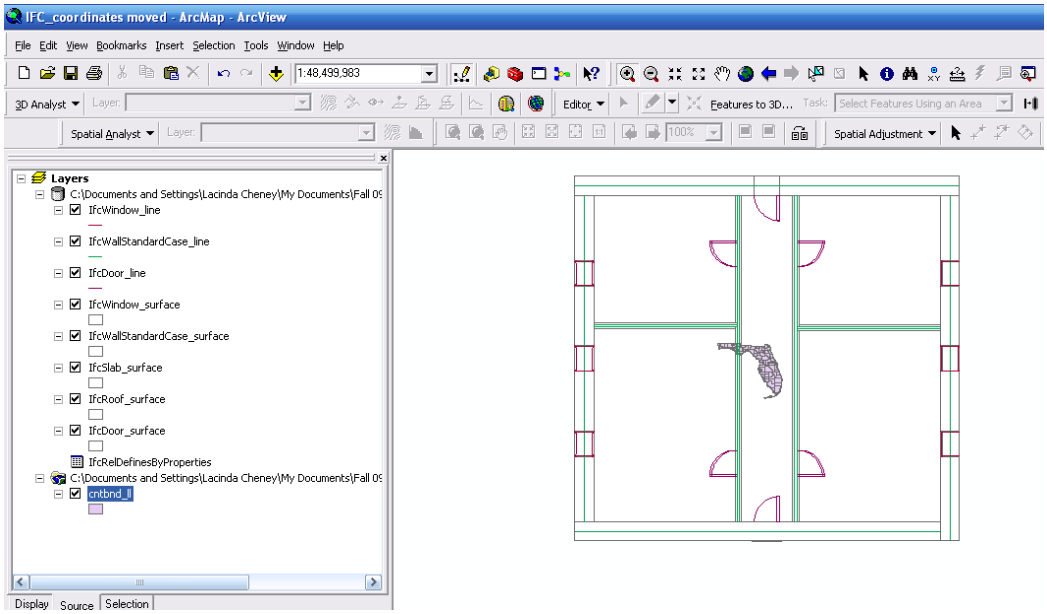


Figure 4-35. Building located over the State of Florida in ArcMap software

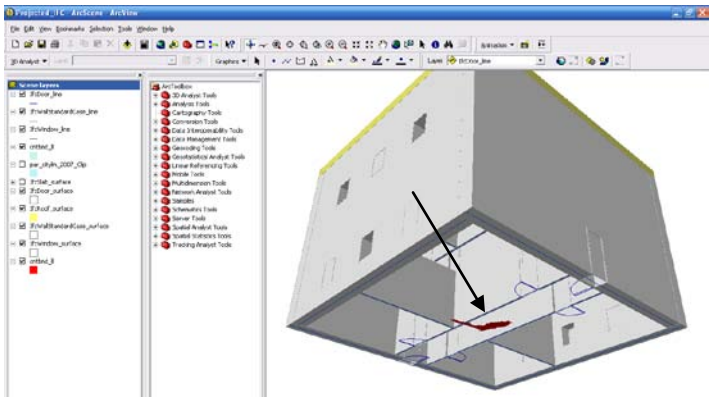


Figure 4-36. Result of changes made in ArcMap software viewed in ArcScene software

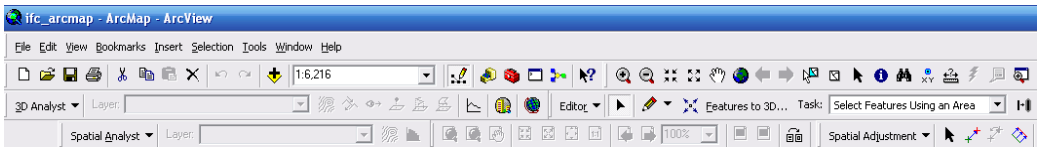


Figure 4-37. Scale button

The next step was to adjust the scale of the building to feet, as it was drawn in Revit Architecture software. The scale button was loaded to the editor tool bar (see Figure 4-37). The entire building was selected by area, and the building was scaled

down in size. The result is the building in plan view (see Figure 4-38). The building was scaled down and moved to Alachua County.

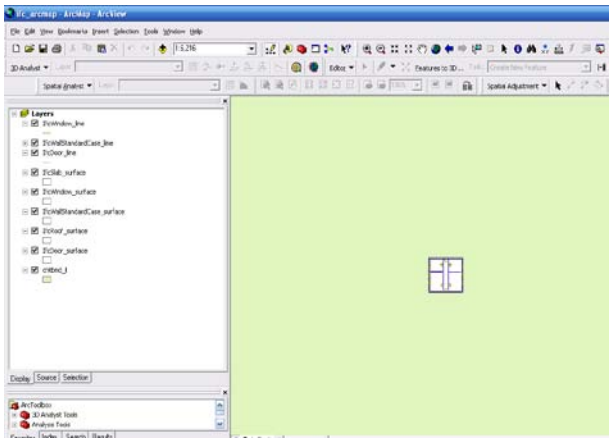


Figure 4-38. Building scaled down in ArcMap software

Once the scale of the geo database was modified in ArcMap software, the geo database was then opened in ArcScene software. The result showed that the building has become a straight line in a vertical direction (see Figure 4-39). The top part of the line is colored red, which is the color of the wall layers. The bottom portion of the line is colored blue which is the color of the slab.

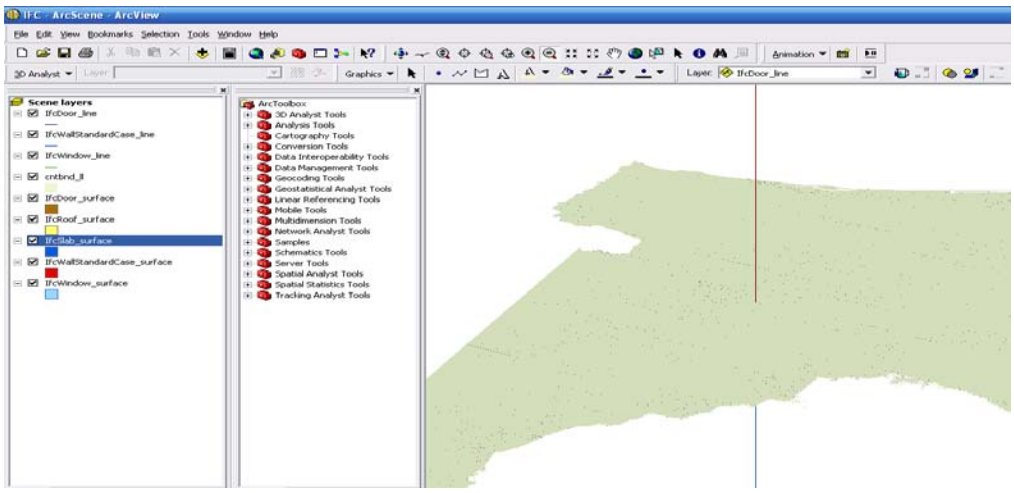


Figure 4-39. Result of building scaling viewed in ArcScene software

Summary of Results

Table 4-4 shows a summary of the tests conducted and results obtained. Next in Chapter 5, the results of the tests will be further discussed.

Table 4-4. Test Sequences and Results

	Software test sequence					
	Test 1A	Test 1B	Test 2	Test 3	Test 4	Test 5A
Sequence	Test model Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®
	Navisworks®	Navisworks®	Navisworks®	Navisworks®	Navisworks®	Globe Link extension
	KML file	KML file	KML file	KML file	KML file	KML file export
	ArcScene software: direct import	ArcScene software: quick import	ERSI KML2SHP version 2.3	ArcScene software: data interoperability and custom formats	ArcGlobe software	Google Earth

	Software test sequence					
	Test 5B	Test 5C	Test 6	Test 7	Test 8A	Test 8B
Sequence	ArcMap software	Google Earth image	Test model Revit Architecture® with and without coordinates	Test model 20' x 20' Revit Architecture®	Test model Revit Architecture®	Test model Revit Architecture®
	KML file	KML file	IFC file export	IFC file export	IFC file export	IFC file export
	Revit Architecture®	Revit Architecture®	ArcScene software – quick import	Notepad binary code modification	ArcMap software-editor – move building	ArcMap software-editor – scale button
	Globe Link import	Globe Link import		Nemetschek®	ArcScene	ArcScene software – building straight line
				ArcMap software		

CHAPTER 5
ANALYSIS OF RESULTS

Tests 1A and 1B: ArcScene Software and KML Files

The two attempts made to import KML files into ArcScene software were both unsuccessful. Both imports resulted in the placemark layer being assigned Z values without a field in the attribute table that had a quantitative value. Because there was not a quantitative value, there was not a starting point to base the extrusion on. ArcScene software has the capacity to export 2D KML files, but the capacity to view 3D KML files is not available.

The geo database created by the quick import option lost a significant amount of information in the file conversion. All of the data that was stored in the KML / KMZ format was compressed into a series of objects in the placemark attribute table.

Test 2: KML to Shape file Conversion

The KML to shape file converter provided by ESRI is not applicable for the software being used in this research. The most applicable and current KML converter for the software used in this research was the data interoperability function found in ArcToolbox software.

Test 3: KML Custom Formats Converter

The geo database created by the custom formats KML converter provides column headings that are more detailed, but the supporting data was null, providing no supporting data to the attribute table. The information in the attribute table was the most valuable component of GIS. Thus, if the converter creating the database was absent from data then the software was not performing correctly.

When the geo database created by the custom formats converter was loaded into ArcGlobe software the resulting placemark indicated that the only information that was transferred, was the latitude and longitude of the building. The features of the building were lost in the conversion of the KML file to the geo database.

The custom formats KML converter involves multiple steps. The benefit received from employing the custom converter was not equivalent to the time spent going through the process of creating a custom format converter. The custom format converter is not recommended as an option to create 3D KML files in ArcGIS® software.

Series Four Test: KML to ArcGlobe Software

ArcGlobe software can be used to display KML files and shape files, as they both are able to be directly imported into the software. The software is a great source for disaster management officials to view the interior of the building and remove layers. The building is accurately depicted with surrounding topology, but the imagery presently available is so low in quality that there is not much benefit. The end user would have to add their imagery for the software to be beneficial with the surrounding topology. The software is limited for the use of cartography, as it does not create maps similar to ArcMap software.

Tests 5A, 5B and 5C: Autodesk® Revit® Extensions

Globe Link: Exporting KML Files

When the building is exported to Google Earth it is placed in an arbitrary location, unless the shared coordinates are assigned in Autodesk® Revit Architecture® software prior to export. The geometry of the building does not stay consistent with the geometry that was modeled. The skewed geometry does not make exporting Autodesk® Revit Architecture® software files directly to KML files the premium choice, because

Autodesk® Navisworks® software exports KML files that are true to the original geometry.

Globe Link: Importing KML File to Autodesk® Revit Architecture® Software

The shape files that were used to create the Gainesville.mxd map contain supporting data that can be queried. The map easily converts to a KML, and the KML file loads directly into Google Earth or into Globe link. Once the file is converted to a KML it loses the capacity to be queried, as the file would have been converted to place marks, images, and polygons. The file can be imported into Globe link which allows the building to be viewed with surrounding topological elements and in different orientations as selected by the user. When the KML file is imported into Revit Architecture software the resolution of the polylines seems to break down. The building is again arbitrarily placed on the map, unless coordinates are assigned.

Tests 6 A and 6B: Exporting IFC to ArcScene™ Software

The process of exporting the demo_project.rvt as an IFC 2x3 file from Revit Architecture software, and converting the IFC 2x3 to a geo database in ArcScene software has both positive aspects and negative aspects. The geometry of the IFC model imported into ArcScene software remained clear, but the level of detail was diminished. The components of the building, such as the doors and the windows, were not clearly represented. The doors were represented as an outline and the full door was not depicted in the building that was displayed in ArcScene software (see Figure 5-1). The windows on one side of the building were not all represented in the model, as shown in Figure 5-1 the two windows on the bottom row of windows and one window on the top row of windows is not visible. The symbology of the window was changed, but the visibility of the absent windows was not enhanced. This is a flaw in the conversion,

but depending on the use of the model the absence of the window visibility may not prevent the model from being effectively used.

Using the model for the purpose of query may involve manipulation to be effective. In the original conversion, the attributes of the walls were all combined, meaning that all of the interior walls and all exterior walls were placed in the same attribute table and within the same layer. The combination of the exterior walls and interior walls into the same attribute table does not allow for easy manipulation of the data by the end user. If the layer of the walls is turned off then all of the walls are turned off, including both the interior and the exterior wall layers. If a user needs to have full view of the building, and the capacity to turn different regions of the building on and off, this would not be possible unless the data is modified. A solution to this problem is to select all of the interior walls by attribute and export it to its own layer; then select the exterior walls by attribute and export this data to an individual layer. Creating two new layers allows the user to turn them on and off and view the model in greater detail.

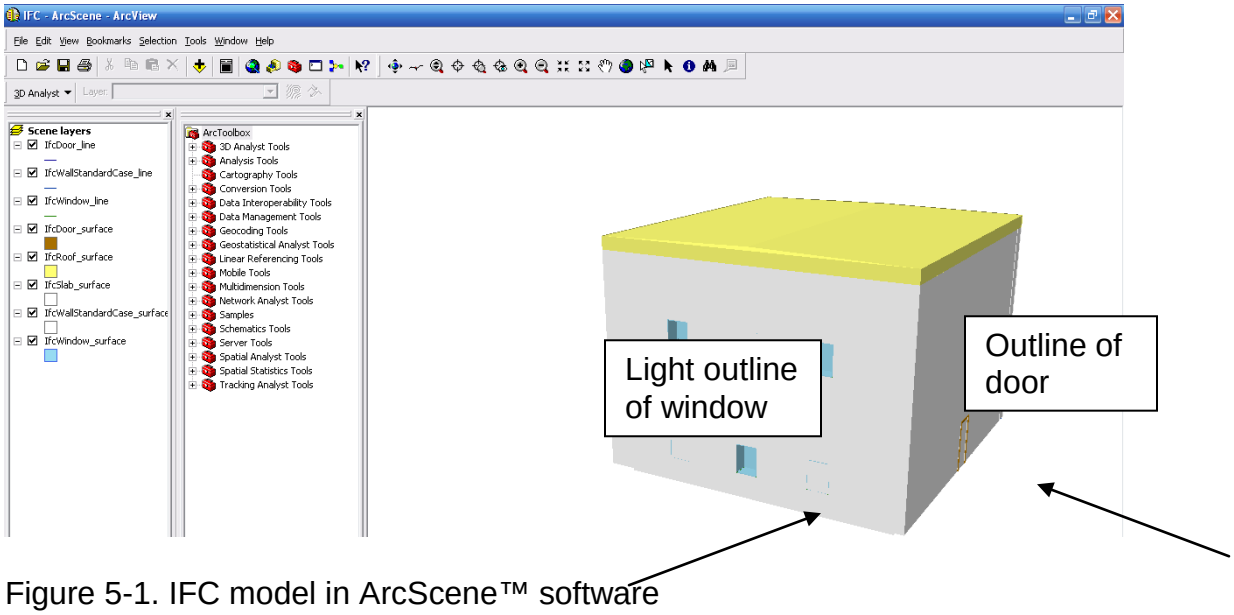


Figure 5-1. IFC model in ArcScene™ software

It can be concluded that the IFC 2x3 export is the not the appropriate IFC version to be utilized when exporting IFC data from Autodesk Revit Architecture software and importing it into ESRI® software. The general geometry of the building remains in place but the dimensions of the building are grossly over scaled and the coordinates of the building are not placed correctly even when the shared coordinates are assigned in Revit Architecture software.

Test 7: Model Coordinates and Model Scale

When the IFC model is converted to a geo database, objects are placed by a combination of elements. First, latitude and longitude are used to establish the geographic reference of the object. Next, the IFC code lines that contain the words Cartesian point for that object are used to place the object, and each object has a mid - point of reference that is used to place the object. The observations made in the IFC viewer and ArcMap software indicated that ArcMap software recognizes IFC code lines that are spelled out as Cartesian Points, but that the data interoperability converter is not smart enough to recognize the units of the IFC model.

Coordinates

The methodology determined that the IFCSite code line of the IFC model was not used to place the building, even though the coordinates were the northeast coordinates of the building. A 20’ x 20’ box was drawn in Autodesk® Revit Architecture® software, exported as an IFC, and converted into a geo database.

The information in the 20’ x 20’ IFC box determined that the ESRI® software recognizes code lines that have Cartesian point information. The building information is placed according to Cartesian points for each object, instead of placing the building as a whole site which is found on the IFCSite code line. The latitude and the longitude of

each IFC object can be overwritten manually in the notepad, and the change is accepted when the IFC file is converted into a geo database. However, this is not a suitable solution for a file that has multiple code lines of supporting information. It is useful if a slight modification is to be made to the IFC file. The error in file conversion seems to rest within ESRI® software data interoperability converter, thus there should be an option that allows for the geographic location to be established.

Model Scale

The unit information is found on code lines 15, 16, and 17 of the IFC model. Revit Architecture software allows for files to be measured in both imperial and metric units. When the scale in Revit Architecture software is changed to metric or imperial, then the units and scale change accordingly in the IFC viewer. The data interoperability converter only converted into decimal degrees, thus an option should be installed that prompts the user to specify units, as the data interoperability converter ignores code lines 15 thru 17.

Tests 8A and 8B: Adjusting Coordinates and Scale in GIS

Adjusting the coordinates within ESRI® software is an easily executed task in ArcMap software. Adjusting the scale in ArcMap software is also an easy task to complete, but the changes made do not visually display correctly. The building scale starts at a very large scale with each wall ranging from 14 to 16 million feet. As the building is scaled down to its original dimensions a vertical straight line is created. The dimensions of the building are being compressed, or are approaching the number zero.

Summary of Results

The series of tests preformed produced varying results, none of the results produced were effective. All of the results contained an element that could be

improved. Neither of the file extensions used in this research provided a complete means to meet the requirements outlined in the literature review. Although each file extension and the software package that it was used with did offer solutions to a few of the motivations for this research.

KML files created in Naviworks and exported to ArcGlobe software provide disaster management teams the opportunity to turn layers on and off, which provides visibility to the interior of the building. Loading map information created in ArcMap software into ArcGlobe software allows developers and city planners to gather information about the surrounding environment and the building in one place. Creating map information in ArcMap software and loading it into ArcGlobe is a time-consuming process. Therefore, for a snap shot of how a building will assimilate into a proposed environment loading the building into Google Earth is a faster solution.

IFC files provide the best solution for displaying a 3D building with its surrounding topology. IFC files can be viewed in 3D in ArcScene software and shape files can be loaded. However, the geo-referencing and the spatial referencing of the model in ArcScene® is not accurate. The spatial reference of the model can easily be adjusted, but the geo-reference adjustment do not provide an accurately scaled model. For IFC models to be useful in ArcScene software the converter used to convert the file must be able to read the scale of the original file.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Introduction

Interoperability between BIM and GIS software allows for data between the building and the surrounding topology to be transferred and the data to be visualized and analyzed. Visualization and analysis allows users during pre development, construction, and during the building life cycle to make informed decisions about the impact that the building has on the built environment. There are unbounded benefits and opportunities that result from BIM and GIS interoperability.

Unfortunately, the software packages used in this research for BIM and GIS interoperability are convoluted and the necessary steps are not clearly defined. The end result does not provide an accurate depiction of the original test model. The results are also limited from the perspective of disaster management. This research explored KML and IFC file extension, and each file extension proved to have limitation and an advantage.

KML

Conclusions

Files created in Revit Architecture maintained the original file integrity when exported to Navisworks. 3D KML files must be created within Navisworks. Navisworks is the optimal software package to use when creating 3D KML files because it maintained the geometry of the building and established the coordinates of the building. KML files by direct export from Revit Architecture software Globe Link extension returned unsatisfactory results, as the geometry of the building was distorted. The preferred method found in this research for exporting BIM KML files is Navisworks.

KML files can be viewed in either Google Earth or ArcGlobe software, depending on the end users needs. ArcGlobe software presently provides the most benefit for disaster management, as it allows different layers of the building to be turned on and off and the interior of the building to be viewed. Additionally, each object can be turned on and off within the layer. For a building to be viewed with its surrounding topology information about the surrounding topology needs to be loaded as layers into ArcGlobe software. Supporting information that would be beneficial in ArcGlobe software includes utility networks, roads, or demographical information. Loading supporting information into ArcGlobe software makes more information accessible to the users for query and evaluation. Supporting information coupled with the 3D KML files allows a user to access information that can be useful in disaster management.

Utilizing ArcGlobe software for city planning would require BIM models of all of the surrounding buildings and clear layer imagery. Creating retroactive BIM models for an entire neighborhood is an arduous task that is not likely to occur. Therefore, ArcGlobe software provides the most benefit when utilized with Navisworks KML files for the purpose of disaster management viewing or planning.

KML files viewed in Google Earth provide a concise and easily assessable opportunity to view the building in its built environment. Information about the surrounding neighborhood is captured in Google Earth and provides information to developers and planners as to how the building will assimilate into the existing built environment. Achieving maximum success for importing KML files in Google Earth would allow 3D KML files of the surrounding buildings to be created and loaded into Google Earth.

Future Research

Future research within KML files is best explored within ArcGlobe software. Visualization of the surrounding topology is presently very low within the software and the resolution of the imagery should be improved. Maps created in ArcMap software contain masses of information. Maps created in ArcMap software must be loaded into ArcGlobe software. Creating maps in ArcMap software and then loading them into ArcGlobe software is a time-consuming process. Enabling ArcGlobe software to have the same map and database capabilities as ArcMap would be an enhancement to ArcGlobe and a great future research topic.

IFC

Conclusions

IFC models are easily exported from of Revit Architecture software and the data interoperability extension in ESRI® software allows the file to be converted in ESRI® software. However, the IFC file is not geo referenced or spatially referenced upon import, and additional steps must be taken to achieve spatial and geo-referencing. Spatially referencing the model can be accomplished by moving the model to the appropriate x y coordinates. The geo-referencing of the building can also be adjusted. Due to the large size of the scale used to import the original model the building becomes a straight vertical line when the scale is adjusted down. The conclusion is that the building's coordinates are approaching an x y of zero. The absence of an IFC model that is capable of being drawn true to original scale in ArcScene software prevents IFC file formats from being a functional solution for integrating BIM and GIS.

Future Research

The current options for exporting IFC are 2x2, IFC 2x3, and IFC BCA ePlan. IFC 2x3G was developed to support geo- referencing and spatial referencing needs that can-not be accomplished in IFC 2x2 and IFC 2x3. IFC 2x3G is being incorporated into IFC 2x4. IFC 2x4 has not yet been released therefore, when exporting from Revit Architecture software into IFC the IFC 2x4 is not an option. IFC 2x4 is set for release in April 2010 at the buildingSmart™ alliance summit in Seoul, Korea (Liebich 2009). For IFC models to be truly useful in ArcGIS software the IFC software needs to be developed to accommodate geo referencing and spatial concerns or ArcGIS software needs to be developed to allow the models to be scaled and coordinates established when it is converted using the data interoperability extension. IFC 2x4 is a promising option that will allow geo referencing of buildings. If developers accept and incorporate IFC 2x4, then exploring the true interoperability nature of IFC 2x4 would be a great future research opportunity.

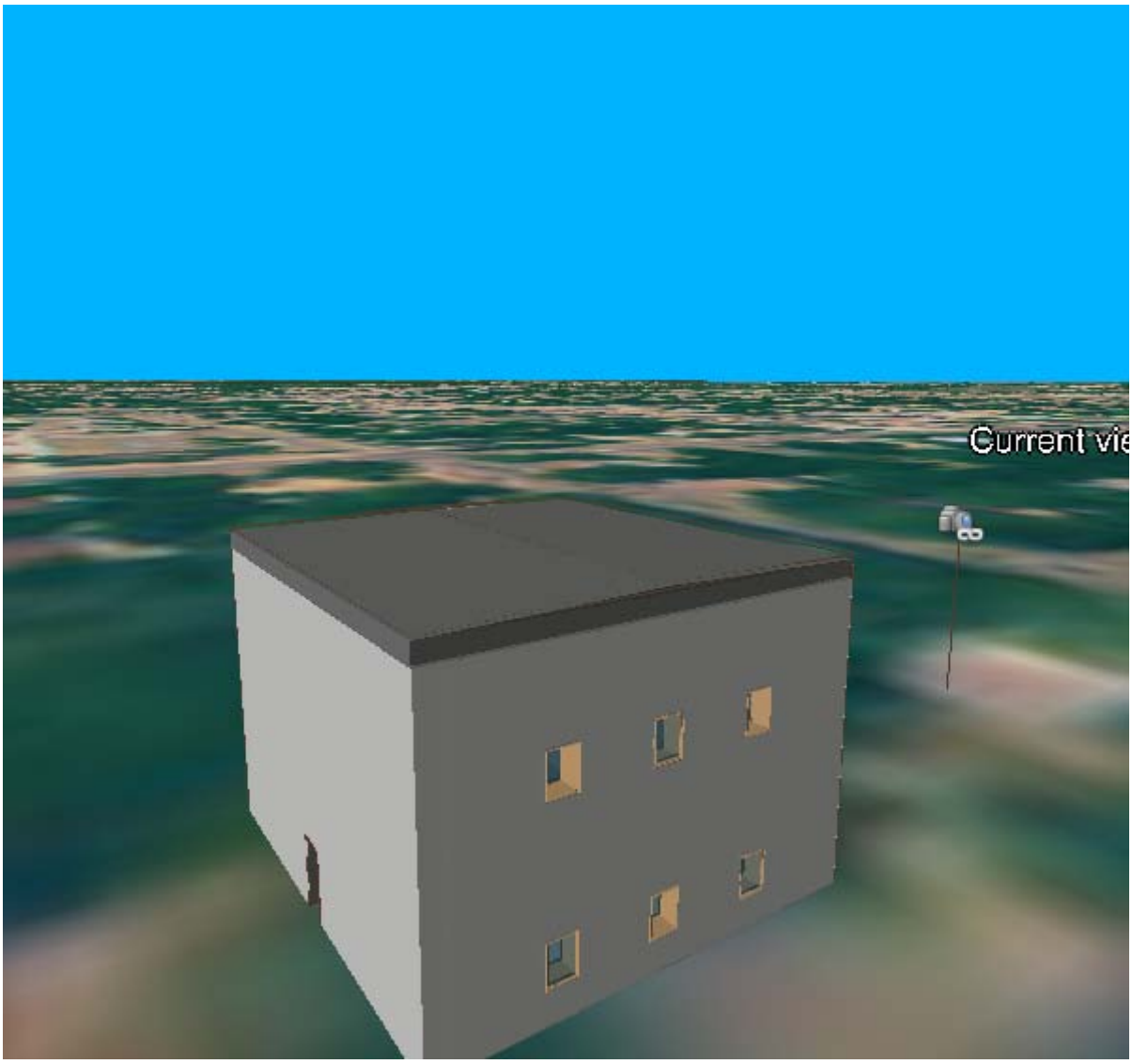
APPENDIX A
CUSTOM FORMATS STEPS

Step	Instruction	Associated Figure
1	Create a new custom format using KML as source format. This can be done using the Quick Import Tool or Adding an Interoperability Connection	
	a. When opening the Formats Gallery, at the bottom of the dialog box, click New. This will launch the Create Custom Format Wizard. Click Next	
	b. Select the Source Format (KML), click Next.	
	c. Load the KML data. Click Next. (You may need the change the file type to KMZ instead of KML.)	
	d. Expose Parameters dialog: You can Select All, or choose which parameters you want to expose. Click Next.	
	e. Give a Short Name and Description of the Custom Format. Then click Next.	
	f. Click Finish. This will Launch Workbench.	
2	Once in Workbench, open Feature Type Attributes for Source Data. (Placemarks) Click "…"	Figure 4-10
3	On the Format Attributes tab, select all attributes to enable them/make them visible. (or you can pick and choose only those you want to expose). The attributes that will convert over are as follows.	Figure 4-11
	* kml_style_url (Basic, Intermediate, Advanced)	
	* kml_parent (Levels)	
	* kml_name (Name of the Placemarkers)	
	* kml_id (placemarker identification number)	
4	Click OK. All the attributes will now be visible for the source KML dataset.	
5	Right-click the destination and choose the context menu option to "Copy Attributes from Feature Type" and then choose the Source Placemarks from the list of feature types in the pull down.	

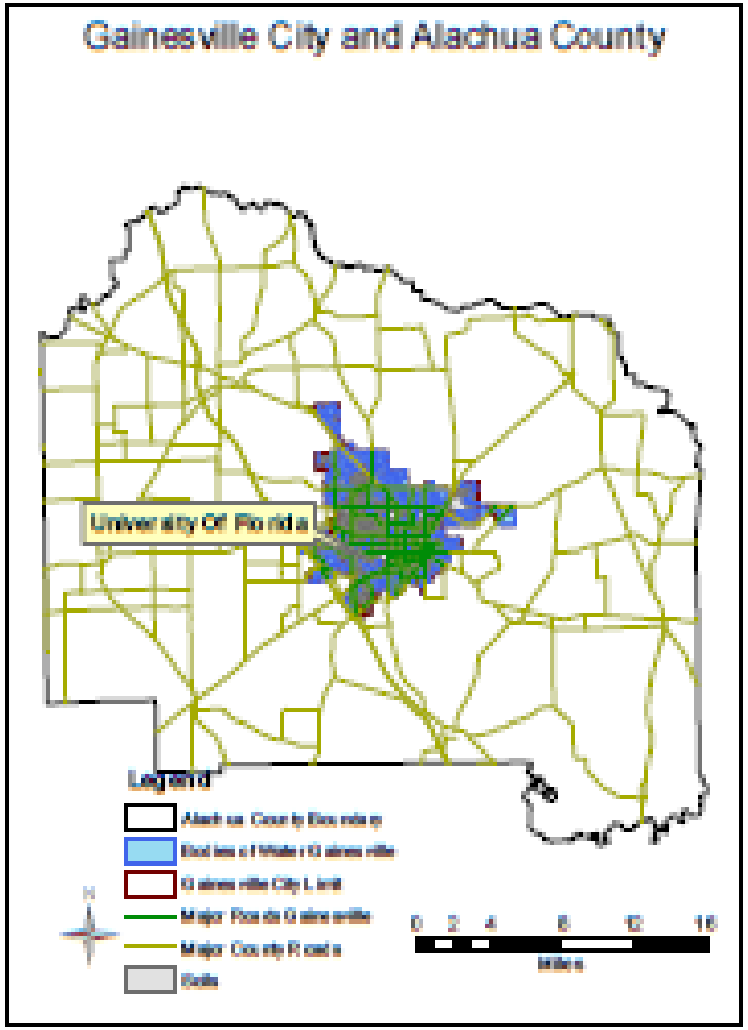
6	Save the custom format by clicking the Save button.	
7	Run Quick Import using your new format as the reader and the same doc.kml file input for source.	
8	View the results in the attribute table either using ArcCatalog or in ArcMap by adding the PlaceMarkers.	

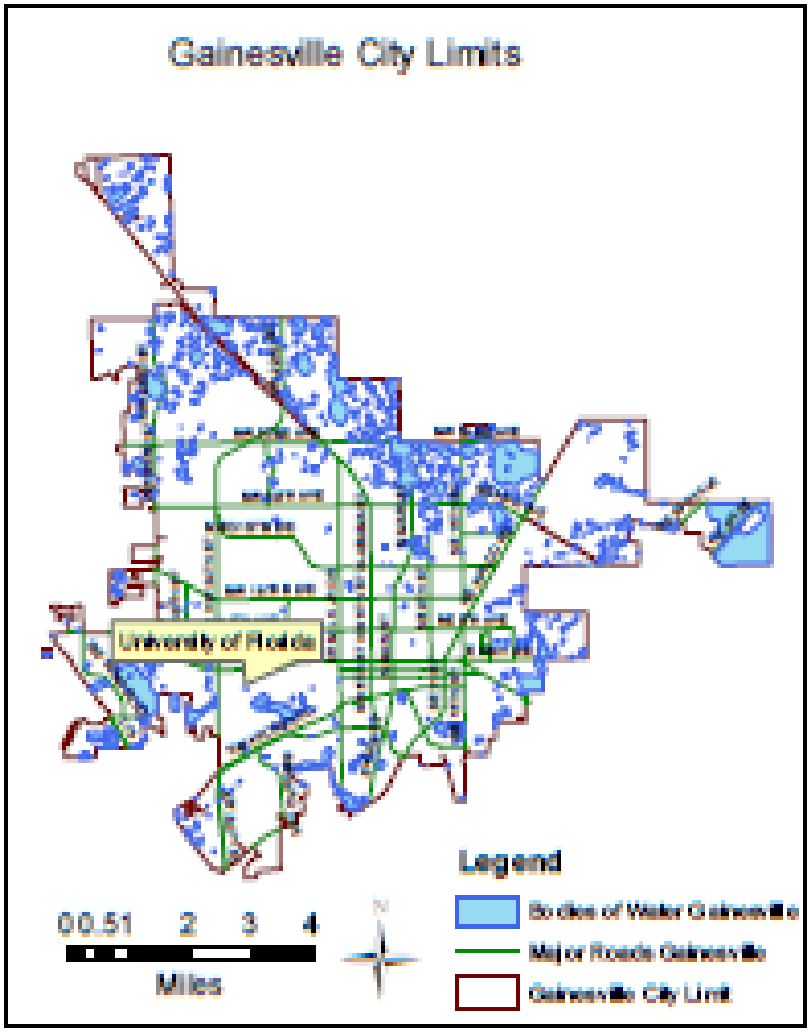
Carnes 2009.

APPENDIX B
ARC GLOBE™ IMAGE



APPENDIX C
ALACHUA COUNTY AND GAINESVILLE CITY LIMITS


Gainesville City and Alachua County
University Of Florida
Legend
0 2 4 8 12 16
Miles


Gainesville City Limits
University of Florida
Legend
0 0.5 1 2 3 4
Miles

FGDL 2010.

APPENDIX D
20’X 20’ IFC FILE

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('IFC2X_PLATFORM'),'2;1');
FILE_NAME('C:\\Documents and Settings\\Lacinda Cheney\\My Documents\\Fall
09\\20x20.ifc','2010-01-29T01:52:14',(''),(''),'Revit Architecture 2009 -
1.0','20080321_1900','');
FILE_SCHEMA(('IFC2X3'));
ENDSEC;
DATA;
#1=IFCORGANIZATION($,'Revit Architecture 2009',$,$,$);
#2=IFCAPPLICATION(#1,'2009','Revit Architecture 2009','Revit');
#3=IFCCARTESIANPOINT((0.,0.,0.));
#4=IFCCARTESIANPOINT((0.,0.));
#5=IFCDIRECTION((1.,0.,0.));
#6=IFCDIRECTION((-1.,0.,0.));
#7=IFCDIRECTION((0.,1.,0.));
#8=IFCDIRECTION((0.,-1.,0.));
#9=IFCDIRECTION((0.,0.,1.));
#10=IFCDIRECTION((0.,0.,-1.));
#11=IFCDIRECTION((1.,0.));
#12=IFCDIRECTION((-1.,0.));
#13=IFCDIRECTION((0.,1.));
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#14=IFCDIRECTION((0.,-1.));
#15=IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#16=IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#17=IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
#18=IFCDIMENSIONALEXPONENTS(1,0,0,0,0,0,0);
#19=IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.3048),#15);
#20=IFCCONVERSIONBASEDUNIT(#18,.LENGTHUNIT.,'FOOT',#19);
#21=IFCDIMENSIONALEXPONENTS(2,0,0,0,0,0,0);
#22=IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.09290304000000001),#16
);
#23=IFCCONVERSIONBASEDUNIT(#21,.AREAUNIT.,'SQUARE FOOT',#22);
#24=IFCDIMENSIONALEXPONENTS(3,0,0,0,0,0,0);
#25=IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.028316846592),#17);
#26=IFCCONVERSIONBASEDUNIT(#24,.VOLUMEUNIT.,'CUBIC FOOT',#25);
#27=IFCSIUNIT(*,.PLANEANGLEUNIT.,$,.RADIAN.);
#28=IFCDIMENSIONALEXPONENTS(0,0,0,0,0,0,0);
#29=IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.01745329251994328),#27
);
#30=IFCCONVERSIONBASEDUNIT(#28,.PLANEANGLEUNIT.,'DEGREE',#29);
#31=IFCSIUNIT(*,.TIMEUNIT.,$,.SECOND.);
#32=IFCUNITASSIGNMENT((#20,#23,#26,#30,#31));
#33=IFCAXIS2PLACEMENT3D(#3,$,$);
#34=IFCLOCALPLACEMENT($,#33);
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#35=IFCAXIS2PLACEMENT3D(#3,$,$);

#36=IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,1.E-009,#35,$);

#37=IFCGEOMETRICREPRESENTATIONCONTEXT($,'Plan',3,1.E-009,#35,$);

#38=IFCGEOMETRICREPRESENTATIONSUBCONTEXT($,'Plan',*,*,*,*,#37,0.01,
.PLAN_VIEW.,$);

#39=IFCPERSON($,$,'user',$,$,$,$,$);

#40=IFCORGANIZATION($,'','',$,$);

#41=IFCPERSONANDORGANIZATION(#39,#40,$);

#42=IFCOWNERHISTORY(#41,#2,$,.NOCHANGE.,$,$,$,0);

#44=IFCPOSTALADDRESS($,$,$,$,('Enter address
here'),$,'Boston','','MA\X\0D');

#45=IFCBUILDING('3qrECqy_5BVhNsX2i87eic',#42,$,$,$,#34,$,$,.ELEMENT.,$,$
,#44);

#46=IFCAXIS2PLACEMENT3D(#3,$,$);

#47=IFCLOCALPLACEMENT(#34,#46);

#48=IFCBUILDINGSTOREY('2JF4e6axWHqu3u0C1FZlmi',#42,'Level
1',$,$,#47,$,$,.ELEMENT.,0.);

#49=IFCCARTESIANPOINT((0.,0.,10.));

#50=IFCAXIS2PLACEMENT3D(#49,$,$);

#53=IFCCARTESIANPOINT((-47.13844968946292,33.83070070976168,0.));

#54=IFCAXIS2PLACEMENT3D(#53,$,$);

#55=IFCLOCALPLACEMENT(#47,#54);

#56=IFCCARTESIANPOINT((40.66666666666664,0.));

#57=IFCPOLYLINE((#4,#56));

#58=IFCSHAPEREPRESENTATION(#36,'Axis','Curve2D',(#57));

#59=IFCCARTESIANPOINT((10.33333333333332,0.));

#60=IFCAXIS2PLACEMENT2D(#59,#12);

#61=IFCRECTANGLEPROFILEDEF(.AREA.,$,#60,40.66666666666664,0.666666 6666666714);

#62=IFCAXIS2PLACEMENT3D(#3,$,$);

#63=IFCEXTRUDEDAREASOLID(#61,#62,#9,9.999999999998435);

#64=IFCCOLOURRGB($,0.5019607843137255,0.5019607843137255,0.5019607 843137255);

#65=IFCSURFACESTYLERENDERING(#64,0.,$,$,$,$,IFCNORMALISEDRATIO MEASURE(0.00390625),IFCSPECULAREXPONENT(10.),.NOTDEFINED.);

#66=IFCSURFACESTYLE('Default Wall',.BOTH.,(#65));

#67=IFCPRESENTATIONSTYLEASSIGNMENT((#66));

#68=IFCSTYLEDITEM(#63,(#67),$);

#69=IFCSHAPEREPRESENTATION(#36,'Body','SweptSolid',(#63));

#70=IFCPRODUCTDEFINITIONSHAPE($,$,(#58,#69));

#71=IFCWALLSTANDARDCASE('2H2oNAxmT66uRlRu1ahU_N',#42,'Basic Wall:Generic - 8":137427',$,'Basic Wall:Generic - 8":249',#55,#70,'137427');

#72=IFCPROPERTYSINGLEVALUE('Reference',$,IFCLABEL('Basic Wall:Generic - 8"'),$);

#73=IFCPROPERTYSINGLEVALUE('LoadBearing',$,IFCBOOLEAN(.F.),$);

#74=IFCPROPERTYSINGLEVALUE('ExtendToStructure',$,IFCBOOLEAN(.F.),$);

#75=IFCPROPERTYSINGLEVALUE('IsExternal',$,IFCBOOLEAN(.T.),$);

#76=IFCPROPERTYSET('1an6WrGZD35vW4wqIFyC6b',#42,'Pset_WallCommon',$,(#72,#73,#74,#75));

#77=IFCRELDEFINESBYPROPERTIES('2W_nOIhv5FbOGJTQffNpdy',#42,$,$,(#71),#76);

#78=IFCPROPERTYSINGLEVALUE('Location Line',$,IFCINTEGER(0),$);

#79=IFCPROPERTYSINGLEVALUE('Base Offset',$,IFCLENGTHMEASURE(0.),$);

#80=IFCPROPERTYSINGLEVALUE('Base is Attached',$,IFCBOOLEAN(.F.),$);

#81=IFCPROPERTYSINGLEVALUE('Base Extension Distance',$,IFCLENGTHMEASURE(0.),$);

#82=IFCPROPERTYSINGLEVALUE('Structural Usage',$,IFCINTEGER(0),$);

#83=IFCPROPERTYSINGLEVALUE('Unconnected Height',$,IFCLENGTHMEASURE(9.999999999998435),$);

#84=IFCPROPERTYSINGLEVALUE('Top Offset',$,IFCLENGTHMEASURE(0.),$);

#85=IFCPROPERTYSINGLEVALUE('Top is Attached',$,IFCBOOLEAN(.F.),$);

#86=IFCPROPERTYSINGLEVALUE('Top Extension Distance',$,IFCLENGTHMEASURE(0.),$);

#87=IFCPROPERTYSINGLEVALUE('Room Bounding',$,IFCBOOLEAN(.T.),$);

#88=IFCPROPERTYSINGLEVALUE('Length',$,IFCLENGTHMEASURE(20.00000000000001),$);

#89=IFCPROPERTYSINGLEVALUE('Area',$,IFCAREAMEASURE(206.6666666666341),$);

#90=IFCPROPERTYSINGLEVALUE('Volume',$,IFCVOLUMEMEASURE(137.777
7777777556),$);

#91=IFCPROPERTYSINGLEVALUE('Related to Mass',$,IFCBOOLEAN(.F.),$);

#92=IFCPROPERTYSINGLEVALUE('Coarse Scale Fill
Color',$,IFCINTEGER(0),$);

#93=IFCPROPERTYSINGLEVALUE('Wrapping at Inserts',$,IFCINTEGER(0),$);

#94=IFCPROPERTYSINGLEVALUE('Wrapping at Ends',$,IFCINTEGER(0),$);

#95=IFCPROPERTYSINGLEVALUE('Width',$,IFCLENGTHMEASURE(0.6666666
666666666),$);

#96=IFCPROPERTYSINGLEVALUE('Assembly Description',$,IFCLABEL('Exterior
Walls'),$);

#97=IFCPROPERTYSINGLEVALUE('Assembly Code',$,IFCLABEL('B2010'),$);

#98=IFCPROPERTYSINGLEVALUE('Wall Function',$,IFCINTEGER(1),$);

#99=IFCPROPERTYSET('1fGkSvnJ10w9iioD$2UPny',#42,'PSet_Revit_Constraint
s',$,(#78,#79,#80,#81,#83,#84,#85,#86,#87,#91));

#100=IFCRELDEFINESBYPROPERTIES('0hRn9j79L6RfTeMnOgM20N',#42,$,$,(
#71),#99);

#101=IFCPROPERTYSET('0p8EJTE1P3YQN6LPVPQ_Vp',#42,'PSet_Revit_Stru
ctural',$,(#82));

#102=IFCRELDEFINESBYPROPERTIES('3EUc4GKyj1X9FfPUZaQlrI',#42,$,$,(#7
1),#101);

#103=IFCPROPERTYSET('1iXD2_dz97neJmLT5U$b9e',#42,'PSet_Revit_Dimens
ions',$,(#88,#89,#90));

#104=IFCRELDEFINESBYPROPERTIES('0YDNDIXjzCM9Hquqadc9wD',#42,$,$,(#71),#103);

#105=IFCPROPERTYSET('3TzQ0T1NH9rgr_b7q8E2uc',#42,'PSet_Revit_Type_Construction',$,(#93,#94,#95,#98));

#106=IFCPROPERTYSET('2i1q_rzMLA1xBhBwSQ70JL',#42,'PSet_Revit_Type_Graphics',$,(#92));

#107=IFCPROPERTYSET('2q3Ptom0D9_gYnnnRz1PG$',#42,'PSet_Revit_Type_Identity Data',$,(#96,#97));

#108=IFCMATERIAL('Default Wall');

#109=IFCPRESENTATIONSTYLEASSIGNMENT((#66));

#110=IFCSTYLEDITEM($,(#109),$);

#111=IFCSTYLEDREPRESENTATION(#38,'Style','Material',(#110));

#112=IFCMATERIALDEFINITIONREPRESENTATION($,$,(#111),#108);

#113=IFCMATERIALLAYER(#108,0.6666666666666666,$);

#114=IFCMATERIALLAYERSET((#113),'Basic Wall:Generic - 8''');

#115=IFCMATERIALLAYERSETUSAGE(#114,.AXIS2.,.NEGATIVE.,0.3333333333333333);

#116=IFCCARTESIANPOINT((-26.80511635612962,33.49736737642829,0.));

#117=IFCAXIS2PLACEMENT3D(#116,#9,#8);

#118=IFCLOCALPLACEMENT(#47,#117);

#119=IFCCARTESIANPOINT((20.,0.));

#120=IFCPOLYLINE((#4,#119));

#121=IFCSHAPEREPRESENTATION(#36,'Axis','Curve2D',(#120));

#122=IFCCARTESIANPOINT((10.,0.));

#123=IFCAXIS2PLACEMENT2D(#122,#12);

#124=IFCRECTANGLEPROFILEDEF(.AREA.,$,#123,20.00000000000001,0.6666666666666643);

#125=IFCAXIS2PLACEMENT3D(#3,$,$);

#126=IFCEXTRUDEDAREASOLID(#124,#125,#9,9.999999999998435);

#127=IFCPRESENTATIONSTYLEASSIGNMENT((#66));

#128=IFCSTYLEDITEM(#126,(#127),$);

#129=IFCSHAPEREPRESENTATION(#36,'Body','SweptSolid',(#126));

#130=IFCPRODUCTDEFINITIONSHAPE($,$,(#121,#129));

#131=IFCWALLSTANDARDCASE('2H2oNAxmT66uRlRu1ahU_i',#42,'Basic Wall:Generic - 8":137448',$,'Basic Wall:Generic - 8":249',#118,#130,'137448');

#132=IFCPROPERTYSINGLEVALUE('Reference',$,IFCLABEL('Basic Wall:Generic - 8"'),$);

#133=IFCPROPERTYSET('2d47B27Ib2_fVm$Ss2jSi2',#42,'Pset_WallCommon',$,(#132,#73,#74,#75));

#134=IFCRELDEFINESBYPROPERTIES('0oR4ZS3MT48ewMJaS_enXn',#42,$,$,(#131),#133);

#135=IFCPROPERTYSINGLEVALUE('Unconnected Height',$,IFCLENGTHMEASURE(9.999999999998435),$);

#136=IFCPROPERTYSINGLEVALUE('Length',$,IFCLENGTHMEASURE(20.),$);

#137=IFCPROPERTYSINGLEVALUE('Area',$,IFCAREAMEASURE(199.9999999999688),$);

#138=IFCPROPERTYSINGLEVALUE('Volume',$,IFCVOLUMEMEASURE(133.33
33333333128),$);

#139=IFCPROPERTYSET('0yraNr34PE0wqafrVWVRr_',#42,'PSet_Revit_Constra
ints',$,(#78,#79,#80,#81,#135,#84,#85,#86,#87,#91));

#140=IFCRELDEFINESBYPROPERTIES('3gIr7fJEDFzgiMlRejQ9xn',#42,$,$,(#13
1),#139);

#141=IFCPROPERTYSET('3dORluwGz3zR0jUoBaHgni',#42,'PSet_Revit_Structur
al',$,(#82));

#142=IFCRELDEFINESBYPROPERTIES('3AEDYHoY9At89PgtU3nQmB',#42,$,$,
(#131),#141);

#143=IFCPROPERTYSET('0S8qPC9Cn7pOsAK4tBh$Ef',#42,'PSet_Revit_Dimen
sions',$,(#136,#137,#138));

#144=IFCRELDEFINESBYPROPERTIES('1I57jLLCj6WxTmTsOIg$F2',#42,$,$,(#
131),#143);

#145=IFCMATERIALLAYERSETUSAGE(#114,.AXIS2.,.NEGATIVE.,0.333333333
3333333);

#146=IFCCARTESIANPOINT((-27.13844968946295,13.83070070976161,0.));

#147=IFCAXIS2PLACEMENT3D(#146,#9,#6);

#148=IFCLOCALPLACEMENT(#47,#147);

#149=IFCCARTESIANPOINT((20.,-0.));

#150=IFCPOLYLINE((#4,#149));

#151=IFCSHAPEREPRESENTATION(#36,'Axis','Curve2D',(#150));

#152=IFCCARTESIANPOINT((10.,-0.));

#153=IFCAXIS2PLACEMENT2D(#152,#12);

#154=IFCRECTANGLEPROFILEDEF(.AREA.,$,#153,20.00000000000001,0.6666666666666679);

#155=IFCAXIS2PLACEMENT3D(#3,$,$);

#156=IFCEXTRUDEDAREASOLID(#154,#155,#9,9.999999999998435);

#157=IFCPRESENTATIONSTYLEASSIGNMENT((#66));

#158=IFCSTYLEDITEM(#156,(#157),$);

#159=IFCSHAPEREPRESENTATION(#36,'Body','SweptSolid',(#156));

#160=IFCPRODUCTDEFINITIONSHAPE($,$,(#151,#159));

#161=IFCWALLSTANDARDCASE('2H2oNAxmT66uRlRu1ahUv9',#42,'Basic Wall:Generic - 8":137485',$,'Basic Wall:Generic - 8":249',#148,#160,'137485');

#162=IFCPROPERTYSINGLEVALUE('Reference',$,IFCLABEL('Basic Wall:Generic - 8"'),$);

#163=IFCPROPERTYSET('3aZNY0vffEUu4PUyZbWezA',#42,'Pset_WallCommon',$,(#162,#73,#74,#75));

#164=IFCRELDEFINESBYPROPERTIES('2eIXwh3B15pR_QSrscWqNJ',#42,$,$,(#161),#163);

#165=IFCPROPERTYSINGLEVALUE('Unconnected Height',$,IFCLENGTHMEASURE(9.999999999998435),$);

#166=IFCPROPERTYSINGLEVALUE('Length',$,IFCLENGTHMEASURE(20.),$);

#167=IFCPROPERTYSINGLEVALUE('Area',$,IFCAREAMEASURE(199.9999999999687),$);

#168=IFCPROPERTYSINGLEVALUE('Volume',$,IFCVOLUMEMEASURE(133.33333333333123),$);

#169=IFCPROPERTYSET('2IwNqI2JL4Ygp1QfWHI5AC',#42,'PSet_Revit_Constraints',$,(#78,#79,#80,#81,#165,#84,#85,#86,#87,#91));

#170=IFCRELDEFINESBYPROPERTIES('3PSmtc9Q90fQB$AFgwa9Wl',#42,$,$,(#161),#169);

#171=IFCPROPERTYSET('2hEQLEOwH2EBmKwLGhYg47',#42,'PSet_Revit_Structural',$,(#82));

#172=IFCRELDEFINESBYPROPERTIES('0o5cnAj$LFafGQDz5JSQuH',#42,$,$,(#161),#171);

#173=IFCPROPERTYSET('1adNrjLLzBEejPb1AbVyC2',#42,'PSet_Revit_Dimensions',$,(#166,#167,#168));

#174=IFCRELDEFINESBYPROPERTIES('2wsfTDXZP6xwaHR9IaNv$l',#42,$,$,(#161),#173);

#175=IFCMATERIALLAYERSETUSAGE(#114,.AXIS2.,.NEGATIVE.,0.3333333333333333);

#176=IFCCARTESIANPOINT((-46.80511635612962,14.16403404309501,0.));

#177=IFCAXIS2PLACEMENT3D(#176,#9,#7);

#178=IFCLOCALPLACEMENT(#47,#177);

#179=IFCCARTESIANPOINT((19.33333333333334,0.));

#180=IFCPOLYLINE((#4,#179));

#181=IFCSHAPEREPRESENTATION(#36,'Axis','Curve2D',(#180));

#182=IFCCARTESIANPOINT((9.666666666666671,0.));

#183=IFCAXIS2PLACEMENT2D(#182,#12);

#184=IFCRECTANGLEPROFILEDEF(.AREA.,$,#183,19.33333333333334,0.6666666666666714);

#185=IFCAXIS2PLACEMENT3D(#3,$,$);

#186=IFCEXTRUDEDAREASOLID(#184,#185,#9,9.999999999998435);

#187=IFCPRESENTATIONSTYLEASSIGNMENT((#66));

#188=IFCSTYLEDITEM(#186,(#187),$);

#189=IFCSHAPEREPRESENTATION(#36,'Body','SweptSolid',(#186));

#190=IFCPRODUCTDEFINITIONSHAPE($,$,(#181,#189));

#191=IFCWALLSTANDARDCASE('2H2oNAxmT66uRlRu1ahUve',#42,'Basic Wall:Generic - 8":137516',$,'Basic Wall:Generic - 8":249',#178,#190,'137516');

#192=IFCPROPERTYSINGLEVALUE('Reference',$,IFCLABEL('Basic Wall:Generic - 8'''),$);

#193=IFCPROPERTYSET('2XuYxoea90WR9MGlSWVRl6',#42,'Pset_WallCommon',$,(#192,#73,#74,#75));

#194=IFCRELDEFINESBYPROPERTIES('3JaHrR2kf1ougsNFaIlmyd',#42,$,$,(#191),#193);

#195=IFCPROPERTYSINGLEVALUE('Unconnected Height',$,IFCLENGTHMEASURE(9.999999999998435),$);

#196=IFCPROPERTYSINGLEVALUE('Length',$,IFCLENGTHMEASURE(20.),$);

#197=IFCPROPERTYSINGLEVALUE('Area',$,IFCAREAMEASURE(193.3333333333032),$);

#198=IFCPROPERTYSINGLEVALUE('Volume',$,IFCVOLUMEMEASURE(128.88888888888685),$);

#199=IFCPROPERTYSET('3yUbtKMSr1JQZ1er0qsLKa',#42,'PSet_Revit_Constraints',$,(#78,#79,#80,#81,#195,#84,#85,#86,#87,#91));

#200=IFCRELDEFINESBYPROPERTIES('2giUJpJ492nQKXQ2kbSU4t',#42,$,$,(#191),#199);

#201=IFCPROPERTYSET('2fiwYvKLHEZOb5z$t8Wgvr',#42,'PSet_Revit_Structural',$,(#82));

#202=IFCRELDEFINESBYPROPERTIES('0ZB3etHDrDUfrmK9xC3R5L',#42,$,$,(#191),#201);

#203=IFCPROPERTYSET('35fkbv$S56JuFzAoeTdopn',#42,'PSet_Revit_Dimensions',$,(#196,#197,#198));

#204=IFCRELDEFINESBYPROPERTIES('1TJ$qrvC97MuZ8j1D6O23U',#42,$,$,(#191),#203);

#205=IFCMATERIALLAYERSETUSAGE(#114,.AXIS2.,.NEGATIVE.,0.3333333333333333);

#206=IFCAXIS2PLACEMENT3D(#3,$,$);

#207=IFCLOCALPLACEMENT($,#206);

#208=IFCSITE('3gcTIKHon7BAv3$1PCSTuV',#42,'Default',$,'',#207,$,$,.ELEMENT.,(42,12,46,800000),(-71,-1,-58,-800000),-0.,$,$);

#209=IFCRELAGGREGATES('05ItcHPqfCTu4bUSf9uCRn',#42,$,$,#43,(#208));

#210=IFCRELAGGREGATES('06qnawxAT1tQkPrrNIRKvM',#42,$,$,#208,(#45));

#211=IFCPROPERTYSINGLEVALUE('Name',$,IFCLABEL('Level 1'),$);

#212=IFCPROPERTYSINGLEVALUE('Elevation',$,IFCLENGTHMEASURE(0.),$);

#213=IFCPROPERTYSINGLEVALUE('Line Weight',$,IFCINTEGER(1),$);

#214=IFCPROPERTYSINGLEVALUE('Color',$,IFCINTEGER(0),$);

#215=IFCPROPERTYSINGLEVALUE('Elevation Base',$,IFCINTEGER(0),$);

#216=IFCPROPERTYSINGLEVALUE('Symbol at End 1 Default',$,IFCBOOLEAN(.F.),$);

#217=IFCPROPERTYSINGLEVALUE('Symbol at End 2 Default',$,IFCBOOLEAN(.T.),$);

#218=IFCPROPERTYSINGLEVALUE('Automatic Room Computation Height',$,IFCBOOLEAN(.T.),$);

#219=IFCPROPERTYSET('1IpL5w0Fr0cRQfFLXUv7FN',#42,'PSet_Revit_Identity Data',$,(#211));

#220=IFCRELDEFINESBYPROPERTIES('29VOs3MYL2vwFbraUpCHE0',#42,$,$,(#48),#219);

#221=IFCPROPERTYSET('2ixXG2dGn3D8cr4kHSiWHB',#42,'PSet_Revit_Constraints',$,(#212));

#222=IFCRELDEFINESBYPROPERTIES('2py$rQmAH3rfgECGDrW1xH',#42,$,$,(#48),#221);

#223=IFCPROPERTYSET('01iKIZ7_5969vDeIXVlqLu',#42,'PSet_Revit_Type_Graphics',$,(#213,#214,#216,#217));

#224=IFCPROPERTYSET('3PpLedq6v6muiUhjN545xf',#42,'PSet_Revit_Type_Constraints',$,(#215));

#225=IFCPROPERTYSET('2CsrzcrifFHvBySi0$HmpI',#42,'PSet_Revit_Type_Dimensions',$,(#218));

#226=IFCRELCONTAINEDINSPATIALSTRUCTURE('1q390c0ULC8vJcbURu8ETV',#42,$,$,(#71,#131,#161,#191),#48);

#227=IFCRELAGGREGATES('3Fu3354En6w8fWLnG_EFbg',#42,$,$,#45,(#48));

#228=IFCRELASSOCIATESMATERIAL('3u2kTuvS1B5hBaw04GKmuY',#42,$,$,(#71),#115);

#229=IFCRELASSOCIATESMATERIAL('3UX4ZYfqnA7wE6T3RelgWK',#42,$,$,(#131),#145);

#230=IFCRELASSOCIATESMATERIAL('0biLGTRHH7CQO_NzSWgmQO',#42,$,$,(#161),#175);

#231=IFCRELASSOCIATESMATERIAL('1MdT5Wfsj6283IbiNWSX2h',#42,$,$,(#191),#205);

#232=IFCRELDEFINESBYPROPERTIES('0YTZ8dzm5CUfIe5g9wN5DN',#42,$,$,(#48),#223);

#233=IFCRELDEFINESBYPROPERTIES('3ZeeK1hofCGwc_rYtBMIWI',#42,$,$,(#48),#224);

#234=IFCRELDEFINESBYPROPERTIES('1T21bbwifC8P$Y0C6Comv7',#42,$,$,(#48),#225);

#235=IFCRELDEFINESBYPROPERTIES('18LdBYvmLC0x67sw76inMO',#42,$,$,(#71,#131,#161,#191),#105);

#236=IFCRELDEFINESBYPROPERTIES('2dBWjrCn1CGuzCfOAURH8D',#42,$,$,(#71,#131,#161,#191),#106);

#237=IFCRELDEFINESBYPROPERTIES('325P2rFor639vntVmUMLIj',#42,$,$,(#71,#131,#161,#191),#107);

#238=IFCRELCONNECTSPATHELEMENTS('3R2nN9T2X6VPpWXjg1WoEh',#42,$,$,$,#71,#191,(),(),.ATEND.,.ATSTART.);

#239=IFCRELCONNECTSPATHELEMENTS('3G9OTwdXXEhObFo2qrMsUP',#42,$,$,$,#71,#131,(),(),.ATSTART.,.ATEND.);

#240=IFCRELCONNECTSPATHELEMENTS('3wDFMfqJzCsgFPbnNUQxkj',#42,$,$,$,#131,#161,(),(),.ATSTART.,.ATEND.);

#241=IFCRELCONNECTSPATHELEMENTS('0LHhq$ZGb6rwBLmGCKEj$v',#42,$,$,$,#161,#191,(),(),.ATSTART.,.ATEND.);

#242=IFCRELCONNECTSPATHELEMENTS('3tsXq7wwD3bOkIn54mpR$t',#42,$,$,$,#71,#191,(),(),.ATEND.,.ATSTART.);

#243=IFCPRESENTATIONLAYERASSIGNMENT('A-WALLMBM',$,(#58,#69,#121,#129,#151,#159,#181,#189),$);

#43=IFCPROJECT('1JfwhAht51Ywj4HrcgzM1$',#42,'C:\\Documents and Settings\\Lacinda Cheney\\My Documents\\Fall 09\\20x20.ifc',$,$,$,$,(#36,#37),#32);

ENDSEC;

END-ISO-10303-21;

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BIOGRAPHICAL SKETCH

Lacinda Cheney is from the mid-west and grew up in a small town outside of Kansas City, MO. She completed her degree in accounting from the University of Missouri – St. Louis. She worked for the Hines Corporation on the H&R Block Building project, which served as the catalyst for her return to graduate school. She enjoys spending time with her family, friends and dancing.