

Automated Site Data Acquisition for Effective Project Control

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A Thesis

In the Department of

Building, Civil, and Environmental Engineering

Presented in Partial Fulfillment of the Requirements

For the Degree of

Doctor of Philosophy (Building Engineering) at

Concordia University

Montreal, Quebec, Canada

December 2013

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SCHOOL OF GRADUATE STUDIES

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ABSTRACT

Automated Site Data Acquisition for Effective Project Control

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Tracking and control of construction projects depend primarily on the accuracy, frequency and time required to collect actual onsite data of construction operations that characterize the work progress. Earned Value Analysis (EVA) is being used for reporting work progress and for forecasting project status at completion and at any future time horizon. Critical to its reliable application is accurate and timely data for quantifying the budgeted cost of work performed. Automated site data acquisition has received considerable attention in recent years to circumvent the limitations of manual data collection. The limitations of existing models lie in their inability to measure the progress of different types of construction activities from inception to completion in near real-time.

The objective of this research is to study and analyze the characteristics of automated data acquisition technologies in construction. This thesis is carried out with a focus on automating the process of data collection and project control. An automated model is developed that integrates project visualization-information aspects, automated site data acquisition and earned value analysis. The developed model consists of two main frameworks; one is for data acquisition and the other for data analysis and processing. Data acquisition is carried out using the integrated automated data acquisition technologies embedded in the tablet PC used in this research as well as others, referred to here as independent, automated data acquisition technologies. The developed model makes full use of 4D BIM to provide visualization and pertinent information of activities in progress. The developed model embraces the human

factors to augment the visualization-information aspects, localization technologies and development of progress templates. The developed model demonstrated the significance of data fusion of a wide range of automated site data acquisition technologies and visualization-information technologies.

A prime focus is placed on extensive field studies and experimental work. Field studies on construction jobsite are conducted utilizing a wide range of technologies such as 3D Scanner, RFID and GPS. Extensive experimental work is conducted to develop deployment protocols for utilization of Ultra High Frequency (UHF) passive RFID in localization and material tracking. The field and lab work resulted in a number of observations, findings, and lessons learned for deployment of passive RFID in construction. The results presented in this study demonstrate the potential use of short range RFIDs in location estimation and material tracking in a cost-effective manner for indoor construction operations. The developed method for location identification and material tracking using RFID technology can be used to obtain information required for scalable, near-real-time decision-making and timely tracking of project status.

The developed methods and algorithms are implemented in prototype software. It consists of two computational frameworks; BIM+ and Control+. BIM+ is Two-Tier software, which utilizes an object-oriented BIM model. So, it can be used as an advanced tool for data acquisition through the user's tablet PC. Control+ is Three-Tier Web-Based software for processing the captured data from the tablet PC and independent automated data acquisition technologies. The developed model, methods, algorithms and software constitute a step ahead of current progress reporting applications and expand upon automated site data acquisition technologies and visualization-information technologies use in construction.

To my adorable mother, beloved family; Mona, Ahmed, Abdallah and Mohamed

ACKNOWLEDGMENT

All praise and thanks are due to Allah for giving me the patience and perseverance to successfully accomplish my Ph.D. study. This thesis is dedicated to my family for their endless support and encouragement throughout my life. Their unconditional love has been source of inspiration. I could never achieve this work without their endless encouragement and help.

I would like to express my sincere gratitude and thanks to many people who have helped me during my graduate studies at Concordia University. I am greatly thankful to my supervisor Dr. Osama Moselhi for his for his invaluable guidance and patience with me throughout my studies. It was a great honor to work under his supervision. I would like also to thank Dr. Tarek Zayed and Dr. Zhenhua Zhu for their help during my work.

I would like gratefully to acknowledge the support of Dr. Saiedeh N. Razavi, Dr. Adel Alshibani and Dr. Samir El-Omari for sharing their knowledge with me. Finally, I would like to thank all my colleagues in the Automation and Construction Laboratory. And special thanks to Sasan Golanraghi, Hani Alzraiee, Ibrahim Bakry, Ahmed Atef, Ahmed Eweda, Tushith Islam, Magdy Omar, Ramy Elfaizy, Fady Halim and Mohammed Gomma for their encouragement and assistance. Your friendship is irreplaceable. I feel so lucky to have you in my life. Many thanks to my friend Ashraf El Hakeem for his sincere support and help during the software programming part in this research.

TABLE OF CONTENTS

LIST OF FIGURES	x
LIST OF TABLES	xiv
Chapter 1: INTRODUCTION	1
1.1 <i>General</i>	1
1.2 <i>Research Motivation and Problem Statement</i>	2
1.3 <i>Objectives</i>	5
1.4 <i>Research Philosophy</i>	6
1.5 <i>Research Methodology</i>	7
1.6 <i>Thesis Organization</i>	10
Chapter 2: LITERATURE REVIEW.....	12
2.1 <i>General</i>	12
2.2 <i>Project Tracking and Control</i>	13
2.2.1 <i>Integrated Tracking and Control</i>	15
2.2.2 <i>Measuring Project Performance</i>	16
2.2.3 <i>Traditional Forecasting Methods</i>	17
2.2.4 <i>Simulation as Forecasting Tool</i>	19
2.3 <i>Automated Data Acquisition Technologies</i>	21
2.3.1 <i>Bar Code</i>	23
2.3.2 <i>Radio Frequency Identification (RFID)</i>	24
2.3.3 <i>Global positioning System (GPS)</i>	28
2.3.4 <i>Multimedia</i>	29
2.3.5 <i>Tablet Computers</i>	30
2.3.6 <i>3D Imaging and Photogrammetry</i>	31
2.3.7 <i>Other Types of Sensors</i>	34
2.4 <i>Localization</i>	35
2.4.1 <i>Signal Measurements</i>	37
2.4.2 <i>Localization Algorithms</i>	38
2.4.3 <i>Indoor Localization Technologies</i>	40
2.4.4 <i>RFID Indoor Localization</i>	42
2.5 <i>Data Visualization</i>	43
2.5.1 <i>Geographic Information System (GIS)</i>	44
2.5.2 <i>Building Information Modeling (BIM)</i>	45
2.6 <i>Summary and Identified Limitations</i>	48
Chapter 3: PROPOSED MODEL	50
3.1 <i>General</i>	50
3.2 <i>Proposed Model</i>	54
3.3 <i>Data Acquisition Framework</i>	58

3.3.1	Tablet PC Data Acquisition	58
3.3.1.1	Building 4D BIM	62
3.3.1.2	User Location Identification	66
3.3.1.3	Zone Configuration	76
3.3.1.4	Real Time Visualization	77
3.3.1.5	Tablet PC Database.....	81
3.4	<i>Data Analysis and Reporting Framework</i>	87
3.4.1	Performance Measurement Module	89
3.4.1.1	Material Localization and Tracking	89
3.4.1.2	Productivity and Quantity Measurement	96
3.4.2	Earned Value Analysis Module.....	119
3.4.3	Central Database.....	126
3.4.4	Reporting Module	130
3.5	<i>Summary</i>	130
Chapter 4: FIELD STUDIES		131
4.1	<i>General</i>	131
4.2	<i>Case Study</i>	132
4.3	<i>Preparations for Field Work</i>	134
4.4	<i>Independent Automated Data Acquisition Technologies</i>	137
4.4.1	3D Scanner	137
4.4.2	Fixed GPS.....	141
4.4.3	CCTV Camera.....	148
4.5	<i>Tablet PC Automated Data Acquisition Technologies</i>	149
4.5.1	Camera	151
4.5.2	Barcode	153
4.5.3	Mobile GPS.....	153
4.5.4	Mobile RFID.....	158
4.6	<i>Summary</i>	162
Chapter 5: EXPERIMENTAL STUDIES OF PASSIVE RFID INDOOR FOR LOCALIZATION		164
5.1	<i>General</i>	164
5.2	<i>Zone Identification Using K-NN Algorithm</i>	165
5.2.1	Field Study.....	167
5.2.1.1	Tag Deployment Topologies	167
5.2.1.2	Closeness of Passive Reference Tags	168
5.2.1.3	Stationary vs. Moving Reader Agent	170
5.2.1.4	Zone Configuration	171
5.2.1.5	Speed of Moving Reader	173
5.2.2	Laboratory Experiments.....	174
5.2.2.1	Closeness of Passive Reference Tags	174
5.2.2.2	Studies on RSSI	175
5.3	<i>Location Identification Using Two-Step Algorithm</i>	179
5.4	<i>Deployment Protocols Using Proximity Algorithm</i>	188
5.5	<i>Summary</i>	193

Chapter 6: COMPUTER IMPLEMENTATION	196
6.1 <i>General</i>	196
6.2 <i>Developed System</i>	196
6.2.1 System Platform	198
6.2.2 BIM+	203
6.2.3 Control+	233
6.3 <i>Summary</i>	256
Chapter 7: CONCLUSIONS AND FUTURE WORK.....	259
7.1 <i>Conclusions</i>	259
7.2 <i>Research Contribution</i>	260
7.3 <i>Limitations</i>	263
7.4 <i>Future Work</i>	264
References	266
Appendix A: Tracking Scraper-Pusher Fleet for Cut-Fill Earthmoving Operations	276
Appendix B: Central Database	278
Appendix C: Data Collection	290
Appendix D: Productivity of Earthmoving Operations in Planning	297
Appendix E: Computer Implementation.....	302

LIST OF FIGURES

Figure 1-1: Research methodology	9
Figure 2-1: Chapter 2 overview	13
Figure 2-2: Earned value method (Li, 2004)	16
Figure 2-3: self-learning model (Li et al., 2006)	19
Figure 2-4: 1D and 2D bar code (McCullouch and Lueprasert, 1994).....	23
Figure 2-5: RFID system components.....	26
Figure 2-6: Portal structure with 4 fixed RFID readers (Song et al, 2006)	28
Figure 2-7: 3D scan and 3D model object recognition (Bosche et al, 2009)	33
Figure 2-8: Switch limit main components (ABB, 2013)	35
Figure 2-9: (a) Trilateration (b) Angulation localization algorithm	38
Figure 3-1: Chapter 3 overview	50
Figure 3-2: Research vision	52
Figure 3-3: Developed Model	55
Figure 3-4: Data acquisition framework overview	59
Figure 3-5: Data acquisition framework architecture.....	60
Figure 3-6: Indoor data acquisition (Montaser and Moselhi, 2012 c).....	63
Figure 3-7: Linking the 3D BIM model to project schedule	64
Figure 3-8: The process of 4D BIM model visualization.....	65
Figure 3-9: GPS user location identification	67
Figure 3-10: RFID reader receives signals	69
Figure 3-11: The process of deploying RFID reference tags	70
Figure 3-12: User location identification using trilateration algorithm.....	71
Figure 3-13: User location identification using trilateration algorithm with imperfect path loss model	72
Figure 3-14: Trilateration algorithm (Montaser and Moselhi, 2013 a)	73
Figure 3-15: Proximity method concept.....	75
Figure 3-16: Proximity algorithm (Montaser and Moselhi, 2013 a)	75
Figure 3-17: Zone Configuration with time	76
Figure 3-18: Area plan and floor plan	77
Figure 3-19: Real time visualization ingredients.....	78
Figure 3-20: The process of real time visualization (part 1)	79
Figure 3-21: The process of real time visualization (part 2)	80
Figure 3-22: Tablet PC database entity relationship (ER) diagram.....	83
Figure 3-23: The process of capturing data using the tablet PC.....	86
Figure 3-24: Data analysis and reporting framework overview	87
Figure 3-25: Data analysis and reporting framework architecture	88
Figure 3-26: Diagrammatic sketch for material location identification	90
Figure 3-27: Material location identification using Proximity algorithm	91
Figure 3-28: Material location identification using Trilateration algorithm	92
Figure 3-29: Material localization and tracking sub-module	94
Figure 3-30: Estimating “Units Activities” percentage complete	95
Figure 3-31: Flowchart for the process of tracking earthmoving operation.....	98
Figure 3-32: Flowchart for the process of the captured data processing.....	99
Figure 3-33: GPS/GIS based tracking (Montaser et al., 2012).....	103
Figure 3-34: GPS captured data processing part 1	104
Figure 3-35: GPS captured data processing part 2	105

Figure 3-36: RFID gate based tracking (Montaser and Moselhi, 2012 b)	108
Figure 3-37: RFID captured data processing (Montaser and Moselhi, 2012 b)	110
Figure 3-38: Cycle time in GPS/GIS and RFID gate tracking method	111
Figure 3-39: RFID reader captured data with excavator	112
Figure 3-40: RFID reader captured data with loader	113
Figure 3-41: The change in control sensor captured data	114
Figure 3-42: RFID and control sensor data integration (Montaser and Moselhi, 2013 b)	114
Figure 3-43: RFID/control sensor captured data processing	116
Figure 3-44: RFID/Control Sensor method and GPS/GIS or RFID Gate method	117
Figure 3-45: The process of stochastically forecasting productivity	124
Figure 3-46: Specific purpose earthmoving operation DES model	125
Figure 3-47: Entity Relationship (ER) diagram for the central database	127
Figure 4-1: Chapter 4 overview	131
Figure 4-2: Genomics office building	132
Figure 4-3: Sample of project progress reports	133
Figure 4-4: Genomics building 3D BIM model (Montaser and Moselhi, 2012 a)	134
Figure 4-5: 4D BIM NavisWorks© model	136
Figure 4-6: RIEGL LPM 100 VHS LADAR	138
Figure 4-7: (a) GPS unit (b) Genomics building (Montaser et al., 2011)	141
Figure 4-8: GPS based daily productivity (Montaser et al., 2012)	143
Figure 4-9: Cycle time components PDFs	145
Figure 4-10: ExtendSim simulation model	145
Figure 4-11: Simulation results vs. upper and lower limit planned estimates	147
Figure 4-12: Sample of CCTV camera captured data	149
Figure 4-13: Sample of CCTV camera captured data	150
Figure 4-14: Sample of Indoor camera captured data	151
Figure 4-15: 4D BIM image vs. actual image for outdoor zone	152
Figure 4-16: 4D BIM image vs. actual image for indoor zone	152
Figure 4-17: Items with barcode inside Genomics building jobsite	153
Figure 4-18: GPS hardware and screen shot	155
Figure 4-19: Post-processed GPS data using GPS PathFinder software	156
Figure 4-20: User route during outdoor field experiment	158
Figure 4-21: RFID hardware	159
Figure 4-22: RFID reader screen shots	160
Figure 4-23: RFID data acquisition from reference tags and material tags	160
Figure 4-24: Different test beds setup and pictures	161
Figure 5-1: Chapter 5 overview	165
Figure 5-2: Two deployment topologies	168
Figure 5-3: On-site scenarios for tag closeness	169
Figure 5-4: Different scenarios for a stationary reader agent	170
Figure 5-5: Scenarios for different zone configurations	172
Figure 5-6: The trajectory of the moving target (reader)	173
Figure 5-7: Concordia university construction automation lab	174
Figure 5-8: Average RSSI vs. distance for four tags	177
Figure 5-9: Regression analysis	178
Figure 5-10: Two-step algorithm (Montaser and Moselhi, 2013a)	179
Figure 5-11: Test beds 1, 2 & 3 setup and site pictures Case Study I	181
Figure 5-12: Test beds 6 setup Case Study II	182
Figure 5-13: Localization error for both algorithms	183

Figure 5-14: Comparison between trilateration and proximity algorithm.....	184
Figure 5-15: Material tracking using trilateration and proximity algorithm	184
Figure 5-16: Box plot for each test beds results (Montaser and Moselhi, 2012 d)	185
Figure 5-17: Summary of statistical analysis results for user localization	186
Figure 5-18: Summary of statistical analysis results for material localization.....	187
Figure 5-19: CDF for estimated error (Montaser and Moselhi, 2013 a)	188
Figure 5-20: Test bed setup (Montaser et al., 2013).....	189
Figure 5-21: Errors observed under different durations in all test beds	191
Figure 5-22: Errors observed in the 9 different predefined locations.....	192
Figure 5-23: Errors observed in all test beds with different durations	192
Figure 5-24: Errors observed in all test beds due to metal proximity	193
Figure 5-25: Errors observed in all test beds due to the number of deployed tags.....	193
Figure 6-1: Chapter 6 overview.....	196
Figure 6-2: Developed system architecture	200
Figure 6-3: ER diagram for the designed Microsoft Access central database.....	202
Figure 6-4: BIM+ use-case diagram.....	205
Figure 6-5: Linking Microsoft Project file to BIM+ (sequence diagram).....	206
Figure 6-6: Linking Microsoft Project file to BIM+	208
Figure 6-7: Mapping 3D Revit objects to project activities (sequence diagram).....	209
Figure 6-8: Mapping 3D Revit objects to project activities (Part 1)	210
Figure 6-9: Mapping 3D Revit objects to project activities (part 2)	211
Figure 6-10: The added attribute “Group” to Revit object.....	212
Figure 6-11: Selected objects to create Group.....	213
Figure 6-12: Assigning MS Project activity to Group name	213
Figure 6-13: Show and hide activities options	214
Figure 6-14: Show specific activity.....	216
Figure 6-15: Show and hide activities manually	217
Figure 6-16: Show and hide activities by date (4D BIM)	219
Figure 6-17: Pictures from the generated 4D Revit visualization	220
Figure 6-18: Area plan vs. floor plan for the basement floor at Genomics building.....	221
Figure 6-19: Area plan for outdoor zones at Genomics building	222
Figure 6-20: C# .Net source code for the process of linking dividing activity to plans.....	223
Figure 6-21: Linking dividing activity to floor plan and area plan	224
Figure 6-22: Getting user zone automatically options.....	226
Figure 6-23: User indoor Location visualization and data acquisition.....	227
Figure 6-24: User outdoor location	229
Figure 6-25: User outdoor Location visualization and data acquisition.....	230
Figure 6-26: Selecting user location manually (Part 1).....	231
Figure 6-27: Selecting user location manually (Part 2).....	232
Figure 6-28: Control+ login page	235
Figure 6-29: Control+ project menu – Weather Conditions.....	236
Figure 6-30: Control+ resource menu	237
Figure 6-31: Truck+ system architecture	239
Figure 6-32: Truck+ sample of class diagram.....	240
Figure 6-33: Truck+ web page layout	241
Figure 6-34: Truck+ use-case diagram.....	242
Figure 6-35: User enters project number	243
Figure 6-36: GPS points layer	244
Figure 6-37: Earthmoving operation spatial boundaries sketches.....	246

Figure 6-38: Generated cycle times and its respective components.....	248
Figure 6-39: Generated tabular report for hauling trucks cycles.....	248
Figure 6-40: Generated tabular report for earned value performance indices.....	249
Figure 6-41: Generated graphical report for Cost Performance Index (CPI) on daily basis .	249
Figure 6-42: Stochastic forecasting overview	251
Figure 6-43: Simulating different fleet configuration	252
Figure 6-44: Control+ BIM/Walkthrough menu	254
Figure 6-45: Control+ CCTV/Time-Lapse menu.....	255
Figure 6-46: Control+ Central database menu	257
Figure 7-1: Research contribution summary	263
Figure A-1: The entity relationship diagram (ER) for the developed database.....	277
Figure C-1: Vertical and horizontal attributes.....	292
Figure C-2: Outdoor scanning positions.....	293
Figure C-3: First floor scanning positions.....	294
Figure C-4: Different resolution 3D scanner images.....	295
Figure C-5: Outdoor scanning and curtain walls glazing created noise	296
Figure D-1: Google Earth generated road profile.....	299
Figure E-1: Add to visible button (Sequence diagram).....	302
Figure E-2: Add to hidden button (Sequence diagram).....	303
Figure E-3: Add all to hidden button (Sequence diagram).....	304
Figure E-4: Add all to visible button (Sequence diagram).....	304

LIST OF TABLES

Table 2-1: Piling progress measurement template	17
Table 2-2: CYCLONE modeling elements (Halpin 1973).....	20
Table 2-3: Comparison between RFID and Barcode.....	25
Table 2-4: Characteristics of radio frequencies.....	27
Table 2-5: Indoor positioning technologies (Li and Becerik-Gerber, 2011).....	41
Table 3-1: GPS data after processing (Montaser et al., 2012).....	106
Table 3-2: RFID data after processing (Montaser and Moselhi, 2012 b).....	109
Table 3-3: Cycle time calculations (Montaser and Moselhi, 2013 b).....	115
Table 3-4: Comparative study	118
Table 3-5: Example of “Units Activities” objects percentage complete estimation	120
Table 4-1: Sample of GPS unit captured data (Montaser et al., 2011).....	142
Table 4-2: GPS productivity and the process duration (Montaser et al., 2012)	147
Table 4-3: Sample of GPS corrected data	157
Table 4-4: Sample of RFID captured data.....	162
Table 5-1: The process of applying K-NN algorithm	166
Table 5-2: Error rate for the two deployment topologies (Razavi et al., 2012).....	168
Table 5-3: Error rates of tag deployment distance (closeness) on site	169
Table 5-4: Error for stationary reader locations vs. a moving reader.....	171
Table 5-5: Error rates for different zone configurations.....	172
Table 5-6: Error rate for the scenarios of a slow moving vs. a fast-moving reader	174
Table 5-7: Error of tag deployment distance (closeness)	175
Table 5-8: Characteristics of test beds (Montaser and Moselhi, 2013a)	180
Table 5-9: Different characteristics of the experiment (Montaser et al., 2013)	190
Table B-1: Central database attributes	278
Table C-1: Genomics tablet PC data acquisition schedule.....	290
Table C-2: Genomics 3D scanning schedule.....	291
Table C-3: LADAR specification.....	292
Table C-4: Outdoor scanning attributes (September 15, 2010).....	293
Table C-5: First floor indoor scanning attributes (October 15, 2010).....	294
Table C-6: Outdoor scanning with different resolution (November 3, 2010).....	295
Table D-1: Values of variables affecting excavator production rates	298
Table D-2: Values of the variables affecting the truck production rate	299
Table D-3: Sample of hauling units’ travel times.....	300
Table D-4: Values of the durations governing truck production rate.....	300
Table D-5: Lower limits and upper limits of productivity	301

Chapter 1: INTRODUCTION

1.1 General

The ever-changing dynamics of construction requires that all parties in a project be kept apprised of issues that can affect cost, schedule and performance of the work. Effective project management requires tracking all aspects of construction project (Ghanem and Abdelrazig, 2006). Tracking and control of construction projects depend primarily on the accuracy, frequency and time required to collect actual data of construction activities onsite that characterize the work progress (Moselhi and El-Omari, 2006). Traditionally, time and cost control functions are done separately using the Work Breakdown Structure (WBS) and the Cost Breakdown Structure (CBS). Integrating time and cost is essential to meaningful and reliable progress reporting and effective control of construction projects. Earned Value Analysis (EVA) developed under the Cost/Schedule Control System Criteria (C/SCSC) by the US Department of Defense (DOD) is presently used in common practice as valid way to monitor project performance (Fleming and Koppelman, 1995). The process of actual data acquisition is essential in generating reliable progress reports using EVA (El-Omari and Moselhi, 2009). Accurate and timely information on the status of project resources and activities are needed to allow managers to effectively assess the overall project status and to make the best possible decisions (Ergen and Akinci, 2007).

Effective tracking system onsite can ensure that sufficient quantities of materials are available for construction needs, and waste at the end of the project is reduced. Location identification in construction can be used to identify the location of materials and equipment and to stay updated on a project's status. Tracking material location and accessing its related

information are challenging tasks. Since, materials are commonly scattered in different areas and may arrive on a daily basis. Material location can be changed several times before they are installed in their final locations. Material management has been identified as one of the areas of construction work with the greatest potential for improvement (Razavi and Haas, 2010). Most material tracking problems involve: (1) time consuming identification and determination of location, (2) error-prone data recording and documentation, and (3) delayed information (Song et al, 2006).

Many project managers have continually relied on traditional methods of reporting project progress. These methods place considerable load on project teams due to the large amount of data that needs processing and the interdependency between data pertinent to various project components. Lack of adequate visual representation often causes construction managers to struggle with large, unwieldy amounts of data. This may cause costly errors that result in delays and cost overruns. Such limitations of traditional tools on one side and the advances in visualization-information technologies on the other have stimulated various research and development efforts to advance new innovative construction visualization techniques that depict construction sequence of operations (Waly and Thabet, 2002).

1.2 Research Motivation and Problem Statement

Current approaches for managing and capturing construction jobsite data are usually labor-intensive and manual. Data collected using labor-intensive methods are usually stored in a paper-based format, which could be lost or misrepresented. Manual data acquisition methods may not be reliable or complete, as they are contingent upon motivation, judgment and skills of site personnel capturing those data. Hence, it is problematic and costly to retrieve and process those data into useful information. Failure to effectively track and access onsite related

information on demand can result in significant delays, rework and additional costs (Navon and Goldschmidt, 2002). Onsite observations of construction sites have documented that field supervisory personnel spend 30–50% of their work time recording and analyzing field data (Cheok et al., 2000a). Most construction projects require approximately 2 to 3 million individual parts from the beginning to the end. Construction site personnel need to carry a sizeable amount of project documents such as drawings and specifications with them in order to accomplish their assigned tasks; otherwise, they have to memorize extensive information about the structures and facilities (Jang and Skibniewski, 2008).

Emerging technologies have been the driving force behind initiatives to automate the process of data acquisition for tracking, control and progress reporting in the last two decades (McCullough and Gunn, 1993, Akinci et al 2002, El-Omari and Moselhi, 2009 and Razavi and Haas, 2010). Automated data acquisition technologies have the potential of being effective in monitoring and tracking of a project progress in real time (Jang and Skibniewski, 2008). Location identification provides support for decision-making (e.g. timely tracking of the project status and proactive safety monitoring). Developments in sensing technologies have enabled the deployment of a variety of technologies for identification, location sensing, and tracking (Moselhi and Alshibani, 2007).

Global Positioning Systems (GPS) has satisfactorily met the need for outdoor location sensing (Navon and Goldschmidt, 2002). However, GPS is not reliable when it comes to indoor areas due to the poor reception of satellite signals. In addition, GPS is still too expensive for the automated tracking of individual material items (Song et al, 2006). Tablet PC capabilities have increased significantly in recent years; integrating various automated data acquisition technologies such as Radio Frequency Identification (RFID), barcode readers, GPS, wireless communication (Wi-Fi and Bluetooth) and a camera for video clips and digital images.

In addition to its traditional advantages, which are durability, mobility, expressivity of display and ease of use (Brilakis, 2007).

Traditionally, project teams use 2D drawings, Gantt-charts, and sketches to provide the necessary details of measuring a project's progress. However, these tools do not provide the information required to generate 3D visualization of project progress. Building Information Modeling (BIM) is gaining momentum in construction industry, especially by large-scale building owners, who required its use on their constructed facilities (McCuen, 2008). BIM allows a three dimension (3D) simulation of a building and its components. This simulation goes beyond demonstrating how different building assemblies can be combined in the project. It can assist in predicting problems, show the construction variables associated with different building designs, and calculate material quantities (Eastman et al., 2008). The 3D BIM model is a static model, built for representing a physical building's geometry and its related information. However, construction processes are dynamic and as such require a dynamic representation (Hartmann et al, 2008).

The past two decades have seen advancement in construction automation, especially in the area of earthmoving operations, structural steel erection, and concrete structures (Elzarka and Bell, 1997, Abeid and Arditi, 2002, Jaselskis and El-Misalami 2003, Yoon et al, 2006, Golparvar-Fard et al. 2009 a, and Turkan et al., 2011). The limitations of developed models lie in their inability to measure the progress of different types of construction activities from inception to completion in near real-time. Existing models are incapable of dealing or even documenting progress with many activities on a site. Those activities are not directly associated with the resources location such as inspection, concrete curing, and interior finishing. Most of these models lack the capability of objectively monitoring nonspatial tasks such as, inspection, tests, calibration, and commissioning that affect activity progress. Digital Imaging and 3D

scanning were used in this area too. However, their use is subject to the motivation and capabilities of the person gathering and processing captured data. Manipulation to captured images or point clouds, such as interpretation, merging, stitching and object fitting is required. These manipulations are performed manually with considerable effort. 3D as-built models generated by digital imaging and 3D scans do not provide any location identification or tracking of building components. For informed decisions and objective assessments of the progress on a construction site, data from a number of sources must be integrated because not all of the necessary information can be captured using a single technology (Ghanem and Abdelrazig, 2006, Razavi, 2010, El-Omari and Moselhi, 2011 and Shahi, 2012). An overview of the existing models indicates room for improvement.

1.3 Objectives

To address the challenges highlighted above, this research aims to study the models used in tracking and control of construction projects utilizing automated data acquisition technologies to improve the efficiency of progress reporting. This thesis address identified gaps in development of efficient automated model for tracking and progress reporting of construction operations, with visualization capabilities. This is to be achieved through the following sub-objectives:

1. Study the progress made in the field of automated site data acquisition and indoor localization.
2. Investigate the use of Ultra High Frequency (UHF) passive RFID for real time indoor localization and material tracking under various conditions. Analyze changes in the accuracy of position location as construction progresses and the indoor environment

- physically evolves. Scrutinize the possibility of utilizing RFID and/or spatial technologies (GPS/GIS) for tracking and control of earthmoving operations.
3. Examine the potential use of different data acquisition technologies such as Light Detection and Ranging (LADAR), Closed Circuit Television (CCTV) camera, RFID (mobile and fixed), GPS (mobile and fixed), barcode, multimedia, tablet PC and wireless communication. Evaluate the best way to integrate them for use in tracking and progress reporting purposes.
 4. Develop an automated model and its respective modules and algorithms to maximize the benefits of 4D BIM visualization and indoor localization in progress reporting.
 5. Develop a method to calculate earned value based on automated data acquisition technologies and progress templates. Design centralized database to organize and manage collected data.
 6. Develop a computational platform (prototype software), which can act as an interface with the user. This prototype shall make it possible to capture actual data on-site and store it in centralized database, as well as process the collected data for progress reporting in near real time.

1.4 Research Philosophy

The research philosophy behind the developments made in this thesis rests on (1) integration as means for benefiting from the advantages and useful features of available technologies, (2) automation while allowing for balanced human interaction, (3) lab experiments and field studies as applicable, (4) understanding of the processes involved with a focus on improving current practice via development of innovative and practical applications and methods. Based on that philosophy and in an effort to understand the process of data acquisition and project control, the following questions was deemed important:

- What are inputs to the process?
- What are outputs of the process?
- What is the function of each input and output?
- How does this function add value to the process?
- What is the sequence of operations inside the process?
- What is the most suitable model that maps the relation between input and output?

And to automate the process of data acquisition and project control, the following questions were deemed important:

- What is the purpose of each step in the process?
- Can this step be eliminated?
- Does this step use the most suitable automated data acquisition technology?
- How can this step be simplified?
- Can more than one step be integrated?

The philosophy and related questions listed above were always helpful in guiding the development made in this thesis.

1.5 Research Methodology

Figure (1-1) illustrates the methodology followed to achieve the objective of this research. The methodology is summarized in five stages: analysis stage, design stage, development stage, implementation, verification and validation stage, and conclusion stage. The analysis stage began with a problem statement and definition of the objectives. Then, it focuses on performing a comprehensive state of the art review on the following domains:

- Project tracking and control
- Automated data acquisition technologies
- Indoor localization
- Data visualization

From the analysis stage, gaps and limitations in the current literature are identified. To respond to the limitations and gaps identified in the analysis stage, a research vision was formed in the design stage. From the research vision, a developed model was shaped to cover the big picture of the control process without losing the details of its ingredients. The developed model consists of automated data acquisition framework and data analysis and reporting framework. Both frameworks were explained in detail in the development stage. While data collection was being conducted in the implementation stage, the developed model framework and algorithms were also gradually designed.

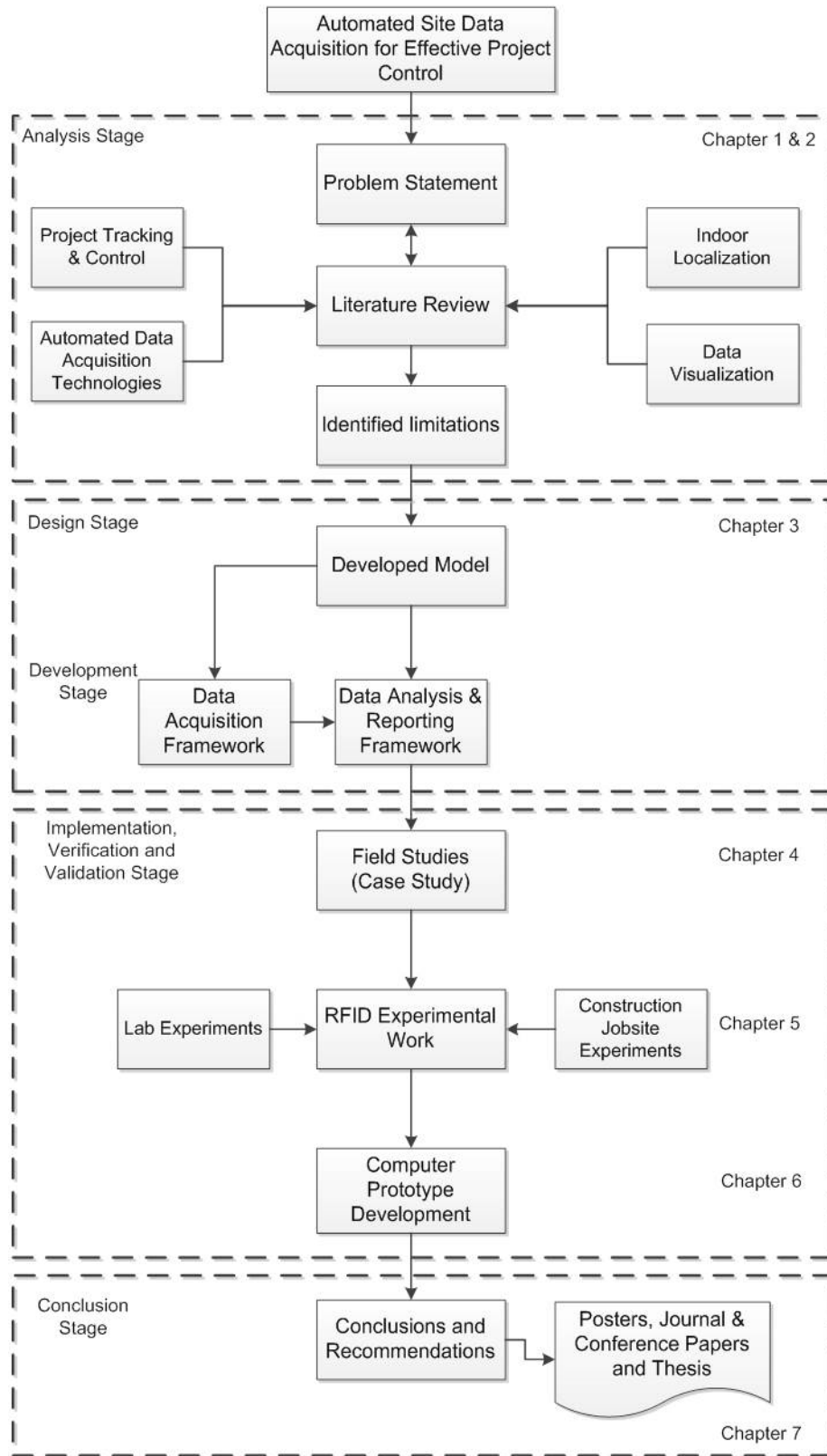


Figure 1-1: Research methodology

Laboratory experiments and field studies were performed in order to assess the feasibility of utilizing this model in the real world. The challenges associated with the practical integration of the developed model within the framework were also addressed at this stage. In addition, computer prototype software was developed to validate the developed model using data captured from a construction jobsite. The finding of this research, lessons learned and its limitations are presented in the conclusion stage.

1.6 Thesis Organization

The thesis consists of seven chapters and five appendices. Chapter 1 presents an overview of the research that includes introduction, problem statement and motivation. This chapter also provides a description of the main and sub-objectives of the research. Finally, it presents a summary of the methodology adopted to achieve the thesis's objective. The literature review is presented in Chapter 2. The review covers the fields of project tracking and control, automated data acquisition technologies, indoor localization and data visualization. The listed topics are viewed with a focus on how they reflect upon the developed model. Summary of the limitations and gaps in existing methods are presented at the end of this chapter.

Chapter 3 begins by presenting the research vision; outlining the main components of the developed model. It also presents the data acquisition framework and its modules. This framework is designed for capturing data from construction jobsites. It consists of two modules; independent data acquisition module and a module established through tablet PC data acquisition, where tablet PC works as integration media for different data gathering technologies. Chapter 3 then focuses on the analysis and reporting framework, where all the captured data is stored and processed for progress reporting purposes. This framework consists

of four modules; central database, performance measurement, earned value analysis and reporting.

Chapter 4 focuses on the data collection stage, which is necessary to implement the developed model. It presents a case study that involves capturing data from a construction jobsite. Wide ranges of technologies were deployed, in this case, such as LADAR, RFID, GPS, CCTV camera and tablet PC. The data captured in this chapter is used later to verify and validate the developed model. Chapter 5 presents in-depth studies for deployment protocols of Ultra High Frequency (UHF) passive RFID for indoor localization. Experimental work was conducted on construction jobsite and in a lab environment. K-Nearest Neighbor (K-NN) algorithm was used as coarse-grained zone detection. In addition, Trilateration and proximity algorithms were used too for fine-grained location identification. This chapter is validation for the two-step algorithm developed in chapter 3 for identification user location and material tracking. The developed software is described in Chapter 6. It covers the designed database, classes, use-cases, sequence diagram and snapshots from its Graphical User Interface (GUI). Chapter 7 highlights contributions and limitations of the development s made in the thesis along with suggested future research work.

Chapter 2: LITERATURE REVIEW

2.1 General

Tracking and control of construction projects depends primarily on the nature, accuracy, frequency and time required to obtain on-site current data of the construction operations that characterize work progress (Moselhi and El-Omari, 2006). Integrating time and cost is essential to effectively monitor project management functions. Earned Value (EV) analysis is conducted by using actual data gathered from construction sites, comparing that data to the planned values and generating progress reports. Accordingly, the process of actual data collection is crucial in generating reliable progress reports (Caldas et al., 2006). Various automated site data acquisition technologies have been utilized to automate the process of data collection required to perform tracking, control and progress reporting in construction projects. These technologies include barcode technology (Tserng and Dzung, 2005), RFID (Song et al 2006), pen-based computers (Elzarka and Bell, 1997), LADAR (Bosche and Haas, 2008), Photogrammetry (Styliadis 2007), and multimedia technology (Abeid and Arditi, 2002). Researchers have also developed a web-based interface to facilitate the information flow between project participants during the control process (Moselhi et al. 2004).

Location identification provides support for the decision-making process and is crucial for the timely tracking of project status. Recent advances in automated data acquisition technologies have enabled the use of sets of sensors for identification, location sensing, and tracking the movements of objects. Location identification in construction projects is a recently evolving area in which the location of resources can be used to acquire precise information about project status (Ergen et al., 2007b, Jang and Skibniewsk, 2007, Moselhi and Alshibani, 2008 and Razavi and Haas, 2010). Lack of adequate visual representation causes construction

managers to struggle to manipulate tremendous amounts of data, which may lead to costly errors and/or project failure. Utilizing visual representations to explain the complex structure of data and eliminate confusing factors has definite advantages (Eddy, 2007). This Chapter provides a literature review on the implementation of EV analysis as a tool to track and control construction projects. It also presents an overview on automated data acquisition technologies and their implementation in the construction industry. A state of the art review for indoor location sensing and RFID localization in construction is included. A section for data visualization in the construction industry was illustrated focusing on GIS and BIM, as shown in Figure (2-1).

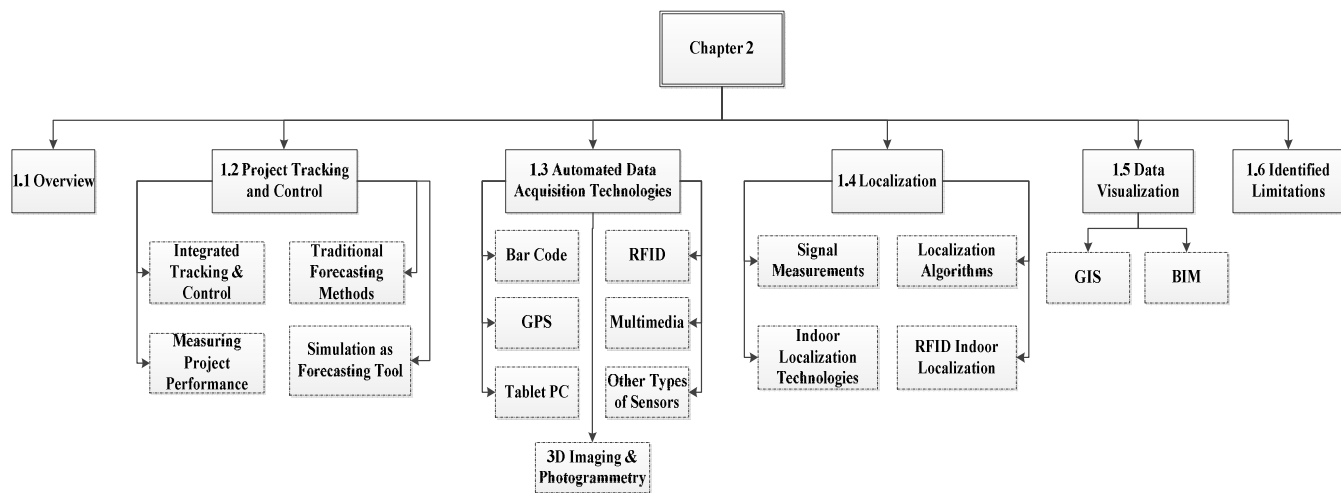


Figure 2-1: Chapter 2 overview

2.2 Project Tracking and Control

Controlling construction projects is a challenging task without a reliable and effective control system. Keeping a project on its planned duration and budget is the main objective of any control system. Tracking and control include three main aspects: (1) collecting data from the construction site; (2) monitoring progress; and (3) comparison of actual performance to the planned baseline and determination of any variations in performance. The project manager can

then make decisions based on the results of the analysis. Performance evaluation methods are used to calculate the variance of time and cost from its control baseline and to assess the value of deviation (Moselhi, 1993). The baseline is subject to change, and the control system is required to be flexible to accommodate any variations in the planning method.

Over the years, a number of methods have been developed to facilitate overall project control. Traditionally, time is tracked and controlled through schedules that are linked to measures of physical progress, while cost is controlled using the percentage complete S-curve method (Li, 2004). The earned value method integrates both time and cost. It has proven to be the most reliable tool for the tracking and control of construction projects. It requires periodic monitoring of actual expenditures and of the scope of accomplishments, and allows for the calculation of cost and schedule variances, along with the performance indices. Performing EV on a regular basis during the course of a project enables early detection of variations from the baseline and this give the management team the chance to organize an appropriate response (Jung and Kang, 2007).

Materials control systems are responsible for ensuring the availability of resources needed for a project; also, they are utilized to handle the waste during a project. Due to their immense importance, Nasir (2009) identified the shortcomings of materials control systems as the most common and substantial factor compromising construction productivity, with an estimated productivity reduction of nearly 40%. In summary, effective materials tracking and control can help increase productivity, avoid delays, reduce the time needed for materials management, and reduce the cost of materials due to decrease of waste. Tracking the exact location of materials had been considered too costly, but recent improvements in automated data acquisition technologies have made it technically and economically feasible (Razavi, 2010).

2.2.1 Integrated Tracking and Control

EVM works by producing three curves depicting the time versus cost relation through the project's life. These curves are used to display and evaluate the project performance. These curves typically have S shape, and they namely are: Budget Cost for Work Scheduled (BCWS), Actual Cost for Work Performed (ACWP), and Budget Cost for Work Performed (BCWP), as shown in Figure (2-2). The curve representing the base line planned project is the BCWS curve. The actual expenditure to date is represented through the ACWP curve. The third and final curve is the BCWP; it represents the budgeted cost of the work that is performed to date, which is the actual value earned for the project. The BCWP is the actual addition to the traditional control system, which only included the BCWS and ACWP (Li, 2004).

The actual progress is measured by BCWP, which is associated with the percentage of work completed. BCWP might differ from the BCWS because the actual quantity installed can be different from the budgeted quantity and/or the actual start date can differ from the scheduled start and/or the unit cost per day can be varied from those budgeted. According to this method, cost and schedule variances are routinely computed during the construction stage for performance evaluation. The cost variance (CV) is the difference between the BCWP and the ACWP, Equation (2.1). Favorable cost conditions are observed when the Cost Performance Index (CPI) is greater than one as shown in Equation (2.2), which indicates that the BCWP (Earned) is more than the ACWP (Spent), and vice versa. The schedule variance (SV) reflects the difference between the BCWP and the BCWS, Equation (2.3). Favorable schedule situations occur when the Schedule Performance Index (SPI) is greater than one as shown in Equation (2.4), indicating that what is being accomplished (BCWP) is more than what is scheduled (BCWS) (Li, 2004).

$$CV = BCWP - ACWP \quad (2.1)$$

$$CPI = \frac{BCWP}{ACWP} \quad (2.2)$$

$$SV = BCWP - BCWS \quad (2.3)$$

$$(SPI) = \frac{BCWP}{BCWS} \quad (2.4)$$

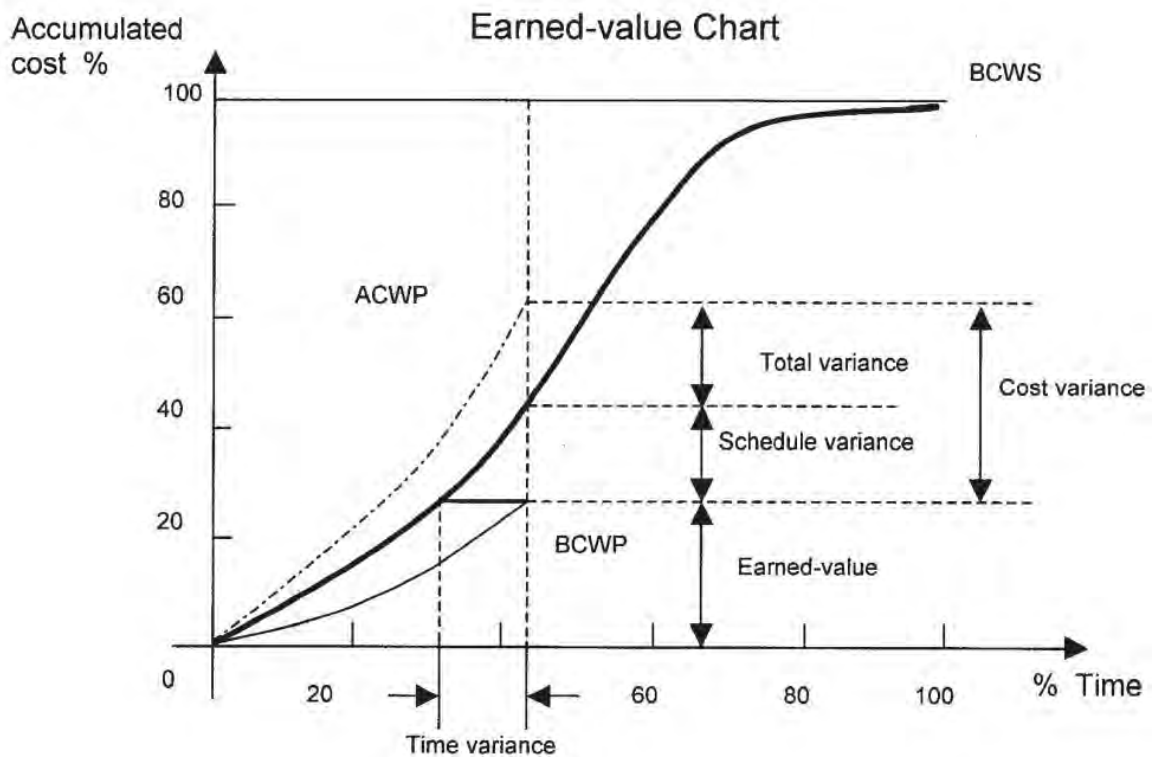


Figure 2-2: Earned value method (Li, 2004)

2.2.2 Measuring Project Performance

Handa and Barcia (1986) pointed out that several methods are available to assess actual progress. The units completed method is used for activities that involve repeated production of easily measured work (e.g. earth moving operation). Incremental milestone is a method used for activities that are sequential with clearly defined milestones. The Start-Finish method is used for activities that do not have interim milestones and/or are difficult to quantify in terms

of time and cost. Supervisor’s opinion is used for activities where detailed analysis is not necessary. The Cost ratio method is used for long-term activities with allocated bulk cost/time. Finally, the weighted units method is used for long-term activities that involve multiple subtasks with different units of measurement (CII, 1987).

Progress measurement template, developed by Moselhi (1993), can be used effectively to evaluate performance and to estimate the Percentage Complete (PC) for an activity. For activities with relatively long durations, interim control points could be introduced. The template divides the activity into control points based on its time and cost characteristics, as shown in Table (2-1). However, the user can overwrite these templates by introducing specifically designed templates that best suit the project at hand. This method has been employed in this research.

Table 2-1: Piling progress measurement template

Work Content	Cumulative % Earned
Rig in position	40
Drive and inspect	80
Trim and finish	95
Hand over	100

2.2.3 Traditional Forecasting Methods

Forecasting project time, cost and productivity is a key function of construction project tracking and control and it is necessary for the evaluation of project status. Forecasting accurately is a difficult task. This difficulty is due to the impact of various factors on project such as weather conditions, change orders, varying project risks, etc. Different techniques have been utilized to build forecasting models, all working under different assumptions and having different limitations, as shown from Equations from (2.5) till (2.9) (Hassanien, 2002, Moselhi

et al, 2004, and Li et al, 2006). Most common forecasting techniques are based on linear trend analysis. Fleming and Koppelman (1994) assumed that the final cost is affected by both the cost efficiency factor and the schedule efficiency factor.

$$EAC = \frac{BAC}{CPI} \quad (2.5)$$

$$D = \frac{Db}{SPI} \quad (2.6)$$

Where

BAC = Budget at Completion,

D = Estimated duration at completion,

Db = Planned duration

$$EAC = \frac{BAC}{CPI \times SPI} \quad (2.7)$$

$$D = \frac{Db}{CPI \times SPI} \quad (2.8)$$

$$EAC = ACWP \text{ (to-date)} + \frac{BAC - BCWS \text{ (to-date)}}{\text{index}} \quad (2.9)$$

Hassanein and Moselhi (2003) proposed a model to forecast linear infrastructure projects time and cost at completion. Their model enables removing specific time periods during which exceptional conditions are known to have prevailed and are not likely to be repeated beyond the reporting date. Li et al. (2006) proposed a “Self-Learning Adjustment” method. In this method, the difference between predicted results and actual occurred values are

used to improve the accuracy of the forecasted results, as shown in Figure (2-3). Alshibani (2008) proposed calculating the BCWP as the ratio of the installed to the budgeted quantities at a given point of time. His total project cost and duration can be forecasted using one of two assumptions. The first assumption is that the current performance at the report date will prevail until the end of the project, and the second one is that the remaining portion of the project will be carried out as originally planned.

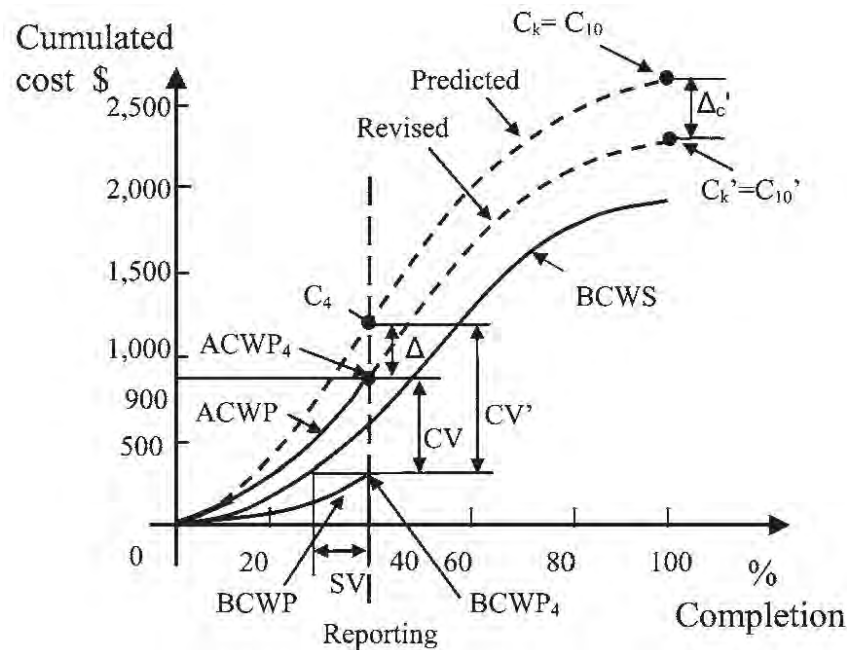


Figure 2-3: self-learning model (Li et al., 2006)

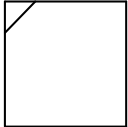
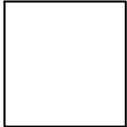
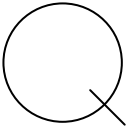
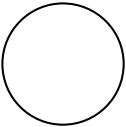
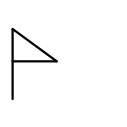
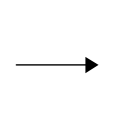
2.2.4 Simulation as Forecasting Tool

Shannon (1998) defined simulations as “the process of designing a model of a real system and conducting experiments on this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system”. Simulation of construction operations allows construction planners and estimators to predict productivity and to evaluate construction operations before starting site work (Alzraiee et al., 2012). Literature reveals considerable work on computer simulation for modeling repetitive

cyclic operations (Zayed, and Halpin, 2001, Marzouk and Moselhi 2004, and AbouRizk, 2010). Discrete Event Simulation (DES) method is the most famous type of simulation. It serves as a powerful tool in analyzing and breaking down complex problems. Consequently, it grabbed the biggest share of researchers' attention, focusing particularly on construction operations.

DES models a system as a network of processes that are sometimes preceded by queues, where state changes occur at discrete points of time. In DES model, each unit flows through the system and reserves resources to complete a job. When, the job is accomplished, the unit releases those resources. Queues temporarily hold units in case resources are not readily available. These actions are called events (Hajjar and AbouRizk, 1999). Tremendous efforts have been exerted by many researchers in the construction field to model and simulate various construction operations. Halpin (1973) developed a powerful modeling element called CYCLONE, which simplified the simulation and modeling process for users with limited simulation background (Table 2-2). CYCLONE was later used as a base for other simulation systems. In 1996, Martinez produced a more evolved simulation tool (STROBOSCOPE). This tool is capable of handling uncertainty not only in time, but also for different resource quantities. Once again, in 1999, Martinez and Ioannou developed the system (EZSTROBE). EZSTROBE's main objective was to reduce the complexity associated with their previous model (STROBOSCOPE).

Table 2-2: CYCLONE modeling elements (Halpin 1973)

Element Name	COMBI	NORMAL	QUEUE	FUNCTION	COUNTER	ARROW
Modeling Element Symbol						

Traditionally, simulation works through utilizing historical data in the form of statistical distributions to represent different processes. The highly dynamic environment of construction projects adds a sense of uniqueness to each project, which questions the validity of using historical data of other projects to represent a project at hand. Hence, there is a need for a method that puts together the capabilities of traditional modeling of construction operations and real time field data acquisition. Many researchers explored real time simulation, such as Guo et al. (2008) and Song et al. (2008). So far, most researchers focused their work on earthmoving construction operations (Montaser et al., 2011, Montaser et al., 2012, Song and Eldin, 2012, Akhavian and Behzadan, 2012 and Vahdatikhaki et al., 2013).

2.3 Automated Data Acquisition Technologies

The accurate and timely collection of information about the status of projects' resources and activities is necessary to support managers in the effective evaluation of project status and in making timely decisions during the execution of on-site work. Effective tracking and control systems require the collection of accurate data from a construction site in a timely manner through a cost efficient methodology. An ineffective tracking and control system can result in costly delays, the need for rework and other additional direct costs (Jang and Skibniewski, 2008). Tracking and control process is a challenging and demanding task in view of the dynamic nature of on-site operations including material delivery and utilization. This process requires the collection of a very large amount of data from construction sites in order to report on a project's overall status so that corrective actions can be taken if needed (Shahi et al., 2013). Although different techniques have been used to automate data collection, the cost of such techniques is still quite high. Current approaches for capturing, storing and managing construction jobsite data are mostly manual and labor-intensive methods. Data collected using manual methods is not reliable or complete, as it is based on the motivation, judgment and

skills of the site personnel. Furthermore, data collected via those methods is typically transferred and stored in a paper-based format. The data will be difficult to search and retrieve, which makes data processing into useful information expensive and unreliable. In other words, potentially useful data may not be accessible to the project's parties when needed, and/or data becomes obsolete (Moselhi and El-Omari, 2006).

Clearly, cost-effective automated data collection is needed. It can increase productivity, reduce cost and increase profit to contractors. The efficiency of large-scale construction operations' tracking and control systems is primarily due to the nature, accuracy, frequency and time required for collecting the onsite data (Moselhi and El-Omari, 2006). Current technological advancements in data acquisition systems have made the consistent management of construction projects feasible by utilizing more accurate and reliable data. Recently, tablet PC capabilities have been enhanced significantly, in addition to their traditional advantages of durability mobility, display expressivity and ease of use (Elzarka and Bell, 1997). Tablets already integrate various automated data acquisition technologies such as barcode readers, RFID readers, wireless communication (Wi-Fi and Bluetooth), GPS and cameras for video clips and digital images. Recent technological advancements in data acquisition systems have made the consistent management of construction projects and their information more feasible. Bar code and Radio Frequency Identification (RFID) are used to automatically identify, track and facilitate generating status documents. GPS, on the other hand, has proven to be an appropriate technology to locate assets' positions for outdoor operations, and with accuracy within centimeters (Navon and Goldschmidt, 2002). Using cameras for data collection allows users to capture a broader perspective of construction activities and operations. Camera-captured images can reduce the time required for inspection

by allowing this task to be done remotely (Abeid and Arditi, 2002 and Brilakis, 2007). The captured data can be transferred to a project management team via an internet connection.

2.3.1 Bar Code

Bar code is an automatic identification solution that streamlines identification and data acquisition. A bar code system consists of three components: tags, a reader and a printer. Bar code tags are classified as either one-dimensional or two-dimensional, as shown in Figure (2-4). A one-dimensional bar code is typically used as an identifier code on an object, while two-dimensional bar code can contain a whole file of information about an object. The second component is the laser scanner (reader), which is capable of reading data coded on a bar code label. Different types of scanners are available: hand held scanners, pen scanners, wall or table mounted scanners, fixed-position scanners and Personal Digital Assistant (PDA) scanners with a built-in barcode reader. The last component is the printer to print bar code tags (Moselhi and Shehab-Eldeen, 2003). Cheng and Chen (2002) integrated bar code and GIS for monitoring construction progress. The scheduled components of the erection progress could be tracked through systematic monitoring of the construction process. Tserng and Dzung (2005) have integrated bar code technology and PDA as a way to facilitate the process of data collection and information sharing between project participants.

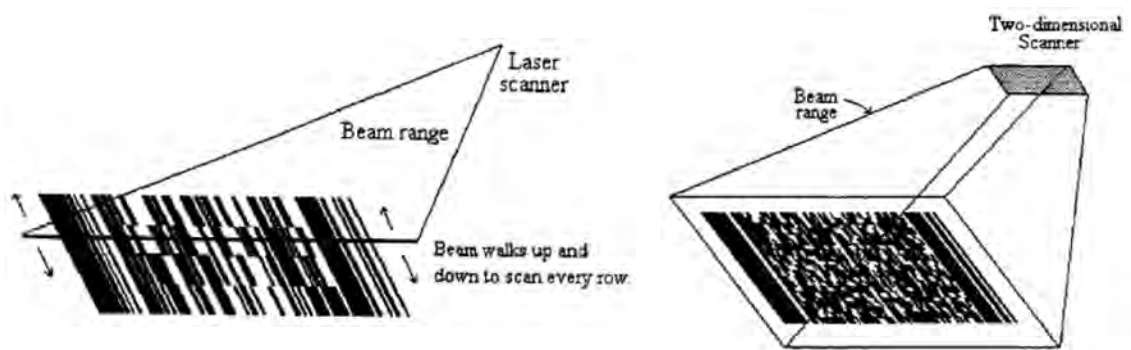


Figure 2-4: 1D and 2D bar code (McCullouch and Lueprasert, 1994)

2.3.2 Radio Frequency Identification (RFID)

RFID works in a way that is similar to bar code technology. Whereas in RFID, data can be stored in tags and retrieved with readers. But these readers can also communicate with the tags using radio frequency waves. Table (2-3) is a comparison between RFID and bar code technologies. With its lower cost and increased capabilities, RFID continued to gain industry acceptance. The basic premise behind RFID systems is marking items with tags. These tags contain transponders that emit messages readable by RFID readers, see Figure (2-5). RFID tags store an identification number or code and other object-related information. RFID tags contain writable memory, which store information to be readable by various RFID readers. Tags can be distinguished as passive or active, according to their power source (Jaselskis and El-Misalami 2003).

Passive tags need to be activated by the electromagnetic energy the reader emits and depend on that power to operate. Therefore, they have shorter read ranges and smaller data storage capacities. Active tags rely on internal batteries for their power supply, which significantly enhances their read ranges and enables additional onboard memory and local sensing. However, using a local power source limits their lifetime to 5–10 years and increases the cost. RFID tags have various specifications, such as their power source, frequency, read range, read rate, data storage capacity, size, operational life, and cost (Akinci et al, 2002).

Table 2-3: Comparison between RFID and Barcode

	RFID	Barcode
Read rate	Fast (Could reach 100 object per scan)	Slow (1 object per scan)
Read Range	High (Could exceed 10m for UHF passive Tags)	Small (centimeters)
Labor-intensive scanning	No	Yes
Storage capacity	Large	Small
Survive in harsh conditions	Yes	No
Long-term data storage	Yes	No
Require line of sight	No	Yes
Ease of positioning for sensing	Easy	Difficult
Cost of a tag	Cheap	Cheapest
Ease of obtaining information	Easy	Easy
Knowledge of items' exact position	Easy	Difficult
Write	Possible	Impossible
Batteries (Power Source)	Yes (Active Tags)	No
	No (Passive Tags)	
Variety of Types	Many according to frequency (LF, HF, UHF and Microwave Frequency)	1D and 2D only
Data security	High	None
Ability to be integrated with other automated data acquisition technologies	Yes (GPS, infrared and ultrasound)	Yes

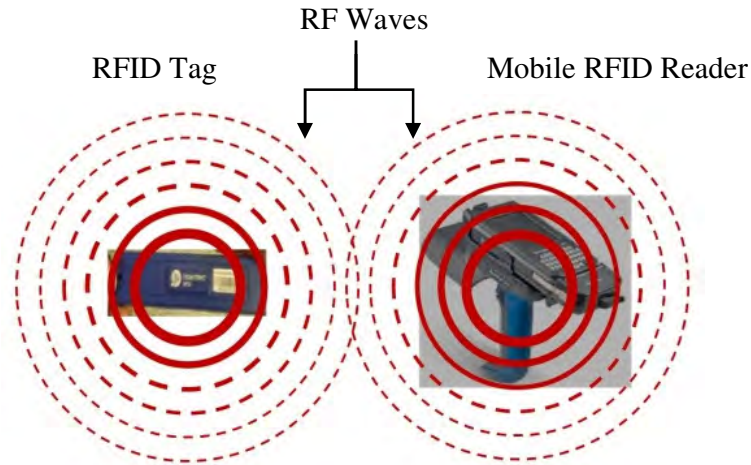


Figure 2-5: RFID system components

A reader retrieves information about the ID number from a database and acts upon it accordingly (Ergen et al, 2007a). An RFID reader can simultaneously communicate with different RFID tags. Thanks to this capability, RFID readers can capture the contents of an entire shipment as it is loaded into a warehouse (Jaselskis et al., 1995 and Ergen et al, 2007b). RFID frequency is key element, one that determines the characteristics of the signals traveling between a reader and tags. The available frequencies include low frequency (LF), high frequency (HF), ultra-high frequency (UHF) and microwave. Presently, UHF is the most widely used, because it offers simple and affordable solutions. The characteristics of each frequency are summarized in Table (2-4) (Tzeng et al., 2008, and Li and Becerik-Gerber, 2011). Jaselskis et al. (1995) presented an RFID system designed to track material delivery vehicles, material-handling equipment and tracking concrete delivery vehicles. They suggested also that RFID card could be issued to construction workers on-site to track their work. Akinci et al. (2002) proposed the use of RFID technology in tracking precast concrete pieces and managing information associated with them throughout a supply chain.

Table 2-4: Characteristics of radio frequencies

	Low Frequency (LF)	High Frequency (HF)	Ultra High Frequency (UHF Passive)	Ultra High Frequency (UHF Active and Semi Passive)	Microwave Frequency
Frequency Range	125-135 kHz	13.56 MHz	865-956 MHz	433-864 MHz	2.45-5.8 GHz
Read Range	< 0.5 m (Passive)	< 1.0 m (Passive)	<5 m (Passive)	≤ 100 m (Semi Passive and Active)	> 100 m (Active)
Metal/fluid impact	Very low	Low	High	High	Very High
Data transfer rate	Low	Medium	High	High	High
Type	Read Only	Read Only	Read Only / Read and write	Read Only / Read and write	Read Only / Read and write
Memory	Small	Small	Small/Large	Small/Large	Small/Large

RFID gates are used at specific locations to identify the arrival dates of materials onsite. The major task of a recognition point is to report the identification of items to the system for further processing (Goller and Brandner, 2011). Utilizing RFID system at laydown yards and portal gates along a project's supply chain paves the way for time savings in material identification, increasing accuracy and shortening time for establishing information on material availability for craftwork planning and reducing searching time for misplaced material (Song et al, 2006). Additionally, RFID gate can be used to register personal protective equipment (PPE) items and generate a warning for missing items (Helmus, 2007). Song et al (2006) developed a gate system using fixed RFID readers to identify pipe spools delivery and obtain other information about these spools, such as purchase order number and arrival time at the storage yard, as shown in Figure (2-6). Lee et al (2008) developed an RFID gate sensor system,

which uses passive RFID tags and wireless network technology for an intelligent logistics management system at construction sites.

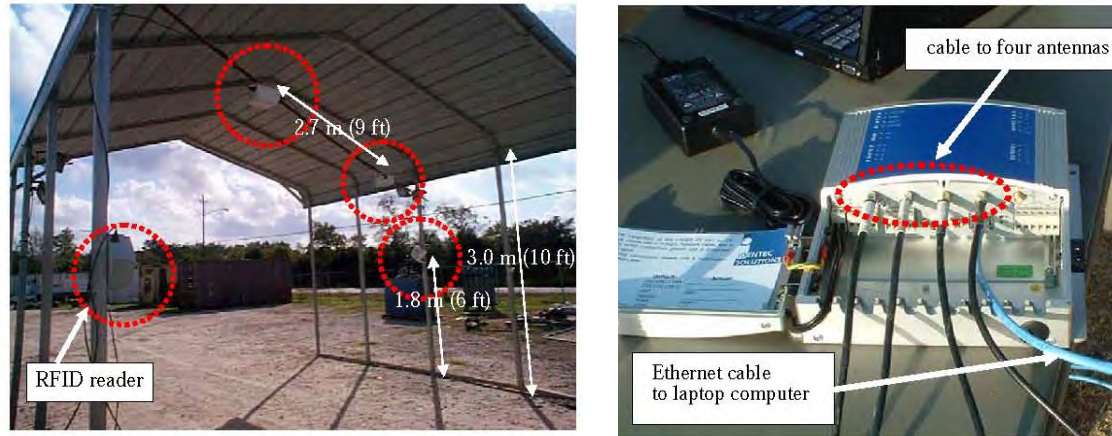


Figure 2-6: Portal structure with 4 fixed RFID readers (Song et al, 2006)

2.3.3 Global positioning System (GPS)

GPS is at present fully practical Global Navigation Satellite System (GNSS). GPS technology has attracted researchers looking for effective ways to track the outdoor location of construction labor and equipment on jobsites (Navon and Goldschmidt, 2002 and Navon et al, 2004). The construction industry has already embraced the use of GPS in control of site surveying and earthmoving operations. GPS can be used to track the location of workers and equipment over a wide range of geographic and geometric scales. The use of GPS for earthmoving operations has reportedly led to an increase of 22 % in productivity and 13 % in cost savings for short haul distance projects. However, for long haul distance, the advantages were less, a productivity increase of 5.57% and cost savings of 4.79% (Han et al 2006). Caldas et al. (2006) developed a system integrating GPS and GIS, in which GPS was used to record the position of pipe spools on a construction project. Moselhi and Alshibani (2007 & 2008) presented a new model for the tracking and control of earth moving operations. Their model

uses spatial technologies, including GPS and GIS, to facilitate automated data acquisition. Their proposed system is designed for highway construction projects.

Song et al (2006) examined the feasibility of applying RFID technology to automate the tracking of materials on construction projects. Using RFID combined with GPS, it was possible to determine the two dimensional location of materials. The objective was not only to track the movement of the object with the use of RFID but to find the exact location of that object. GPS would first identify the precise location of the material and then there would be no need to install many sensors to track the material's movement. The supervisor walks around the site, and the position of the reader at any time is known. Despite GPS have proven to be a significant addition to existing sensing and tracking tools, GPS usage is limited to outdoor projects. This is attributed to the substantial degradation in GPS signal in indoor environment.

2.3.4 Multimedia

Information can be collected in the form of digital photographs, video clips, and/or sound and stored on a computer. During the reporting period, multimedia information is extremely useful for its visualization capabilities (Liu 1995). Cameras are used in construction projects to determine, assess, document, and correct work tasks. Cameras can provide project managers with a broader perception of construction activities and operations. It allows managers to use them for real time visualization wherever internet connectivity is available, especially from a distance and at a standardized viewpoint. Pictures and videos are valuable information tools to highlight problem areas (Abeid and Arditi, 2002). Camera users can log into a web user interface and see if building sections or components have been completed or if rework is needed, allowing for the quick identification of issues or problems while construction is still underway. Images can reduce the time needed for inspection by allowing this task to be done remotely (Brilakis, 2007). Time-lapse recording allows long operations to be viewed in a

short time. Researchers applying multimedia technology in the construction industry have focused on support areas such as as-built information, claim management, and inspection tested. Liu et al (1995) developed a system called M-LOG to store and retrieve as-built information. Construction logs report document project information regarding weather, work accomplishment, on-site resources including labor, equipment, and materials.

Abeid et al (2003) introduced an automated real time monitoring system (PHOTO-NET II) for construction projects. It accepts digital images taken from different cameras, stores them and links them to a database. The pictures taken from cameras are placed on a website from which a computer can capture and store them in a database. Site visits can thus be both reduced and optimized. Another significant documentation advantage stems from the standardization of site pictures. Using cameras for tracking workforce, materials, and equipment across a site can show a number of key imbalances in a project. Time-wasting, task completion times, and inefficiencies can be recognized and adjusted for better optimization of project resources. These forms of utilization are in addition to the more common usage of reducing theft and vandalism of site equipment and material (Bohn and Teizer, 2009).

2.3.5 Tablet Computers

Tablet computers (Tablet PC) are tools that support automated data collection. Tablet computers are becoming less costly and more powerful and suit the construction industry very. The burden of moving around in a construction site with many drawings and papers can be eliminated with the application of tablet PC. The user can access drawings, specifications, and bills of quantities on the spot without losing any time searching for a document. The portability of tablet PC suits construction fields. Data entry is performed by writing on the screen with a pen, or by selecting the desired option from pop-up lists. Thus, there is no need to fill out forms or to remember information and then enter it later into a computer. Data entry is done at the

place where it is collected (McCullouch and Gunn 1993). In a survey, Alemany (1999) showed that supervisors who used computers at work saved time on paperwork and spent more time on supervision.

This could have multiple positive impacts on productivity and quality. Providing construction workers with tablet PCs that can help them locate tools, equipment, and materials, send requests for information and access relevant schedule information. Eventually tablet PCs allow workers to spend more time on direct work and less idle time waiting for answers or looking for tools and materials (Elzarka and Bell, 1997). McCullouch and Gunn (1993) worked on a system to automate the process of data acquisition from construction sites using tablet PC. The system was designed to obtain information pertinent to material consumption and labor working hours. Thabet (1997) developed an automated model for data acquisition; it integrated a CAD model where project drawings are stored, with a pen-based computer. This data acquisition model included object-oriented database designed to relate electronic forms, used with pen-based computer, with the drawing of each activity.

2.3.6 3D Imaging and Photogrammetry

3D imaging refers to systems that are used to measure or to capture existing conditions. In the past, this type of measurement was conducted with single point measurement systems such as total stations, or camera-based systems that relied on photogrammetric techniques. Currently, these instruments are generally categorized as laser scanners and optical range cameras. 3D images are used for a range of applications from the creation of accurate as-built of process plans undergoing modification to the rapid surveying of highways and mines. Laser Detection and Ranging (LADAR) is a 3D laser scanner that is mainly used for spatial measurement. Other applications include surveying, earthmoving operations, monitoring the

progress of concrete casting, highway alignment, paving operations and construction quality control (Lytle, 2011).

LADAR scanning yields the collection of 3D points or “point clouds”. Point clouds are given in x, y, z, coordinates. LADAR technology works by sending illumination pulses to an object where the distance between that object and the LADAR is called the “Range”. Every pulse makes a point in a point cloud that represents a range image. Bosche and Haas (2008) and Bosche et al (2008 & 2009) developed a novel method of inferring the presence of model objects in range images. Their approach focused on the comparison of a 3D image of a construction scene with a simulated scan of a 4D building model using similar scan parameters. The approach was successfully demonstrated in a steel construction project, as shown in Figure (2-7). Turkan et al., (2011) and Turkan (2012) presented a system integrating 3D object recognition technology and schedule information into a combined 4D object-based construction progress tracking system. During the construction of a reinforced concrete structure, they performed an extensive field study to investigate the performance of the system.

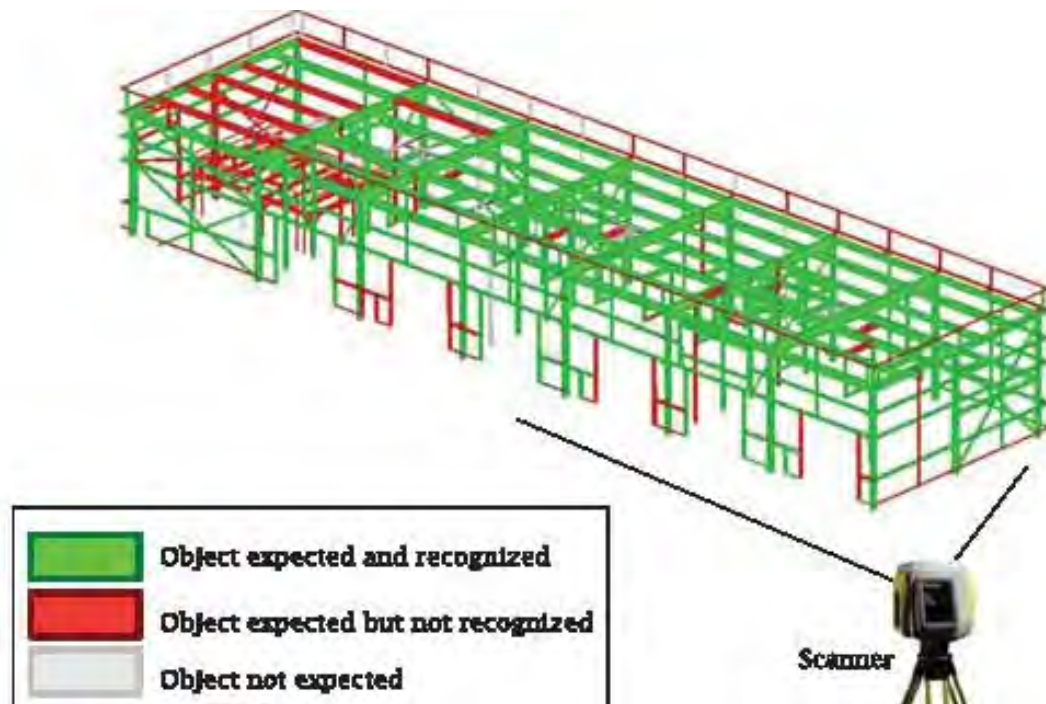
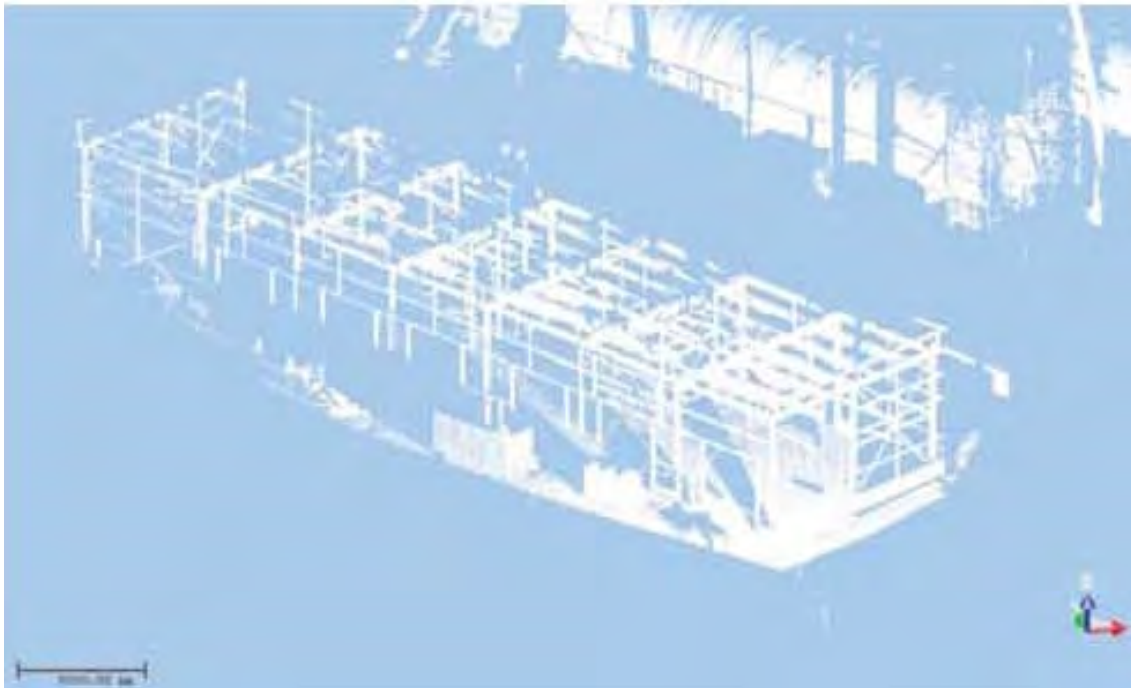


Figure 2-7: 3D scan and 3D model object recognition (Bosche et al, 2009)

Photogrammetry is the extraction of the geometrical properties of an object from photographic images (Styliadis 2007). The value of photo images is that they can obtain

information about texture and color, which is an advantage to photogrammetry over laser scanning (Zhu et al., 2010). Golparvar-Fard et al. (2009 a & b) developed a methodology for construction progress monitoring that leverages the large number of photographs that are already taken on construction sites for production documentation. By analyzing imagery taken daily, a time-based visualization can be generated which compares the 4D as-built data with the 4D as-planned data within a common user interface. Photogrammetry and 3D scanning was integrated to track changes for work accomplished. Integrating 3D imaging and photogrammetry mitigates the limitations associated with each of them individually, such as the number of scans required and the time needed for each scan to produce satisfactory results during the 3D modeling process (Moselhi and El-Omari, 2008 and El-Omari, 2008).

2.3.7 Other Types of Sensors

There is a variety of automated site data acquisition technologies that could be used in the process of tracking and control. In this section, two types are highlighted due their significance in the context of this research. They are control sensor and switch limit. Control sensors are a type of sensors that detects the occurrence of events and reports those events. It could be connected to an equipment control system via microcontroller. Accordingly, when the equipment operator makes a certain action, the control sensor designated events are triggered, and it is registered by the microcontroller memory. The other type of sensor is the switch limit, which is shown in Figure (2-8). Mechanical switch limits are switches that are mechanically activated. Therefore, they have some sort of arm, lever, knob and plunger, which is automatically activated by making contact with another object. As the object makes contact with the actuator of the switch, it eventually moves the actuator to its “limit” where the contacts change state. Example of switch limit is the one connected to the fridge door, when the fridge

door is opened, it activates and switches on the light and later shuts off the light when the door is closed (ABB, 2013).

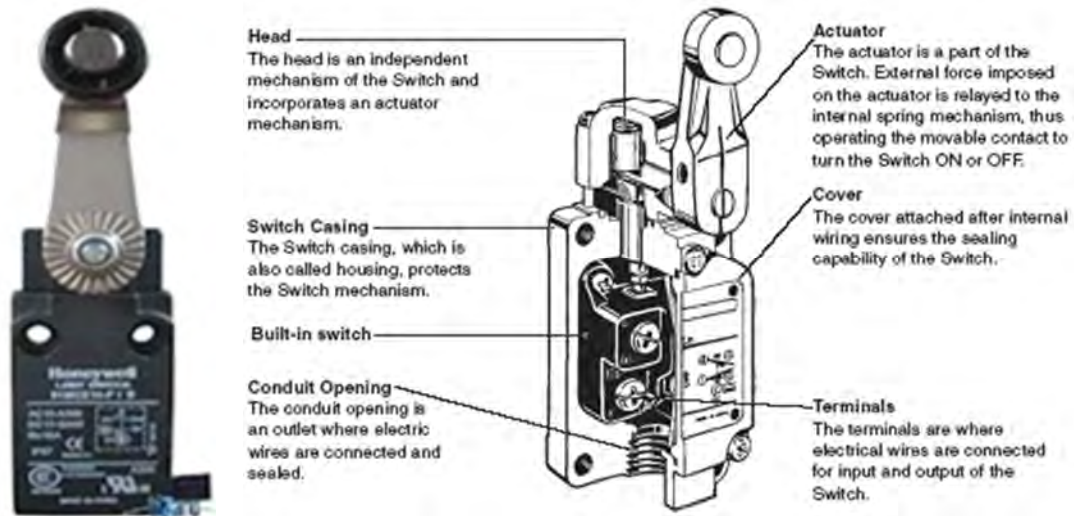


Figure 2-8: Switch limit main components (ABB, 2013)

2.4 Localization

The aim of object localization is to determine the location information of the object of interest through spatial relationship observations between the object and known references. To collect and estimate spatial object information, localization system needs to be implemented, which can then periodically or continuously observe the object (Tzeng et al., 2008). Global Positioning System (GPS) has certainly met the need for outdoor location sensing and can now provide positions with centimeters accuracy under non-stationary situations (Navon and Goldschmidt, 2002). However, GPS has some limitations. First, GPS is not a valid solution for indoor or urban outdoor areas, due to the poor reception of satellite signals. In addition, GPS is still expensive to be used extensively for automatic tracking of individual items. Tagging hundreds of materials with GPS for tracking would be excessively expensive along with other costly means for identification and monitoring (Song et al, 2006).

Localization could be categorized into two types; these are coarse-grained localization and fine-grained localization. Coarse-grained localization is also commonly referred to as range-free or connectivity-based localization. In contrast with fine-grained localization, coarse-grained localization does not utilize any measurement technique, such as the techniques described later on. Coarse-grained localization uses sensors, called anchors, having known locations. The known locations of these anchor sensors are used to estimate the locations of other sensors. This estimation is based on connectivity information, through knowing which of the anchor sensors is within the communication range of this sensor. The connectivity method does not attempt to measure the distance from an object to the reference points. However, it determines whether the object is near one or more anchor sensors in known locations. This category of localization has a minimum requirement for information and consequently does not yield high accuracy.

The K-Nearest Neighbor (K-NN) algorithm is recognized as one of the most widely used methods for solving this type of problems. K-NN is used for classifying objects locations based on the closest anchor sensors. In case the sensors communication connectivity exists between the reader and any of the anchors sensors, the reader reads the tag. Such a read event contributes one neighborhood to the problem of the zone identification. Combining this neighborhood restricts the possible zone reader. Therefore, the K nearest neighbors is the last K reads that occurred prior to the most recent read (Duda and Hart 1973). On the other hand, fine-grained localization utilizes manipulation on signal measurements received from the localization sensor and hence it is more accurate. The following section describes in detail the different signal measurements used and the algorithms used for fine-grained localization.

2.4.1 Signal Measurements

Signal measurements used for localization are Received Signal Strength (RSS), Angle of Arrival (AOA) and Time of Arrival (TOA). TOA is a localization method that can measure signal traveling time between the signal source and signal receiver. The system has to predefine the velocity of the signal. If there are several signal receivers, which measure the same signal at various points, the localization system can use a variation of TOA and/or the Time Difference of Arrival (TDOA). TDOA measurement takes into consideration different signal travel times from the single source to different receiver locations. GPS, Ultrasound signals, and Ultra-Wide Band (UWB) are localization technologies that use time measurement (Hightower and Borriello, 2001). AOA is a signal measurement method that considers the direction of signal propagation. For precise measurements of signal arrival angles, the receiver contains different signal-receiving arrays. However, if the signal can be reflected by the surroundings, it becomes less accurate than TOA. Thus, AOA is more suitable in outdoor environments and open spaces than indoor environments or congested areas (Patwari et al, 2005).

RSSI is one of the most common measurement signal types. Signal strength has a close relationship to the distance between the sender and receiver. A certain signal, such as Radio Frequency (RF), ultrasound or vibration decreases as it travels through media, and the localization system can then determine spatial information using the degree of signal attenuation. In order to estimate the distance between fixed and mobile devices, RSSI measurements are made so that the distance can be estimated using a propagation (path loss) model. However, RSSI implies a certain degree of error due to the multipath effect. Signal strength measurement localization systems have two main advantages, cost effectiveness and straightforward implementation (Choi, 2011). RSSI signal measurements technique was used in this research.

2.4.2 Localization Algorithms

Signal measurement (TOA, AOA, or RSSI) localization techniques estimate the location of a signal source. Three main algorithms have been developed to locate a target: Triangulation, Proximity and Scene Analysis. Triangulation is an algorithm for determining the location of an object, based on geometric properties and mathematical formulation. There are two different techniques of triangulation: Trilateration and Angulation, as depicted in Figure (2-9).

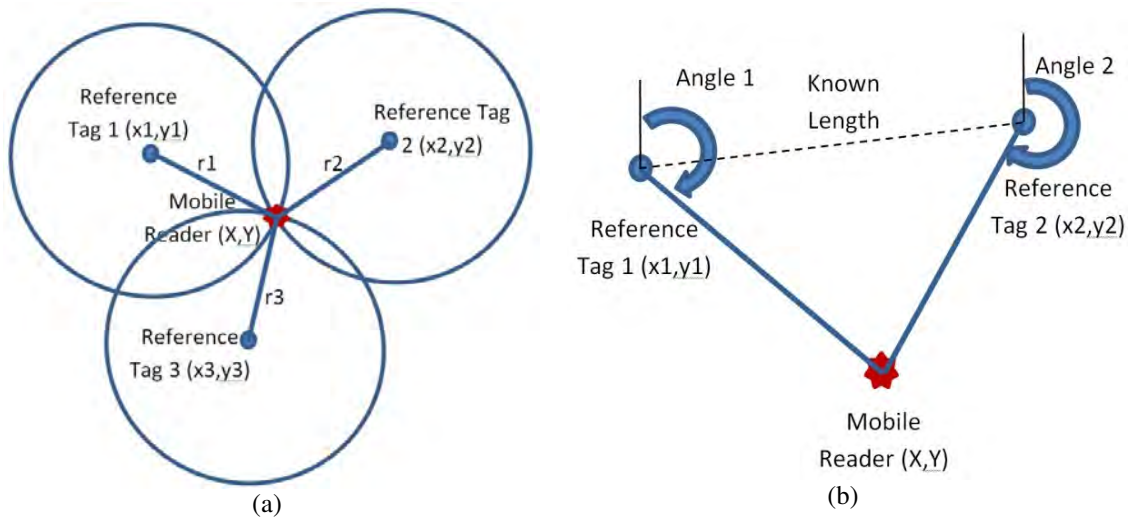


Figure 2-9: (a) Trilateration (b) Angulation localization algorithm

Trilateration uses distances and angulation uses angles to determine the position of an object in a coordinate system. Trilateration determines the position of an object by measuring its distance from different reference positions. Trilateration systems measure distances with different signal measurements methods: TOA, TDOA, or RSSI. A localization system needs at least three distances from different receivers, the system can then draw three circles; each circle's radius is equal to a measured distance, and the center for each circle is the known signal receiver's position. The intersection of the three circles represents the signal source's location, as shown in Figure (2-9 a). Angulation is a signal direction (or angle) based-localization

method to determine the position of an object. In a 2-dimensional Cartesian coordinate system, two angles and the distance between the reference points are used, as shown in Figure (2-9 b) (Gonçalo and Helena 2009). Trilateration algorithm was applied in this research.

Proximity algorithm requires the measurement of the nearness of a number of neighboring points, which are close to the target and whose locations are fixed and known. When a tag or a reader is attached to a target, it continuously communicates with the readers or tags deployed in the area, and the received signal strength or time of arrival is observed and used to determine the nearness of these reference positions. The measured nearness, along with the corresponding known locations, is used to estimate the location of a target. Thus, the proximity guarantees the most straightforward and easiest implementation for object localization. RFID and Infrared based localization systems have adopted the proximity approach (Li and Becerik-Gerber, 2011). Proximity algorithm was also used in this research.

Scene analysis technique utilizes a pre-observed data set of the monitored scene to estimate the location of a signal source. Fingerprinting is the most well-known scene analysis based-location sensing technique. The system compares current received signal measurements and prior observed measurements from known locations. Then, the system estimates the source location as the one with the most matched fingerprints. Pre-application mapping is required, during which the location sensing infrastructure, the readers or tags, are deployed in the sensing area, and the signal strengths of the reference positions are measured and recorded to establish a signal strength fingerprint map (Woo et al, 2011). This approach requires additional information data storage to maintain the pre-observation data. The signal strength is the most common measurement with the scene analysis technique (Fu and Retscher, 2009). It is very difficult to apply this algorithm during construction due to the changing dynamics of construction operations.

2.4.3 Indoor Localization Technologies

Wide ranges of technologies are used for indoor location sensing. Ultrasound and infrared were used as localization technologies. An ultrasound signal is emitted from an object, and the localization system can determine the source location using calculations of the signal flight time to multiple receivers (Priyantha et al, 2000). Inertial navigation systems (INS) allow a user carrying a package of motion and rotation sensors and a microprocessor to sense its own location independently of external infrastructure. Unfortunately, INS systems accumulate errors and require periodic recalibration (Fox et al, 2003). Various GPS-based solutions have been introduced to expand the use of GPS to indoor environments. High-sensitivity GPS, for example, uses highly signal-sensitive receivers developed for weak-signal conditions. As well, Assisted GPS (A-GPS) sends assisting information, such as satellite orbit data, to the receiver to speed its satellite acquisition time and improve performance (Diggelen, 2002).

Ultra Wide Band (UWB)-based solutions use short pulses for communication between tags and receivers, and ensure high accuracy by requiring the deployment of a large amount of infrastructure and actual communication for positioning at long range (Aryan, 2011). Wireless Local Area Network (WLAN)-based solutions can be easily set up and require few base stations. They use the RF signal strength and the magnitude of the electric field as an indicator of the distance between a source and a receiver. This distance information is then used to obtain the user's location by triangulation (Woo et al, 2011). RFID-based solutions require the installation of RFID readers and reference tags around the building, and rely on the signals traveling to estimate the distance or proximity of the tags. These reference tags have a well-known location, and they transmit the location of the target objects to the readers (Choi, 2011). Hybrid positioning systems could provide more advantages to improve positioning accuracy as well as cost benefits such as combining two systems instead of one for outdoor activities

and another one for indoor activities. Jiang et al (2010) proposed a system that provides outdoor positioning using GPS and UWB to provide indoor positioning.

Li and Becerik-Gerber (2011) conducted a comparative study for different indoor location sensing technologies, taking into consideration the following factors: accuracy, affordability, line of sight, wireless communication, context independence, onboard data storage, power supply, and wide application in the building industry (Table 2-5). They concluded that RFID technology is considered the most suitable indoor location sensing technology.

Table 2-5: Indoor positioning technologies (Li and Becerik-Gerber, 2011)

Tech.	Accuracy	Afford . (\$/m2)	No line of sight required	Wireless Comm.	Contex t Inde.	On- board data storage	Built- in power supply	Wide app. in the building industry
GPS	1-2 cm	380	X	X	X	√	√	√
INS	1.1-4.15 m	20	√	X	√	√	√	X
Infrared	30-50 cm	17	X	√	X	X	X	X
UWB	6-50 cm	140	√	√	X	X	X	X
WLAN	4.53-6.89 m	3	√	√	X	X	X	√
RFID	1.55-3.11 m	25	√	√	X	√	X	√

RFID technology has onboard data storage capacity, which enables the tags to act as distributed databases and decentralizes the tagged objects' information, making it available wherever the objects exist. It also supports wireless communication, which allows the identification and data transfer to be done in a non-contact fashion. Choi (2011) made the same

conclusion, since passive UHF RFID-based localization overcomes the limitation of conventional indoor localization systems, such as their high cost of installation and maintenance, because of its relatively inexpensive price, the absence of a power source, and the lightweight of passive RFID tags. These conclusions justify the applicability of UHF RFID technology in the construction industry, which is a dynamic work environment.

2.4.4 RFID Indoor Localization

RSSI is the main signal measurement used with RFID indoor localization. TOA and AOA signal measurements are not utilized with RFID indoor localization due to the multipath effect that disturbs the received signal strength. Trilateration, proximity and scene analysis algorithms could be used with RFID technology for indoor localization. However, scene analysis is not suitable for building under construction. Those algorithms are performed based on the attenuation methods; using path loss models relate the received power to the distance. Indoor RF wave's propagation is characterized by reflections, diffractions and dispersion in the internal structures. Transmitted signals follow different paths to the receiver, which results in fluctuations in the received signal. This effect is known as multipath propagation, and is mainly affected by the type of materials used in the construction of the building and by the surrounding objects (Gonçalo and Helena 2009).

There are two approaches for utilizing RFID in indoor location sensing systems. The first approach is the "mobile tag fixed reader" and is used by tagging moving targets and placing RFID readers at fixed locations (Borriello et al, 2004). In this approach, when a reader is reading one tag, the system verifies that the mobile target carrying the tag is inside the read range of the readers. This approach is feasible for applications, in which mobile targets move around well-partitioned and separated areas through checkpoints. Readers are usually placed at checkpoints to detect the movement of the targets. However, when the accuracy

requirements are higher, or the number of checkpoints increases, this “mobile tag fixed reader” approach becomes impractical. In contrast to this approach, a “super-distributed tag infrastructure” approach is used (Chon et al, 2004). In this approach, a large number of tags are distributed in the area, and each mobile agent carries an RFID reader. Context-aware information can automate the delivery of spatial information to on-site personnel, with which targets, including building components, equipment, tools and people, can be easily located and target-specific information can be accessed (Li and Becerik-Gerber, 2011). In this research “super-distributed tag infrastructure” is used.

2.5 Data Visualization

In construction industry, the lack of adequate visual representation means that project team members have to struggle with large amounts of data, which can lead to costly errors or even project failure. Construction progress visualization is needed to explain the complicated data and eradicate confusing factors (Eddy, 2007). Construction Industry Institute (CII) studies showed that the cost of rework could range from zero to 25% of the installed cost of construction. However, the use of visualization representations such as 3D models by management team can reduce that amount of rework by an average of 65%. The efficient use of space on a construction site is a site-specific, difficult task and is often left to the intuition of the construction manager. Poor spatial planning has been deemed one of the major sources of productivity loss (Thabet and Beliveau 1997).

On large construction projects, project management teams often suffer from not being able to mentally visualize a project complexity. Thus, they are frequently not able to make the best decisions to mitigate risks. Visual representation is one way to overcome this problem. Visual models represent the spatial aspects of schedules and communicate schedules more

effectively than traditional methods such as bar charts (Eastman et al., 2008). By themselves, 3D models do not have the ability to show the exact status of a project at a specific period, and so are of little help in progress control. In order to create a construction schedule from 2D drawings, planners have to visualize the sequence of construction in their minds. This is an extremely difficult task since workspace logistics and resource utilization are highly dynamic by nature. Most site organizations plan their works based on the conceptual site layout and drawings, which are rarely updated during the project duration. Thus, site managers have not fully benefited from recent advancements in visualization-information technologies (Chau et al., 2005).

3D models have some basic information that results from shapes, sizes and locations. This is the geometric database. Each element has geometric attributes. In addition to the geometric attributes, which describe the physical model, each element in a model can have any number of non-geometric attributes associated with it. One non-geometric attribute might be an activity ID from a time schedule (Aslani et al., 2009). Golparvar-Fard and Pena-Mora (2007) proposed several semi-automated vision-based approaches to improve and promote the communication of progress information and decision-making.

2.5.1 Geographic Information System (GIS)

GIS is essentially a combination of computerized mapping and database management systems (Hassanien, 2002). It is used to represent and analyze the geographic features present on the earth's surface. GIS database is a collection of information about objects and their relationships to each other. It includes a wide range of information such as geographic, environmental, political and social (Bansal and Pal, 2009). GIS allows maps to be drawn from its database and data is referenced from the maps. When a database is updated, the associated map can be dynamically updated. The primary purpose of a GIS is to display, query and analyze

spatial data. GIS is used in many applications as a decision-making and problem-solving tool. Considerable work has been done using GIS for various purposes such as monitoring project schedules (Min and Jiann, 2002), automated data acquisition (Hassanien and Moselhi, 2002), and the remote controlling of earthmoving equipment (Marco and Fioerenzo, 2003).

Hassanien and Moselhi (2002) used GIS to develop a model for automating data acquisition and analysis for planning and scheduling highway construction projects. Min and Jiann (2002) have developed an automated schedule monitoring system for precast building construction. The system integrates a barcode, GIS, and a database management system to assist engineers in controlling and monitoring the erection process on a real time basis. The erection process was selected because it is the most critical activity in precast building construction. Macro and Fioerenzo (2003) developed a remote control system for a fleet of earthmoving and construction equipment. The system uses GIS, CAD and GPS for controlling and monitoring operations that involve heavy equipment.

2.5.2 Building Information Modeling (BIM)

The National Building Information Model Standard (NBIMS) defines BIM as “*A digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder*” (NIBS, 2007). Building information modeling (BIM) is gaining momentum in the architecture/engineering/construction (AEC) industry, especially since owners such as the US Army Corps of Engineers (USACE) implemented initiatives requiring future projects involving the design and construction of facilities include BIM. In 2005, the United States

General Services Administration (GSA) announced that starting 2006, AEC firms would be required to provide a building information model with their designs (McCuen, 2008).

The goal of adopting a BIM is to provide a comprehensive view of the building by including (drawings, specification, details, etc...) in a single-source model (Krygiel et al., 2008). BIM databases contain physical and functional characteristics of a structure since a BIM model is composed of smart objects rather than lines, arcs, and text. All of these characteristics are mainly due to BIM's capability to realize the building through all of the stages in the form of a database (Fu et al., 2006). BIM users can obtain information about any single element, or for all elements in a project, to inform decisions about the project. Examples of data included with an element are material quantities, costs of elements, time considerations related to the element, building performance, operations and maintenance, and several other items essential in the lifecycle of facility (McCuen, 2009). Motamedi and Hammad (2009 a & b) and Motamedi et al. (2011) integrated BIM and RFID for lifecycle management of facilities components. They added the data taken from BIM database to RFID tags attached to the components. The idea of making components data readily available on the tags provides easy access for facility managers through real-time connection to the central database or a portable device.

With its potential to assemble the whole project virtually before any actual construction begins, BIM adds a level of accuracy to both quantity and quality issues. Building materials can be demonstrated in real time scenarios rather than requiring manual analysis (Krygiel et al., 2008). By drawing building elements only once for a project in a plan view, the projections of all elevations and sections are generated automatically. One of the direct benefits is the reduction in drawing time; therefore, designers can mainly focus on other design issues (Krygiel et al., 2008). 3D BIM model is a static model, built to represent a building. This could

be seen as a shortcoming for the construction process since it is a dynamic process and merits a dynamic presentation.

4D BIM is a visual representation that combines an object oriented 3D BIM model with time. 4D BIM is information visualization that is easier to understand than traditional methods. Traditionally, project managers use 2D drawings, bar charts, and sketches to clarify the construction design, but these visualizing methods do not integrate the temporal or spatial dimensions. 4D BIM models are a form of visual representation of a project that also takes into consideration the temporal aspect of how project teams plan to actually build a project, according to construction schedules (Hartmann et al., 2008). 4D BIM could be used strategically by on-site management for progress visualization and presentation, locating equipment such as material hoists, checking access/openings for equipment, storage visualization and the utilization and estimation of quantities.

Moreover, 4D BIM can assist site personnel at brainstorming sessions and discussions about access, storage and sequencing of works (Chau et al., 2005). Better visualization facilitates team collaboration in removing logical errors in construction operations. Owners of the constructed facilities may have little experience in construction projects, and are often unable to truly participate in the construction plan development process unless a simple method of visualization and communication is made available to them (Kang et al., 2007). 4D BIM visualization seems to be an effective way of enhancing the many different types of human perception and it can help anticipate potential construction conflicts during the operational stages (Chan et al., 2004, and Staub-French et al., 2008).

2.6 Summary and Identified Limitations

The literature was reviewed in areas pertinent to automated data acquisition technologies, indoor localization and data visualization. The literature review was conducted with prime focus on the impact of those areas on the development of efficient project control process. The following gaps and limitations are identified accordingly:

- Geometry restriction assumptions for loading and dumping areas and lacks the full utilization of GPS data to identify the travel and return durations such as the model of Alshibani (2008).
- Inability to differentiating between individual hauling trucks and absence of complete representation of earthmoving cycle such travel, dumping and return durations as in the model of Rezazadeh Azar and McCabe (2011).
- Expensive technology implementation such the On Board Instrumentation System (OBIS) of CAT Product Link (2013) and its black box format, which prevents users from accessing its respective algorithms and modifying it as they see fit.
- Inability of predicting fleet performance deterministically or stochastically using OBIS. Limited work on the use has been done utilizing data sensed from equipment itself such as the utilization of control sensor.
- Inability of measuring progress for different types of construction activities such as the models of Ghanem and Abdelrazig (2006), Chin et al. (2005) and Shi (2009). These models were limited to the delivery and erection of steel structures and did not provide any location identification for the tracked material.
- The generated 3D models built from images or point clouds are unable to identify objects that have been delivered to the site or the objects that have been installed but away from their designed location by a distance greater than the tolerance specified such as the

models of Golparvar-Fard et al. (2009b), Cheok et al. (2000b), Bosché and Haas (2008) and Turkan (2012). The data acquisition of these models has some subjectivity as it depends on the motivation and capabilities of the site personnel capturing data.

- All the previous models lack the capability of data fusion among more than one technology and lack the full utilization of BIM technology.
- Inability to provide real time localization due to the mathematical and computational complexity such as the model of Razavi (2010). This model was unable to track indoor activities or material delivery.
- El-Omari (2008) developed model did not present the integration methods or algorithms that were used to track labor, equipment and material. In addition, the integration was limited to calculating the quantity of excavation completed.
- Shahi (2012) developed model was limited to just data extraction from the 3D BIM model elements, with no visualization capabilities. The model was limited to indoor material tracking utilizing UWB and did not provide material any tracking for material delivery or outdoor material location.
- All previously mentioned models are incapable of tracking progress of finishing and non-spatial activities such as inspection, concrete curing, and interior finishing.
- The limitations of existing models lie in their inability to measure the progress of different types of construction activities from inception to completion in near real-time.
- Most forecasting techniques utilized in those models for repetitive construction operations use deterministic approaches or stochastic approaches that are based on historical data of similar past projects. Utilizing such data impacts the accuracy of simulation results for it does not account for the unique characteristics of the construction operation being considered.

Chapter 3: PROPOSED MODEL

3.1 General

The aim of this chapter is to provide a comprehensive description of the developed model. This chapter presents the methods and algorithms of the developed model as well as the steps of the process used to integrate automated site data acquisition technologies, visualization-information technologies and earned value analysis. The model was developed to support the tracking, control and progress reporting of construction jobsites. Figure (3-1) depicts this chapter's main sections. The developed model is built on integration and automation of methods and algorithms to support the process of project control. Figure (3-2) outlines the concept of and vision behind its development. The developed model combines project scope, time, resources and location for project's controls purpose. The model is developed to embrace the human factor and expert knowledge in the use of specially designed progress templates.

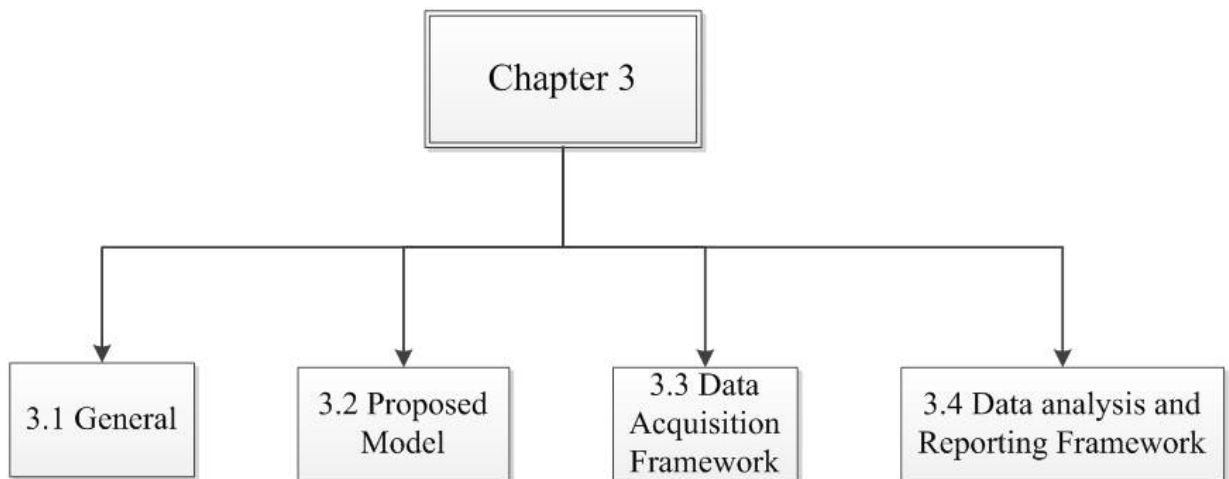


Figure 3-1: Chapter 3 overview

The process of project control starts during the planning stage. Where project scope is defined clearly and then the project is broken down to complete the Work Breakdown Structure (WBS). WBS is divided also until it reaches the project's activity level. The integration between project activities and time yields project schedule, which is activities time phased plan. Creating project schedule is the first step in the area of project control. A further step is taken by integrating scope (Activity), time and earned value analysis to generate project baseline (S-Curve), as shown in Figure (3-2). Project activities consist of objects that are spatially scattered in the project. Therefore, every object has a specified location that is identified spatially in the project's 2D plans and 3D models or project map for outdoor environment. These 3D models and maps were used alongside with the project baseline (S-Curve) for project control. However, this method of control lacks an important ingredient, which is the information part. In addition, this method had the limitation of being visually static. A huge leap happened by the introduction of Building Information Modeling (BIM) and Geographic Information System (GIS). Both technologies enriched visualization models by integrating information from GIS geospatial database along with BIM database.

Researchers and industry professionals were eager for more project control. Therefore, they focused more on project assigned resources. This step was established to identify the progress made by resources on activity or task level. The integration of time and activities' resources produces the concept of productivity. Many manual methods were developed to identify resources productivity such as work sampling, craftsman questionnaire and delay survey. A further step was taken by integrating activities' resources and its changing location for tracking purposes. This integration was initially done through manual methods. For example, tracking if material had been delivered or not and tracking material's locations on site. Another huge leap happened in the last two decades by introducing automated site data

acquisition technologies to construction industry. This helped a lot in integrating resource's changing location and time for tracking, productivity analysis and consequently controlling project's time and budget.

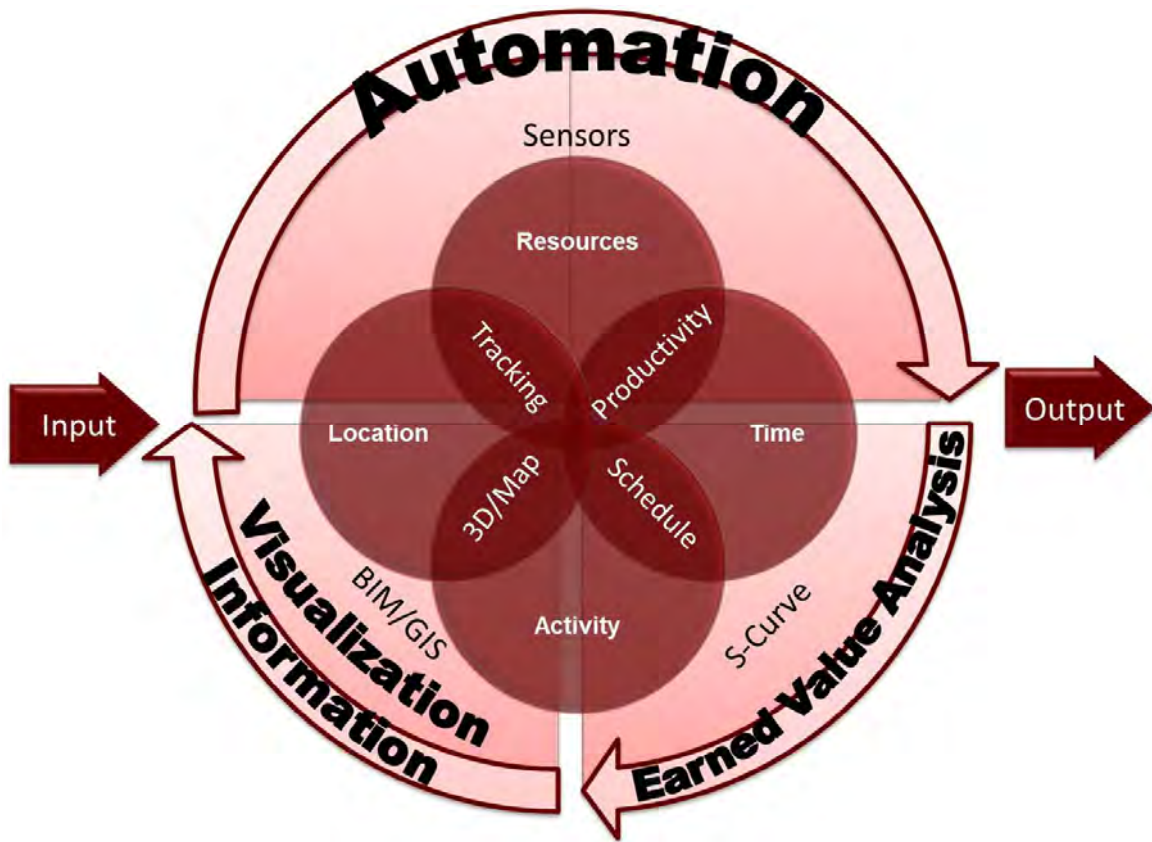


Figure 3-2: Research vision

Figure 3-3: Research vision

Literature reveals that most of the researches and industry professionals' efforts dealt with the different aspects of project control as separate and isolated problems. For example, earthmoving activities were dealt with in literature from two perspectives. Some efforts focused on tracking the quantity of excavated soil only, which is the output of the earthmoving operation. Others focused only on tracking the hauling trucks, which is the input of earthmoving operation. Similarly, in case of material, the efforts were focused on tracking

delivery or outdoor location or indoor location but without giving much attention to how that material was handled until commissioning. Therefore, the area of project controls still needs more attention in controlling both input and output of the process. Accordingly, literature, for most of its parts, lacks integrated models that combine projects' different aspects for the purpose of control.

The developed model in this research stems from Figure (3-2), which forms the research vision. The developed model combines project scope, time, resources and location for project's controls purpose. This is done through the fusion of earned value analysis, visualization aspects and automated site data acquisition technologies. The developed model was not developed currently to replace the human factor. However, it was developed to embrace the human factor combined with construction knowledge through using specially designed progress templates. A number of characteristics have been identified and deemed necessary for the model to be effective for project controls, they are listed as follows:

- The model should work with minimum interaction between the user and its different modules. In case of any user's interaction, it should reduce the user subjectivity to the minimum limit.
- The model should be structured in modules, each of which should then be broken down into separate sub-modules according to their functionality. The model's automated modules should be mainly working independently. This modularity will guarantee manageable modifications on specific modules.
- The model should be capable of extracting and exchanging data from/with visualization-information technologies such as BIM and GIS.

- The model should be able to handle different types of project data. In addition, it should be able to represent projects with various hierarchical breakdown structures.
- The model should capture the onsite data in an electronic format in real time and be capable of handling large amounts of data on daily basis. The processing and analyzing of the captured data should be in near real time.
- The model should be cost effective and be capable of integrating cost and schedule functions. In addition, it should compute the cost and schedule variances at each activity level and project level.
- The model should automate the process of performance measurement and be accurate in forecasting project cost and time. The model should automate and facilitate progress reporting for project team members. The model should be multi-user that allows different users to access the project captured data and progress reports.
- The model should be able to support the reusing of attributes and to support the sharing of attribute values. The Internet-based model already allows overall data reusing and sharing among team members.
- The model should keep all the project-performed data especially repetitive work as historical data for future reference. In addition, the data, which have a repetitive nature, are utilized to develop standard templates for domain-specific works.
- The design of the model has to be flexible enough to allow the extensibility of it in the future to meet various requirements.

3.2 Proposed Model

The developed model consists of two main frameworks; each encompassing methods, procedures and algorithms as illustrated in Figure (3-3). The first framework is the data acquisition framework. It is responsible for capturing onsite data. The second framework is the

data analysis and reporting framework, which is utilized for storing, processing and analyzing the captured data for control and reporting purposes.

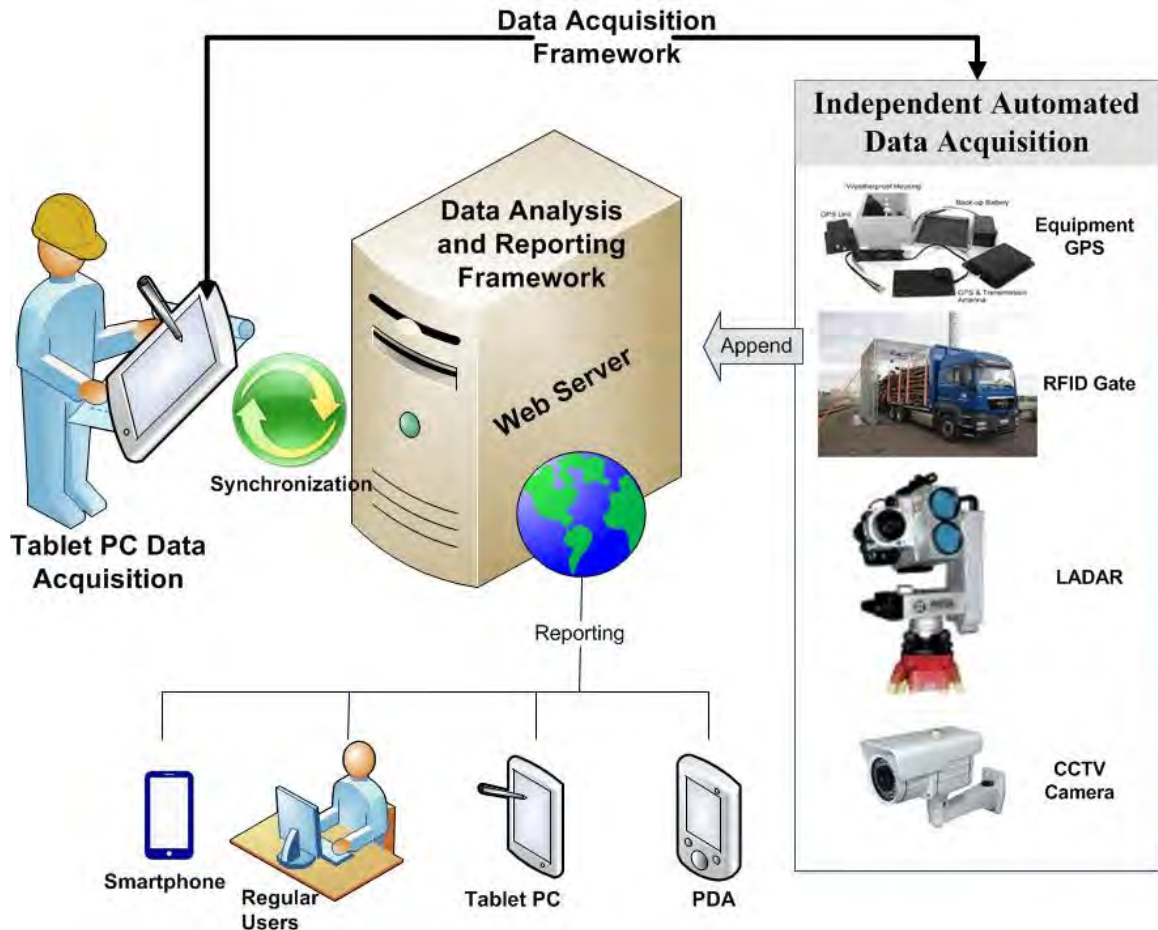


Figure 3-4: Developed Model

The data acquisition framework captures onsite data through two main components. The first component is done through an onsite monitoring person, equipped with a tablet PC. The tablet PC has the 4D BIM of the project to provide visualized presentation that represents the status of construction work. As well, the tablet PC includes data acquisition technologies to enable the onsite personnel of capturing data in real time. The tablet PC has barcode reader, RFID reader, GPS, Wi-Fi, Bluetooth, a camera for images and videos and a speaker microphone for voice recording.

The second component of the data acquisition framework includes the “Independent Automated Data Acquisition Technologies”. It consists of diverse technologies such as GPS units, RFID readers fixed on project gates, LADAR and Closed Circuit Television (CCTV) cameras. This component is flexible enough to host additional data acquisition technologies besides the ones that already exist. Both components of the data acquisition framework collect the onsite progress data and send it to the data analysis and reporting framework, which is on a web server containing the previously captured data from the automated data acquisition technologies and all project information. The captured data is used to represent the actual progress, which is then compared to the as-planned baseline progress, using earned value analysis (EVA) to measure the project’s performance. The data analysis and reporting has four main modules. These modules are central database, performance measurement module, earned value analysis module and reporting module. Through that framework, the data is stored and analyzed. Then, the updated data is generated to be sent back to the data acquisition framework on the tablet PC for the next update cycle. Reports at project, activity, and resource levels are produced and sent via internet to project team members.

The project activities tracked through this model are clustered into three main categories:

- “Units Activities”: This category includes electromechanical equipment, curtain walls, precast concrete panels, etc. These activities consist of units tracked through tracking its attached low-cost UHF passive RFID tags. Materials belonging to these activities are tagged using RFID labels or RFID encapsulated rugged tags, which are attached via screws or epoxy adhesive according to the specifications of each material. The process of material tagging is conducted at the fabricator's shop with ID similar to the one in 3D BIM model. For packed material such as wood doors and frames, gypsum board panels, etc., it is tagged using printed label RFID tags. Two tags are used, one for the pack as a whole to include

information about the packed quantity at delivery and another printed label tag attached to each item in the pack. On the other hand, materials such as bricks and bulk ones are not tracked using such method. However, other techniques are used to track this category. Tracking the tagged material “Units Activities” is achieved by identifying its location through its RFID tags. The tracking process starts from the point of on-site delivery of the material until arriving to the installation zone. Upon arrival to its related zone, progress template is then used until the commissioning of the activity.

- “Bulk Activities”: This category includes earthmoving operations, reinforced concrete activities etc. Tracking these activities requires tracking the recourses utilized in these activities as well as tracking the output of the activity. For instance, in earthmoving operations, three different tracking methods were developed utilizing different technologies. The first tracking method utilizes GPS mounted on hauling trucks and Geographical Information System (GIS). The second tracking method deploys RFID gates in dumping and project areas. Finally, RFID and control sensor are integrated to track also earthmoving operations. The three methods achieve the part of tracking the input to the activity. Tracking the output is done through erecting weighting sensors to hauling trucks to quantify the amount of soil inside the truck. Else, LADAR and cameras are used to scan the site on daily basis to quantify the total amount of excavated soil.
- “Finishing and Non-Spatial Activities”: This category includes painting, floor tiling, calibration, testing and commissioning etc. Activities in this category are tracked by utilizing the integration of 4D BIM model visualization, the tablet PC’s user real-time localization and supported by progress templates on the tablet PC.

3.3 Data Acquisition Framework

As stated earlier the Data Acquisition Framework consists of two main separate sources for capturing the required data: 1) the independent automated data acquisition and 2) the tablet PC data acquisition, as depicted in Figure (3-4). The first collects data using GPS, RFID gates, CCTV cameras and LADAR. Then, the data is transferred automatically to the web server for storage and processing. This process is totally automated with no human intervention. While the second source, the tablet PC, collects data with human intervention. The site personnel is equipped with the tablet PC and ready to periodically go through the indoor and outdoor project zones, according to the required reporting frequency, to collect the progress data. Then, the captured data is transferred to the web server, as shown in Figure (3-5). The following section focuses on the process of tablet PC data acquisition.

3.3.1 Tablet PC Data Acquisition

The first step is building a 3D BIM model that includes all project components and information. The indoor and outdoor construction areas are divided into exclusive zones, stored in the 3D BIM model. Then, the 3D BIM is integrated with the project schedule to generate the 4D BIM model (Montaser and Moselhi, 2012 c). The user walks both inside and outside onsite collecting the progress data utilizing the automated data technologies capabilities of the tablet PC. For indoor activities, the tablet PC is utilized to identify the location of the site personnel collecting data.

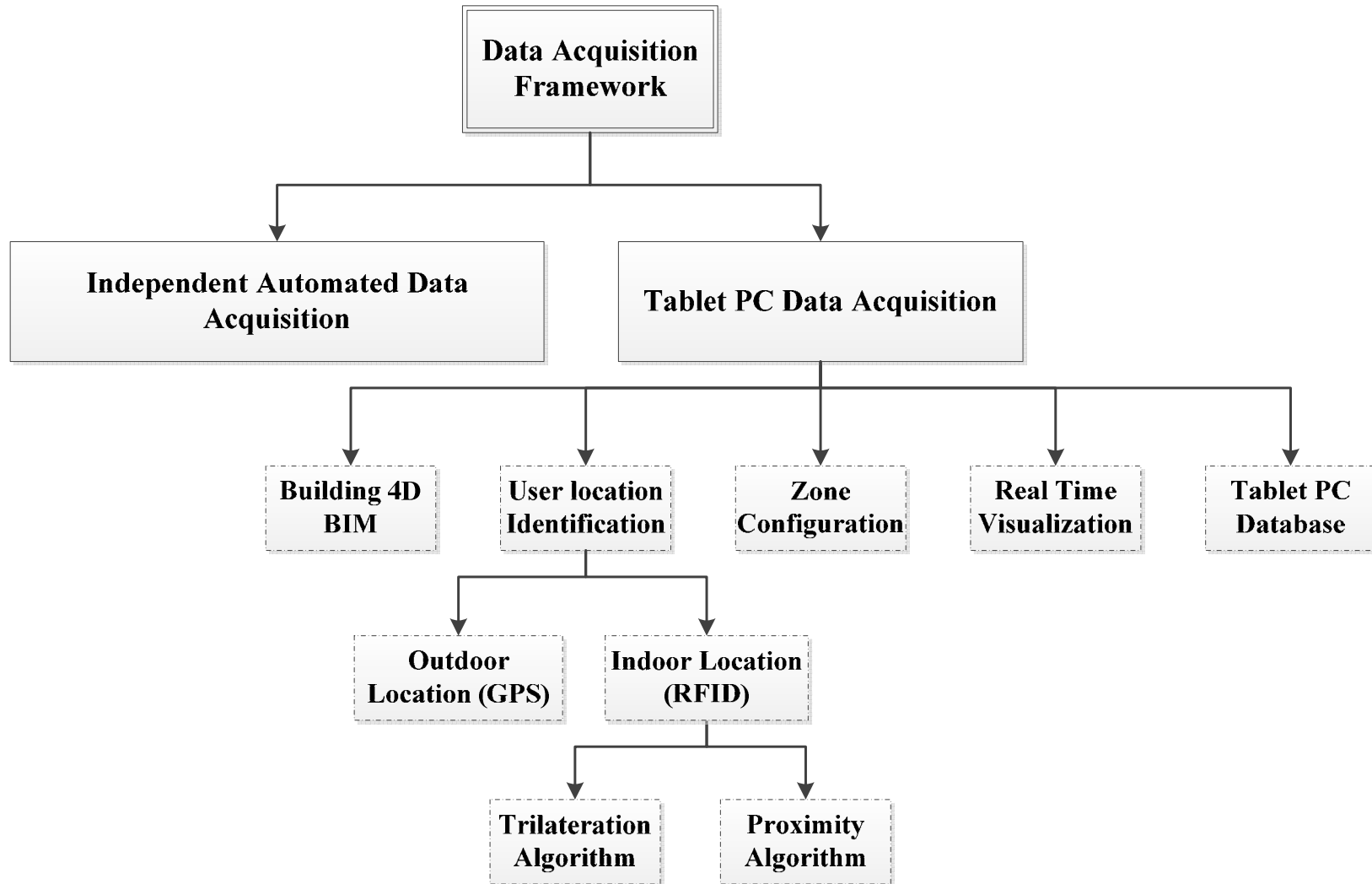


Figure 3-5: Data acquisition framework overview

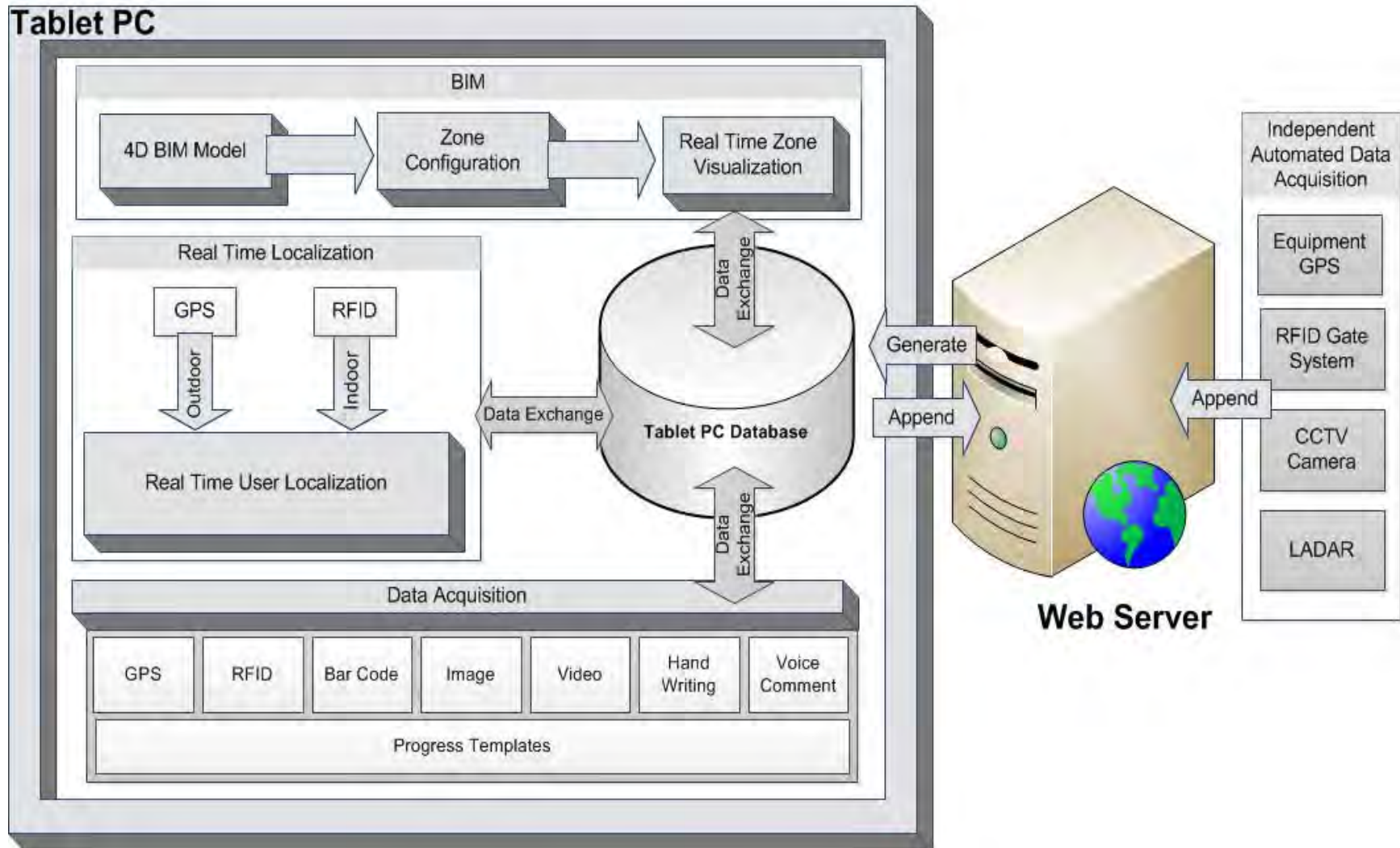


Figure 3-6: Data acquisition framework architecture

This location identification is done utilizing the RFID reader and the low-cost previously attached reference passive RFID tags, as indicated in Figures (3-6). Having identified the user's current location, the following steps are followed:

- Based on the location identified, the zone is retrieved from the 4D BIM model and isolated in 3D to visually display to the user on the tablet PC the current zone. In each zone, the user then utilizes the tablet PC capabilities to capture data in various formats such as scanned RFID data and barcode data, as well as audio records. The user can take snapshots with the camera and write comments and notes about these zone related activities.
- The user also fills out progress templates related to the current zone. These templates contain lists of the ongoing activities and unchecked finished activities that guide the user to where the input is needed. Moreover, these templates could have the as-planned pictures extracted from the 4D BIM, visually representing the zone and highlighting the ongoing activities. The user utilizes the templates for data input for those activities where applying automated site data acquisition technologies would be costly and technically impossible. For example, if the barcode is not accessible or the illumination is too low to take an image.
- The captured data from each zone is linked to its respective spatial zone in the tablet PC database. This data is also used for documentation purposes and then synchronized with the web server for online data storage. The 3D BIM thus becomes richer in its as-built data and the user can access and search this well organized and documented data easily. This data gained two new attributes, which is the date/time it was captured in and the zone it was captured from. Then, project manager can access and analyze this data for different purposes such as progress, safety, timing and taking corrective actions if needed.
- After finishing the first zone, the model highlights for the user the next zone to go and proceed for data collection. The user could choose the next zone manually or follow the

model recommendations. The former steps are repeated until all zones have been covered and confirmed by the model. Detailed description of the above steps is described in the following five subsections.

3.3.1.1 Building 4D BIM

4D BIM integrates the building project 3D model and its construction schedule. A realistic project baseline schedule should be developed, including project activities and their early start (ES) and early finish (EF) dates. The 3D BIM model, first, imports the planned data directly from scheduling software such as Microsoft Project, in database format. Figure (3-7) depicts the flowchart of the procedure used to link the 3D BIM model to project schedule. It then maps the 3D BIM model objects to project schedule baseline activities. As such, different groups of these 3D BIM objects are assigned to its respective activities. Zone progress templates are created for the user based on mapping each activity in progress objects to its related zone. Figure (3-8) shows the flow chart for manipulating 4D BIM for visualization purposes and the template creation process (Montaser and Moselhi, 2012 a). For each group, a series of decisions are made to classify whether it belongs to a finished activity, an activity in progress or an activity to be executed in the future. Before making these decisions, the user enters the current date. The system compares the current date to the ES and EF dates of each group, and controls each group's visibility accordingly. Future activities, those that have not yet started, are hidden from the developed 4D BIM.

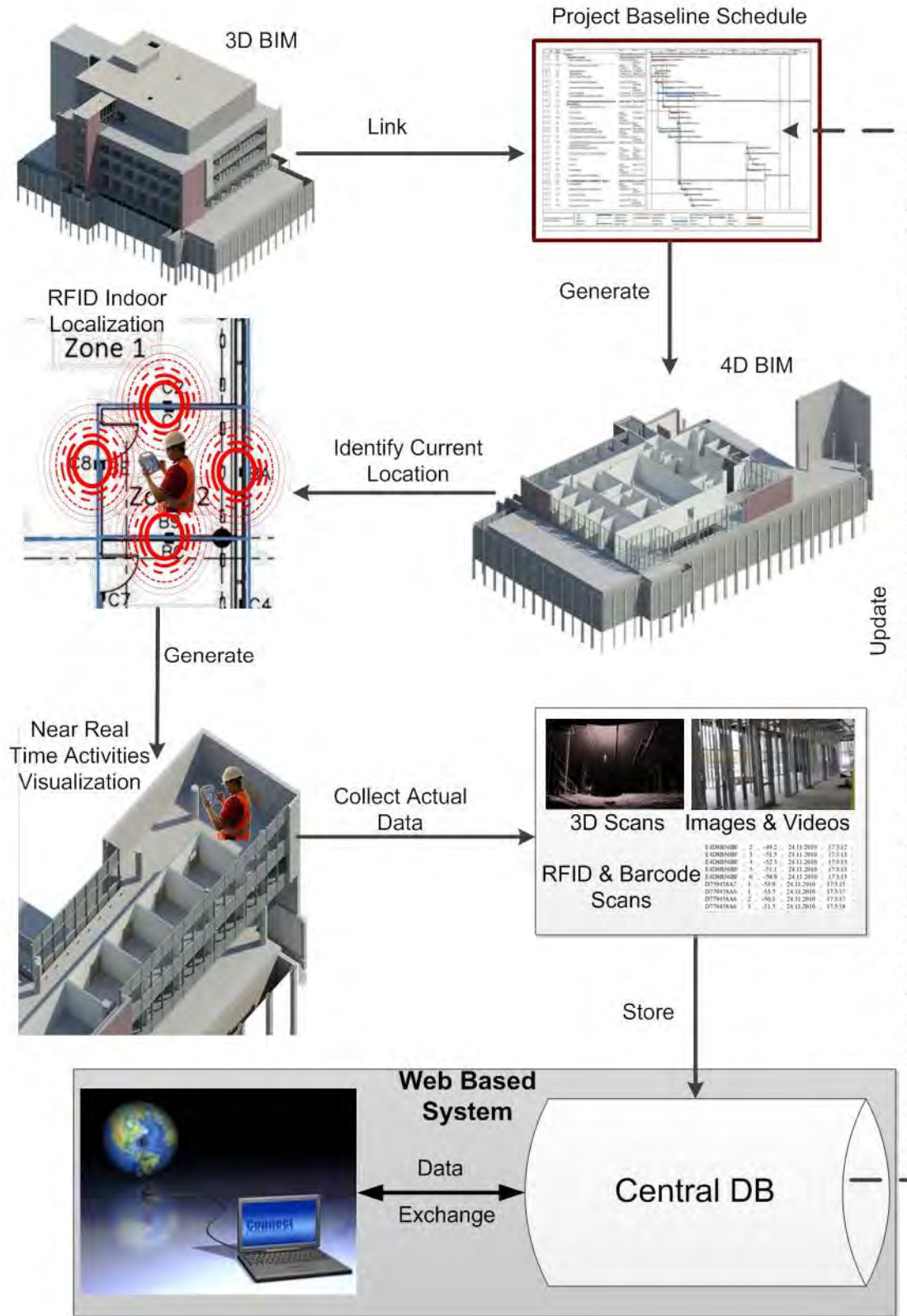


Figure 3-7: Indoor data acquisition (Montaser and Moselhi, 2012 c)

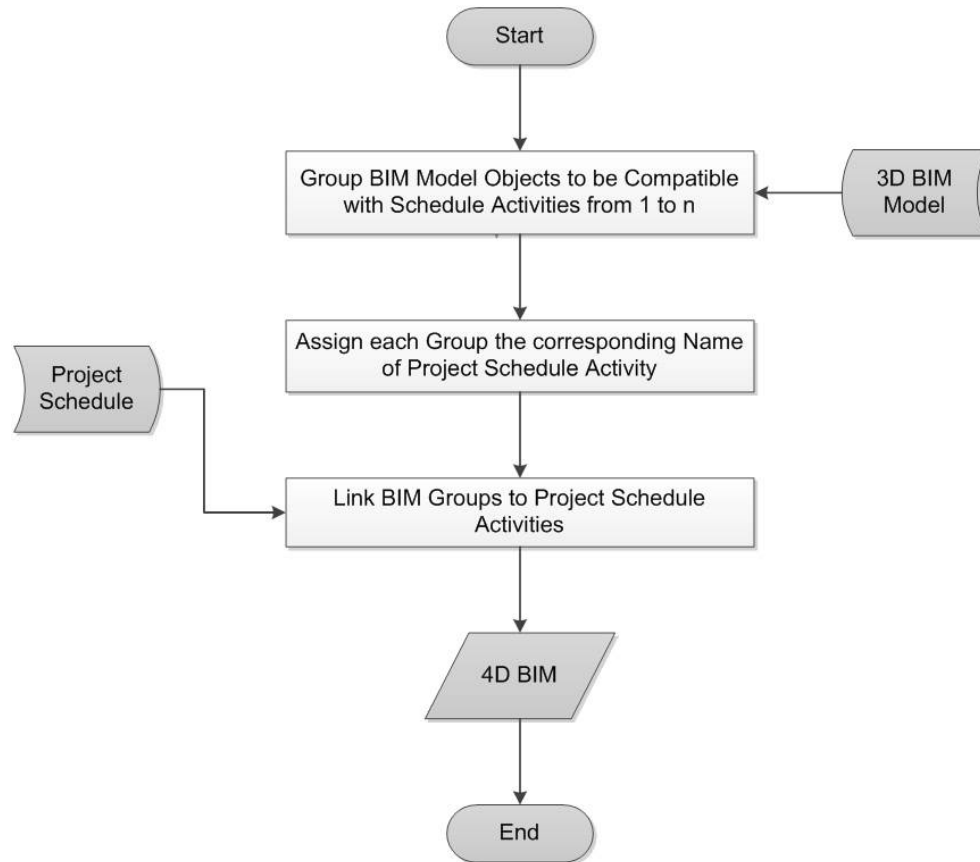


Figure 3-8: Linking the 3D BIM model to project schedule

For finished activities, the 4D BIM checks if each group has been inspected and checked as being finished, or if according to the as-planned schedule it is finished but not yet checked or inspected. The 4D BIM makes the finished and checked activities visible in their final forms, and displays unchecked finished activities in a red highlighted form. The activities currently in progress are displayed in yellow. The activities displayed in red and yellow are divided spatially among identified zones. Therefore, the tablet PC provides the user with the zones where progress data should be captured. In addition, a progress template is generated for each active zone to indicate the status of the red and yellow activities objects as well as the predefined states for each object in a zone, for example objects erected, inspected or commissioned (Montaser and Moselhi, 2012 c).

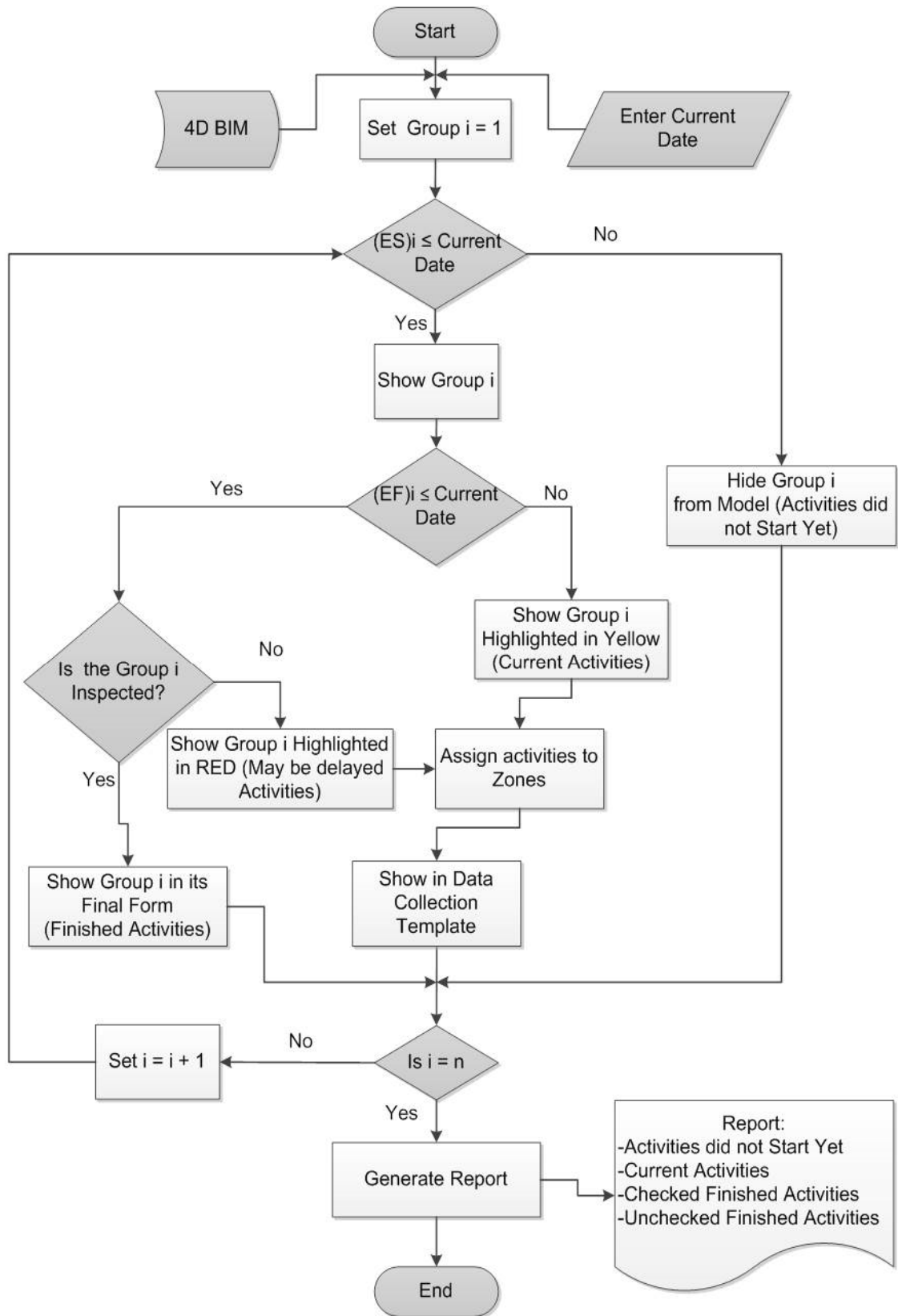


Figure 3-9: The process of 4D BIM model visualization

3.3.1.2 User Location Identification

The identification of site personnel's location is necessary to allow integrating this location with the 4D BIM model to obtain real time location-visualization for the user. For material localization, identification of site personnel's location is vital for project control and progress reporting. A two-step algorithm was developed to identify both user and material locations. The first step in the algorithm is to identify the user current location. Then, the second step in the algorithm is to identify the material location making use of user locations. For outdoor zones, tablet PC's GPS is used to identify user current location. However, it is not feasible to use GPS for indoor zones. Therefore, Ultra High Frequency (UHF) passive RFID was explored in this research to locate user and material's for indoor zones. In addition, RFID is integrated with GPS for outdoor material tracking. Tablet PC's RFID reader is utilized for that purpose. User location includes two cases, the case of an outdoor zone and the case of an indoor zone. The case of outdoor zone location identification is straightforward.

The user starts operating the GPS to receive satellite signals to identify the current location, as depicted in the flowchart Figure (3-9). GPS signals can be affected by several sources of error during transmission. The errors sources include (1) satellite and receiver clock biases (2) ionospheric and tropospheric refraction (3) satellite ephemeris errors (4) multipathing (5) instrument miscentering (6) antenna height measurement (7) satellite geometry (8) receiver noise. GPS errors and correction procedure are described in detail in (Blewitt, 1997). Therefore, a real time data correction is performed. The procedure used in this research is Differential GPS (DGPS) to obtain more accurate results for outdoor localization. Chapter 4 will provide more information about the DGPS procedure followed and the methods used for errors correction.

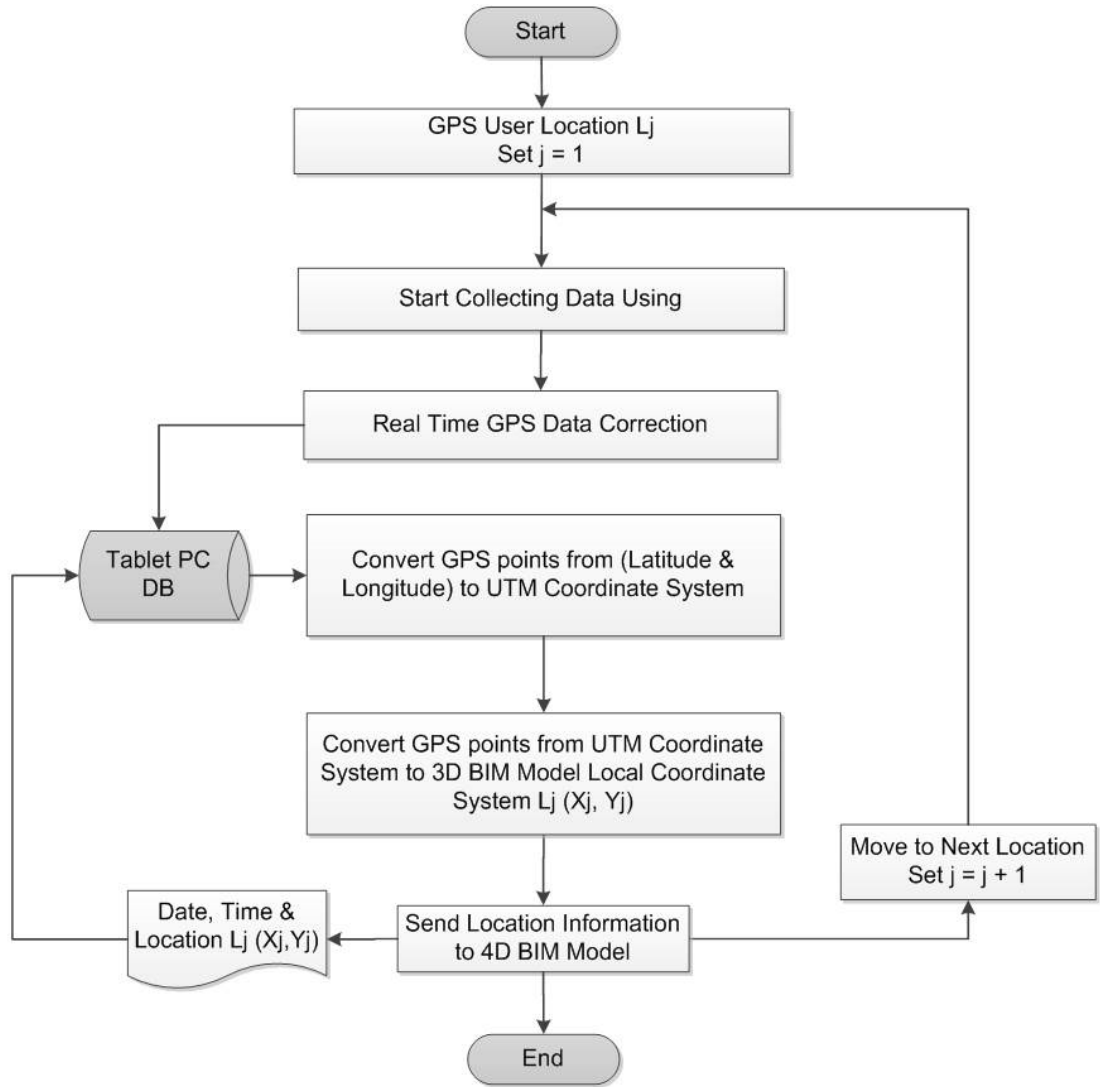


Figure 3-10: GPS user location identification

GPS data at a point is in the form of latitude (Φ), longitude (λ) and height (h), which is mainly a form of astronomical observations (Satellite reference coordinate system). Hence, this data needs to be converted into the Universal Transverse Mercator (UTM) coordinate system, which is a geodetic coordinate system (X, Y, Z). Equations (3.1) till (3.4) make the transformation between the two coordinate systems. In these equations, North latitudes are considered positive and South latitudes are negative. Similarly, East longitudes are considered positive and West longitudes are negative.

$$X = (R_N + h) * \cos \Phi * \cos \lambda \quad (3.1)$$

$$Y = (R_N + h) * \cos \Phi * \sin \lambda \quad (3.2)$$

$$Z = [R_N * (1 - e^2) + h] \sin \Phi \quad (3.3)$$

$$R_N = \frac{a}{\sqrt{1 - e^2 \sin^2 \Phi}} \quad (3.4)$$

In these equations, the World Geodetic System 1984 (WGS84) is used. WGS84 is the standard for use in cartography, geodesy, and navigation in Canada. It comprises a standard coordinate frame for the Earth (the datum or reference ellipsoid). R_N is the radius in the prime vertical of the ellipsoid. In the WGS84, e is the eccentricity of the reference ellipsoid and equals to 0.08181919084, in Equation (3.4). In Equation (3.4), a is the semi major axis of the ellipsoid and equals to 6,378,137 m. Further transformation is performed to transform the captured data into the 3D BIM model local coordinates system. This is done through calculating the vector 3D transformation matrix, refer to the procedure described in Leick (1995). At the end, the user current location L_j (X_j , Y_j) is obtained, as depicted in the flowchart Figure (3-10).

The second case for user location identification is the case of an indoor user. This section is focuses on the use of RFID for localization for indoor zones. In the current two-step algorithm, RFID technology is utilized for capturing spatial data of indoor operations. A number of low cost passive RFID tags are distributed on the jobsite. Each passive RFID tag is used as a reference point with known location (Landmark) within a predefined zone. In this research, reinforced concrete columns, shear walls and wall edges were used as landmarks (Montaser and Moselhi, 2012 d). The indoor construction area is divided into exclusive zones. The known locations of reference tags are used to estimate the location of the user, based on the Received Signal Strength Indicator (RSSI) transmitted from reference tags. The user at a

given location operates the RFID reader at a time t_0 and captures the signals received from the reference and material tags, as shown in Figure (3-10). Where, the squares at the corners represent the reference tags. This process is repeated at a set of time intervals; referred to here as Δt . In the field experiments, Δt ranged from 15 to 60 seconds. The reason for such estimation of Δt for the RFID is explained later in Chapter 5.

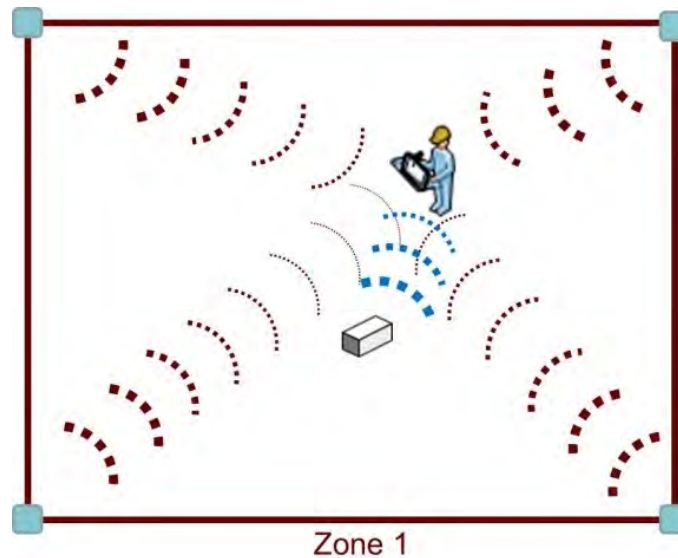


Figure 3-11: RFID reader receives signals

The location of reference tags is identified with subscript (i), and the location of the user (site personnel who carries the mobile RFID reader) is identified with subscript (j). Subscript (k) is used for tracked material temporal location onsite and subscript (f) is used to represent the final location of a tracked material, obtained directly from the project's 3D BIM model. Figure (3-11) illustrates the process of deploying RFID reference tags, which starts by assigning RFID reference tags to each zone's landmarks. The coordinates (x_i, y_i) of each reference tag (i) are then stored in the tablet PC database. All reference tags are deployed at the same height. This step is performed once per floor and is used as the input for location identification.

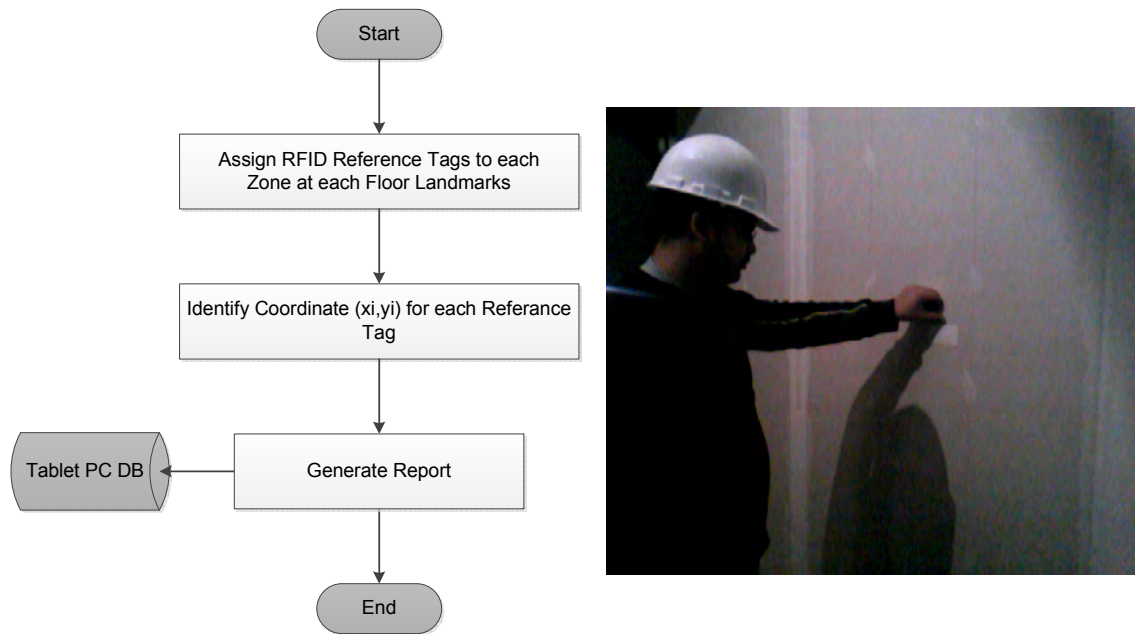


Figure 3-12: The process of deploying RFID reference tags

Tag ID is used to distinguish RFID reference tags from material tags. Tablet PC database is used to filter these tags based on their respective IDs, and to ensure the use of signals from related reference tags only. If a tag ID is for tracking material, then it is stored in the database to be processed later along with its related data. However, if the tag ID is not a reference tag or a material tag, then it is ignored along with its associated information. Trilateration and Proximity algorithms were used to identify both user and material locations. Both algorithms are considered as RSSI based localization algorithms. The following section explains in detail how both were utilized to achieve the first step of the two-step algorithm to identify the user current location for indoor zones (Montaser and Moselhi, 2013 a).

In the “Trilateration Algorithm”, user’s location L_j is identified location with coordinates (X_j, Y_j) using signals captured from reference tags, as shown in Figure (3-12). As a result, the coordinates of the unknown user is obtained as in Equations (3.5) and (3.6).

$$x = -\frac{1}{2} \frac{(d_1^2 - y_1^2 - x_1^2)(y_2 - y_3) + (d_2^2 - y_2^2 - x_2^2)(y_3 - y_1) + (d_3^2 - y_3^2 - x_3^2)(y_1 - y_2)}{x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)} \quad (3.5)$$

$$y = -\frac{1}{2} \frac{(d_1^2 - y_1^2 - x_1^2)(x_2 - x_3) + (d_2^2 - y_2^2 - x_2^2)(x_3 - x_1) + (d_3^2 - y_3^2 - x_3^2)(x_1 - x_2)}{y_1(x_2 - x_3) + y_2(x_3 - x_1) + y_3(x_1 - x_2)} \quad (3.6)$$

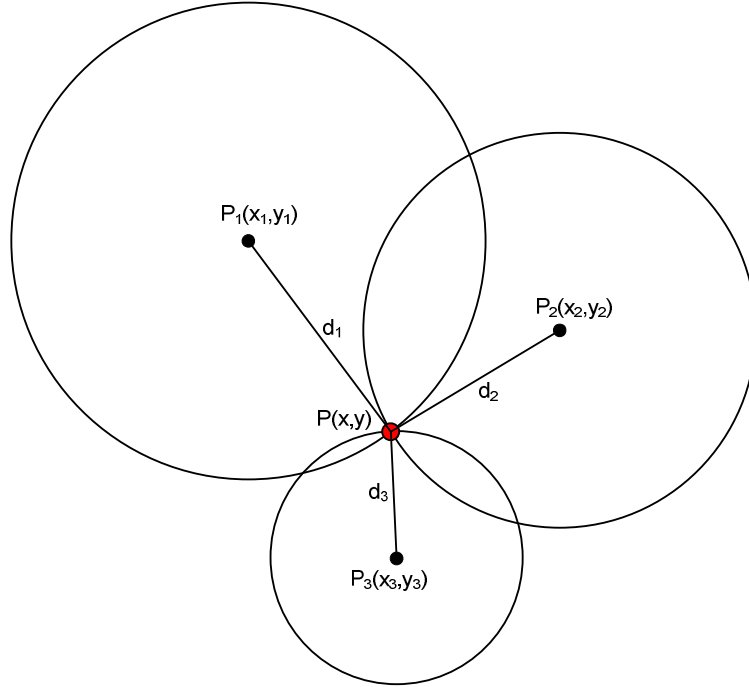


Figure 3-13: User location identification using trilateration algorithm

However, with imperfect information and inaccuracy in the path loss model (i.e. $R2 \neq 1$) the circles do not intersect at a single point. In this situation, the intersection of the three circles is an area, as shown in Figure (3-14). The centroid of that area is the user location as calculated in Equations (3.7) and (3.8) (Sarda, 2011). The algorithm applies trilateration method after filtering reference tag data, as in the flowchart shown in Figure (3-14). The trilateration method requires a path loss model to convert RSSI to distance (d). The developed path loss model is explained in Chapter 4.

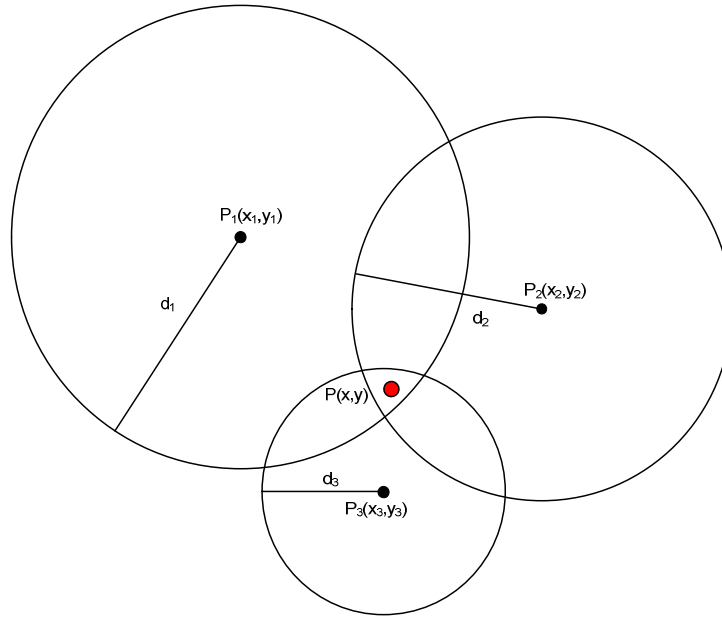


Figure 3-14: User location identification using trilateration algorithm with imperfect path loss model

$$X1 = \frac{[(d_1^2 - d_2^2) + (x_2^2 - x_1^2) + (y_2^2 - y_1^2)] * 2 * (y_3 - y_2) - [(d_2^2 - d_3^2) + (x_3^2 - x_2^2) + (y_3^2 - y_2^2)] * 2 * (y_2 - y_1)}{(2 * x_2 - 2 * x_3) * (2 * y_2 - 2 * y_1) - (2 * x_1 - 2 * x_2) * (2 * y_3 - 2 * y_2)} \quad (3.7)$$

$$Y1 = \frac{(d_1^2 - d_2^2) + (x_2^2 - x_1^2) + (y_2^2 - y_1^2) + x * (2 * x_1 - 2 * x_2)}{(2 * y_2 - 2 * y_1)} \quad (3.8)$$

The trilateration method determines the position of the user by measuring the distance from several reference tags. All the readings collected from each reference tag are averaged and converted into equivalent distance (\$d_i\$) using the path loss model. When the localization algorithm identifies at least a set of three distances from three different reference tags, the algorithm generates circles; their centers are the known positions of the reference tags (\$x_i, y_i\$). The intersection of these circles determines the expected signal source's location. If the intersection is not at a point, but rather an area, the center of gravity (C.G.) of that area is used instead. The coordinates of the user could be calculated (\$X_j, Y_j\$) accordingly. It is worth noting that, in many cases, there is more than one intersection area.

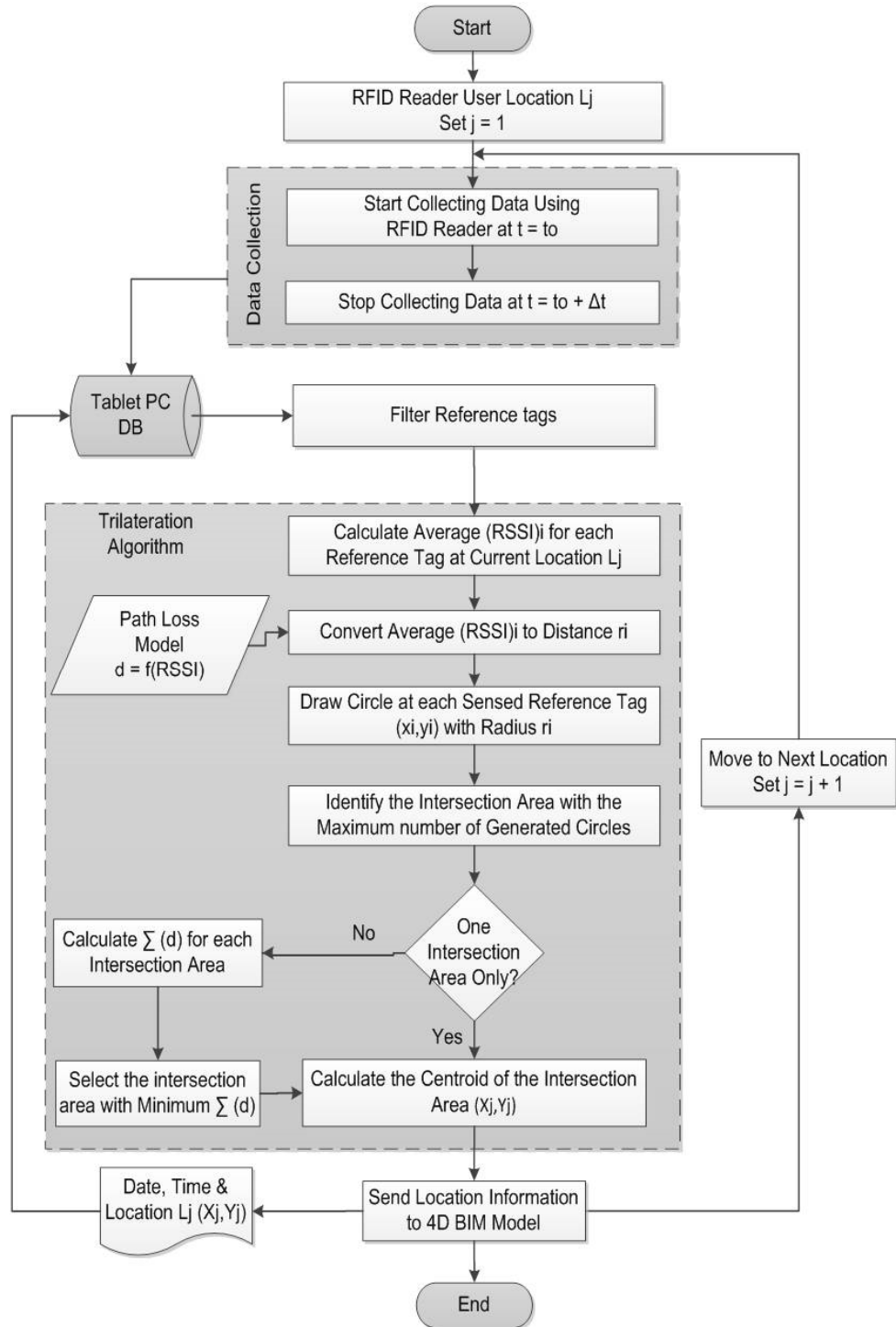


Figure 3-15: Trilateration algorithm (Montaser and Moselhi, 2013 a)

In such cases, the following heuristic rule is applied: “If more than one area of intersection exists, then the C.G. of the area formed by the circles having the least summation

of their radii is used". This rule acts as a useful filter, removing noisy out-of zone-signals. The user moves to the next location in the same zone or to another zone on the jobsite and the same procedure is repeated. The generated location $L_j (X_j, Y_j)$ is stored in the tablet PC database with its corresponding time for further utilization in the second step of the algorithm for material localization. Figure (3-13) depicts the user standing in a zone surrounded by three reference tags with coordinates (x_1, y_1) , (x_2, y_2) and (x_3, y_3) and corresponding average signal strength (RSSI) 1, (RSSI) 2 and (RSSI) 3. This provides sufficient data to determine the user location (X_1, Y_1) .

In the "Proximity Algorithm" the same data collection steps that were followed in the trilateration method are repeated in this algorithm. However, the proximity algorithm uses RSSI as a weighting method to express how near the reader is to the reference tags. RSSI is a measurement of the power present in a received radio signal. Therefore, the higher the RSSI number (or the less negative in some devices), the stronger the signal is, meaning that the user is closer to that tag. For example, if there are two reference tags and the user received RSSI equals 30 from the first tag and 40 from the second tag, as shown in Figure (3-15 a). Then the user location is on the line connecting the two reference tags and more near to the RSSI 40 tag, as shown in Figure (3-15 b). However, if there are a third tag and the user receiving 35 RSSI from it; see Figure (3-15 c). Then the user location is in the middle between the three tags and the location is calculated according to the weighted average of RSSI received from each reference tag, as shown in Figure (3-15 d). The readings collected for each reference tag were averaged and converted into a related weight (W_i), which represents how much closer the reader is to that tag, as shown in Figure (3-16). The coordinates of the user (X_j, Y_j) are calculated using Equation (3.9).

$$X_j = \frac{\sum_{i=1}^n x_i * W_i}{\sum_{i=1}^n W_i} \quad \& \quad Y_j = \frac{\sum_{i=1}^n y_i * W_i}{\sum_{i=1}^n W_i} \quad (3.9)$$

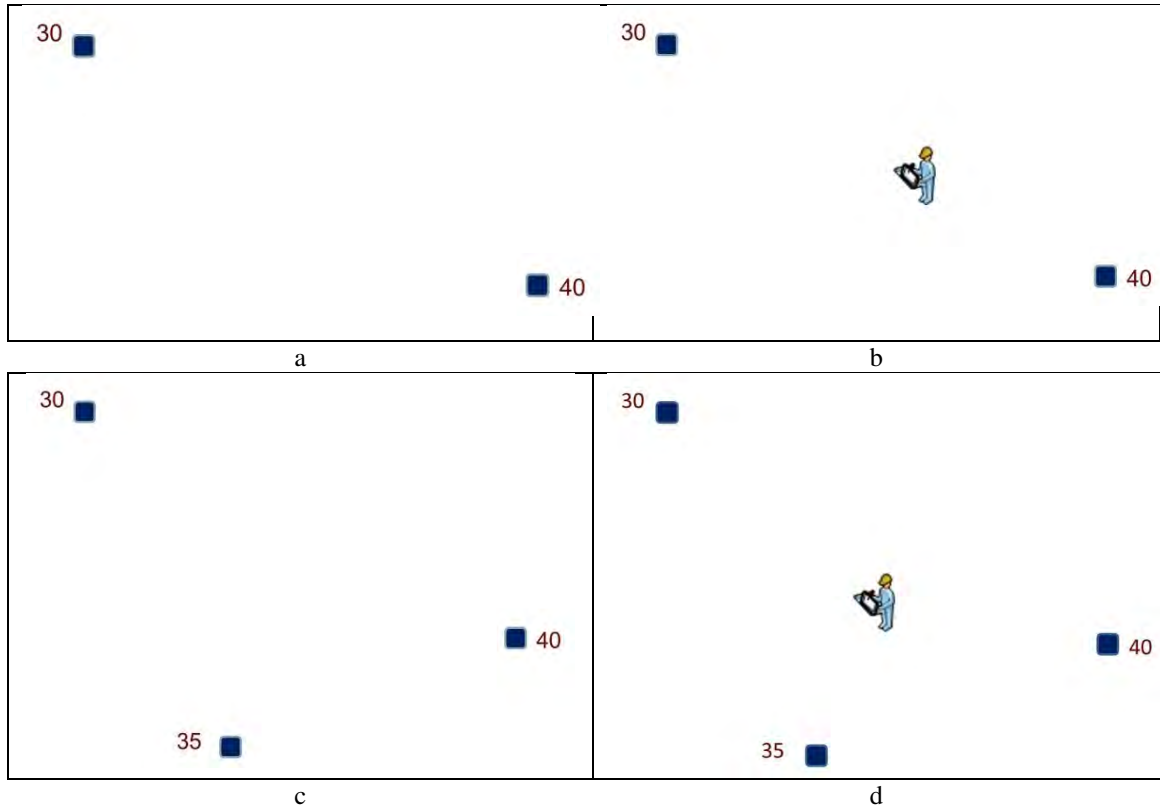


Figure 3-16: Proximity method concept

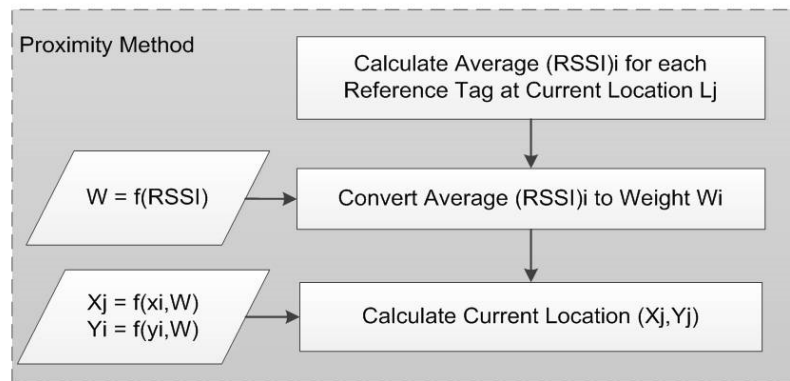


Figure 3-17: Proximity algorithm (Montaser and Moselhi, 2013 a)

3.3.1.3 Zone Configuration

Project zones are main ingredient to the developed model for the part of localization and 4D BIM integration. However, project zones are not a static boundary. On the contrary, it evolves with time during the project construction. During construction of a given floor in a project, there is an important time (t) that changes the approach for zone configuration. This time marks the commencement of floor dividing activity (i.e. partitions) such as gypsum board or brickwork interior walls activity. Before the beginning of this activity, the floor is an open big space. However, when this activity starts, the floor is divided into architectural spaces (rooms and corridors). For each floor, two plans are created, one before the beginning of floor dividing activity and is called “Area Plan”. The other plan is called “Floor plan”, which is used after the floor dividing activity starts, as depicted in Figure (3-17).

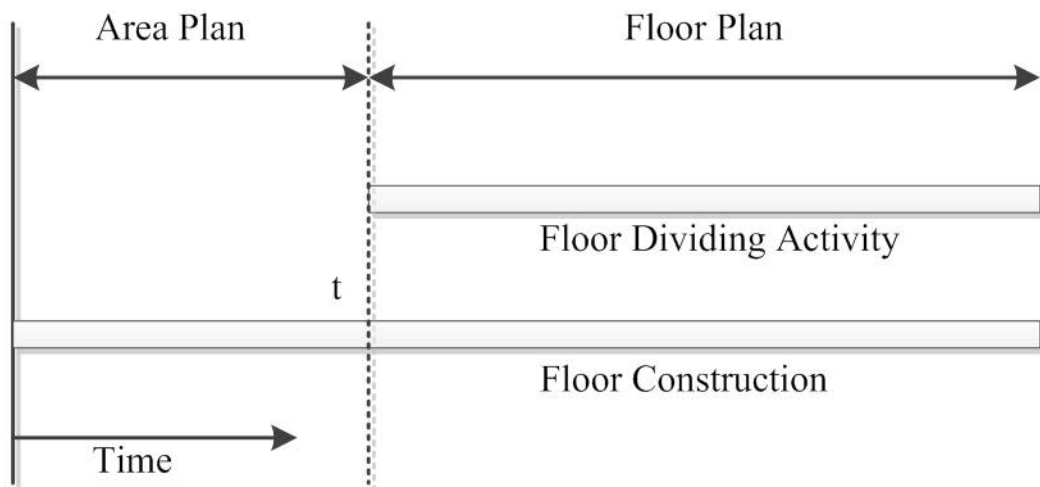


Figure 3-18: Zone Configuration with time

Floor plan resembles the architectural zoning of the floor after construction of the dividing activity. However, in the area plan, the user defines the zones without having to abide by the spaces that will be formed after the floor dividing activity commences. Before the beginning of the dividing activity, most of the work in the floor is electromechanical work.

Figure (3-18) shows the difference between both plans, where the area pan has four zones and the floor plan has eight zones. The concept of area plan is used also for outdoor areas and roofs, where there is no architectural zoning for this area. The concept of area plan creates fewer zones and saves time and effort during inspection and data collection. However, the area and floor plan model only the 2D requirement for identifying the zone. For indoor zones, the height from the slab soffit until next floor slab soffit is considered the third dimension of the zone. For outdoor zones, the third dimension equals the height from the foundation level until the roof level.

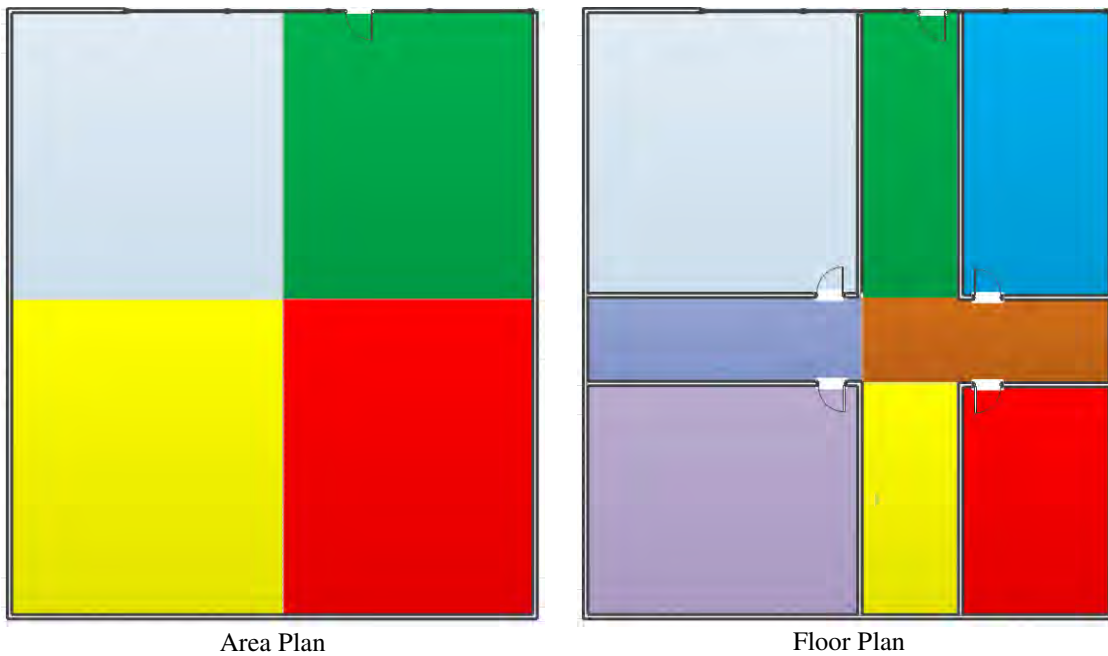


Figure 3-19: Area plan and floor plan

3.3.1.4 Real Time Visualization

Real time visualization allows the user to visualize the current zone in the developed 4D BIM model to capture progress data. The ingredients for real time visualization are zone configuration, 4D BIM model, activity (objects) and the user identified current location, as shown in Figure (3-19). Therefore, the steps for this type of visualization start by specifying the date for data collection, as depicted in Figures (3-20) and (3-21).

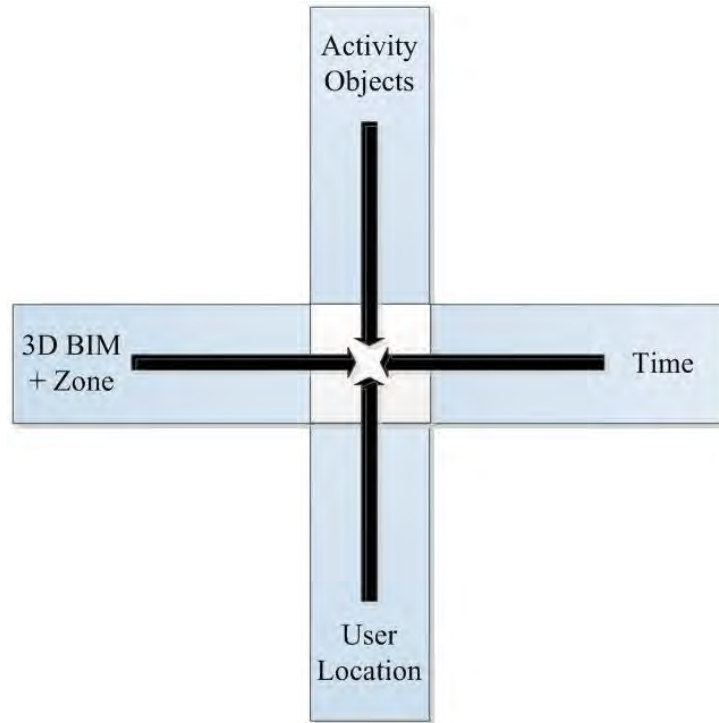


Figure 3-20: Real time visualization ingredients

4D BIM model visualization changes according to the specified date. Afterwards, the user should specify whether he is capturing data in an indoor or outdoor environment. RFID or GPS is then utilized based on the user decision to specify the user location, zone and floor if he is indoor. In case the user is outdoor, area plan is utilized for real time visualization. If the user is indoor environment, the utilization of floor plan or area plan is decided based on the specified date entered earlier. Then, the user's current zone is isolated in the 4D BIM model. The isolation process is conducted through applying bounding volume to the current zone. The shape of that volume is decided in 3D based on the zone configuration described earlier. The application of zone bounding volume supports the process of identifying objects from the 4D BIM model that resides inside that volume.

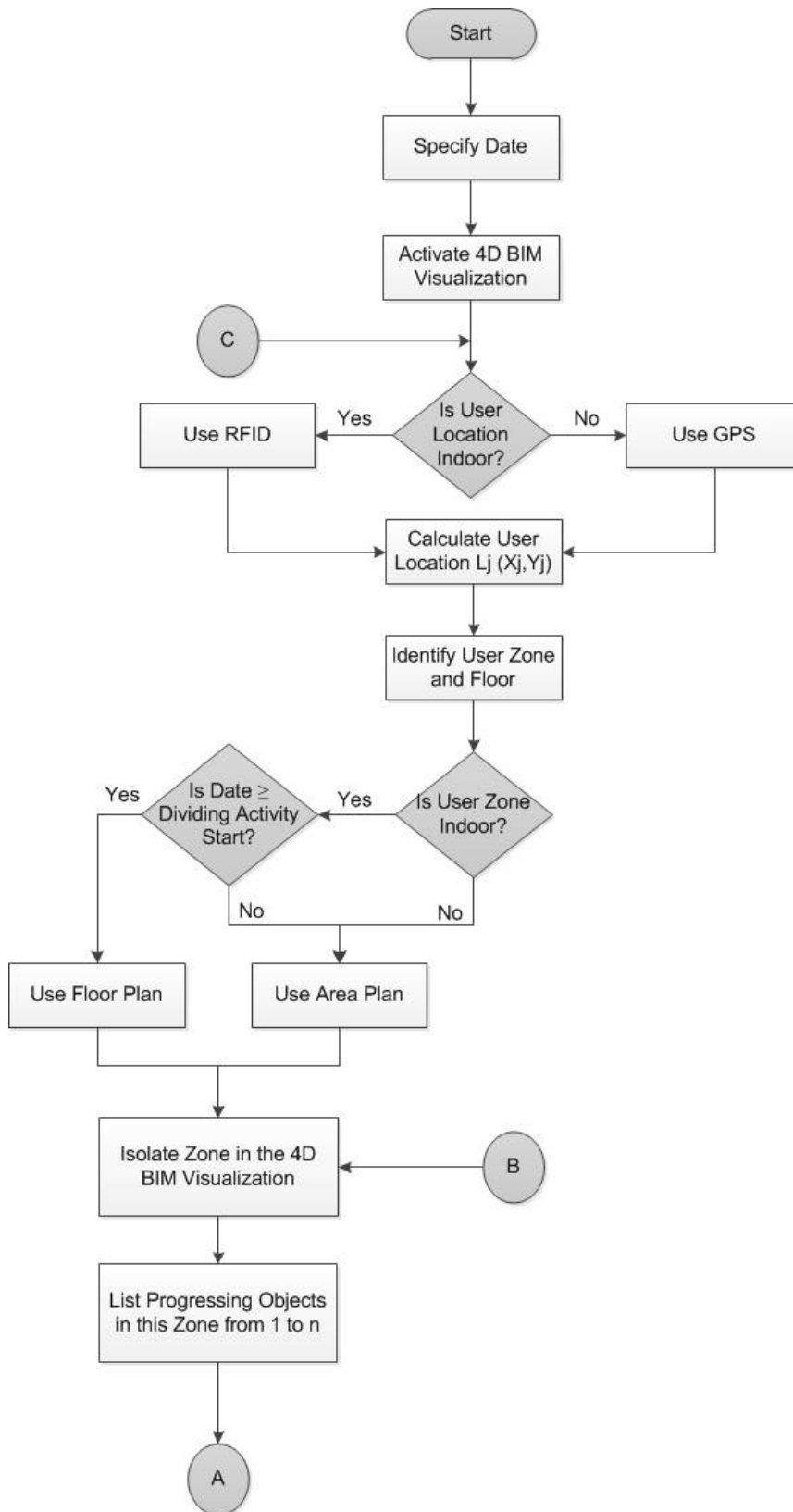


Figure 3-21: The process of real time visualization (part 1)

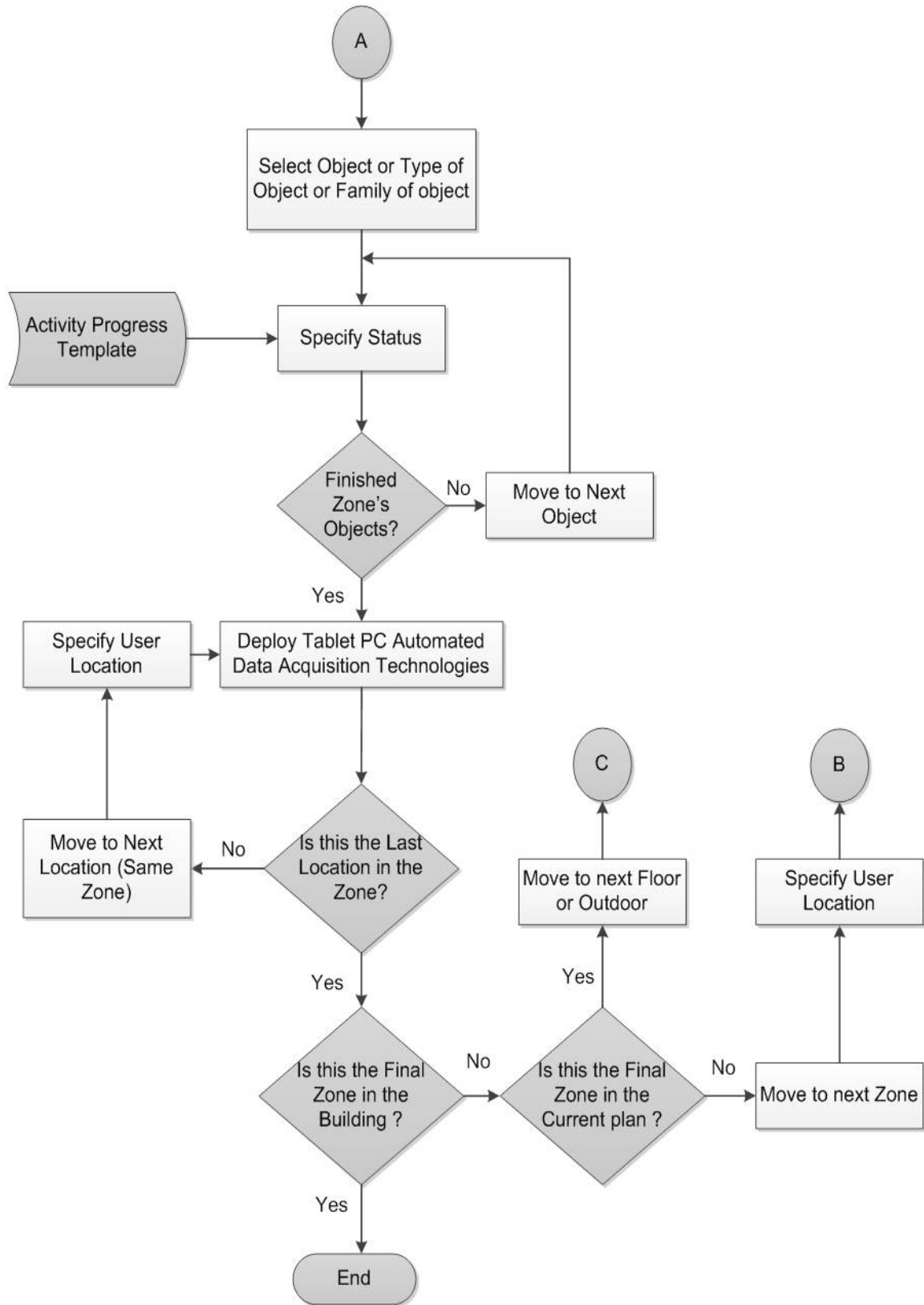


Figure 3-22: The process of real time visualization (part 2)

Afterwards, a list of progressing objects appears for the user based filtering only the objects that belongs to activities in progress inside the current zone bounding volume. Then, the user is asked to specify those objects' status. The user can select object from that list based on specific criteria. For example, the user can select circular concrete column with certain diameter or select all circular concrete columns with certain diameter or all concrete columns in that zone. This facilitates the data collection process for the user. Since, the selected object or objects belongs to the same activity, then progress templates provide for the user an easy way to specify objects' progress status.

After using progress templates for tracking objects under progress in this room, the user can use the tablet PC automated data acquisition technologies such as using barcode reader, taking images or videos for the zone, recording voice or taking hand written notes. Afterwards, the user can choose to move to the next location in the same zone to capture additional data. Knowing that, the user should at least capture data from each zone from three different locations not at the same line, as will be explained later in section (3.4.1.1) for material localization. When the user finishes capturing data from all locations in a zone then the developed model checks if data has been captured from all project zones or not yet. If not all zones are inspected, the model guides the user to the next step. This loop continues until the user finishes all project zones and captures their respective data through automated data acquisition technologies and progress templates.

3.3.1.5 Tablet PC Database

This database is considered the core of the tablet PC data acquisition, and is designed to organize and store all the data captured from the construction site. The database consists of sixteen entities (or tables) such as project, zone, reference tags, tablet PC, GPS files, RFID reader file and user location entities. Figure (3-22) shows the entity relationship diagram for

the developed database. Entities are basic objects with an independent physical or conceptual existence. Relationship types involve one-to-one (1:1), one-to-many (1:M), and many-to many (M: N) relationships. Key attributes are used to distinguish entities. Each entity has a unique identifier called a primary key, where a key can be a single attribute or a combination of several attributes (a composite key). In addition, an auto number data type could be employed as a primary key for the entities.

The ID's of the projects along with their characteristics (duration, location, budget...etc.) are considered as the attributes for the project entity. The project entity is considered as the origin of the database and all other entities stem from it. Project entity attributes are user input. The project consists of many zones that are classified as indoor or outdoor. The zone ID and the floor number define the Zone entity primary key. These zones are extracted from the 3D BIM model and its floor and area plans. Since, the project has many zones. The relationship between project entity and zone entity is one to many. In each zone, RFID reference tags are attached on each zone's landmarks. Therefore, the connecting relationship between the zone entity and reference tag entity is one to many as well. The RFID reference tag entity has three main attributes. The user enters those attributes and they are tag ID, xi and yi, which represent the coordinates of the tags with respect to the BIM model local coordinate system. It should be noted that as more than one tablet PC can be used for a project, the relationship between project entity and tablet PC entity is one to many. All tablet PCs incorporate different ID numbers along with their automated data acquisition technologies such as GPS and RFID reader. The user enters tablet PC attributes.

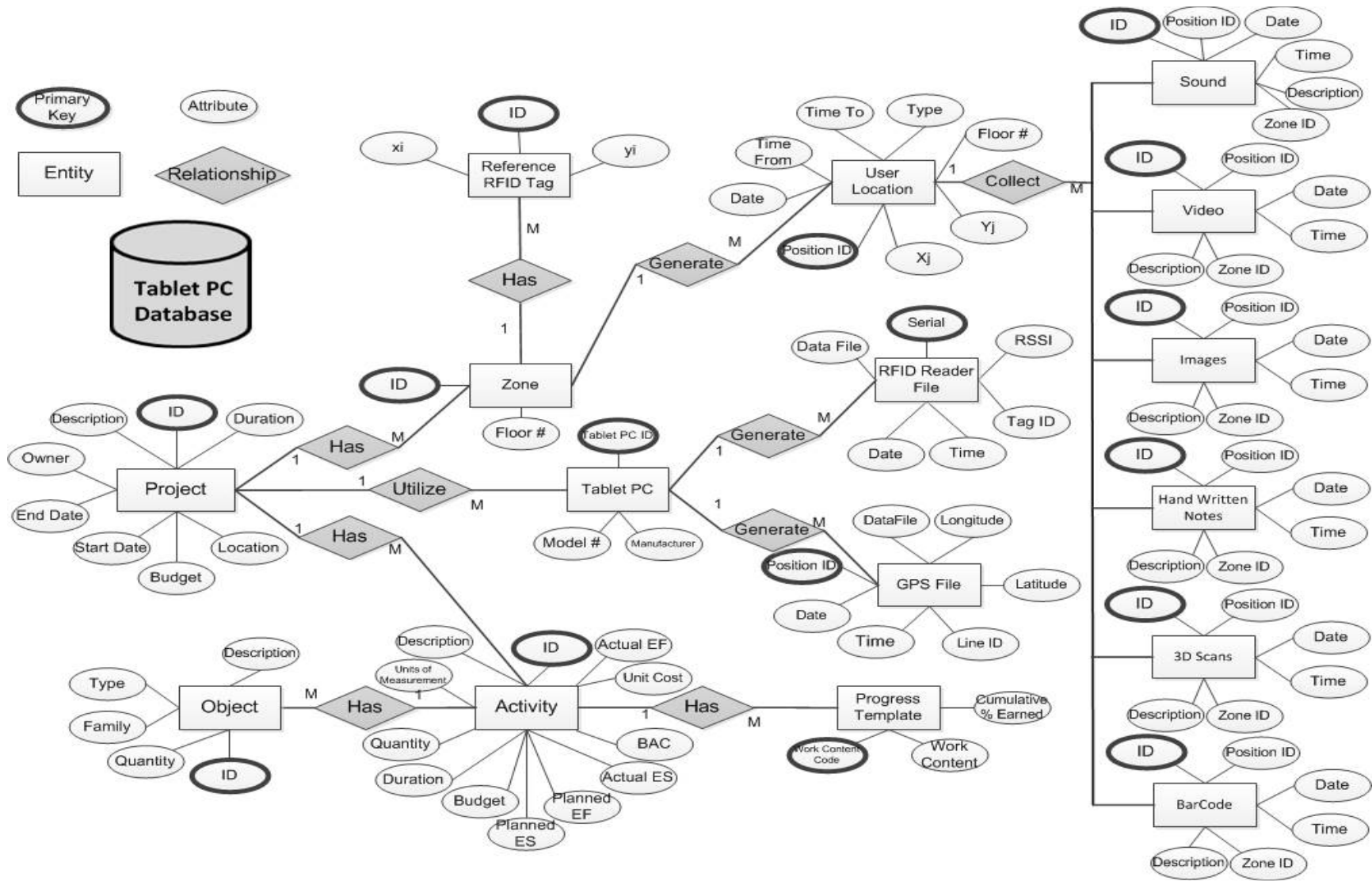


Figure 3-23: Tablet PC database entity relationship (ER) diagram

Project entity is connected to activity entity through one to many relationship. Activity entity represents the project scope of work on time phase. Consequently, it is actually the project schedule and units of measurement and quantity of work. The scheduling tool provides the attributes for this entity such as planned dates and description. The activity's quantity is extracted directly from the 3D BIM model. Each activity is divided spatially in the 3D BIM model into objects. Therefore, the relationship between the object entity and activity entity is many to one. This entity and its related attributes are extracted from the 3D BIM model. The extracted data includes geometrical properties of the object such as length, surface area and volume. Therefore, it is necessary to select one of these attributes that exactly matches the units of measurement of the activity. For example, if the activity quantity is measured in (m³) then the quantity of the object extracted from the 3D BIM should be in (m³) too. This procedure facilitates the aggregation of objects quantities to match exactly the activity's total quantity. It is also worth noting that the activity is divided into 3D BIM objects, which is spatially scattered in the 3D BIM zones. Therefore, this relationship among activities, objects and zones is crucial specially when mapping activities in progress to 4D BIM model zones.

When the tablet PC is used in outdoors, the tablet PC's GPS generates GPS file entity identifying the outdoor user location. The relationship between the tablet PC and GPS generated file entity is one to many. Since, the user utilizes the tablet PC in many locations and every location has its own GPS file. The entity data is filled by the GPS captured data. Real time correction and transformation algorithms are applied to the GPS captured data. Then, the identified outdoor user location (X_j,Y_j) is deposited in the user location entity. On the other hand, when the tablet PC is used indoors, the tablet PC's RFID reader generates RFID reader file. RFID reader file entity is considered the main repository for the captured RFID data. It consists of six attributes and they are serial number, tag ID, data file, date, time and RSSI. The

serial number is automatically generated to represent how many records the RFID reader captured. The user current location (X_j, Y_j) is identified through Integrating both the data from RFID reader file entity along with reference RFID tags entity and applying Trilateration or Proximity algorithm in real time. The relationship between the tablet PC and RFID generated file entity is one to many because, the user utilizes the tablet PC in many locations and every location has its own RFID file. The identified indoor user location is stored in the user location entity. This RFID file entity is used later for material indoor localization and tracking. The user location entity is the result of processing the RFID reader file or GPS file. It also specifies the time consumed by the user in this location through “time from” and “time to” attributes. User location entity is connected by many to one relationship to zone entity.

After identifying the user’s location (indoor or outdoor), the user utilizes the tablet to visualize his current zone location via the 4D BIM model. Then, progress templates interact with the user, requesting the status of the zone objects that was mapped earlier to the progressing activities. The user then utilizes the tablet PC’s capabilities, as indicated in Figure (3-23) for documentation of progress. Progress template entity represents the steps for construction activity objects. Therefore, it is connected to activity entity with many to one. Progress templates represent the construction knowledge of the. Since in many cases, it proves to be more efficient and straightforward in jobsite implementation than automated sensors.



Figure 3-24: The process of capturing data using the tablet PC

The data captured are presented in the database using six entities. They are sound, video, image, hand written note, barcode and 3D scan. The first five entities belong to the tablet PC acquisition and the 3D scan entity belongs to the independent data acquisition as described earlier. The designed database allows for 2 types of 3D scanners; one that requires activation from a tablet PC and the other does not. In the first type, the 3D scan entity has to be linked to the user location. In case the 3D scanner works independently, the 3D scan entity has to be linked to the project entity. Since, the user in the same location can capture many data such as images then the relationship between the automated data acquisition technologies entities and the user location entity is many to one. The data collected, in different formats, have two new main attributes, time and location. This procedure facilitates data analysis and retrieval for progress reporting as well as for the remote monitoring of the project status.

3.4 Data Analysis and Reporting Framework

The data analysis and reporting framework consists of four modules: 1) Performance measurement module, 2) Central database module, 3) Earned value analysis module and 4) Reporting module as outlined in Figure (3-24). The process of the developed data analysis is outlined in Figure (3-25). Each of its components is described below. The central database plays a vital role in data exchange. The data exchange takes place between performance measurement module and earned value analysis module. The performance measurement module is responsible for analyzing the project performance through “material localization and tracking” sub-module and “productivity and quantity measurement” sub-module. The reporting and analysis framework is integrated in a web-based platform. The web-based platform interacts with the reporting module inside the web server to generate reports for project team members. The progress templates and the project schedule are updated through the central database utilizing the processed information.

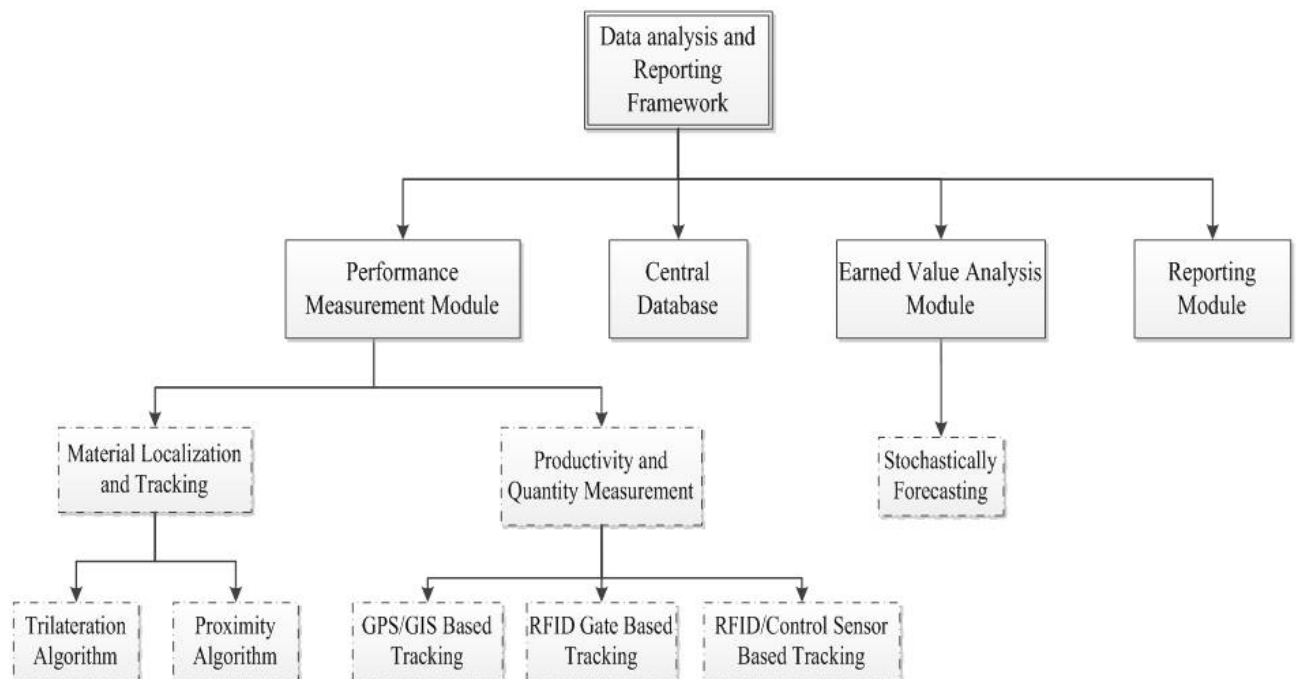


Figure 3-25: Data analysis and reporting framework overview

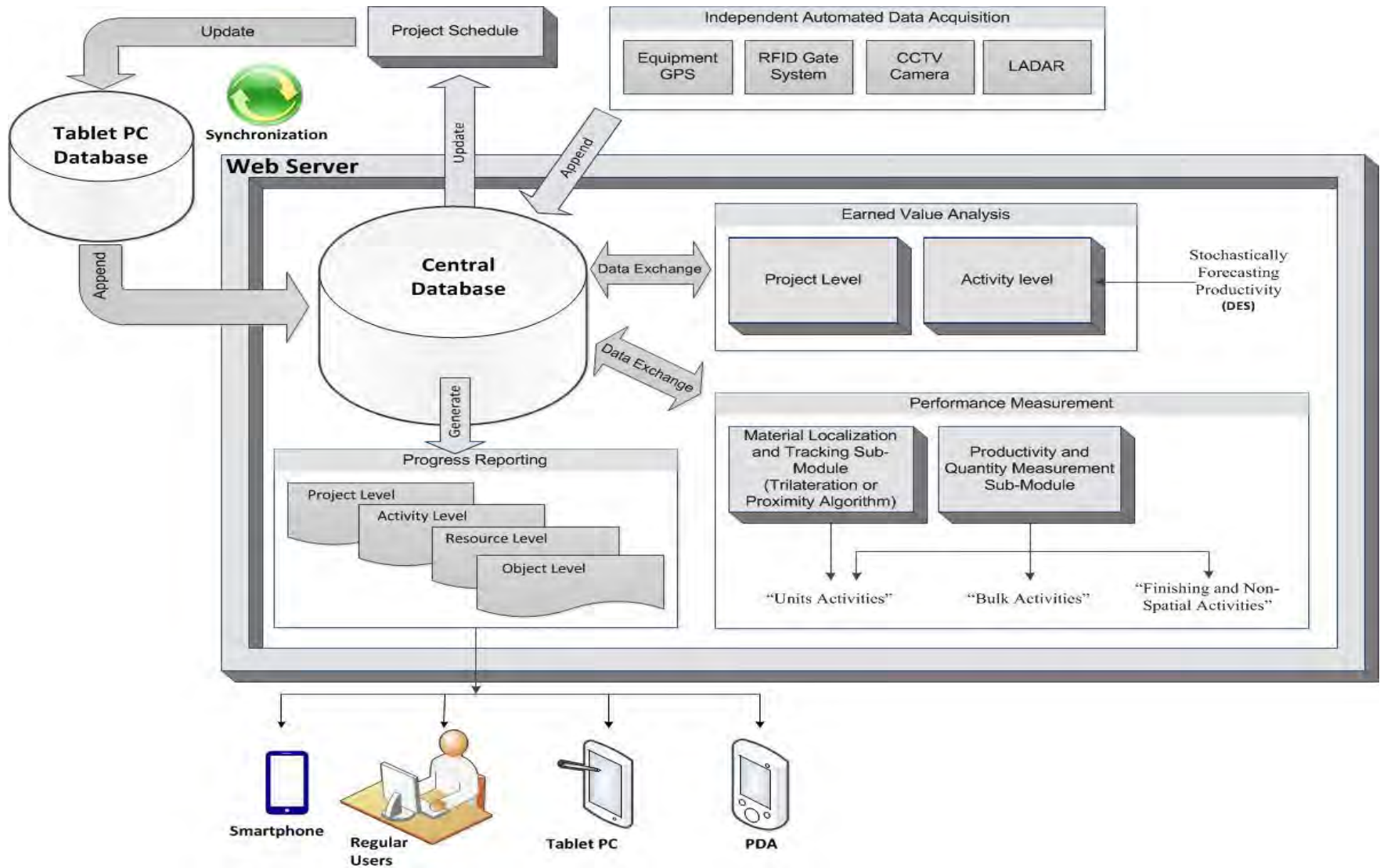


Figure 3-26: Data analysis and reporting framework architecture

3.4.1 Performance Measurement Module

Performance measurement module consists of two sub-modules; “Material localization and tracking” and “Productivity and quantity measurements”. The material localization and tracking sub-module is used to track the “Units Activities”, starting from the time their delivery onsite. After the unit material objects have been located on the final installation zone, the second sub-module, productivity and quantity measurement, takes over. It extracts activities’ different percentage completion from progress templates and extracts activities’ quantities from 3D BIM model to facilitate percentage complete calculation. The productivity and quantity measurement sub-module is used alone to process the data related to “Bulk Activities”, “Finishing and Non-Spatial Activities”. This sub-module calculates the quantities, productivity and percentage complete for those activities. The two sub-modules are described below.

3.4.1.1 Material Localization and Tracking

After delivery of material on site, it is distributed for use at different locations. For both indoor and outdoor zones while the user is in location L_j , the tablet PC’s RFID reader receives signals from material tags. Identifying material's location is the second step in the developed two-step algorithm. The user's location is calculated as described earlier using RFID for indoor zones or using GPS for outdoor zones. However, the algorithm cannot instantaneously calculate the material location (L_k), since it needs signals from different user locations. The trilateration algorithm determines the position of the material by measuring its distance from previously identified user locations. All material readings collected from each user location is averaged and converted into equivalent distance (d_j), using the developed path loss model. When the localization algorithm identifies a set of at least three distances from different user locations, the algorithm generates circles and the centers are the known position of the user

(X_j, Y_j) . Similarly, by applying the same procedure of the first step of the user localization algorithm for indoor zones but replacing reference tags (i) by user location (j) and applying the same heuristic rule, the material location is calculated. Figure (3-26) shows the schematic diagram for applying these procedures for indoor or outdoor zones.

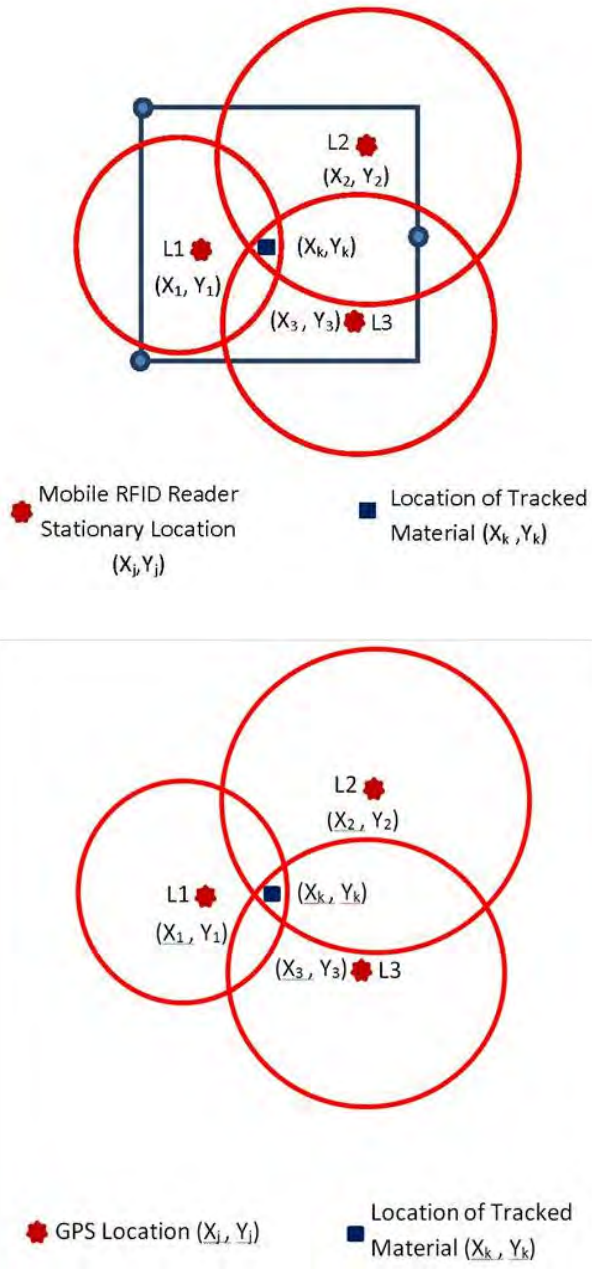


Figure 3-27: Diagrammatic sketch for material location identification

As shown in Figure (3-26), the user moves to another location, for example L2 (X2,Y2) and the RFID reader again receives signals from material (k). Also, when moving to a third location L3 (X3,Y3), the reader keeps on receiving a signal form the same material (k). Upon receiving a signal from material (k) from at least three different locations, the location of material (k) is calculated as (Xk,Yk). Figure (3-27) shows the flowchart for the procedure of material location identification using the proximity algorithm and using Equation (3.10) to calculate the material coordinates. Figure (3-28) shows the flowchart for the proposed method of material location identification using the trilateration algorithm (Montaser and Moselhi, 2013 a).

$$X_k = \frac{\sum_{j=1}^n X_j * W_j}{\sum_{j=1}^n W_j} \quad \& \quad Y_k = \frac{\sum_{j=1}^n Y_j * W_j}{\sum_{j=1}^n W_j} \quad (3.10)$$

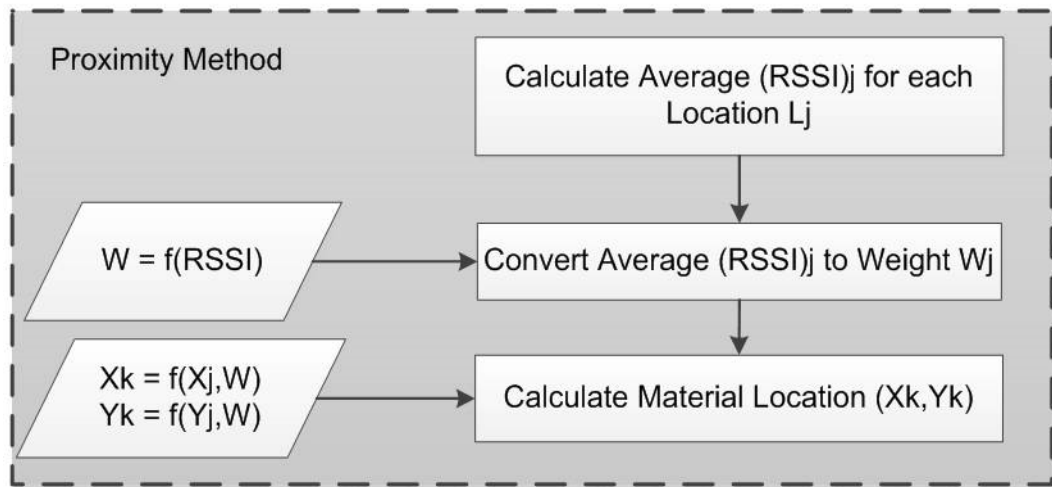


Figure 3-28: Material location identification using Proximity algorithm

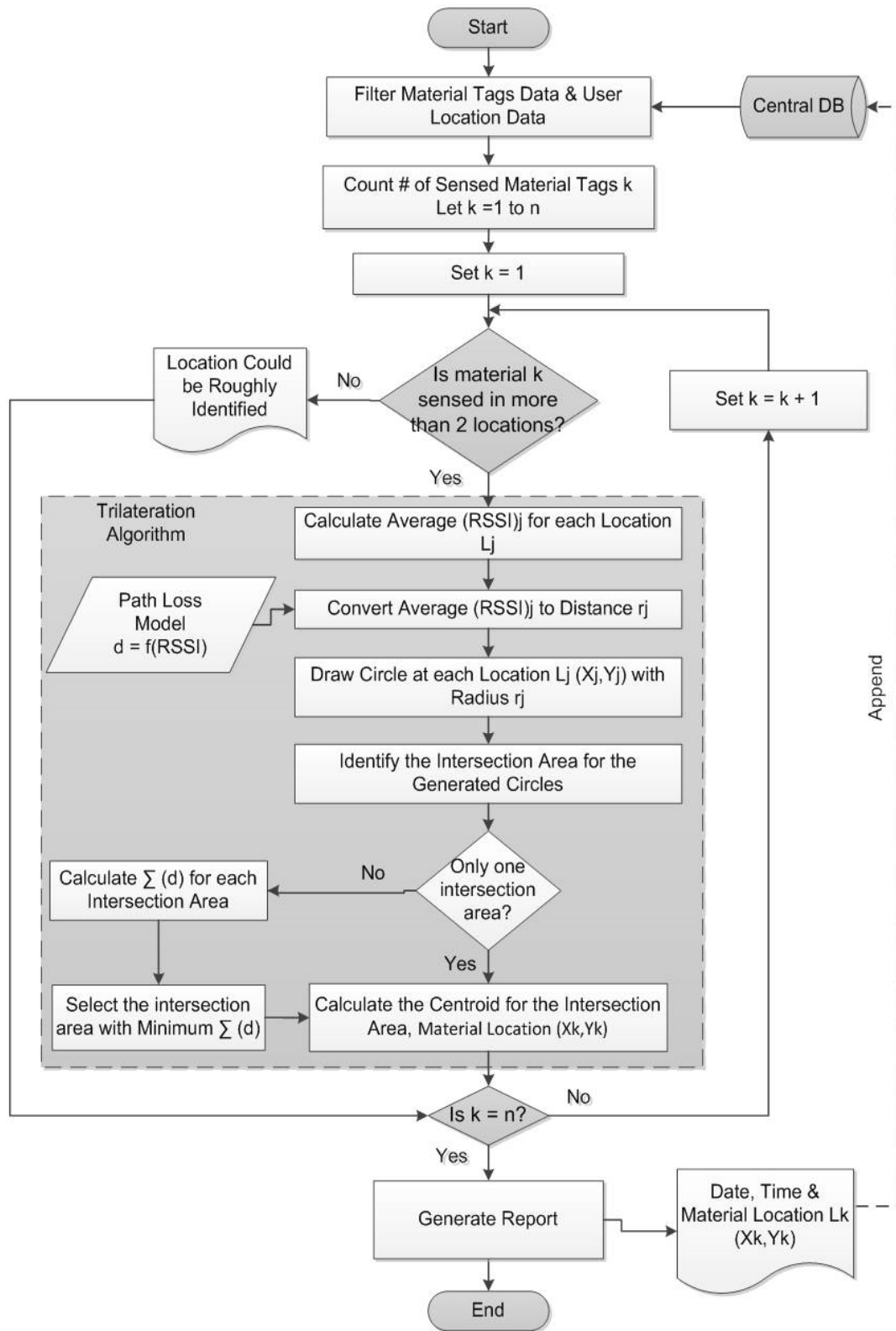


Figure 3-29: Material location identification using Trilateration algorithm

This process is repeated daily during the user's walkthrough for data collection. At that point, material location could be identified and tracked on daily bases. The gate RFID reader detects the material delivery. While, the user walkthrough detects the material temporal location, Lk, using GPS and RFID for outdoor zones and RFID only for indoor zones as shown in Figure (3-30). The material location is compared to material final location (Lf) on daily bases to know whether the material is placed and/or installed in its final location or still in handling processes. Upon the arrival of the material to its final zone, the productivity and quantity measurement module takes over. Figure (3-30) shows the procedure for estimating "Units Activities" percentage complete based on material localization and tracking sub-module

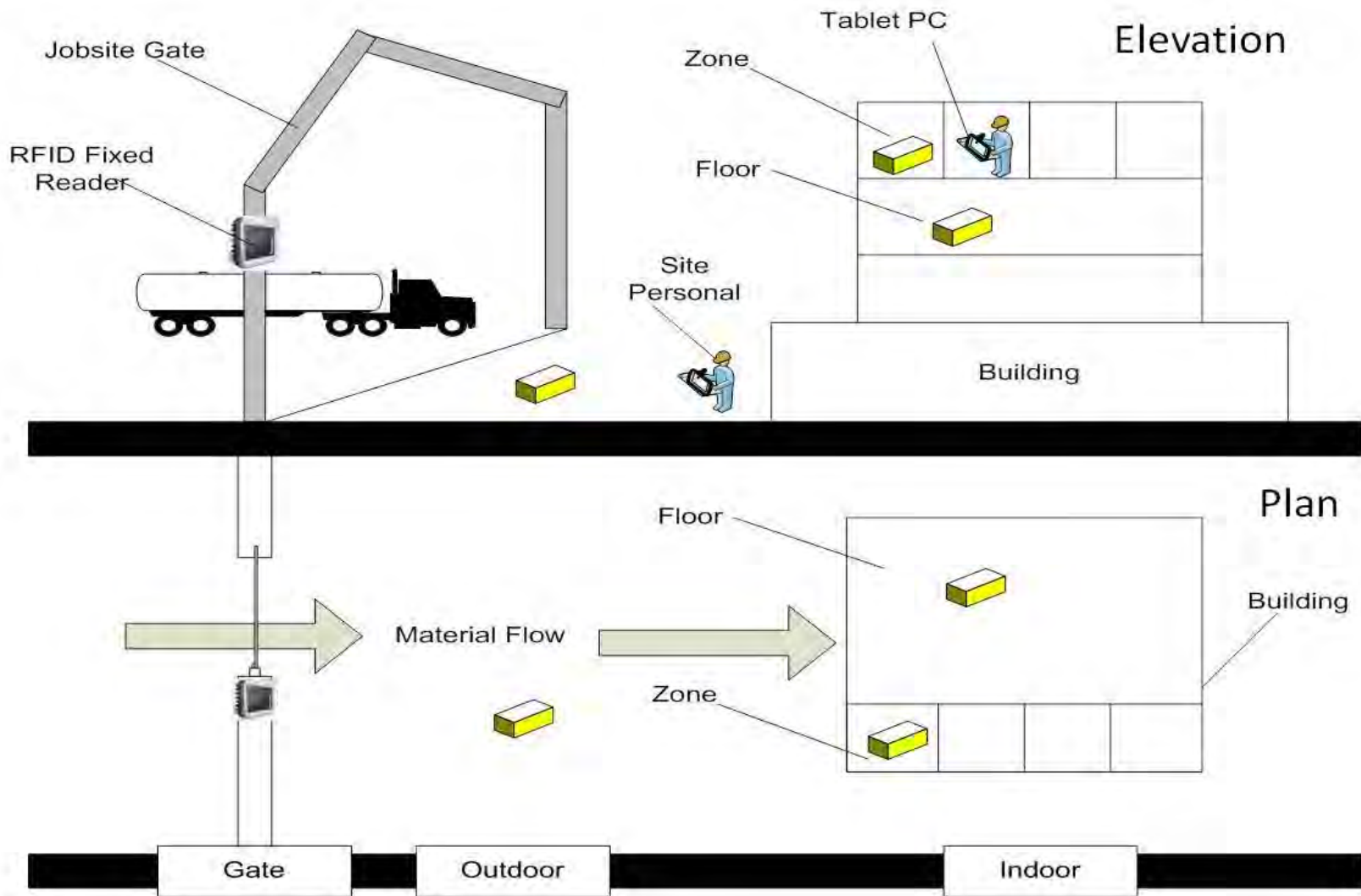


Figure 3-30: Material localization and tracking sub-module

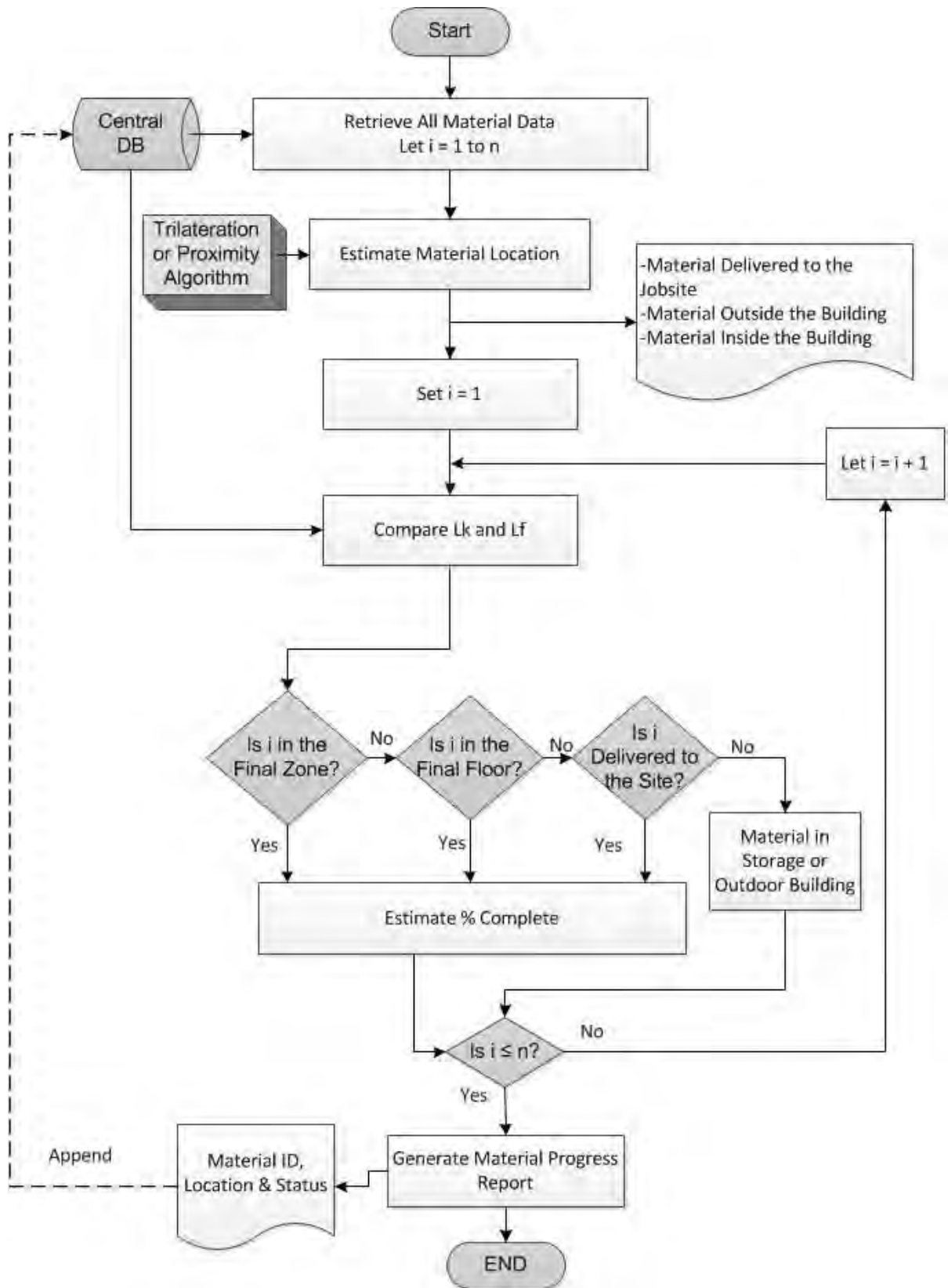


Figure 3-31: Estimating “Units Activities” percentage complete

3.4.1.2 Productivity and Quantity Measurement

This sub-module is automated to track the status and productivity “Bulk Activities” and “Finishing and Non-Spatial Activities”. It is also used in tracking and monitoring of “Units Activities” when the material reaches its final installation zones. For example, in case of earthmoving operations this sub-module is applied to track and monitor the activity resources such as hauling trucks. It estimates the productivity and the related quantities of the activities in daily basis to generate the percentage complete for that activity. Regarding other types of activities such as painting, gypsum board partitions etc., the integration of 4D BIM model, user location identification and progress templates provide the user with the required forms and queries in binary format (Done or Not) to be filled in different zones and their respective locations. For example, when the user location is identified and referenced to the 4D BIM model, the model interacts with the user requiring information for the object status. The interaction of the user in this case is simply stating whether the item on the measurement template of the activity being tracked is done or not. Depending on the inputs, the central database interacts with the BIM model to extract the quantities and aggregate it to reach the percentage completed at the activity level.

As an example of “Bulk Activities”, earthmoving operations were considered. For earthmoving operations, three different tracking methods were developed using different independent automated data acquisition technologies. The first tracking method utilizes GPS mounted on hauling trucks and Geographical Information System (GIS) for visual representation and data analysis. The second tracking method uses RFID gates in dumping and project areas and attaching low cost passive RFID tags to hauling trucks. The RFID gates identify and record the time each truck enters or exits one of these gates. The third method uses RFID and control sensor (or Switch Limit) to track the hauling trucks. Low cost passive RFID

tags are attached to hauling trucks and fixed RFID readers are attached to loaders or excavators. The read range of the used RFID tag is centimeters, to be activated only when a loader with an attached RFID reader is loading a truck. On the other hand, control sensor is connected to the truck control system and operated by the motion of its movable bed. The function of control sensors is to record the signal time when the truck operator gives an order to the truck control system to raise or lower truck bed.

The hauling trucks are tracked based on the interaction between the central database and the automated site data acquisition technologies. This process starts by assigning automated site data acquisition technology, as shown in Figure (3-31). The assigned tracking technologies start reporting the hauling truck captured data. Then, the data is transferred to the web server. The data is then processed automatically, without any human intervention, to calculate total cycle time for each truck and its respective loading, travel, dumping and return durations. Truck characteristics and excavated soil properties are retrieved from the central database to calculate the actual productivity of the hauling truck. Actual productivity is a function of hauling truck number of trips made at certain period, which requires calculating truck different cycle time durations. Consequently, calculating cycle time accurately is key element for estimating onsite actual productivity. The three developed methods are capable of capturing large volume of data on daily basis, processing and analyzing the captured data, calculating onsite productivity, measuring actual performance based on earned value concept and comparing the actual versus planned to derive variances if any, and deterministically forecast time and cost for the operation.

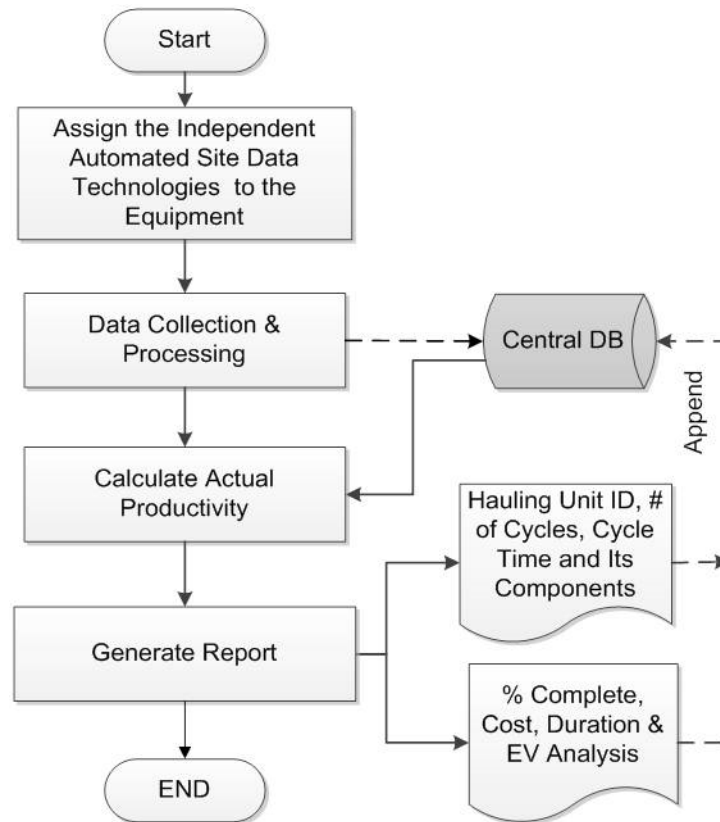


Figure 3-32: Flowchart for the process of tracking earthmoving operation

Figure (3-32) shows a detailed flowchart of the procedure for processing and analyzing the data captured (Montaser et al., 2012). Central database provides the list of project working hauling trucks and retrieves all respective data. For each truck, five main events are identified and their corresponding registered times T1, T2, T3, T4 and T5 respectively. By identifying those five events, the cycle time component is calculated as following:

- Loading Time (L) = Registered time of Event 2 - Registered time of Event 1
- Travel Time (TR) = Registered time of Event 3 - Registered time of Event 2
- Dumping Time (D) = Registered time of Event 4 - Registered time of Event 3
- Returning Time (R) = Registered time of Event 5 - Registered time of Event 4

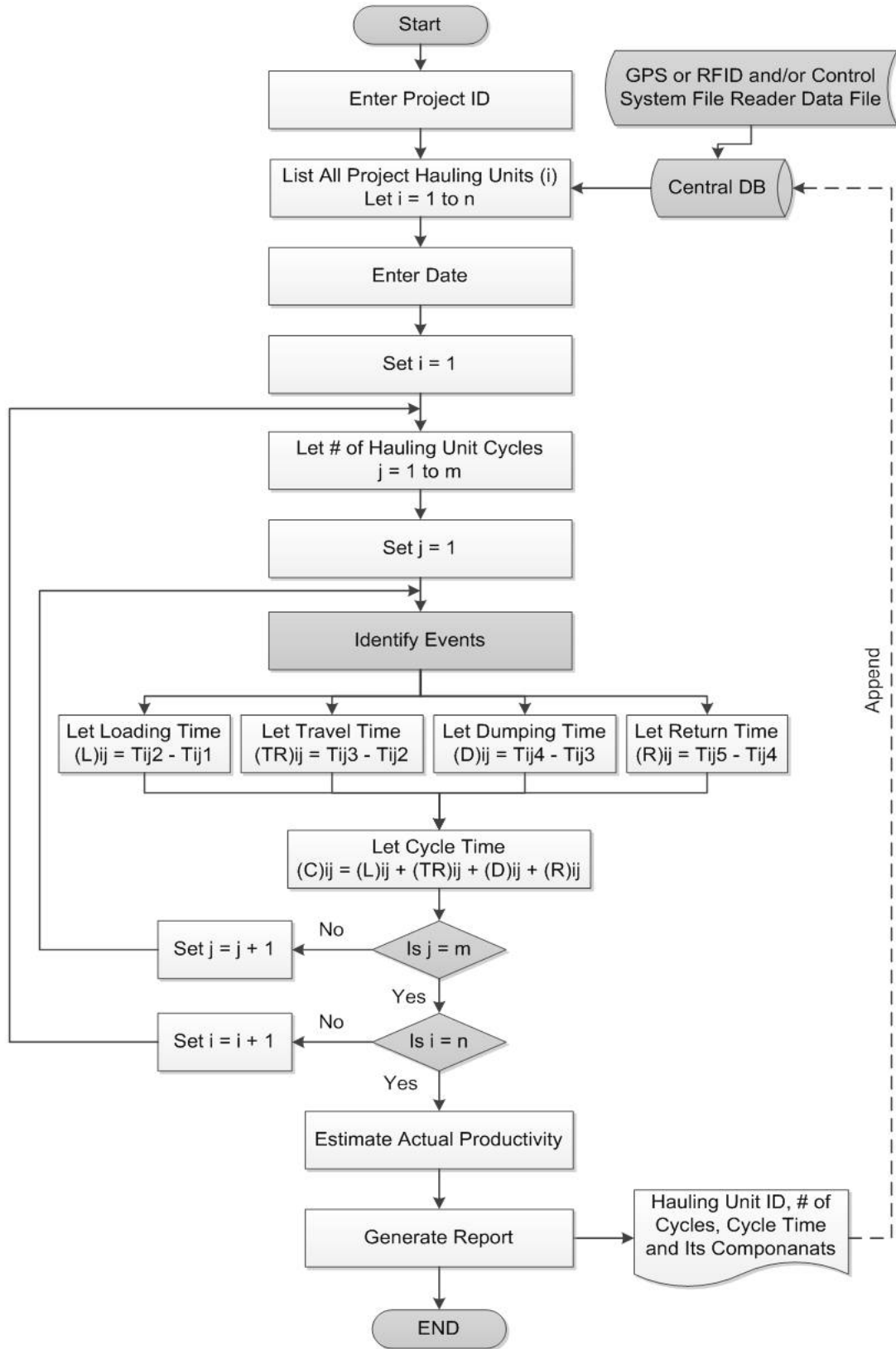


Figure 3-33: Flowchart for the process of the captured data processing

Trucks loading time provides a clear picture of the number of trucks inside the loading area and whether it matches the number of loaders (excavators). It assists in identifying whether there are trucks queue or not and how long is the queue. Similarly, dumping time could help in detecting dumping area congestion. Such information supports project managers in detecting the causes behind any unacceptable performance. Accordingly, the total cycle time (C) is calculated by the summation of loading time, travel time, dumping time and return time. For each hauling truck, the capacity and project soil properties are retrieved from the central database to calculate the truck productivity and to estimate the quantity of hauled excavation. It is assumed that the truck is loaded with its full capacity; according to truck manufacturer data and soil type. Those steps are repeated for each cycle and each truck and the total cycle time and its components are identified and appended to the central database. The first step is to identify the desired project. Then, the central database provides the list of project working hauling trucks and retrieves all respective data. Since, the number of hauling trucks, the number of trips per truck and the capacity of each truck are known; the daily-excavated quantity could be calculated. In conclusion, the total quantities are calculated using Equation (3.11).

$$Q_t = \sum_{i=1}^n (\text{Number of Truck Calculated Cycles})_t \times \text{Truck Capacity} \quad (3.11)$$

Where:

Q_t = is the quantity of excavated soil at day t

n = Number of hauling trucks utilized in the project

GPS/GIS Based Tracking method integrates GPS and GIS to track hauling trucks and consequently the earthmoving operation onsite. GPS units are mounted on hauling trucks to identify its locations during the earthmoving operation cycle. The data captured using GPS is

automatically transferred to onsite server and subsequently to the central database. GIS works as web-based graphical interface, where the user interacts and defines the earthmoving operation spatial boundaries and query reports. The GPS starts reporting the hauling truck location and respective data. GPS data are in the form of truck positions over short time intervals. GPS captured data is truck identification ID, date, time, longitude and latitude. Then, the data is transferred to the main server, where the central database resides (Montaser et al., 2011 and 2012).

Truck cycle time consists of four main components, which are loading, traveling, dumping and return. The loading time is the time that the truck is inside the loading area. Travel time is the time spent between exiting loading area until entering dumping area. Dumping time is the time that the truck is inside the dumping area. Return time is the time required for the truck to travel back from dumping area to loading area to start new cycle. In order to allow the user to add layers to the GIS map, a drawing tool should be developed for each cycle component (i.e. loading, travel, dumping and return). Using the drawing tools, the user draws the polygon around the project area. The drawing tool should be flexible enough to enable the user to draw regular, irregular and circular shapes. Therefore, if the GPS data point resides inside this polygon, it means that the truck is in the loading process. Similar procedure is done for the dumping area. For the travel and return road, the user draws a poly line. This poly line represents the optimum travel and return roads, which should be calculated during planning stage of earthmoving operation. Optimum means, it is the roads that achieves the minimum travel and return durations and consequently the maximum productivity. If the drawn poly line inside streets, it automatically retrieves the street dimensions (centerline and width) from the GIS map database. On the other hand, if the poly line is on unpaved roads, an offset with predetermined value is applied to the poly line to form a polygon. Figure (3-33) shows a

diagrammatic sketch of the data capturing scheme and classification of the components of the earthmoving operation. The user defines the polygons and poly lines one time at the beginning of the project and its corresponding data is saved automatically in the central database.

Each GPS data point is mapped on the GIS map, which is used to display geographically, as a separate layer, the moving truck. The truck data point is classified as the truck crosses from one polygon to another and the time that polygon was crossed is identified. Then, it is classified as loading, travel, dumping, or return. Figures (3-34) and (3-35) depict the process of classifying the points and identifying the cycles that the truck has done through a series of decisions. The five main events in each cycle are identified to be used afterwards for cycle time calculations. Table (3-1) shows the GPS data after processing.

It should be noted that loading (dumping) time include the exact direct loading (dumping) time in addition to the truck maneuvering time in loading (dumping) area. Also, If the truck is outside the optimum travel and return roads, another rule is applied to calculate the travel and return time. The rule is based on the truck direction. If the direction is from the loading area to dumping area, it is classified as travel and vice versa for return. The time spent outside the optimum travel and return roads is calculated and considered as cycle time inefficiencies of the operation and it is reported to the project manager. This procedure provides for the user a capability to define if-then rules in the central database, which could help in situations such as driver break time or to fuel the truck.

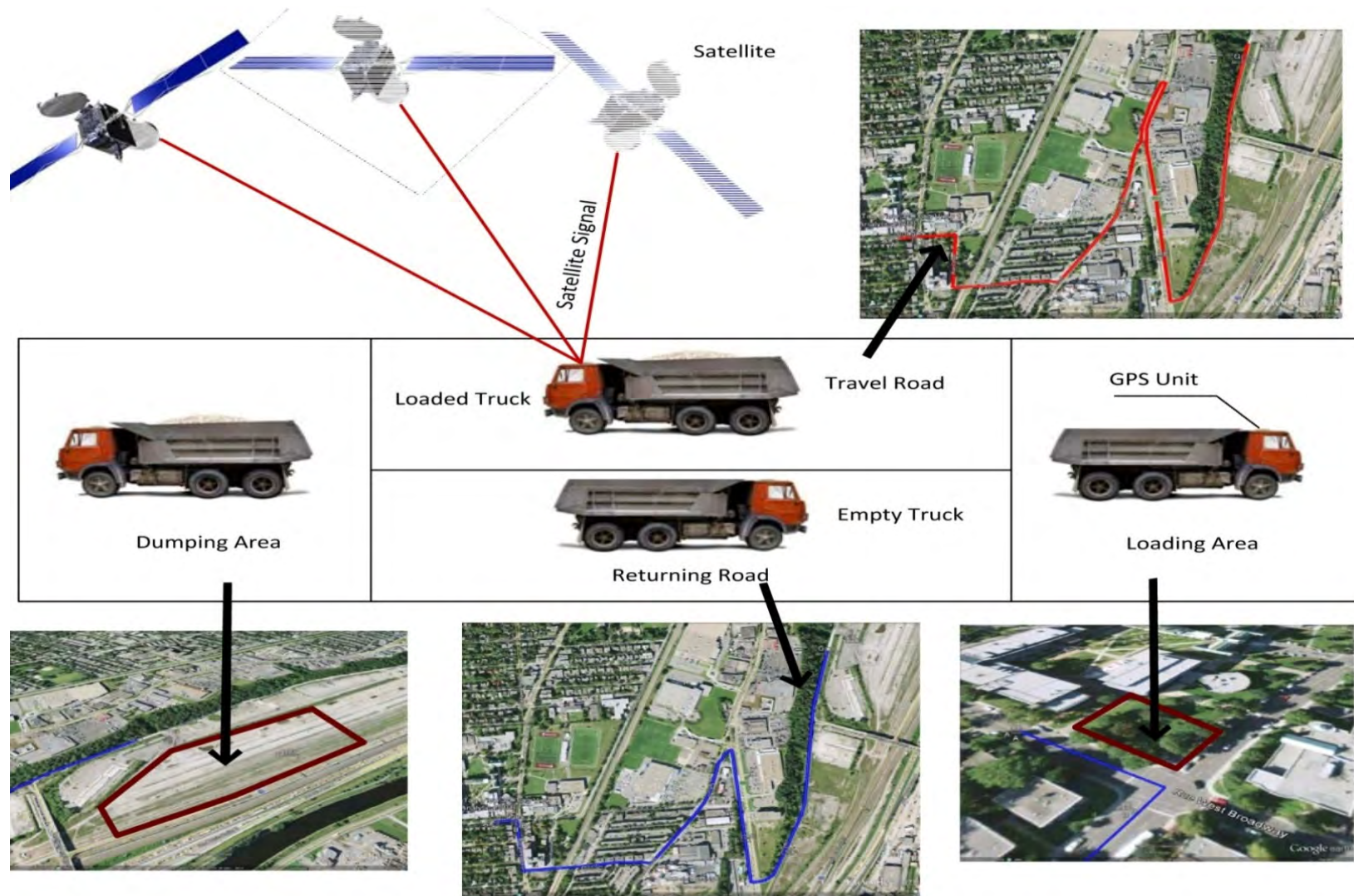


Figure 3-34: GPS/GIS based tracking (Montaser et al., 2012)

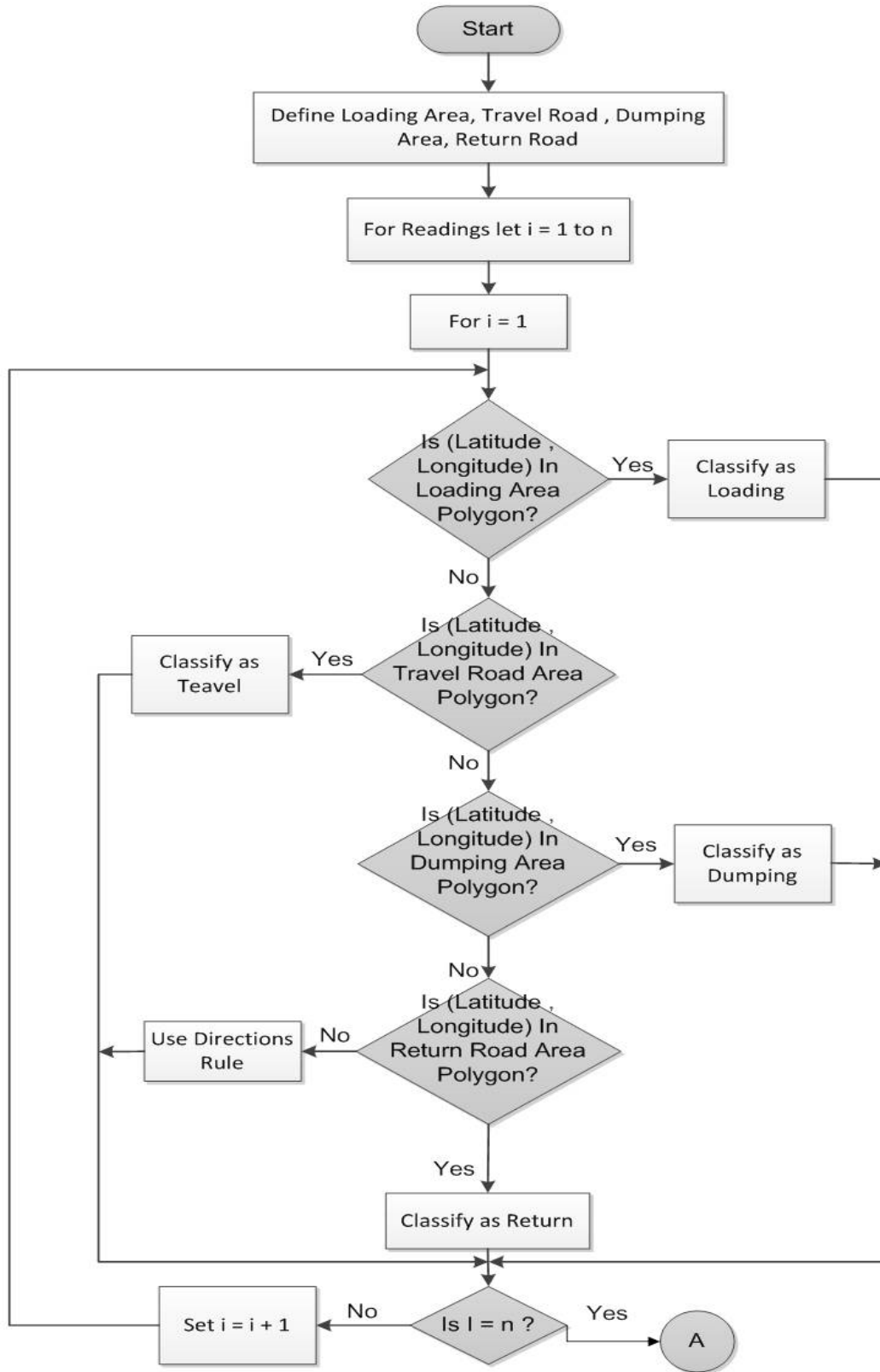


Figure 3-35: GPS captured data processing part 1

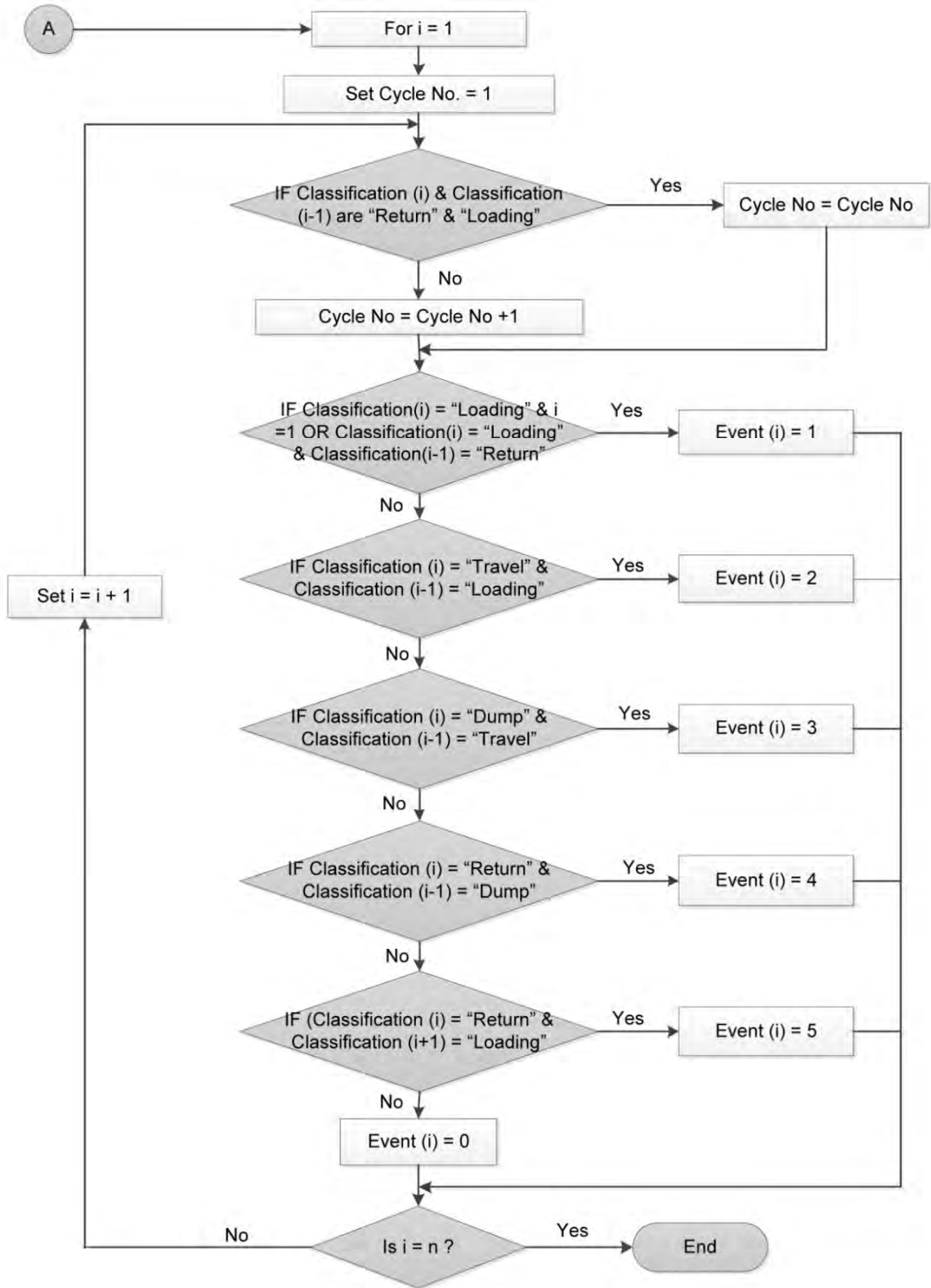


Figure 3-36: GPS captured data processing part 2

Table 3-1: GPS data after processing (Montaser et al., 2012)

Date	Time	Latitude	Longitude	Classification	Event	Time (min)	Cycle #	Cycle Time
08/04/2010	8:12:06	45.45667	-73.64062	Loading	1		1	0:25:05
08/04/2010	8:15:05	45.4566	-73.64045	Loading				
08/04/2010	8:15:11	45.4543	-73.63966	Travel	2	0:03:05		
08/04/2010	8:17:11	.	.	.				
08/04/2010	8:21:11	.	.	.				
08/04/2010	8:26:11	45.45729	-73.62556	Travel				
08/04/2010	8:26:20	45.45602	-73.62363	Dump	3	0:11:09		
08/04/2010	8:26:11	.	.	.				
08/04/2010	8:27:58	.	.	.				
08/04/2010	8:28:06	45.45634	-73.62273	Dump				
08/04/2010	8:29:11	45.45738	-73.62531	Return	4	0:02:51		
08/04/2010	8:30:11	.	.	.				
08/04/2010	8:37:46	.	.	.				
08/04/2010	8:37:11	45.45532	-73.64124	Return	5	0:08:00		

RFID Gate Based Tracking method is developed to calculate the total cycle taken by the truck and the total number of cycles needed to accomplish the scope of work. This method has two components; the first is using RFID gates in both dumping and loading zones and the second is by attaching low cost passive RFID tags to hauling trucks. The main RFID hardware components used are RFID fixed reader and RFID encapsulated tags or RFID label tags. For passive RFID label tags, it is not rugged. However, it can be used inside the truck itself. It can be mounted directly on the windshield glass at the front of trucks. Rugged encapsulated tag is mounted on the driver's door of trucks. An illustration of the method is shown Figure (3-36). The developed method uses fixed RFID readers for the gate system at the loading and dumping

areas. This allows collecting RFID signals from entering and departing trucks into and from the two areas. Once an empty truck enters the loading area, the fixed RFID reader (RFID Reader 1) receives signals from the RFID tag attached to the truck. This process is repeated in a similar sequence, but using Reader 2 at the dumping area. In between, i.e. over the hauling and return roads, no signal is received. RFID reader generates a file with five fields: a) RFID tag ID, which was read, b) the number of times this tag was read, c) RSSI d) date, e) time. By fusing the data from both RFID Readers 1 and 2 for individual truck, the activities durations within a complete cycle can be clearly defined (i.e., loading time, travel time, dumping time and return time). The data collected from both RFID Readers 1 and 2 is transferred to the computer onsite and subsequently transferred to the server in the head office of the contractor (Montaser and Moselhi, 2012 b).

Figure (3-37) illustrates the method to identify the main five events upon performing the data fusion of the two readers. Event 1 represents the commencement of the loading process. The approximation here has to do with limiting signal range of the passive tag used in the developed method. When a truck leaves the loading area after finishing loading the excavated material, RFID reader 1 registers Event 2. Event 3 is registered from RFID Reader 2 when the hauling truck enters the dumping area, which also confirms the end of the hauling activity. Upon dumping the excavated material, the hauling truck exits dumping area and RFID Reader 2 registers the commencement of Event 4. A cycle is completed upon return of the truck to the loading area (i.e. commencement of Event 5). Table (3-2) shows an example of the cycle time calculations computed by the developed method.

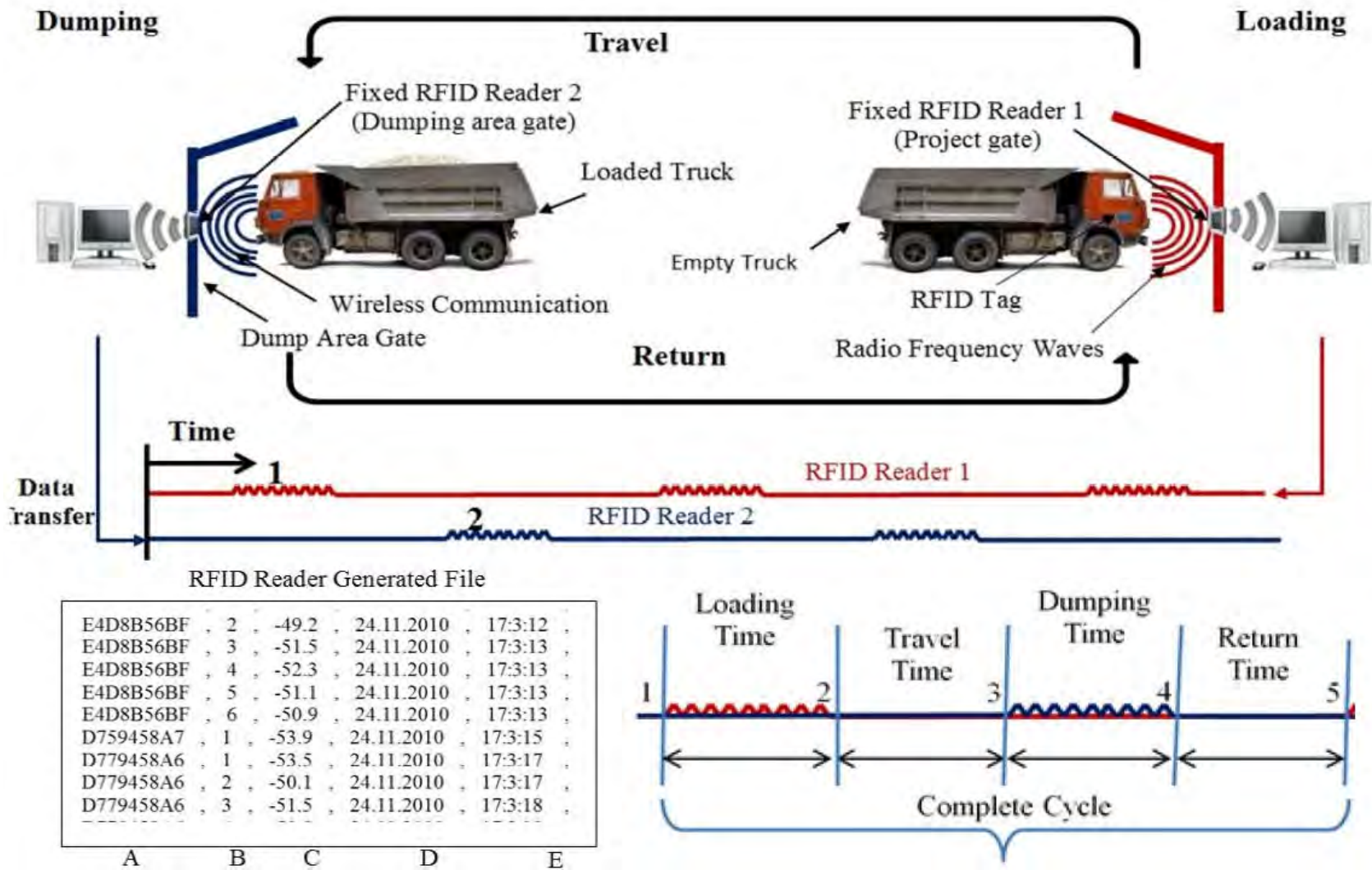


Figure 3-37: RFID gate based tracking (Montaser and Moselhi, 2012 b)

Table 3-2: RFID data after processing (Montaser and Moselhi, 2012 b)

Date	Time	Tag ID	RFID Reader	Event	Time (min)	Type	Cycle #	Cycle Time
24.11.2010	8:12:06	BF	1	1				
24.11.2010	.	BF	1					
24.11.2010	.	BF	1					
24.11.2010	.	BF	1					
24.11.2010	.	BF	1					
24.11.2010	8:15:11	BF	1	2	0:03:05	Loading Time		
24.11.2010	8:40:27	BF	2	3	0:25:16	Travel Time		
24.11.2010	.	BF	2					
24.11.2010	.	BF	2					
24.11.2010	.	BF	2					
24.11.2010	.	BF	2					
24.11.2010	8:42:38	BF	2	4	0:02:11	Dumping Time		
24.11.2010	9:03:43	BF	1	5	0:21:05	Return Time	1	0:51:37

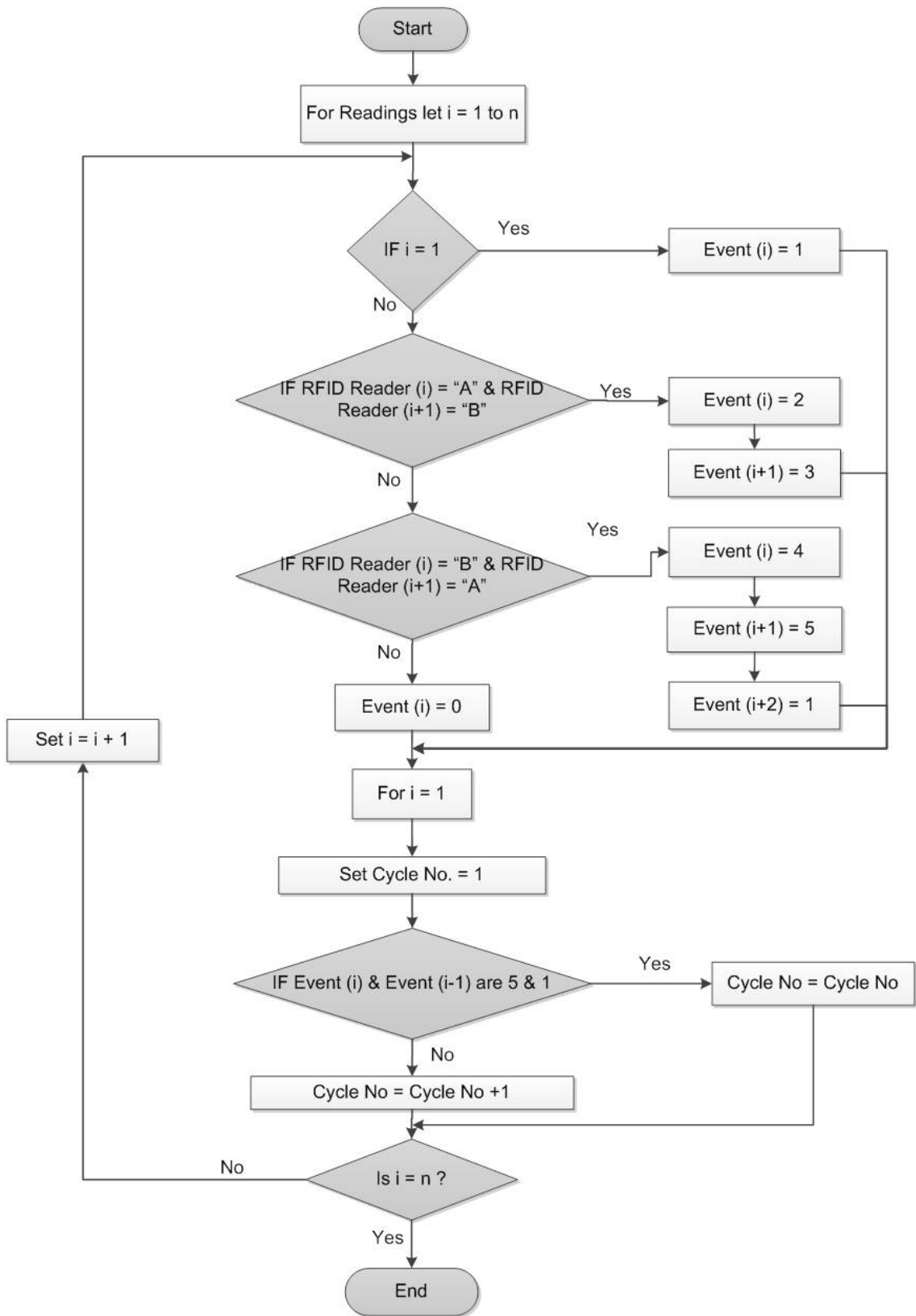


Figure 3-38: RFID captured data processing (Montaser and Moselhi, 2012 b)

Both GPS/GIS and RFID gate methods assumes that the loading and dumping times are calculated once the truck enters or exists the loading or dumping areas. This assumption adds to exact direct loading or dumping time additional time for truck maneuvering in the loading or dumping area as shown in Figure (3-38).

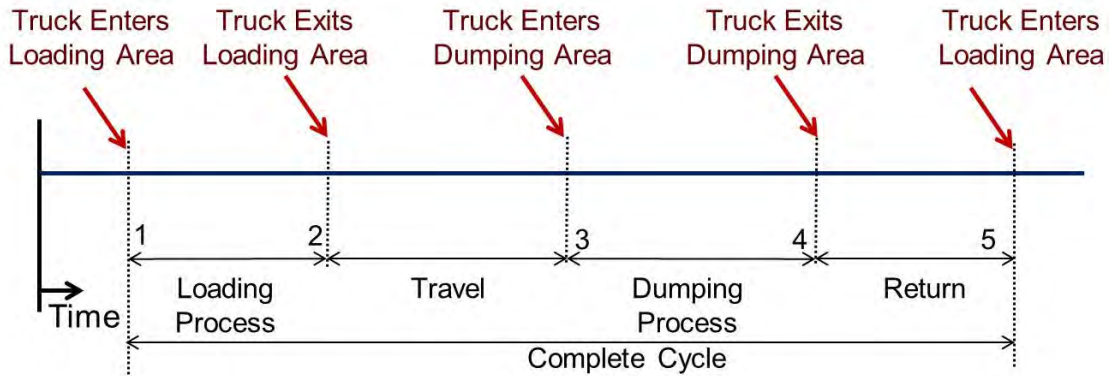


Figure 3-39: Cycle time in GPS/GIS and RFID gate tracking method

RFID/Control Sensor Based Tracking method, low cost passive High Frequency (HF) RFID tags are attached to hauling trucks and fixed RFID readers are attached to excavators (loaders). RFID is utilized to detect truck proximity to excavator (loader) for loading, which improves tracking method accuracy for loading time. The read range of the used RFID tag is less 1m, to be activated only when the excavator (loader) with the attached RFID reader is loading the truck. Then, the RFID reader starts capturing the RFID signals from the truck tag. On the other hand, control sensor is connected to the truck control system and operated by the motion of its movable bed. The function of control sensors is to record the signal time when the truck operator gives order to the truck control system to raise or lower truck bed during the dumping process. In addition, switch limit could be utilized instead of the control sensor to detect the movement of truck bed in dumping process to calculate the exact dumping time. The control sensor sends its data via cable to microcontroller. Truck microcontroller has a wireless communication module that could send and receive data to/from RFID readers. The data

captured by RFID from hauling truck's passive tag and control sensor is transferred wirelessly. Fusing the data captured from RFID reader and control sensor is used to identify loading, travel, dumping and return time that constitute the hauling truck cycle time and consequently the productivity of the fleet (Montaser and Moselhi, 2013 b).

Figure (3-39) depicts RFID hardware implementation method, where the passive tag is attached to the hauling truck bed, which is the nearest location to the excavator during loading. RFID reader is fixed to the excavator front with the antenna attached to the excavator bucket. This setup in addition to tag read range allows the RFID reader to receive tag signals when the excavator is loading the truck. The signal is represented by a zigzag line to indicate the loading process. The excavator is stationary in its location; loading its bucket and dumping the soil in the truck bed. This process is repeated until the hauling truck is loaded with its full capacity. In this state, the response of excavator's RFID reader is continuous zigzag line during the loading process. The time from the beginning of the zigzag line till its end represents the loading time in this cycle.



Figure 3-40: RFID reader captured data with excavator

The same RFID setup is used in case of using a loader to load the hauling truck. However, the loader sequence of work is different as shown in Figure (3-40). As, it moves to the soil stock pile forward and backward per each bucket load. For each loader bucket load, the RFID reader response is continuous zigzag line then straight line due to the loader movement away from the truck to the soil stock pile till it enters the reading range once again. Accordingly, the time from the beginning of the first zigzag line until the end of the last zigzag line represents the loading time in this cycle. In this process, the RFID reader generates a file with five fields: a) RFID tag ID, which was read and represents the truck ID, b) the number of times this tag was read, c) received signal strength, d) date, e) time. Figure (3-41) shows a graphical representation of control sensor's captured data when the hauling truck bed is raised for dumping excavated soil and lowering it afterwards. The change in control sensor status happens due to the hauling truck bed motion. The control sensor captured data are date, time, truck ID and status (On or Off).

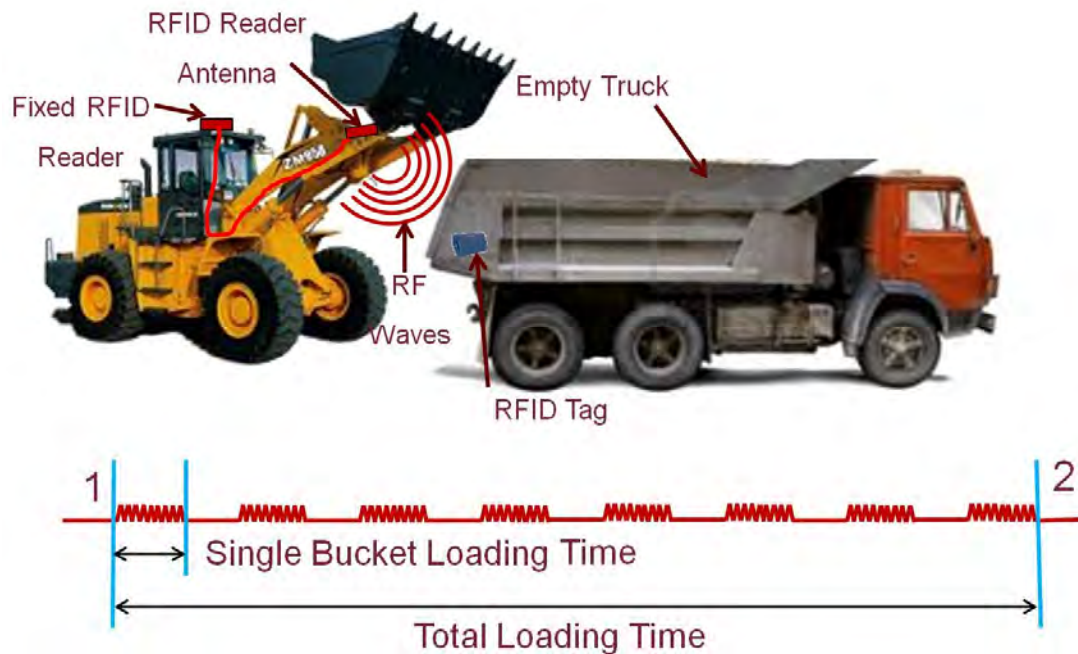


Figure 3-41: RFID reader captured data with loader

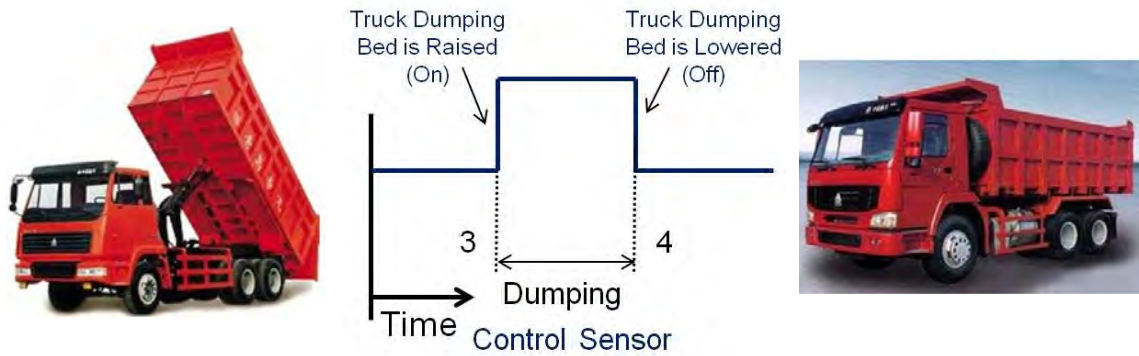


Figure 3-42: The change in control sensor captured data

Figure (3-42) illustrates the main five events that describe the entire earthmoving process, upon performing the data fusion of the two sensors. These five events represent a complete cycle in the operation being modeled. Event 1 represents the commencement of the loading. As long as the hauling truck is within the excavator's (loader's) read range, the reader keeps receiving signals from the truck. Event 2 registered at the end of the zigzag line in case of an excavator, or at the end of last zigzag line in case of a loader. Event 3 is registered from control sensor when the truck operator gives order for dumping which is indicated by raising the truck bed. Upon dumping the excavated material, the operator gives order to lower the truck bed then the control sensor registers the commencement of Event 4. A cycle is completed upon return of the truck to the loading area (i.e. commencement of Event 5).

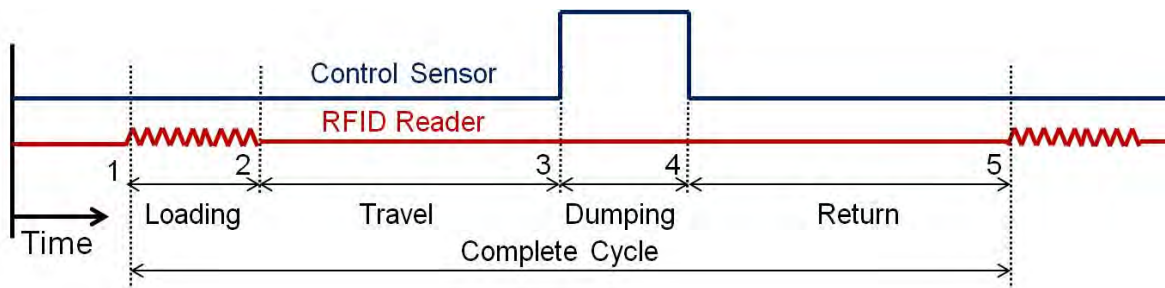


Figure 3-43: RFID and control sensor data integration (Montaser and Moselth, 2013 b)

Figure (3-43) shows the process of raw data processing. Then the total cycle time can be calculated by the summation of loading time, travel time, dumping time and return time. These steps are repeated for each truck in the project as shown in Table (3-3). For each truck, the number of cycle times, total cycle time duration and its components durations are identified then appended to the central database. Unlike the previous two methods for tracking the hauling truck, this method detects the exact loading and dumping time without adding any other duration, like queuing and maneuvering to get into position. The three developed methods allow project teams to check jobsite conditions remotely and study the efficiency of the planned operations. It provides them also with tools for detecting potential problems in loading areas, dumping areas and travel hauling and return roads. The RFID/Control Sensor method could be integrated with the GPS/GIS or RFID Gate method to provide more information regarding the loading, travel, dumping and return areas and the integrated method accuracy will be enhanced considerably as shown in Figure (3-44).

Table 3-3: Cycle time calculations (Montaser and Moselth, 2013 b)

Date	Time	Truck ID	Control Sensor Status	RFID Reader	Event	Time (min)	Type	Cycle Time (min)
24.11.2010	8:12:06	230		230	1			
24.11.2010	.	230		230				
24.11.2010	.	230		230				
24.11.2010	.	230		230				
24.11.2010	.	230		230				
24.11.2010	.	230		230				
24.11.2010	8:15:11	230		230	2	0:03:05	Loading Time	
24.11.2010	8:40:27	230	On		3	0:25:16	Travel Time	
24.11.2010	8:42:38	230	Off		4	0:02:11	Dump Time	
24.11.2010	9:03:43	230		230	5	0:21:05	Return Time	0:51:37
24.11.2010	9:03:47	230		230	1			

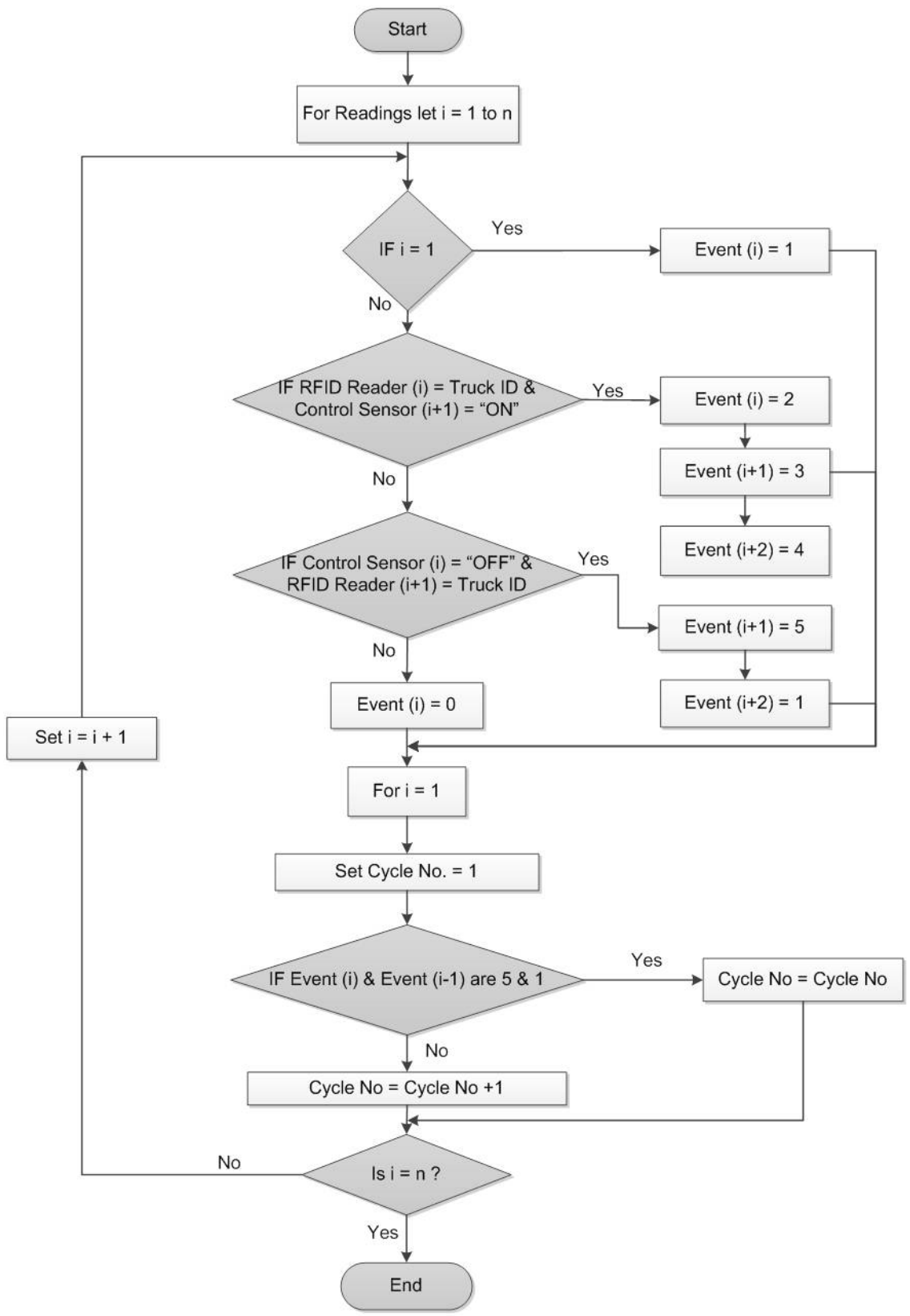


Figure 3-44: RFID/control sensor captured data processing

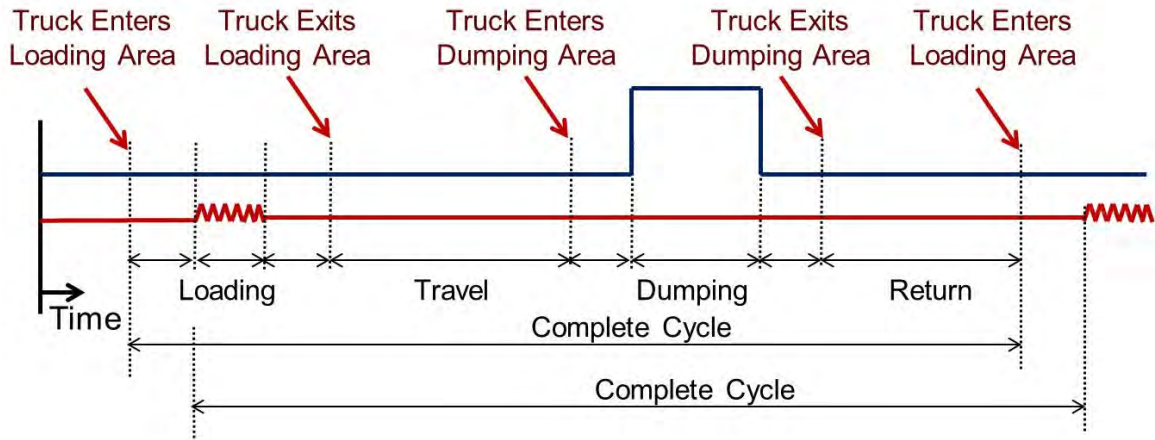


Figure 3-45: RFID/Control Sensor method and GPS/GIS or RFID Gate method

Table (3-4) depicts the comparison among the three different tracking methods. GPS utilizes satellite wireless communication and requires direct line of sight. Hence, RFID technology is considered more useful than GPS in tracking hauling units in dense downtown areas populated with high-rise buildings, which obstruct satellite signals. Knowing that, the number of trucks, excavators and site entrances (exits) are considered variables for the initial cost. It is assumed that the costs of maintenance and software implementation are equal for the three methods. The following notations were used to conduct initial cost comparison among the three methods:

Number of hauling trucks = X

Number of excavators (loaders) = Y

Number of site exits or entrances = E

RFID Reader Cost = C

RFID Tag Cost = R

GPS unit Cost = G

Control Sensor Cost = S

Table 3-4: Comparative study

Criteria/Method	GPS/GIS	RFID Gate	RFID/Control Sensor
Detect cycle time	Yes	Yes	Yes
Detect # of cycles	Yes	Yes	Yes
Calculate productivity	Yes	Yes	Yes
Detect exact loading time	No	No	Yes
Detect exact dumping time	No	No	Yes
Can detect labor and material entering or exiting the project	No	Yes	No
Track effectively the truck along travel and return roads	Yes	No	No
Effective for tracking building earthmoving operations	Yes	Yes	Yes
Effective for tracking highway earthmoving operations	No	No	Yes
Can detect truck weight	No	No	No
Initial Cost	GX	RX+CE	(S+R)X+CY

Regarding the assumption of hauling truck is loaded with it is full capacity; a weighting sensor could be attached under the hauling truck to estimate the weight of soil in the truck. As well, a digital camera could be used at the project gates to take images for the truck and estimate the volume of excavated material in the truck. Similarly, CCTV camera images around the site could be used to estimate the volume of excavated material in the truck. The developed three methods are used to estimate the input to the earthmoving operation. However, the output of the operation could be measured using 3D scanner and photogrammetry, though scanning the site on daily basis as proposed by El-Omari (2008).

Other machine-based sensors could also be integrated with these methods to identify idle time and broken equipment time, which will provide an alerting system for project team. Near real time control of on-site earthmoving operations, facilitates early detection of discrepancies between actual and planned performances and support project managers in taking timely corrective measures. In case of utilizing scraper in highway construction, Montaser and Moselhi (2013 c) developed a method to track Scraper-Pusher fleet for Cut-Fill highway earthmoving operations, refer to Appendix A.

3.4.2 Earned Value Analysis Module

Measuring project's performance in a timely and effective manner is an important task. It allows managers to diagnose and identify areas that need more awareness and to take corrective actions if needed. This section presents the utilization of earned value analysis in the data analysis and reporting framework. This module works on object level and aggregates different values until it reaches the activity level. Similarly, the same procedure is followed to aggregate different values at the activity level to reach the project level. In case of "Units Activities" combination of material localization and tracking sub-module and productivity and quantity measurement sub-module are utilized. Table (3-5) shows an example for estimating percentage complete for a fan coil unit activity, which is considered an example of "Units Activities".

This procedure estimates percentage complete on object level, knowing that each activity consists of many objects. So, an aggregation process is established based on objects until it reaches the activity level using Equation (3.12). This aggregation is done using two different methods. For activities that are measured by number of units, as the case is in electromechanical installation, the aggregation is based on the object's relative cost in activity

under study. The second method of aggregation is for activities that are measured in quantity, as in m³, m² or linear m, Equation (3.13) is used to aggregate from object level to activity level.

Table 3-5: Example of “Units Activities” objects percentage complete estimation

Task	Work Done	Cumulative % Earned	Sub-Module
HVAC (Fan Coil Units)	Delivered to site	60%	Material Localization and Tracking
	Inside Building	65%	
	Inside Final Zone	70%	
	Fixed to the Ceiling	75%	Productivity and Quantity Measurement
	Ducting and Fittings	80%	
	Testing	90%	
	Handing Over	100%	

$$\% \text{ Complete for Activity} = \sum_{i=1}^n (W_i \times \text{Cumulative \% Earned}_i) \quad (3.12)$$

$$\% \text{ Complete for Activity} = \sum_{i=1}^n (Q_i \times \text{Cumulative \% Earned}_i) \quad (3.13)$$

Where:

W_i = is the object relative cost

Q_i = is the quantity of object

i = the object ID

n = Number of activity objects

In case of “Finishing and Non-Spatial Activities”, progress template is utilized to estimate percentage complete from productivity and quantity measurement module. In case of “Bulk Activities” such as earthmoving operations, the quantities calculated from tracking hauling units is used to calculate percentage complete as mentioned earlier in productivity and quantity measurement module. The cumulative excavated quantities until day t equals to Q_t plus the cumulative excavated quantities at $(t-1)$. This quantity is divided by the total excavation quantity to identify the actual percentage complete. Percentage complete is used afterwards in earned value analysis for progress reporting purpose and to estimate the actual cost and duration. BCWP is calculated according to the percentage complete calculated on daily basis.

According to earned value analysis, three main indicators are used for performance analysis; namely as: Budget Cost for Work Scheduled (BCWS), Actual Cost for Work Performed (ACWP), and Budget Cost for Work Performed (BCWP). BCWS for each activity is known from the planning stage and saved in the central database. Therefore, BCWP is calculated according to Equation (3.14). ACWP is entered by the user from actual on site expenditures related to each activity. Upon the completion of estimating the BCWS, BCWP and ACWP for each activity, this module progresses with calculating Cost Variance (CV), Schedule Variance (SV), Cost Performance Index (CPI) and Schedule Performance Index (SPI), as indicated in Equations from (2.1) until (2.4). These indexes are used to identify the possible cause(s) of unacceptable performance. Then, the module indicates whether the activity status for time (behind schedule or on schedule or ahead of schedule) and cost (over budget or on budget or under budget). The module deterministically forecasts the cost Estimated at Completion (EAC) at any future set date, as indicated in Equations from (2.5) until (2.9) using two assumptions: (1) the established performance at the report date continues until completion

(EAC1) or (2) the remaining work is performed as originally planned and the previous performance was exception (EAC2). These assumptions are providing practical scenarios for the project manager to select from.

$$\text{BCWP (Activity)} = \% \text{ Complete} \times \text{BCWS} \quad (3.14)$$

Until now, all calculation were conducted on activity level, to take it up to the project level and to do earned value analysis Equations (3.15, 3.16 and 3.17) are used to calculate project BCWS, BCWP and ACWP. Similarly, this module progresses with calculating project performance indexes (CV, SV, CPI, SPI) but for the project level as indicated in Equations from (2.1) till (2.4). Additionally, this module estimates the time and cost status for project at the reporting date and forecasts it at any future set date as indicated in Equations from (2.5) until (2.9).

$$\text{Project BCWS} = \sum_{i=1}^n (\text{BCWS}) \quad (3.15)$$

$$\text{Project BCWP} = \sum_{i=1}^n (\text{BCWP}) \quad (3.16)$$

$$\text{Project ACWP} = \sum_{i=1}^n (\text{ACWP}) \quad (3.17)$$

Where:

i = Activity ID

n = Number of activities

Most forecasting methods for repetitive cyclic construction operations use deterministic approaches or stochastic approaches but based on historical data of similar past projects. These methods did not consider uncertainty. Utilizing such data is an obstacle for

accurately simulating the status of these operations on current projects. For example in case of earthmoving operations, the cycle time differs as the travel time of trucks can be affected by several dynamic factors, such as weather conditions, operating conditions in the excavation area and traffic on travel roads. Accordingly, Discrete Event Simulation (DES) is utilized in this research to forecast activity future performance. This method is applied only to repetitive cyclic activities such as earthmoving operation. Therefore, the developed method demonstrates the stochastic value of hauling trucks captured data and uses the actual collected data of the elapsed periods. Since, this data naturally inherits in itself variables of stochastic nature such as weather. DES is used to forecast fleet productivity and consequently the forecasted activity's duration and cost. It is also used to experiment with different fleet configuration and its impact on forecasted time and cost (Montaser et al., 2011 and 2012). The captured data for loading, hauling, dumping and returning are used to generate representative Probability Distribution Functions (PDF). Those PDFs are used as an input for the DES model to evaluate the current operation and to highlight the performance bottlenecks and to experiment the fleet configuration if needed.

In addition, if the activity during the elapsed period experienced delay, corrective actions could be planned based on generating different fleet configurations using DES. This method is automated but requires human intervention in selecting different scenarios such as the number of excavators, hauling units and their capacity. It is built based on the interaction between the system and the central database where the past period cycles time and its component has been stored. Figure (3-45) shows the method general flowchart, starting by generating the PDF for cycle time components from the captured data retrieved. PDF should be generated for each cycle time component (i.e. loading time, travel time and dumping time) that best fits the process including its associated parameters (e.g. mean value and standard

deviation). The fitted functions are then used as an input for the simulation model to generate and evaluate different scenarios (Montaser et al., 2011 and 2012).

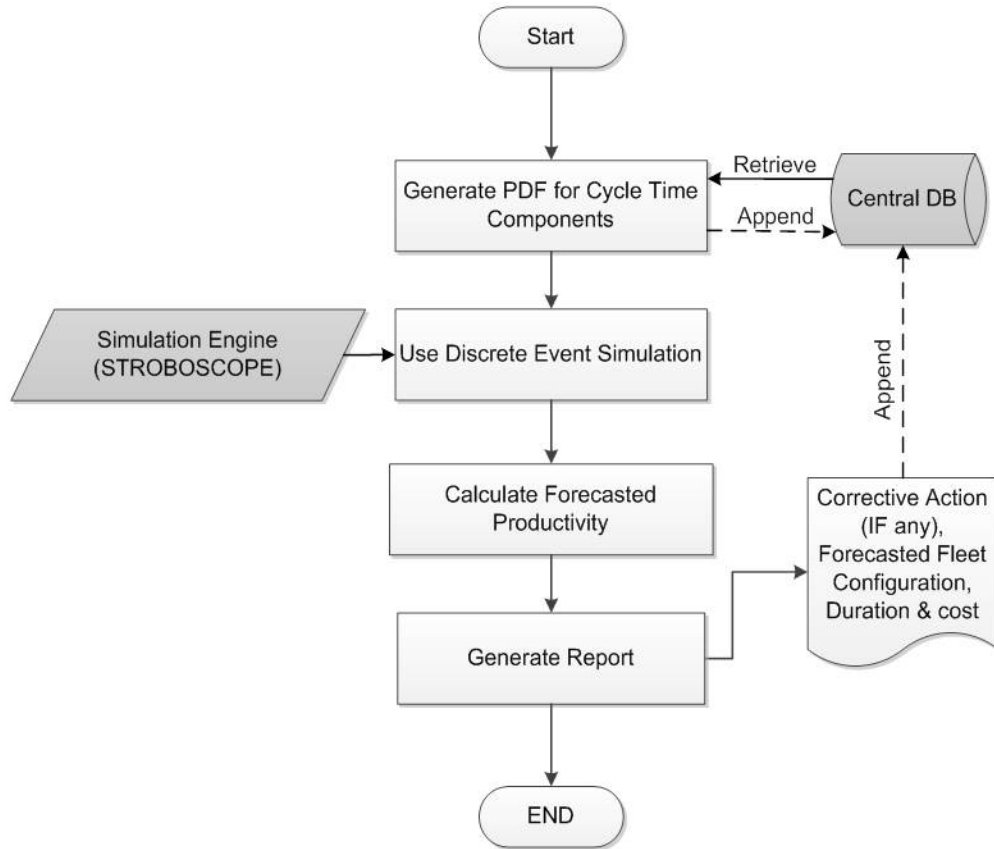


Figure 3-46: The process of stochastically forecasting productivity

In this research StrobeScope discrete event simulation engine was utilized, where it is installed on the web server. Specially designed DES model for earthmoving operations is deployed as depicted in Figure (3-46). This DES model is a typical model and used for data manipulation and processing to calculate the stochastic forecasted productivity and to experiment different fleet configurations in case of any corrective action. The DES model retrieves the earthmoving operation data such as total quantity of earthwork, number of hauling trucks and excavators, hauling truck capacity and PDF for different cycle time components from the central database. The DES reports to the user the forecasted fleet productivity and its

associated cost and time. The user interacts with the DES model to change the fleet configuration only. Then, different scenarios are generated for the user, which could help in time or cost optimization and making informed decisions. The simulation model equations are from (3.18) till (3.25)

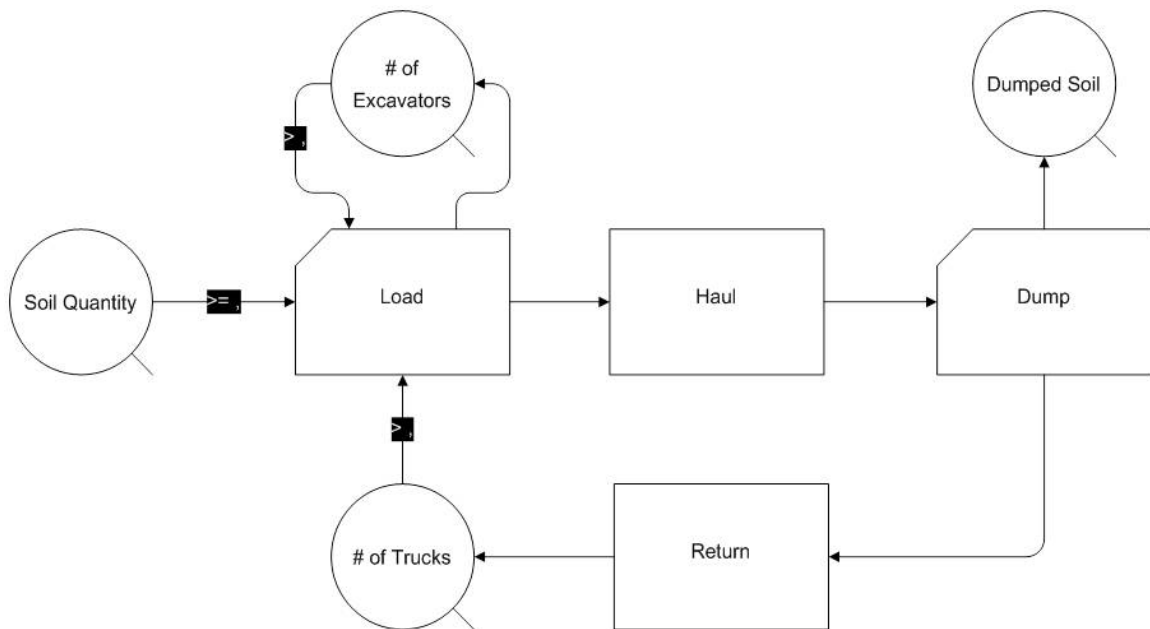


Figure 3-47: Specific purpose earthmoving operation DES model

$$\text{Excavator Idle Ratio} = \frac{\text{The time weighted average of the content of Excavator Queue}}{\text{Number of Excavators}} \quad (3.18)$$

$$\text{Excavator Utilization} = 1 - \text{Excavator Idle Ratio} \quad (3.19)$$

$$\text{Truck Idle Ratio} = \frac{\text{The time-weighted average of the content of Truck Queue}}{\text{Number of Trucks}} \quad (3.20)$$

$$\text{Truck Utilization} = 1 - \text{Truck Idle Ratio} \quad (3.21)$$

$$\text{Time of operation in hours} = \text{Simulation Time} / 60 \quad (3.22)$$

$$\text{Production rate (m}^3\text{/hr)} = \frac{\text{The current content of Dumped Soil Queue}}{\text{Time of operation in hours}} \quad (3.23)$$

$$\text{Total cost of operation} = [\text{Truck cost (\$/hr)} * \text{Number of Trucks} + \text{Excavator cost (\$/hr)} * \text{Number of Excavators}] * \text{Time of operation (hr)} \quad (3.24)$$

$$\text{Unit cost (\$/m}^3\text{)} = \frac{\text{Total cost of operation}}{\text{The current content of Dumped Soil Queue}} \quad (3.25)$$

3.4.3 Central Database

Construction operations are information intensive. The optimum monitoring of such operations requires storing and retrieving a large amount of data on daily basis. Therefore, a central database has been designed to support the management functions of the developed model and to minimize the user interaction. The performance measurement and the earned value analysis modules interact with the central database. It is specially designed to organize, store and manage captured data from construction sites, providing queries to retrieve the information needed for reporting the project status. Relational database management systems are better suited for this type of model (Figure 3-47), since it contains structured data, relationships and schema design.

The central database developed here is considered the core of the data analysis and reporting framework. The database consists of forty one (41) entities (or tables). Tablet PC database explained in section (3.3.1.5) is considered part of the central database but on the tablet PC. However, the central database structure is on a web server to facilitate on-line data storage, retrieval and analysis. Resources entity involves the main three resources in any construction project, which are equipment, labor and material.

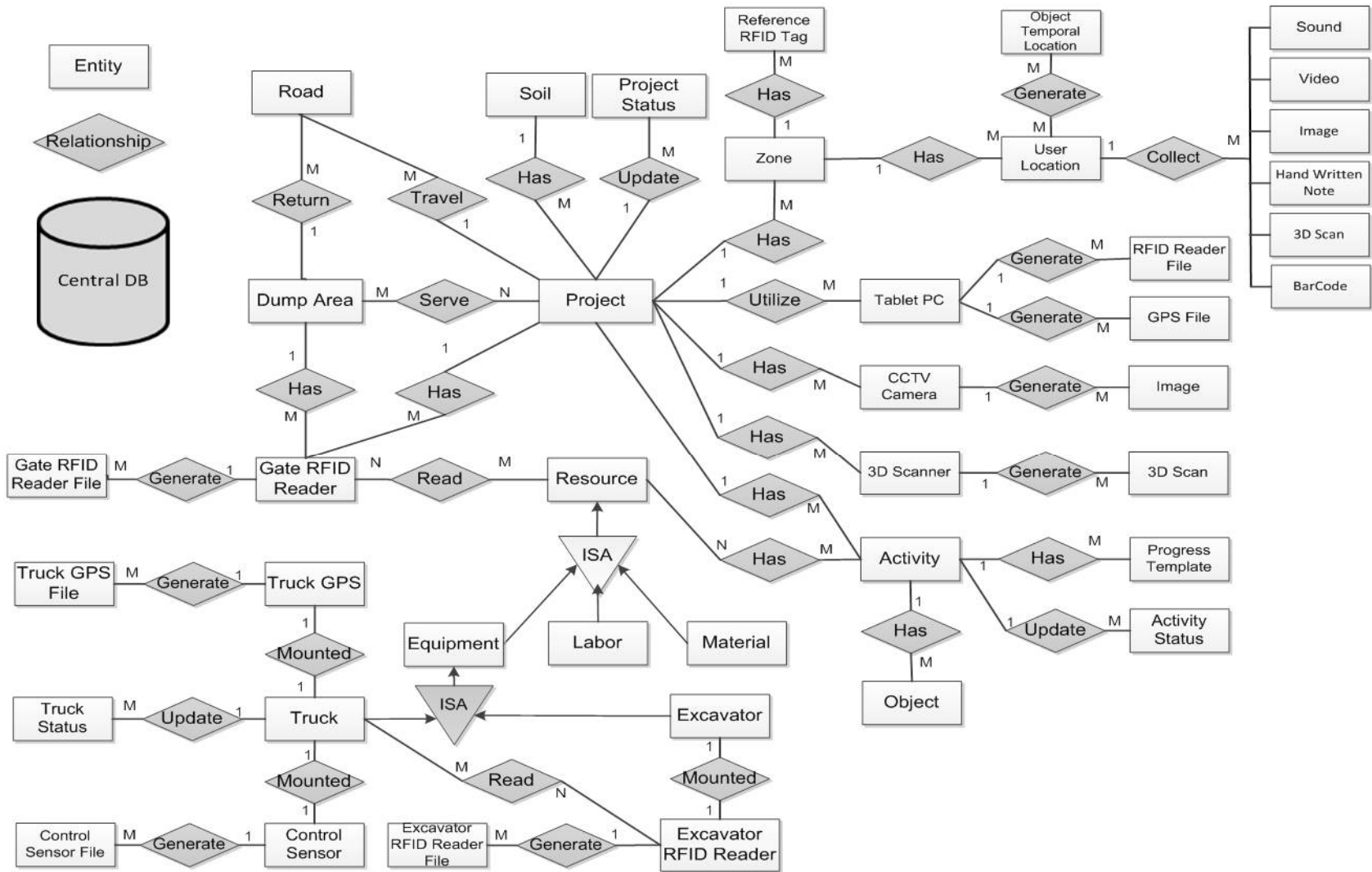


Figure 3-48: Entity Relationship (ER) diagram for the central database

The three entities are connected to resource entity with child to parent relationship as each one of them inherits attributes from the parent entity. The resource entity in addition to its three child entities are user defined. The main scope of the equipment entity in this research is to resemble the fleet configurations such as excavator and truck fleet. Both entities have the main attributes for the fleet configuration such as capacity. Also, truck and excavator entities are user input. Truck GPS entity is connected to the truck entity with one to one relationship, and in case of tracking all equipment this relationship could be connected to the equipment entity instead of only truck entity. Truck GPS is defined by the user. Truck GPS file entity is considered the output of the mounted GPS, and it is a separate file for each day's data. So, this entity is connected by many to one relationship to truck GPS entity. Road entity is important for describing the truck optimum travel and return route.

Road entity is connected to project entity and dumping area entity with many to one relationship and it is user defined. This entity is also important when comparing its points with the output from the truck GPS file. Dump area entity represents the area that serves the project for dumping excavated soil. It is connected to project entity with many to many relationship. Since, many projects can use the same dump area or one dump area could serve many projects and this entity is user defined.

Soil entity represents project soil characteristics as reported in the project geotechnical report. Soil entity is connected to the project entity with one to many relationship based on an assumption that each project has one soil type only. Gate RFID reader entity is connected to the resource entity with many to many relationship as resource can be read by many readers. For example, the same truck can be read at least by two readers, one in the project area and the other in the dump area. This entity is also connected to the project and dump area entities with many to one relationship as one project or dump area could have more than one gate and

consequently many RFID gates. RFID gate entity is utilized for registering the material delivery time and date. Additionally, it is used to record labor entering and exiting from the construction jobsite to calculate each labor time sheet. In case of using control sensor to track the exact dumping time, then control sensor entity is connected to the truck entity with one to one relationship. The control sensor output is stored in the control sensor file entity and it is connected to control sensor entity with many to one relationship.

To track the truck proximity to the excavator, an RFID reader is mounted on the excavator. So, the relationship between the excavator RFID reader entity and excavator entity is one to one. The results of the excavator RFID reader is deposited in the excavator RFID reader file. Truck status entity is considered the output for processing the data from GPS/GIS or RFID gate or RFID/control sensor tracking methods. This entity has many to one relationship with the truck, as it reports the truck status on daily basis. CCTV camera and 3D scanner are parts of the independent automated data acquisition technologies that were utilized. Accordingly, each entity was created for each technology and both are connected to project entity with many to one relationship. The captured data from the CCTV camera is stored in the image entity. The same procedure is followed with the output of the 3D scanner.

Object temporal location entity is the output for processing user location and RFID localization for indoor zones, or RFID and GPS for outdoor zones. This location is calculated on daily basis. This entity is connected to user location by many to many relationship. Activity status entity is connected to activity entity with many to one relationship and this entity is considered the output for processing the captured on site data from different automated acquisition technologies supported by the interaction going on between site personnel and tablet PC. Project status entity is considered the final output for the developed model as it reports on project level and it is connected to project entity by many to one relationship. For

more details about each entity, attributes and how it is utilized in the developed model refer to Appendix B.

3.4.4 Reporting Module

The purpose of reporting module is to generate textual, tabular and graphical reports to facilitate project tracking, control and forecasting. These reports are generated to depict progress at all control levels. Performance reports are generated daily, weekly and monthly according to the activity and user preferences. A project level management requires an overview of project progress and milestones. Since the reporting module exists on web server, all team members could access it via internet. This module provides progress information including:

- A summary of status of the schedule, budget and expected completion date.
- Report on the current progress since last update to date.
- Report the cumulative progress to date and report on the end forecast.

3.5 Summary

This chapter presents the research vision and the developed model and its frameworks, modules, sub-modules, methods, procedures and algorithms. The developed model embraced integration and automation; utilizing a wide range of technologies in an adaptive way to facilitate timely tracking and progress reporting. The developed model integrates project visualization-information aspects, automated site data acquisition and earned value analysis.

Chapter 4: FIELD STUDIES

4.1 General

This chapter describes the field studies conducted to evaluate existing automated site data acquisition technologies. The fieldwork focused on deployment of these technologies on actual construction jobsite. These studies led to the identification of challenges associated with utilizing each technology separately and exploration of the likely advantage of integrating technologies and using them to estimate project progress. Figure (4-1) presents the chapter overview. The results of these studies were conducted concurrently with model development and refinement of its application. The captured data from the field studies helped in the process of model verification and validation. This chapter has three main sections. It starts by a brief description of the construction project used in this research. The second section explains the independent automated data acquisition technologies deployed on the jobsite. The last section describes the tablet PC used in this research and its integrated automated data acquisition technologies.

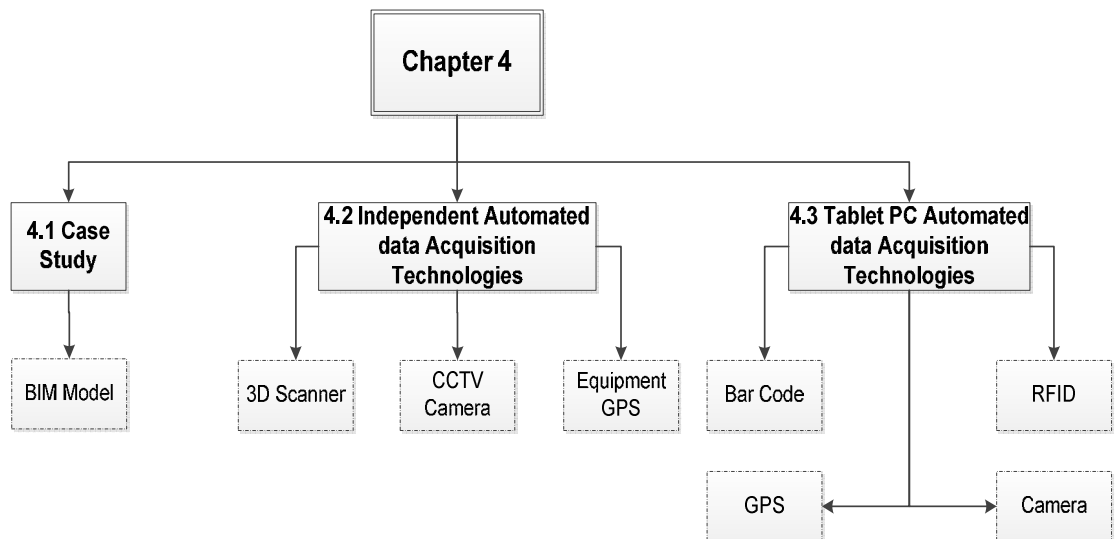


Figure 4-1: Chapter 4 overview

4.2 Case Study

Field studies were conducted during the construction of the Center for Structural and Functional Genomics (CSFG) at Concordia University in 2010-2011, as shown in Figure (4-2). The project is located at the corner of Sherbrook St. West and West Broadway St. in Montreal. It forms an expansion to the existing Science Complex. Construction of the building started on April 2010 and completed by June 2011. The building consists of basement floor, ground floor, first floor, second floor, mechanical floor and roof. The total built up area is 6000 m². The building is a reinforced concrete structure, except the mechanical and fire escape stairs, which are of steel structures. The contractual budget was \$20 million with contractual duration of 12 months.

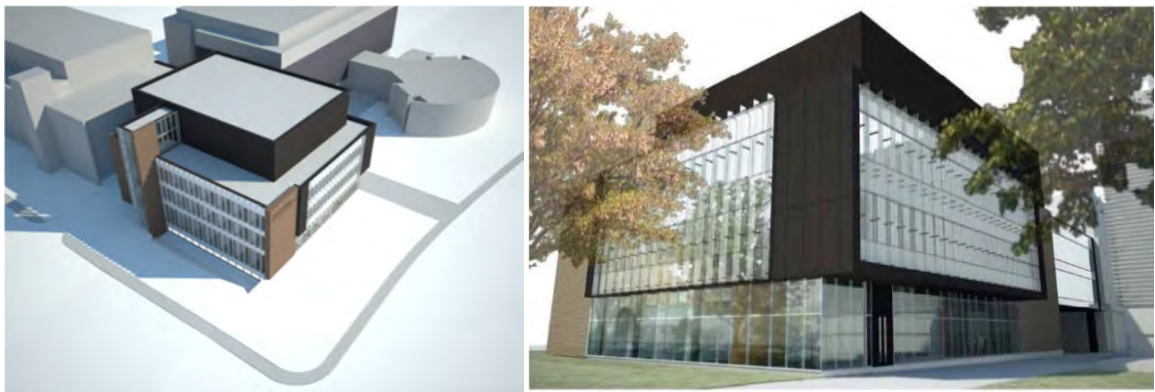


Figure 4-2: Genomics office building

The progress report provided by the prime contractor has five main sections along with few appendices where few of the most important documents are attached. The daily reports submitted by the contractor provide the minimum amount of information regarding the project. It was noticed that no quantities are reported and no man-hours tracked. Although the level of details in the daily reports is not high, they were used along with the site daily pictures and the invoiced percentages to update the baseline schedule, as depicted in Figure (4-3). In addition,

daily pictures were also used to identify the actual progress and work logic versus the planned schedule.

DATE: 05 / 05 / 10 PAGE: 41
 NOM DU PROJET: NCR Genomignel # PROJET: 32595

RAPPORT:
 Excavation - Sochi mura 3^e left + Forage
 Petrifond - Finir Forage Fosse AVE-20-21 et 45a40 et 39a37
 - Erreur de Petrifond sur Fosse
 Coffrage - Préparé pour tourner - Planification
 Muret - Tuyau dans Existant Passage S-1 Eau Domestique
 Elée - Fils Tourer & Tuyau dans Existant S. Bois + Chemin Massif
 Vent - Embut Diffuseur dans Existant
 Beton Prefab - Embut Marche du S.P.
 Verreault - Demolition plafond Existant

VISITEURS:
 P.S. Erreur de Petrifond sur Fosse 20-21
 Coffrage retardé de 2 jours.

CONDITIONS ATMOSPHÉRIQUES Temp.: AM ____ °C PM ____ °C SOIR ____ °C

EFFECTIFS AU CHANTIER

SPECIALITÉ	JOUR	SOIR	SPECIALITÉ	JOUR	SOIR	SPECIALITÉ	JOUR	SOIR
DÉMOLITION			PORTES ALUMINIUM			GICLEURS		
EXCAV. ET REMBL.	6		COLOMB. MÉT./GYPSE			CALORIFUGAGE		
AMÉN. EXTÉRIEUR			TUILES ACOUSTIQUES			AUTRES TRAVAUX		
COFFRAGE	2		ISOLATION			GARDIENNAGE		
ACIER ARMATURE			TUILE CÉRAMIQUE			Petrifond	6	
FINI DE BÉTON			COUVRE-PLANCHERS			Beton Prefab	3	
MAÇONNERIE			PEINTURE			Inspection	1	
STRUCT. ACIER			DIVISION TOILETTE			VERREAULT:		
MÉTAUX OUVRÉS			ASCENSEUR			• ADMINISTRATION		
MENUISERIE			PLOMB./CHAUFFAGE	3		• COORDINATION	1	
ÉBÉNISTERIE			VENTIL./CLIMAT.	2		• JOURNALIER		
IMPERMÉABIL.						• MENUISERIE	1	
TOITURE						4.5	1	
REVÊT. MÉTAL			ÉLECTRICITÉ	2				
FENÊTRES/M. RID.								
TOTAL	8		TOTAL	7		TOTAL	14	
						GRAND TOTAL	29	

Demande de paiement					
Page/Nombre total de pages	Date	Demande :			
Page 2 de 7	30-04-2010	03			
Description des travaux	Ventilation des coûts	Travaux exécutés à date		Demandes antérieures	Présente demande
		%	Montants		
CONTRAT ORIGINAL					
Conditions générales et autres		26,6%			
Cautionnement		100,0%			
Frais et profits de l'Entrepreneur		25,0%			
Permis de coupe					
Excavation et remblayage régulier		48,9%			
Excavation de sols contaminés B-C		100,0%			

Figure 4-3: Sample of project progress reports

4.3 Preparations for Field Work

Initial visits to the jobsite of the project were made and the blue prints released for construction as well as the construction schedule in MS project were reviewed to get familiar with the various aspects of the project. More than forty (40) jobsite visits were made. Appendix C provides a summary of the site visits schedule and the type of data captured. The Architectural and Structural plans provided by Concordia University were in the form of 2D CAD drawings, and there was no BIM model for the building. A 3D BIM model was created as a part of the developed model. The BIM model was developed using the project 2D drawings. Revit Autodesk software was used to develop the 3D BIM model, as shown in Figure (4-4) (Montaser and Moselhi, 2012 a).

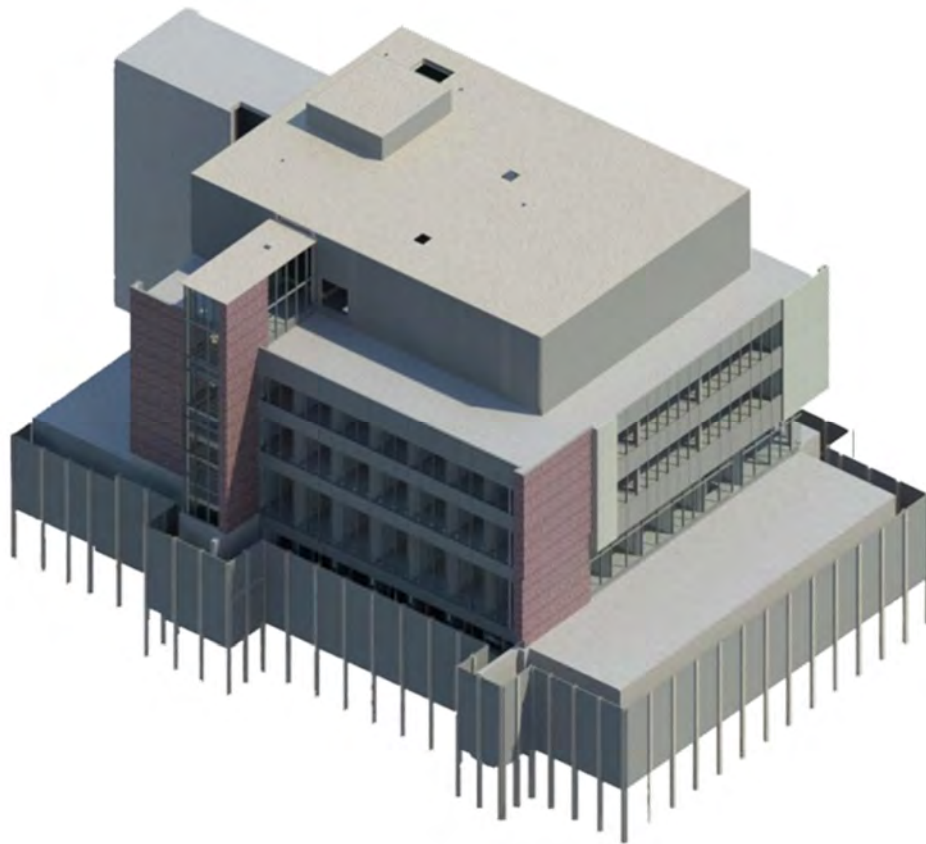


Figure 4-4: Genomics building 3D BIM model (Montaser and Moselhi, 2012 a)

All of the construction data, such as objects' materials as well as their specifications were either available in related documents or assigned during site visits to the building. Since the developed objects have parametric relationship with each other, the sections, elevations, and perspectives were generated automatically. The model consists of 7450 parametric object.

In early stages of this research, NavisWorks Autodesk was used to generate 4D BIM model for the project. NavisWorks was used to link schedule with the 3D BIM model objects. The 3D Revit model objects were exported to Navisworks along with the construction schedule. Once the Microsoft Project schedule and 3D model were imported into Navisworks detailed relationships were developed to link each schedule activity to its corresponding objects of the model. The software automatically simulates the construction sequence as per the project schedule, as shown in Figure (4-5). The output of the 4D model was in the form of a simulation video where an animated sequence of construction can be seen. Different colors were assigned to objects in the developed 4D BIM model to express their respective status of progress. At any given time, the 4D model can reflect the time schedule in a visual manner. Objects with user selected colors means that they are already executed, while objects green highlighted color means that there is a construction activity in progress. At the top left of the simulation screen a detailed date specifies the name of the activity being executed along with the exact time and duration. However, the process of utilizing Microsoft Project for scheduling, Revit for 3D BIM modeling and NavisWorks for 4D BIM modeling was cumbersome. Since, any changes in the schedule or the 3D BIM model necessitate beginning the process of exporting both data from scratch again to NavisWorks to generate the 4D BIM model. In addition, some data were lost when exported from 3D Revit model into NavisWorks software.

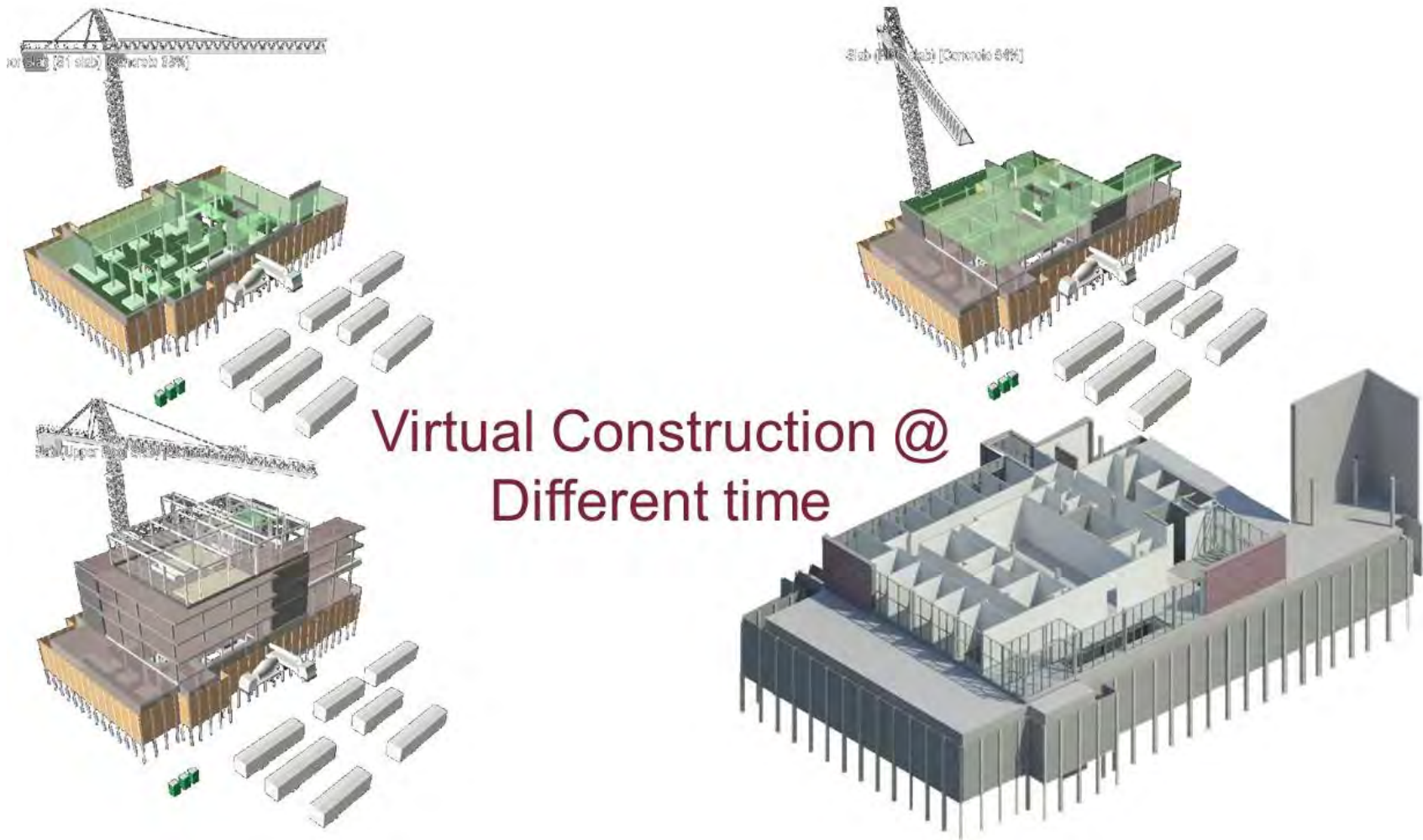


Figure 4-5: 4D BIM NavisWorks© model

This challenge dictates making modification in Revit software to accommodate the option of generating 4D BIM Model internally without using third party software. This development is described in Chapter 6.

4.4 Independent Automated Data Acquisition Technologies

Independent automated data acquisition technologies are those not embedded or integrated with the tablet PC. In this research different technologies belonging to this category were investigated, which are 3D scanner (LADAR), Fixed GPS and CCTV camera. The data captured from both 3D scanner and CCTV camera were analyzed and their respective advantages and limitations identified. The data collected using these two technologies, were not processed in numerical examples. The developed model database was designed to include all sources of data capturing technologies including LADAR and CCTV. The following subsections explain the deployment of each technology, data captured and their respective limitations.

4.4.1 3D Scanner

The construction site was scanned using Riegl LPM 100 VHS 3D scanner, as shown in Figure (4-6). It is a long-range scanner with a range of 200 m (Riegl, 2013). Fourteen (14) jobsite visits were conducted at different time spans and whether conditions to scan the outdoor and indoor zones. For every outdoor scanning five different positions were utilized to scan the building. For indoor scanning two positions were utilized in the first floor and a similar approach was followed in the second floor. The duration to scan the outdoor zones or indoor zones used to be in the range of four to five hours. Appendix C provides information regarding scanning schedule and the studied scanning characteristics. Those characteristics are the vertical and horizontal range and resolution, duration, 3D scanner location, date the planned

and actual number of point clouds. The scanner was utilized to scan construction sites at different stages. Many scans had to be performed from different positions to get enough information. 3D scanner facilitates capturing point clouds for the structure under study. It provides a geometrical presentation of the as built condition of the project. However, it is still yet expensive compared to the other automated data acquisition technologies utilized for the purpose of project control. Its setup is similar to surveying equipment such as total station, which facilitates its usage in construction sites. The increase of deployment frequency for tracking progress combined with its heavy weight made its utilization a difficult task. The scanner used in this research and its attachments weighed about 25Kg. Similar, to other surveying equipment, the setup of the 3D scanner for each position is time consuming. Scanning position configuration and its selection is crucial for capturing data. Yet, this process is done manually and based on user judgment.



Figure 4-6: RIEGL LPM 100 VHS LADAR

In addition, the 3D scanner setup attributes, which are the vertical and horizontal range and resolution, necessitate a tradeoff between time and quality. The less the resolution (i.e. the step angle used in the scanning process) the better data quality is acquired but requires more scanning time and more data to process. The area of planning the process of scanning and

selecting scanning positions still needs more efforts to optimize it. The integration of this area with 4D BIM model would facilitate the process of geometrical optimization of those scanning positions.

For outdoor scanning, there were some limitations in utilizing such technology. Weather conditions were one of those limitations. The used scanner minimum operating temperature is -5°C , which prevented utilizing it outdoor after starting the month of December. It is known from literature that glass and reflecting surfaces cause a problem during capturing data through the scanner due to the laser beam not returning to the scanner. However, it was interesting to find out during the tracking of curtain walls progress that this phenomenon could make more noise to the captured point clouds. It was noticed that the items that were not scanned by the scanner and were behind the scanner started to appear in the point clouds inside the building. These add more noise to captured data and would cause problems in case of using priori object recognition techniques with the point clouds. This is because noisy data could coincide with the location of objects that were not constructed yet, which would misleadingly report its progress.

In addition, filtering this data would be problematic due to the ignorance of its existence. So, it would be recommended to take pictures for the scanned position all around to know the surroundings that could appear in the point clouds. Outdoor scanning was also utilized to track the progress of the building's concrete structure. However, the data captured was not enough since the scans capture only the floors slabs' edge and the structural elements on the perimeter only and nothing about the intermediate structural elements. This problem will increase in case of higher and bigger area of buildings. In addition, the scans were conducted on the finalized concrete structure, which represents a portion of the concrete activities. Reinforcement bars, formwork, concrete pouring, stripping formwork and concrete

curing are difficult to be tracked using the 3D scanner. Scanning formwork and temporary structures is a cumbersome process. Accessibility to top view was not possible, so scanning from underneath yielded noisy data arising primarily from the supporting formwork and other obstructions including formwork and rebar in 3D BIM model is a very difficult process and could change during construction. This would raise too much questions about the feasibility of such technology to track cast in situ concrete structures.

For indoor scanning, there were also some limitations for utilizing such technology. As construction progresses, it becomes very difficult to utilize. For example, at early stages to scan the whole floor, 4 different scanning positions were required. But after the partitions activities started the floor was divided into 64 rooms and spaces, which mandated 64 different scanning positions. Additionally, due to the reflection of 3D scanner laser beams, all insulated HVAC ducts and glass partitions were noisy or not captured. The scanning was conducted after working hours, for both indoor and outdoor scanning. This procedure reduced the noise in the captured point clouds due to the site congestion during working hours due to the movement of labor and equipment. Nevertheless, there was too much noise due to the stationary equipment and material, which generated shadows and obstructions to the line of sight of the scanner.

The output of the point clouds were manipulated through Riprofile software from Reigel. The point clouds were exported as (.Dxf) files to be viewed on CAD software. Many trials were performed to superimpose the 3D scans on the 3D BIM model. However, it was not successful because the utilized 3D scanner did not have a GPS. In addition, it was not possible to integrate GPS because the used scanner was old; it was acquired for earlier research in 2002. Therefore, the scanned point clouds were not georeferenced. Modeling 3D point is a time consuming process that lacks the capability of capturing material types, textures, and colors of scanned objects. In addition, it depends on manual manipulation that depends on user's visual

identification. Additionally, it depends on the accuracy and the degree of detail of the BIM model, which could have many changes and modifications.

4.4.2 Fixed GPS

In this research, GPS device was mounted on a hauling truck to capture the spatial data along designated hauling roads for the project. This section presents the verification and validation to the GPS/GIS based tracking method and stochastically forecasting performance. Figure (4-7 a) shows the GPS unit and Figure (4-7 b) depicts the excavation process of Genomics building (Montaser et al., 2011).



Figure 4-7: (a) GPS unit (b) Genomics building (Montaser et al., 2011)

The GPS unit was attached to the hauling truck during the whole excavation process of the project. The captured data was reported every 2 minutes and it depicts the exact truck position in terms of latitude and longitude, as shown in Table (4-1). The fleet used in this project consists of an excavator serving a number of hauling trucks. The soil to be excavated is sandy clay with density of 2900 lb/CY and a swell factor equals to 0.81 according to the geotechnical report.

Table 4-1: Sample of GPS unit captured data (Montaser et al., 2011)

Unit # 213							
Date	Time	Information	Location	Speed (Km/h)	Heading	Latitude	Longitude
06/05/2010	7:20:18	Moving		60	SE	45.49302	-73.65086
06/05/2010	7:22:18	Moving		60	SE	45.48339	-73.62866
06/05/2010	7:32:18	Moving		2	W	45.4575	-73.64226
06/05/2010	7:34:18	Stopped for 3m	3446 West Broadway AV, Montréal, QC, CA			45.45676	-73.64086
06/05/2010	7:38:02	Moving		14	SW	45.45631	-73.6405
06/05/2010	7:38:18	Moving		21	SW	45.45556	-73.64119
06/05/2010	7:42:07	Moving		26	SW	45.45491	-73.6322
06/05/2010	7:42:11	Moving		31	SW	45.45456	-73.63248
06/05/2010	7:42:12	Moving		30	SW	45.45449	-73.63253
06/05/2010	7:42:18	Moving		13	SW	45.45419	-73.63275
06/05/2010	7:44:18	Moving		50	NE	45.45263	-73.63131
06/05/2010	7:46:18	Moving		14	SE	45.45737	-73.62521
06/05/2010	7:50:18	Moving		15	SW	45.45668	-73.6218
06/05/2010	7:52:18	Moving		33	SW	45.45692	-73.62621
06/05/2010	7:54:18	Moving		18	NE	45.45154	-73.63451
06/05/2010	7:58:18	Moving		6	SW	45.45332	-73.63744
06/05/2010	8:00:18	Stopped for 2m	Corner of Elmhurst AV and Harley AV, Montréal, QC, CA			45.45465	-73.63992
06/05/2010	8:02:18	Moving		14	NE	45.45509	-73.64033
06/05/2010	8:04:18	Stopped for 9m	3448 West Broadway AV, Montréal, QC, CA			45.45673	-73.6409
06/05/2010	8:13:21	Moving		18	S	45.45509	-73.64147

The total quantity of excavated soil is 14 000 bCY. In early stages of this research, a spreadsheet application was developed to facilitate the calculation of cycle times (i.e., the time for loading, hauling, dumping, and returning). GPS data pertinent to the direction and velocity are used to confirm the identification of each cycle activity. The developed spreadsheet application calculates the duration of each of the identified activities, and hence the cycle time. The collected GPS data consist of 104 complete cycles. In addition, Appendix D provides the methods used to estimate of upper and lower limit productivity planned for Genomics building excavation process. An average daily value of the extracted durations is used to compare the actual GPS productivity to the planned estimated productivity, as shown in Figure (4-8) (Montaser et al., 2012).

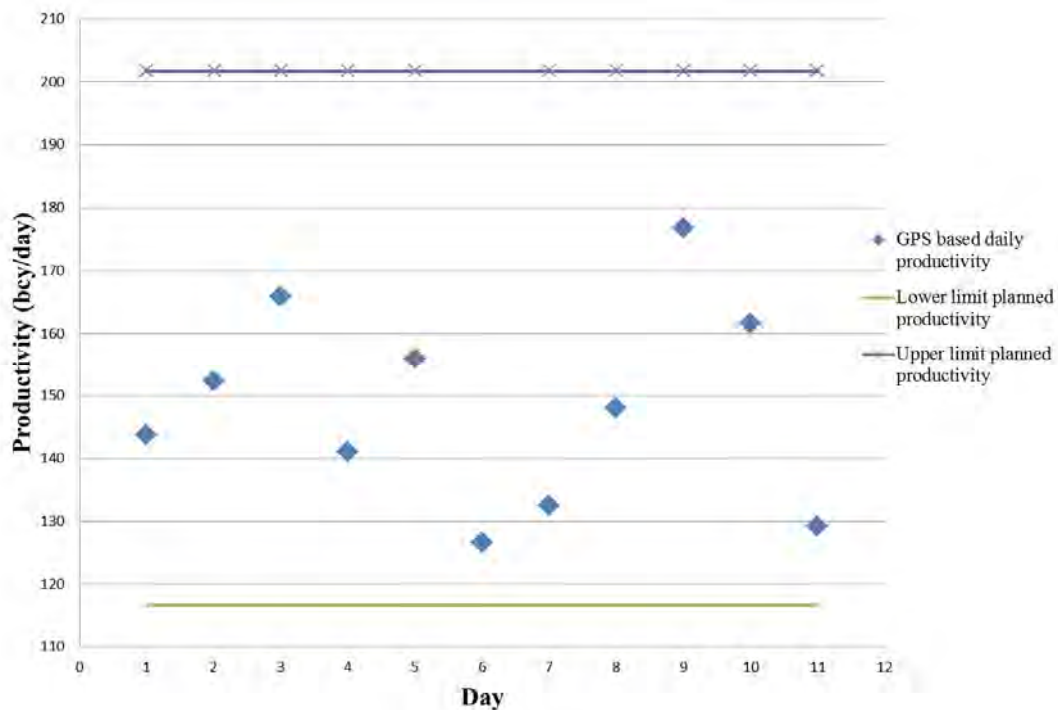


Figure 4-8: GPS based daily productivity (Montaser et al., 2012)

The calculated durations were used to develop Probability Density Functions (PDF) for loading, travelling, dumping and returning times. “Crystal Ball” software was used to fit

the data and construct the four functions (Oracle, 2013). For each cycle component, “Crystal Ball” identifies the probability function that best fits the process at hands. Its output is in the form of a graph and its associated statistical parameters describing the distribution (e.g. mean value and standard deviation). “Crystal Ball” identifies the quality or goodness of each fit using Anderson-Darling method.

The best-fit distribution produced for the loading time was lognormal distribution, with a mean value of 4.43 min, and a standard deviation of 2.30 min, as shown in Figure (4-9 a). The best-fit distribution produced for the travelling time was also lognormal distribution, with a mean value of 10.03 min, and a standard deviation of 3.43 min, as shown in Figure (4-9 b). Similarly, the best-fit distribution produced for the dumping time was lognormal distribution, with a mean value of 5.80 min, and a standard deviation of 1.33 min, as shown in Figure (4-9 c). Finally, the best-fit distribution produced for the returning time was a lognormal distribution, with a mean value of 9.59 min, and a standard deviation of 2.47 min, as shown in Figure (4-9 d).

The fitted PDFs were then used as input for a simulation model to forecast stochastically productivity, time and cost of the process. After that, the PDFs were used to experiment and evaluate different scenarios to forecast in a timely manner corrective actions and better appreciate the main characteristics of the simulated operations, including the impact of the uncertainty associated with the model parameters. In the early stages of this research, simulation was carried out using the “ExtendSim” software, which contains common simulation tools and instruments (ExtendSim, 2013). The simulation model is shown in Figure (4-10). It has four main components: the loading, travelling, dumping and the returning operations.

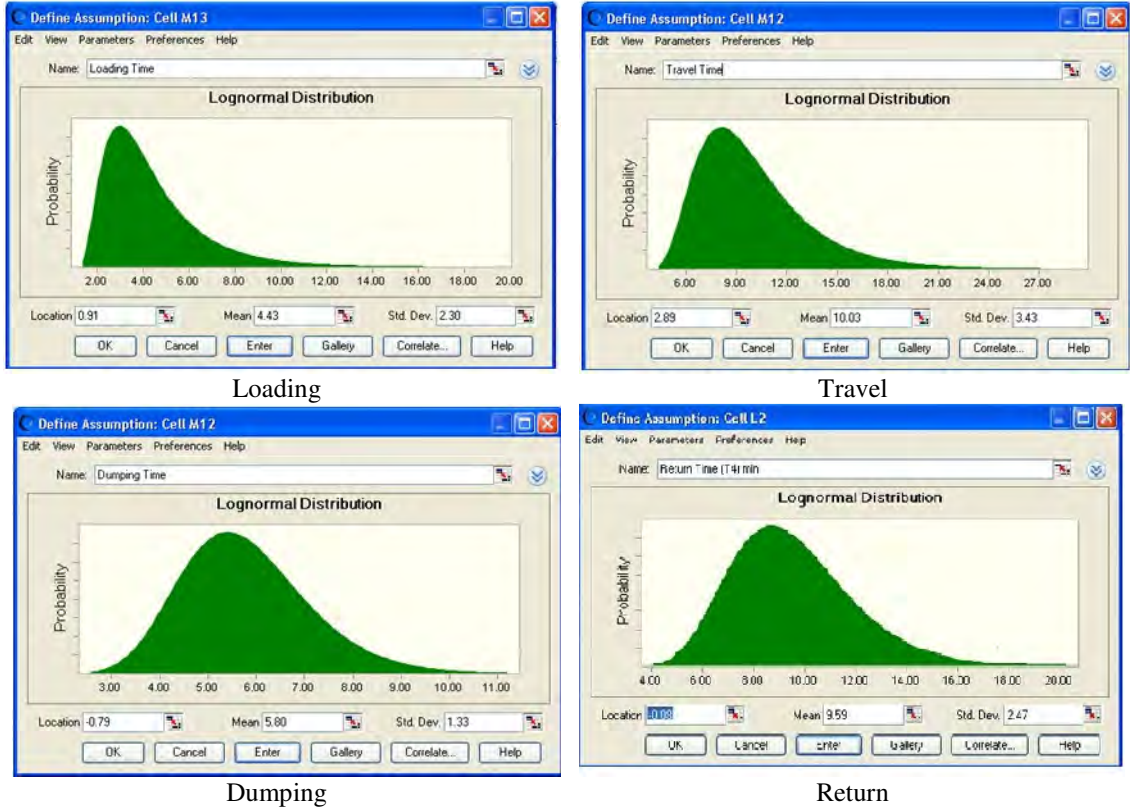


Figure 4-9: Cycle time components PDFs

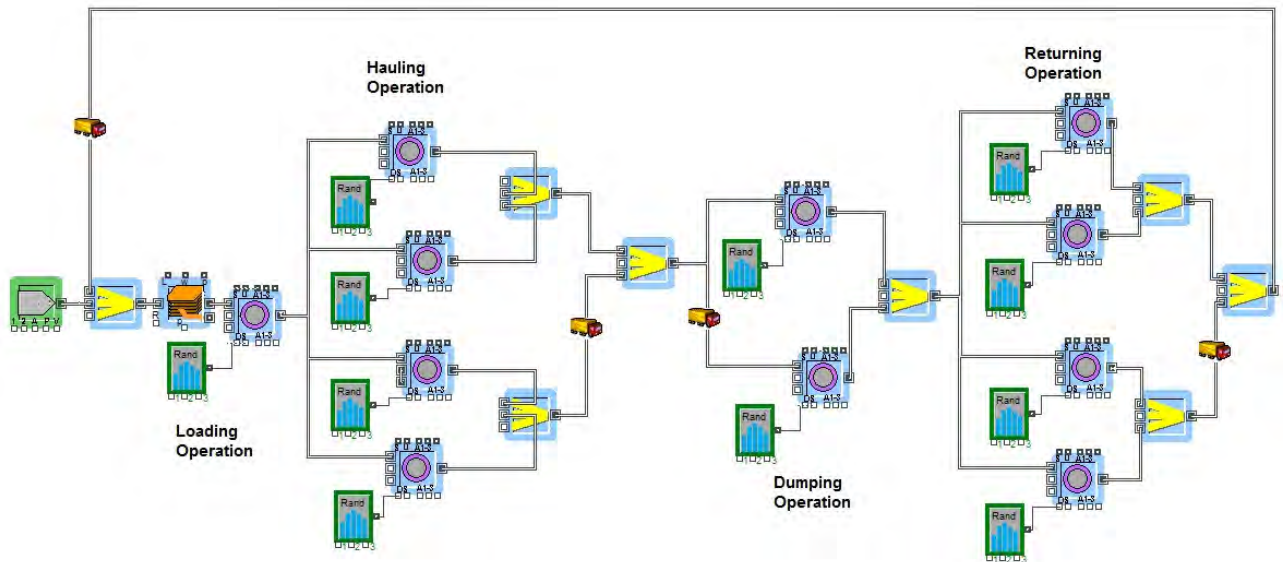


Figure 4-10: ExtendSim simulation model

In “ExtendSim” software, each operation block has the capacity of handling one unit at a time. This is sufficient for modeling the loading operation, where trucks are loaded one by one. However, for other operations like hauling and returning, it is not possible to model several

trucks on the same road simultaneously. So, several operations blocks were needed to model such operations having a capacity of more than one unit. In this respect, the loading operation is represented by an operation block preceded by a stack block to present the trucks waiting in queue before loading. The travelling and returning operations are represented by four different operation blocks. The dumping operation is modeled using two operation blocks, representing the capacity of the dumpsite. Uncertainty impact is incorporated in the present method, as the simulation model is developed based on actual GPS data captured during ongoing onsite operations, which implicitly account for uncertainty. The number of trucks was increased incrementally in search for a balance with the production of the excavator and the change in productivity and total earthmoving duration was monitored. In a similar manner, the productivity and earthmoving operation duration were also calculated for the upper and lower limit of the planning stage. The results are calculated as shown in Table (4-2).

The results of estimating productivity for different fleet configurations are shown in Figure (4-11) for both, the planning upper and lower estimates, and the simulation model results. The results shows that the simulated mean of the production rate falls between the upper and lower planned limits and closer to the lower limit, which is taking the same trend line for the average daily GPS data. The results of the simulation model indicate that maximum fleet productivity is achieved using 11 trucks, while the planning phase deterministic model results show that maximum productivity can be achieved using only 8 and 9 trucks for lower limit and upper limit cases, respectively. It is interesting to note that the unaccounted for uncertainty impact can significantly influence estimated production rates, particularly in urban areas.

Table 4-2: GPS productivity and the process duration (Montaser et al., 2012)

No of Trucks	Production Rate (bcy/hr)	Duration (hr)	Duration (Day)
2.00	53.27	254.98	32
3.00	78.37	173.30	22
4.00	102.97	131.91	17
5.00	125.74	108.02	14
6.00	145.14	93.58	12
7.00	162.14	83.76	11
8.00	173.60	78.24	10
9.00	179.43	74.70	10
10.00	181.81	74.55	10
11.00	182.19	74.51	10
12.00	182.29	74.51	10
13.00	182.29	74.51	10

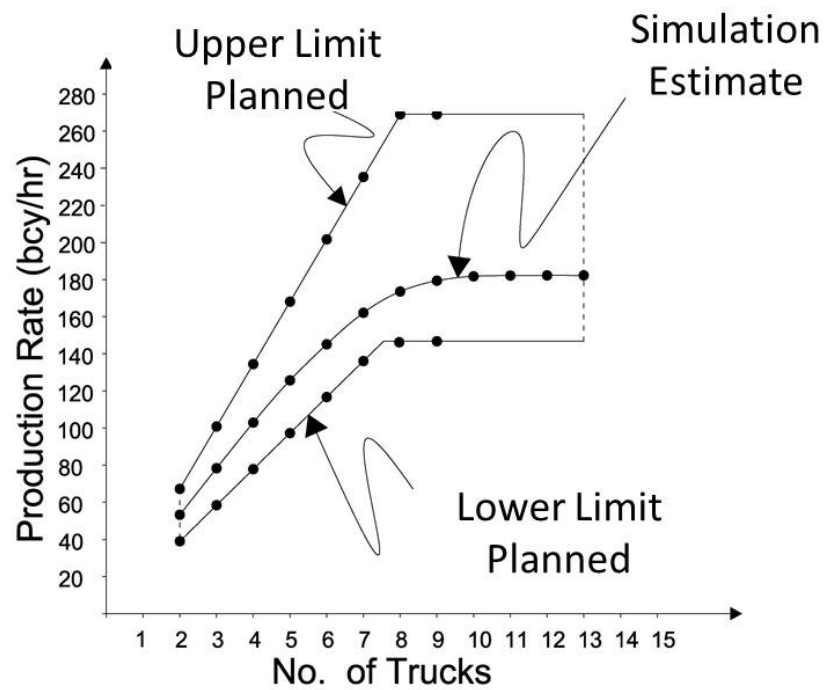


Figure 4-11: Simulation results vs. upper and lower limit planned estimates

In Chapter 6, StroboScope DES engine was used instead of ExtendSim due to many reasons. For each truck or excavator, the model should be changed manually to add loading travel route or loading block, which is a troublesome process. In addition, the user should enter the PDFs manually and the software itself could not be integrated as a part of automated module. However, StroboScope engine has the capability to be integrated with other modules. In addition, the change in the number of trucks or excavators could be changed without reconfiguring the simulation model manually.

4.4.3 CCTV Camera

The use of CCTV camera with time-laps capability allows capturing long time operations and displaying them in a relatively short time. This capability assists in productivity measurements and outdoor material tracking. Genomics building contractor installed CCTV camera at an early stage in the project, as shown in Figure (4-18). Camera type was Sony CP 380 (Sony, 2013). The CCTV camera captured images were very useful specially in validating the GPS/GIS based tracking. However, like any other technology, CCTV camera has its own limitations. One of the major limitations is the weather conditions such as rain, fog and poor illumination, which obstruct the camera's line of sight. For example, in Figure (4-12), the image taken at May 14, 2010 was not clear due to the rain at that day. Yet, CCTV camera is still one of the best solutions to visually check construction jobsites remotely.



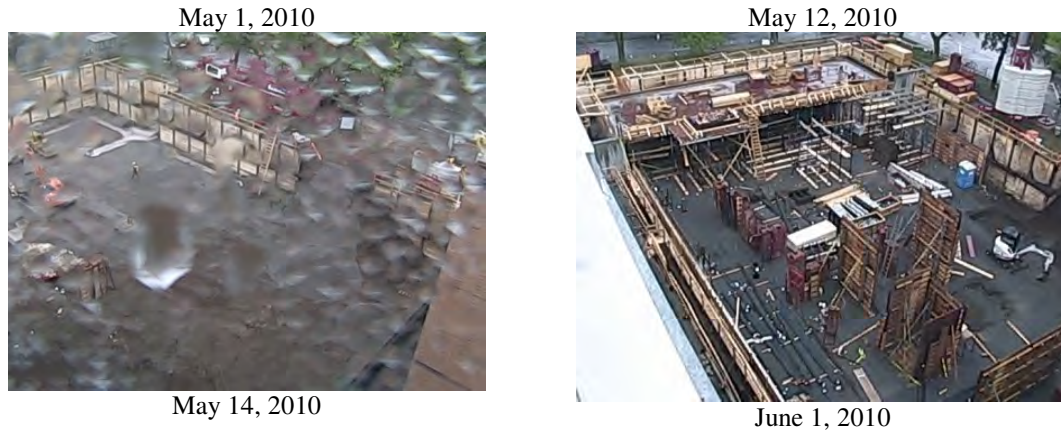


Figure 4-12: Sample of CCTV camera captured data

4.5 Tablet PC Automated Data Acquisition Technologies

Tablet PC is considered one of the most important components in the developed model. This is because it hosts many automated data acquisition and visualization technologies. The tablet PC used in this research is a rugged Panasonic Toughbook®H2 handheld tablet PC, as shown in Figure (4-13). It has 10.1" sunlight-viewable LED screen, fast Intel® Core™i5 vPro™ processor and 1.7GHz with Turbo Boost up to 2.7GHz Intel®. In addition, it has 40 GB hard drive, Smart Cache 3MB, 4GB SDRAM (DDR3-1333MHz), twin batteries (6.5 hours with both batteries), ports such as USB, serial and Ethernet and IP65 sealed all-weather design (Panasonic, 2013). The data captured from the tablet PC camera was not utilized in the numerical examples presented in the thesis.

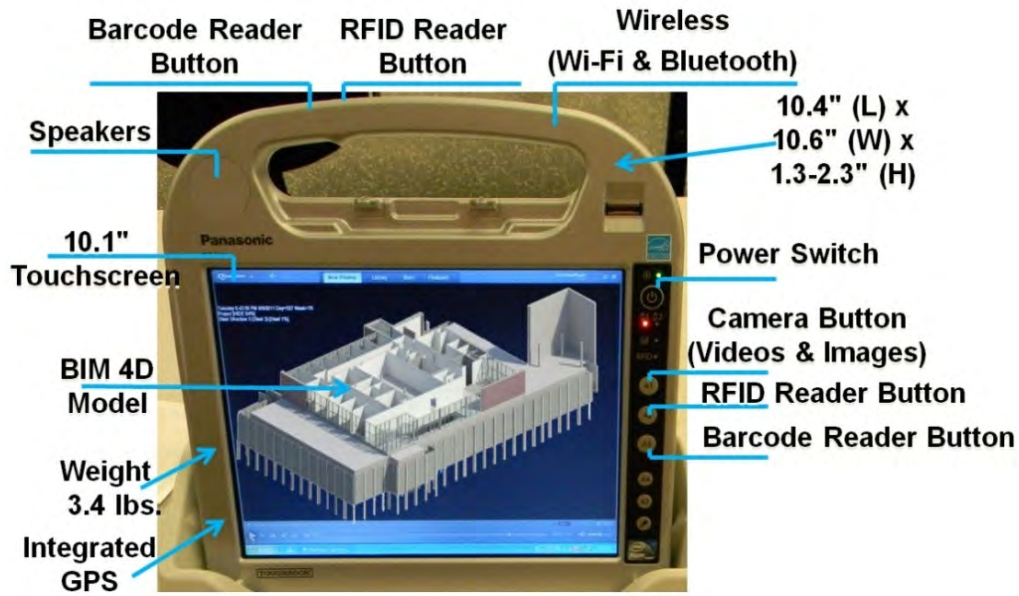


Figure 4-13: The tablet PC utilized during the field studies

The tablet has a docking station to be connected to the tablet in case it is used as laptop. The tablet is connected through the docking station to the 3D scanner for setting the scanning attributes and storing the captured data. The tablet has wireless capabilities such as Bluetooth, 3G mobile internet network and Wi-Fi. In addition, barcode and RFID readers are embedded in the tablet. However, it could only read high frequency RFID tags, which have a maximum read range of 1m. So, Intermec mobile RFID reader IP30 was acquired to work with ultra-high frequency tags that were deployed in the developed model (Intermec, 2013). GPS could be embedded in the tablet PC. However, the tablet used in this research did not have GPS. So, Trimbel GeoXT mobile GPS was acquired for outdoor localization. The tablet PC, mobile RFID reader and mobile GPS communicate and exchange data via Bluetooth standard communication protocol. The following sections explain the utilization of tablet PC capabilities for data acquisition.

4.5.1 Camera

Multimedia information, including digital images and videos are acquired from site to capture construction progress on site. Images and videos captured with a digital camera on a daily basis are stored into the developed tablet PC database. Figures (4-14) show indoor images at different construction time span. Similar to other technologies, the camera also has some limitations, as its location and other related attributes are subject to site personnel judgment.



Figure 4-14: Sample of Indoor camera captured data

Then, the experience, camera orientation and overlap between images are considered influential factors to be considered. Illumination is another factor that constrains camera

deployment in certain situation such as electromechanical shafts with poor lighting. The tablet PC is used to capture the images whether from indoor or outdoor zones. The captured images get new attributes from the developed model, which are location and date/time. It could be compared visually to the pictures obtained from the 4D BIM model, as shown in Figures (4-15) and (4-16). Instead of manual methods of interpretations, object recognition and photogrammetry could be utilized combined with the 4D BIM for data processing.



Figure 4-15: 4D BIM image vs. actual image for outdoor zone



Figure 4-16: 4D BIM image vs. actual image for indoor zone

4.5.2 Barcode

Barcode is used for identifying items. Most of the electromechanical items delivered to Genomics building were tagged with Barcode, as shown in Figure (4-17). Identifying those items and retrieving their respective data is a benefit for tracking progress of the jobsite. If the barcode reader captured an item, its current zone could be identified accurately based on the location of the user who scanned that barcode.



Figure 4-17: Items with barcode inside Genomics building jobsite

4.5.3 Mobile GPS

In this research, Trimble GeoXT GPS was used to identify site personnel location in outdoor zones. It is a high performance GPS receiver combined with a rugged handheld

computer with a powerful 520 MHz processor, 128 MB RAM, and 1 GB of onboard storage, as shown in Figure (4-18 a). TerraSync software was installed on the handheld GPS. It collects and updates geographical data, as shown in Figure (4-18 b). Differential GPS (DGPS) correction should be applied to the captured GPS data. DGPS requires one or more additional receivers, called base stations or reference stations (Trimble, 2013), which are located at known points. Data collected at base stations is used to determine GPS measurement errors and compute corrections to these errors. Errors are corrected with DGPS either in real time or during post-processing (Trimble, 2013). Both methods were performed in this research.

For real-time DGPS correction, the base station calculates and broadcasts the error for each satellite as each measurement is received, which enables corrections while the user is in the field and collects GPS data. Real time DGPS corrections are generated and broadcasted in real-time by privately or self-owned GPS base stations, or by a wide range of government agencies. Real-time DGPS sources include external beacon and radio sources, as well as Satellite Based Augmentation Systems (SBAS) such as VRS networks in Canada. VRS networks use multiple base stations to calculate the DGPS corrections that are then delivered to the user from a Geostationary satellite (SBAS) or from a radio or cellular phone (Can-Net, 2013).

For example, corrections generated by a VRS network are commonly broadcasted over an internet server. A VRS network uses data from several base stations to provide corrections that are generally more accurate than corrections from a single base station. Factors that affect real time DGPS accuracy include how often the corrections are updated, how far the users is from the base station, and whether the coordinate system used by the correction source matches the coordinate system used by the GPS receiver (Can-Net, 2013). VRS base station was 50 Km far from Genomics building jobsite. Therefore, cellular connectivity was added to the Trimble

GeoXT GPS handheld via the TDL 3G cellular modem, which was acquired with the GPS, as shown in Figure (4-18 c). It was connected to the GPS via wireless Bluetooth. TDL 3G provides continuous network/internet access to real time VRS corrections. In this research, Concordia University acquired the VRS corrections license service for one-month to experiment with it through TDL 3G cellular modem (Trimble, 2013).

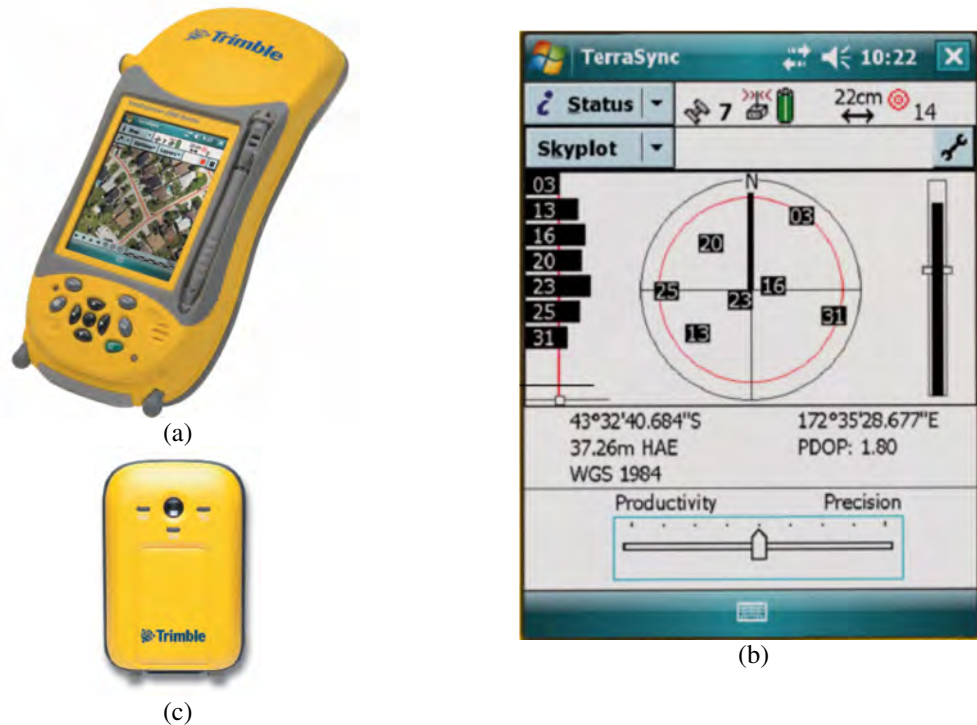


Figure 4-18: GPS hardware and screen shot

For post-processed DGPS correction, the collected GPS data is transferred to the tablet PC via wireless Bluetooth. Since, the construction jobsite was in Concordia University Loyola campus, wireless Wi-Fi connection was available. Measurements from the base station are downloaded and GPS data processed through GPS Pathfinder Office software version 4.10 that was earlier installed on the tablet PC, as shown in Figure (4-19). Typically, post-processed DGPS uses only one base station. Factors that affect the accuracy of post-processed DGPS include; the type of receiver and antenna used at the base station, the distance between the base

station and the user location where the data was collected, the accuracy of the base station position, and the logging interval at the base station (Trimble, 2013).

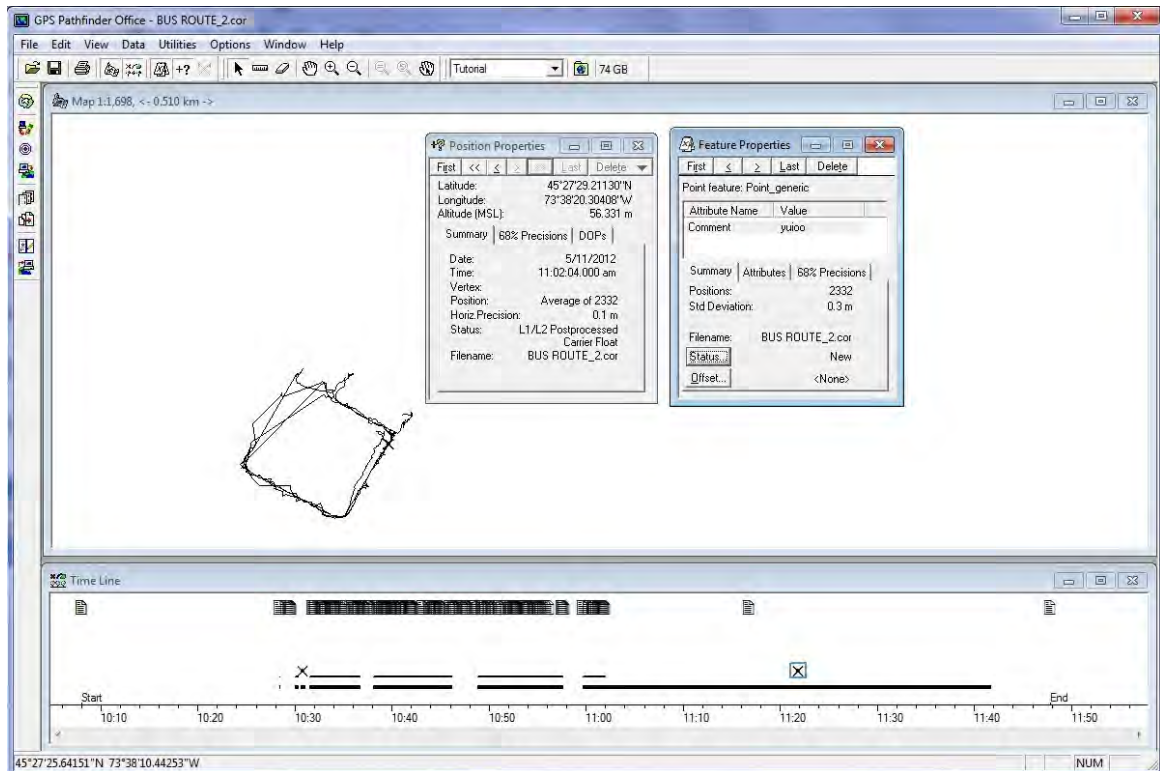


Figure 4-19: Post-processed GPS data using GPS PathFinder software

The GPS Pathfinder software provides all the functionality needed to manage and process data collected using GPS. It provides the tools needed to correct, view, and edit Global Positioning System (GPS) data collected in the field, and to export it in a format suitable for GIS, CAD, or database system. Both the wireless Wi-Fi and GPS PathFinder software were available on the tablet and the GPS PathFinder converted the data into Microsoft Access database format. Accordingly, this method was integrated with the developed model. Therefore, the data is first transferred wirelessly from the GPS to the tablet PC and then processed through GPS PathFinder software. At the end, it is saved on database format (.mdb)

to be used later by the developed model to identify the user outdoor location, as shown in Table (4-3).

Table 4-3: Sample of GPS corrected data

Position ID	Longitude	Latitude	GPS Date	GPS Time	Avg. Vert. Prec.	Avg. Horz. Prec.
1	-73.63999	45.45696	3/17/2011	10:29 AM	0.46281	0.28646
2	-73.63999	45.45695963	3/17/2011	10:29 AM	0.46281	0.28646
3	-73.63999	45.4569598	3/17/2011	10:29 AM	0.46281	0.28646
4	-73.63999	45.45695919	3/17/2011	10:29 AM	0.46281	0.28646
5	-73.63999	45.45695942	3/17/2011	10:29 AM	0.46281	0.28646
6	-73.63999	45.45696021	3/17/2011	10:29 AM	0.46281	0.28646
7	-73.63999	45.45695986	3/17/2011	10:29 AM	0.46281	0.28646
8	-73.63999	45.45696048	3/17/2011	10:29 AM	0.46281	0.28646
9	-73.63999	45.45696043	3/17/2011	10:29 AM	0.46281	0.28646
10	-73.63999	45.45696036	3/17/2011	10:29 AM	0.46281	0.28646
11	-73.63999	45.45696018	3/17/2011	10:29 AM	0.46281	0.28646
12	-73.63999	45.45695952	3/17/2011	10:29 AM	0.46281	0.28646
13	-73.63999	45.45696015	3/17/2011	10:29 AM	0.46281	0.28646
14	-73.63999	45.45695994	3/17/2011	10:29 AM	0.46281	0.28646
15	-73.63999	45.45696013	3/17/2011	10:29 AM	0.46281	0.28646

Then, the developed model converts the location from latitude and longitude to the BIM model local coordinates system for outdoor real time visualization. The data gathered in

one of the field experiments, after the differential correction was performed, were then saved into a (.kml) file to be visualized in Google Earth, as shown in Figure (4-20). The Navisworks 4D BIM model was exported to the same (.kml) file for visualization.

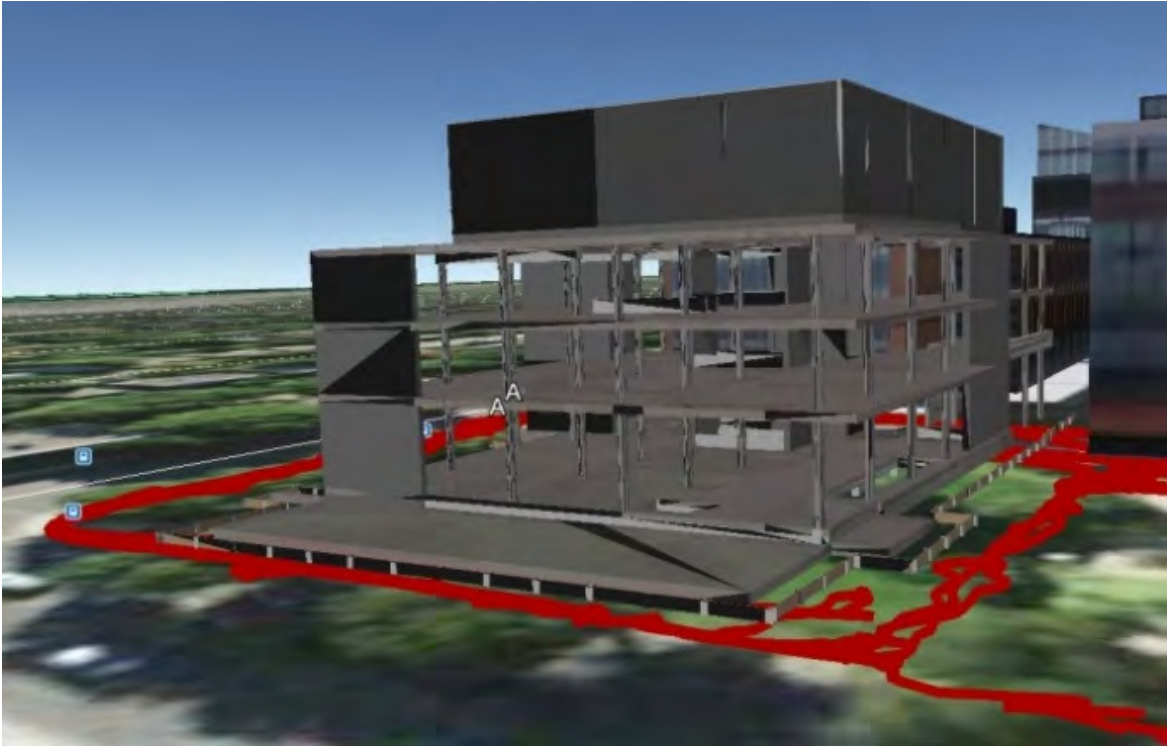


Figure 4-20: User route during outdoor filed experiment

4.5.4 Mobile RFID

The RFID hardware components used in this research are RFID mobile reader (IP30), RFID encapsulated tags (IT67), RFID smart label tags and RFID labels tag printer (PM4i), as shown in Figure (4-21). RFID hardware could collect data in dirty, harsh and hazardous conditions. For example, the encapsulated RFID tag used, could work in temperatures ranging from -40°C to 66°C and could be attached using screws, rivets, double-sided adhesive strips or a variety of other methods. Regarding its memory size, it has a capacity of 512 bit. In addition, RFID mobile readers could work under similar harsh conditions such as in temperatures ranging from -15°C to 50°C . They are protected from dirt, dust, oil, other non-

corrosive material, and splashing water. Readers' connectivity could be through Bluetooth, Ethernet or Wi-Fi and can host applications written in JavaScript. The read range for encapsulated tags is 5m and 3m for label tags. The encapsulated RFID tag costs approximately \$5 per tag. Passive RFID tags used in these experiments were printed RFID labels, which cost 2 cents each. The tag labels and the printer are shown in Figure (4-21) (Intermec, 2013).



a)RFID mobile reader



b)RFID encapsulated tag



c)RFID label tag



d)RFID tag printer

Figure 4-21: RFID hardware

Figure (4-22) depicts screen shots from RFID reader during field operation. RFID reference tags were fixed at known locations during the construction of the Genomics building. Additionally, RFID tags were also attached to material on the jobsite for localization and tracking purposes, as shown in Figure (4-23). Figure (3-24) depicts two different test beds and its respective setup and pictures. The output of the RFID reader file is in the form of text file (.txt). Sample of this data is presented in Table (4-4). This file is transferred wirelessly to the tablet PC and saved as Microsoft Access database formats (.mdb) for processing by the developed model to identify the user indoor current location. Chapter 5 presents detailed experimental work conducted utilizing that RFID hardware for localization and material tracking using different algorithms and deployment protocols.

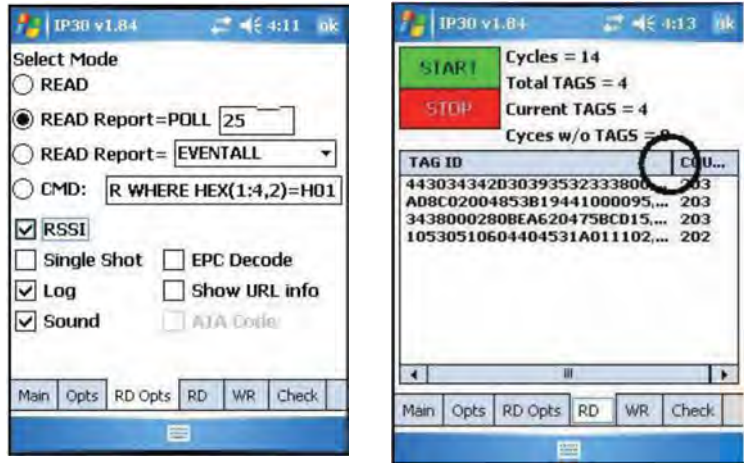


Figure 4-22: RFID reader screen shots



Figure 4-23: RFID data acquisition from reference tags and material tags

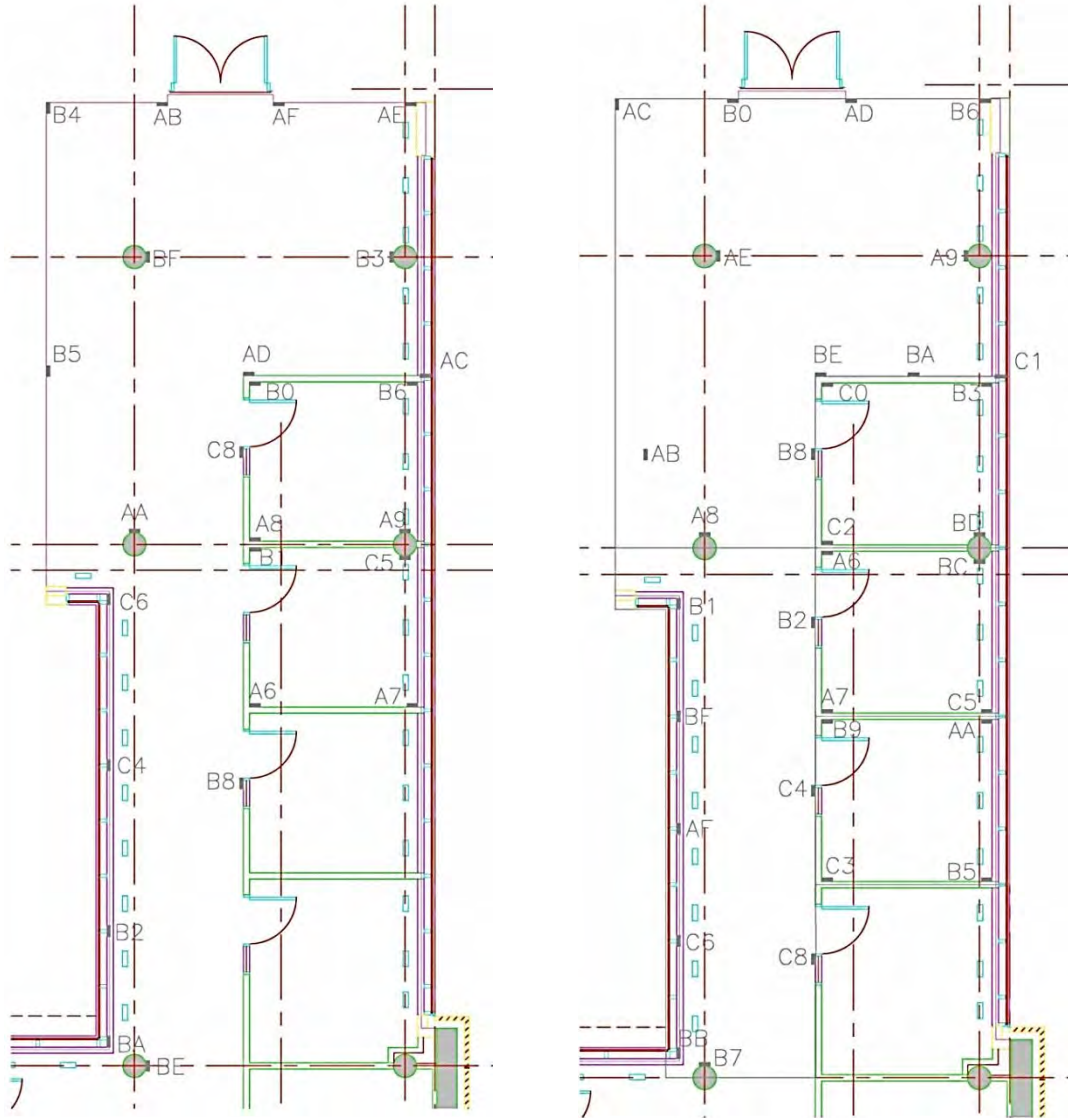


Figure 4-24: Different test beds setup and pictures

Table 4-4: Sample of RFID captured data

Serial #	Tag ID	RSSI	Date	Time
1	B0	-54.1	1.3.2011	12:08:49
2	AD	-56.5	1.3.2011	12:08:49
3	B0	-54.4	1.3.2011	12:08:50
4	AD	-57.4	1.3.2011	12:08:50
5	B0	-53.5	1.3.2011	12:08:50
6	AD	-56.4	1.3.2011	12:08:50
7	B6	-59.6	1.3.2011	12:08:51
8	AD	-58.7	1.3.2011	12:08:51
9	A8	-57.8	1.3.2011	12:08:51
10	B0	-57	1.3.2011	12:08:52
11	AD	-57.9	1.3.2011	12:08:52
12	A8	-58.8	1.3.2011	12:08:52
13	B3	-55.4	1.3.2011	12:08:53
14	B3	-55.9	1.3.2011	12:08:53
15	B3	-56.1	1.3.2011	12:08:54
16	B3	-56.1	1.3.2011	12:08:55
17	B7	-58.7	1.3.2011	12:08:55
18	B7	-59.2	1.3.2011	12:08:56

4.6 Summary

This chapter presents the field study conducted on a construction jobsite. This study encompasses a wide range of automated site data acquisition. The used technologies are Closed Circuit Television (CCTV) camera, 3D scanner, GPS (mobile and fixed), mobile RFID, barcode, and tablet PC. This chapter presents the findings of the field study highlighting the challenges and limitations of utilizing each technology individually on construction jobsites.

This study focuses also on the data captured from each technology to be integrated in the developed model database. The study encompasses excavation and earthmoving operations, concrete framing, curtain walls, HVAC installations, and internal finishing works. These studies led to exploration of the likely advantage of integrating different technologies and using them to estimate project progress.

Chapter 5: EXPERIMENTAL STUDIES OF PASSIVE RFID INDOOR FOR LOCALIZATION

5.1 General

This chapter addresses a range of factors that are vital for the deployment of UHF passive RFID technology in indoor construction projects. The RFID deployment protocols introduced in this chapter present guidelines for the near-optimal utilization of RFID technology on construction jobsites. It utilizes both construction site and controlled lab studies to identify patterns and settings of deployment parameters. In this research, a number of UHF passive RFID tags are distributed to capture indoor spatial data with the aid of a mobile RFID reader. Each passive RFID tag is used as a reference point with a known location (LANDMARK) within a predefined zone. The indoor areas are divided into exclusive zones, and each zone is spatially covered with a number of passive RFID tags.

This Chapter has three main sections, as shown in Figure (5-1). The first addresses coarse-grained localization for zone detection using K-Nearest Neighbor (K-NN) algorithm. It focuses on different deployment protocols for reference tags and provides guidelines for RFID utilization in indoor zone detection. The second part of this chapter presents a fine-grained localization through a two-step algorithm to automate the process of location estimation and material tracking. The two-step algorithm uses Received Signal Strength Indicator (RSSI) for signal measurements with two different algorithms (Trilateration and Proximity). Finally, the third part of this chapter discusses in depth factors that influence the accuracy of utilizing proximity algorithm for indoor localization.

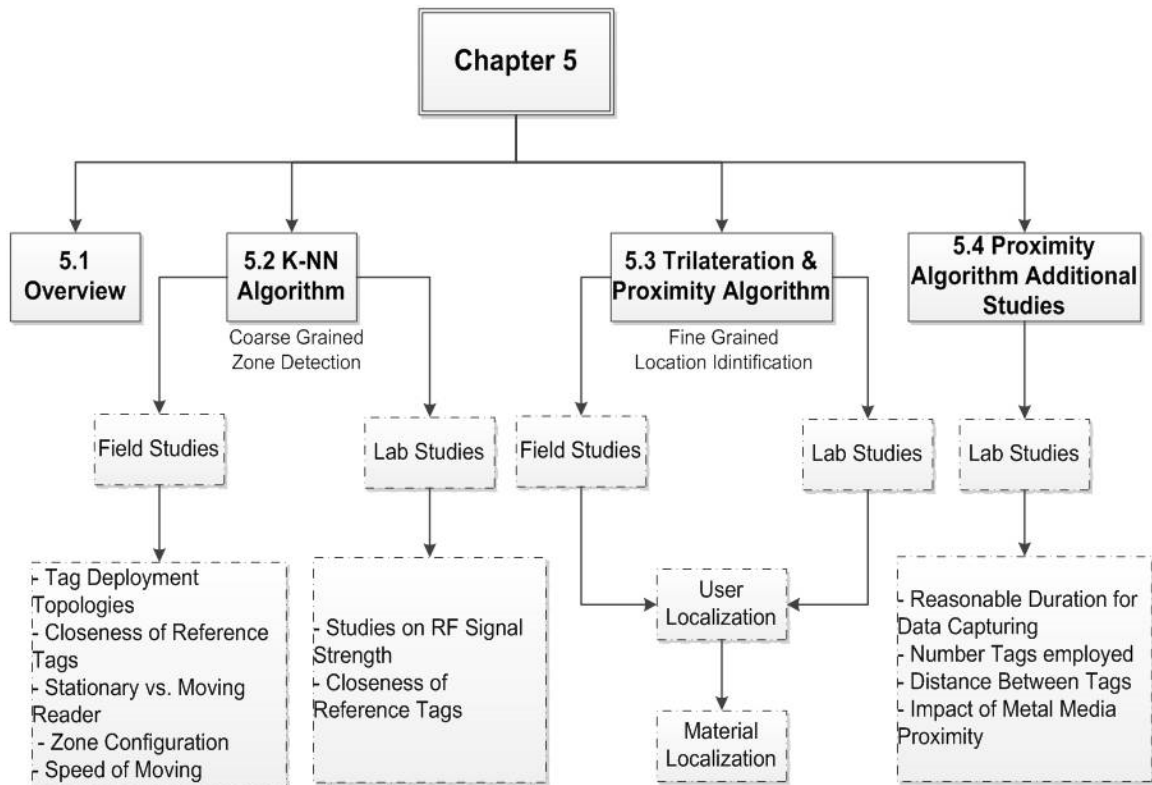


Figure 5-1: Chapter 5 overview

5.2 Zone Identification Using K-NN Algorithm

This study combines the use of UHF passive reference RFID tags and K-Nearest Neighbor algorithm (K-NN) for indoor course-grained zone detection of the RFID mobile reader user. The study aims at providing a set of guidelines for the deployment of UHF passive RFIDs in building construction, with respect to:

- Tag deployment topologies,
- Distance between deployed tags,
- Stationary vs. moving reader user,
- Zone configuration and,
- Impact of moving target speed.

A total number of 10038 data sets for on-site and controlled lab experiments were acquired and analyzed. The total number of logged data sets was 5269 for construction site experiments and 4769 for the controlled experiments (Razavi et al., 2012). K-NN is a memory based classification of tasks. In this research, the time stamp is used as a metric to define the closest neighbors. Therefore, the K-nearest neighbors is the last k reads that occurred prior to the most recent read. The K-NN algorithm is then; (1) finds the K closest reference points that have been read, and according to their log time, and (2) classifies the location of the reader into one of the predefined zones based on the majority of readings. Table (5-1) depicts the process of applying K-NN algorithm to the captured data.

Table 5-1: The process of applying K-NN algorithm

Tag ID	Date	Time	Tag Zone	Real Time Actual Zone	Calculated Zone At K = 5	Detection
B0	1.3.2011	12:08:49	2	1		
AD	1.3.2011	12:08:49	1	1		
B0	1.3.2011	12:08:50	2	1		
AD	1.3.2011	12:08:50	1	1		
B0	1.3.2011	12:08:50	2	1		
AD	1.3.2011	12:08:50	1	1	2	1
B6	1.3.2011	12:08:51	2	1	1	0
AD	1.3.2011	12:08:51	1	1	2	1
A8	1.3.2011	12:08:51	2	1	1	0
B0	1.3.2011	12:08:52	2	1	2	1
AD	1.3.2011	12:08:52	1	1	2	1
A8	1.3.2011	12:08:52	2	1	2	1
B3	1.3.2011	12:08:53	1	1	2	1
B3	1.3.2011	12:08:53	1	1	2	1
B3	1.3.2011	12:08:54	1	1	1	0
B3	1.3.2011	12:08:55	1	1	1	0
B7	1.3.2011	12:08:55	4	1	1	0
B7	1.3.2011	12:08:56	4	1	1	0
B7	1.3.2011	12:08:57	4	1	1	0

For correct zone detection, value equal to zero is placed. However for incorrect zone detection, value equals to one is placed. The error rate is derived from Equation (5.1).

$$\text{Error Rate} = \frac{\text{Number of incorrect detections}}{\text{Total number of data set} - K} \quad (5.1)$$

5.2.1 Field Study

The field study was carried out during the constructing of Genomics building, described in Chapter 4, for the five chosen deployment protocols, with two to six different scenarios for each. Six distinctive active work areas on the third floor were defined as zones. Passive RFID tags, in the form of labels, were installed on the walls in each zone. The zones had different sizes and shapes; the tags were placed at the same elevation, which is 1.5m. The studied area covers 132 m² of the overall floor area. The areas of the zones 1 to 6 are 52m², 12m², 12m², 32m², 12m² and 12m² respectively.

5.2.1.1 Tag Deployment Topologies

A set of experiments were conducted to analyze the effect of the reference tags' deployment topology on the error of zone detection as shown in Figure (5-2). Particular attention was placed on utilizing tags on two topologies: corners and mid-walls. The first topology experiment focused on corner-deployment with 275 data sets and 4 zones having an approximate total area of 108m² (Figure 5-2, left hand side). The second Topology experiment focused on mid-wall deployment, with 846 data sets and 6 zones with an approximate area of 132m² (Figure 5-2, right hand side). The experimental results showed that the lowest error rate was achieved when K=40. At that K value, the results indicated that mid-wall deployment performed better than corner-deployment as shown in Table (5-2). This could be attributed to the issue of interference at the corners of the structure.

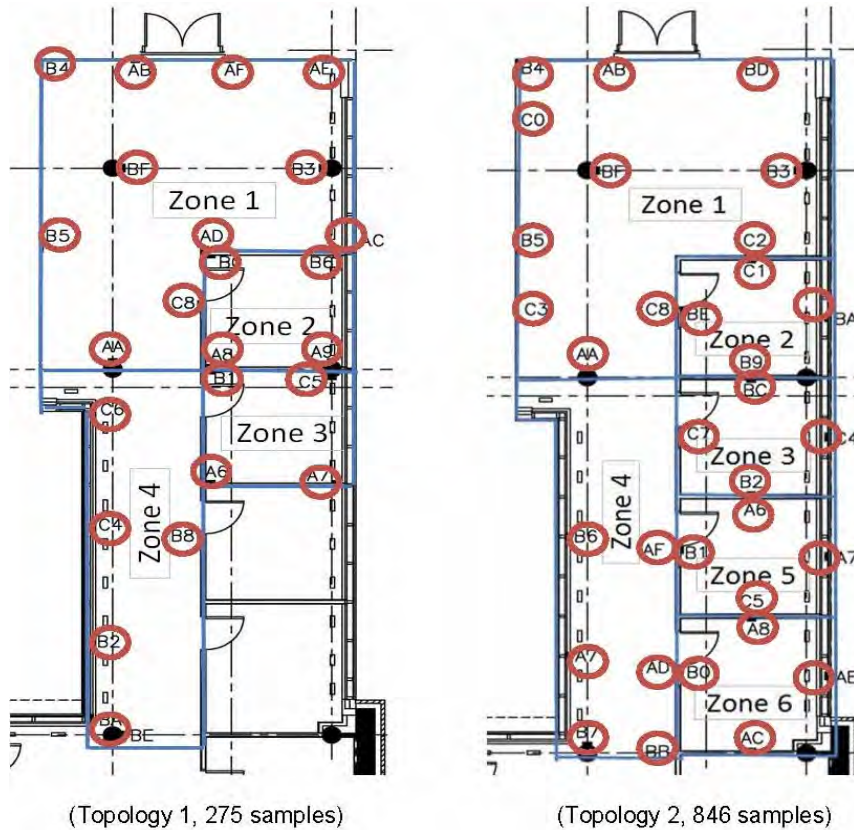


Figure 5-2: Two deployment topologies

Table 5-2: Error rate for the two deployment topologies (Razavi et al., 2012)

Scenarios	Data Sets #	Different number of K for K-NN algorithm							
		5	10	15	20	25	30	35	40
Corner deployment	275	39%	31%	27%	28%	31%	33%	35%	35%
Mid-wall deployment	846	39%	36%	33%	33%	31%	32%	29%	28%

5.2.1.2 Closeness of Passive Reference Tags

Identifying the near optimum distance between tags required to cover a zone is the ultimate objective for studying this parameter. The impact of the distance between adjacent deployed tags is studied for two scenarios. Scenario 1 represents the deployment of 26 tags

using corner deployment topology with an average distance of 1.5-2 times the Read-Range (RR) and 846 data sets. Scenario 2 adds one tag between any two tags of scenario 1, the added tags deployed mid-wall. It has overall 40 tags, 589 data sets, and four zones with an area of 108m², Figure (5-3). The results presented in Table (5-3) indicate that a closeness of 1RR results is better detection than 1.5 RR.

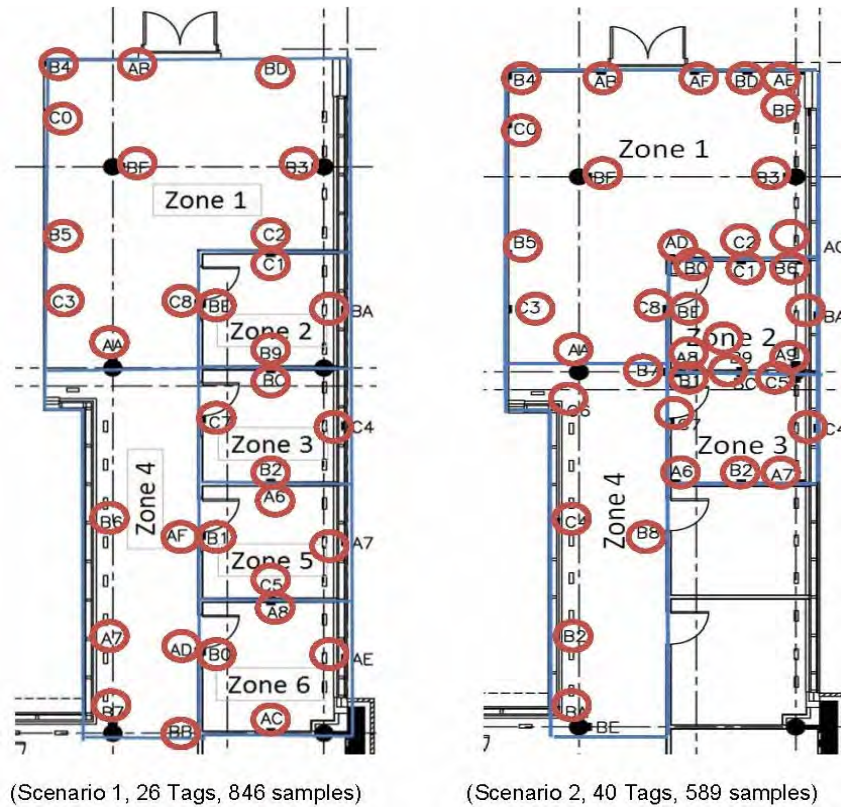


Figure 5-3: On-site scenarios for tag closeness

Table 5-3: Error rates of tag deployment distance (closeness) on site

Scenarios	Data Set #	Different number of K for K-NN algorithm							
		5	10	15	20	25	30	35	40
1.5 RR	846	39%	36%	33%	33%	31%	32%	29%	28%
1RR	589	44%	35%	30%	29%	27%	24%	23%	22%

5.2.1.3 Stationary vs. Moving Reader Agent

To assess the impact of the movement of site personnel with the mobile RFID reader on the results, a number of data logging scenarios were tested on-site. Four scenarios with a stationary reader in a pre-defined stationary location and a scenario with moving site personnel were conducted and compared. A total number of 338 data sets were used for the stationary-reader scenarios and 275 data sets for the moving-reader scenario. The arrows in Figure (5-4) represent the reader's stationary locations during data logging. The results indicated that the data acquired using a stationary reader can be more accurate than that generated using a moving reader, as shown in table (5-4).

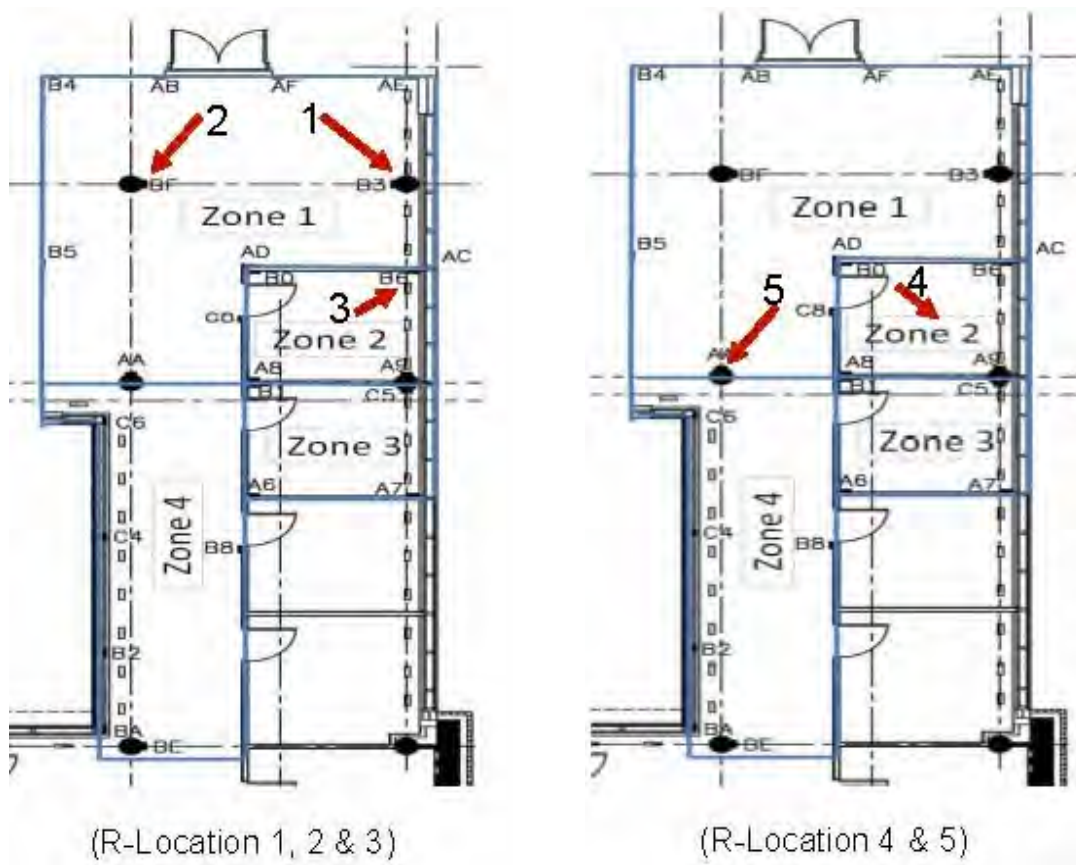


Figure 5-4: Different scenarios for a stationary reader agent

Table 5-4: Error for stationary reader locations vs. a moving reader

Scenarios	Data Set #	Different number of K for K-NN algorithm							
		5	10	15	20	25	30	35	40
Fixed Location1	62	40%	21%	16%	16%	19%	24%	29%	32%
Fixed Location 2	53	17%	15%	15%	17%	17%	17%	17%	17%
Fixed Location 3	39	15%	5%	13%	21%	23%	26%	28%	15%
Fixed Location 4	88	31%	31%	30%	33%	34%	38%	40%	41%
Fixed Location 5	96	47%	35%	25%	24%	15%	11%	16%	19%
Moving reader	275	39%	31%	27%	28%	31%	33%	35%	35%

Fixed-reader location 2 represents the most robust solution, with the lowest error rate over the entire range of the study. It is interesting to note that the highest error rates were found with fixed location 4, where the reader is standing in the middle of the smallest zone of 2RR×1.5RR. This perhaps can be attributed to the relatively short distances from the surfaces and corners to which tags are mounted.

5.2.1.4 Zone Configuration

Zone configurations may vary through the project cycles and can be related to the sequence of the construction schedule. A single experiment with 1361 data sets was used for three scenarios with different zone arrangements, as presented in Figure (5-5). In these hypothetical zone arrangements, zone 2 has three different dimensions: 2RR × 1.5 RR, 2RR × 3 RR, and 2RR × 4.5 RR. Table (5-5) presents the experimental results for the various zones configurations in this case study. It should be noted that zone configuration effectiveness is in direct relationship with the deployed RFIDs’ reading range. It is clear that the third scenario, where the defined area for zone 2 is larger than the other two, has the lowest error rate. This

result can be credited to a lower interference effect from the nearby zones when the zone dimension is significantly larger than double the reading range.

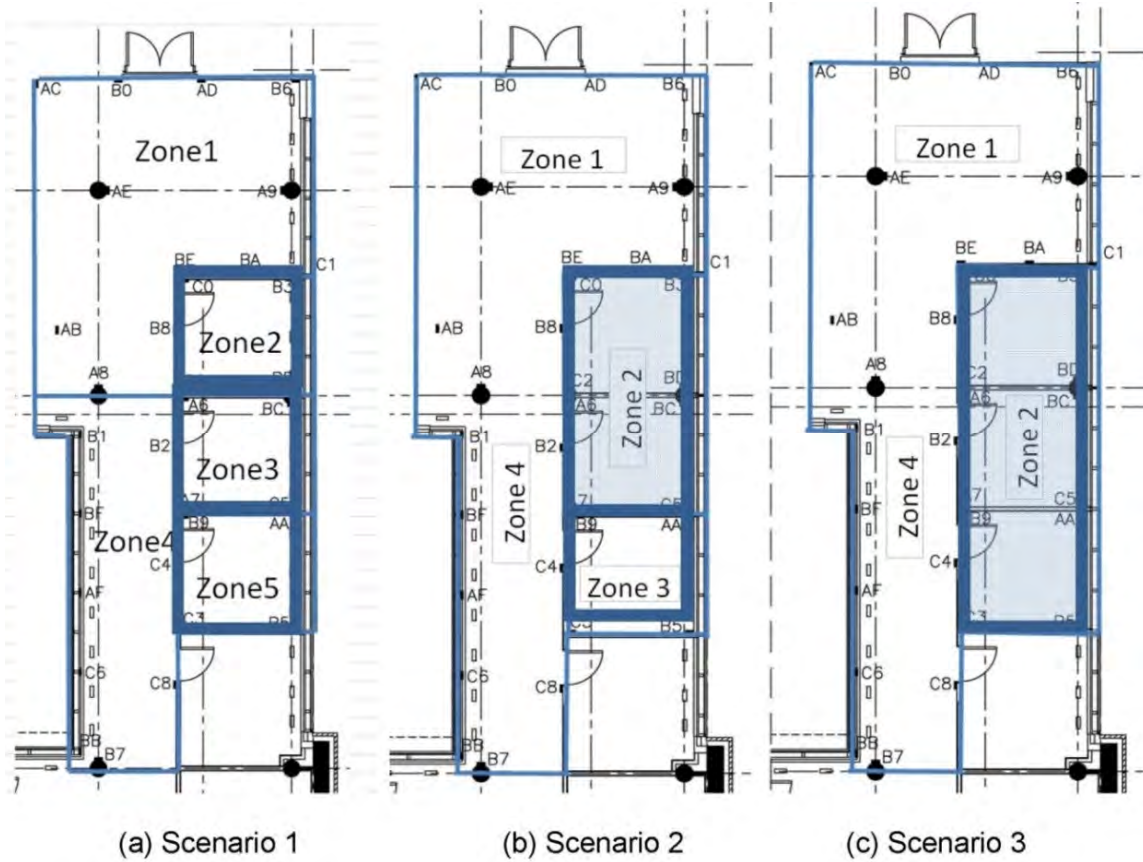


Figure 5-5: Scenarios for different zone configurations

Table 5-5: Error rates for different zone configurations

Scenarios	Data Set #	Different number of K for K-NN algorithm							
		5	10	15	20	25	30	35	40
2RR × 1.5 RR	1361	29%	29%	28%	24%	25%	26%	27%	27%
2RR × 3 RR	1361	27%	26%	26%	24%	25%	26%	27%	28%
2RR × 4.5 RR	1361	21%	22%	22%	22%	23%	23%	24%	24%

5.2.1.5 Speed of Moving Reader

When the site personnel moves at different speeds, there may be different impacts on the overall accuracy of the acquired site data. The next set of experiments assessed this impact by considering two scenarios; a fast moving and a slow-moving reader. In both scenarios, the moving target/reader walks along the trajectory path, shown in Figure (5-6), which has an overall length of 58m (from point A to point B). The fast-moving reader walked along the path in approximately 2.5 minutes, and the slow-moving reader passed through the same path in approximately 6.5 minutes. A total number of 1954 data sets were used in this set of experiments. The acquired results for these scenarios are presented in Table (5-6). The results indicate that a slow-moving reader yields a lower error rate. This result also supports the outcome of a stationary vs. a moving reader agent.

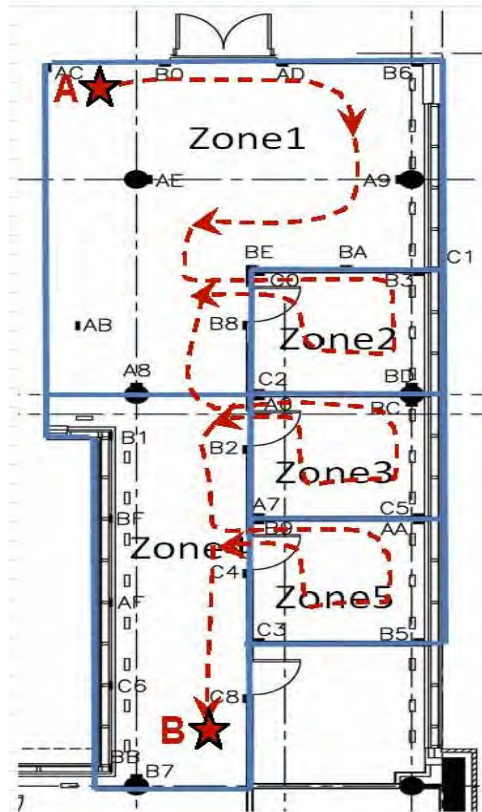


Figure 5-6: The trajectory of the moving target (reader)

Table 5-6: Error rate for the scenarios of a slow moving vs. a fast-moving reader

Scenarios	Different number of K for K-NN algorithm							
	5	10	15	20	25	30	35	40
Slow Moving (6.5 minutes)	17%	16%	12%	13%	11%	10%	9%	10%
Fast Moving (2.5 minutes)	44%	35%	30%	29%	27%	24%	23%	22%

5.2.2 Laboratory Experiments

Experiments were also conducted in a controlled lab environment to better study the effects of the closeness of reference tags and of RSSI. These experiments were conducted in the construction automation lab in the Engineering and Visual Arts building at Concordia University as shown in Figure (5-7).

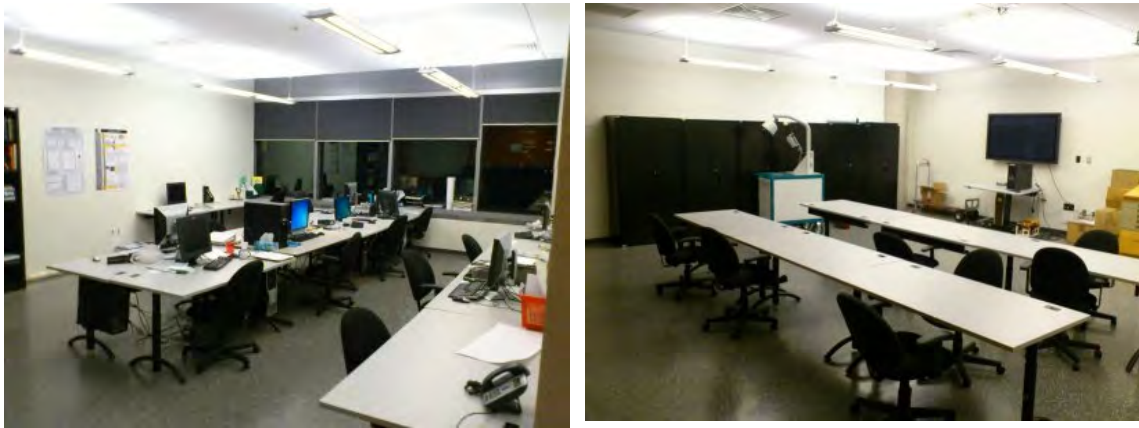


Figure 5-7: Concordia university construction automation lab

5.2.2.1 Closeness of Passive Reference Tags

Four scenarios for tag closeness were set up, with distances of 0.5 RR , 1RR , 1.5 RR , and 2 R, which were tested with 2752, 982, 544, and 491 data sets, respectively. The area under study has the dimension 4RR×4.5 RR, divided into four equal zones with dimensions of

2RR×2.25RR and tags that were mounted on the walls. Table (5-7) summarizes the outcomes of this experiment.

Table 5-7: Error of tag deployment distance (closeness)

Scenarios	Data Set #	Different number of K for the K-NN algorithm							
		5	10	15	20	25	30	35	40
0.5RR	2752	0.4%	0.7%	0.9%	1.2%	1.4%	1.7%	2.0%	2.3%
1RR	982	1.0%	1.9%	2.5%	3.5%	4.2%	5.0%	3.7%	2.4%
1.5RR	544	5.5%	6.3%	7.4%	9.0%	10.5%	12.2%	12.3%	12.9%
2RR	491	2.7%	3.9%	4.9%	6.7%	7.8%	9.2%	10.4%	11.8%

It was found that a tag closeness of 0.5 RR yields the best overall detection rate, followed by 1RR, 2RR, and 1.5 RR scenarios. It was also observed that in a controlled environment the overall performance of the detection algorithm is best for a K value of 5, with higher K values, associated with higher error rates. This pattern remained the same for all K values in the controlled experiment. In the 1.5RR deployment scenario, three tags were installed in each zone, two of which were less than the 0.5RR distance from the hypothetical boundary of these zones. In the 2RR scenario, however, only two tags were used in each zone, with a relatively greater distance from the zones' boundary.

5.2.2.2 Studies on RSSI

The Received Signal Strength Indicator (RSSI) is a measurement of the power present in a radio signal received by an antenna. The RSSI value is the relative received signal strength in a wireless environment, in arbitrary units. A higher RSSI value (or the less negative in some devices) indicates a stronger signal. According to the power laws,

the RSSI absolute value has an inverse relationship with distance. When radio signal travels in the space, their strengths diminish with the increase of the distance. According to this power law, the received signal strength at the receiver can be used for estimating the distance between the transmitter and the receiver. In the ideal environment, the RSSI at the receiver can be modeled by the following equation (Zhang et al., 2010), which represents the path loss model, Equation (5.2):

$$P_r = c * \left[\frac{P_t}{d^\alpha} \right] \quad (5.2)$$

Where:

P_r is the received signal strength at the receiver.

P_t is the signal strength at the transmitter.

d is the distance between the transmitter and the receiver.

c is a constant.

α is the signal loss coefficient, which depends on the environment .

The accuracy of RSSI-based methods is highly dependent on the accuracy of the path loss model. The model explained earlier is easy to manipulate, but it generates a significant error rate because the RSSI is complex in nature. The complexity is caused by various uncontrolled environmental effects such as multipath fading, shadows, and terrain, surrounding materials and obstacles. Therefore, other techniques are needed to assure a suitable level of accuracy. Figure (5-8) presents the results of a set of experiments conducted in a controlled laboratory environment to acquire a path loss model. The

experiments depict the average of RSSI for every 10cm increments in distance between tag and reader. The experiment has been repeated for four different tags. The model was developed using 6704 data sets. Each data set consists of a number of signals captured at a specific distance. The path loss model is regression model, which helps to depict trends in the existing data. In order to choose the right regression model for the data, three different regression types of logarithmic, linear and second-degree polynomial were performed and the results compared and the results presented in Figure (5-9). In this research the linear regression model was used as path loss model (i.e. relationship between reader RSSI and the distance from the tag D), as depicted in Equation (5.3).

$$\text{RSSI} = -6.182 D - 32.682 \quad (5.3)$$

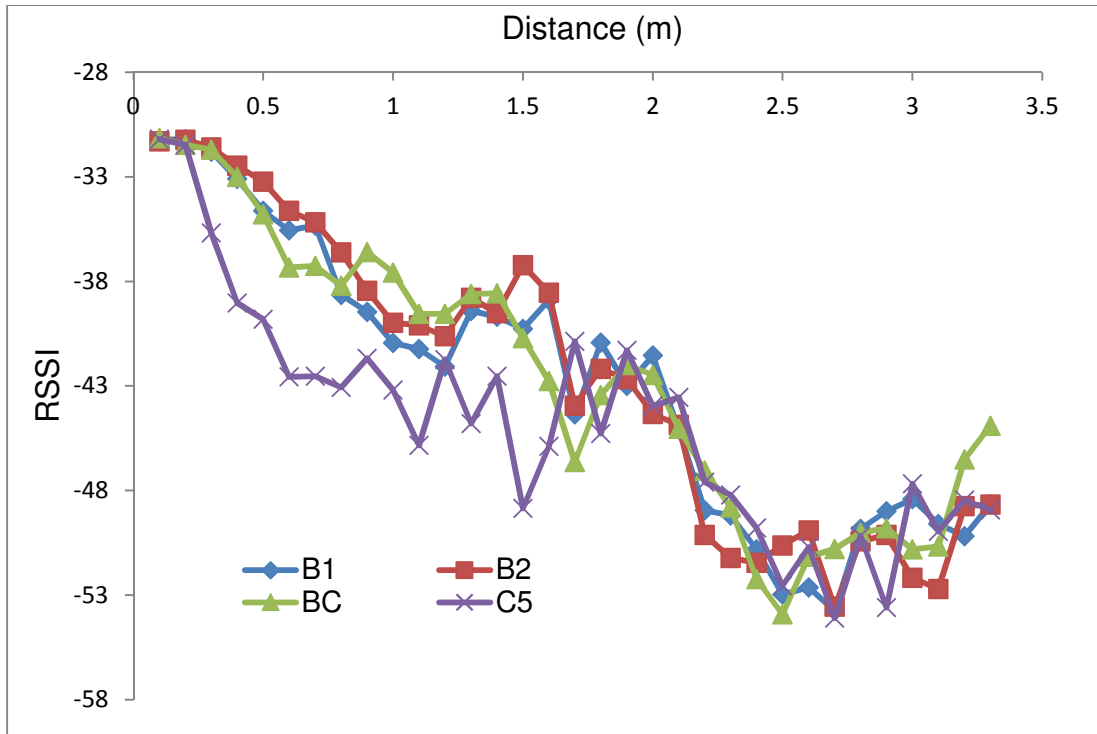


Figure 5-8: Average RSSI vs. distance for four tags

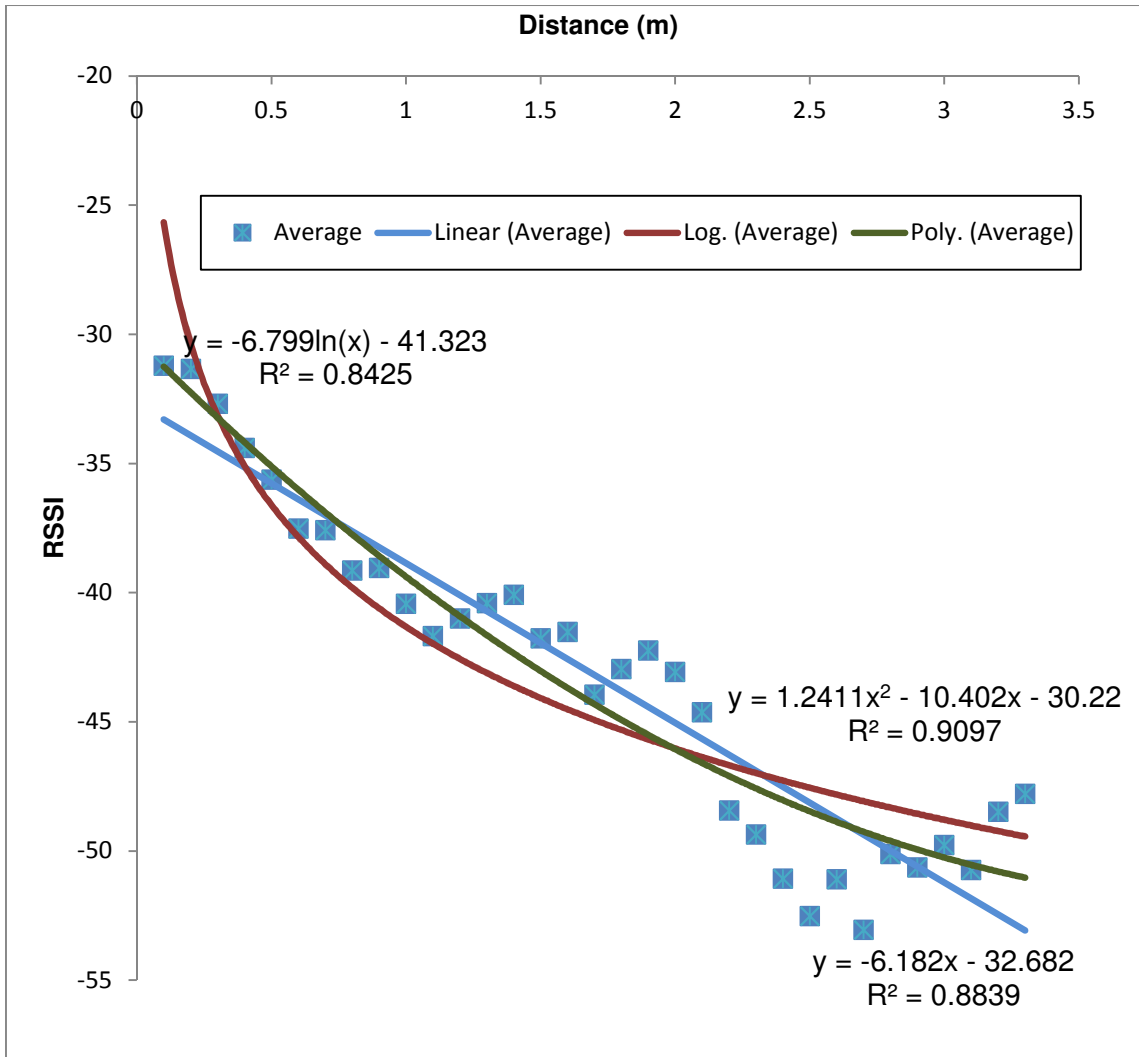


Figure 5-9: Regression analysis

5.3 Location Identification Using Two-Step Algorithm

A two-step algorithm was presented to automate the process of identifying user location in real time estimation and identifying material location in near real time, refer to Chapter 3. It uses RSSI for signal measurements and two different localization algorithms (Trilateration and Proximity) are used. The main components of the developed two-step algorithm are outlined in Figure (5-10) (Montaser and Moselhi, 2012 d and 2013 a).

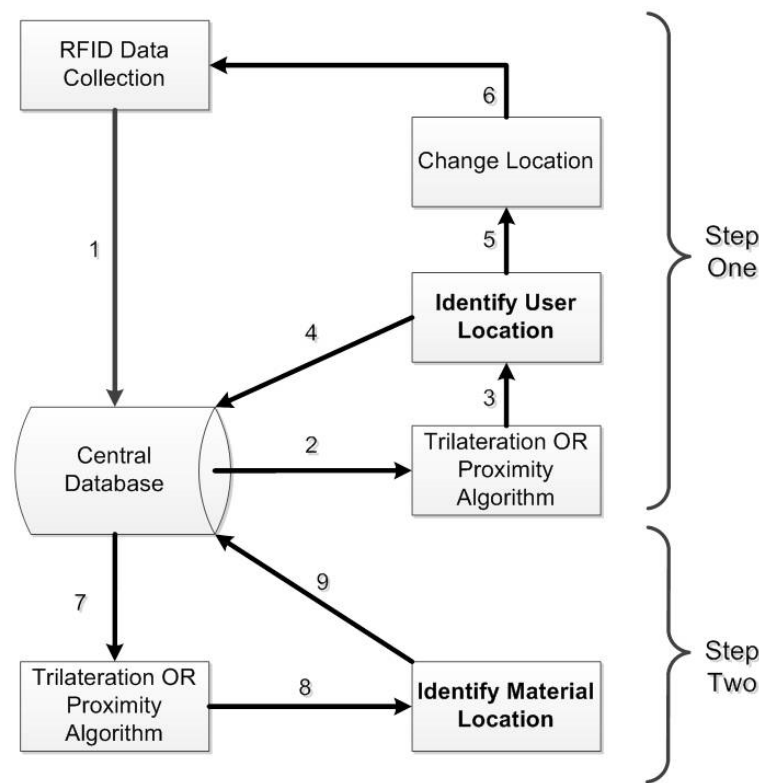


Figure 5-10: Two-step algorithm (Montaser and Moselhi, 2013a)

For validating the two-step algorithm and demonstrating the use of its components, experiments were conducted. A set of experiments were conducted during the construction of Genomics building at Concordia University. Five test beds were setup at different time spans and different locations on construction jobsite. Carrying out the tests at different time spans was required to prove that the proposed algorithm is feasible during the changing environment

of construction operations. Other experiments were conducted in the Construction Automation Lab, at Concordia University. Test bed 6 was setup in a lab environment. Table (5-7) shows the characteristics of each test bed, including the total number of data sets collected, date, location, test bed area and number of tags used in the test bed. Figures (5-11) and (5-12) show the setup and images of all test beds where the rectangles refer to the locations of attached reference tags. The error is derived from Equation (5.4), which is the distance in meters between the estimated and actual locations.

$$\text{Error} = \sqrt{(X - X_c)^2 + (Y - Y_c)^2} \quad (5.4)$$

Where

(X, Y) is the actual predefined location

(X_c, Y_c) is the calculated location using Trilateration or Proximity algorithm

Table 5-8: Characteristics of test beds (Montaser and Moselhi, 2013a)

Test Bed #	Test Bed 1	Test Bed 2	Test Bed 3	Test Bed 4	Test Bed 5	Test Bed 6
Date	01/12/2010	03/12/2010	08/12/2010	01/3/2011	14/04/2011	24/12/2011
Location	Jobsite (3rd Floor)	Jobsite (2nd Floor)	Jobsite (3rd Floor)	Jobsite (2nd Floor)	Jobsite (3rd Floor)	Lab Environment
Total Number of Predefined Locations	18	18	18	15	15	45
Total No of data set	418	494	451	729	438	5915
Covered Area (m²)	75.24	75.24	75.24	108	120	61
No of Deployed Tags	24	24	24	25	33	25
Average Covered Area(m²/#)	3.135	3.135	3.135	4.32	3.6363	2.44

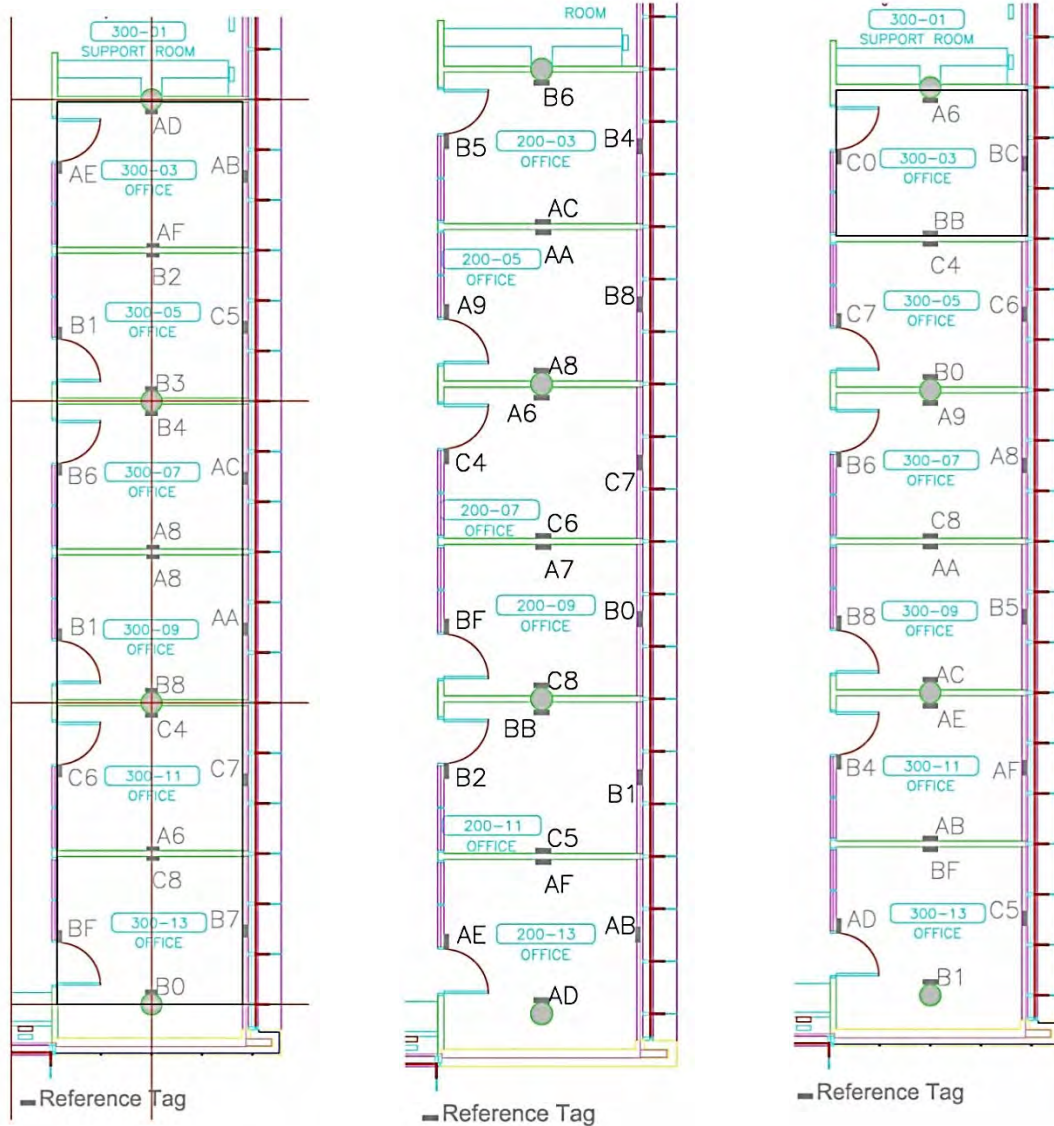


Figure 5-11: Test beds 1, 2 & 3 setup and site pictures Case Study I

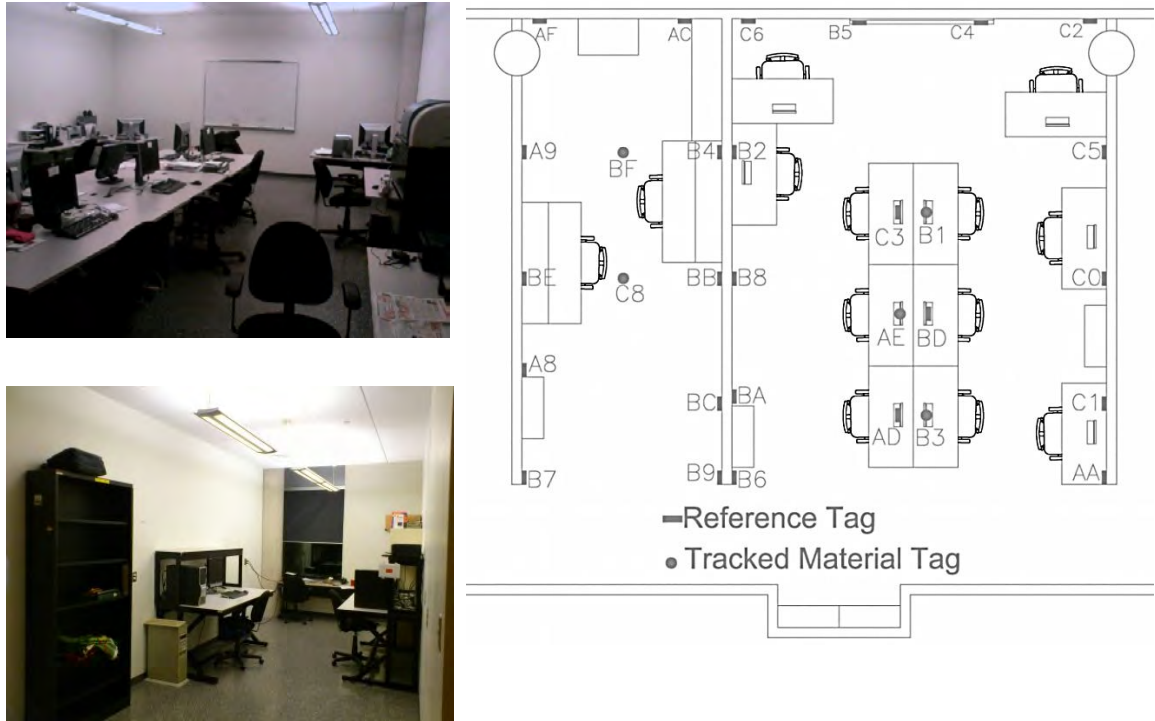


Figure 5-12: Test beds 6 setup Case Study II

Figure (5-13) shows graphical display of the errors in the calculated locations of the mobile user. The triangles represent the user's previously marked locations where the user stands and starts capturing RFID signals. The circles and squares represent, respectively, the calculated location using trilateration and proximity algorithms respectively. Figure (5-14) shows graphical comparison between the two algorithms. There are five sensed reference tags. Four of them related to the user zone and the fifth one is far away from the user zone. Using trilateration algorithm automatically selects the intersection area of most circles and due to the fifth reading is away from that intersection it is not be considered in calculations. However, proximity algorithm considers all readings and do not have this mechanism so the results are more affected by noise from reference tags that far from the user zone. Figure (5-15) shows tracking material labeled C8 utilizing user location numbers 14, 15 and 18.

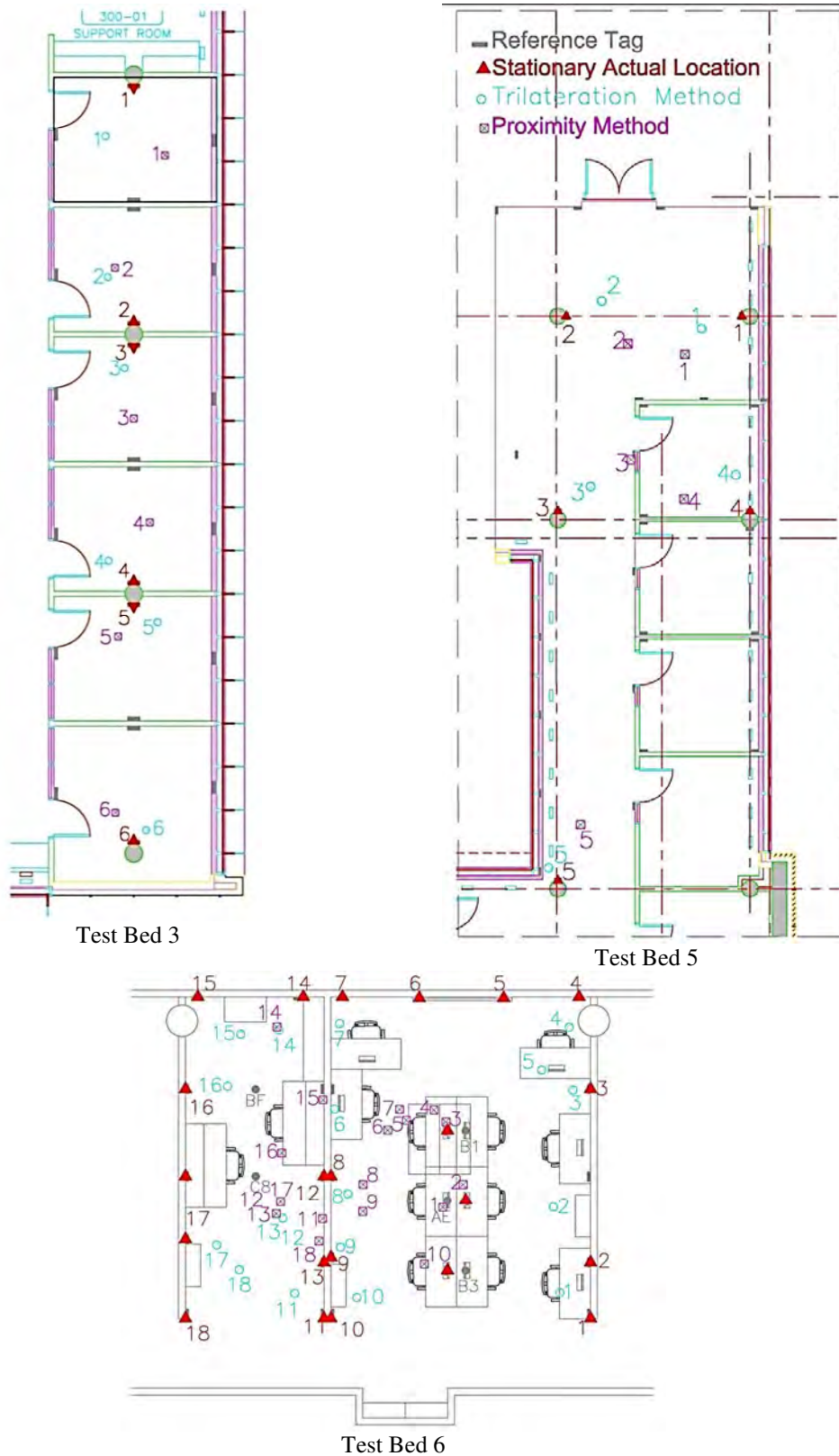


Figure 5-13: Localization error for both algorithms

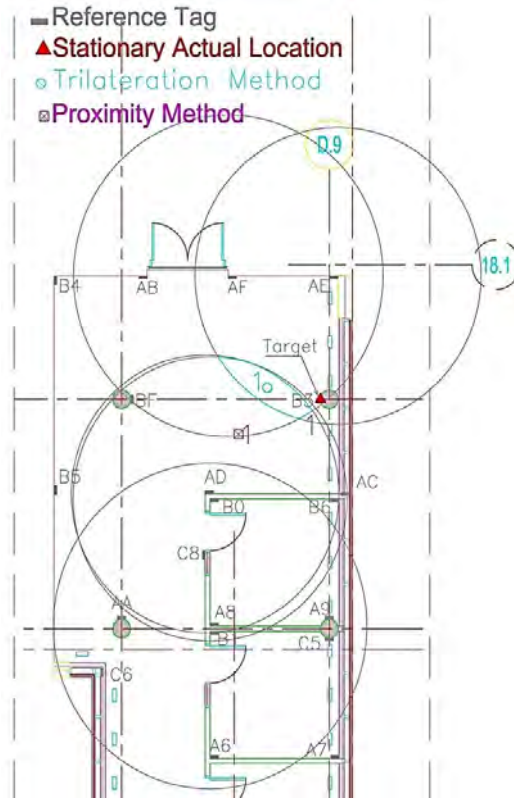


Figure 5-14: Comparison between trilateration and proximity algorithm

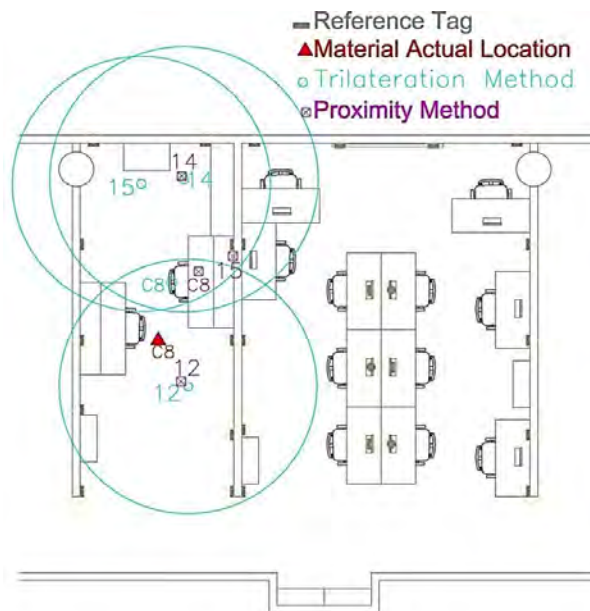


Figure 5-15: Material tracking using trilateration and proximity algorithm

Figure (5-16) shows box plot for all test beds. Summary of statistical analysis for both trilateration and proximity algorithms is displayed in Figure (5-17). It depicts the accuracy of in identifying locations of the user obtained from all test beds. Similarly, a statistical analysis was performed for material location identification and the results are summarized in Figure (5-18) for both algorithms. The developed two-step algorithm yields 100% accuracy for zone identification of the user and tracked material in all test beds. Cumulative Distribution Function (CDF) was used to show the localization error and to measure the localization performance at a given confidence level as shown in Figure (5-19). The CDF also indicated the error accumulation in material location is due to the dependency on user location. In case of trilateration algorithm, the error accumulation was increased rapidly while in case of proximity algorithm, the error accumulation was steady.

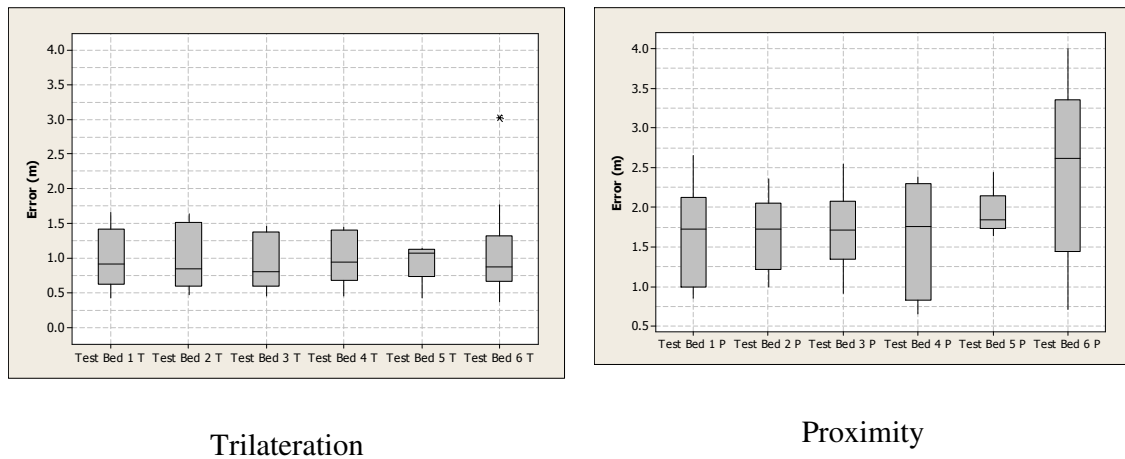


Figure 5-16: Box plot for each test beds results (Montaser and Moselhi, 2012 d)

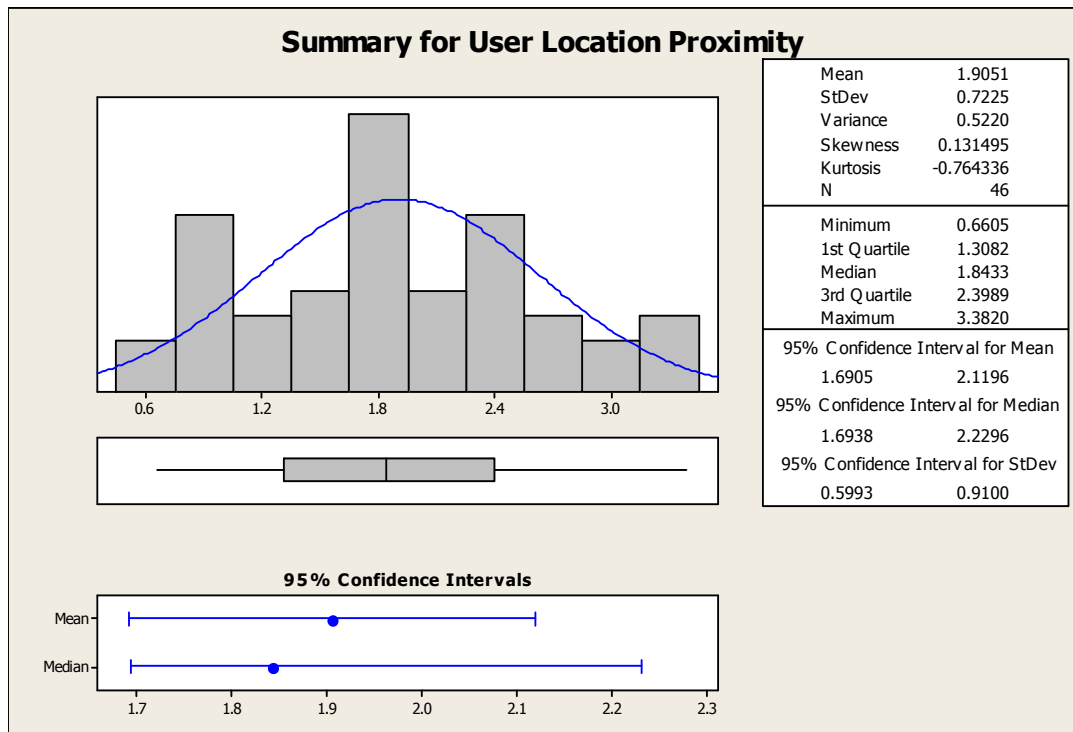
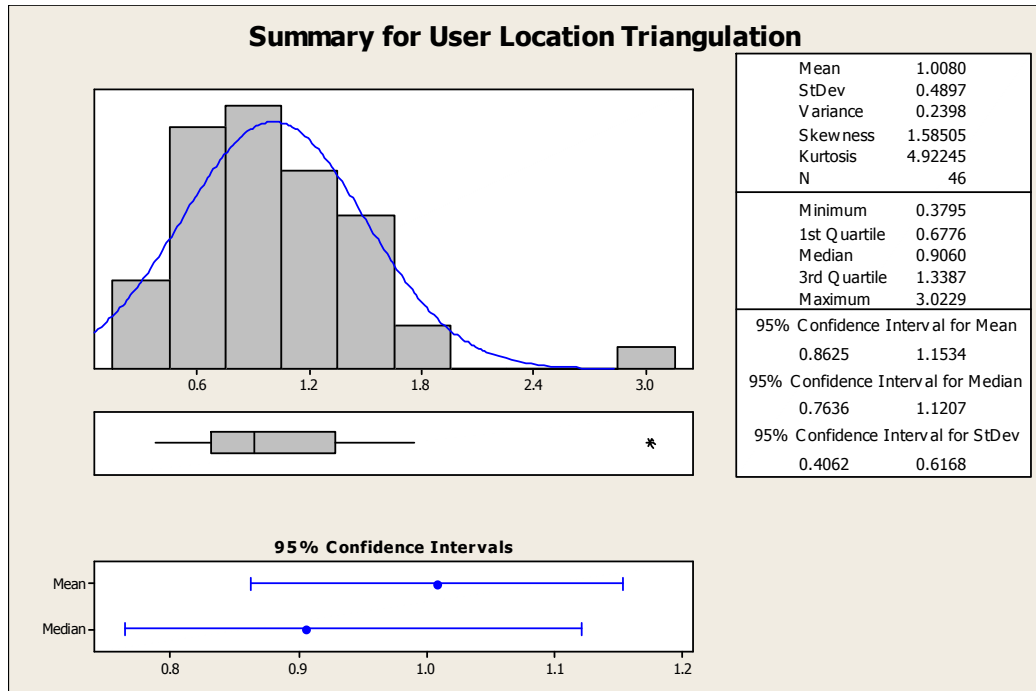


Figure 5-17: Summary of statistical analysis results for user localization

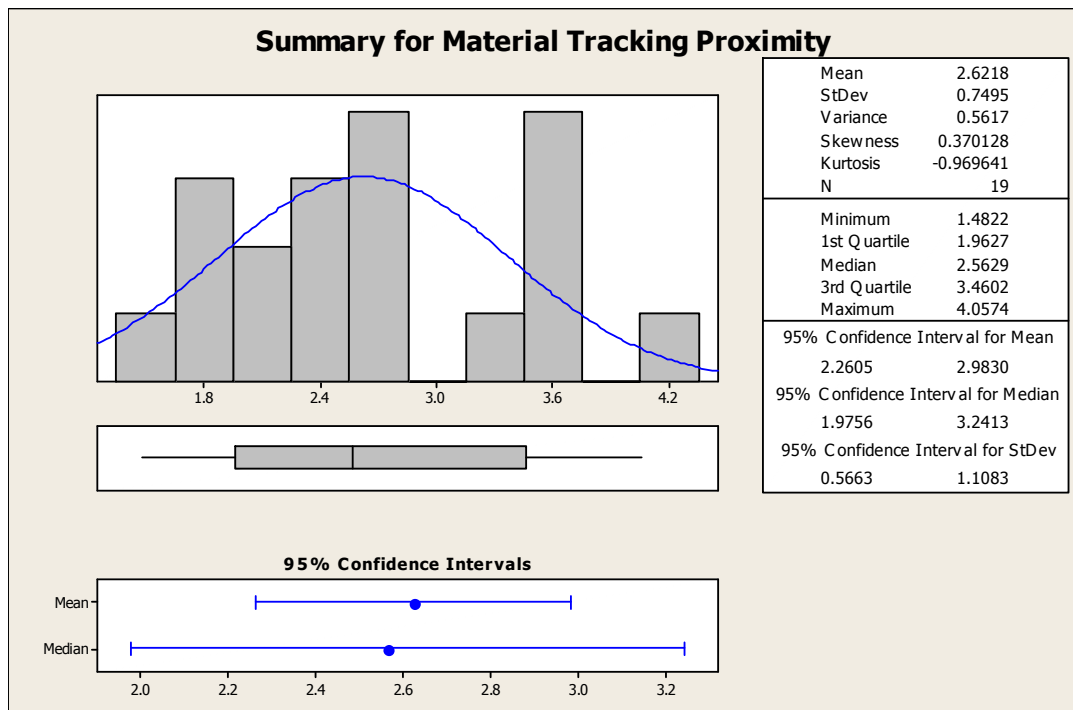
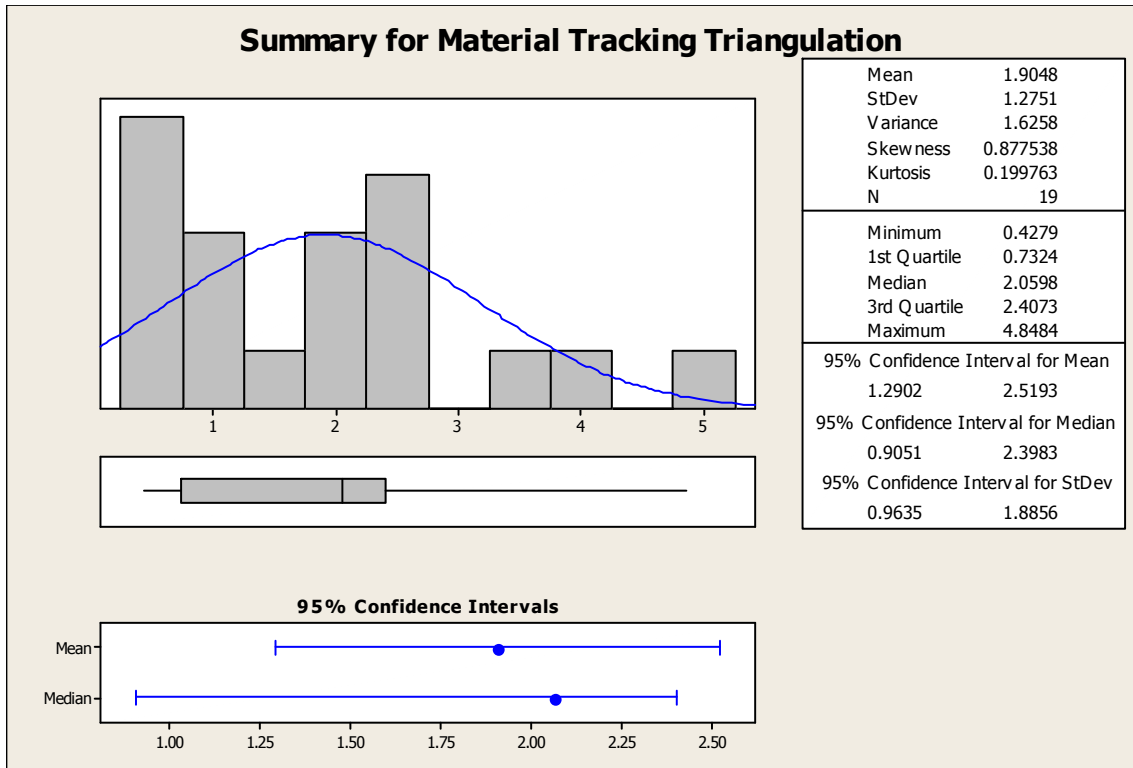


Figure 5-18: Summary of statistical analysis results for material localization

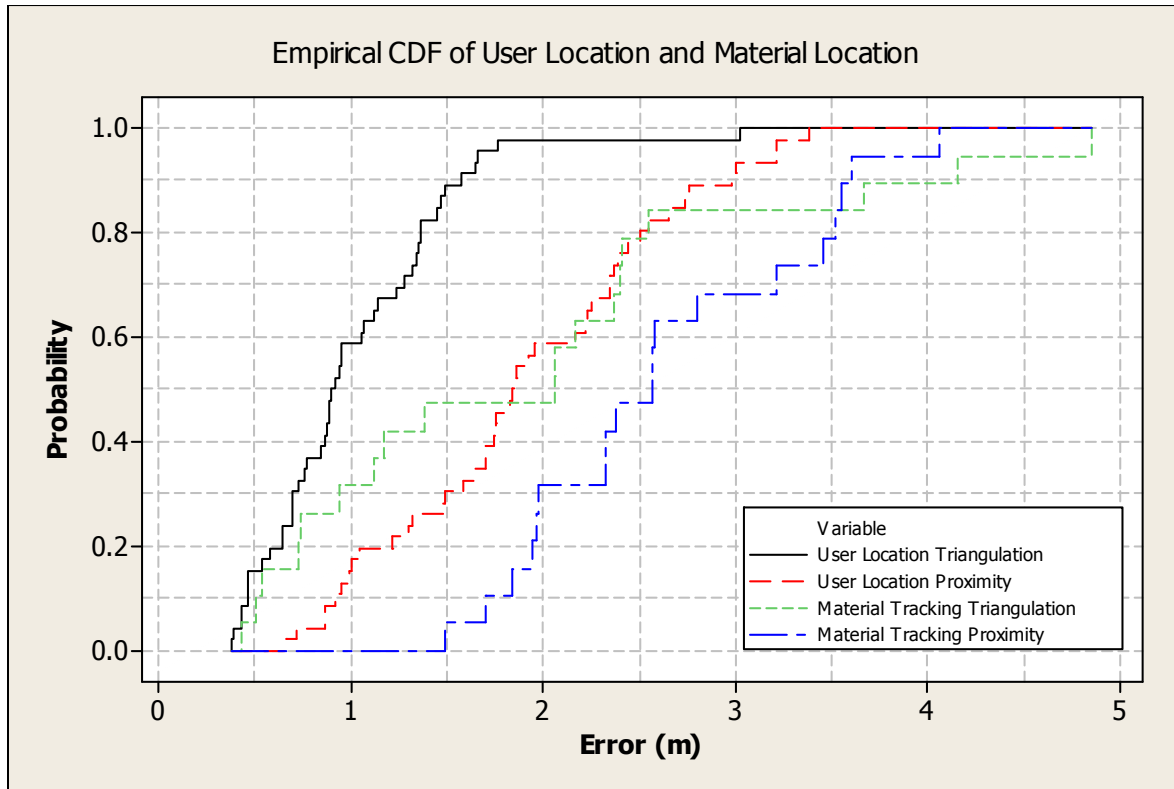


Figure 5-19: CDF for estimated error (Montaser and Moselhi, 2013 a)

The results also indicated that trilateration algorithm is relatively more accurate than proximity algorithm for both user and material localization. However, the trilateration algorithm suffers from drawbacks such as the dependency on path loss models (location-environment dependent models), which is not robust enough to represent the characteristics of radio waves and its interference in a dynamically changing construction environment. In addition, the computational time required for identifying location using trilateration algorithm is much more than that of the proximity algorithm due to the mathematical complexity of trilateration algorithm, which gives advantage to proximity algorithm in real time localization.

5.4 Deployment Protocols Using Proximity Algorithm

This section presents a lab experimental work conducted to facilitate the use of RFID. As, it addresses the impact of metal media proximity to RFID tags, the reasonable duration for

data capturing, number of RFID tags employed and the distance between them. RSSI was used as the main attribute for signal measurement to process the captured data. Proximity algorithm was used to analyze the capture RSSI to calculate the RFID reader location. Five hundred and fourteen (514) experiments were conducted. Figure (5-20) depicts an area of 3m by 3m (Test Bed) that was setup for the experiments. There are a number of low cost reference tags fixed on the perimeter of the test bed. The Distance between reference tags is X . Three different numbers of RFID reference tags are deployed in the experiment 16, 8 and 4 with distance between tags equals to 0.75m, 1.5m and 3m respectively. The test bed is with distance equal to Y from metal media. This distance is varied from zero to 3m in increments of 0.75m. Data is collected using mobile RFID reader from nine different predefined locations from within the zone at each experiment. The user at the predefined location operates the mobile RFID reader and captures the signals received from the reference tags (Montaser et al, 2013).

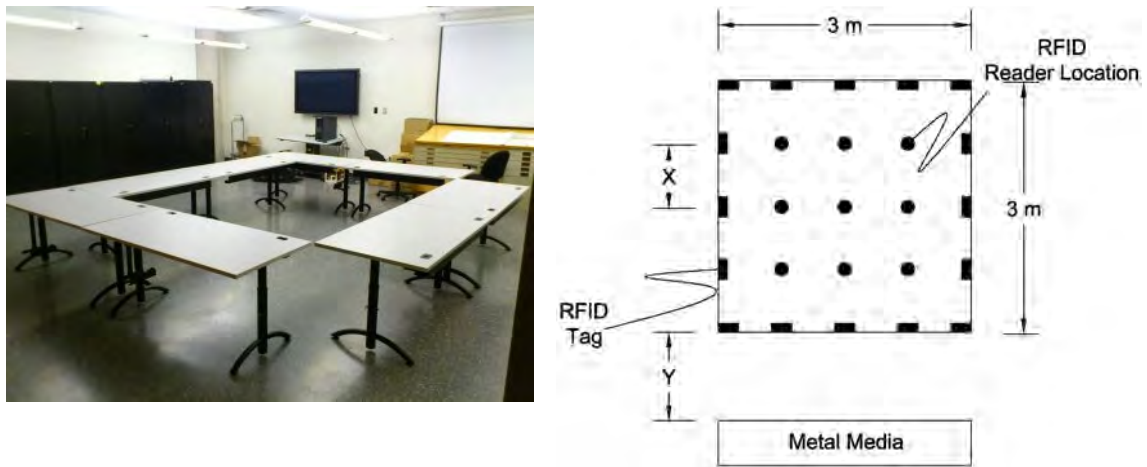


Figure 5-20: Test bed setup (Montaser et al., 2013)

This process is then repeated at a set of time intervals, referred to here as Duration. Data is collected for different durations of 15, 30, 45 and 60 seconds at every point of the nine locations. The different scenarios of each set of experiment are summarized in Table (5-9). The collected data were captured from nine locations for each test bed at four time intervals. Results

of the data analysis are studied under four main categories: duration, number of tags, locations of tags and metal interference.

Table 5-9: Different characteristics of the experiment (Montaser et al., 2013)

Experiment #	X (m)	Y (m)	15 sec	30 Sec	45 Sec	60 Sec	Metal Proximity Group	Total # of RFID Tags Group
1	0.75	3	√	√	√	√	A	1
2	0.75	2.25	√	√	√	√	B	1
3	0.75	1.5	√	√	√	√	C	1
4	0.75	0.75	√	√	√	√	D	1
5	0.75	0	√	√	√	√	E	1
6	1.5	3	√	√	√	√	A	2
7	1.5	2.25	√	√	√	√	B	2
8	1.5	1.5	√	√	√	√	C	2
9	1.5	0.75	√	√	√	√	D	2
10	1.5	0	√	√	√	√	E	2
11	3	3	√	√	√	√	A	3
12	3	2.25	√	√	√	√	B	3
13	3	1.5	√	√	√	√	C	3
14	3	0.75	√	√	√	√	D	3
15	3	0	√	√	√	√	-	-

Figure (5-21) shows the errors in all 15 test beds over the 4 data capturing durations studied. As a general trend observed in all the experiments, there is a peak in error when the data is captured at zero distance between the test bed and metal media as observed in test beds 5 and 10. In test bed 15, there was zero distance between the test bed and metal media, and there were only 4 tags present with two tags not functioning due to the proximity to the metal. The readings of test bed 15 did not result in a meaningful translation of finding the location of objects.

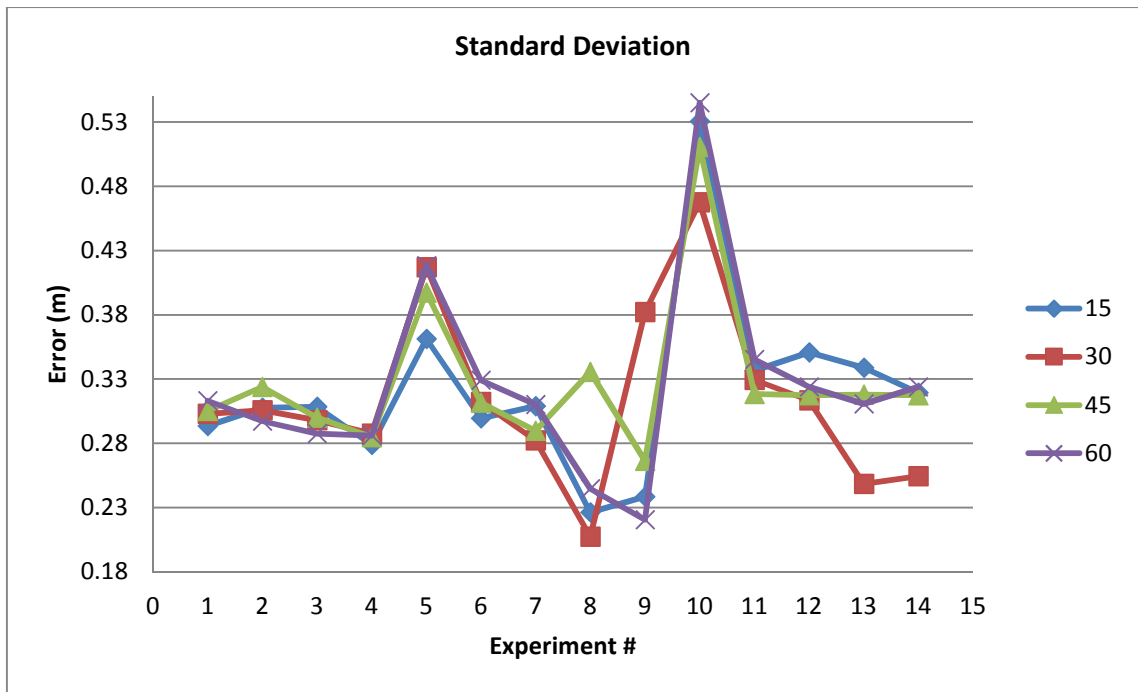
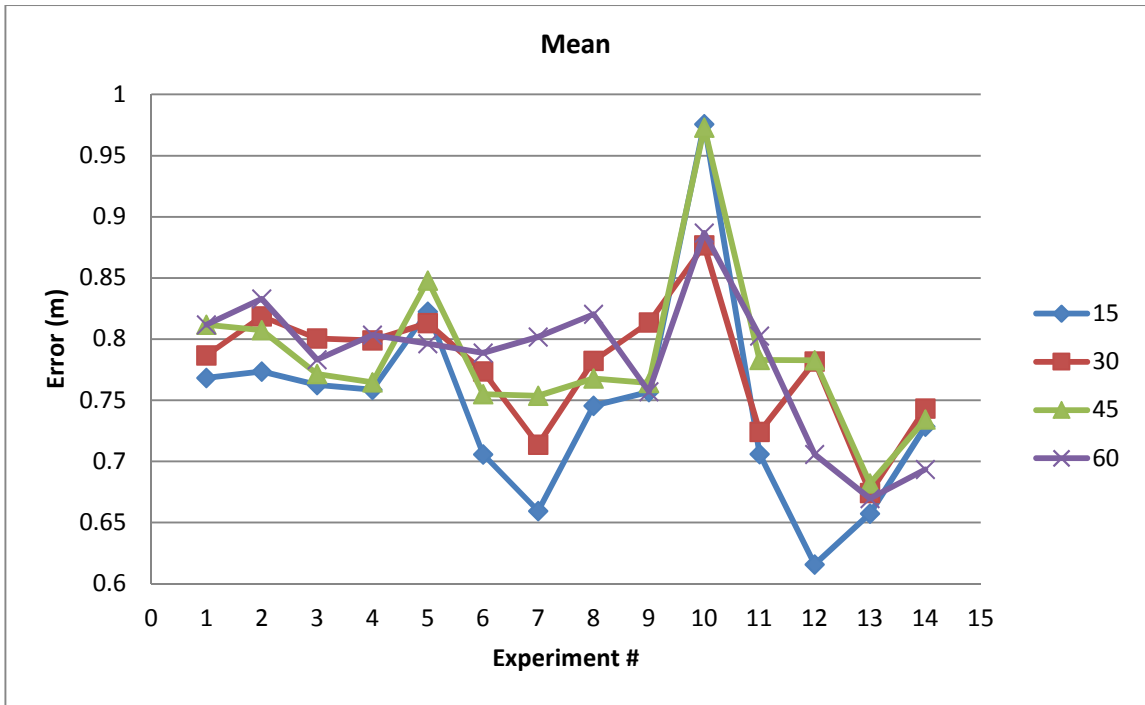


Figure 5-21: Errors observed under different durations in all test beds

Figure (5-22) shows the best location to capture data is at the center of the test bed where there is the equal distribution of signals received from the RFID reference tags. The

accuracy of localization decreases as the reading locations diverge from the center of the zone. Results of the experiment revealed that the least error prone sets of readings were captured while the duration for data collection was minimal (15 seconds). As the time window of data capturing increased, the error in identifying location increased as well. It is concluded that shorter duration time leads to less amount reflections of radio waves from the surrounding, as shown in Figure (5-23).

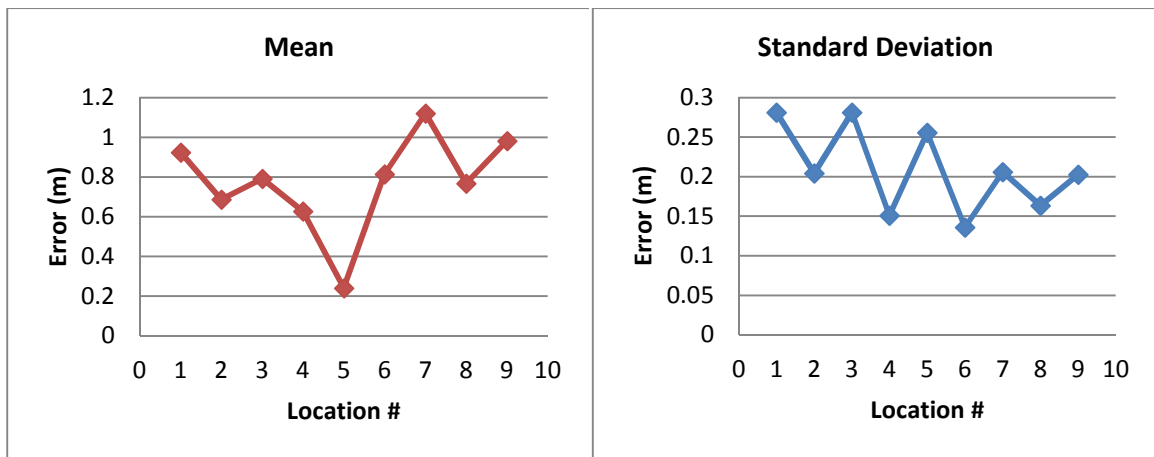


Figure 5-22: Errors observed in the 9 different predefined locations

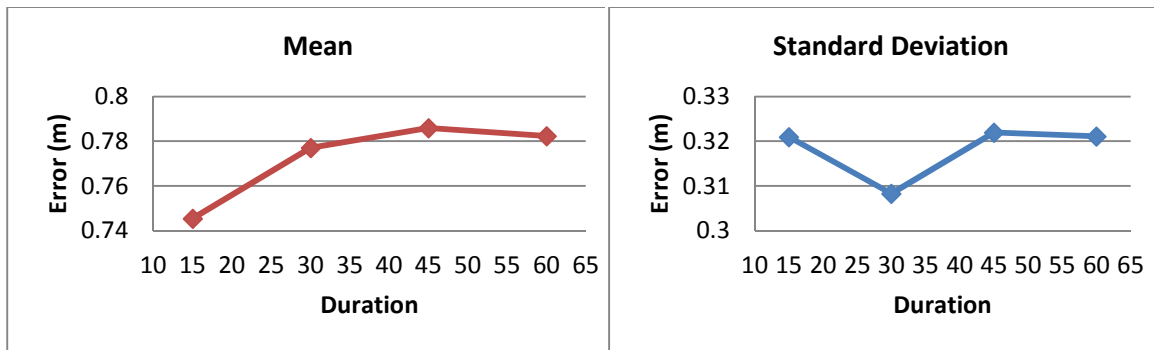


Figure 5-23: Errors observed in all test beds with different durations

The effect of metal medium was one of the other factors under study. In the test beds group E that was at zero distance to the metal object, the errors are substantially greater than the other groups, as depicted in Figure (5-24). Figure (5-25) indicates that the more tags was

deployed in the experiment, the higher the error with the main reason being the interference of many RFID tag waves existing. However, when there are less numbers of tags the risks of not yielding results was higher especially with the presence of metal media with zero distance to tags.

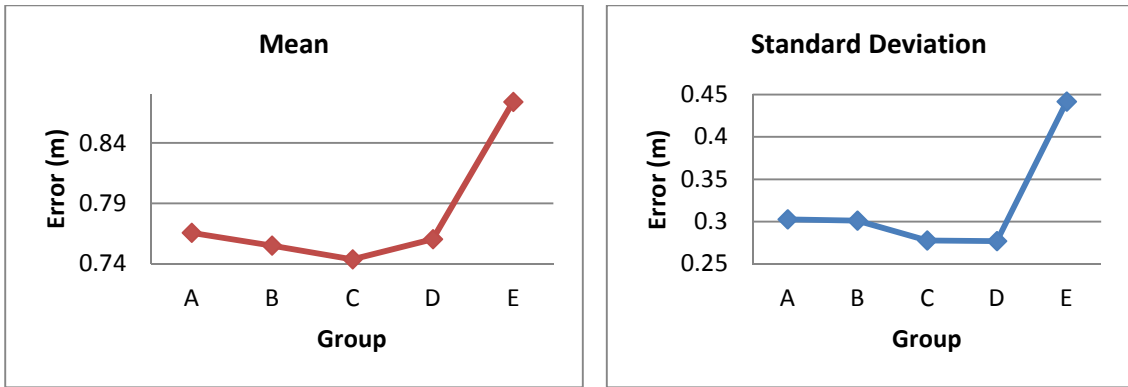


Figure 5-24: Errors observed in all test beds due to metal proximity

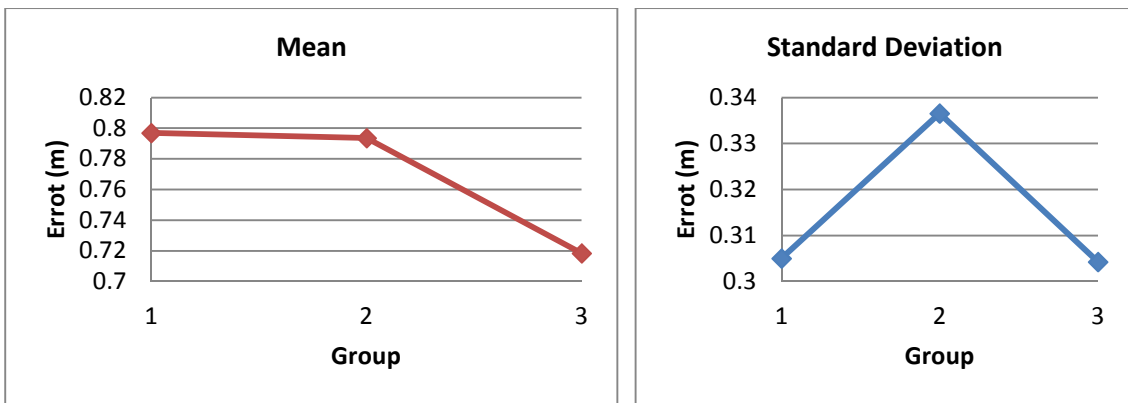


Figure 5-25: Errors observed in all test beds due to the number of deployed tags

5.5 Summary

The experimental results of applying K-NN algorithm for coarse-grained zone detection indicated that the speed of the moving target/reader has a measurable impact on the accuracy of the acquired data. A slow-moving reader yielded lower error rates than fast-moving readers. It was also found that zone configuration effectiveness has a direct relationship to the

deployed RFID read-range. This result is credited to the lower interference effects of adjacent zones. The results indicated that mid-deployment performs better than corner-deployment. Also, the results obtained from the on-site and controlled experiments show different trends for the impact of K value on the error rate. The higher the K value, the higher was the error rate for the controlled experiments, while in the on-site experiment, the higher K values resulted in lower error rates.

Regarding applying trilateration and proximity algorithms, the results shows mean error of 1.0 m and 1.9m for user location identification and material tracking using trilateration algorithm, respectively. The results shows mean error of 1.9 m and 2.6m for user location identification and material tracking using proximity algorithm, respectively. The developed two-step algorithm detects user location and material zones with 100% accuracy. The main limitations of the trilateration algorithm are the need to generate path-loss model for each type of tag used, the variability associated with deployment of tags, the uncontrolled influence of noisy signals and potential interference from equipment and/or vehicles located between tags and between tags and the mobile reader.

Further studies were conducted using proximity algorithm. These studies include the effects of four factors on localization using RFID tags in 15 different settings. The results prove that least erroneous settings to capture data proves to be the in the test bed furthest away from the metal object, where the reader is located at the center of test bed, has the least duration of data capturing and the least number of surrounding tags. The best duration was found to be the 15 second in the test bed with the least number of tags; as the short amount of time to capture data did not allow creation of a lot of interference among the emitted signals. Within each test bed, errors occurred most at points where the received signals were not well distributed in a 360 degree vicinity of the data capturing point. It means that the center point of each test bed

resulted in lowest errors and the points located on the extremities led to the highest errors. Finally, metal objects were found to have major impact on the accuracy of the captured data; to the level where reliable values for errors could not be calculated in the test beds attached to metal objects. In summary, the results of the experimental study and related findings are expected to provide guidelines to the users of RFID technology for localization in indoor construction. It also demonstrates the potential of utilizing short range RFIDs in location estimation and material tracking with a cost-effective manner for indoor construction jobsites.

Chapter 6: COMPUTER IMPLEMENTATION

6.1 General

This chapter presents the computer implementation of the developed model. It also highlights the developed system's frameworks, modules, algorithms and the interaction between its components. It describes the user interface, which is designed to enable the user to collect and store data from construction sites and subsequently query reports. Figure (6-1) depicts chapter overview.

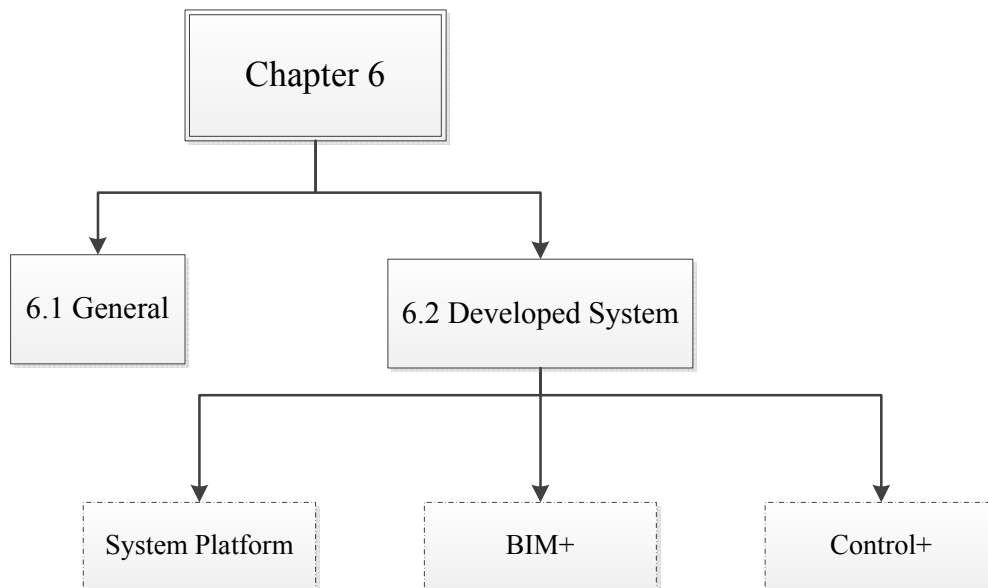


Figure 6-1: Chapter 6 overview

6.2 Developed System

The developed model was implemented in prototype software, which has similar structure to the developed model, as described in Chapter 3. The tablet PC data acquisition is implemented and applied through BIM technology. BIM is capable of recognizing building objects in its fixed asset hierarchy (Family - Type - Object) while being a user-friendly for

creating a building's indoor and outdoor zones. It links those objects to the zone that hosts them by relating an object's ID to a zone's ID. Different software developers such as Autodesk, Bentley and CATIA have applied the BIM concept. None of these systems' providers provides any BIM web application. All of them are standalone applications installed on the user computer that could be connected to internet.

Each has its pros and cons; however, Autodesk Revit customization capabilities have been significantly extended over the past few years. Revit Application Programming Interface (API) allows users to program with any .NET compliant language such as VB .NET and C# .NET. Revit has thus been selected here to be customized so that the integrated tablet PC data acquisition system be applied in its API and added as add-In.

The developed Revit add-in is named (BIM+). BIM+ provides the user with 4D BIM real time visualization for the current zone through utilizing GPS or RFID or even using user manual selection. It also supports the user in capturing the onsite progress data through utilizing progress templates or tablet PC embedded data acquisition technologies. The data analysis and processing framework was implemented as a web-based system that is named (Control+). Control+ receives the project captured data whether from BIM+ or the independent automated data acquisition technologies. Then, it stores the data in the central database. Afterwards, project team members can access Control+ via internet to view generated progress reports. Web-based systems generally do not suffer from the software incompatibility problems that are present in other standalone applications. Any computer that has a web browser such as Internet Explorer or Firefox can access such a system to query and view project progress reports.

6.2.1 System Platform

A typical system application usually consists of three elements: presentation, application logic, and data. Presentation focuses on interacting with the user. Application logic performs calculations based on developed algorithms and determines the flow of the application execution. Data elements manage information that is shared between the users. The most often used systems are two-tier and three-tier architectures. For example, in web-based systems, it refers to both architecture as client/server. A client is defined as a requester of services and a server is defined as the provider of services. Two-tier client/server architecture groups presentation and application logic components on the client computer. It provides data sharing through Internet connection (Quatrani, 2002). The structure of three-tier architecture involves the presentation-tier, the application logic/middle-tier, and the data tier. Adjacent tiers are connected through the Internet. By contrast, with two-tier architecture, a middle tier was added between the user interface in the client computer and the database in the web server. The presentation-tier components manage user interaction and request services. The event handler embedded in the user interface responds to the user's request and triggers the middle-tier data processing components. The middle-tier components perform queuing, executing, and requesting to the database. ODBC (Open Database Connectivity) connects the data processing component with the Database to facilitate data entry and retrieval. The major data processing runs on the middle-tier server (Larman, 1998).

The independence of a middle-tier from presentation and data tiers offers numerous benefits including:

- Multi-language support: system components can be developed using different programming languages when needed.

- Centralized components: components are centralized for easy development, maintenance, and deployment.
- Efficient data access: the numbers of database connections are minimized since the database faces the components only in the middle-tier.
- The middle-tier components can be secured centrally using a common infrastructure. Access can be granted or denied on a component-by-component basis. The database is hidden from the client.
- Simplified access to external resources: access to external resources, for example, to other applications or databases, is simplified.

Taking the above into consideration, two-tier standalone architecture was chosen for BIM+ system development. However, for Control+ three-tier client-server architecture was chosen for the system development, as shown in Figure (6-2). BIM+ is two-tier where the first tier is established in Revit software. BIM+ tier one represents the user interface and the application logic. An add-in is developed inside Revit platform to enable the user from achieving the desired tasks. Tier two in BIM+ is the data tier where the tablet PC database resides. This tier is responsible for storing data captured using the tablet PC automated data acquisition and other connected mobile devices such as mobile RFID and mobile GPS. The data captured is extracted from the tablet PC database to be processed through the add-in developed logic inside Revit to be presented to the user on the Revit interface.

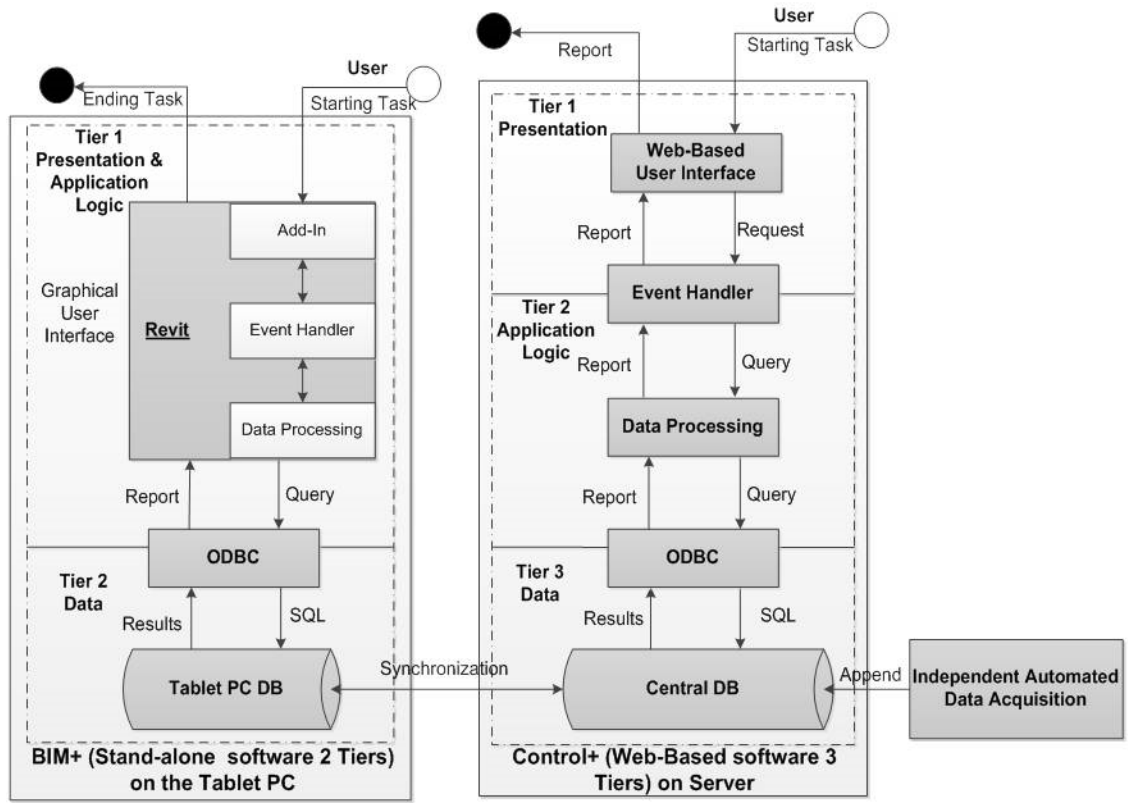


Figure 6-2: Developed system architecture

Control+ is designed to analyze and process all project captured data whether it is captured using the independent automated data acquisition technologies or through BIM+ system. Tier one in Control+ represents the presentation tier, which is mainly a web-based interface for the system. The user interacts with the web-based interface through predefined queries regarding project progress. The interface results are in a form of predefined web-based reports answering the user's queries. Control+ tier two and tier three reside on the web server. Tier two is Control+ logic where all developed algorithms and procedures in the data analysis and processing framework are implemented. The system central database resides in tier three, where all the captured data for project progress is stored.

Database provides a platform to organize, store and retrieve projects' planned and actual performance data in a logical and efficient manner. The Database Management Systems (DBMS) queries the stored project data from the database using SQL (structured query language) to generate different management reports for control purposes. Therefore, Microsoft Access has been chosen as the DBMS for BIM+ tablet PC database and Control+ central database, as shown in Figure (6-3). Microsoft Visual C# .Net programming language was used in the system development due to its compliance with Revit APIs, Microsoft Project and Microsoft Access.

The Unified Modeling Language (UML) is chosen to develop the prototype software in this research. UML is a language for specifying, visualizing, and constructing of software systems, where objects are diagrams and documents that comprise the system models. The Class diagram is the diagram that represents concept, data, and relationships of a system. The attributes of the classes are the parameters needed to execute the operations. The operations of the classes execute the tasks (Quatrani 2002). System functionality is the way a system would behave. It is documented in a use-case diagram. This diagram illustrates the system intended functions, surroundings, boundaries, internal and external relationships. It includes the components of actors as well as those of the use-case model, the system boundary, the use-case communication, and the use-case relationships. Actors are not part of the system. They represent any user or any external software that interacts with the system. Use-case diagram describes the dialogues between the system and its actors and represents the functionality provided by the system (Larmen 1998). .

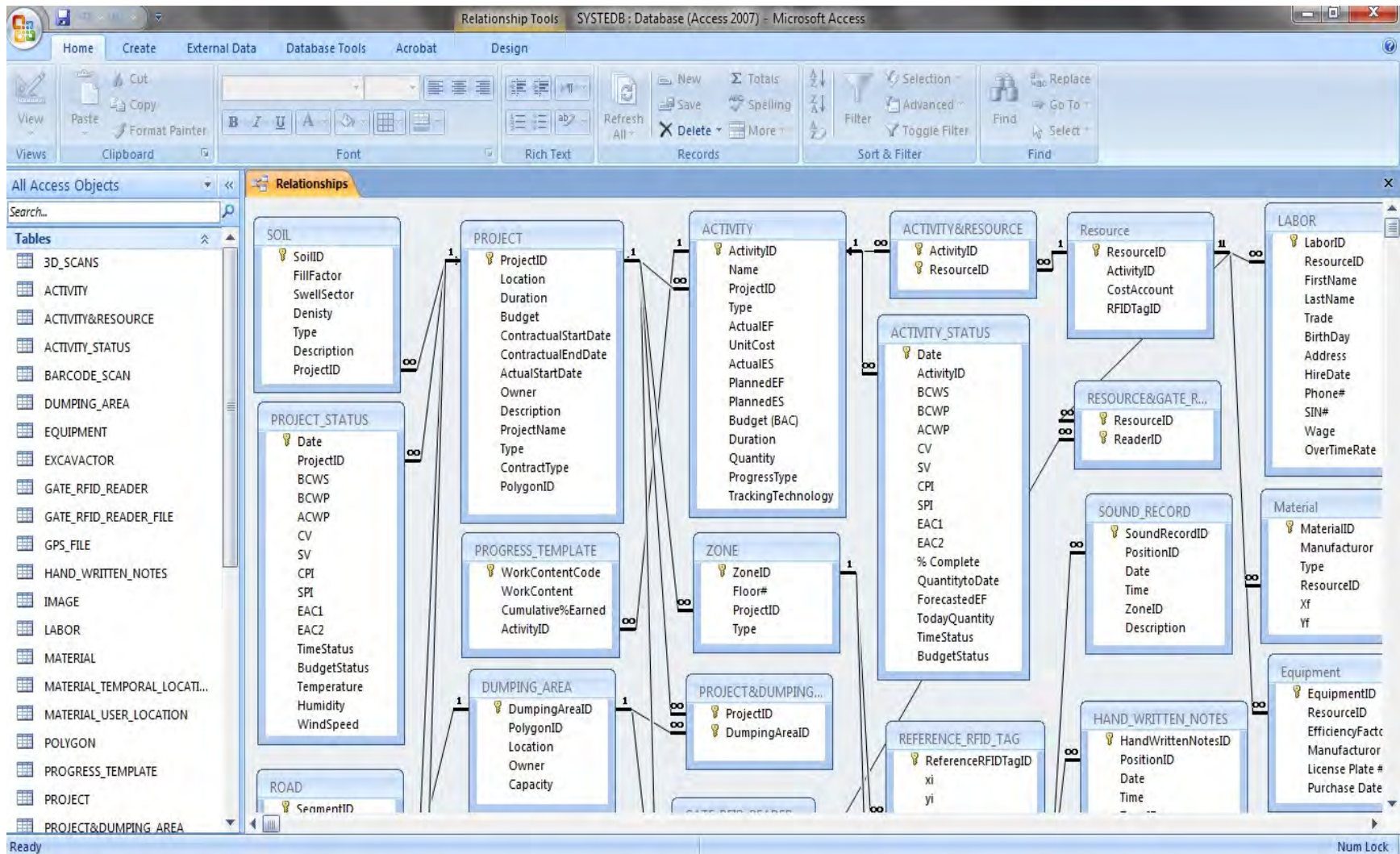


Figure 6-3: ER diagram for the designed Microsoft Access central database

Sequence diagrams of a use-case are developed to represent the implementation scenarios of the developed prototype system. A sequence diagram is an interaction diagram that shows how operations are carried out and what and when messages are sent. It is organized according to implementation time. The time progresses as going down the diagram. The objects involved in the operation are listed from the left to the right according to their accumulated time in the message sequence. Sequence diagrams give dynamic views of a system. They focus on the messages involved in completing a single process and present the mechanism for actions inside the system (Quatrani 2002). The following sections describe the implementations, validations, and the uses of the prototype software. It aims at demonstrating the capabilities of the developed system, according to the description of the developed model in previous chapters. Typical implementation scenarios, represented by developed classes, use-case and sequence diagrams, are introduced. In addition, software screen shots and steps are explained.

6.2.2 BIM+

This section presents the developed automated tool BIM+, which was developed using the “Visual C# .NET” in Revit’s API. Revit was selected to be customized so that the automated data acquisition using the tablet PC can be applied in its API and integrated as add-in utility. BIM+ was implemented to the selected case study, described in Chapter 4, as a proof of concept and for testing the system. The 3D BIM model has all of the parameters and attributes for building zones and objects. Each parameter and attribute is associated with a unique ID to avoid conflicts when dealing with data exchange between Revit and tablet PC database. The generated 3D BIM model feeds the developed BIM+ data, such as the number of spaces, the area of each space, the object families and family types, in order to identify objects inside each space, and later facilitate integration of the 3D model with the construction schedule. Data input by the user(s) and/or data converted or calculated is stored in the tablet

PC database tier. BIM+ is able to extract and store data inside the tablet PC database. Based on this ID uniqueness feature, all objects' characteristics could be exported from the 3D BIM model and imported to the data tier.

In addition to the unique ID that each object has, BIM objects also have two important characteristics that are family and type. Family represents the main description of objects such as wall, door, window, etc. While, type represents specific kind of a family object such as internal wall 1 hour fire rated or wooden door single flush panel. The developed system utilizes these two aspects of BIM objects to categorize the whole building. Figure (6-4) depicts the use-case diagram for BIM+. It shows system boundary, functionality and actors. There are three actors in BIM+, two of them are users and the third is external software. The first actor is the experienced user, who is familiar with the project 3D BIM model and the construction schedule of the building being modeled such as project manager or the project scheduler. The experienced user authentication reveals BIM+ full customization and configuration functions. The experienced user is responsible for linking the Microsoft Project file to BIM+ and maps the 3D BIM objects to project activities through utilizing the control visibility options. Visibility options have three different use-cases that are show by activity, show and hid activities manually and show activities by date. "Show activities by date" use-case is considered the 4D BIM model that was customized in Revit. The visibility options given to the experienced user facilitate the process of modifying or changing activities objects in case of any design modification or change order. In addition, the experienced user links the floor plans and area plans with the dividing activity that was extracted from the MS project schedule.

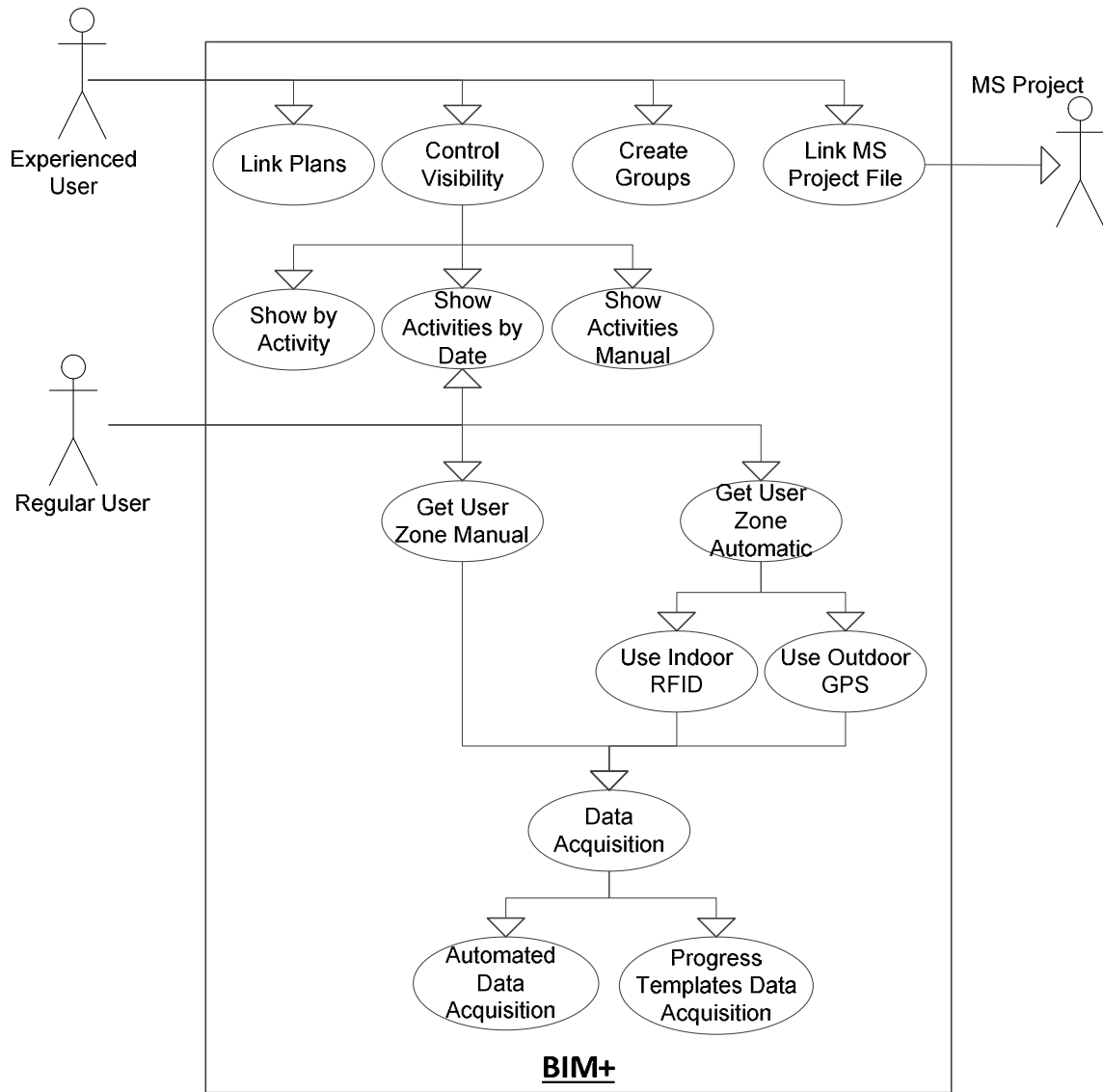


Figure 6-4: BIM+ use-case diagram

The second actor is the regular user. This user is the site personnel responsible for utilizing BIM+ for data acquisition purposes. Hence, the user utilizes “show activities by date (4D BIM)”, “get user zone manually” and “get user zone automatically” use-cases. If the user gets the current zone automatically then two use-cases are generated that are “Use RFID for Indoor” or “Use GPS for Outdoor”. Whether the user gets the current zone manually or automatically, “data acquisition” is the next use-case to be used. Then, the data acquisition use-case branches into two use-cases that are automated data acquisition and progress templates

data acquisition. The final actor is Microsoft Project software, which is external software to the system boundaries. BIM+ should first be customized and configured for the current project in hand. The experienced user does this step and should link the MS project schedule file to BIM+. This is done according to the sequence diagram shown in Figure (6-5).

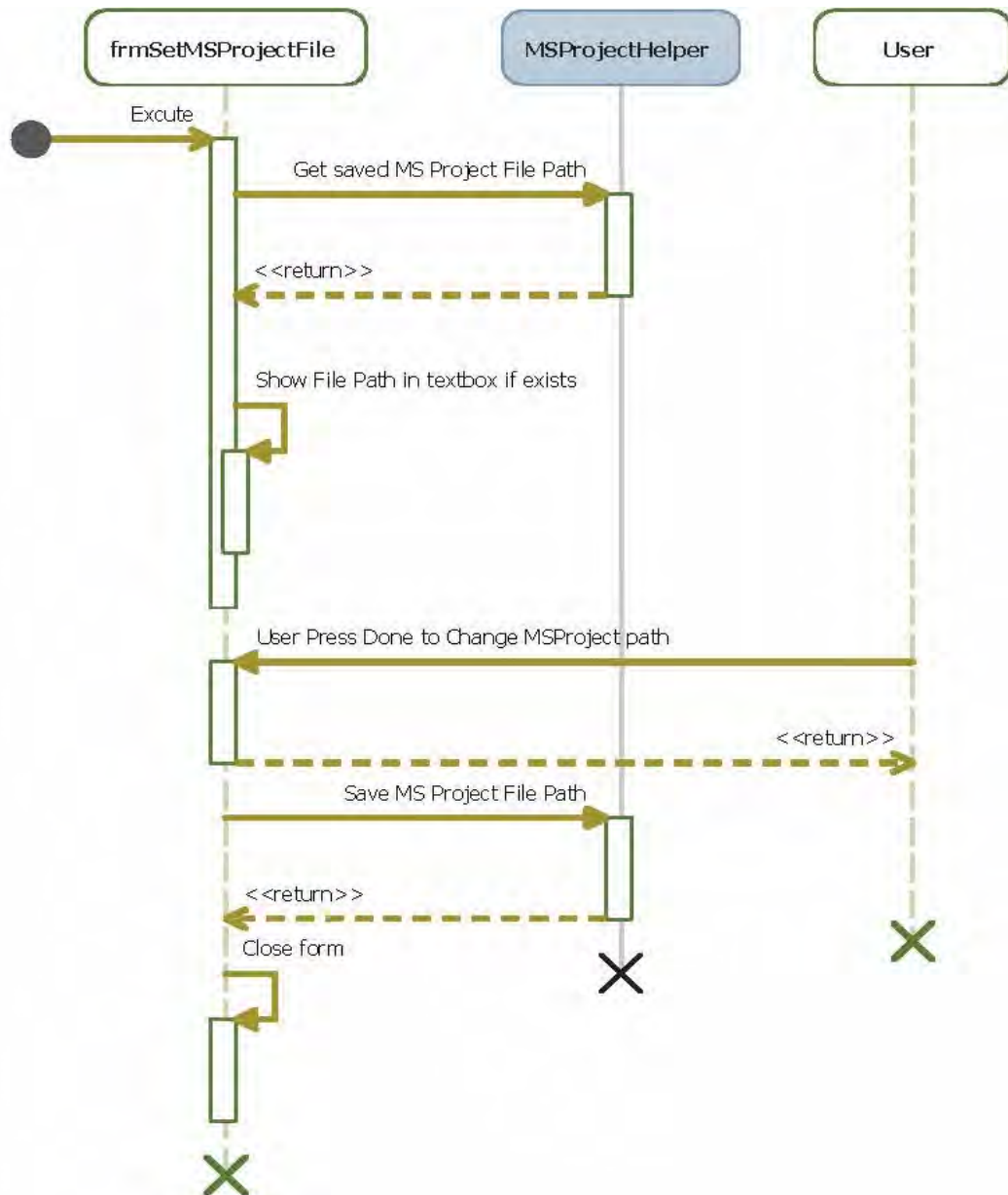


Figure 6-5: Linking Microsoft Project file to BIM+ (sequence diagram)

The user first activates the developed add-in menu in the Revit screen and subsequently selects from a pull-down menu “Set MS Project File” and completes the process depicted in Figure (6-6). BIM+ closes the file explorer dialog and puts the selected file path into displayed writable textbox. The user presses the “Done” button so, BIM+ checks for if the file exists, which is part of process verification. Then, it saves the new MS project path into the system configuration file to use it as default MS Project path and closes the change MS Project form.

The second step, performed by the experienced user, is to map 3D BIM objects to its respective activity, as in the sequence diagram shown in Figure (6-7) and the process operations highlighted in Figure (6-8). In creating group of elements, the user can link one object or a set of objects to one activity as diagrammatically shown in Figure (6-9). Prior to that linkage, MS Project schedule must be activated and verification is performed to make sure that the schedule has more than one activity. If the MS project file have list of activities, it displays two buttons “Finish” and “Close”. Then, the system allows the user to select multiple objects from the 3D Revit model and link them to one of the activities being displayed. After selecting multiple objects, the user selects the MS Project activity from a pull-down menu “Choose Group Name” and completes the process depicted in Figure (6-9). Upon completion of the linking process, the object(s) inherits the attributes of the associated activity such as activity name, early start and early finish, which are then used for generating the 4D BIM model. This process is repeated until all 3D Revit objects are mapped to associated MS Project activities.

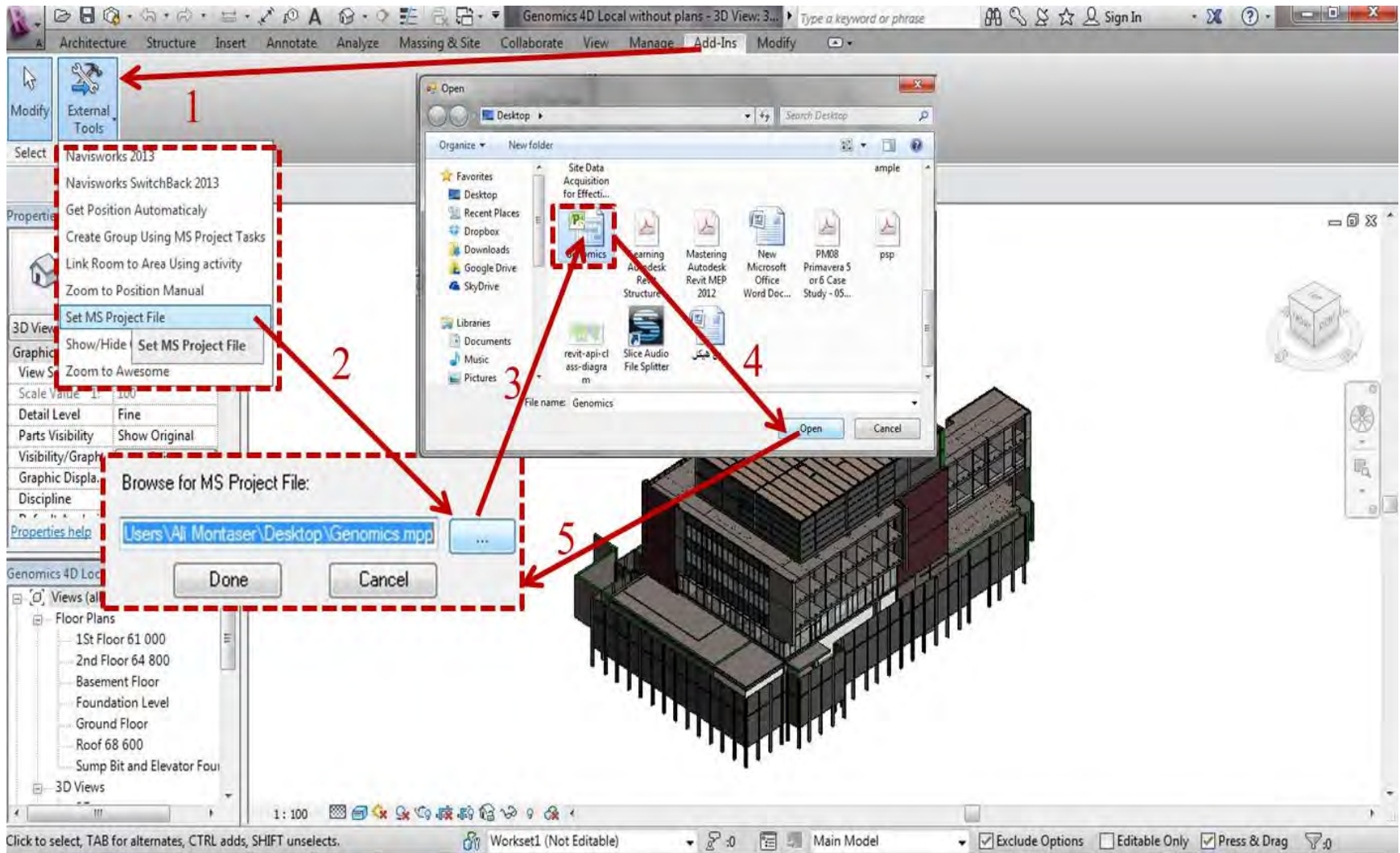


Figure 6-6: Linking Microsoft Project file to BIM+

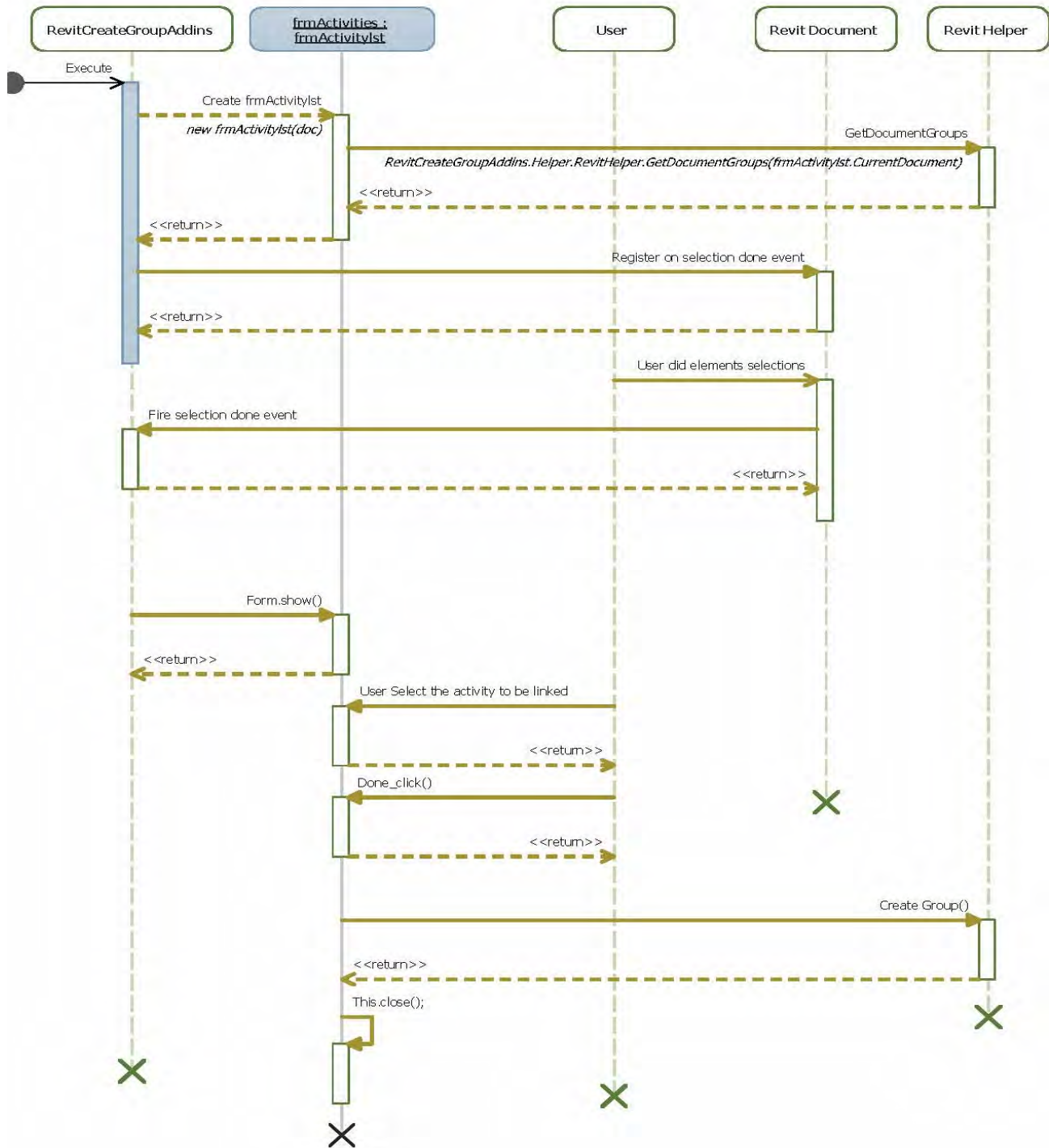


Figure 6-7: Mapping 3D Revit objects to project activities (sequence diagram)

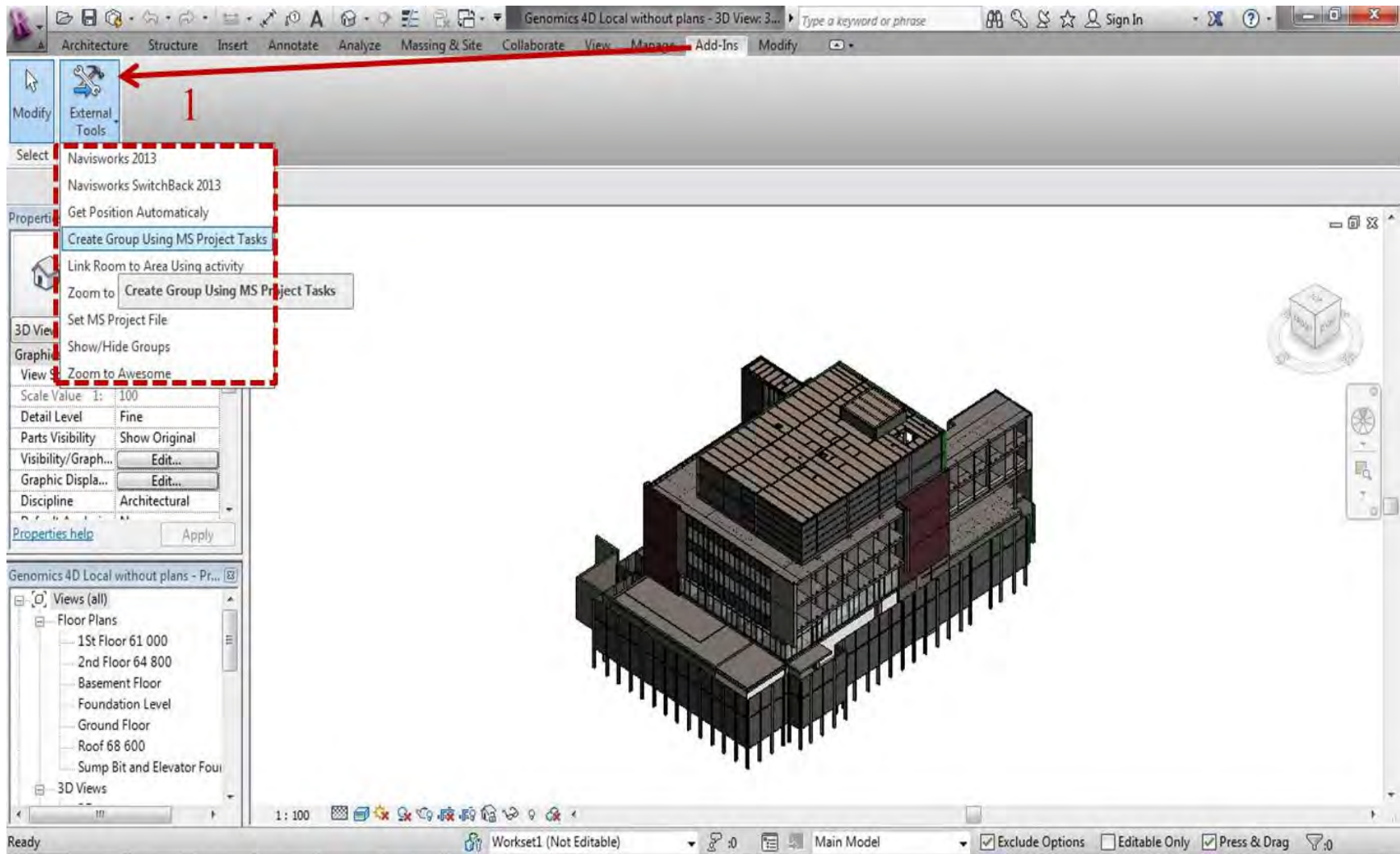


Figure 6-8: Mapping 3D Revit objects to project activities (Part 1)

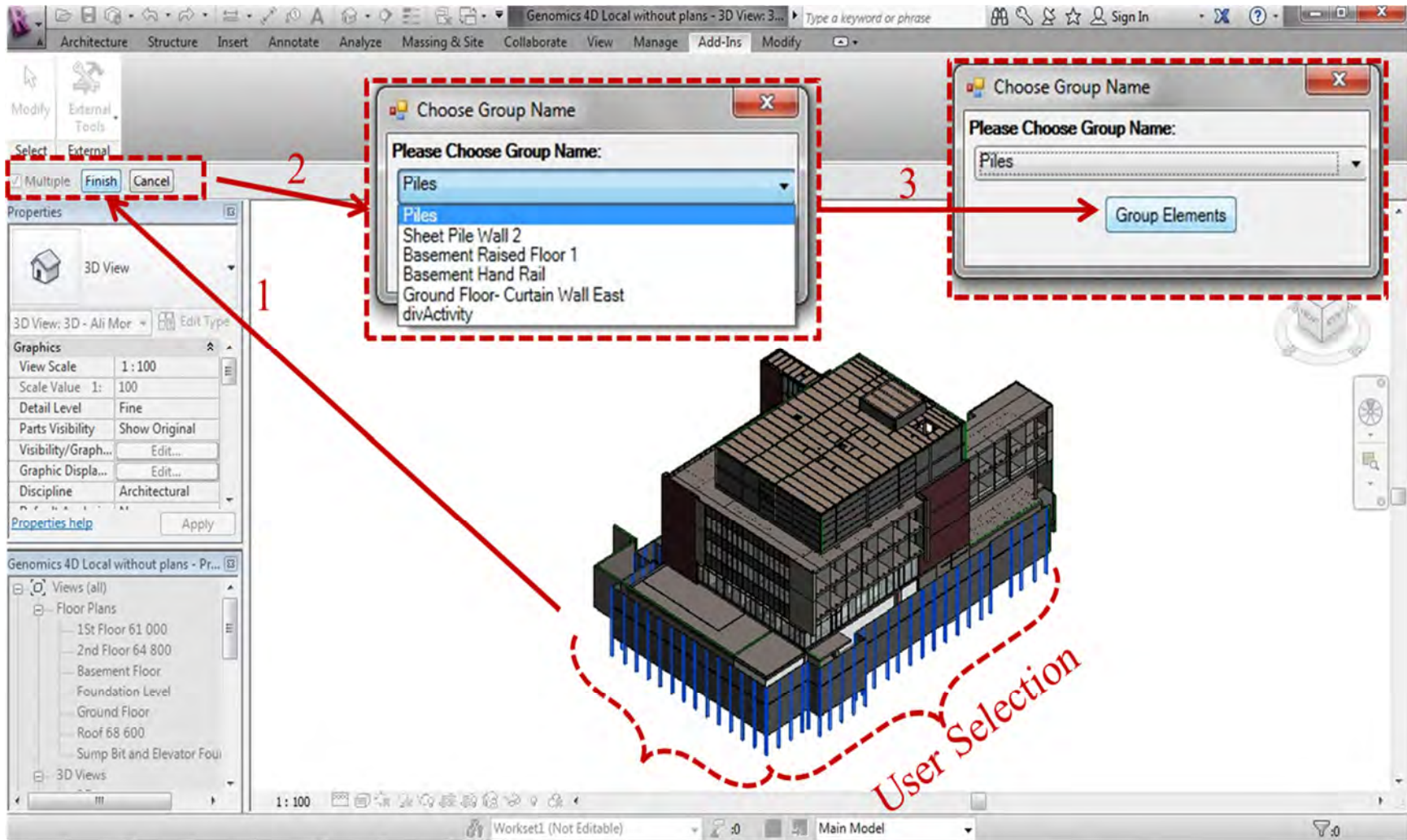


Figure 6-9: Mapping 3D Revit objects to project activities (part 2)

Each object in Revit, referred to as element, has a set of attributes such as ID, family, type. These attributes vary from object to another and they are either generic or specific object. A new attribute was added to all Revit objects to facilitate the linking process, as shown in Figure (6-10). It is referred to it as “Group”, which represent one object or a set of objects. The user selects a set of objects such as supported deep excavation piles, as shown in Figure (6-11), then; the name of “Group” is made identical to the activity name. The sequence of this process was designed and implemented to be from outside to inside and from top to bottom. Upon finishing one group, objects of that group will be hidden to provide access to the other objects. The mechanics of linking identified objects to the relevant scheduled activity is performed interactively as shown in Figure (6-12).

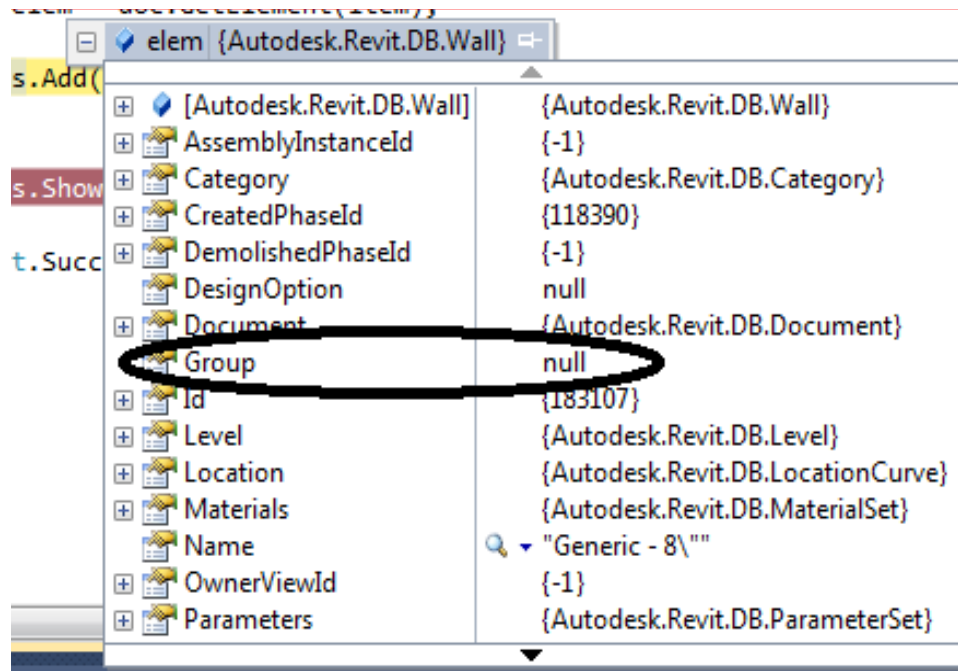


Figure 6-10: The added attribute “Group” to Revit object

pickedRef	Count 100
Pile 1	{Autodesk.Revit.DB.Reference}
Pile 2	{Autodesk.Revit.DB.Reference}
Pile 3	{Autodesk.Revit.DB.Reference}
Pile 4	{Autodesk.Revit.DB.Reference}

Figure 6-11: Selected objects to create Group

doc.get_Element(set.ElementAt(0))	{Autodesk.Revit.DB.V
[Autodesk.Revit.DB.Wall]	{Autodesk.Revit.DB.V
AssemblyInstanceId	{-1}
Category	{Autodesk.Revit.DB.C
CreatedPhaseId	{118390}
DemolishedPhaseId	{-1}
DesignOption	null
Document	{Autodesk.Revit.DB.D
Group	{Autodesk.Revit.DB.G
Id	{Autodesk.Revit.DB.C
Level	{Autodesk.Revit.DB.L
Location	{Autodesk.Revit.DB.L
Maximize	{Autodesk.Revit.DB.N
Name	Piles
OverviewView	{-1}
Parameters	{Autodesk.Revit.DB.P
ParametersMap	{Autodesk.Revit.DB.P
PhaseCreated	null
PhaseDemolished	null
Pinned	false
UniqueId	"2b4b2421-b7c2-4d4
ViewSpecific	false
WorksetId	{0}

Figure 6-12: Assigning MS Project activity to Group name

Controlling visibility of activities is crucial in BIM+. Therefore, three different options were developed to identify which activities are visible and which are hidden. To activate the visibility controls, the user activates the add-in menu and selects “Show/Hide Groups”. Then, BIM+ checks that at least one activity is linked to the 3D Revit objects. Otherwise, the system pops up an error message instructing the user to map the 3D Revit objects to the MS Project activities first. If this check is false then the system displays “Group Visibility Control” form. The form contains three different options, as shown in Figure (6-13). The user has to select one of the three options.

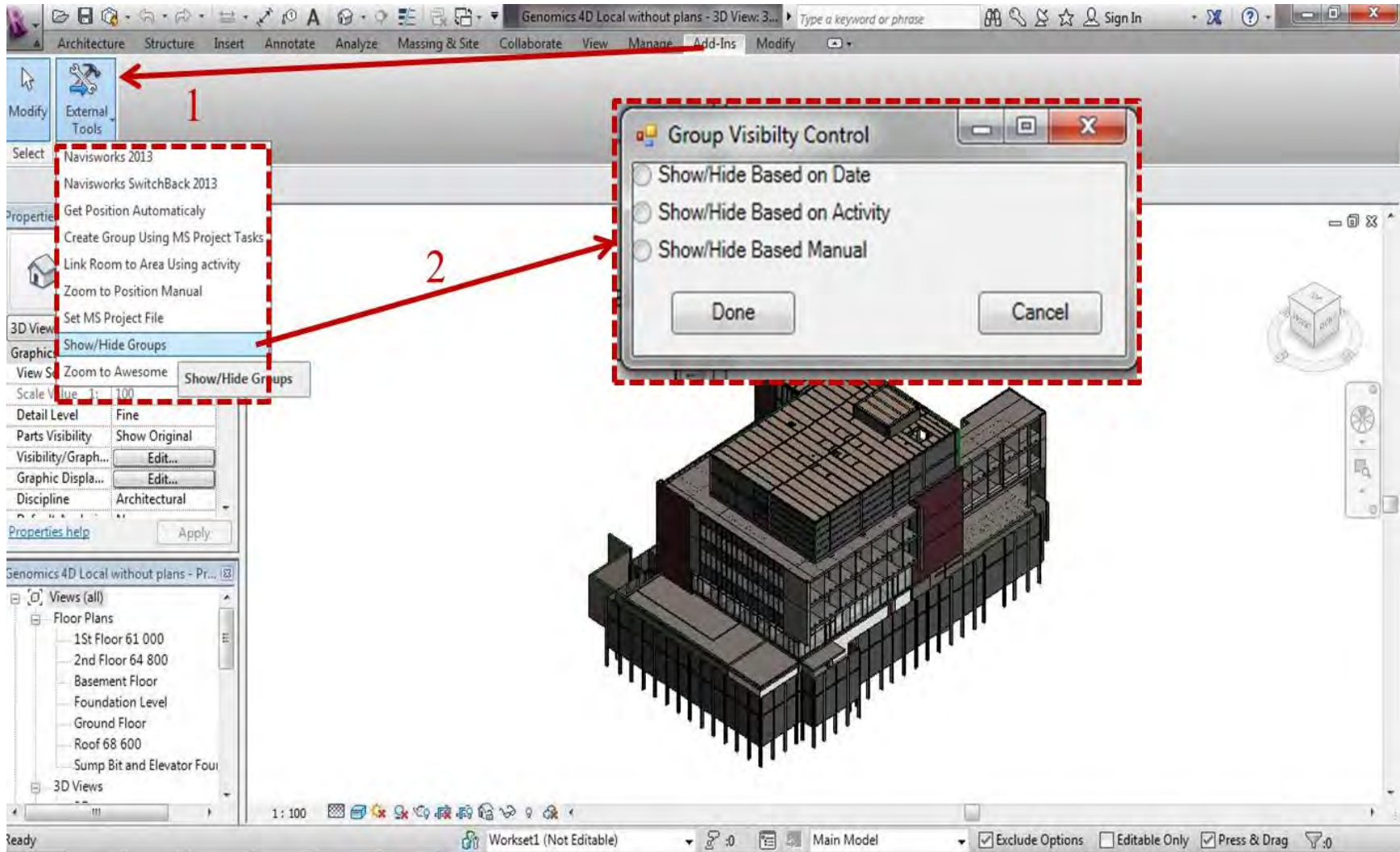


Figure 6-13: Show and hide activities options

If the user selects “Show/Hide Based on Activity” then the system shows under that option a drop down list with all activities that were linked to 3D Revit objects. The user selects one activity that required to be displayed. The system displays the selected activity on the current view and hides all other activities. In Figure (6-14), the Basement Gypsum Board Walls activity was shown. If the user selects “Show/Hide Based Manual” then the system displays a form containing all displayed activities under the visible list and all hidden activities in other list. The user selects the needed activity to be displayed and press move or selects the needed activity to be hidden and press move. In addition, the user could select to move all activities from one list to the other and vice versa. The user presses done button to apply the above actions to Revit current view. Figure (6-15) shows that all roof and upper roof activities were hidden from the view as per the selection in the lists. Showing specific activity or activities become very handy to the experienced user specially, in the cases of design modification or change orders. Therefore, the user can isolate the activity objects, modify it, and link it again to the MS Project activity.

The third option is to show/hide activities by date. This option represents the methodology for applying the 4D BIM concept inside Revit without the need for third party software. This use-case could be utilized by the experienced user and the regular user. This use-case considered the first step for the regular user before capturing on site progress data. When the user selects the option of “Show/Hide Based on date”, two calendars appear. The first calendar to specify the start date and the second calendar for the end date. The system applies the algorithm explained in Chapter 3 for showing and hiding activities on specific date range.

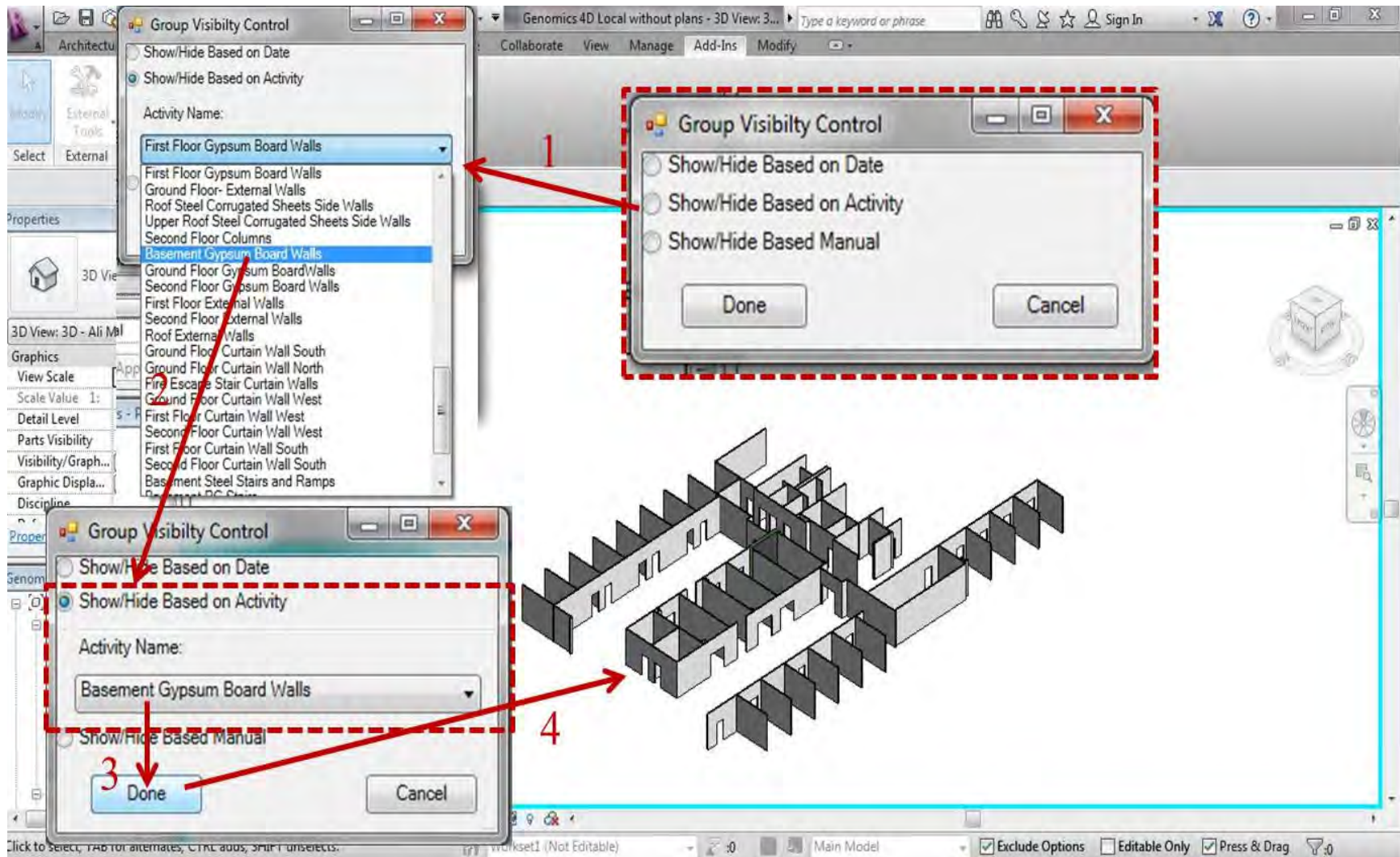


Figure 6-14: Show specific activity

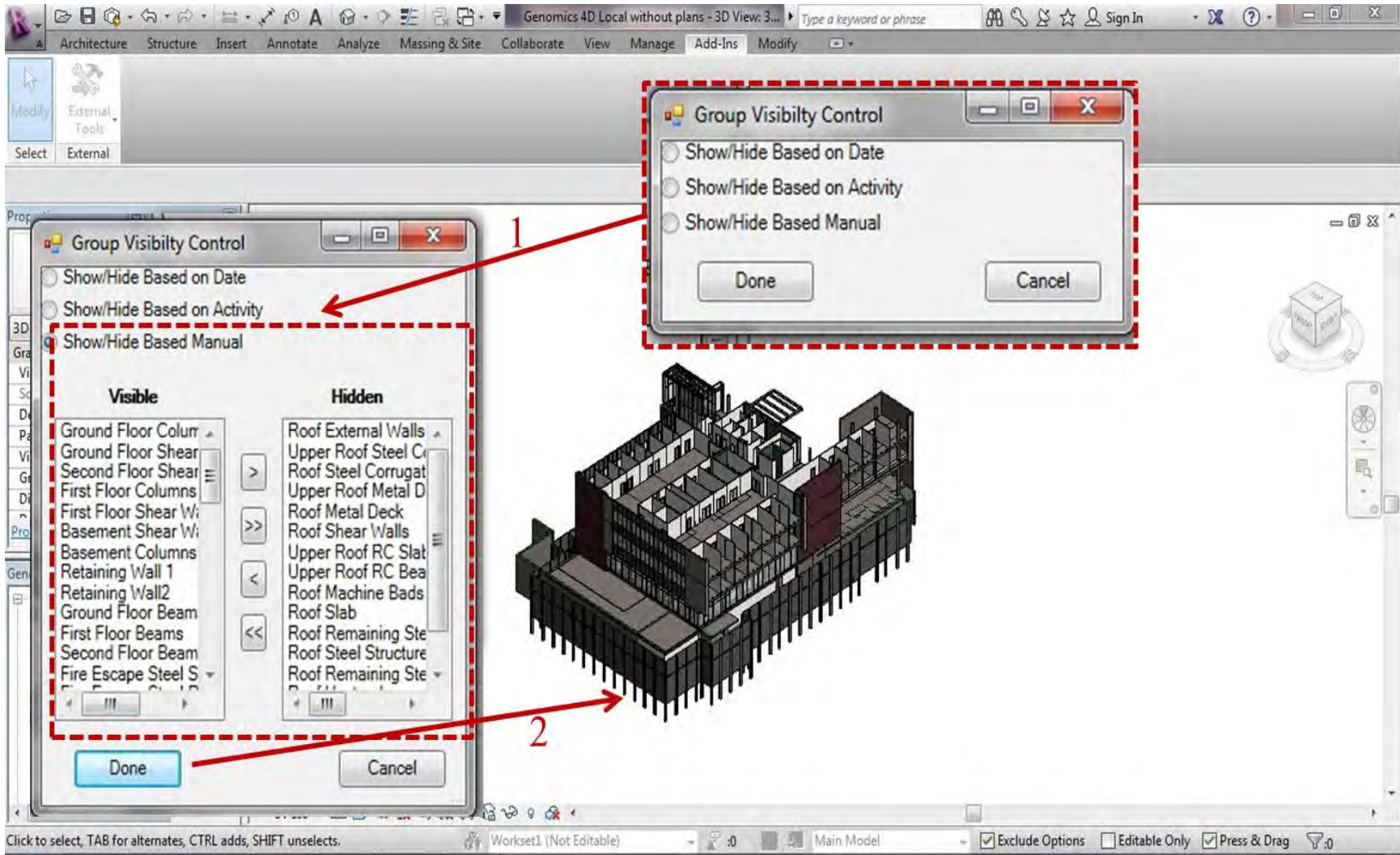


Figure 6-15: Show and hide activities manually

The system displays the result on the current Revit view, as shown in Figure (6-16). Figure (6-17) presents images from the 4D Revit BIM model at different locations inside Genomics building. The final customization and configuration for the project inside BIM+ is the zone configuration process. For each indoor floor there should be two plans, one is the area plan and the other is the floor plan. The link between the plans is the floor dividing activity. Figure (6-18) depicts the area plan and the floor plan for the basement floor. The experienced user should create the two plans for each floor. In addition, the experienced user should create area plan for outdoor areas and roof floors, as shown in Figure (6-19). Then, the user manually starts assigning zones for each plan whether it is floor plan or area plan. This process could not be automated since it differs according to the user preferences.

After creating all plans and its respective zones, the experienced user starts linking every floor plan and area plan with its corresponding dividing activity. The user opens the add-in menu and selects the “Link Room to Area Using Activity”. BIM+ displays form contains three drop down lists. The first one contains all Rivet floor plans and the second drop down list has all MS Project activities. The final drop down list consists of all Rivet area plans. The user selects the floor plan, area plan and the respective dividing activity. BIM+ searches in Revit configuration file for the selected floor/area/activity and check whether these items have been linked before or not. If it was linked, then the system send an error message for the user notifying that item has been selected before. Figure (6-20) depicts the developed C# .Net source code in Revit API to link the dividing activity with the floor and area plans. The system saves this linked combination, as shown in Figure (6-21). The process is repeated for each floor. By the end of this process, the project would be customized on BIM+ for data acquisition. Afterwards, the rule of the regular user starts, which is the site personnel responsible for capturing on site progress from indoor and outdoor zones.

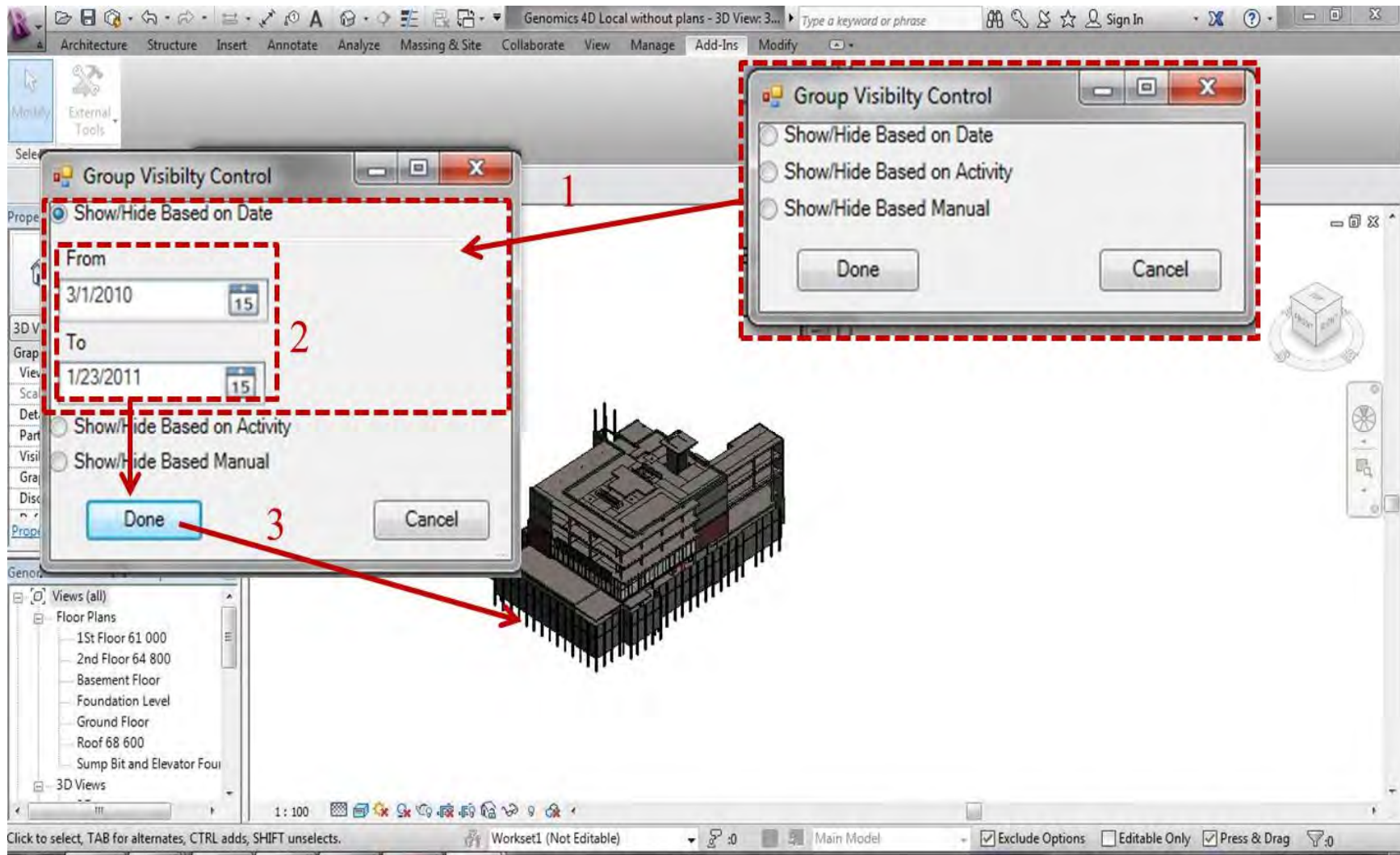


Figure 6-16: Show and hide activities by date (4D BIM)

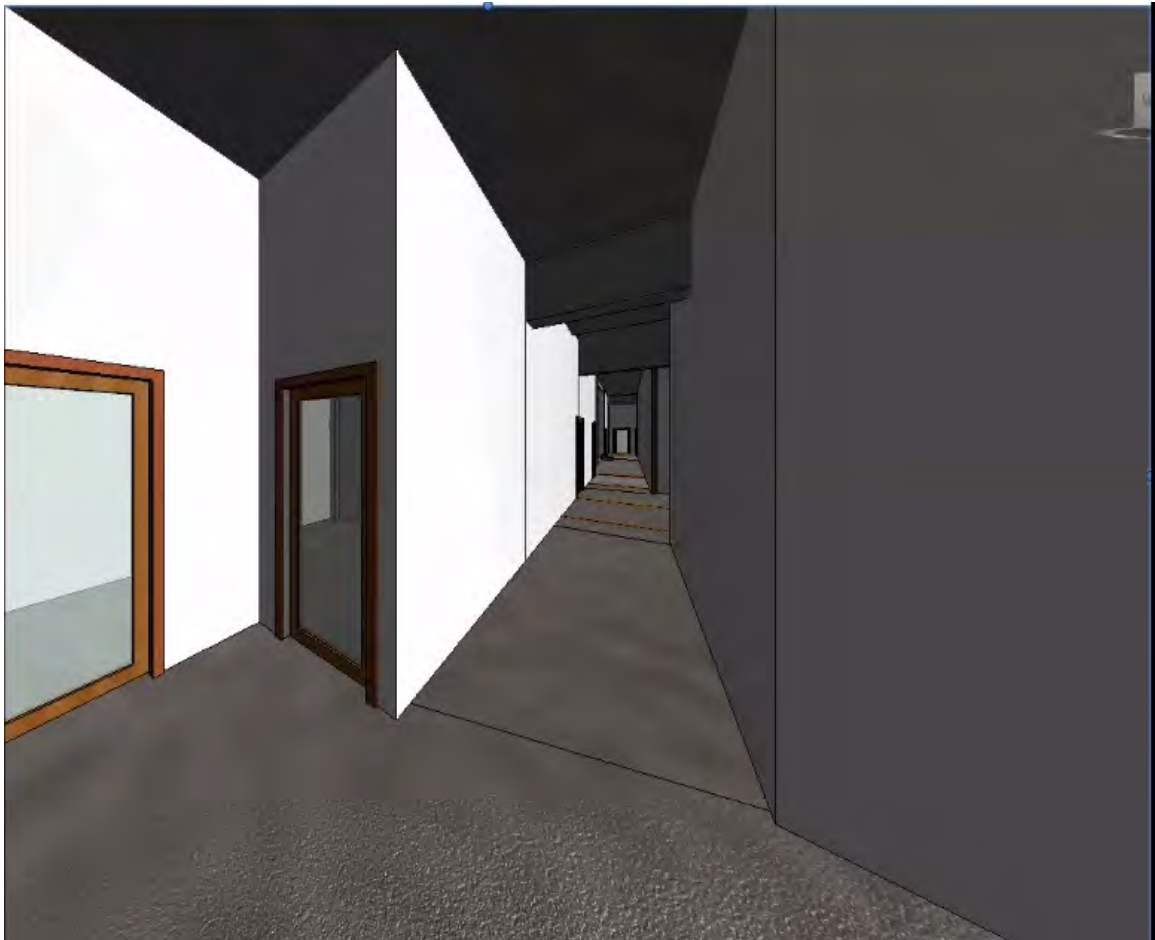
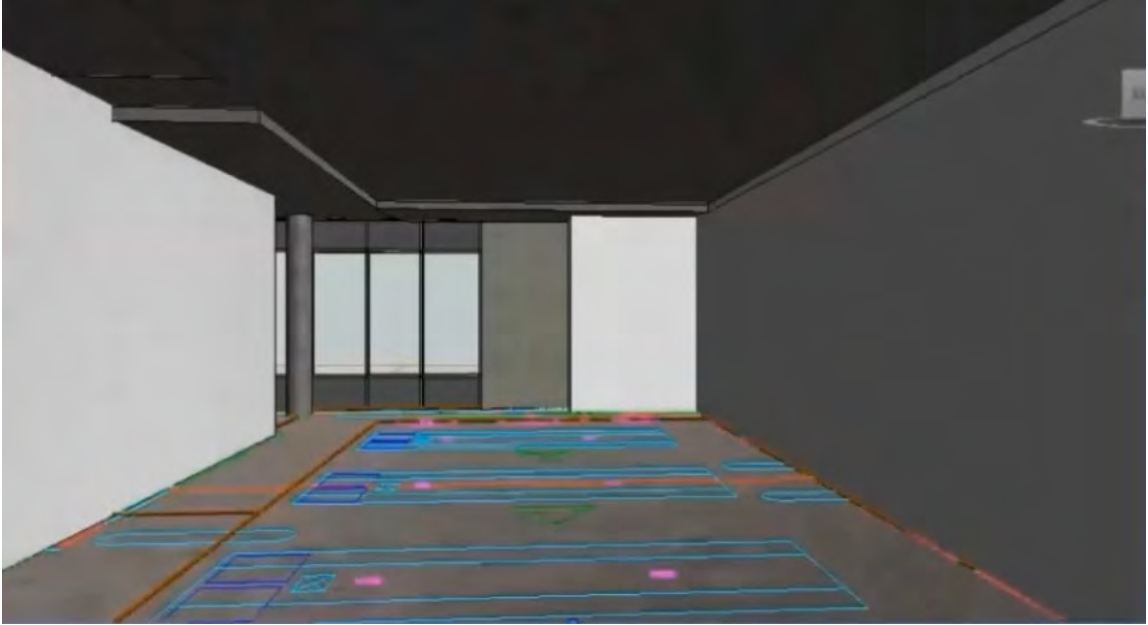


Figure 6-17: Pictures from the generated 4D Revit visualization

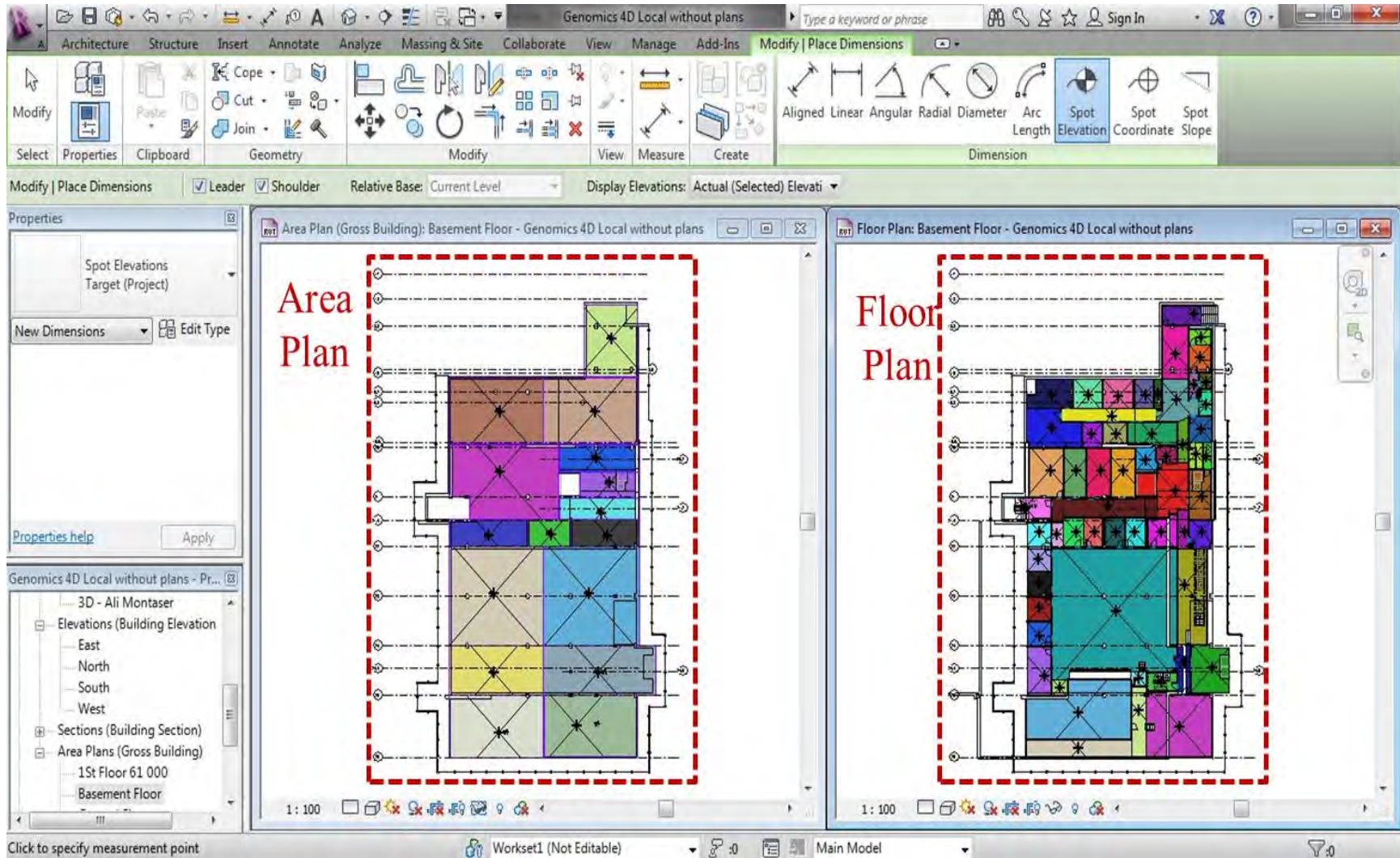


Figure 6-18: Area plan vs. floor plan for the basement floor at Genomics building

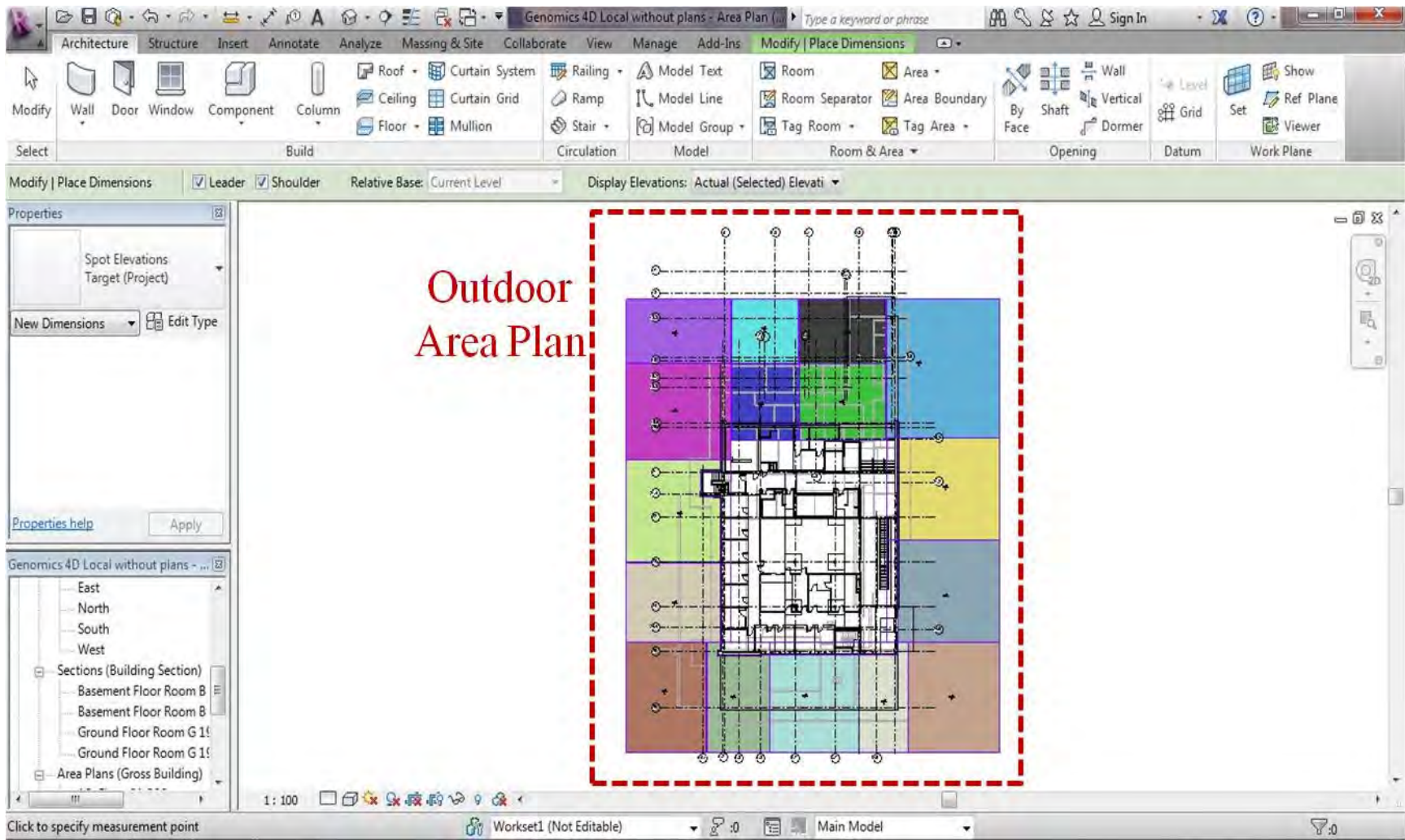


Figure 6-19: Area plan for outdoor zones at Genomics building


```

// Link Button Click event handler;

private void btnLink_Click(object sender, EventArgs e)
{
    xmlEntity.InsertXmlEntities(new xmlEntity() { ActivityName =
(cboActivities.SelectedItem as MSPActivity).Name, AreaName =
(cboAreas.SelectedItem as CustomView).Name, FloorName = (cboPlans.SelectedItem as
CustomView).Name });
    lstXmIs = xmlEntity.GetXmlEntity();

    MessageBox.Show("Done");
}

// Insert the linked entity to xml file;

public static void InsertXmlEntities(xmlEntity currententity)
{
    System.Configuration.Configuration config =
Helper.MSPProjectHelper.GetConfig();
    string strLinkFilePath = Environment.GetFolderPath(
Environment.SpecialFolder.ProgramFilesX86)+config.AppSettings.Settings["LinkFile
Path"].Value;

    XDocument xRoot = XDocument.Load(strLinkFilePath);
    XElement eleroot =
xRoot.Descendants("Links").FirstOrDefault();

    XElement ele = new XElement("Link");
    XAttribute attActivityName = new XAttribute("Activity",
currententity.ActivityName);
    XAttribute AreaName = new XAttribute("Area",
currententity.AreaName);
    XAttribute FloorName = new XAttribute("Floor",
currententity.FloorName);

    ele.Add(attActivityName, AreaName, FloorName);

    eleroot.Add(ele);
    xRoot.Save(strLinkFilePath);
}

• Xml file Sample:-
<?xml version="1.0" encoding="utf-8"?>
<Links>
    <Link Activity="first one" Area="Level 1" Floor="Level 1" />
</Links>

```

Figure 6-20: C# .Net source code for the process of linking dividing activity to plans

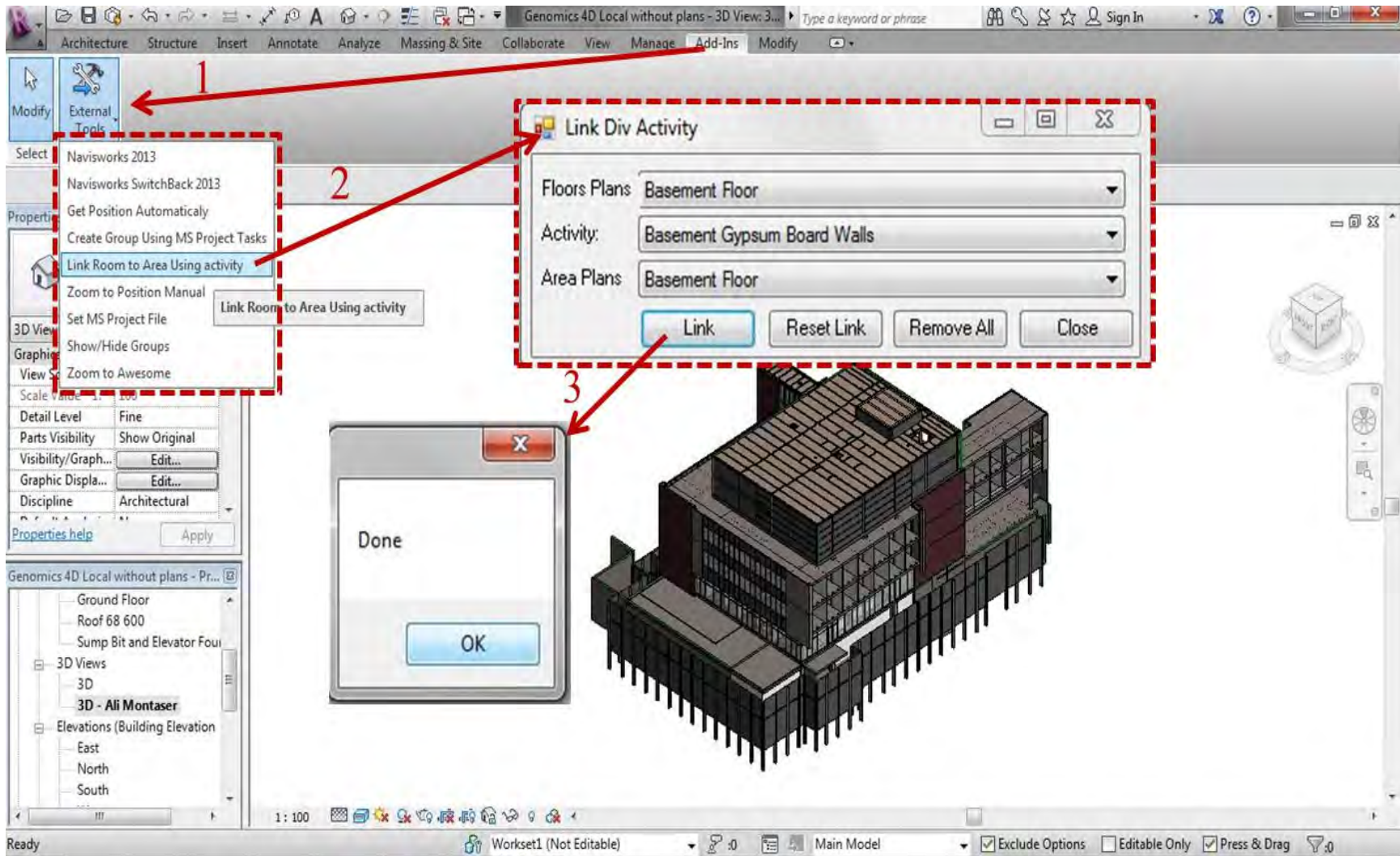


Figure 6-21: Linking dividing activity to floor plan and area plan

The regular user can then start the data acquisition process by defining the 4D Revit model date range. The user at that point can visualize a 4D BIM model for the status of the project at the current date. The user activates the add-in menu and selects “Go to Position Automatically”. In this case, the user has to specify whether the current zone is indoor or outdoor, as shown in Figure (6-22). If indoor, then the system starts communicating via Bluetooth with the RFID reader. The user has to operate the RFID for 15 seconds and close it. Since, all RFID reader captured data is saved as text file on specified location on the RFID reader memory, BIM+ accesses this data and stores it in the tablet PC database. According to the captured data, BIM+ identifies which floor this data belongs to. Also according to the current date, the system specifies whether the dividing activity for this floor started or not and then specifying whether to use the area or floor plan for this floor.

BIM+ applies the first step in the two-step algorithm through applying proximity algorithm to identify the user current location coordinates. After identifying the coordinates and the used plan, the system identifies the user current zone. BIM+ creates two rivet sections for the current zone. The created sections are named automatically according to the following order (Floor name – Zone name – Date – Time). Then, BIM+ orients the Revit 3D view into the created sections. The system displays the list for all elements exists in selected zone that belongs to activities in progress only. The user has the option to select single object from the list. Then, the user can highlight this object in the 3D view or highlight the objects belong to the same type in the view or all the objects belong to the same family in the view. Since, this object (objects) belongs to an activity in progress. Then, BIM+ retrieves from the tablet PC database its respective progress template steps and displays it on the Revit view, as shown in Figure (6-23).

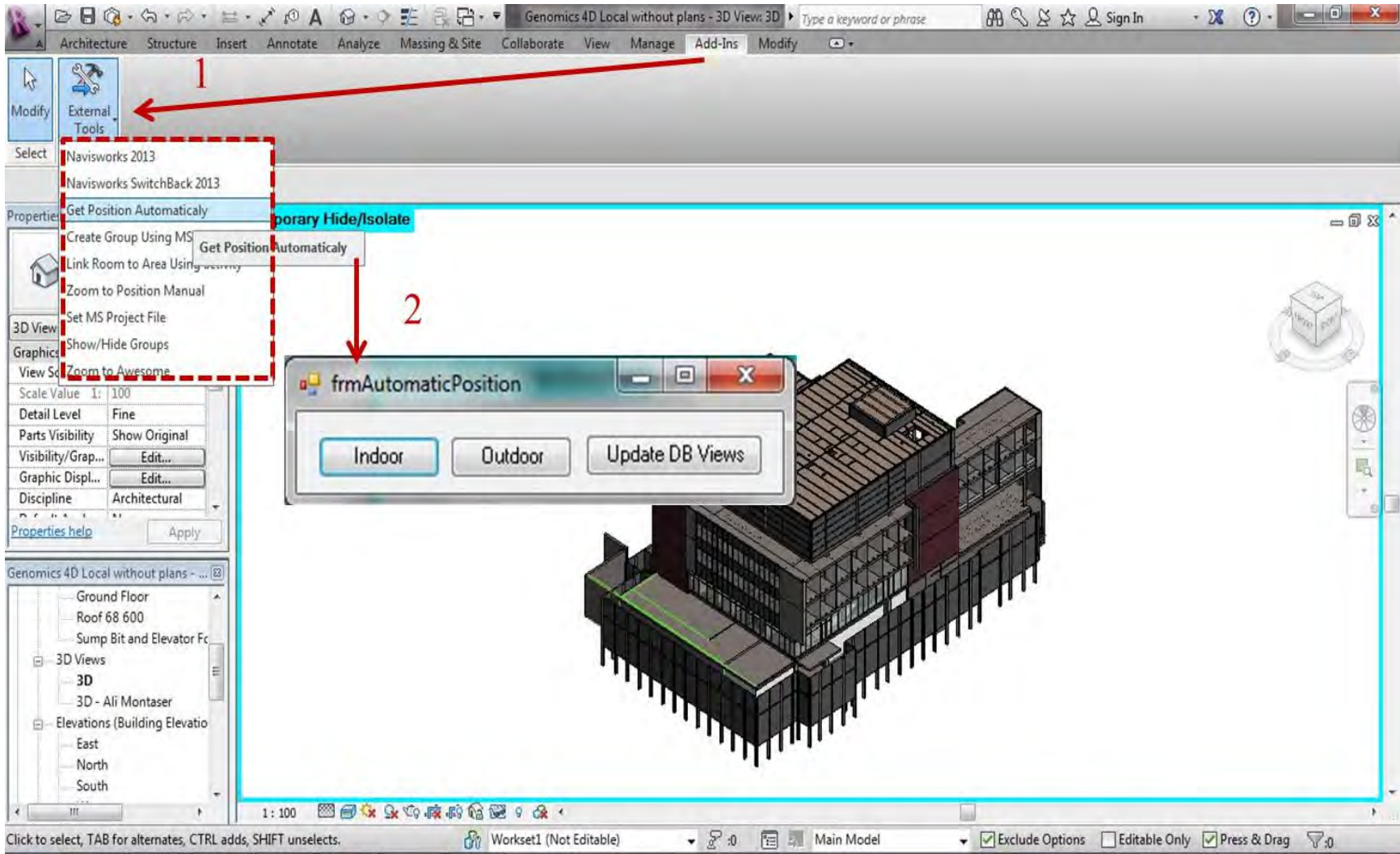


Figure 6-22: Getting user zone automatically options

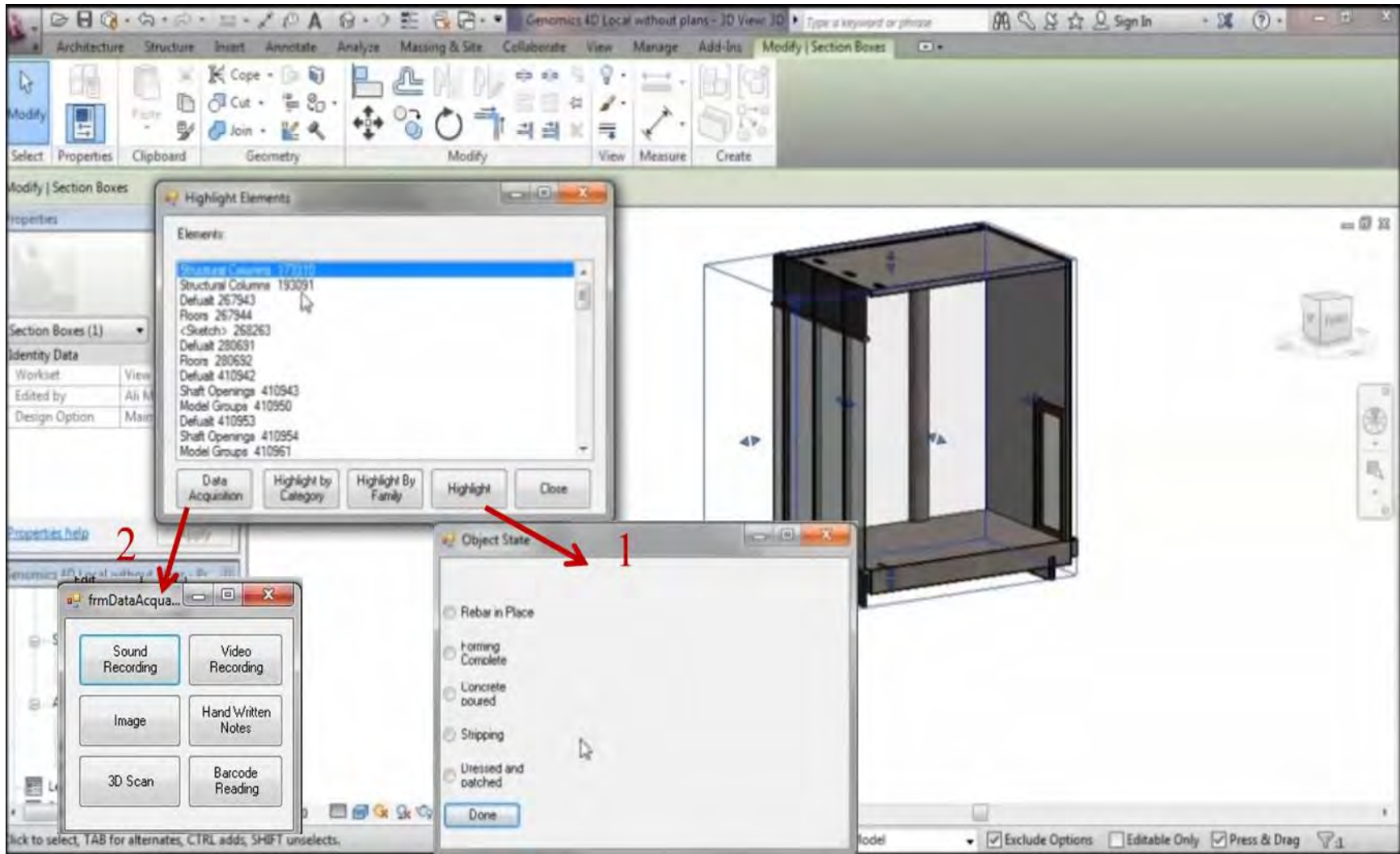


Figure 6-23: User indoor Location visualization and data acquisition

The user interactively utilizes the developed progress templates to capture the work performed at the object level. The user also continues with the automated data acquisition using the technologies embedded in the tablet PC. The system checks first, if there was an object that the user did not specify its status using progress template. If this was the case, the system highlights those objects in the objects list to finish them first. If this was not the case, the system generates the data acquisition form. The data acquisition form has six buttons that are sound recording, video recording, image, hand written notes, 3D scan and barcode reading. All of them, except the 3D scan button, once the user pushed its button its respective technology works and starts capturing data. When the user pushes the 3D scan button the 3D scanner software starts working.

Similar procedure is followed if the user is in outdoor zone and selects the outdoor option to extract the user coordinates from the mobile GPS. However, if the user selects this option for the first time then some configuration needs to be done, as shown in Figure (6-24). A pop up window appears requesting the user to enter the coordinates of the building benchmarks in global coordinates (i.e. Latitude and Longitude) and the equivalent in local coordinates (i.e. building local coordinates system x, y). This input provides BIM+ with the transformation parameters required to convert the GPS data from global coordinate system to the building local coordinate system. Figure (6-25) depicts the user location in outdoor zone. To add more practicality to BIM+, the user also can select the current zone manually, as shown in Figure (6-26) and (6-27).

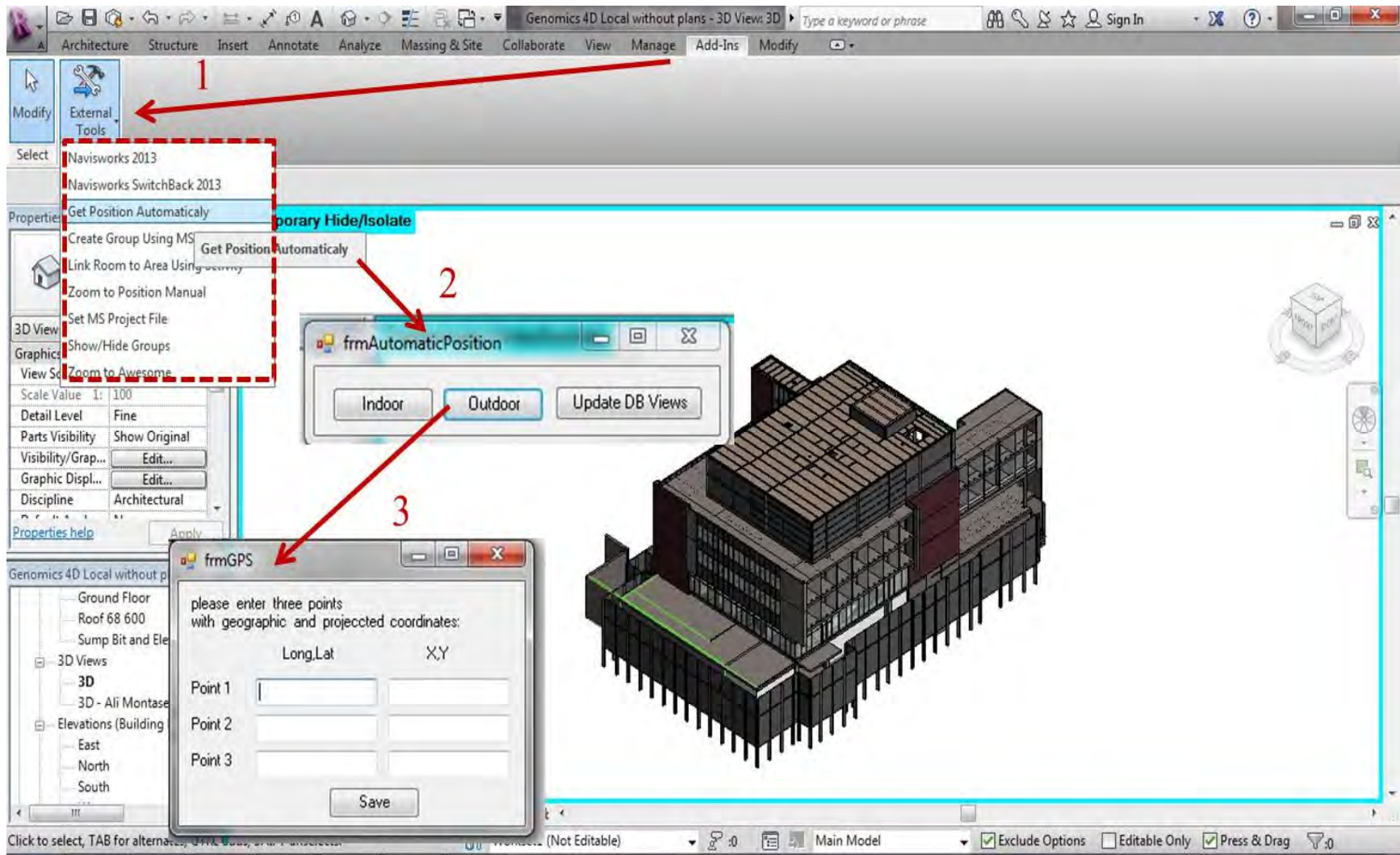


Figure 6-24: User outdoor location

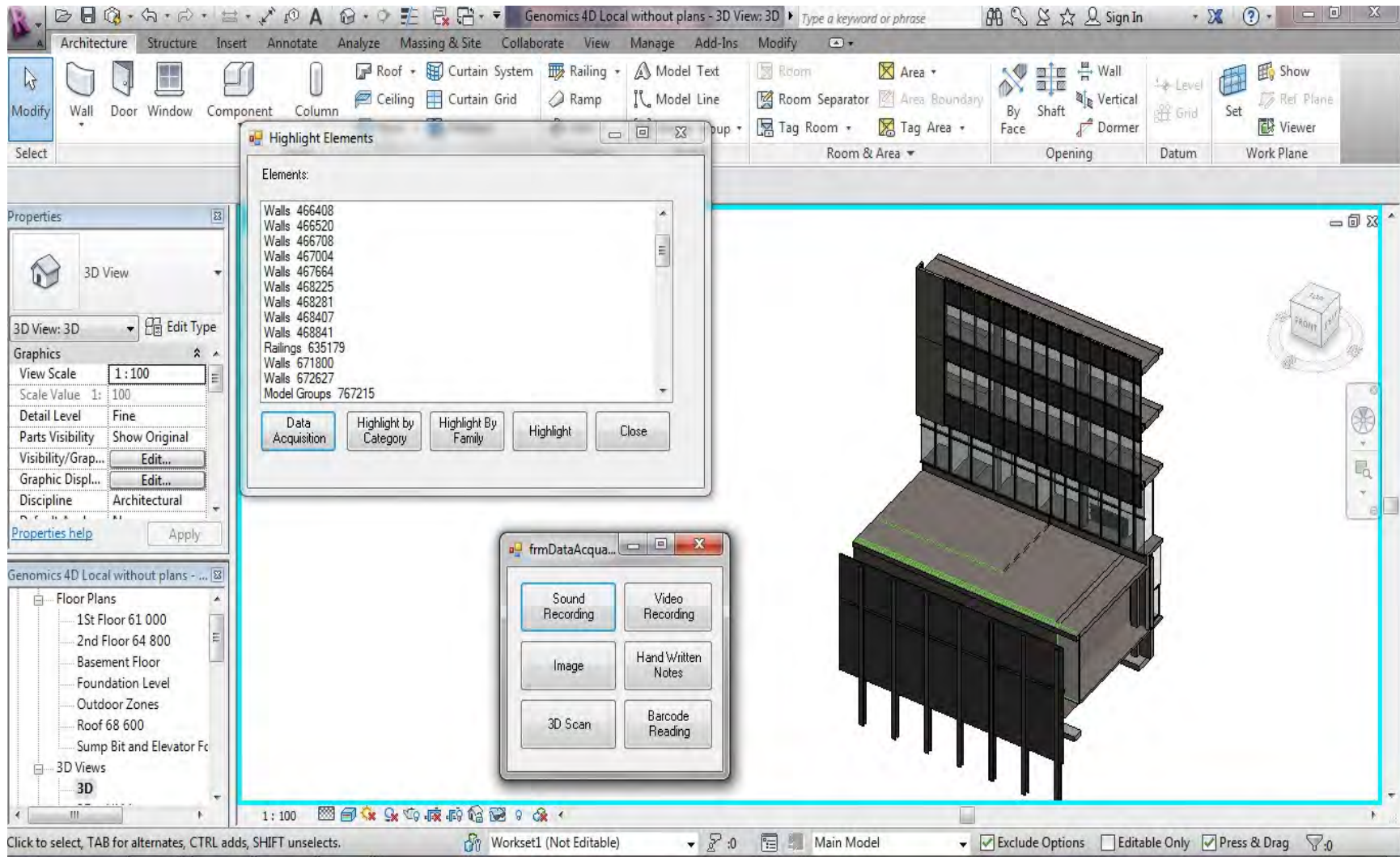


Figure 6-25: User outdoor Location visualization and data acquisition

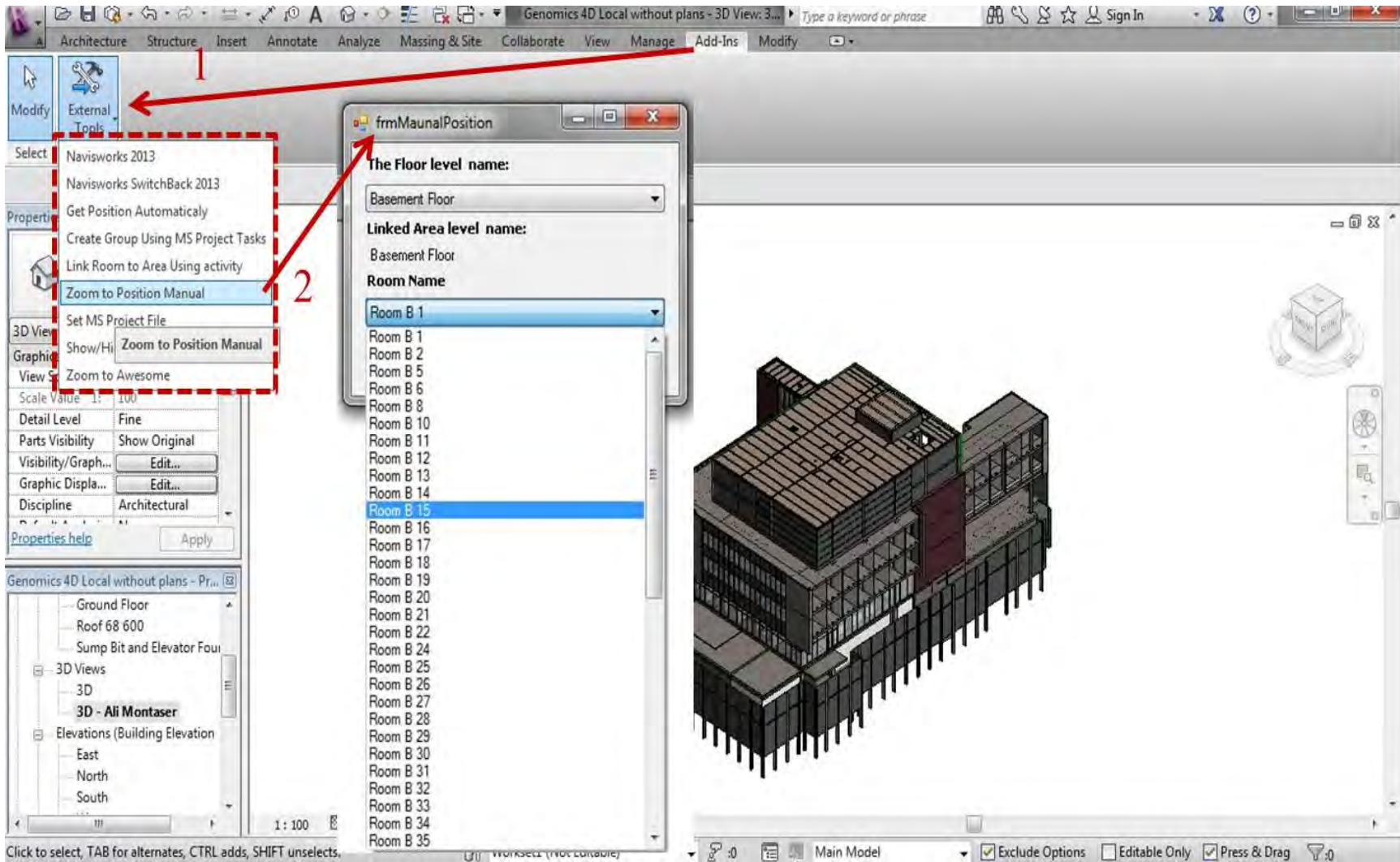


Figure 6-26: Selecting user location manually (Part 1)

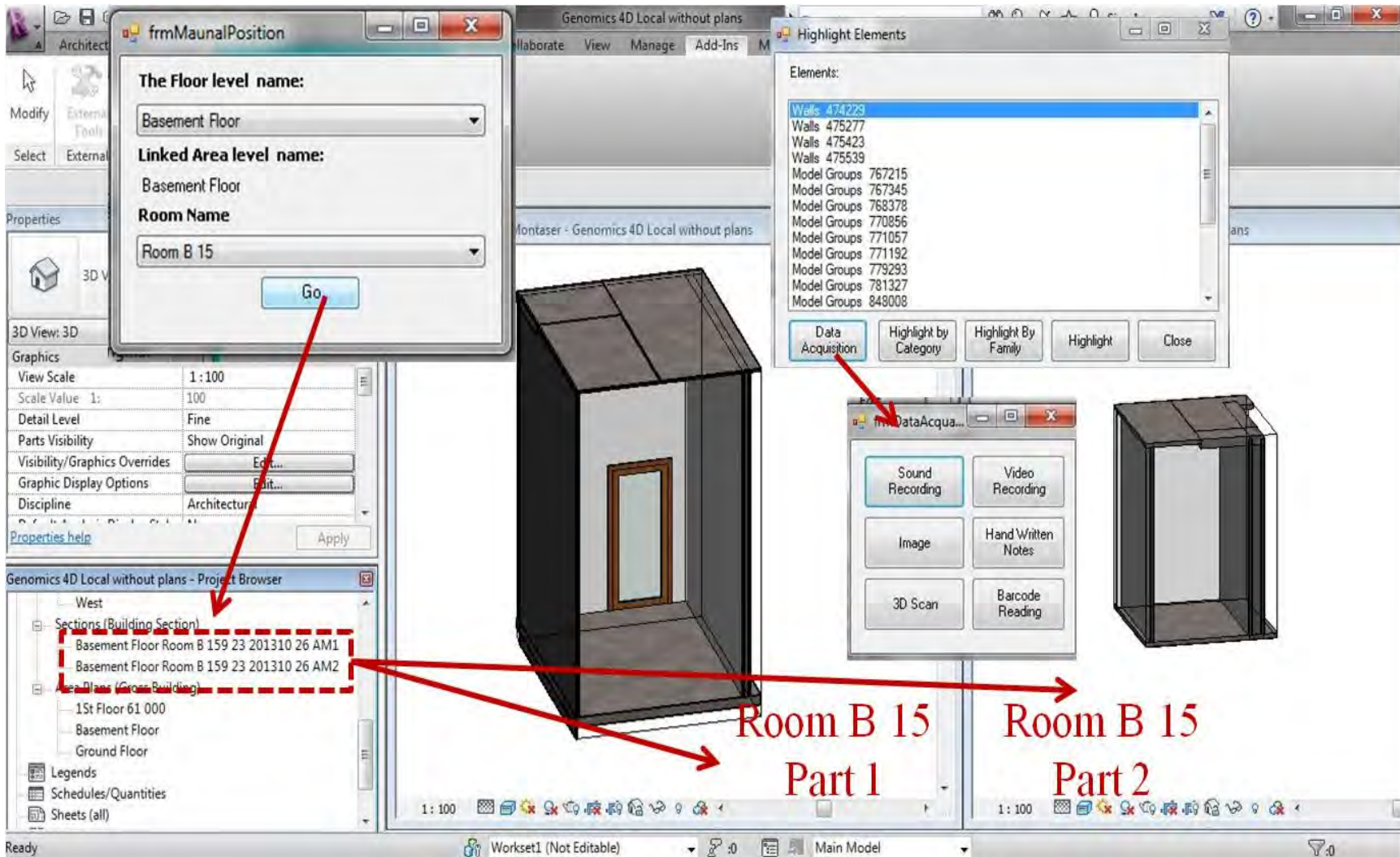


Figure 6-27: Selecting user location manually (Part 2)

6.2.3 Control+

Control+ is the part of the system that is responsible for data processing and analysis. It utilizes three-tier architecture. Tier one is the presentation tier, where the user interacts with web-based graphical interface. Tier two, the application logic, consists of different integrated modules. Tier two embraces modularity in design, which enhances the system capabilities and data reuse. Tier three represents the central database of the system. Control+ utilizes Service Oriented Architecture (SOA) as its software design methodology. It is a design pattern based on structured collections of discrete software modules, known as services, which collectively provide the complete functionality of a large software application (Velte et. al., 2009). SOA allows simultaneous use and easy mutual data exchange between the three tiers and third party software such as Revit and Microsoft project.

This web-based service is accessible over standard Internet protocols, independent of platforms and programming languages, and has two main roles. The first is the service provider, which is the web server. The web server creates a web service and publishes its interface and access information over the World Wide Web. The web service in that case is tier one of the system. The second role is the service consumer, which is the software user. The user accesses the software via internet using desktop computer or mobile device such as Smartphone, tablet PC or Personal Digital Assistance (PDA). Windows Communication Foundation (WCF) technology is deployed to implement the SOA web-based software. WCF is a runtime and a set of APIs in Microsoft .NET framework. WCF is a tool used as intermediate level between the web application and the web server. It also processes the main functionality of system.

Figure (6-28) shows the login page for Control+ web page. The user should enter the user name, password and project number. Based on those entries, the authentication level for the user is decided (i.e. what reports are available and what are not available). The web page heading consists of five main menus that are Project, Resource, BIM/Walkthrough, CCTV/Time-Lapse and Central DB. Under the Project menu five items, which are General Information, Project Status, Weather Conditions, Updated Schedule and Activity Status. If the user selects the “Weather Conditions” then the user has to select the date. The system retrieves the project location from the central database and access online weather database to retrieve the weather data, as depicted in Figure (6-29). Control+ generates web-based reports for user preview based on the data processed and retrieved from the central database and data entered by the user such as selecting date or specifying certain activity. However, Project menu is part of this research future work.

Figure (6-30) shows the Resource menu that consists of Material, Equipment and Labor items. Material item consists of two main reports that are retrieved from the central database and user date selection. Material Delivery report is generated from the RFID gate data acquisition system. While Material Location report is generated from RFID and GPS for outdoor zones and from RFID for indoor zones. Labor item generates labor time through the data captured from RFID gate data. Similarly, the equipment in site report is generated under the Equipment item. Resource menu is part of this research future work. However, Truck+ module under Equipment item is fully functioning as will be described below.

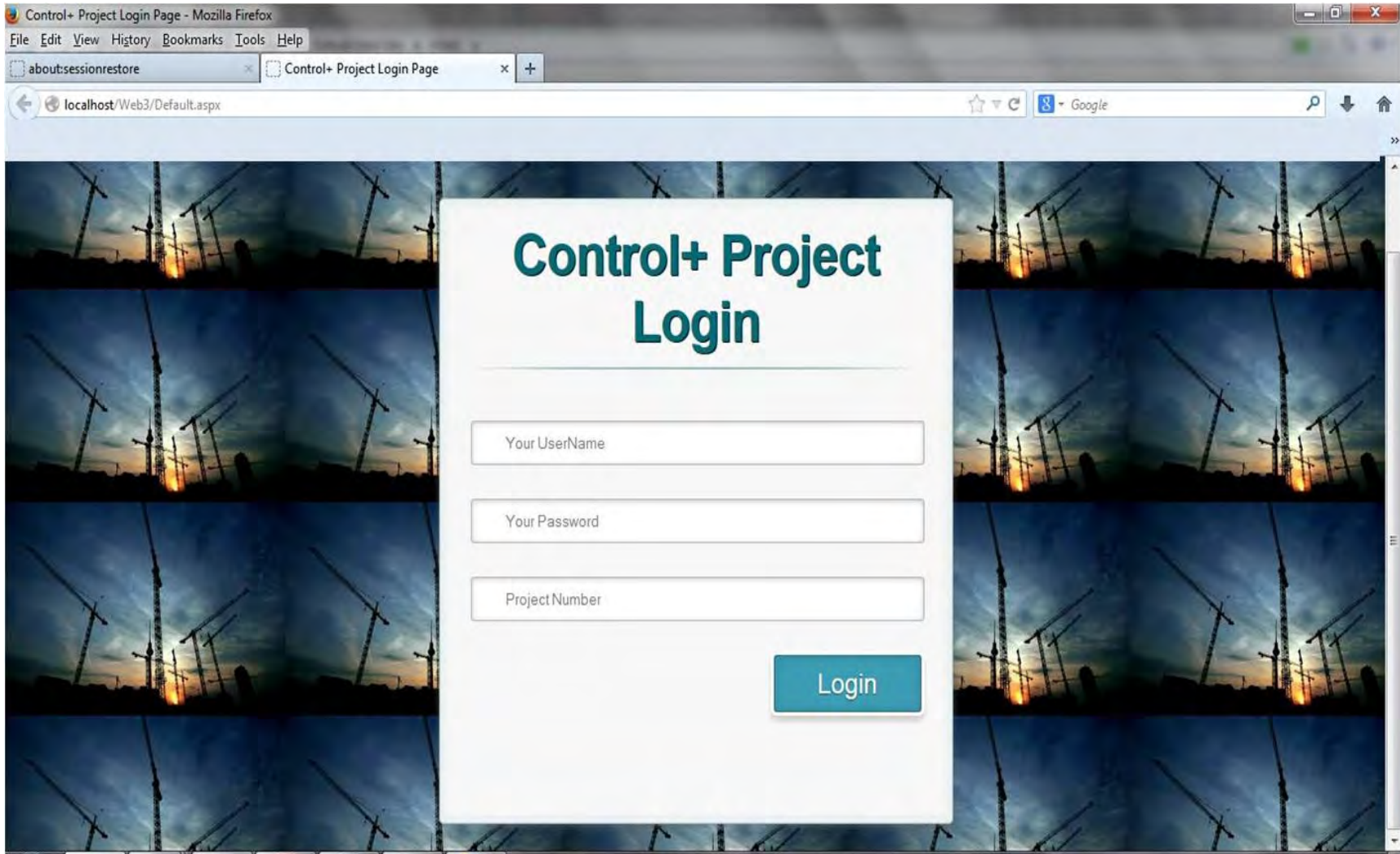


Figure 6-28: Control+ login page

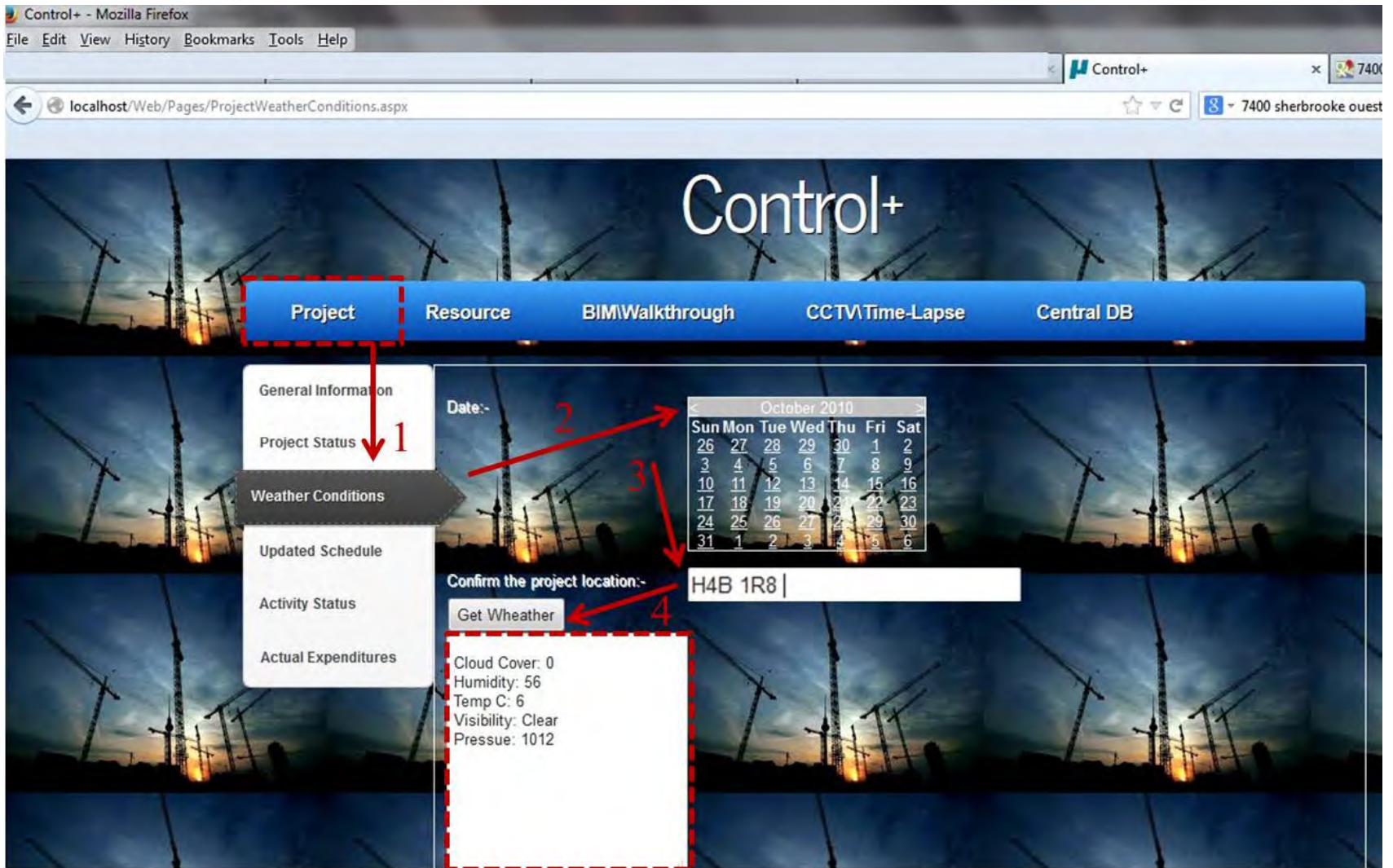


Figure 6-29: Control+ project menu – Weather Conditions

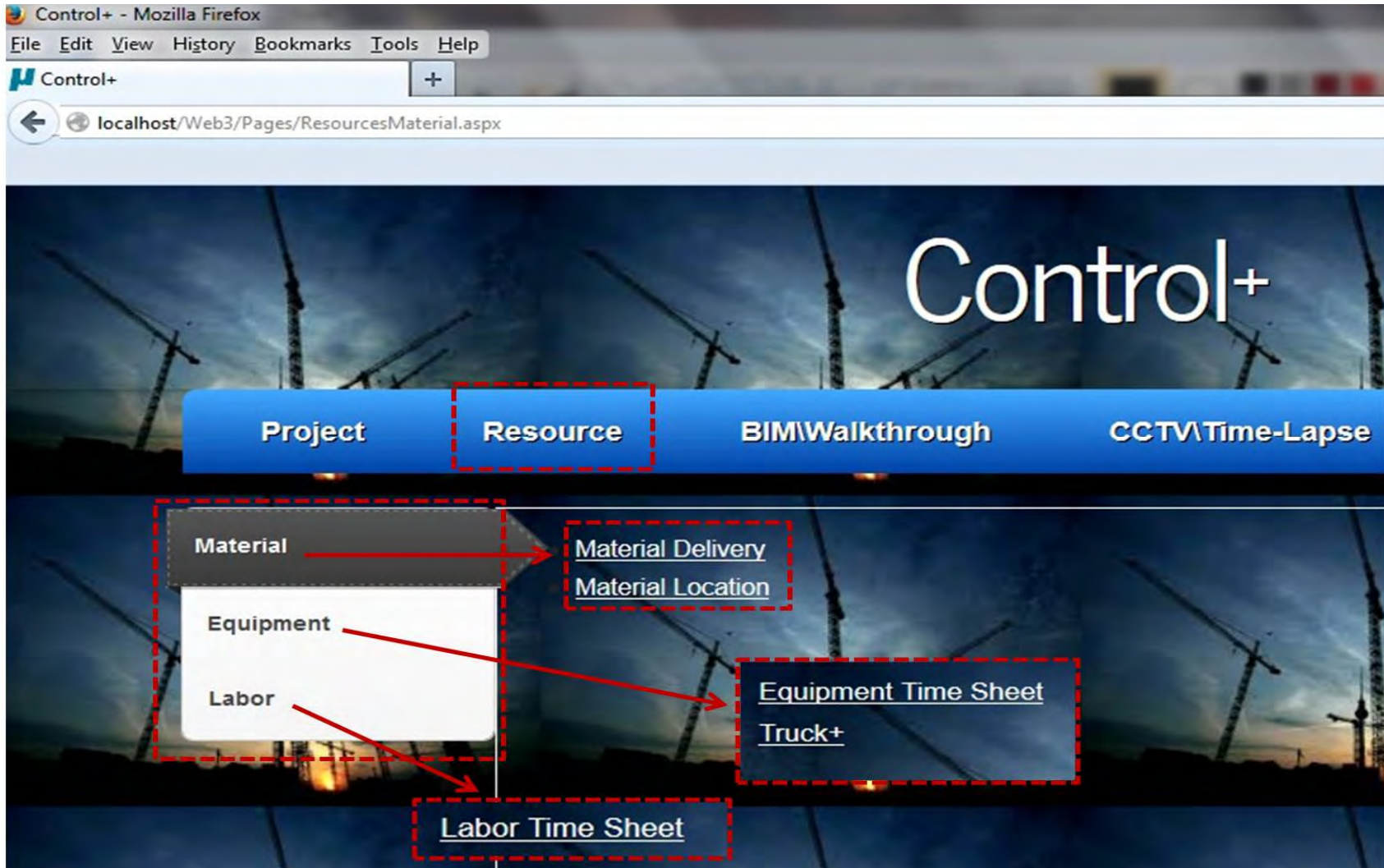


Figure 6-30: Control+ resource menu

Truck+ module has been developed to automate the process of estimating, monitoring and forecasting productivity of hauling trucks. This prototype is based on algorithms of the GPS/GIS based tracking method and stochastically forecasting performance explained earlier in Chapter 3. The utilization of SOA design method allows Truck+ to simultaneously use and easy mutual data exchange between the system modules, central database and other third party software such as Stroboscope DES engine. The user launch Control+ web-based interface first. Then, it redirects the user to Truck+ GIS user interface. The GIS web-based user interface is within the presentation tier, which handles the system communication with the user. Truck+ system architecture is shown in Figure (6-31).

The GIS component of the software consists of ArcGIS bas map, ArcGIS template for Silverlight and ArcGIS APIs for Silverlight. ArcGIS Base Map is free map service provided by ESRI (Economic and Social Research Institute) containing the street and satellite layers. ArcGIS Template for Silverlight is a free template created using Silverlight technology and contains all basic functionality for any map viewer system such as map panning, zooming and navigation at any part of the selected GIS map. ArcGIS APIs for Silverlight are many DLLs (Dynamic-link library), which add many controls that doesn't exists in the default web browser such as map controls that contain the base map (street and satellite map) and scale bar. It utilizes the powerful mapping, geocoding, and geoprocessing capabilities provided by ArcGIS server (ArcGIS, 2013). It is also used to facilitate communication with GPS spatial data and graphically representing them in the GIS map.

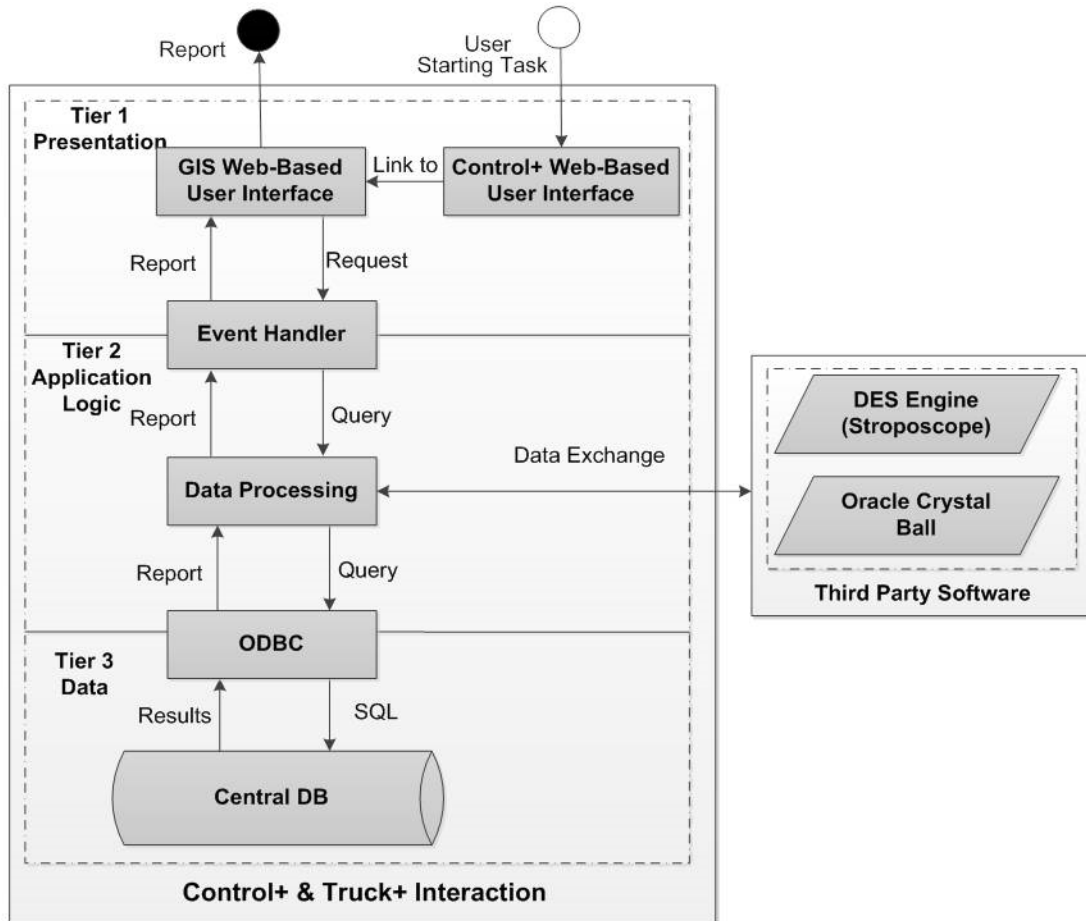


Figure 6-31: Truck+ system architecture

In addition, Microsoft Silverlight is used as a web plug-in to give the web browser more functionality. This tool is implemented to enable ArcGIS APIs from providing the mapping functionality of GPS points. Finally, Crystal Reports technology is used to develop and generate custom reports layout. It facilitates graphically design data extraction from different data sources such as MS Access central database, ArcGIS base map and user inputs. Figure (6-32) shows Truck+ sample of class diagram.

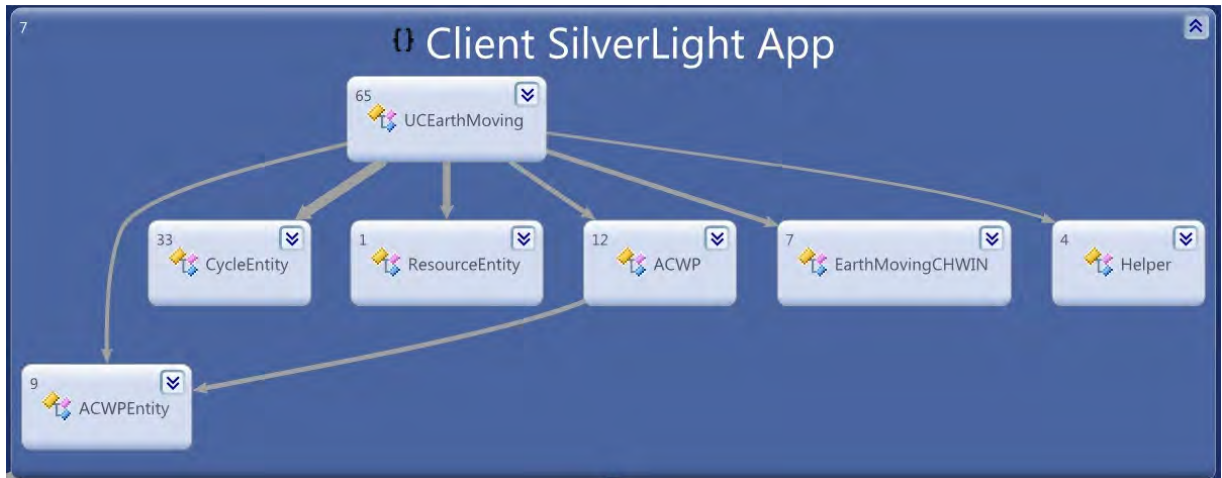


Figure 6-32: Truck+ sample of class diagram

For validating Truck+ system and demonstrating the use of its components, case study was conducted to make use of the construction of Genomics building at Concordia University that was described earlier in chapter 4. Truck+ Graphical User Interface (GUI) is designed to be user friendly, straightforward data entry and eliminate redundancy of data. GUI accepts both graphic and non-graphic data entry. The graphic data entry is done through the GIS provided drawing tools. The non-graphic data entry is through a set of buttons, dialog windows and radio buttons. The main screen of Truck+ web page layout consists of one main view in the center displaying the world map, as depicted in Figure (6-35). The top right corner of the screen displays magnifying glasses button, overview map button, map legend button and hide/display map visualization options button. In left side of those four buttons, there are three radio buttons for map visualizations options, which are street view, topographic view and imagery view. The lower right corner of the screens shows the scale bar and display-navigation controls. The upper left corner has two buttons the open project button and the help button.

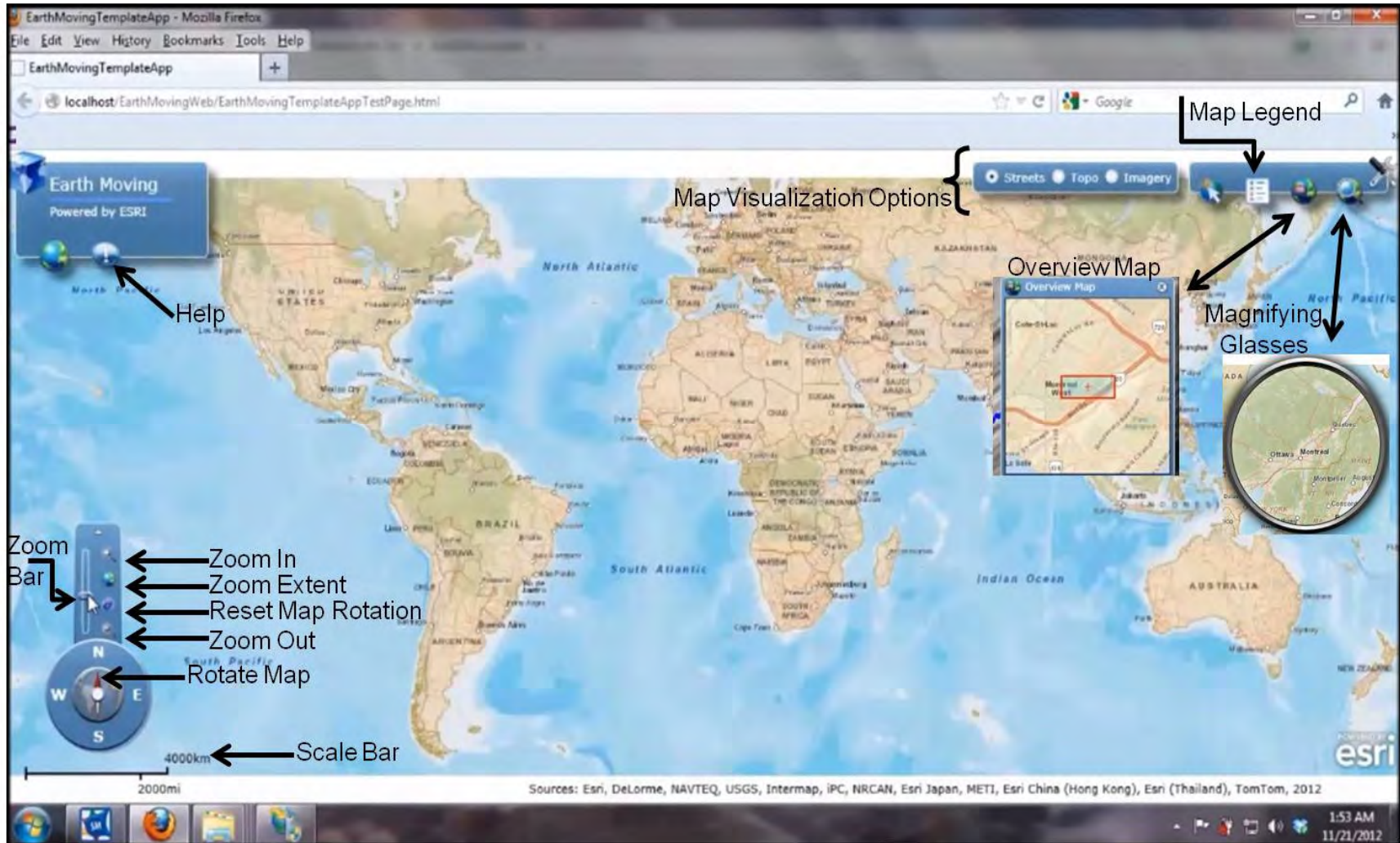


Figure 6-33: Truck+ web page layout

Figure (6-34) depicts the use-case diagram for Truck+. It shows system boundary, functionality and actors. There are four actors in Truck+, two of them are users and the other two are external software. The first actor is the experienced user, whom is familiar with the project such as project manager or the person planned the earthmoving operation. The experienced user authentication reveals Truck+ full functions. This user is able of drawing the spatial boundaries of the earthmoving operation (i.e. loading, travel, dumping and return). This user draws the boundaries one time and it is saved later in the central database. The second actor is the regular user, which could be any stakeholder with interest in the earthmoving operation.

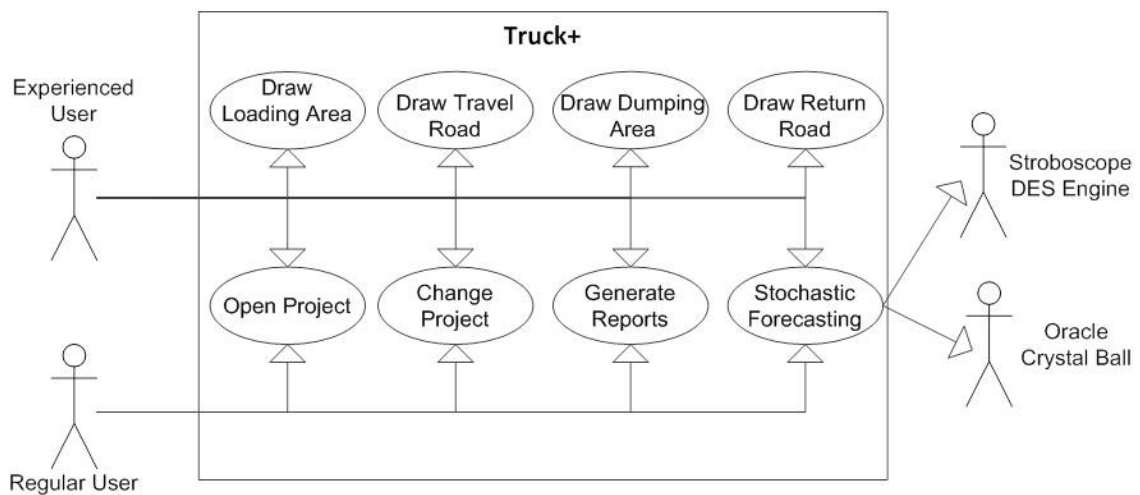


Figure 6-34: Truck+ use-case diagram

This user shares Truck+ other functionalities with the experienced user, which are open project, change project, generate reports and stochastic forecasting use-cases. The other two actors are external to Truck+ system boundaries, which are external software (i.e. Stroboscope DES engine and Oracle Crystal Ball software). Both software are used when the user trigger the stochastic forecasting function in Truck+. When the user press open project button, a dialog box appears. It requests the user to enter the project number, as shown in Figure (6-35).

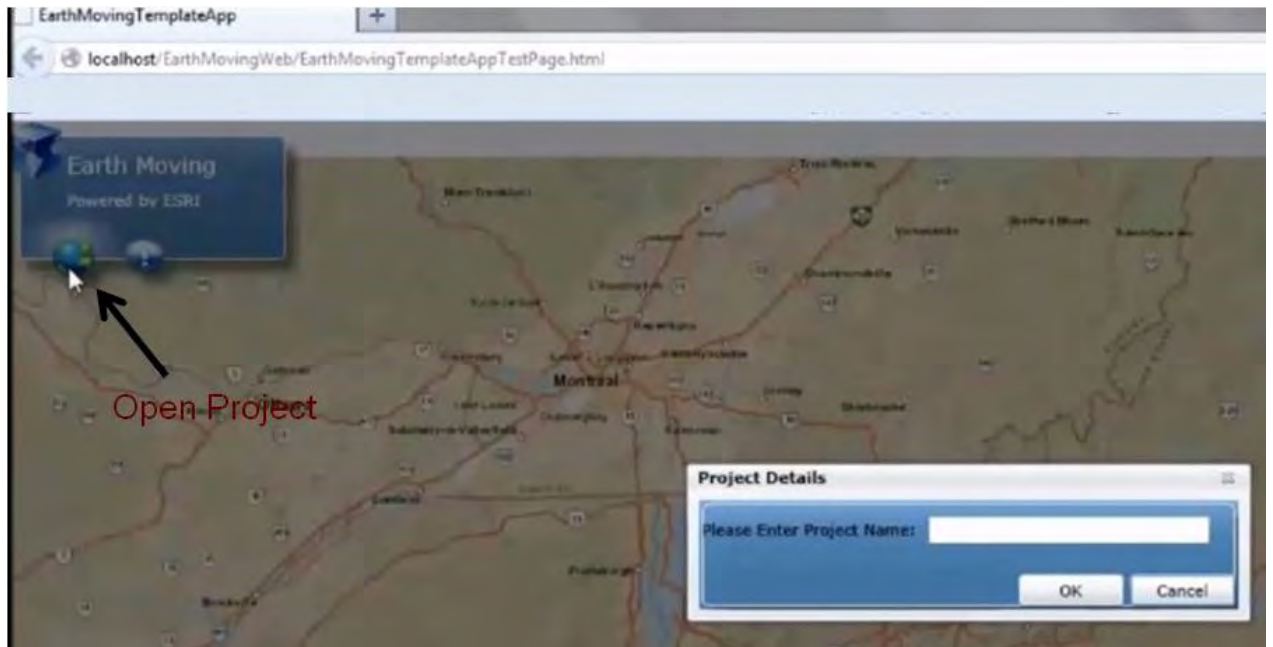


Figure 6-35: User enters project number

Upon entering the project number, the GIS interface (Tier1) automatically requests from the system logic (Tier 2) connection to the central database (Tier 3) for loading the project respective data. The system searches in the central database for the project number in the projects entity. If the system found an exact match, then it starts searching for the GPS points in the truck GPS file entity. In parallel, the system searches also if there are sketch drawn previously for the spatial boundaries. Then, the system extracts the GPS data and displays it in the GIS map as a separate layer (blue points) for graphical representation. If the spatial boundaries were found the system displays it also on separate layers. Truck+ zooms automatically to the extents of the GPS points, as shown in Figure (6-36). In the middle of the left side, a form appears to facilitate user interaction for data entry. The user can change the project by pressing on the change project button. Then, a similar procedure to open project is followed.

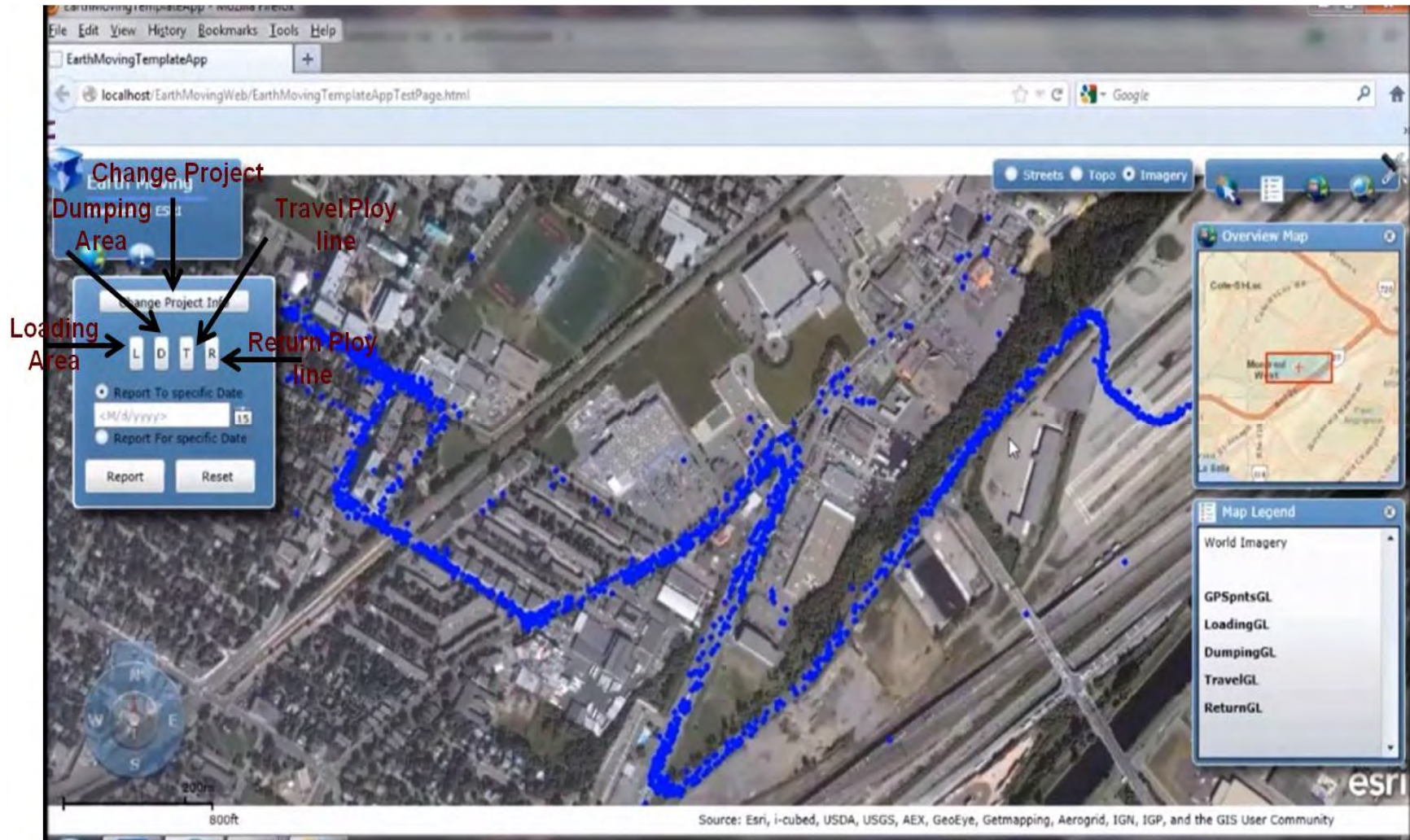


Figure 6-36: GPS points layer

Under the change project button, there are four buttons (L, D, T and R), which are the drawing tools for drawing loading polygon, dumping polygon, travel poly line and return poly line respectively. Those four buttons are only active for the experienced user and not active for the regular user. Therefore, the experienced user pushes the (L) button and starts drawing loading area on its respective layer. The interface enables the user to draw polygon sketch on the map and waits till the user finishes the polygon. The user can zoom and pan the map during this process. Afterwards, the interface disables this button and sends the coordinates of the loading polygon sketch to the central database to be saved, as shown in Figure (6-37). To change the loading polygon sketch, the user has to select the polygon and then press the reset button to redraw it. A similar procedure is followed during sketching the dumping area polygon.

For sketching the travel road, the user presses the (T) button and instead of drawing polygon, the user drawing dashed poly line. This line is transformed into polygon according to the road that it was drawn on. If it was street road then the centerline and width is extracted from the GIS map. However, if it was not on street then a message box appears for the user to enter the poly line offset from both sides. Then, the created polygon is saved in the central database. In the same way, the return road poly line is drawn. Each sketched polygon or poly line layer is added to map legend in lower right corner, as presented in Figure (6-37). These layers are utilized to classify each GPS point according to the algorithms mentioned in Chapter 3. At this stage, the user should select one of the radio buttons, which to choose whether reporting for specific data or reporting from project start to specific data. The project start data is extracted from the central database.

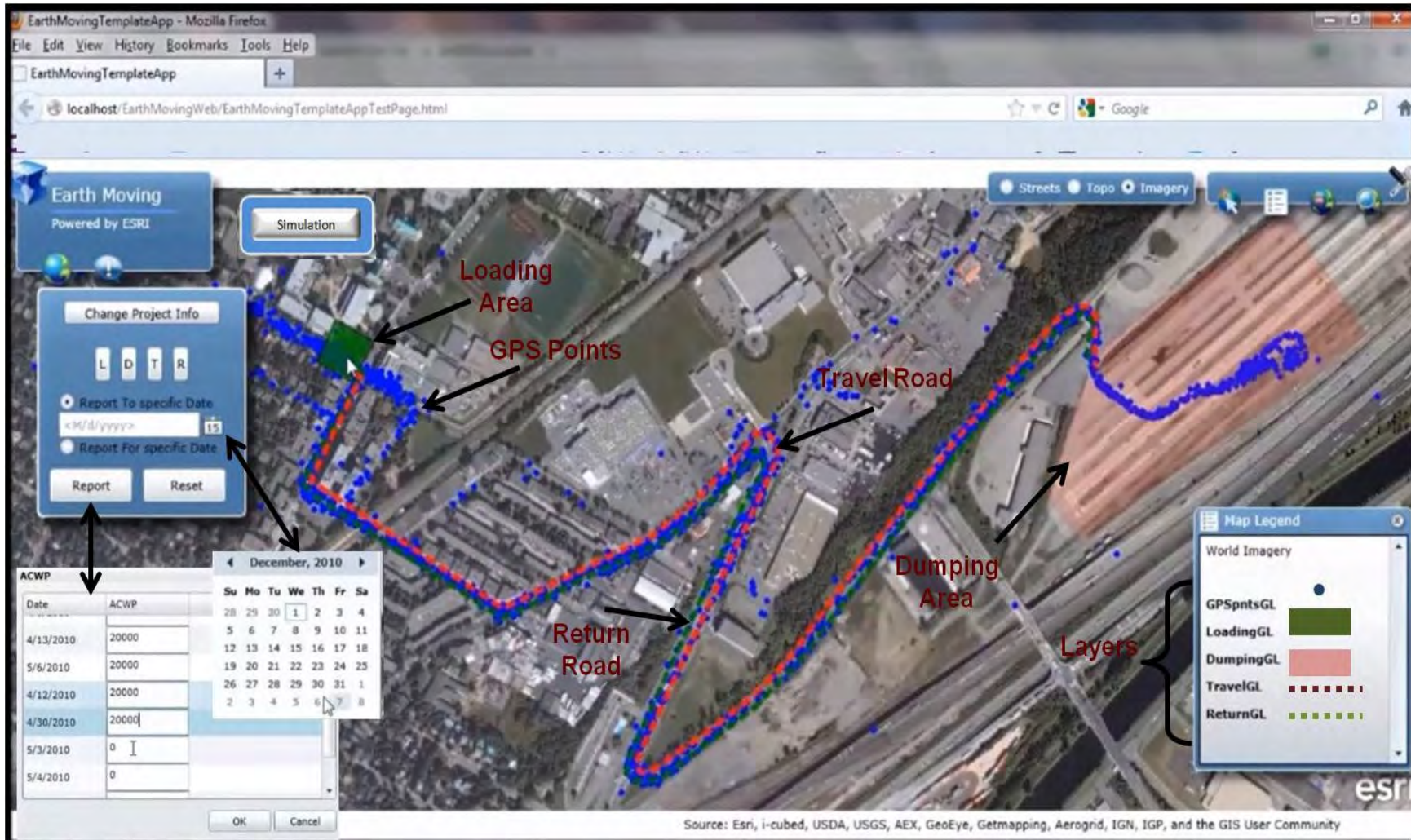


Figure 6-37: Earthmoving operation spatial boundaries sketches

According to the user selection, a calendar appears to select dates. Then the user is required to enter the ACWP for each day, which represents the actual expenditure for earthmoving operation to perform earned value analysis, as shown in Figure (6-37). The system checks if the user finished drawing loading, dumping, travel and return sketches. Then, the system filters the GPS points that belongs to date that the user selected. If the user selected “Report To specific Date” then system gets all GPS points from project start date to the desired date. If the user selected “Report for specific Date” then the system gets all GPS points for the desired date only. The system generates the report for each hauling truck and determines the cycle’s times and its respective components.

Tabular format reports have been used to present each truck cycle time and it respective components, as shown in Figure (6-38). Figure (6-39) depicts the number of cycles each truck did in front of each date, which is utilized in conjunction with the truck capacity to calculate the excavated material percentage complete. Then, earned value analysis is conducted to determine the operation performance indices, variances from planned and different deterministic forecasts scenarios for the operation as shown in Figure (6-40). Graphical format reports are developed to display information at varying degree of detail such as CPI per day, as shown in Figure (6-41).

Report Number of Pages

Project Name: 930 From 4/8/2010 To 12/30/2010 Reporting Period

Resource Name: 230

Cycle#	Loading			Travel			Dumping			Return			Cycle Duration
	From	To	Duration	From	To	Duration	From	To	Duration	From	To	Duration	
1	4/9/2010 8:41 AM	4/9/2010 9:00 AM	00:00:00	4/9/2010 9:00 AM	4/9/2010 9:14 AM	00:14:00	4/9/2010 9:55 AM	4/9/2010 10:54 AM	00:59:00	4/9/2010 8:40 AM	4/9/2010 9:06 AM	00:10:00	00:36:00
2	4/9/2010 10:08 AM	4/9/2010 10:09 AM	00:00:00	4/7/2010 2:57 PM	4/9/2010 10:18 AM	1:19:20:54	4/7/2010 3:07 PM	4/8/2010 10:21 AM	1:19:13:54	4/7/2010 2:59 PM	4/8/2010 10:19 AM	1:19:19:54	5:09:54:42

Resource Name: 233 Hauling Truck ID

Cycle#	Loading			Travel			Dumping			Return			Cycle Duration
	From	To	Duration	From	To	Duration	From	To	Duration	From	To	Duration	
45	4/13/2010 3:20 PM	4/13/2010 3:24 PM	00:03:45	4/13/2010 3:25 PM	4/13/2010 3:47 PM	00:22:30	4/13/2010 3:35 PM	4/13/2010 3:38 PM	00:03:00	4/13/2010 3:25 PM	4/13/2010 3:47 PM	00:22:30	00:51:45
46	4/13/2010 3:49 PM	4/13/2010 3:53 PM	00:04:30	4/13/2010 3:54 PM	4/13/2010 4:20 PM	00:26:15	4/13/2010 4:05 PM	4/13/2010 4:10 PM	00:04:30	4/13/2010 3:54 PM	4/13/2010 4:18 PM	00:24:00	00:59:15

Figure 6-38: Generated cycle times and its respective components

Date	230	231	232	233	234	235
4/12/2012	11	10	11	11	11	11
5/12/2012	13	13	13	13	13	13
6/12/2012	10	10	9	10	10	10
7/12/2012	2	2	2	2	2	2
10/12/2012	10	9	9	10	10	10
11/12/2012	10	10	10	10	10	10
12/12/2012	2	2	2	2	2	2
13/12/2012	1	1	0	0	0	0
14/12/2012	5	5	5	5	5	5
17/12/2012	9	9	9	9	9	9
18/12/2012	16	15	15	15	15	15
19/12/2012	12	12	12	12	12	12
Total # of Cycles	101.00	98.00	97.00	99.00	99.00	99.00

Figure 6-39: Generated tabular report for hauling trucks cycles

Activity Status:

Date	BCWS	BCWP	ACWP	CV	SV	CPI	SPI	EAC1	EAC2	TodayQuantity	QuantityToDate
10/12/2012	150000	162300	147277	15022	12300	1.102	1.082	160136	161447	204	22610
PercentageComplete		ForecastedEF			TimeStatus			BudgetStatus			
85%		05/02/2013			Ahead of Schedule			Under Budget			

Figure 6-40: Generated tabular report for earned value performance indices

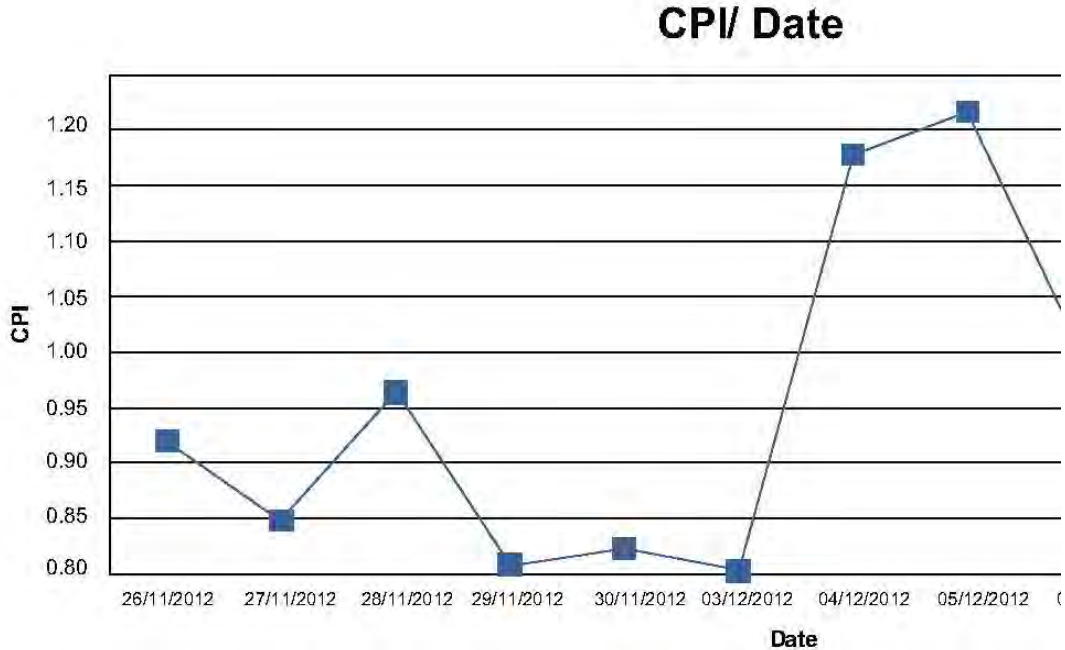


Figure 6-41: Generated graphical report for Cost Performance Index (CPI) on daily basis

To stochastically forecast performance for cyclic repetitive operations, Stroboscope DES engine was used. However, DES requires Probability Density Function (PDF) for each operation. So, Oracle Crystal Ball was utilized to generate best fit PDF of the cyclic operations. Therefore, Truck+ was integrated with Stroboscope and Oracle Crystal Ball to stochastically forecast progress of earthmoving operations. In addition, this integration was used also to experiment the different fleet configuration impact on productivity, time and cost of the operation. Since, Stroboscope DES engine and Oracle Crystal Ball are external software utilized by the system. Then, it should be installed on the user computer. All runtime in this case is done on the user computer not the web server. Also, a typical Stroboscope earthmoving

DES model is created to simulate the process. This model is saved in a predefined path on the user computer too. However, the user can change the model location and browse for the new location.

The variables in the DES model are the number of hauling trucks, truck capacity, number of loaders, the quantity of remaining excavation, truck cost per hour and the loader cost per hour. The system retrieves all this data from the central database. To generate PDF for each cycle time component, the user specifies the data range (i.e. start date and finish date). Then, the system extracts the cycle time components from the central database and filters it to the specified data range. In addition, there is an option to exclude dates from this data range. This enables removing specific time periods during which exceptional conditions are known to have prevailed and are not likely to be repeated. Oracle Crystal Ball is utilized afterwards to generate best fit PDF for each cycle time component based on the captured data specified date range.

When the user presses simulation reporting, the results is send to an excel file on the user computer desktop. The results are the operation forecasted loader utilization, truck utilization, production rate, time, total cost and the unit cost of excavated material. Since, the forecasting process was done stochastically through PDFs. Then, the results is not crisp values, it is in the form of average, standard deviation, maximum and minimum values, as shown in Figure (6-42). In case, the user wants to experiment with the different fleet configuration but with the same PDFs. Then the user could enter the minimum and maximum number of trucks and loaders in the form. Similarly, the same procedure is followed but with different scenarios, as shown in Figure (6-43).

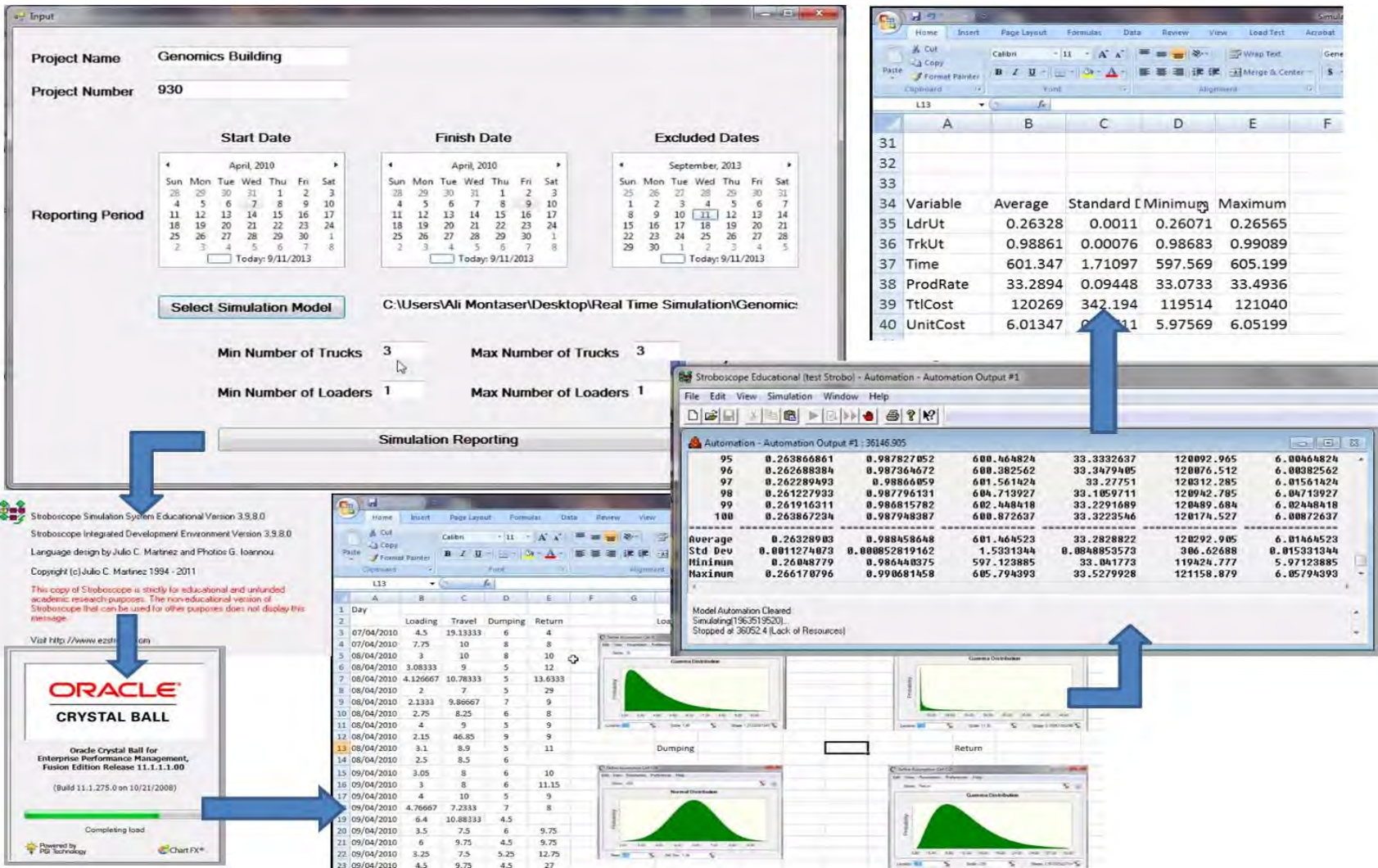


Figure 6-42: Stochastic forecasting overview

Input

Project Name: Genomics Building
 Project Number: 930

Start Date: April, 2010
 Finish Date: April, 2010
 Excluded Dates: September, 2013

Reporting Period: Today: 9/11/2013

Select Simulation Model: C:\Users\Ali Montaser\Desktop\Real Time Simulation\Genomic

Min Number of Trucks: 3 Max Number of Trucks: 10
 Min Number of Loaders: 1 Max Number of Loaders: 1

Simulation Reporting

Stroboscope Education Toboj - Automation - Automation Output #7

Automation - Automation Output #7 : 0

4	0.263361051	0.989856338	602.657997	33.2204803	120531.599	6.02657997
5	0.262871352	0.988337954	604.357546	33.1216939	120871.509	6.04357546
6	0.263553459	0.988403019	602.94173	33.2041238	120508.346	6.0294173
7	0.263841081	0.989457152	598.559248	33.4489385	119711.85	5.98559248
8	0.263179714	0.989000137	601.658435	33.2665555	12031.687	6.01658435
9	0.267461974	0.989522948	598.355106	33.4572625	119671.021	5.98355106
10	0.261626519	0.988060731	600.237908	33.3497561	120047.582	6.00237908
11	0.262868881	0.988069506	601.72207	33.2653621	120344.414	6.0172207
12	0.264243771	0.98808039	601.9998	33.244823	120099.96	6.019998
13	0.262449431	0.988363391	602.89859	33.2006389	120579.718	6.0289859

Stopped at 36173.9 (Lack of Resources)
 Model Automation Cleared
 Simulating(377722052) |

Execution Time = 10.282 seconds

Model Automation Cleared
 Simulating(1386073001)
 Stopped at 35893.7 (Lack of Resources)

Simulation Scenario - Microsoft Excel

	A	B	C	D	E	F	G	H
43								
44								
45	# of Loaders	# of Trucks	LdrUt	TrkUt	Time	ProdRate	TtlCost	UnitCost
46	1	3	0.26328	0.98861	601.347	33.2894	120269	6.01347
47	1	4	0.2633	0.98846	601.323	33.2907	120265	6.01323
48	1	5	0.26324	0.98844	601.511	33.2807	120302	6.01511
49	1	6	0.26338	0.98847	601.308	33.2921	120262	6.01308
50	1	7	0.26328	0.9885	601.206	33.2971	120241	6.01206
51	1	8	0.26336	0.9886	601.285	33.2924	120257	6.01285
52	1	9	0.26343	0.98842	601.175	33.3	120235	6.01175
53	1	10	0.26324	0.98854	601.548	33.2789	120310	6.01548
54								
55								
56								

Figure 6-43: Simulating different fleet configuration

Afterwards, the user can go back to Control+ to view the other progress reports. Figure (6-52) shows the components of the “BIM/Walkthrough” menu. It gives the user the capability to preview the data captured using BIM+ supported by tablet PC whether from outdoor or indoor zones. “jQuery” technology was integrated with the design of Control+ to preview the captured data. “jQuery” is a multi-browser “JavaScript” library designed to simplify the user preview interaction of HTML (HyperText Markup Language) files. It is free and open source software that allows the creation of powerful dynamic web pages and web applications. jQuery's syntax is designed to make it easier to navigate a document, select elements, create animations and handle events (jQuery, 2013). The user selects first the data type to be previewed, which are image, video, sound or notes. Then, the user selects the date when the data acquisition process happened from an interactive calendar. Figure (6-44) depicts the developed C# .Net source code in BIM/Walkthrough menu.

The user then selects whether the requested data are from indoor or outdoor environment. According to the previously selected date, Control+ provides for the user a list of plans for different floors to choose from. Afterwards in the right section of the web page a preview of area plan or floor plan extracted from Revit software is displayed to the user. The user selects one zone to preview the captured data. In the lower part of the web page, a preview window appears to display the type of data requested. Under that window, there are several navigation controls for the user to utilize. Similarly in the “CCTV/Time-Lapse” menu, the user selects the data type and the date to preview the captured data from the CCTV camera on site, as shown in Figure (6-45).

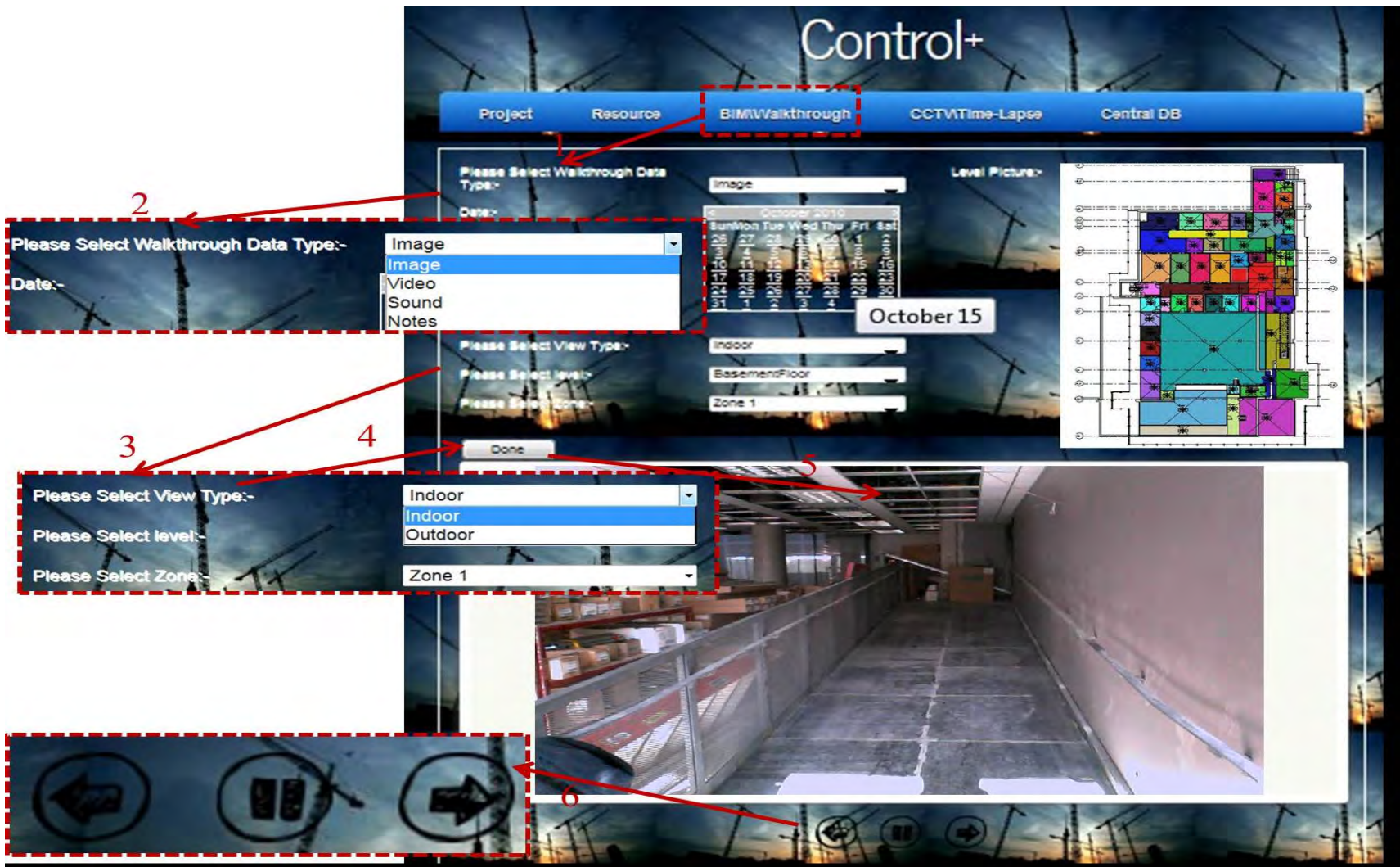


Figure 6-44: Control+ BIM/Walkthrough menu

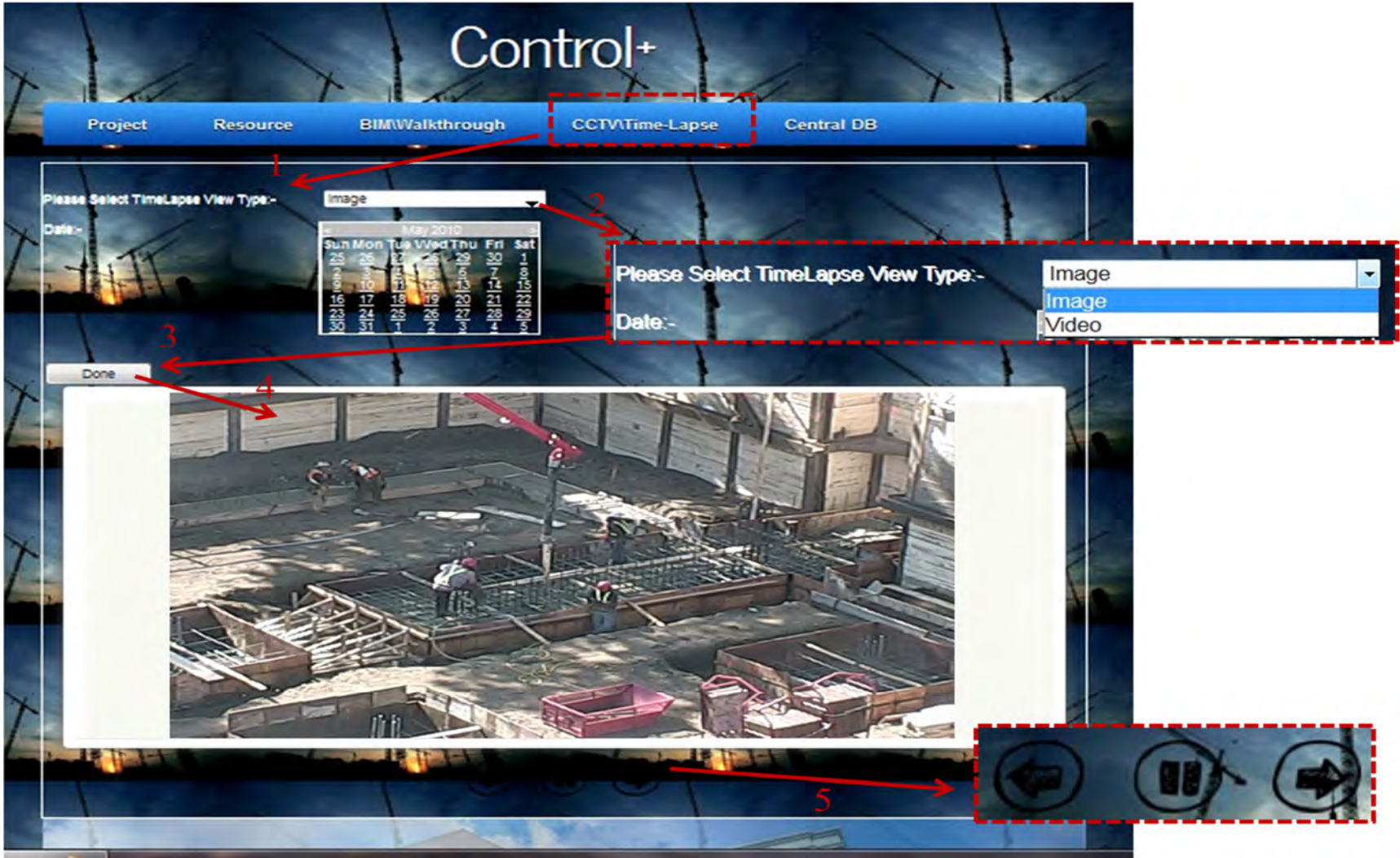


Figure 6-45: Control+ CCTV/Time-Lapse menu

The “Central DB” menu is used to facilitate data entry and editing for the central database. A set of web forms for different tables in the central database have been developed to support the process of populating the databases. These web forms serve as the interface of the designed MS Access central database. According to the user authentication level, this forms provides for the user data inserting, updating, deleting, and viewing capabilities. To input, update, and/or delete data, the users can trigger the “Central DB” menu residing in Control+ presentation tier. Figure (6-46) depicts a sample of web forms for entering the project information and resource information. These web forms are designed to provide simple and user-friendly interfaces. Control+ provides for project team members the capability to preview and query project captured data and progress reports remotely in near real time.

6.3 Summary

This chapter presents the computer implementation of the developed model. It also highlights the developed system’s frameworks, modules, algorithms and the interaction between its components. It covers the designed database, classes, use-cases, sequence diagrams and snapshots from its Graphical User Interface (GUI). It describes the user interface, which is designed to enable the user to collect and store data from construction sites and subsequently query reports. The developed software is coded using “Visual C# .Net” programming language. It consists of two computational frameworks; BIM+ and Control+. BIM+ is Two-Tier software, which utilizes object-oriented BIM model. So, it can be used as an advanced tool for data acquisition through the user’s tablet PC. Control+ is Three-Tier Web-Based software for processing the captured data from the tablet PC and independent automated data acquisition technologies.

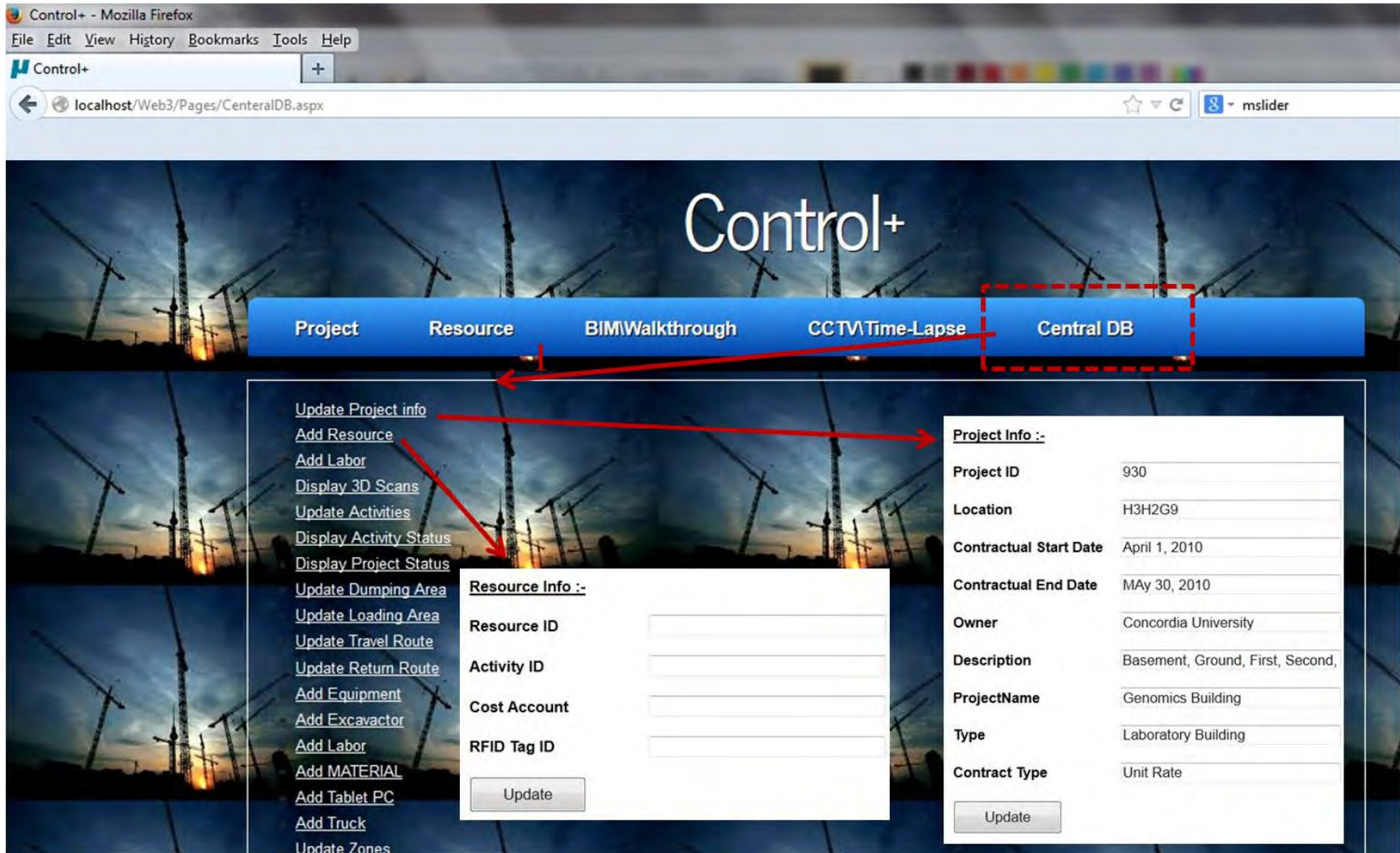


Figure 6-46: Control+ Central database menu

A complete sample (sequence diagrams and source code) of one function in BIM+ is included in Appendix E. This function is a key function in the development of the 4D BIM model, where objects in the 3D BIM model are linked to scheduled activities. Similar work was carried for the rest of the software developed in this chapter.

Chapter 7: CONCLUSIONS AND FUTURE WORK

7.1 Summary and Conclusions

This research presents study, concepts and design of automated model for data acquisition and progress reporting to support time and cost tracking of construction projects. The developed model integrates project visualization-information aspects, automated site data acquisition and earned value analysis. Project visualization-information is achieved by utilization of GIS and 4D BIM that integrates 3D BIM model and project schedule. Automated site data acquisition technologies are clustered into two categories. The first utilizes tablet PC that integrates RFID, barcode, GPS, wireless communication and camera technologies. It also utilizes 4D BIM to provide visualization capabilities to the process of data acquisition. The second category, referred to as “Independent Automated data Acquisition” integrates other technologies beyond those housed in the tablet PC. The latter category consists of equipment mounted GPSs, RFID readers mounted on project gates, 3D scanner and Closed Circuit Television (CCTV). Data is collected on site and stored in a web-server for later processing to generate progress reports. At the core of the developed model lies a data analysis and processing framework that stores, retrieves and processes the captured data to support project tracking and control. The collected data is used to represent the actual progress, which is then compared to the as-planned baseline schedule. Earned Value Analysis (EVA) is then used to measure the project performance.

Field studies were conducted on each technology, which led to identification of limitations associated with each technology. Therefore, the advantage of integrating different technologies and the data fusion for the captured data were explored to estimate the project status for progress reporting purposes. In-depth studies were conducted to determine

deployment protocols of Ultra High Frequency (UHF) passive RFID for indoor localization. Experimental work was conducted on construction jobsite and in a lab environment. K-Nearest Neighbor (K-NN), Trilateration and proximity algorithms were used for location identification. Prototype software was developed, using “Visual C#. Net” programming language, to demonstrate the use of the developed model and validate its methods and algorithms. This model is expected to enable project team members to track cost and time not only at the activity and project levels, but also at the resource and object level in addition to generating progress reports in a timely manner.

7.2 Research Contribution

Figure (7-1) summarizes the research contribution. The contributions of this research are expected to circumvent the limitations associated with the current practice and existing tracking and progress reporting models. Specifically, the research conducted explores and describes the:

1. State of the art review on project control models, automated site data acquisition technologies, indoor localization and visualization-information technologies were carried out.
2. Research vision created to augment the essence and purpose of project control. This vision provided inspiration and guidance in shaping the model developed in this thesis.
3. In-depth experimental work conducted in the lab and field studies performed in search for efficient integration of wide range of technologies in the developed of automated model for construction tracking and progress reporting.
4. Utilization of low-cost passive RFID for indoor localization and material tracking. This exploration constitutes several contributions:

- Developing deployment protocols for user's indoor zone identification (Coarse-grained localization) through K-NN algorithm.
 - Developing two-step algorithm for indoor location identification (Fine-grained localization) through utilizing trilateration or proximity algorithms.
 - Comparing the performance of trilateration and proximity algorithms to identify the most suitable one for the developed model.
 - Developing deployment protocols for indoor location identification through proximity algorithm.
 - An integrated method was developed for tracking material from site arrival till it is in the installation zone. RFID gate is used to report material delivery. RFID and GPS are integrated to track material outdoor, while RFID alone is used to track material indoor.
5. Development of an automated model that seamlessly facilitates the integration of visualization-information technologies, automated site data acquisition technologies and earned value analysis for the purpose of project control and progress reporting. The developed model is capable of generating reports in different granularity (i.e. project level, activity level, object level and resource level).
6. Developments of innovative method and its related algorithms to benefit from BIM in progress reporting. This method constitutes several contributions:
- Developing algorithm for integrating 3D BIM model with project schedule to generate the 4D BIM.
 - Developing new method for zone configuration taking into account the progress of zone's floor. This method chooses the zones based on linking floor dividing activity from project schedule and floor plans.

- Creating a novel method and its respective algorithms to generate user location real time visualization on tablet PC through integrating the 4D BIM model and user location whether it is identified using GPS for outdoor zones or RFID for indoor zones or manually.
 - Integrate progress templates and user location real time visualization to make BIM acts as a data acquisition tool for different types of activities.
7. Design of a new methods and its respective algorithms to track and control earthmoving operations in near real time using:
 - Spatial technologies (GPS/GIS).
 - RFID gates
 - RFID and control sensor or switch limit
 8. Development of automated method to calculate earned value based on automated data acquisition technologies and progress templates. Development of method to forecast earthmoving fleet productivity, time and cost stochastically based on Discrete Event Simulation (DES) and actual data captured from site.
 9. Design of tablet PC and central databases to organize and manage captured data in this research.
 10. Development of computational platform (prototype software), which acts as an interface with the user. This prototype can facilitates the capturing of actual data on-site and store it in centralized database, as well as process the collected data for progress reporting in near real time.
 11. Utilization of actual construction project to demonstrate the use of developments made in the course of this research

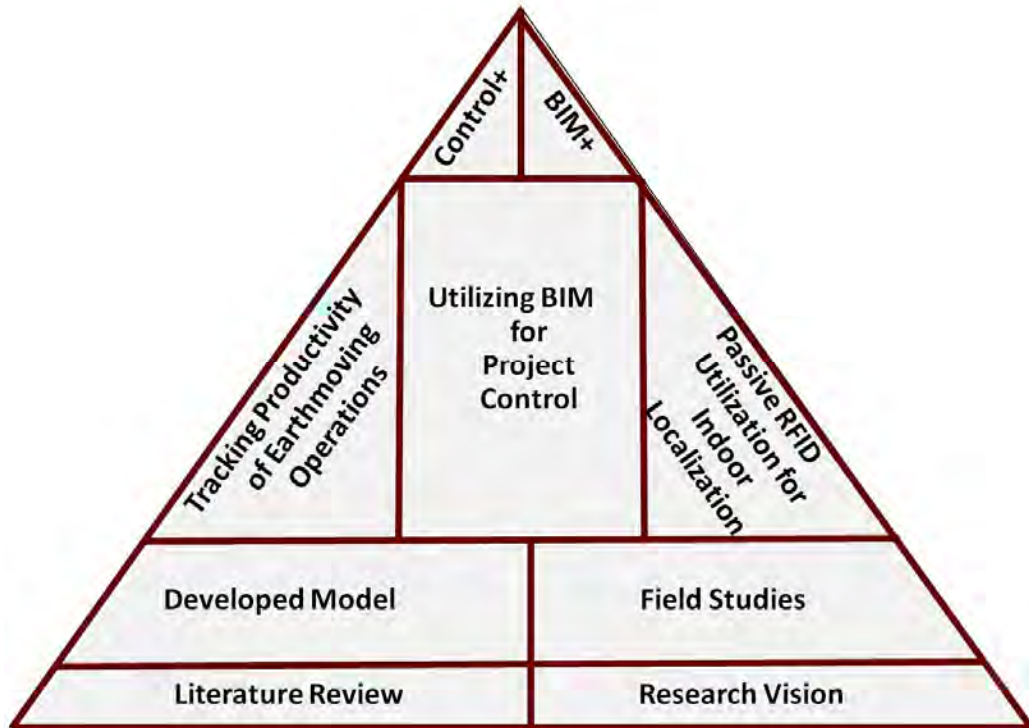


Figure 7-1: Research contribution summary

7.3 Limitations

The following limitations were taken into account during the creation, validation, and implementation of the data fusion and data management models developed in this research:

1. The parallel and iterative design, development and implementation of the model, resulted in some of the model's objectives were developed after the field implementation. So, it was not validated such as the utilization of RFID gates and RFID and control sensor to track earthmoving operations.
2. The model was therefore validated in part through field studies and experimental work in both field and lab environments. A full case study implementation of the model is suggested for future work, during which final refinements or design changes to the model could be introduced.

3. The process of capturing data using the mobile RFID or GPS was carried out and transferred via Bluetooth to the tablet PC manually, which could be done automatically through hardware communication protocols.
4. In DES stochastic forecasting, it was assumed that all trucks have the same capacity and same Probability Density Functions (PDF). A new DES simulation engine can be developed to take these factors into consideration.
5. Control+ developed system was limited to certain processing and reporting functionalities limit.

7.4 Future Work

The following are some recommendations for future work areas:

1. Development of a reasoning model to map the relationship between the inputs and outputs of the control process. This model should explain the reasons behind unacceptable performance and to suggest corrective action accordingly.
2. Expand the utilization of DES stochastic forecasting based on actual data to other construction operations and explore other methods of forecasting productivity, time and cost.
3. Extend the use of the developed model to include tracking material through the supply chain and procurement process.
4. Integrating CCTV outdoor cameras with user's mobile RFID reader to identify outdoor user's location and material tracking. This can be made possible through georeferencing the CCTV camera images.

5. Explore the possibility of extending BIM+ to be a Web-Based solution running through cloud computing. Extend BIM+ to be fully functional planning and scheduling tool instead of using scheduling third party software.
6. Complete and extend the functionalities of Control+ to be a complete cloud computing solution for progress reporting.

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Appendix A: Tracking Scraper-Pusher Fleet for Cut-Fill

Earthmoving Operations

This appendix presents an automated method for tracking and estimating productivity of Scraper-Pusher fleet in near real time utilizing wireless technologies for cut-fill earthmoving operations. RFID and equipment switch limit are the technologies used in the developed method. Low cost UHF rugged encapsulated passive RFID tags are attached to scrapers and fixed RFID readers are attached to pushers. The read range of used RFID tag is centimeters, to be activated only when the pusher with the attached RFID reader is pushing the scraper for loading operations. Then, the RFID reader starts capturing the RF signals from the scraper tag. On the other hand, switch limit is connected the scraper bowl to monitor its motion. The movement of scraper bowl activates the switch limit. The function of switch limit is to record the time when the scraper bowl opens or closes. The switch limit sends its captured data via cable to micro controller that is attached to the scraper. Scraper micro controller has a wireless communication module that sends and receives data to/from RFID readers.

The data captured by RFID from scrapers RFID tag and switch limit are transferred wirelessly to a specially designed relational database in as web server, as shown in Figure (A-1). The collected data is analyzed and processed automatically, without human intervention. Fusing the data captured from RFID reader and switch limit is used to identify loading, travel, dumping and return times that constitute the scraper cycle time. Consequently, the productivity of scraper-pusher fleet is estimated for the whole earthmoving operation. The results are reported to project team members via internet. For further details about the developed algorithm and system architecture, refer to (Montaser and Moselhi, 2013 c).

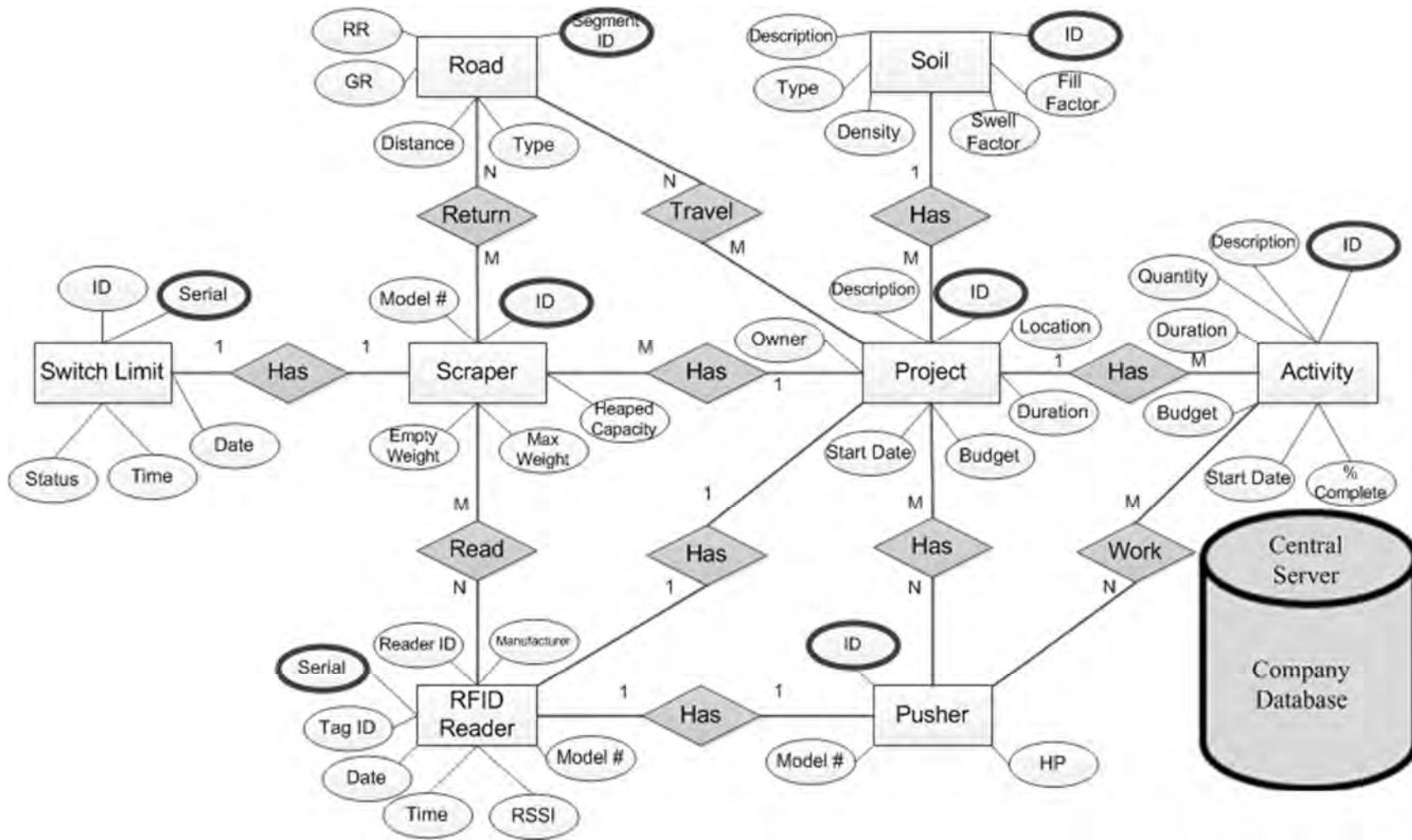


Figure A-1: The entity relationship diagram (ER) for the developed database

Appendix B: Central Database

Table B-1: Central database attributes

Table	Attribute Name	Data Type	Description
Project	ProjectID	Number	Primary Key (User Input)
	Location	Text	User Input
	PlannedDuration	Number	User Input
	PlannedBudget	Number	User Input
	ContractualStartDate	Date/Time	User Input
	ContractualEndDate	Date/Time	User Input
	ActualStartDate	Date/Time	User Input
	ActualEndDate	Date/Time	User Input
	ActualDuration	Number	User Input
	Owner	Text	User Input
	Description	Text	User Input
	ProjectName	Text	User Input
	Type	Text	User Input
	ContractType	Text	User Input
	PolygonID	Number	Provided by System
	SoilID	Number	Provided by System
Project Status	Date	Date/Time	Primary key (Provided by System t)
	ProjectID	Number	Provided by System
	BCWS	Number	Provided by System = \sum (BCWS Activities)
	BCWP	Number	Provided by System = \sum (BCWP Activities)
	ACWP	Number	Provided by System = \sum (ACWP Activities)
	CV	Number	Provided by System = (BCWP – ACWP)
	SV	Number	Provided by System = (BCWP – BCWS)
	CPI	Number	Provided by System = (BCWP / ACWP)

Table	Attribute Name	Data Type	Description
	SPI	Number	Provided by System = (BCWP / BCWS)
	EAC1	Number	Provided by System = (BAC / CPI)
	EAC2	Number	Provided by System = (ACWP + (BAC – BCWP))
	TimeStatus	Text	Provided by System
	BudgetStatus	Text	Provided by System
	Temperature	Number	Primary key (Provided by System from MS Project)
	Humidity	Number	Primary key (Provided by System from MS Project)
	WindSpeed	Number	Primary key (Provided by System from MS Project)
	Rain	Number	Primary key (Provided by System from MS Project)
Activity	ActivityID	Number	Primary key (Provided by System from MS Project)
	Name	Text	Provided by System from MS Project
	ProjectID	Number	Provided by System from MS Project
	Type	Text	Provided by System from MS Project (Critical or Not Critical)
	ActualEF	Date/Time	Provided by System (Last Date of Activity Status and should be confirmed by the user)
	UnitCost	Number	User Input
	ActualES	Date/Time	Provided by System (First Date of Activity Status)
	PlannedEF	Date/Time	Provided by System from MS Project
	PlannedES	Date/Time	Provided by System from MS Project
	Budget	Number	Provided by System from MS Project
	Duration	Number	Provided by System from MS Project
	Quantity	Number	Provided by System 3D BIM Model
	TotalFloat	Number	Provided by System from MS Project
	FreeFloat	Number	Provided by System from MS Project
	WeatherSensitivity	Yes/No	User Input
	ProgressType	Text	User Input
	UnitsofMeasurement	Text	User Input
	TrackingTechnology	Text	User Input

Table	Attribute Name	Data Type	Description
Activity Status	Date	Date/Time	Primary key (t Provided by System)
	ActivityID	Number	Provided by System
	BCWS	Number	Provided by System = (BAC x Elapsed Duration / Duration)
	BCWP	Number	Provided by System = (% Complete x BCWS)
	ACWP	Number	User Input
	CV	Number	Provided by System = (BCWP – ACWP)
	SV	Number	Provided by System = (BCWP – BCWS)
	CPI	Number	Provided by System = (BCWP / ACWP)
	SPI	Number	Provided by System = (BCWP / BCWS)
	EAC1	Number	Provided by System = (BAC / CPI)
	EAC2	Number	Provided by System = (ACWP + (BAC – BCWP))
	PercentageComplete	Number	According to Activity progress Type (in Case of Truck = QuantityToDate / Total Quantity) or from Progress Template
	QuantityToDate	Number	Provided by System = (TodayQuantity + QuantityToDate(t-1))
	ForecastedEF	Date/Time	Provided by System = (ActualES + (Duration / SPI))
	TodayQuantity	Number	Provided by System (in Case of Truck = \sum [TruckCapacity x Total Number of Cycles] x Soil Fill Factor)
	TimeStatus	Text	Provided by System
BudgetStatus	Text	Provided by System	
Progress Template	WorkContentCode	Number	Primary key (User Input)
	WorkContent	Text	User Input
	Cumulative%Earned	Number	User Input
	ActivityID	Number	User Input
Tablet PC	TabletPCID	Number	Primary Key (User Input)
	ModelNumber	Number	User Input
	Manufacture	Text	User Input
	ProjectID	Number	User Input

Table	Attribute Name	Data Type	Description
Tablet PC RFID Reader File	Serial	Number	Primary Key (RFID Captured Data)
	Data File	Attachment	Primary Key (RFID Captured Data)
	RSSI	Number	RFID Captured Data
	ReaderDate	Date/Time	RFID Captured Data
	ReaderTime	Date/Time	RFID Captured Data
	RFIDTagID	Number	RFID Captured Data
	TabletPCID	Number	RFID Captured Data
Tablet PC GPS File	PositionID	Number	Primary Key (GPS Captured Data)
	Data File	Attachment	Primary Key (GPS Captured Data)
	Date	Date/Time	GPS Captured Data
	Time	Date/Time	GPS Captured Data
	Lattitude	Number	GPS Captured Data
	Longitude	Number	GPS Captured Data
	Altitude	Number	GPS Captured Data
	LineID	Number	GPS Captured Data
	TabletPCID	Number	GPS Captured Data
User Location	UserPositionID	Number	Primary Key (Provided by System)
	TabletPCID	Number	Provided by System
	Date	Date/Time	Provided by System
	TimeFrom	Date/Time	Provided by System
	TimeTo	Date/Time	Provided by System
	Latitude	Number	Provided by System (Outdoor)
	Longitude	Number	Provided by System (Outdoor)
	Xj	Number	Provided by System (Indoor)
	Yj	Number	Provided by System (Indoor)
	Floor#	Number	Provided by System (Indoor)
	ZoneID	Number	Provided by System (Indoor or Outdoor)
	Type	Text	Indoor or outdoor (Provided by System)

Table	Attribute Name	Data Type	Description
Object Temporal Location	MaterialPositionID	Number	Primary Key (Provided by System)
	MaterialID	Number	from 3D BIM Model
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Latitude	Number	Provided by System (Outdoor)
	Longitude	Number	Provided by System (Outdoor)
	Xk	Number	Provided by System (Indoor)
	Yk	Number	Provided by System (Indoor)
	Floor#	Number	Provided by System (Indoor)
	ZoneID	Number	Provided by System (Indoor or Outdoor)
	Type	Text	Indoor or outdoor (Provided by System)
Zone	ZoneID	Number	Primary Key (from 3D BIM Model)
	Floor#	Number	3D BIM Model
	ProjectID	Number	Provided by System
	Type	Text	Indoor or outdoor (from 3D BIM Model)
Reference RFID Tag	ReferenceRFIDTagID	Number	Primary Key (Provided by System)
	xi	Number	User Input
	yi	Number	User Input
	ZoneID	Number	User Input
Soil	SoilID	Number	Primary Key (Provided by System)
	FillFactor	Number	User Input
	SwellSector	Number	User Input
	Denisty	Number	User Input
	Type	Text	User Input
	Description	Text	User Input
Road	SegmentID	Number	Primary Key (Provided by System)
	ProjectID	Number	Provided by System
	DumpingAreaID	Number	Provided by System

Table	Attribute Name	Data Type	Description
	Type	Text	Provided by GIS Sub-Module
	StartLongitude	Number	Provided by GIS Sub-Module
	StartLatitude	Number	Provided by GIS Sub-Module
	StartAltitude	Number	Provided by GIS Sub-Module
	EndLongitude	Number	Provided by GIS Sub-Module
	EndLatitude	Number	Provided by GIS Sub-Module
	EndAltitude	Number	Provided by GIS Sub-Module
	Distance	Number	Provided by GIS Sub-Module
	Grade Resistance	Number	Provided by System
	Rolling Resistance	Number	Provided by System
Dumping Area	DumpingAreaID	Number	Primary Key (User Input)
	PolygonID	Number	User Input
	Location	Text	User Input
	Owner	Text	User Input
	Capacity	Number	User Input
Gate RFID Reader	ReaderID	Number	Primary Key (User Input)
	ModelNumber	Number	User Input
	Manufacture	Text	User Input
	ReaderType	Text	User Input
	ProjectID	Number	User Input
	DumpingAreaID	Number	User Input
Gate RFID Reader File	Serial	Number	Primary Key (Gate RFID Captured Data)
	Data File	Attachment	Primary Key (Gate RFID Captured Data)
	RSSI	Number	Gate RFID Captured Data
	ReaderDate	Date/Time	Gate RFID Captured Data
	ReaderTime	Date/Time	Gate RFID Captured Data
	RFIDTagID	Number	Gate RFID Captured Data
	ReaderID	Number	Gate RFID Captured Data

Table	Attribute Name	Data Type	Description
Resource	ResourceID	Number	Primary Key (User Input)
	ActivityID	Number	User Input
	CostAccount	Number	User Input
	RFIDTagID	Number	User Input
Material	MaterialID	Number	Primary Key (from 3D BIM Model)
	Manufacturer	Text	3D BIM Model
	Type	Text	3D BIM Model
	ResourceID	Number	User Input
	Xf	Number	3D BIM Model
	Yf	Number	3D BIM Model
Labor	LaborID	Number	Primary Key (User Input)
	ResourceID	Number	User Input
	FirstName	Text	User Input
	LastName	Text	User Input
	Trade	Text	User Input
	BirthDay	Date/Time	User Input
	Address	Text	User Input
	HireDate	Date/Time	User Input
	Phone#	Number	User Input
	SIN#	Number	User Input
	Wage	Number	User Input
	OverTimeRate	Number	User Input
Equipment	EquipmentID	Number	Primary Key (User Input)
	ResourceID	Number	User Input
	EfficiencyFactor	Number	User Input
	Manufacturer	Number	User Input
	LicensePlate	Number	User Input
	PurchaseDate	Number	User Input

Table	Attribute Name	Data Type	Description
Truck	TruckID	Number	Primary Key (User Input)
	ModelNumber	Number	User Input
	EquipmentID	Number	User Input
	EmptyWeight	Number	User Input
	MaxWeight	Number	User Input
	HeapedCapacity	Number	User Input
	GPSID	Number	User Input
Truck GPS	GPSID	Number	Primary Key (User Input)
	ModelNumber	Number	User Input
	Manufacture	Text	User Input
	TruckID	Number	User Input
Truck GPS File	Serial	Number	Primary Key (GPS Captured Data)
	Data File	Attachment	Primary Key (GPS Captured Data)
	Date	Date/Time	GPS Captured Data
	Time	Date/Time	GPS Captured Data
	GPSID	Number	GPS Captured Data
	Heading	Number	GPS Captured Data
	Speed (KM/h)	Number	GPS Captured Data
	Latitude	Number	GPS Captured Data
	Longitude	Number	GPS Captured Data
	Altitude	Number	GPS Captured Data
	Information	Text	GPS Captured Data
Truck Status	Date	Date/Time	Primary Key (Generated by System)
	Cycle#	Number	Primary Key (Generated by System)
	TruckID	Number	User Input
	Event1	Date/Time	Generated by System
	Event2	Date/Time	Generated by System
	Event3	Date/Time	Generated by System

Table	Attribute Name	Data Type	Description
	Event4	Date/Time	Generated by System
	Event5	Date/Time	Generated by System
	LoadingTime	Number	Generated by System
	TravelTime	Number	Generated by System
	DumpingTime	Number	Generated by System
	ReturnTime	Number	Generated by System
	CycleTime	Number	Generated by System
	ActualProductivity	Number	Generated by System = (TruckCapacity / CycleTime)
Excavator	ExcavatorID	Number	Primary Key (User Input)
	ModelID	Number	User Input
	EquipmentID	Number	User Input
	BucketCapacity	Number	User Input
	MaxDumpingHeight	Number	User Input
	MaxDiggingDepth	Number	User Input
Sound Record	SoundID	Auto Number	Primary Key (Generated by System)
	Position ID	Number	Based on User Location (Provided by System)
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Zone ID	Number	Based on User Location (Provided by System)
	Sound	Attachment	Data captured by the user
	Description	Text	Entered by the user
Video Record	VideoID	Auto Number	Primary Key (Generated by System)
	Position ID	Number	Based on User Location (Provided by System)
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Zone ID	Number	Based on User Location (Provided by System)
	Video	Attachment	Data captured by the user

Table	Attribute Name	Data Type	Description
	Description	Text	Entered by the user
Image	ImageID	Auto Number	Primary Key (Generated by System)
	Position ID	Number	Based on User Location (Provided by System)
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Zone ID	Number	Based on User Location (Provided by System)
	Image	Attachment	Data captured by the user
	Description	Text	Entered by the user
Hand Written Notes	HandWrittenNotes ID	Auto Number	Primary Key (Generated by System)
	Position ID	Number	Based on User Location (Provided by System)
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Zone ID	Number	Based on User Location (Provided by System)
	HandWrittenNotes	Attachment	Data captured by the user
	Description	Text	Entered by the user
Barcode	BarCode ID	Auto Number	Primary Key (Generated by System)
	Position ID	Number	Based on User Location (Provided by System)
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Zone ID	Number	Based on User Location (Provided by System)
	BarCode	Text	Data captured by the user
	Description	Text	Entered by the user
3D Scan	3DScan ID	Auto Number	Primary Key (Generated by System)
	Position ID	Number	Based on User Location (Provided by System)
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Zone ID	Number	Based on User Location (Provided by System)

Table	Attribute Name	Data Type	Description
	3DScan	Attachment	Data captured by the user
	Description	Text	Entered by the user
Control Sensor	ControlSensorID	Number	Primary Key (User Input)
	ModelNumber	Number	User Input
	Manufacture	Text	User Input
	TruckID	Number	User Input
Control Sensor File	Serial	Number	Primary Key (Control Sensor Captured Data)
	Data File	Attachment	Primary Key (Control Sensor Captured Data)
	Date	Date/Time	Control Sensor Captured Data
	Time	Date/Time	Control Sensor Captured Data
	ControlSensorID	Number	Control Sensor Captured Data
	Status	Binary (On/Off)	Control Sensor Captured Data
Excavator RFID Reader	ReaderID	Number	Primary Key (User Input)
	ModelNumber	Number	User Input
	Manufacture	Text	User Input
	ReaderType	Text	User Input
	ExcavatorID	Number	User Input
Excavator RFID Reader File	Serial	Number	Primary Key (Excavator RFID Captured Data)
	Data File	Attachment	Primary Key (Excavator RFID Captured Data)
	RSSI	Number	Excavator RFID Captured Data
	ReaderDate	Date/Time	Excavator RFID Captured Data
	ReaderTime	Date/Time	Excavator RFID Captured Data
	RFIDTagID	Number	Excavator RFID Captured Data
	ReaderID	Number	Excavator RFID Captured Data
CCTV Camera	CCTVCmeraID	Number	Primary Key (User Input)
	ModelNumber	Number	User Input
	Manufacture	Text	User Input
	ProjectID	Number	User Input

Table	Attribute Name	Data Type	Description
	LocationX	Number	User Input
	LocationY	Number	User Input
	LocationZ	Number	User Input
CCTV Camera Image	ImageID	Auto Number	Primary Key (Generated by System)
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Image	Attachment	Data captured by the Camera
	Description	Text	Entered by the user
	CCTVCamerID	Number	Provided by System
3D Scanner	3DScannerID	Number	Primary Key (User Input)
	ModelNumber	Number	User Input
	Manufacture	Text	User Input
	ProjectID	Number	User Input
3D Scan File	3DScan ID	Auto Number	Primary Key (Generated by System)
	Position ID	Number	Based on Scanner Location (Provided by System)
	Date	Date/Time	Provided by System
	Time	Date/Time	Provided by System
	Zone ID	Number	Based on Scanner Location (Provided by System)
	3DScan	Attachment	Data captured by the scanner
	Description	Text	Entered by the user
Object	ObjectID	Number	Primary Key (from 3D BIM Model)
	Family	Text	3D BIM Model
	Type	Text	3D BIM Model
	Description	Text	Entered by the user
	Quantity	Number	3D BIM Model

Appendix C: Data Collection

Table C-1: Genomics tablet PC data acquisition schedule

ID	Date	Technology			
		Images	Barcode	RFID	GPS
1	Sep. 15, 2010	√			
2	Sep. 22, 2010	√	√		
3	Oct. 06, 2010	√	√		
4	Oct. 13, 2010	√	√		
5	Oct. 15, 2010	√	√		
6	Oct. 20, 2010	√	√		
7	Oct. 22, 2010	√	√		
8	Oct. 27, 2010	√	√		
9	Oct. 29, 2010	√	√		
10	Nov. 03, 2010	√	√		
11	Nov. 05, 2010	√	√		
12	Nov. 10, 2010	√			
13	Nov. 17, 2010	√			
14	Nov. 24, 2010	√		√	
15	Dec. 01, 2010	√		√	
16	Dec. 03, 2010	√		√	
17	Dec. 08, 2010	√		√	√
18	Dec. 14, 2010			√	√
19	Dec. 15, 2010	√			√
20	Jan. 13, 2010				√
21	Jan. 20, 2010	√			√
22	Jan. 27, 2010	√			√
23	Feb. 03, 2010	√		√	
24	Feb. 10, 2010	√		√	
25	Mar. 01, 2010	√		√	
26	Mar. 17, 2010	√			√
27	Mar. 23, 2010	√			√
28	Apr. 23, 2010	√		√	
29	Apr. 26, 2010				√
30	May 11, 2010	√			√

Table C-2: Genomics 3D scanning schedule

ID	Date	Type	Remarks
1	Sept., 15, 2010	External	5 different scanning positions
2	Oct., 13, 2010	External	5 different scanning positions
3	Oct., 15, 2010	Internal	Second Floor, 2 different scanning positions
4	Oct., 20, 2010	External	4 different scanning positions
5	Oct., 22, 2010	Internal	Second Floor, 2 different scanning positions
6	Oct., 27, 2010	External	5 different scanning positions
7	Oct., 29, 2010	Internal	First Floor, 2 different scanning positions
8	Nov., 3, 2010	External	1 scanning position, 5 different resolution
9	Nov., 5, 2010	Internal	First Floor, 2 different scanning positions
10	Nov., 10, 2010	Internal	Second Floor, 2 different scanning positions
11	Nov., 11, 2010	Internal	First Floor, 2 different scanning positions
12	Dec, 1, 2010	Internal	Second Floor, 2 different scanning positions
13	Dec, 3, 2010	Internal	First Floor, 2 different scanning positions
14	Dec, 8, 2010	Internal	Second Floor, 1 position, 9 different resolution

Table C-3: LADAR specification

Attribute	Specification
Scanning Range	Horizontally up to 360°
	Vertically up to 150°
Positioning accuracy	± 0.01 gon
Scanning speed	40 gon/sec
Measurement range	2m up to 200m
Measurement accuracy	± 2cm

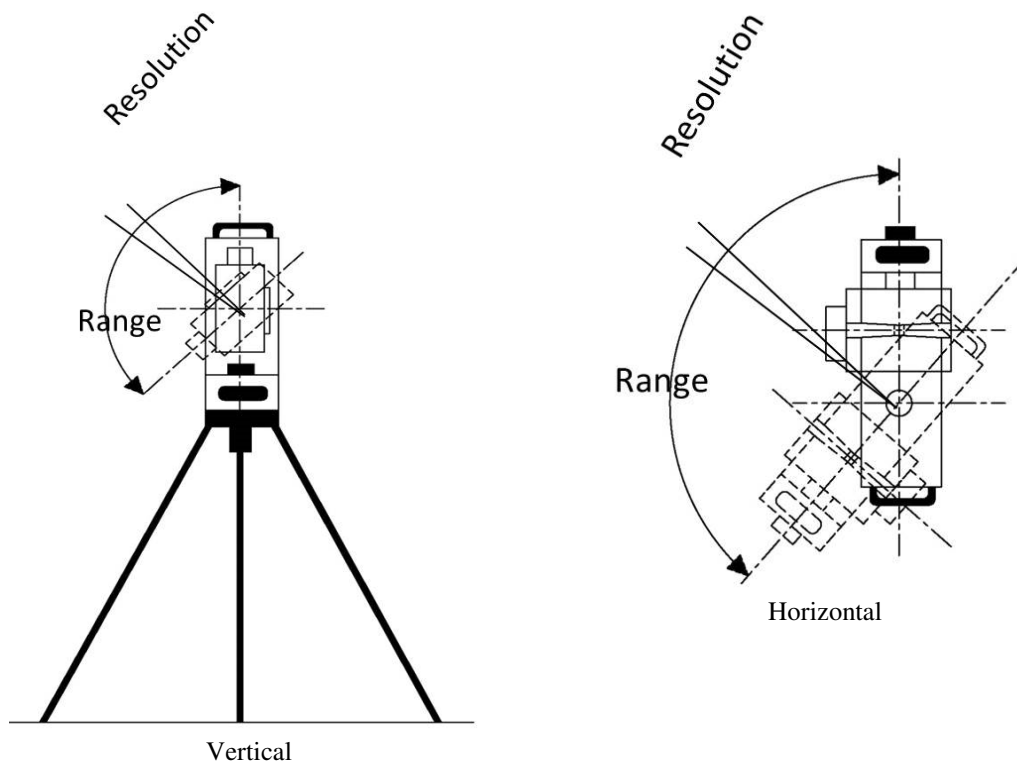


Figure C-1: Vertical and horizontal attributes

Table C-4: Outdoor scanning attributes (September 15, 2010)

Day	Attributes	Point 1	Point 2	Point 3	Point 4	Point 5
Sep., 15, 2010	Vertical Range & Resolution	(140°,0.5°)	(140°,0.5°)	(140°,0.5°)	(132°,0.5°)	(130°,0.5°)
	Horizontal Range & Resolution	(135°,0.5°)	(120°,0.5°)	(150°,0.5°)	(100°,0.5°)	(150°,0.5°)
	Duration (min)	18	16	20	13	18
	Planned # of point Clouds	76151	67722	84581	53265	78561
	Actual # of point Clouds	53917	41150	61143	34872	63753

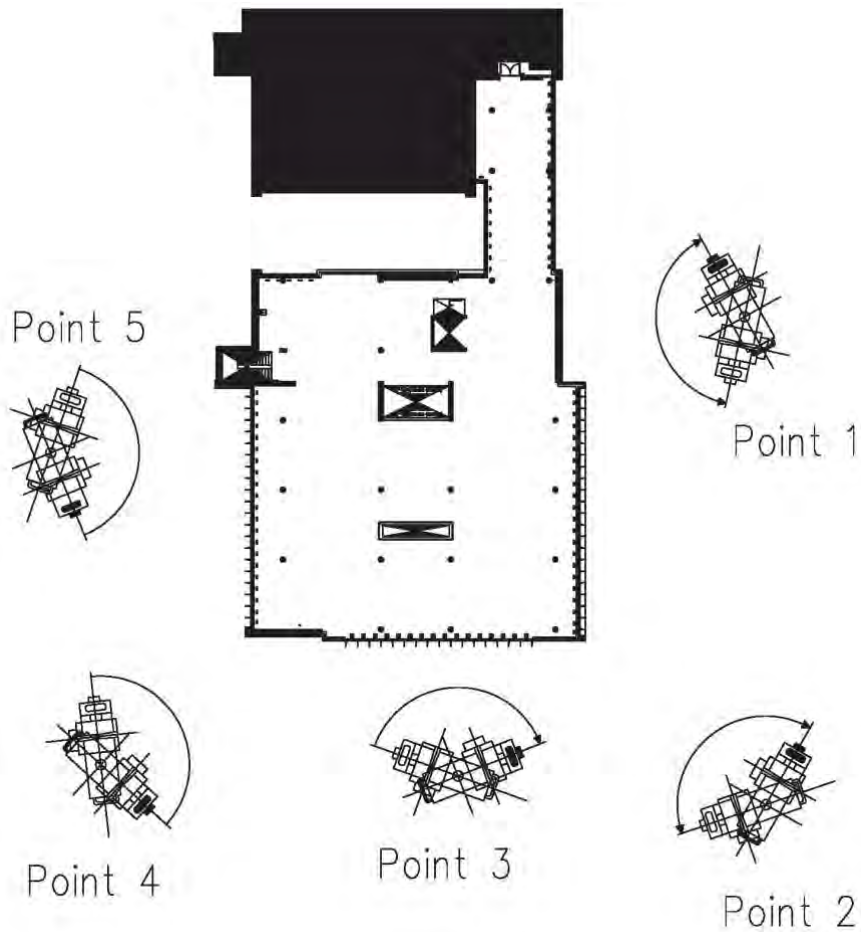


Figure C-2: Outdoor scanning positions

Table C-5: First floor indoor scanning attributes (October 15, 2010)

Day	Attributes	Point 1	Point 2
Oct., 29, 2010	Vertical Range & Resolution	(145°,0.5°)	(145°,0.5°)
	Horizontal Range & Resolution	(354°,0.5°)	(354°,0.5°)
	Duration (min)	48	48
	Planned # of point Clouds	206901	206901
	Actual # of point Clouds	201465	205061

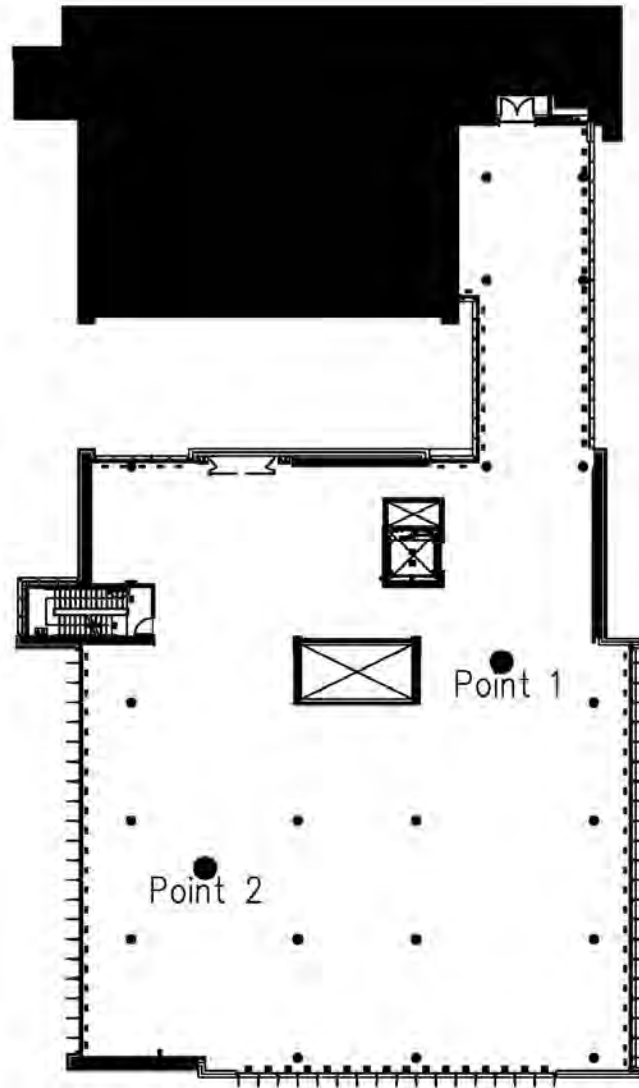


Figure C-3: First floor scanning positions

Table C-6: Outdoor scanning with different resolution (November 3, 2010)

Day	Attributes	Resolution				
		5°	1°	0.5°	0.25°	0.2°
Nov., 3, 2010	Vertical Range	140°	140°	140°	140°	140°
	Horizontal Range	130°	130°	130°	130°	130°
	Duration (min)	2	9	18	34	42
	Planned # of point Clouds	783	18471	73341	292281	456351
	Actual # of point Clouds	542	13254	53022	211690	295475



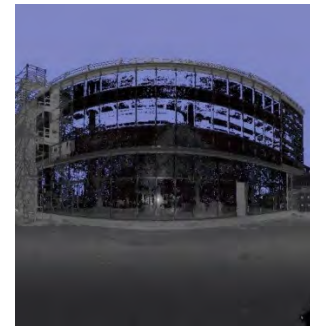
5°



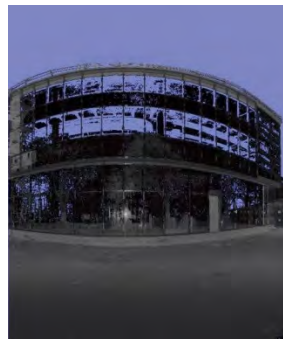
0.5 °



1 °



0.25 °



0.2 °

Figure C-4: Different resolution 3D scanner images

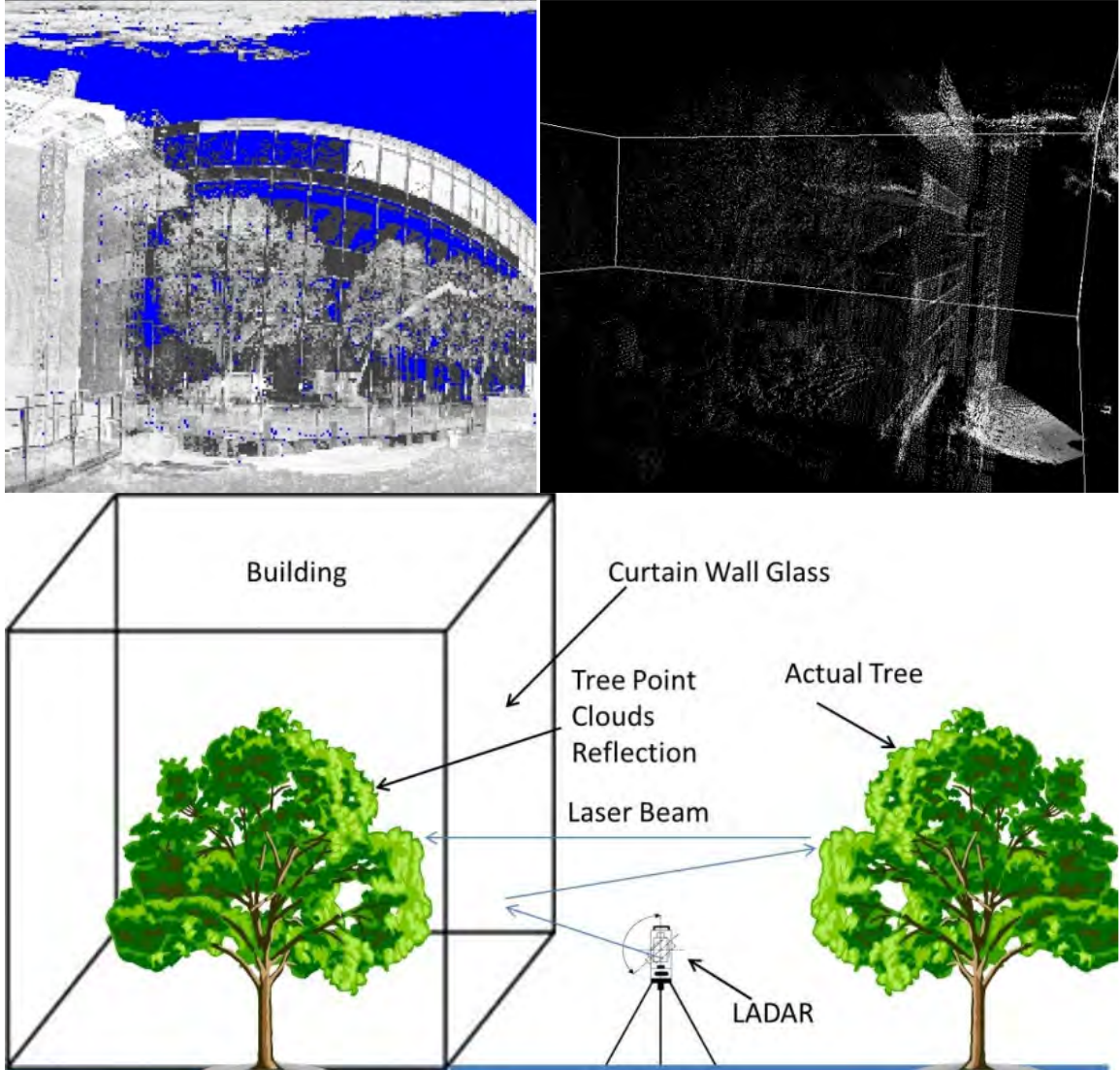


Figure C-5: Outdoor scanning and curtain walls glazing created noise

Appendix D: Productivity of Earthmoving Operations in Planning

This appendix provide the methodology utilized to calculate the planned upper and lower limit productivity of trucks in earthmoving operations, for more details refer to Montaser et al. (2011 and 2012). The process of estimating the productivity of the excavator(s) and of the hauling unit(s) is described below. Equation (D.1) is used to estimate the excavator production rate (Peurifoy and Schexnayder 2006). Since each variable in that equation has a range of values, see Table (D-1), the application of it leads to a range of production rates for the excavator. The production rate of a hauling truck is calculated using Equation (D.2) until (D.7).

$$\text{Excavator Production Rate} = \frac{3600 \times Q \times F}{t} \times \frac{E}{60 \text{ min/hour}} \times \text{Swell Factor} \quad (\text{D.1})$$

Where

Q is the heaped bucket capacity in loose cubic yard,

F is the bucket fill factor,

T is the excavator cycle time in seconds, and

E is an efficiency factor in minutes per hour

$$\text{Balance number of excavator bucket loads} = \frac{\text{Truck capacity}}{\text{Bucket capacity}} \quad (\text{D. 2})$$

Truck load weight = Excavator bucket capacity X Number of bucket loads to the truck X

Density of excavated soil (D. 3)

$$\text{Truck loading time} = \text{Number of excavator bucket loads} \times \text{Excavator cycle time} \quad (\text{D.4})$$

Table D-1: Values of variables affecting excavator production rates

Variable	Optimistic	Pessimistic	Remarks
Bucket Capacity	Considered as constant		As per contractor selection
Soil Type	Considered as constant		As per the site investigation report
Fill Factor	110%	100%	As per soil type - (Peurifoy and Schexnayder, 2006)
Cycle Time(sec)	t min	t max	Equipment manufacturer
Swell Factor	Considered as constant		As per the site investigation report
Efficiency (min\hr)	55	40	(Peurifoy and Schexnayder, 2006)

$$\text{Travel time} = \text{Segment length} / \text{Travel speed} \quad (\text{D.5})$$

More details on the calculation of the total resistance and on the use of performance charts can be found in Peurifoy and Schexnayder (2006). From the appropriate truck performance chart, the maximum speed associated with the calculated total resistance for each segment can be found and then the travel time determined using Equation (D.5). The time required to complete the earthmoving operations can be calculated using Equation (D.8). Equation (D.7) has many variables, and each variable has a range of values, which leads to a range of production rates for the truck under consideration. The optimistic and pessimistic production thresholds are shown in Table (D-2).

$$\text{Number of trucks (N)} = \frac{\text{Truck Cycle Time (min)}}{\text{Excavator Loading Time (min)}} \quad (\text{D. 6})$$

$$\text{Truck Production Rate} = \frac{\text{Efficiency} \left(\frac{\text{min}}{\text{hr}} \right) \times \text{No. of trucks} \times \text{truck Capacity (cy)} \times \text{Swelling Factor}}{\text{Truck Cycle time (min)}} \quad (\text{D.7})$$

$$\text{Time required} = \text{Quantity of excavation} / \text{Fleet production rate} \quad (\text{D.8})$$

Table D-2: Values of the variables affecting the truck production rate

Variable	Optimistic	Pessimistic	Remarks
Truck Capacity	Considered as a constant		As per manufacturer data sheets
Soil Type	Considered as a constant		As per site investigation report
Swell Factor	Considered as a constant		As per site investigation report
RR (lb\ton)	40	65	As per road surface type (for asphalt roads)
Efficiency (min\hr)	55	40	(Peurifoy and Schexnayder 2006)

The project selected for this study was Genomics building, described in details in Chapter 4. Figure (D-1) depicts the road profile of the haul road as extracted from Google Earth. Accordingly, a sample of the project data was organized as shown in Table (D-3). The rolling resistance was considered to be equal to 55 lb/ton for the asphalt roads on the route. Table (D-4) depicts the range of values affecting the production rate of the hauling units. Using the data presented above, assuming 8-hour workdays and varying the number of trucks used in the operation, the upper and lower limits of the production rate of each excavation fleet considered were calculated presented in Table (D-5).



Figure D-1: Google Earth generated road profile

Table D-3: Sample of hauling units' travel times

Description	Distance(ft)	RR (%)	GR (%)	TR (%)	Speed (mph)	Time (min)
Hauling	847	2.75	-0.432	2.318	28	0.34375
	433	2.75	-0.69088	2.059	30	0.164015
	945	2.75	-0.179	2.571	27	0.397727
	1805	2.75	0.610306	3.360	23	0.891798
	815	2.75	0	2.750	26.5	0.349485
Returning	850	2.75	0.432	3.182	32.5	0.297203
	830	2.75	0	2.750	33.5	0.281547
	1900	2.75	-0.61031	2.140	34	0.635027
	2200	2.75	-1.016	1.734	34	0.735294
	1755	2.75	-1.508	1.242	34	0.586564

Table D-4: Values of the durations governing truck production rate

Variable	Upper Limit	Lower Limit
Load Time (min)	2.75	3.67
Dump Time (min)	1.5	2.5
Travel Time (min)	17.76	21.5
Cycle Time (min)	22.01	27.67

Table D-5: Lower limits and upper limits of productivity

No. of Trucks	Lower limit				Upper limit			
	Production Rate (bcy/hr)	Duration (hr)	Duration (Day)	The Controlling Equipment	Production Rate (bcy/hr)	Duration (hr)	Duration (Day)	The Controlling Equipment
2	38.898	349.163	44	Truck	67.239	201.993	26	Truck
3	58.348	232.775	30	Truck	100.859	134.662	17	Truck
4	77.797	174.581	22	Truck	134.479	100.996	13	Truck
5	97.246	139.665	18	Truck	168.099	80.797	11	Truck
6	116.696	116.387	15	Truck	201.719	67.331	9	Truck
7	136.145	99.760	13	Truck	235.339	57.712	8	Truck
8	146.772	92.538	12	Excavator	268.959	50.498	7	Truck
9	146.772	92.538	12	Excavator	269.082	50.475	7	Excavator
10	146.772	92.538	12	Excavator	269.082	50.475	7	Excavator

Appendix E: Computer Implementation

This appendix includes sample of sequence diagrams and “Visual C# .Net” source code for the developed BIM+ software presented in Chapter 6 of this thesis. Similar to BIM+, class diagrams, sequence diagram were developed for various functions of Control+ and Truck+ prototype software with its respective “Visual C# .Net” source code.

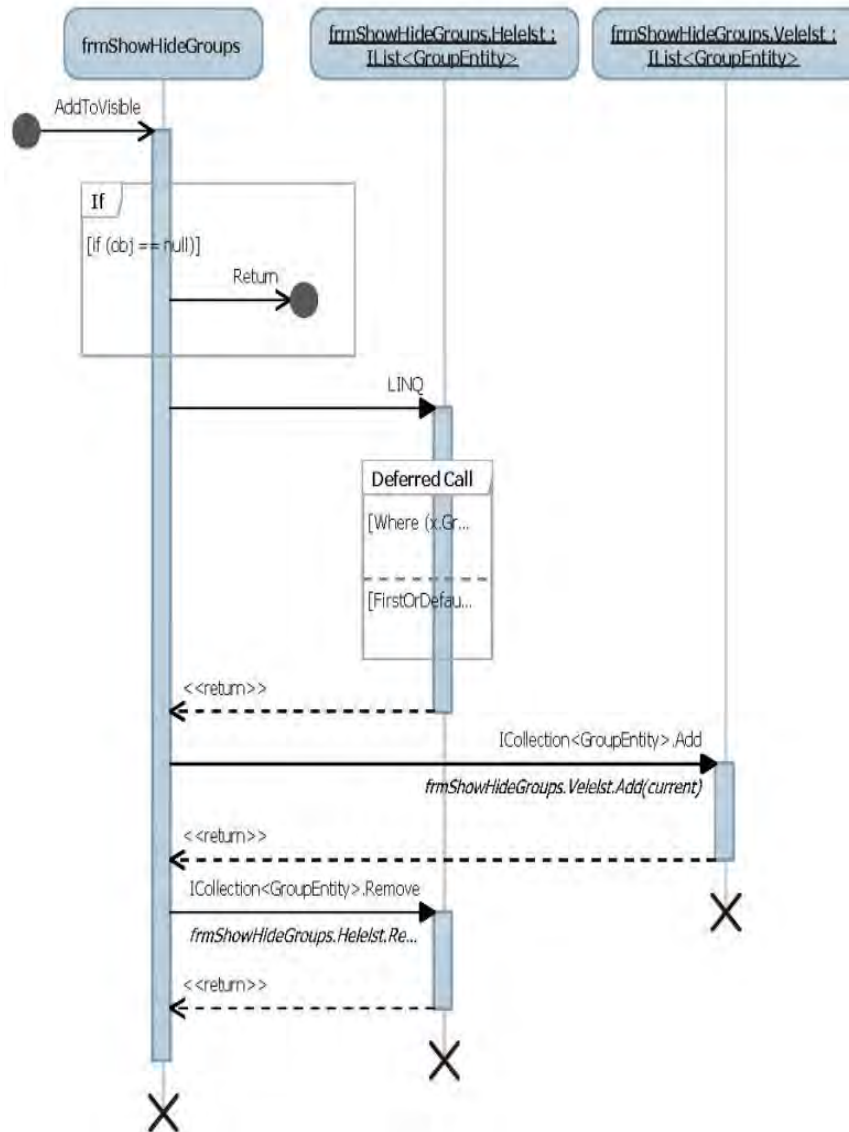


Figure E-1: Add to visible button (Sequence diagram)

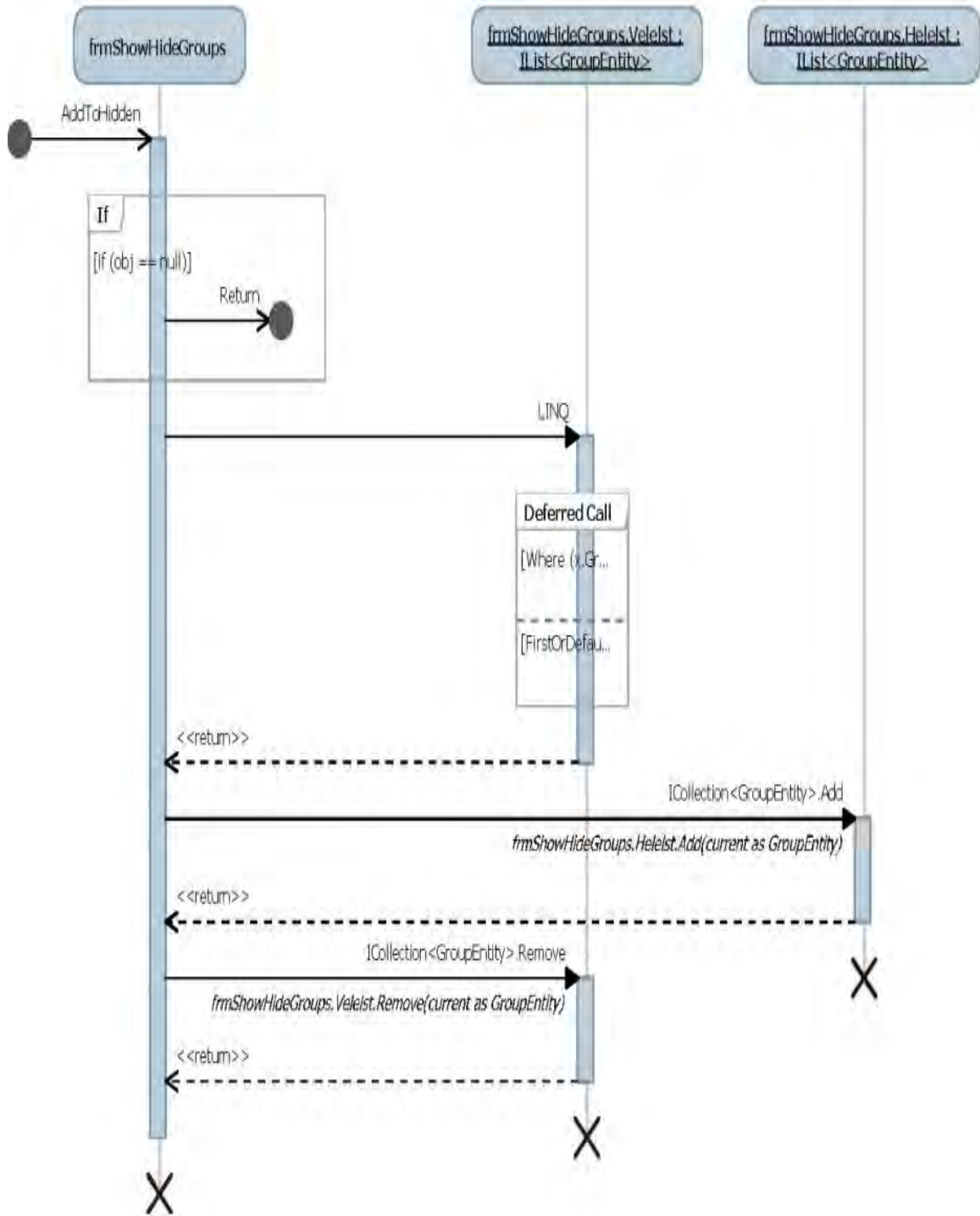


Figure E-2: Add to hidden button (Sequence diagram)

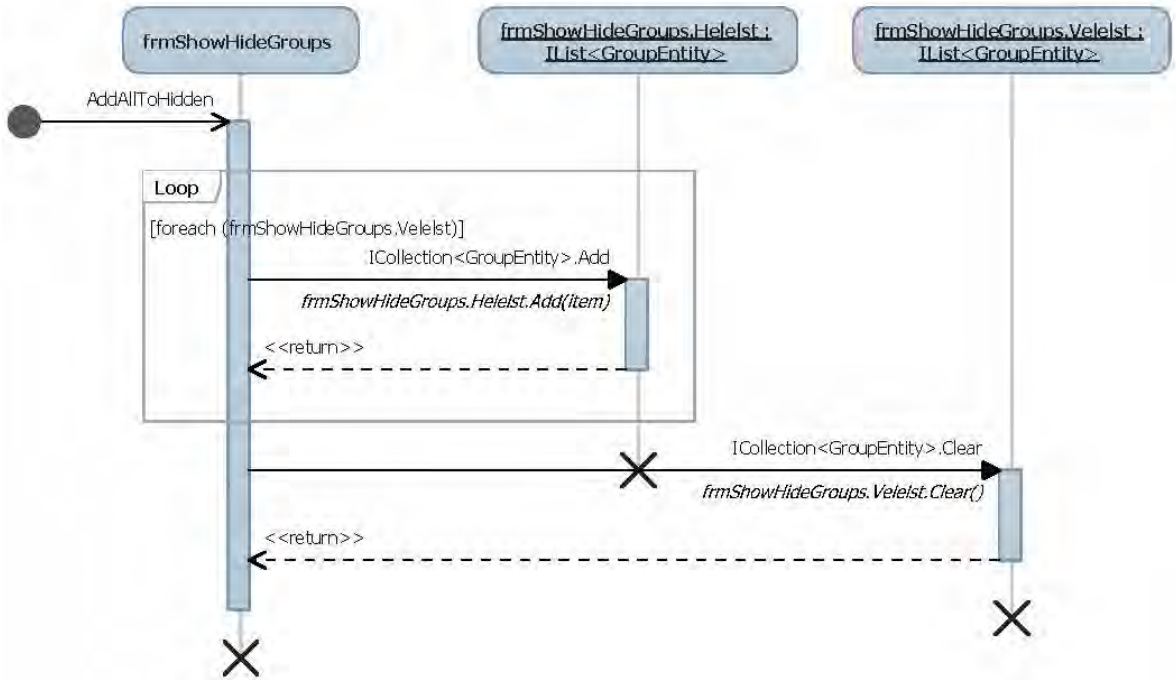


Figure E-3: Add all to hidden button (Sequence diagram)

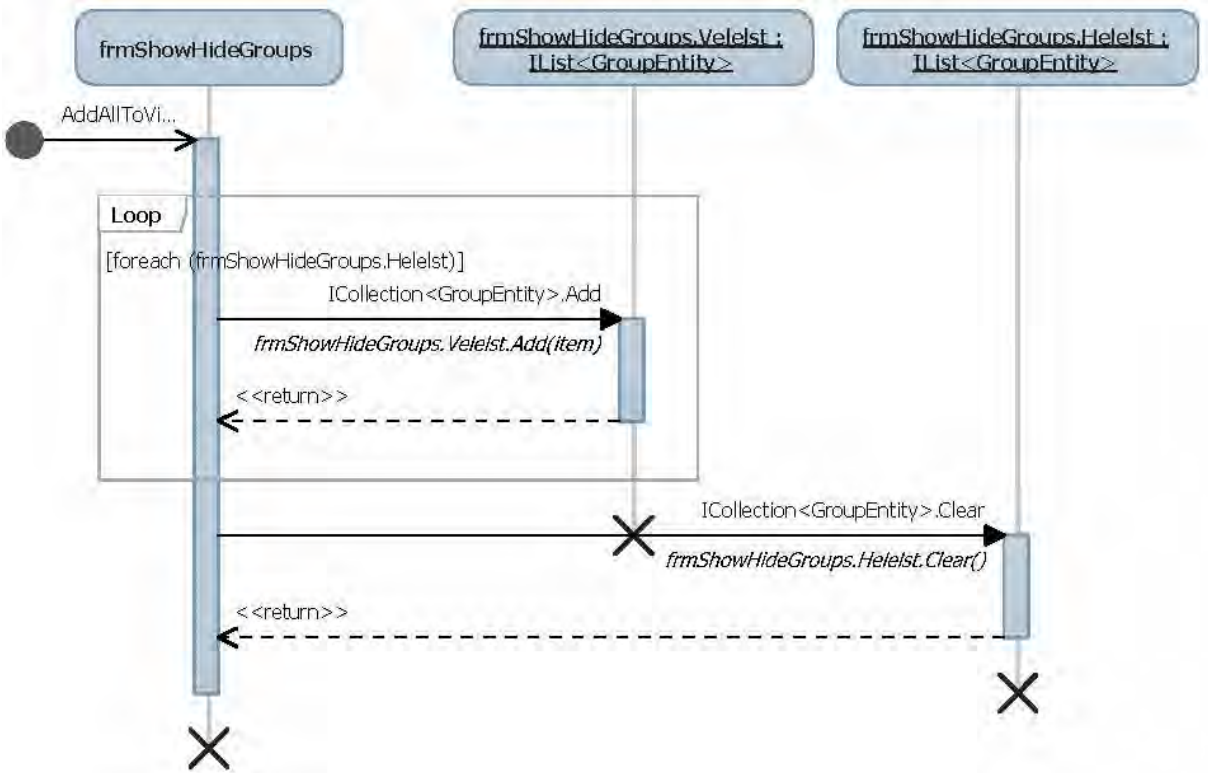


Figure E-4: Add all to visible button (Sequence diagram)

BIM+ Visual C# .Net Code

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Xml.Linq;

namespace RevitCreateGroupAddins.Entities
{
    public class xmlEntity
    {
        string _ActivityName;

        public string ActivityName
        {
            get { return _ActivityName; }
            set { _ActivityName = value; }
        }
        string _FloorName;

        public string FloorName
        {
            get { return _FloorName; }
            set { _FloorName = value; }
        }
        string _AreaName;

        public string AreaName
        {
            get { return _AreaName; }
            set { _AreaName = value; }
        }

        public static List<xmlEntity> GetXmlEntity()
        {
            List<xmlEntity> lstXmIs = new List<xmlEntity>();

            System.Configuration.Configuration config =
            Helper.MSProjectHelper.GetConfig();
            string strLinkFilePath = Environment.GetFolderPath(
            Environment.SpecialFolder.ProgramFilesX86)+
            config.AppSettings.Settings["LinkFilePath"].Value;

            XDocument xRoot = XDocument.Load(strLinkFilePath);
            List<XElement> eles = xRoot.Descendants("Link").ToList();
            foreach (var item in eles)
            {
                XElement xeIe = new XElement("Link");

                lstXmIs.Add(new xmlEntity()
                {
                    ActivityName = item.Attribute("Activity").Value,
                    AreaName = item.Attribute("Area").Value,
                    FloorName = item.Attribute("Floor").Value
                });
            }
            return lstXmIs;
        }
    }
}
```

```

    }

    public static void DeleteXmlEntities()
    {
        System.Configuration.Configuration config =
        Helper.MSPProjectHelper.GetConfig();
        string strLinkFilePath = Environment.GetFolderPath(
        Environment.SpecialFolder.ProgramFilesX86)+config.AppSettings.Settings["LinkFilePa
        th"].Value;

        XmlDocument xRoot = XmlDocument.Load(strLinkFilePath);
        xRoot.Descendants("Link").Remove();
        xRoot.Save(strLinkFilePath);
    }

    public static void DeleteXmlEntity(xmlEntity entity)
    {
        System.Configuration.Configuration config =
        Helper.MSPProjectHelper.GetConfig();
        string strLinkFilePath = Environment.GetFolderPath(
        Environment.SpecialFolder.ProgramFilesX86)+config.AppSettings.Settings["LinkFilePa
        th"].Value;

        XmlDocument xRoot = XmlDocument.Load(strLinkFilePath);

        List<XElement> eles = xRoot.Descendants("Link").ToList();
        XElement cEle = eles.Where(c => c.Attribute("Activity").Value ==
        entity.ActivityName).FirstOrDefault();
        if (cEle != null)
        {
            cEle.Remove();
            //eles.Remove(cEle);
            xRoot.Save(strLinkFilePath);
        }
    }

    public static void InsertXmlEntities(xmlEntity currententity)
    {
        System.Configuration.Configuration config =
        Helper.MSPProjectHelper.GetConfig();
        string strLinkFilePath = Environment.GetFolderPath(
        Environment.SpecialFolder.ProgramFilesX86)+config.AppSettings.Settings["LinkFilePa
        th"].Value;

        XmlDocument xRoot = XmlDocument.Load(strLinkFilePath);
        XElement eleroot = xRoot.Descendants("Links").FirstOrDefault();

        XElement ele = new XElement("Link");
        XAttribute attActivityName = new XAttribute("Activity",
        currententity.ActivityName);
        XAttribute AreaName = new XAttribute("Area", currententity.AreaName);
        XAttribute FloorName = new XAttribute("Floor",
        currententity.FloorName);

```

```

        ele.Add(attActivityName, AreaName, FloorName);

        eleroot.Add(ele);
        xRoot.Save(strLinkFilePath);
    }

using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace RevitCreateGroupAddins.Entities
{
    public class RFIDOutputEntity
    {
        public int Serial { get; set; }

        public string DataFile { get; set; }

        public string RSSI { get; set; }

        public DateTime ReaderDate { get; set; }

        public int RFIDTagID { get; set; }

        public int TabletPCID { get; set; }
    }
}

using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace RevitCreateGroupAddins.Entities
{
    public class CustomView
    {
        string _Name;

        public string Name
        {
            get { return _Name; }
            set { _Name = value; }
        }

        Autodesk.Revit.DB.View _CurrentView;

        public Autodesk.Revit.DB.View CurrentView
        {
            get { return _CurrentView; }
            set { _CurrentView = value; }
        }
        List<CustomElement> _lstElements = new List<CustomElement>();

        public List<CustomElement> LstElements

```

```

    {
        get { return _lstElements; }
        set { _lstElements = value; }
    }

    private double _z;

    public double Z
    {
        get { return _z; }
        set { _z = value; }
    }

    public Autodesk.Revit.DB.ElementId id { get; set; }
}

```

```

using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using Autodesk.Revit.UI;
using Autodesk.Revit.DB;
using Autodesk.Revit.DB.Architecture;
using RevitCreateGroupAddins.Helper;

```

```

namespace RevitCreateGroupAddins.Addins
{

```

```

[Autodesk.Revit.Attributes.Transaction(Autodesk.Revit.Attributes.TransactionMode.Manual)]

```

```

[Autodesk.Revit.Attributes.Regeneration(Autodesk.Revit.Attributes.RegenerationOption.Manual)]

```

```

    public class WalkThroughAddins : IExternalCommand
    {
        public Result Execute(
            ExternalCommandData commandData,
            ref string message,
            ElementSet elements)
        {
            UIApplication uiapp = commandData.Application;
            UIDocument uidoc = uiapp.ActiveUIDocument;
            Document doc = uidoc.Document;

            ViewFamilyType vft
            = new FilteredElementCollector(doc)
                .OfClass(typeof(ViewFamilyType))
                .Cast<ViewFamilyType>()
                .FirstOrDefault<ViewFamilyType>(x =>
                    ViewFamily.Section == x.ViewFamily);

            ViewSheetSets vs = doc.ViewSheetSets;
            foreach (ViewSheetSet item in vs)
            {

```

```

    }
    FilteredElementCollector a
= new FilteredElementCollector(doc)
    .OfClass(typeof(SpatialElement));
    BoundingBoxXYZ sectionBox = null;
    foreach (SpatialElement e in a)
    {
        Room room = e as Room;

        if (null != room)
        {
            sectionBox = RevitHelper.ListRoomData(room);
        }
    }
    using (Transaction tx = new Transaction(doc))
    {
        tx.Start("Create Wall Section View");

        ViewSection.CreateSection(doc, vft.Id, sectionBox);

        tx.Commit();
    }
    return Result.Succeeded;
}
}
}

using System;
using System.Collections.Generic;
using System.Linq;
using System.Web;
using System.Data.OleDb;
using System.Data;

namespace RevitCreateGroupAddins.Helpers
{
    public class HelperFunctions
    {
        private static HelperFunctions _HelperInstance;

        public static HelperFunctions HelperInstance
        {
            get
            {
                if (_HelperInstance == null)
                {
                    _HelperInstance = new HelperFunctions();
                }
                return _HelperInstance;
            }
        }

        private string DBPath;
        private string ConnectionString;
        private string ActivityHafar;
    }
}

```

```

public OleDbConnection con;
private string mdbConnectionString;
private string mdbcon;

private HelperFunctions()
{
    try
    {
        System.Configuration.Configuration config =
Helper.MSProjectHelper.GetConfig();

        DBPath = config.AppSettings.Settings["DataBasePath"].Value;
        ConnectionString =
config.AppSettings.Settings["ConnectionString"].Value;
        mdbConnectionString = ConnectionString + "";
        mdbcon = mdbConnectionString + DBPath;
    }
    catch (Exception)
    {
        throw;
    }
}

#region Helper Functions

public void OpenDBConnection()
{
    try
    {
        if (con != null)
        {
            if (con.State == ConnectionState.Open)
            {
                return;
            }
        }
        con = new OleDbConnection(mdbcon);
        con.Open();
    }
    catch (Exception)
    {
        // throw;
    }
}

public void CloseDBConnection()
{
    try
    {
        if (con != null)
        {
            if (con.State == ConnectionState.Open)
            {
                con.Close();
                con.Dispose();
            }
        }
    }
}

```



```

        }
    }
    catch (Exception)
    {
        throw;
    }
}

private DateTime ConvertStringToDateTime(string input, int monthPosition,
int dayPosition)
{
    try
    {
        string[] arr = input.Split('/');
        DateTime dt = new DateTime(Convert.ToInt32(arr[2]),
Convert.ToInt32(arr[monthPosition]), Convert.ToInt32(arr[dayPosition]));
        return dt;
    }
    catch (Exception)
    {
        return new DateTime();
        throw;
    }
}

#endregion
}
}
}

```