AN AMBIENT INTELLIGENT ENVIRONMENT FOR ACCESSING BUILDING INFORMATION IN FACILITY MANAGEMENT OPERATIONS; A HEALTHCARE FACILITY SCENARIO

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Masoud Gheisari

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AN AMBIENT INTELLIGENT ENVIRONMENT FOR ACCESSING BUILDING INFORMATION IN FACILITY MANAGEMENT OPERATIONS; A HEALTHCARE FACILITY SCENARIO

Approved by:

Dr. Javier Irizarry, Advisor
School of Building Construction
Georgia Institute of Technology

Dr. Bruce N. Walker
School of Psychology & Interactive Computing
Georgia Institute of Technology

Prof. Kathy Roper
School of Building construction
Georgia Institute of Technology

Dr. Sarel Lavy
Department of Construction Science
Texas A&M University

Dr. Daniel Castro-Lacouture
School of Building Construction
Georgia Institute of Technology

Date Approved: November 08, 2013

Especially dedicated to my late Dad & Mom
And to my beloved siblings Ata, Rahmat, Habib, Aref, & Mojgan

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AECO	Architecture, Engineering, Construction, and Operations
AJAX	Asynchronous JavaScript and XML
AHA	American Hospital Association
AmI	Ambient Intelligent
ANOVA	Analysis of Variance
AOA	Angle of Arrival
AR	Augmented reality
ASHE	American Society for Healthcare Engineering
ASQ	After Scenario Questionnaire
ASUQ	After Scenario Usability Questionnaire
AV	Augmented Virtuality
BIFM	British Institute of Facilities Management
BIM	Building Information Modeling
BLS	Bureau of Labor Statistics
CAD	Computer Aided Design
CDC	Center for Disease Control
CI	Confidence Interval
CM	Corrective Maintenance
CMMS	Computerized Maintenance Management System
CSS	Cascading Style Sheets
DOA	Direction of Arrival
FM	Facility Management
GDTA	Goal Directed cognitive Task Analysis
GPS	Global Positioning System
HCI	Human-Computer Interaction
HFM	Healthcare Facility Management
HMD	Head Mounted Display
HTML	HyperText Markup Language
HVAC	Heating, Venting, and Air Conditioning
IBM	International Business Machines corporation
ICT	Information and Communication Technology

IFC	Industry Foundation Class
IFMA	International Facility Management Association
IMR	Intelligent Mixed Reality
InfoSPOT	Information Surveyed Point for Observation and Tracking
IRB	Institutional Review Board
ISO	International Organization for Standardization
IT	Information Technology
KHARMA	KML/HTML Augmented Reality Mobile Architecture
KML	Keyhole Markup Language
KPI	Key Performance Indicator
MAR	Mobile Augmented Reality
MEP	Mechanical, Electrical, and Plumbing
MMR	Mobile Mixed Reality
NHST	Null Hypothesis Significance Testing
OSHA	Occupational Safety and Health Administration
PC	Personal Computer
PDA	Personal Digital Assistant
PM	Preventive Maintenance
PSSUQ	Post Study System Usability Questionnaire
PVAT	Proportions of Variances Accounted by Treatment
RM ANOVA	Repeated Measure Analysis of Variance
RSSI	Signal Strength Indicators
SA	Situation Awareness
SD	Standard Deviation
SME	Subject Matter Expert
TDOA	Time Difference of Arrival
TOA	Time of Arrival
UMAR	Ubiquitous Mobile Augmented Reality
VM	Virtual Model
XML	Extensive Markup Language

SUMMARY

The Architecture, Engineering, Construction, and Operations (AECO) industry is constantly searching for new methods for increasing efficiency and productivity. Facility managers, as a part of the owner/operator role, work in complex and dynamic environments where critical decisions are constantly made. This decision-making process and its consequent performance can be improved by enhancing Situation Awareness (SA) of the facility managers through new digital technologies. SA, as a user-centered approach for understanding facility managers' information requirement, together with Mobile Augmented Reality (MAR) was used for developing an Ambient Intelligent (AmI) environment for accessing building information in facilities. Augmented Reality has been considered as a viable option to reduce inefficiencies of data overload by providing facility managers with an SA-based tool for visualizing their "real-world" environment with added interactive data. Moreover, Building Information Modeling (BIM) was used as the data repository of the required building information. A pilot study was done to study the integration between SA, MAR, and BIM. InfoSPOT (Information Surveyed Point for Observation and Tracking) was developed as a low-cost solution that leverage current AR technology, showing that it is possible to take an idealized BIM model and integrate its data and 3D information in an MAR environment. A within-subjects user participation experiment and analysis was also conducted to evaluate the usability of the InfoSPOT in facility management related practices. The outcome of statistical analysis (a one-way repeated measure ANOVA) revealed that on average the mobile AR-based environment was relatively seamless and efficient for all participants in

the study. Building on the InfoSPOT pilot study, an in-depth research was conducted in the area of healthcare facility management, integrating SA, MAR, and BIM to develop an AmI environment where facility mangers' information requirement would be superimposed on their real-word view of the facility they maintain and would be interactively accessible through current mobile handheld technology. This AmI environment was compared to the traditional approach of conducting preventive and corrective maintenance using paper-based forms. The purpose of this part of the research was to investigate the hypothesis of "bringing 3D BIM models of building components in an AR environment and making it accessible through handheld mobile devices would help the facility managers to locate those components easier and faster compared to facility managers' paper-based approach". The result of this study shows that this innovative application of AR and integrating it with BIM to enhance the SA has the potential to improve construction practices, and in this case, facility management.

CHAPTER 1

INTRODUCTION

The research objective of the proposed research is to test the hypothesis that Intelligent Mixed Reality (IMR) can enhance facility management data access through seamless integration of facility information with the physical environment. Recent developments in Mobile Augmented Reality (MAR) have allowed the design and implementation of new Human Computer Interaction (HCI) paradigms that are inexpensive and accessible via current mobile technologies (e.g. smart phones or tablet devices). The Facility Management (FM) industry is constantly searching for new methods to increase efficiency and productivity. The Healthcare Facility Management (HFM) domain is the testing bed of this research. This area was selected for study because of the high positive impact that enhanced decision support systems will have for the productivity and success of the projects healthcare facility mangers undertake, and the sustainability of critical healthcare infrastructure networks. Healthcare facility managers are working in complex and dynamic environments of healthcare facilities where critical decisions are constantly made; this decision-making process and its consequent performance can be improved by enhancing ambient intelligence of the healthcare facility managers using MAR.

Uncertainties when making decisions are a reality that affects the FM industry. One of the areas where errors by decision-makers might have devastating consequences is the Healthcare FM domain. It is important to understand the information needs of decision-makers in this critical area, in order to provide the right information for decision-making in specific locations. The user-centered Situation Awareness (SA) approach, which has been used to determine the information needs of individuals performing goal-oriented tasks such as disaster management or aviation and military operations, was employed in this research. Many attributes of the facility management industry parallel these fields. Two of such attributes include accomplishing project goals and ensuring safe operations in dynamic environments.

Fundamental research was conducted to model the information requirement of healthcare facility managers through the Situation Awareness approach, with an emphasis on facility-specific maintenance issues. An untested, innovative intelligent environment integrated with information systems, which makes extensive use of natural user interactions, was proposed and tested. The hypothesis was that this system would help the facility managers to locate the right object within complicated environment of the facilities. This research expanded our knowledge of how natural interaction with information models would enhance the information access in goal-oriented tasks performed in an ambient intelligent environment.

This research helped to: (1) Understand the information needs of facility management personnel in goal-oriented positions which are critical to the decision-making process in dynamic healthcare environments; (2) Understand the current status of BIM, MAR, and handheld mobile technologies in the facility management practices; (3) Fuse BIM and MAR to develop an ambient intelligent environment for accessing information through available handheld mobile technologies; (4) Quantify the effect of natural user interfaces on information access in an ambient intelligent environment through usability evaluation; and (5) Identify barriers to information access in such an

Ambient Intelligent environment. By defining and implementing an ambient intelligent environment for goal-oriented positions, critical information will be readily available to other stakeholders in the project, thereby contributing to improvements of the productivity of the facility and sustainability of the healthcare infrastructure, as well as preventing unforeseen conditions that may otherwise result in additional expenses or catastrophic problems. The following chapter discusses the motivation behind this research and its impact on overall AECO domain.

CHAPTER 2

MOTIVATION AND IMPACT

Healthcare facilities include hospitals, clinics, dental offices, out-patient surgery centers, birthing centers, and nursing homes (OSHA, 2012). In 2008, healthcare was one of the largest industries in the U.S., providing 14.3 million jobs (BLS, 2011), of which 40% were in hospitals, 21% in nursing and residential care facilities, and 16% in physicians' offices (BLS, 2011). Out of 20 fastest growing occupations, 10 of them are healthcare-related. It has been predicted that between 2008 and 2018 healthcare will generate 3.2 million new jobs, more than any other industry (BLS, 2011).

Hospitals are considered the biggest facilities compared to the others in the healthcare segment. In terms of hospital utilization, hospital inpatient care had 36.1 million discharges with 4.9 days as the average length of stay in 2009 (CDC, 2009). In 2008, the number of visits to the hospital emergency room was 123.8 million, of which 16.6 million resulted to hospital admission (CDC, 2008). Hospitals are 24-hour working facilities that employ a wide variety of trades, from medical staff to mechanical maintenance, medical equipment maintenance, housekeeping, food service, building and grounds maintenance, laundry, and administrative staff (OSHA, 2012). These facilities should be working perfectly all the time; any deficiency in terms of the facility management might be catastrophic. Enhancing the decision-making process of healthcare facility managers will not only prevent the devastating consequences of errors in this area, but will also increase the productivity of the facility and sustainability of the healthcare infrastructure.

An area of research that can contribute to the improvement of the facility management in the healthcare industry is the area of information technology and cognitive science research. This research engages this effort through research in the area of ambient intelligence for AECO related tasks and Situation-Awareness-based Mobile Augmented Reality tools. Handheld and portable devices, as well as the ubiquity of the Internet, have dramatically increased the ease and reach of effective communications among participants in the AECO domain (Bedard, 2003). However, there has been no concerted effort to enhance decision-making in dynamic environments. Hjelm (2000) indicated the need for research on technologies that can improve the usability of handheld computing devices. Bedard (2003) identified augmenting human capabilities as an important area that warranted further research. He indicated that one of the lessons learned from decades of information technology developments in AECO was that success often depends on how naturally new technology blends with the way people work. In order to keep the human professional in charge and to enable him/her to solve meaningful problems in a manner that is as natural as possible, new approaches that are more user-oriented should be used to augment human capabilities. Technologies at the interface between the professional and the computing environment become essential for achieving this goal. Technologies, such as haptic devices, natural language and vision interfaces, could do away with the tediousness of typing on a physical keyboard and clicking a mouse to effectively communicate with computer systems.

Presently, research efforts are focused on data collection (Mrawira, Rankin, & Nunoo, 2002) and to some extent on improving the wireless infrastructure for access to the collected information. These efforts do not consider the information needs of the user when defining information access needs for timely and informed decision-making. The user, working on critical facilities or jobsites, should neither be overloaded with irrelevant information nor be hampered by inappropriate services and cumbersome in- and output techniques (Reinhardt, Garrett, & Scherer, 2000).

Many research efforts have been directed at task-level work without considering goal-oriented applications of IT. Examples of context sensitive task-related applications include a work diary and a mobile application supporting errors and omissions management in the field (Menzel, Eisenblatter, & Keller, 2004). These prototypes were developed through interviews with construction workers but did not follow any scientific principle to define information needs, preventing this approach from being considered for general application to other roles in the AECO domain. The lack of general design and development criteria leads to the consequence that systematic, intensive field-testing of prototypical solutions seems to be the only way to define the use of mobile IT (Menzel et al., 2004). This research challenges that conclusion and postulates that, in order to realize the potential benefits from mobile IT integration into the AECO domain, it is absolutely necessary to develop and define guidelines, standards, and specifications for software design considering the role-based information needs of users and focusing on natural user interaction as a vehicle for accessibility of information. This notion is supported by Garrett (2003), who points to the need for new interfaces and information models to support multimodal data streams as a way to enhance mobile data access. Without these, he stated that we would end up with unmanageable, complex, chaotic environments from which very little sense-making will be possible. This research has employed a goal-directed task analysis to develop a framework to determine the information needs of a specific user in an ideal Ambient Intelligent (AmI) environment for facility management practices and study the usability implications of such an environment. The specific aims of this research, along with its significance and accompanying research questions are identified and explained further in Chapter 3.

CHAPTER 3

OBJECTIVES

The first aim of this research is to gain a better understanding of the role-based information needs of individuals for decision-making in dynamic healthcare environments through a Situation Awareness approach. Narrowing down from general facility management domain to the healthcare facility management as complex infrastructure and focusing only on experts in the HVAC system (operational level) would lead to a group of individuals who are the target of this research. This new knowledge will contribute to the design of cognitive models that can help in testing performance of role-based decision support systems in a variety of domains.

Significance: Information overload is a problem that affects decision-makers in many domains. This problem is augmented by factors, such as user needs for different levels of information detail and different information integration needs (Anumba, Ugwu, Newnham, & Thorpe, 2001; O'Brien, Issa, & Flood, 2003; L. C. M. Tang, Zhao, Austin, Darlington, & Culley, 2007), in addition to the unique role-based goals of individuals. A systematic method for user information needs is essential for advancing the performance of role-based decision support systems. The AECO domain, specifically the area of healthcare facility management is selected as a test bed to explore the following research questions. This area is selected for the high positive impact that enhanced decision support systems will have for the productivity and success of the projects healthcare facility mangers undertake, and the sustainability of critical healthcare infrastructure networks.

Research question: What are the information needs of healthcare facility managers that will contribute to their Situation Awareness (SA) at operational level of facility maintenance?

The second aim is to define the guidelines for the integration of SA-based decision support framework and Building Information Modeling (BIM) in an Ambient Intelligent (AmI) environment where mobile natural user interfaces would provide the user with required data to facilitate their critical decision-making process. Part of this aim is also to benchmark a prototype of such a system's speed and accuracy in providing the needed information and in reducing information "clutter" on the designed user interface.

Significance: The speed and accuracy with which decisions can be made in dynamic environments can be the difference between success and catastrophic consequences. It is of paramount importance to design these systems with the goal of high performance information access. With the increase of mobile device use in many domains, considering Human Computer Interaction (HCI) factors becomes extremely important as well. One feature of mobile device use in the AECO domain that has been identified as one of the most important is fast access to job-related information. As a new paradigm in Information Technology, Intelligent Mixed Reality (IMR) would use mobile devices as the infrastructure to build an intelligent environment where users would access job-related information. This research would explore the following research questions following a user-centered approach for development and evaluation purposes.

Research questions: What are the user interaction requirements for MAR-based information access systems? Can a BIM+MAR integrated environment address the identified issues with mobile device use for information access in the AECO domain, specifically in the area of healthcare facility management?

CHAPTER 4

LITREATURE REVIEW

The literature in this section informs and lays the foundation for the research questions and the methodology to be used in this research. The theoretical framework is presented in Figure 1.

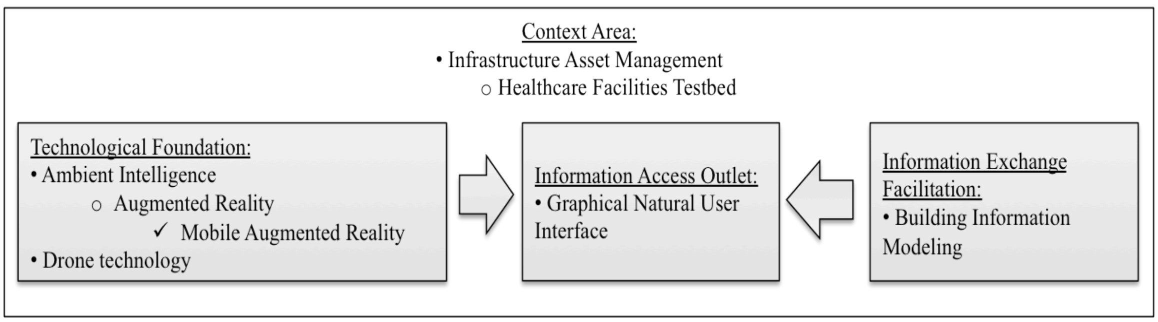


Figure 1: Theoretical Framework of the Project

Facility Management (FM) and Healthcare FM

Facility management covers an large scope of real estate management, financial management, change management, human resources management, health and safety, contract management, building and engineering services maintenance, and domestic services (Atkin & Brooks, 2009). Langston and Lauge-Kristensen (2002) have categorized this large scope and identified three levels of FM: (1) operational-level which deals with activities such as short-term management of the facility maintenance and repairs, security, and gardening (2) tactical-level which deals with activities such as adding value to the organizational planning, support services, and management of processes and (3) strategic-level which deals with activities that guide the organization toward meeting its objectives. Various definitions have been used for FM. The British Institute of Facilities Management (BIFM) defines FM as "the integration of processes within an organization to maintain and develop the agreed services which support and improve the effectiveness of its primary activities" (BIFM, 2012). The United States Library of Congress defines FM as "The practice of co-ordinating the physical workplace with the people and work of the organization; integrates the principles of business information, architecture and the behavioural and engineering sciences" (Chanter & Swallow, 2007). Most recently, the International Facility Management Association (IFMA) defined FM as "a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process, and technology" (IFMA, 2009). Previously IFMA had defined FM as "the practice of coordinating the physical workplace with the people and work of the organization" (Lavy & Shohet, 2007). The change in definitions shows that FM has matured from a "practice" to a multidisciplinary "profession" (Lavy & Shohet, 2007). In the FM profession, the role of a facility manager "is to meet the business challenges that confront the organization it is supporting, for reaching the optimum balance between people, physical assets and technology" (Then, 1999). Effective facility management is vital to the success of an organization by contributing to the achievement of its strategic and operational objectives (Chanter & Swallow, 2007). Shohet and Lavy (2004) recognized that a successful FM is "highly dependent on cost effectiveness and performance management".

Facility managers work in a complex environment in which they have to keep up with a large amount of information provided by various domains. One of the complex types of the facilities, in which facility managers might be faced with large amounts of information in a daily or even hourly basis and require critical decisions, is healthcare facility management. Hospitals are considered the largest facilities compared to others in the healthcare segment. In 2010 there were 5,754 U.S. registered hospitals with total expenses more than 750 billion dollars (AHA, 2012). In terms of hospital utilization, hospital inpatient care had 36.1 million discharges with 4.9 days as the average length of stay in 2009 (CDC, 2009). In 2008, the number of visits to the hospital emergency room was 123.8 million, of which 16.6 million resulted to hospital admission (CDC, 2008).

Hospitals are 24-hour working facilities that employ a wide variety of trades, from medical staff to mechanical maintenance, medical equipment maintenance, housekeeping, food service, building and grounds maintenance, laundry, and administrative staff (OSHA, 2012). In a comprehensive study on Healthcare Facility Management (HFM), Shohet and Lavy (2004), recognized the following six core domains (See Figure 2): (1) *Maintenance Management,* which includes service life planning, budgeting and setting priority of maintenance activities based on preferred maintenance policy. (2) *Performance Management*, which consists of monitoring and managing the performance of the facility's systems using several quantitative means. These quantitative means are also known as Key Performance Indicators (KPIs) and should be identified, characterized and defined in advance to assist in comparing the performance of a facility to other healthcare facilities. (3) *Risk Management*, which considers high levels of performance for different systems and components inside a healthcare facility (e.g. electricity, medical gases, healthcare waste system or fire protection means). Shohet and Lavy (2004) have pointed out that any minor breakdown to these systems will cause "both casualties and financial losses". (4) *Supply Services*

Management which consists of finding "the optimal mix of maintenance proficiencies for the use of in-house and outsourced staff" (Shohet & Lavy, 2004), as well as determining "the best combination of other services, such as cleaning, security, gardening, catering, and laundry" (Shohet & Lavy, 2004). (5) *Development,* that, based on the definition provided by Shohet and Lavy (2004), includes "strategic long-term planning, upgrading of existing facilities, rehabilitation, renovation, remodeling and reconstruction". (6) *Information and Communication Technology (ICT)* which integrates the previous five core domains and provides the "desired environment required for the challenging decision making and development prevalent in healthcare FM" (Shohet & Lavy, 2004).

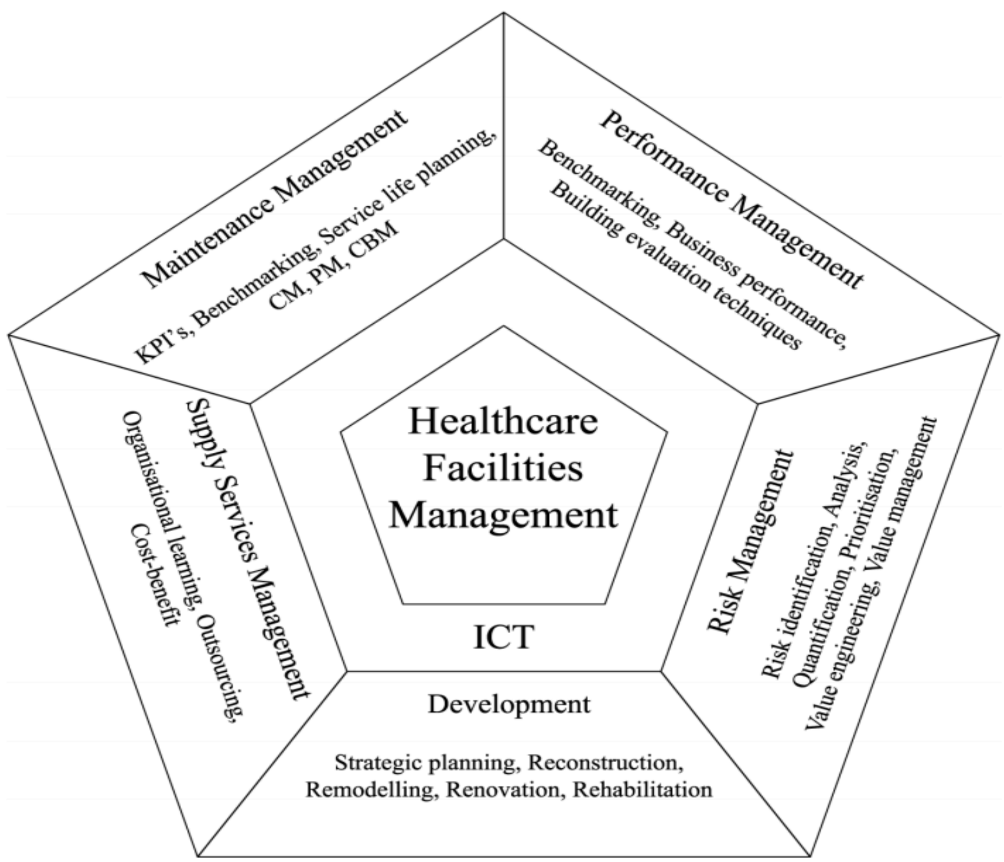


Figure 2: Healthcare facility management core domains (Shohet & Lavy, 2004).

The American Hospital Association (2010) defines a healthcare facility Manager's primary job responsibilities in the following general areas: maintenance and operations; code compliance; planning, design, and construction; finance management; and administration. In the area of operation and maintenance of building systems the healthcare facility managers should have an understanding about systems such as: HVAC (Heating, Ventilation, and Air Conditioning); refrigeration; steam and hot water; medical gas; electrical distribution; emergency power; fire protection; plumbing; medical equipment; safety and security; elevators and pneumatic tube; and grounds keeping (AHA, 2010).

Healthcare facilities are usually busy and filled with unexpected events (Calde, Goodwin, & Reimann, 2002). These facilities should be working perfectly all the time and any deficiency in terms of the facility management might be catastrophic. Enhancing the decision-making process of healthcare facility managers will not only prevent the devastating consequences of errors in this area, but will also increase the productivity of the facility and sustainability of the healthcare infrastructure. In the complex and data-rich domain of HFM, developing an ICT integrated environment that enhances the decision-making process of facility managers would be beneficial. BIM can play the role of a data repository and would provide easy access to building component information or spatial information in an ICT integrated environment.

Situation Awareness (SA)

A widely accepted definition of Situation Awareness (SA) is, "knowing what is going on so you can figure out what to do" (Adam, 1993). Basically, SA is having awareness about what is happening around, in order to make decisions based on that information, now and in the future. In more detail, SA clarifies what is needed for reaching the goals of a specific job by understanding what important information is to be used in the decision-making process. Actually this means "only those pieces of information that are relevant to the task at hand are important for SA" (M. R. Endsley, Bolte, & Jones, 2003). Formally, SA has been defined by Endsley (M.R. Endsley, 1988; Mica R. Endsley, 1995; M.R. Endsley, 2000) as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". In other words, the formal definition of SA is categorized into three hierarchical phases: Perception of elements in current situation; Comprehension of current situation; and Projection of future status. The relationships between these phases and task/system and individual factors are illustrated in Figure 3. Endsley et al (1998) have expanded these hierarchical phases as follows:

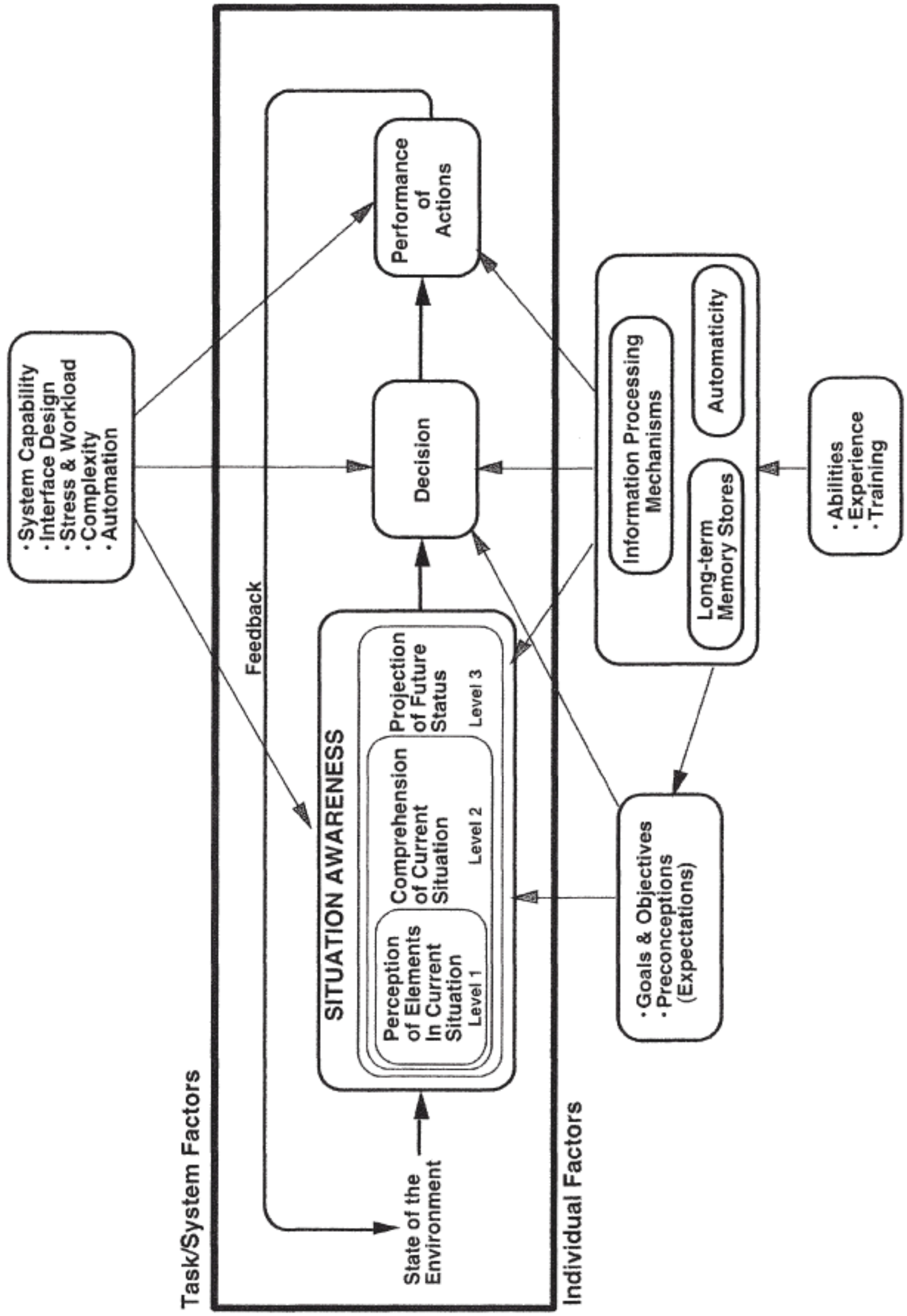


Figure 3: Endsley's model of situation awareness, adapted from (Mica R. Endsley, 1995)

Level 1 SA, Perception of the elements in the environment: “The first step in achieving SA involves perceiving the status, attributes, and dynamics of relevant elements in the environment. For example, a pilot needs to accurately perceive information about his/her aircraft and its systems (airspeed, position, altitude, route, direction of flight, etc.), as well as weather, air traffic control clearances, emergency information, and other pertinent elements” (M.R. Endsley et al., 1998).

Level 2 SA, Comprehension of the current situation: “Comprehension of the situation is based on a synthesis of disjointed Level 1 elements. Level 2 SA goes beyond simply being aware of the elements that are present to include an understanding of the significance of those elements in light of the pilot’s goals. Based upon knowledge of Level 1 elements, particularly when put together to form patterns with other elements, a holistic picture of the environment will be formed, including a comprehension of the significance of information and events” (M.R. Endsley et al., 1998).

Level 3 SA, Projection of future status: “It is the ability to project the future actions of the elements in the environment, at least in the near term, that forms the third and highest level of Situation Awareness. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA)” (M.R. Endsley et al., 1998).

Improved SA can lead to better decision-making and performance (M. R. Endsley & Garland, 2000). As highlighted in Figure 4, there is a relationship between environment, situation awareness, decision-making, and performance. Within the SA process, at the first level, the operator should perceive relevant information (Level 1 SA), then integrate this data with task goals (Level 2 SA), and at the end, predict future events based on his own understanding (Level 3 SA).

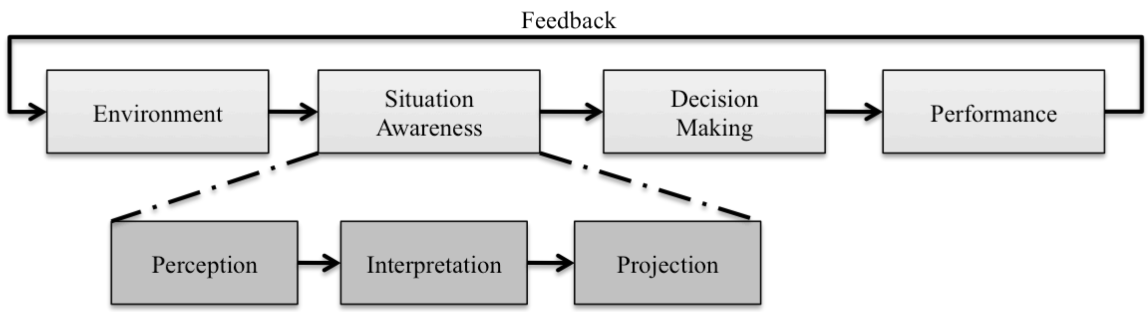


Figure 4: Situation awareness feedback loop, adapted from (M. R. Endsley & Garland, 2000)

Although it is stated that improved SA can result in better decision-making, this may not be true in all situations. There are other factors such as strategy, experience, training, personality, and organizational and technical constraints that can also affect the decision-making process (M. R. Endsley & Garland, 2000). There are cases where situation awareness is lost and individuals are usually slower in finding problems within the system resulting in the need for additional time to diagnose the problem and perform corrective actions (Mica R. Endsley & Esin O. Kiris, 1995). As even small lapses in situation awareness may cause serious problems, different manner of application domains have started to embed this concept in their potential areas (Mica R. Endsley, 1995).

Various domains, such as fighter aircrafts, electronic systems and automation technology, driving and ground transportation, energy production and distribution, space operations, nuclear power plant management, and medicine, are applying the SA methodology (M.R. Endsley, 2000). One example is Son et al. (2008) application of SA in a disaster response system. They found that SA is very relevant to (1) ensuring the effectiveness of a current disaster response system cognitively and physically, and (2) in understanding the system's supportiveness of the responders at both strategic and operational levels. In addition, they found that for effective situation aware decision making support, IT-based systems should be designed to support individual responder as well as group decision making, considering complex socio-behavioral-technical interaction at individual, team and inter/intra-organizational. They concluded that SA would support users' ability to get the required information on an as-needed basis under dynamic and complex conditions, which would result in improvements in decision-making and response efforts. Gheisari et al. (2010) applied the very same concept to construction safety management. They found that the main goal of a safety manager is "providing a safe workplace for parties in construction to reduce accidents, injuries, and hazards on jobsite." For achieving this main goal, safety managers should accomplish three major sub goals; (1) performing inspections for hazards on jobsite, (2) providing training for parties working on jobsite, and (3) managing accidents. They concluded that this SA-based technique has great potential of improving safety management practices on jobsites by identifying critical information and requirements for decision-making. The facility management area has not applied this methodology in spite the clear parallels to many goal driven domains. This study takes the initial steps in the application of Situation Awareness to the facility management area.

Situation Awareness (SA) Applied in the Facility Management (FM) Domain

Due to the complex environment of the facility management domain, facility managers cannot easily filter and organize information in an accurate manner. This results in less than optimal decisions being made.

Figure 5 illustrates a proposed conceptual model based on the SA concept, which can help facility managers to overcome the complexity of provided information on their working environment. SA can filter the large amount of information and provide the facility manager with organized and required information. The organized information requirements not only can shape the mental picture of the facility manager but also have the potential to be used as a basis for developing human-computer interfaces and applications. The improved mental picture together with human-computer interfaces can prosper the decision making process of facility managers and can lead to the achievement of their goals in the facility management domain. Goals such as reducing errors and improving task performance can lead to the improvement of facility manager's practices on their working environment. Application of an SA-centric method is not intended to provide a one-size-fits-all solution to facility management related issues. Its purpose is to increase SA and assist facility managers by enhancing access to relevant information that may lead to improved performance. It is each specific facility manager who is ultimately responsible for the final analysis of the available information and the corresponding course of action. Although this method may measure the measurable, management personnel should be vigilant of other factors that can influence decision-making.

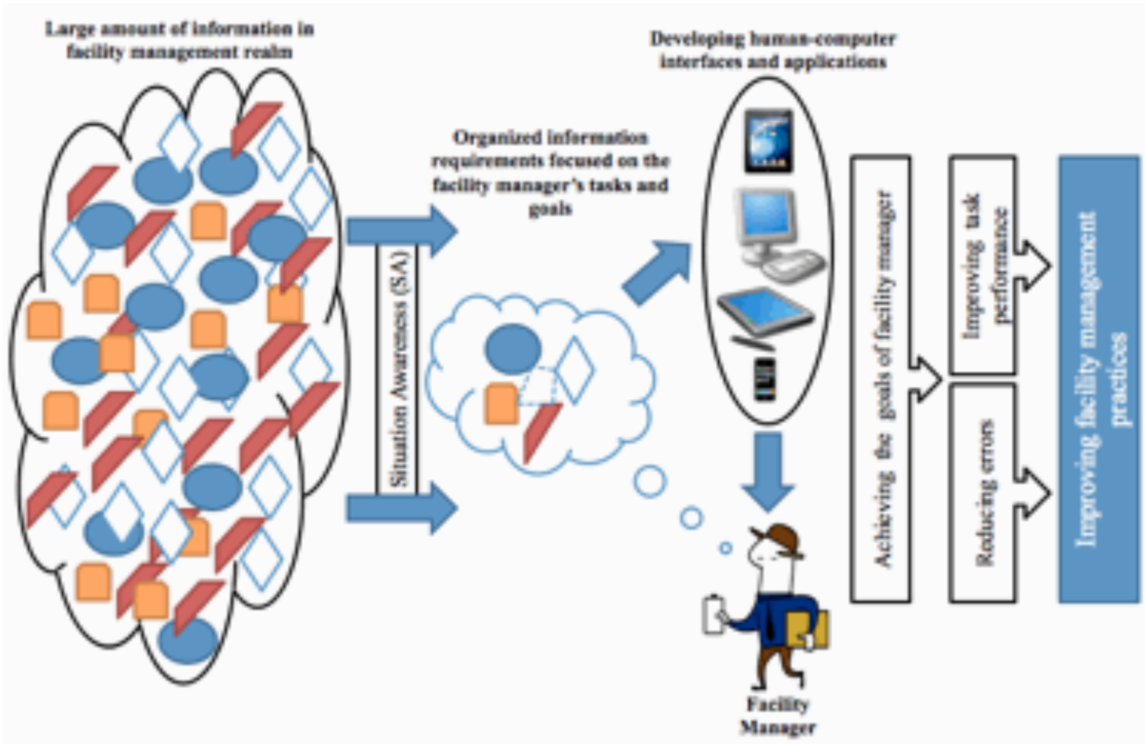


Figure 5: The conceptual model of FM and SA integration (Gheisari & Irizarry, 2011)

Situation Awareness (SA) Impacts on Healthcare Facility Management (HFM)

Situation awareness integration with healthcare facility management practices has the biggest impact on Information and Communication Technology (ICT) within healthcare built environment. ICT integrates all the core domains of healthcare built environment and provides the "desired environment required for the challenging decision making and development prevalent" (Shohet & Lavy, 2004).

There are tons of data being produced and disseminated for the facility managers, but they have limited ability to find the bits that are needed and process them together with all other bits to get to the actual piece of information required to do the decision making. Using ICT to bring more data does not equal more information for making critical decisions. SA can be used for solving this information gap through better system design. SA can be used to develop ICT user interfaces that allow people to effectively manage the information available to gain a high level of understanding of what is happening around them. SA, rather than showing information that is centred around a technology that produce it, integrates this information in ways that fit the goals, tasks, and needs of the healthcare facility managers. This philosophy is not borne "primarily from a humanistic or altruistic desire, but rather from a desire to obtain optimal functioning of the overall human-machine technology system" (M. R. Endsley et al., 2003).

The other huge impact of situation awareness integration with healthcare facility management practices is on Performance Management within healthcare built environment. Performance Management consists of monitoring and managing the performance of the facility's systems using several quantitative means. In this case, situation awareness would play the role of the engine that drives the train for decision-making and performance in complex, dynamic environment of a healthcare facility. SA increases the overall human/system reliability by the provision of recommendations on what to do under critical circumstances. SA would provide a synergy between the managers and the computers that leads to more optimal monitoring of the facility performance.

SA+HFM integration also impacts the Risk Management within healthcare built environment. Risk Management considers high levels of performance for different systems and components inside a healthcare facility (e.g. electricity, medical gases, healthcare waste system or fire protection means). Endsley and Kiris (1995) found out that 88% of human error was due to problems with situation awareness. This means, people mostly do not make bad decisions or perform their tasks poorly; they misunderstand the situation they are in. Shohet and Lavy (2004) have pointed out that, in the case of healthcare facility systems, any minor breakdown will cause both "casualties and financial losses". Thus, the best way to support human performance and prevent such catastrophes is to support the development of high levels of situation awareness within healthcare built environment.

Building Information Modeling (BIM) in Facility Management Practices

Building Information Modeling (BIM) is the process of developing and using 3D representations of building objects together with their related properties and relationship with other objects in the building. This assigned information to each building object can be used for data mining and to perform a wide range of simulation studies and calculations (Innovation, 2007). Advances in AECO point to BIM as the new standard for Computer Aided Design (CAD) in the AECO domain. The differences between BIM and traditional 2D CAD are (1) BIM consists of a set of intelligent contextual semantic 3D models where each object is defined as a specific element in the whole system of the building while 2D CAD provides independent 2-dimensional views of the building where any changes in one view requires the task of manually updating the required changes in the other views, and (2) BIM uses "smart objects" where all the required physical, functional and project life cycle information can be attached to, while 2D CAD drawings are graphical entities only (Innovation, 2007).

BIM solutions are used mostly because of three useful characteristics (Wagner & Schmalstieg, 2003): (1) they utilize digital databases; (2) they manage the interrelated databases so updates in one part result in the update of other parts; and (3) they store information that can be used later by other industry specific applications. Also there are some other practical benefits of BIM such as: (1) providing faster and more effective processes of information; (2) better design of building through quick and rigorous analysis, simulation, and performance benchmarking; (3) controlled whole-life costs and environmental data; (4) automated assembly of structure systems using digital product data; (5) better customer service through accurate 3D visualization; and (6) lifecycle data can be used in facility management (Innovation, 2007). In summary the key generic attributes of BIM are robust geometry, semantic richness, integrated information and lifecycle support (Innovation, 2007). These characteristics show that BIM is not only capable enough to be used in the design and construction phases but also can be applied in the latter stages of the facility life cycle. BIM is capable to be used for different purposes such as visualization, code reviews, forensic analysis, cost estimating, construction sequencing, conflict/inference/collision detection, and facility management (Azhar, Hein, & Sketo, 2008).

There is a disassociation between the design/construction phase and the facility management phase that can also be improved using BIM solutions. BIM's extension of Industry Foundation Classes (IFCs) can increase efficiencies and communication between stakeholders and managers throughout the lifecycle of a building, from design to management (Wither, Tsai, & Azuma, 2011). IFCs are an ISO norm that describes object specifications and are interoperable between CAD software packages making them a good format for sharing data among various types of building stakeholders.

Facility management, as the phase right after construction, can also benefit from BIM not only for 3D visualization purposes but also for space planning, renovation or maintenance practices. An integrated BIM system is capable to comprehensively support facility management practices for owners. Eastman et al. (2008) describes the motivating options for owners to adopt BIM technologies while operating the facility in the cases of design assessment, complexity of infrastructure, sustainability, cost reliability and management, schedule management, and facility and information asset management (Table 1). In the case of facility management, Eastman et al. (2008) also points out that BIM would help to (1) efficiently perform building commissioning, (2) quickly populate and edit facility management databases, (3) manage facility assets (e.g. Mechanical, Electrical and Plumbing systems) with BIM asset management tools, and (4) use visual and intelligent modules to rapidly assess the impact of retrofit/maintenance on the facility. In another study, Becerik-Gerber et al. (2011) pointed out that BIM could be implemented and beneficial for different application areas of facility management such as locating building components, facilitating real-time data access, 3D visualization, marketing, checking maintainability, creating and updating digital assets, space management, planning and feasibility studies for non-capital construction, emergency management, controlling and monitoring energy, and personnel training and development. These motivating options and application areas would play a very important role while using BIM in complex assets. Integrating BIM with new approaches of accessing information such as Augmented Reality (AR) would provide facility managers with an intuitive and easy approach of interacting their required information from BIM models.

Table 1: Motivating options for owners to adopt BIM technologies (Eastman et al., 2008)

Motivation Option	Description	Motivation Option	Description
Design Assessment	Integrate development of programmatic requirements	Cost Reliability & Management	More reliable estimates early in the process with conceptual BIM estimating
	Improve program compliance through BIM spatial analyses		Faster, better-detailed, and more accurate estimates with BIM quantity takeoff tools
	Receive more valuable input from project stakeholders through visual simulation	Schedule Management	Reduce time to market through the use of parametric models
	Rapidly reconfigure and explore design scenarios		Reduce schedule duration with 3D coordination and prefabrication
	Simulate facility operations		Reduce schedule-related risk with BIM-based planning
Complexity of Infrastructure	Coordinating infrastructure through fully integrated 3D models of MEP, architectural, and structural systems		Quickly respond to unforeseen field conditions with 4D-coordinated BIM models
	Producing higher-quality and maintainable infrastructure through inter- active review of coordinated models	Facility and Information Asset Management	Commission a building more efficiently
	Preventing litigation through collaborative creation and sign-off of building information models		Quickly populate a facility management database
Sustainability	Reduce energy consumption through energy analysis		Manage facility assets with BIM asset management tools
	Improve operational productivity with model creation and simulation tools		Rapidly evaluate the impact of retrofit or maintenance work on the facility

In this research, an Ambient Intelligent environment has been proposed for the complex infrastructure of hospitals in which facility managers would use a Mobile Augmented Reality-based tool to access operational-level information of building components (e.g. Mechanical, Electrical, Plumbing systems) provided by an integrated BIM model. Facility managers in hospitals, which are complex infrastructure that provide vital 24/7 services, would definitely benefit from this integration and interactive access to their facility information. This integration together with virtually accessing maintenance-related information would lead to higher quality and maintainable infrastructures (Eastman et al., 2008).

Ambient Intelligence (AmI) and Mobile Augmented Reality (MAR)

The aim of ambient intelligence is to integrate ubiquitous computing with an environment that is sensitive and responsive to the presence of people (Aarts, Harwig, & Schuurmans, 2001). In an ambient intelligent system, networked-intelligent devices provide people with information and services wherever they are and whenever they need them (Aarts, 2004). Cook et al. (2009) defined Ambient Intelligence system as ‘‘a digital environment that proactively, but sensibly, supports people in their daily lives’’. In other words, AmI means “an environment must recognize the people that live in it, adapt itself to them, learn from their behavior, and possibly show emotion” (Aarts, 2004). The general idea of AmI can be used in smart homes, health monitoring and assistance, hospitals, transportation, emergency services, education, and workplaces. In a smart home, several items in a house can be connected together and act without human intervention. Many of the AmI technologies in smart homes can be adapted to be used in hospitals (Sanchez, Tentori, & Favela, 2008). In hospitals, AmI has been previously applied in different areas such as enhancing patient and professional safety, following patients' evolution after surgical intervention, and improving the experience of hospital visitors (Cook et al., 2009). In this research AmI was considered for the first time in the area of healthcare facility management practices to provide facility managers with an intelligent BIM-based environment to access facility information.

Augmented Reality (AR), as a part of the intelligent mixed reality, is "an evolution of traditional virtual reality environments" (Riva, 2003) and is "the most ambitious expression of AmI" (Riva, 2003). AR would provide an environment that computer interfaces would seamlessly integrate into reality so that the interaction between users and other individuals or the environment itself would be "in the most natural and intuitive way" (Riva, 2003). According to Azuma (Azuma, 1997), "AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, Augmented Reality supplements reality, rather than completely replacing it". Carmiganiani and Furht point out that Augmented Reality should be (1) "interactive and registered in 3D" and (2) "combine real and virtual objects" (Furht, 2011). Milgram and Kishino (Milgram & Kishino, 1994) defined their reality-virtuality continuum as a range that spans from real environment to the virtual environment (See Figure 6). Augmented Reality (AR) and Augmented Virtuality (AV) are in between where AR is closer to reality and AV is closer to virtuality.

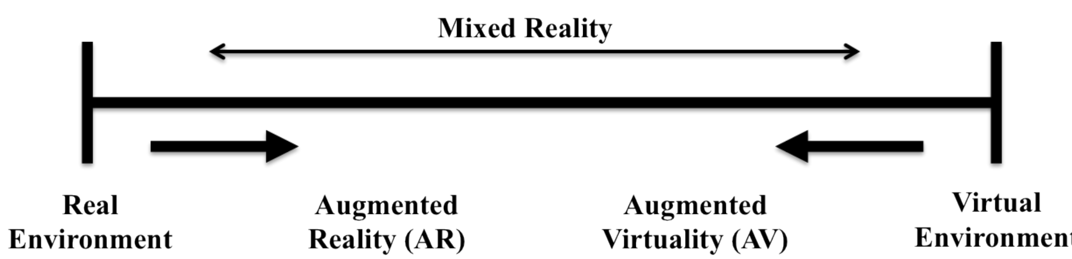


Figure 6: Milgram's reality-virtuality continuum (Milgram, Takemura, Utsumi, & Kishino, 1994)

As Henrysson and Ollila (Henrysson & Ollila, 2004) pointed out in their study on Ubiquitous Mobile Augmented Reality (UMAR), AR can help solve real-world problems because "there is no need for distracting domain switching". As seen in (A. Tang, Owen, Biocca, & Mou, 2003), a study on effectiveness of AR in assembly tasks to sequence and coordinate human procedural action, AR reduced error by 82% and decreased mental effort over traditional methods of instruction including print manuals, computer-assisted instruction monitors, and computer assisted instruction Head Mounted Displays (HMDs). The same study, (A. Tang et al., 2003) also shows that AR reduces head and eye movement increasing user performance, reduces attention switching and helps to memorize better within a real-world reference frame, but it might cause attention tunneling where user's focus is only on the cued area at the cost of other areas.

MAR has been the subject of research for years evolving in complexity not only in terms of software but also in hardware. From HMDs to handheld mobile devices or glasses (e.g. Wrap 1200 and STAR 1200 by Vuzix or Moverio BT-100 by Epson), the field of MAR is constantly changing as technology rapidly improves and makes AR more accessible to the consumer. MAR most important aspect is to identify location and orientation of the user to retrieve the context as to present context-aware information (Karlekar et al., 2010). Research by Feiner et al. (1997) on a Touring Machine show early MAR development where users wore a HMD coupled with a secondary handheld display and a stylus to access information about the world around them. Tinmith (Piekarski & Thomas, 2001) is also a long running AR project from late 1990s to early 2000s where HMD/backpack had partnered with a hand, finger-tracked glove to let users reconstruct and manipulate 3D geometries on-site and in real-time, eliminating the need to do importing/exporting from desktop to mobile. Two years later, Wagner and Schmalstieg (2003) deviated from HMDs and created the first self-tracking AR system on a Personal Digital Assistant (PDA) with an attached camera that utilized the AR Toolkit (Kato &

Billinghurst, 1999). More recently several studies have utilized AR and mobile phones (Henrysson, Billinghurst, & Ollila, 2005; Henrysson & Ollila, 2004). As mobile phones and tablets replace the HMDs, great opportunities have been provided for AR applications that do not require bulky, socially unacceptable hardware. For example Takacs et al. (2011) developed a large-scale mobile AR system that would recognize buildings in live video and register it with pre-existing 3D models, therefore providing only the relevant augmentations in the correct perspective of the smartphone display. Another similar MAR system on a smartphone which was developed by Wu et al. (2011) had a server and client component where geo-referenced 3D data was processed on the server and delivered to mobile client based on GPS.

Localization Strategies for Developing MAR Experiences

Tracking techniques generally fall into the following categories: sensor-based, vision-based, or hybrid. Sensor-based systems can rely on acoustical, optical, mechanical, inertial or magnetic sensors and "are analogous to open loop systems whose output is perceived to have error" (Bajura & Neumann, 1995). Sensor-based systems employ methods like location fingerprinting as seen in Microsoft's RADAR (Bahl & Padmanabhan, 2000) and a study on labor tracking on construction sites (Woo et al., 2011), triangulation as seen in Intel's Place Lab (LaMarca et al., 2005a), multilateration as seen in an implementation of MIT's Cricket System (Popa, Ansari, Riihijarvi, & Mahonen, 2008), proximity as seen in LANDMARC (Ni, Liu, Lau, & Patil, 2004), and dead-reckoning as utilized in inertial and motion sensors (Fuchs, Aschenbruck, Martini, & Wieneke, 2011) like gyroscopes. They calculate measurements like Received Signal Strength Indicators (RSSI), Time of Arrival (TOA)/Time Difference of Arrival (TDOA), and Angle of Arrival (AOA) or Direction of Arrival (DOA) (Deak, Curran, & Condell; Hui, Darabi, Banerjee, & Jing, 2007). But, they are error-prone due largely to component accuracy limitations. It was found that solely utilizing a sensor-based system indoors would introduce significant error variables. Table 2 shows different methods of sensor-based tracking techniques and common disadvantages related to each method have been explained.

Table 2: Different methods of sensor-based tracking technique

Tracking Technique	Method	Issues
Sensor-based	GPS	• Has low user coverage indoors (4.5%) (LaMarca et al., 2005a) • Requires direct lines of sight from a user's receiver to at least 3 orbital satellites (Khoury & Kamat, 2009; Rolland, Davis, & Baillot, 2001) • Suffer from accuracy and availability due to occlusion by buildings and signal reflections • Position errors due to coarse granularity (Karlekar et al., 2010)
	Wi-Fi	• Has high user coverage indoors (94.5%) (LaMarca et al., 2005a) • Accuracy indoors 15-20 meters (LaMarca et al., 2005a)
	Bluetooth	• Has 98% accuracy but needs to have full coverage in a room, target devices need to be stationary for long periods of time (Bargh & Groote, 2008)
	Ultrasonic Sensors	• Are sensitive to temperature, occlusion, ambient noise, require significant infrastructure, and have a low update rate (Rolland et al., 2001)
	Infrared	• Have short-range and are limited because of line-of-sight requirements as seen in Active Badge (Want, Hopper, Falcao, & Gibbons, 1992)
	Radio Frequency (IEEE 802.11, WLAN)	• Do not require line-of sight, but require extensive infrastructure. They have a median accuracy of 2-3 meters (Bahl & Padmanabhan, 2000) • RFID approach lacks in scalability as seen in SpotON (Hightower, Want, & Borriello, 2000)
	Radio Frequency (UWB)	• Signals can pass through walls and offer centimeter accuracy and are relatively expensive to integrate due to high infrastructure costs (Deak et al.; Gezici et al., 2005)
	Inertial Sensors	• Prone to drift • Require constant recalibration (Karlekar et al., 2010)

Other tracking technologies can be categorized as vision-based (utilizing a camera/monocular vision system). Vision-based systems "calculate camera pose relative to real-world objects and are analogous to closed-loop systems which correct errors dynamically” (Feng, Duh, & Billinghurst, 2008). In these systems, tracking of objects in the scene amounts to calculating pose, position and orientation (Bajura & Neumann, 1995), between the camera and the objects (Comport, Marchand, Pressigout, & Chaumette, 2006). These systems are more reliable than sensor-based systems and can dynamically correct errors (Feng et al., 2008). Vision-based systems can be classified as feature-based, or model-based (Pressigout & Marchand, 2006). Feature-based systems can track 2D features such as geometrical primitives, object contours, regions of interest or textures. Model-based systems track edges or textures as they relate to models of the tracked objects from 2D and 3D CAD/templates. Table 3 shows different methods of vision-based tracking techniques and common disadvantages related to each method have been explained.

Table 3: Different methods of vision-based tracking technique

<table>
<tr><th>Tracking Technique</th><th colspan="2">Methods</th><th>Issues</th></tr>
<tr><td rowspan="3">Vision-based</td><td rowspan="2">Feature-based</td><td>Natural Features</td><td>• Track naturally occurring features (points, lines, edges, textures) as seen in (Neumann & You, 1999) and (Vacchetti, Lepetit, & Fua, 2004)
• Depends on system recognizing distinguishable “markers”</td></tr>
<tr><td>Artificial Markers</td><td>• Rely on easily identified artificial features (fiducials)
• Limited by line-of-sight
• Not feasible for large or uncontrolled environments (Reitmayr & Drummond, 2006)
• Example: AR Toolkit (Kato & Billinghurst, 1999)</td></tr>
<tr><td colspan="2">Model-based</td><td>• Track from 2D/3D CAD
• Can leverage existing natural features and extend the range of the tracking area (Feng et al., 2008)
• Prone to occlusion errors and changes in illumination as seen in (Comport et al., 2006; Pressigout & Marchand, 2006; Reitmayr & Drummond, 2006)
• Tracking 3D objects simultaneously, robustly, accurately in real-time frame by frame using 3D CAD (triangles) and 3-4 key frame images (Youngmin, Lepetit, & Woontack, 2008)</td></tr>
</table>

Other tracking technologies can be categorized as hybrid systems where a combination of sensor- and vision-based techniques would be used for tracking purposes. An example of a hybrid system would be the research done by Bell et al. (2001) in which edge-based system tracks the pose of a camera on handheld AR and uses a 3D model for tracking coupled with inertial sensors (natural edges + 3D model + inertial sensors). This hybrid system is more accurate than using either sensors or vision-based tracking alone.

Augmented Reality Challenges in Facility Management Practices

In the facility management domain it is often required to relate physical objects to associated information. This makes AR a good candidate to aid users within facility management practices with their routine tasks because their live view of a space can be supplemented by the information they need, all in one interface. Traditionally, those facility managers need to shift the domains they were working from the physical domain to a printed or digital manifestation of the information related to it. Moreover, since those AECO-related users are constantly moving through the spaces they are working in, having a portable, mobile device would be beneficial if they were to employ AR in their tasks. There are previous studies about Mobile Augmented Reality (MAR) application in the AECO domain. Shin and Dunston (2008) have studied the possible application areas of AR to the construction domain for enhancing performance. The majority of these studies and applications are in the outdoor environment (Behzadan, 2008; Behzadan & Kamat, 2005, 2007). They mainly focus on the design (Dunston, Wang, Billinghurst, & Hampson, 2003) or construction (Chen & Huang, 2012; Golparvar-Fard, Pena-Mora, & Savarese, 2009; Park, Lee, Kwon, & Wang, 2012; Wang & Dunston, 2006) phases but there are also a few studies on MAR application in facility management (Irizarry, Gheisari, Williams, & Roper, 2013 ; Irizarry, Gheisari, Williams, & Walker, 2012) or indoor environment (Kuo, Jeng, & Yang, 2012).

In AR applications for facility management, it is crucial in a video-see-through approach (one where a user views augmentations through a live camera view) that augmentations align properly with the real world. According to Azuma (1997), “one of the most basic problems currently limiting augmented reality applications is the registration problem". Misalignment of augmentations could lead to inefficiencies in workflows and faulty data/asset management. As stated by Bajura and Neumann (1995), there are 4 causes of registration errors in combined real and virtual images:

1. The tracking system's origin is not aligned with the world coordinate system. In mobile augmented reality systems this could result when sensor-based systems fail to provide accurate readings due to issues like line-of-sight or calibration errors. All augmentations would be displaced from their proper positions.
2. The virtual origin-to-object transformation is not the same as the real origin-to-object transformation for a particular object.
3. The virtual camera position is not the same as the real camera position. This error might arise in some mobile augmented reality systems that employ inertial and motion based sensors resulting in misregistration and drift.
4. The virtual camera-to-image mapping doesn't accurately model the real camera. In mobile augmented reality, augmentations may misregister due to inaccurate calibrations of center of projection, field of view, or distortion.

Tablet computers can be considered as a low-cost, low intrusive interaction tool that are becoming very popular and would provide a more natural interaction between the physical and virtual world through their multi-touch window to the facility. Mobile AR together with an integrated BIM model would let the healthcare facility manager access building information through natural interaction with human-computer interfaces. Figure 7 illustrates the hierarchy of concepts from Ambient Intelligent (AmI) to Mobile Augmented Reality (MAR). The MAR together with an integrated BIM model would let the healthcare facility manager access building information through natural interaction with human-computer interfaces.

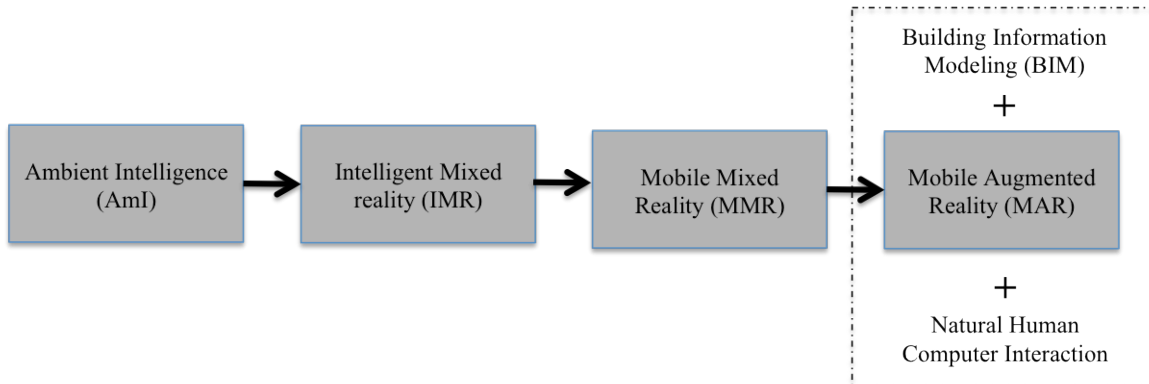


Figure 7: The hierarchy of concepts from AmI to MAR

CHAPTER 5

METHODOLOGY

The project overview has been illustrated in Figure 8 and the related activities are described next. The whole research encompasses three phases of (1) requirement analysis, (2) prototype development, and (3) evaluation and analysis (a user participation experiment).

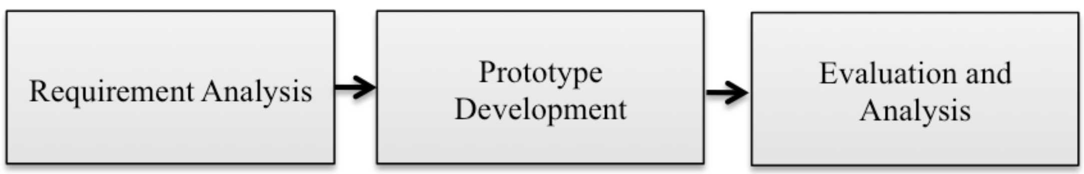


Figure 8: General project overview

Requirement Analysis

BIM and Mobile Augmented Reality (MAR) use and their integration for facility management practices are still new concepts and there is little empirical data on this these topics. The author has used different approaches such as semi-structured interviews, online-surveys and scenarios to investigate BIM and MAR use and their integration for ideal and efficient facility management practices. As illustrated in Figure 9, this part of the study started with face-to-face interviews to assess professional facility managers and their daily operations. An online survey was also used to assess facility managers' characteristics, technology use and working environment as well as the current status of BIM application in their practices. An online video scenario has also been used to illustrate to facility managers how a BIM-MAR integrated environment can provide them with mobile access to their required information. Facility managers' feedback on usability, applicability, and challenges of such environment has also been investigated through a follow-up survey. The following sections explain each part of the methodology in more details.

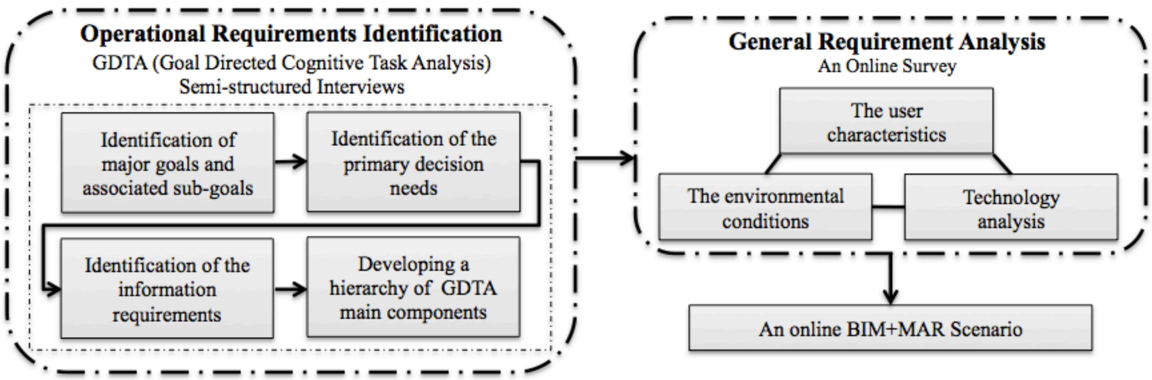


Figure 9: Requirement analysis

Operational Requirements Identification

For designing a system, which supports SA, the operator must identify and illuminate the individuals' needs/tasks in the team, their interaction with one another to meet the common goals, and their information needs to perform the tasks. In this research, a form of cognitive task analysis, Goal Directed Task Analysis (GDTA), was used for this purpose (Bolstad, Riley, Jones, & Endsley, 2002). The GDTA was employed broadly for analysing SA requirements of individuals (Mica R. Endsley, 1993; Mica R. Endsley & Rodgers, 1994). Reasons for selection of the GDTA include: (1) it is not tied to the technology being used to carry out the task (i.e., it is independent of how tasks are done within a given system but it depends on what information is needed); (2) it does not just focus on people's data needs, but on how the data can be used within decision-making and the goal attainment process; and (3) it focuses on obtaining an accurate depiction of the SA requirements and key goals for each individual (Strater, 2001).

Operational requirement identification part in Figure 9 illustrates the overview of the GDTA-based methodology. The GDTA has three main components: goals, decisions, and SA requirements (M. R. Endsley et al., 2003). It focuses on: (1) the basic goals of the operators; (2) the major decisions for accomplishing these goals; and (3) the SA requirements for each decision. The knowledge obtained through the GDTA can help designers to design systems and in this case an AmI-based HFM system that enhances SA of facility managers together with their decision-making and performance. The steps involved in a GDTA semi structured interview are as follows (M. R. Endsley et al., 2003):

1. Identification of key decision-makers: the key decision-makers who are playing the significant role should be chosen for applying the GDTA methodology.

2. Identification of major goals and associated sub-goals for each decision-maker: each decision-maker should be asked about his/her main goal.

3. Identification of the primary decision needed for each sub-goal: each decision-maker should be enquired about the sub-goals, which are necessary to accomplish the main goal.

4. Identification of the SA information requirements for making those decisions and performing each sub-goal: The sub-goals would serve to set the direction for clarifying the primary decision needed for each sub-goal and the information needs to accomplish those sub-goals.

Identification of key decision makers would be a very important step that clarifies the target population of this study. Considering facility managers in general as the target population of this study would lead to significant challenges in performing the GDTA methodology. Based on the author's previous experience in applying GDTA to the FM domain (Gheisari & Irizarry, 2011), not narrowing down the target population of the facility management practices to a specific groups would lead to discrepancy of SA goals or requirements between various facility management SMEs. The problem happens due to very large scope of facility management domain and the very different backgrounds of the SMEs. These issues would influence their priorities, goals, and requirements as facility managers. Professional and experienced managers should be chosen considering a very detailed scope for the operational level of the healthcare facility management. Narrowing down from general Facility Management domain to the Healthcare FM as complex infrastructures and focusing only on experts in the HVAC system (operational level) would lead to a group of technicians who are working as a facility manager or under the supervision of a facility manager and would provide an appropriate set of goals and requirement as the result of the GDTA. These technicians, their requirements, as well as their working environment would be investigated in detail in the General Requirement Analysis section.

GDTA involved semi-structured interviews in which the interviewer would ask each Subject Matter Expert (SME) about his/her main goal as a healthcare facility manager. The SMEs and the operations they usually perform should be defined in the general requirement analysis. The interviewer would continue to enquire about the sub-goals, which are necessary to accomplish the main goal. These sub-goals would serve to set the direction of the remainder of the interview and clarifying the information needs to accomplish the sub-goals of a healthcare facility manager. Creating a comprehensive GDTA for a particular job would take anywhere from 3 to 10 interviews, depending on the complexity of the position (M. R. Endsley et al., 2003). One-on-one interviews were conducted with those managers following the GDTA methodology. The interviews lasted approximately one hour and were audio recorded for the purpose of reviewing responses. A study protocol was prepared and reviewed by the Georgia Tech Institutional Review Board (IRB) for compliance with Human Research Subjects regulations. Based on the protocol, subjects provided their consent before the interviews. The information obtained from the GDTA was organized into a figure depicting the hierarchy of the three main components of the GDTA (i.e., goals/subgoals, decisions relevant to each subgoal, and the associated SA requirements for each decision).

The GDTA hierarchy, together with the feedback provided from the survey and scenario questionnaire, would form the basis for designing an MAR-based guideline for accessing healthcare facility information and supporting healthcare facility managers in achieving SA-requirements of their goals.

General Requirement Analysis through an Online Survey

Within the whole AECO practices, the most important element that should be studied in detail is the element of human. Humans are the most precious capital in AECO industry and understanding their requirement, characteristics, and the way they do their tasks would be of great value for development of tools or systems that would facilitate their practices. For gaining this purpose an online survey was designed to target a wide range of Facility Managers and determine their characteristics, working environment, and technology use/familiarity. International Facility Management Association (IFMA) and American Society of Healthcare Engineers (ASHE) were considered as potential sources of survey respondents.

The user characteristics part of the survey was investigating general Facility Managers characteristics considering issues such as gender, skill levels, training, and background knowledge, age ranges, visual acuity and hearing capabilities, languages to be accommodated, special clothing or other equipment to be accommodated (such as gloves, masks, or backpacks) for development of a system or an IT tool that can facilitate their practices. (M. R. Endsley et al., 2003).

The other important issue that should be studied is the environmental conditions that the facility managers are working at. Ambient noise levels, lighting levels, susceptibility to weather and temperature variations, vibration, privacy, expected pace of operations, and position of use (e.g., sitting, standing, while mobile) are some issues that should be considered as the environmental conditions to build systems that can ultimately serve facility managers most efficiently (Endsley, Bolte et al. 2003). Figure 10 illustrates a typical working environment of a HVAC Technician in Grady Hospital, Atlanta, GA.

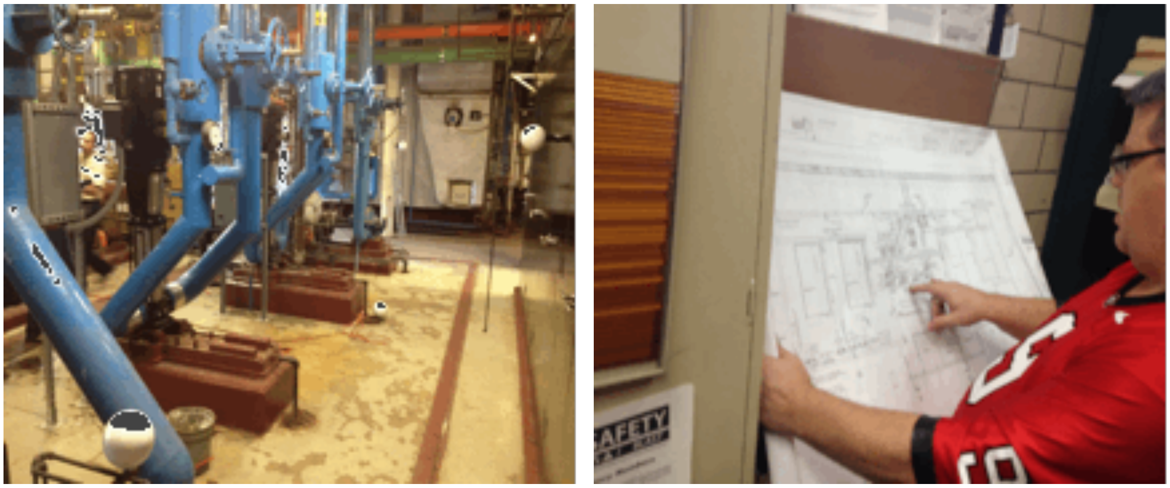


Figure 10: A typical working environment of a HVAC Technician in a healthcare facility (Grady Hospital, Atlanta, GA, USA)

In the technology analysis part of the online survey, Facility Mangers' use and familiarity with different type of technologies and tools would be investigated. Building any system for facility mangers should consider their current use and familiarity of different types of technology for their different tasks. Since the application of BIM, MAR, and handheld mobile devices (e.g. iPad or iPhone) is still new in the operational level of facility management and there has not been enough empirical studies on this topic, considering the focus of this research, this section of survey was used to explicitly investigate the current status of these technologies in facility management practices.

The proposed Ambient Intelligent Platform requires some technological components to be developed. Virtuality (BIM) and Reality (Facility) should be integrated using Augmentation to provide an Augmented-Reality-based environment. This environment would be accessible for the facility managers using Natural Human-Computer Interaction. The user will need different levels of intelligence support based on their location or direction of view and the system should be capable to adapt itself based on these requirements. In this platform, the system would require visual data based on where the user is in the facility and also the direction he/she is looking. The initial steps to achieve this vision led to the development of InfoSPOT, which relies on the BIM to provide AR-based information for facility managers (Joyce, 2012).

This survey was accompanied with an annotated video scenario (See section 5.1.3), describing the ideal integration of BIM, MAR, and handheld mobile devices for performing an operational maintenance task. This video provided the targeted facility managers with an initial familiarity of those elements and their integration for performing facility management related tasks and would result in getting better feedback and comments from facility managers in general as well as the HVAC technicians.

An Online BIM+MAR Scenario: ARWindow

This survey was also accompanied with an annotated video scenario called ARWindow Scenario, describing the ideal integration of BIM, MAR, and handheld mobile devices for performing an operational maintenance task (Figure 11). In this scenario specific pieces of information were augmented to the facility manger's mobile tablet computer (e.g. iPad) from the BIM model of the facility, based on the facility manager's task, location in the facility, and direction of view. This video would provide the targeted facility managers with an initial familiarity of those elements and their integration for performing facility management related tasks and would result in getting better feedback and comments from facility managers in general. The video was uploaded on YouTube and then embedded at the end of an online survey and followed by some questions to get Facility Mangers' feedback and comments on it. The video is accessible through the following link: https://www.youtube.com/watch?v=RS24RpfatxY. This section discusses the same scenario in text format. As previously mentioned this scenario served to collect SMEs' feedback on HFM practices in an Augmented-Reality-based environment.

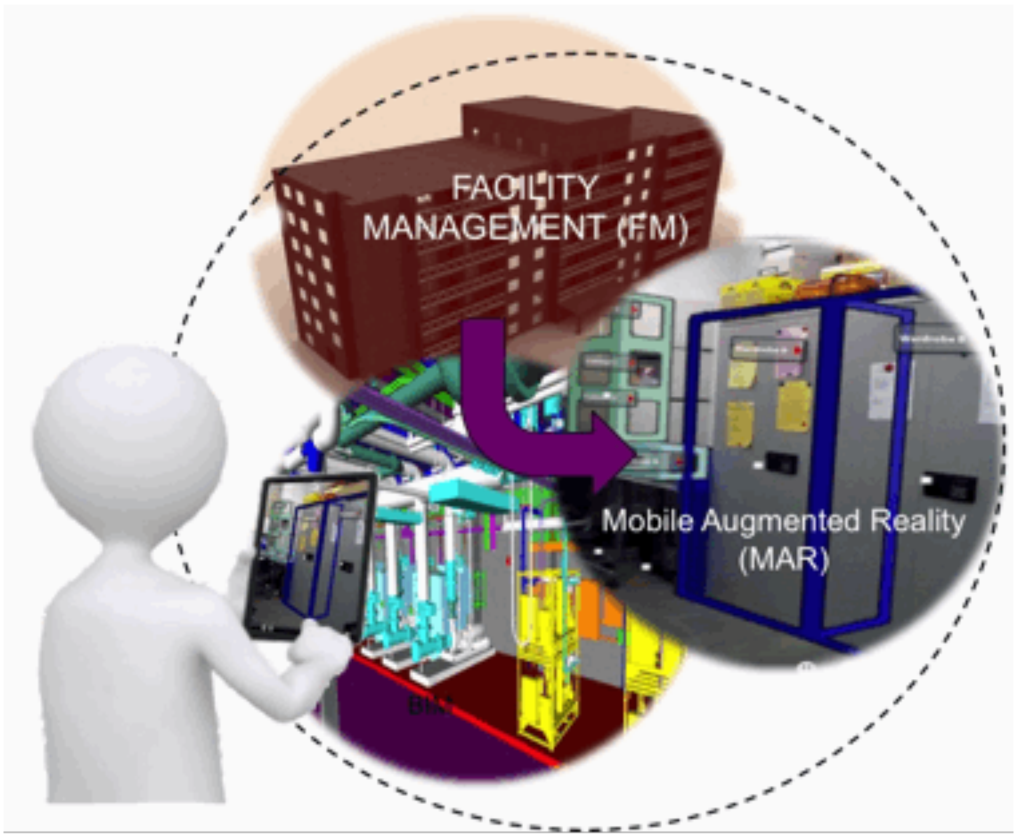


Figure 11: An ambient intelligent environment for facility operation inspection

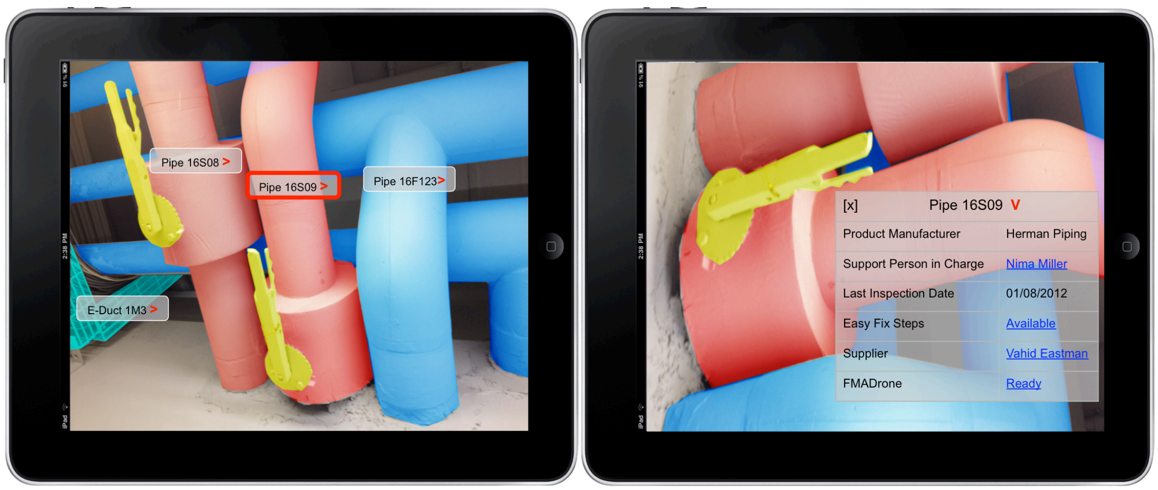
The Scenario: In this hypothetical scenario, Ryan Eastman is a facility manager at a 22-story hospital, in Anytown USA. One of Ryan's tasks is to go around the facility and check the status of the Mechanical, Electrical and Plumbing (MEP) systems. He receives a daily work order of some problematic MEP systems in the hospital. Figure 12-a shows Ryan's real-world view of the hospital and Figures 12-b and 12-c shows how his required information would be augmented on his real-world view of the hospital through his tablet computer. As illustrated in Figure 12-b, he has just solved the lighting problem on the

10th floor (the task in green) and is heading to the 16th floor to inspect a leaking pipe (the task in red). He uses his tablet computer as an interaction tool where all the required information has been augmented to his real worldview of the facility. As illustrated in Figure 5-b, a directional arrow shows Ryan which route in the building he should follow to perform his next task: inspecting a leaking pipe on the 16th floor. Only a specific part of the information that is required for performing the current task (information about piping system of the facility) would be augmented on Ryan's user interface (Figure 12-c). All this information would be provided from the BIM model of the facility that is the main data repository of all the objects in the facility.

(a) Real-world view of the facility (b) Navigation and task list (c) Filtering information from BIM model

Figure 12: Providing an augmented layer of information on real view of the facility manager

Based on Ryan's current task of fixing the leaking pipe on the 16th floor, Pipe 16S09 has been highlighted in red as a problematic component (Figure 13-a). When Ryan touches the augmented tag attached to the 16S09 pipe, an augmented table of required information is displayed (Figure 13-b). Different information such as product manufacturer, support people in charge, supplier, last inspection date, and the availability of easy fix steps have been provided in the table. Ryan would touch the “Easy Fix Steps” to see whether he can fix the leaking pipe following the steps provided.



(a) The problematic component in red (b) Information table

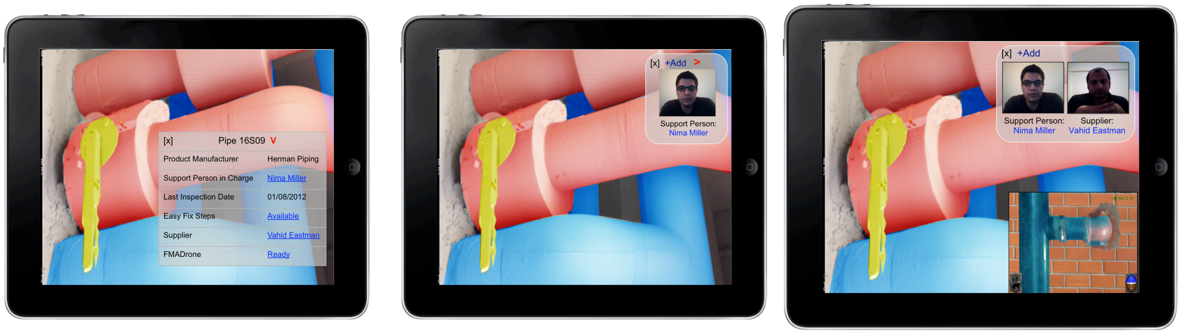
Figure 13: System interface

A set of augmented visual steps for fixing the leaking problem would be displayed on the tablet. The first step is to press the handle on the pipe valve. The required instruction has been provided in red on the interface (Figure 14-a). As soon as Ryan presses the handle, the related instruction would change into green, representing the successful performance of part one of the fixing pipe task and then the next part of the task (rotating the handle to the left side) would turn into red intelligently (Figure 14-b). When Ryan performs the last part of the fixing task, all the instructions turns into green (Figure 14-c) meaning he has followed all the instructions correctly. Although the system is BIM-based but is also sensitive to changes in the environment and uses image recognition to report those changes.

(a) Part 1: Pressing the handle (b) Part 2: Rotating the handle (c) Successful performance of part 1 and 2

Figure 14: Easy fix steps

Although Ryan has performed the “Easy Fix Steps” correctly, the problem has not been fixed yet. So Ryan closes the “Easy Fix Steps” window and touches the “Support Person in Charge” in the Information Table (Figure 15-a) to start a videoconference with the technician (Nima Miller) while providing him with real time video of the problematic object in the MEP system (Figure 15-b). Nima believes that the leaking problem is because of the age of the valve and recommends its replacement. Now, Ryan invites the supplier (Vahid Eastman) to the videoconference to let him know what exactly they need for fixing the leaking pipe so Vahid can provide the exact part to them (Figure 15-c). Ryan just resolved this problem and is going to inspect the next problem in his work order.



(a) Information table

(b) Videoconferencing with technician (Nima)

(c) Multiple views while video conferencing with technician and supplier

Figure 15: Collaboration between facility manager (Ryan) and technician (Nima) and supplier (Vahid)

Prototype Development

The methods and procedures used to generate the MAR-based system prototype have been illustrated in Figure 16. First, a BIM model of a healthcare facility (e.g. a hospital) was acquired and checked for accuracy to built environment conditions. This first step is based on the assumption of having an as-built BIM model of the facility. For the new healthcare faculties, it's now more common to develop the BIM model from design to construction and hand it to the Facility Management group afterwards. But most of the existing healthcare facilities do not have any BIM model. Considering this issue, the BIM model of an existing facility was developed using the laser scanning technology. Practically speaking, building the whole MAR system on the BIM model of the facility, means that the developer should provide the accurate BIM model of the facility at the end of the construction to the facility management group. Any inconsistency of the model with the real environment should be resolved through surveying the test area and making adjustments to the BIM model. Second, the BIM model was separated into geometry and data files. The BIM geometry was exported to the .fbx file format to be used in a visualization-based 3D modeling software. BIM Geometry can be converted into many data formats including, but not limited to .fbx, .dxf, .dwg, etc. Testing was done on each of the geometry export options available through Autodesk REVIT. Each file format was measured against several variables that have typically indicated errors in the format conversion process. These errors were stated by McHenry and Bajcsy (McHenry & Bajcsy, 2008) in a technical report and are mainly due to software/hardware incompatibility and product data quality. The BIM data will then be exported to Open Database Connectivity (ODBC). Each instance of geometry in the BIM model is associated with a unique identifier and corresponding data. Third, the exported BIM geometry was optimized using several manual-modeling techniques to reduce complexity. These techniques include welding overlapping vertices, eliminating unnecessary geometry, and mesh simplification. Next, panoramas was generated with the purpose of replacing 3D models in the prototype. The camera in a tablet device usually has a field of view of approximately 45mm. A camera was placed in the 3D scene containing the optimized model and 360-degree panoramas was taken for use in the AR conditions of the system.

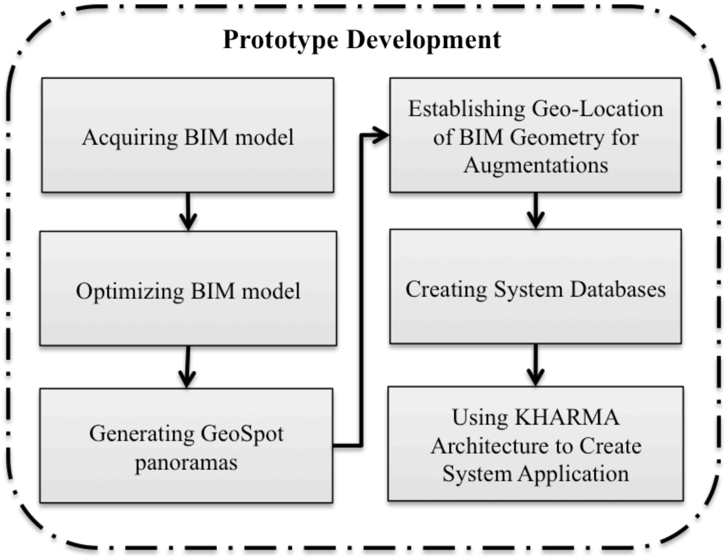


Figure 16: MAR-based System Development Diagram

Optimized geometry will then be imported into Google SketchUp powered by Google Maps and Google Earth software to establish geo-referenced locations for augmentation markers in the facility. Prior to import into the software, the researcher will locate several augmentation spots in the asset. These spots are to represent graphic markers of several objects in the test area that users of the prototype could select to view required HFM-related information. The centroids of each spot was observed and latitude, longitude, and altitude was recorded in a database. Finally, the KHARMA architecture was utilized to create the system prototype.

Developed by researchers at the Georgia Tech Institute of Technology, KHARMA (Hill, MacIntyre, Gandy, Davidson, & Rouzati, 2010) extends upon KML, an XML language used to describe geo-referenced maps, images, and models, and utilizes HTML, JavaScript, CSS, and AJAX techniques to provide augmentations to a mobile client. KHARMA was used because of its low-cost, ease of implementation, and its ability to utilize surveyed locations called GeoSpots. According to Azuma (1997), "one of the most basic problems currently limiting Augmented Reality applications is the registration problem". In AR applications for facility management, it is crucial in a video-see-through approach (one where a user views augmentations through a live camera view) that augmentations align properly with the real world. Misalignment of augmentations could lead to inefficiencies in workflows and faulty asset management, which makes the use of GeoSpots beneficial for the system. This problem might lead to more serious issues when the target facility is a healthcare asset.

GeoSpots create geo-reference points of latitude and longitude associated with different descriptive information. Users can tell their device they are located at the GeoSpot and augmentations was delivered to their screen relative to that GeoSpot. GeoSpots are a good solution for the proposed system because it makes it possible to get more accurate registration and indoor localization than with native tablet hardware alone and eliminates the need for fiducial markers that would not really be feasible in a true facility management situation requiring thousands of unique tags for all objects in a managed space. Equipped with a three-axis gyroscope, accelerometer, Wi-Fi, and digital compass hardware, a tablet device utilizing the GeoSpots would reduce the problem of "when the real and virtual do not align properly the illusion is compromised" (Azuma, 1997). Previous research also validated that relying solely on the tablet hardware alone would cause large registration and indoor localization issues, therefore the utilization of GeoSpots is necessary to maintain the AR illusion for users. Some tablets come equipped with Global Positioning Technology (GPS) but even if these models are employed in our study, research has shown that no improvements would have been seen in registration or localization. A study by LaMarca et al. (2005b) in which users would carry GPS devices during different portions of their typical day demonstrated this point. The results showed that GPS devices showed low user coverage (4.5%). LaMarca et al. (2005b) surmised that this was likely due to users typically spending most of their time indoors where GPS technology suffers from multi-path effects, interference, and noise. Instead of GPS, the tablets use WiFi for localization. As the same study by LaMarca et al. (2005b) indicates, WiFi had higher user coverage than GPS (94.5%) with an accuracy of 15-20 meters. But, facility managers often need to query and organize objects that are within centimeters of each other, which makes standalone WiFi unsuitable for this application. Other research indicates new techniques or implementation of other common built-in hardware found in today's mobile devices could become better sources for localization in indoor environments in the future. A study by Bargh and Groote (2008) implements a system that utilizes merely Bluetooth technology to locate someone indoors with 98% accuracy. The downfall of the prototype is the requirement of full Bluetooth sensor coverage in a room and target devices needing to be stationary for long periods at a time (longer than a few seconds) that is unsuitable for facility management practices.

While GeoSpots allows users to accurately position themselves initially, drift and lag caused by commodity grade sensors in the tablet creates registration errors after initialization which could only be avoided if the tablet location is manually recalibrated every few seconds. One study in particular by Wither et al. (2011) was used in this research to circumvent these tracking inaccuracies inherent in using only the tablet hardware. Wither employs a "magic lens" approach to AR utilizing pre-prepared panoramas of specific locales and placing augmentations over them. Pre-prepared panoramas allow for consistent alignment of augmentations and removed registration errors found in the live video feeds used by typical mobile AR applications.

Evaluations and Analysis

An experiment for the evaluation of the impact of MAR-based information accessing system on healthcare facility management tasks was performed. The experiment consisted of using a tablet computer device as a mobile AR tool to locate a facility component in a specific test area. The user's task was defined based on the outcome of the GDTA as well as the online survey. The experimenter would measure different subjective, objective, and workload variables. As same as with the GDTA semi-structured interviews, Georgia Tech's Institutional Review Board (IRB) was evaluated and approved the study protocol. The subjects were required to fill out a demographic information form before starting the experiment and had to speak their thoughts aloud while performing the tasks in the experiment. Different statistical methods were used to study statistical as well as practical significance of the variables measured.

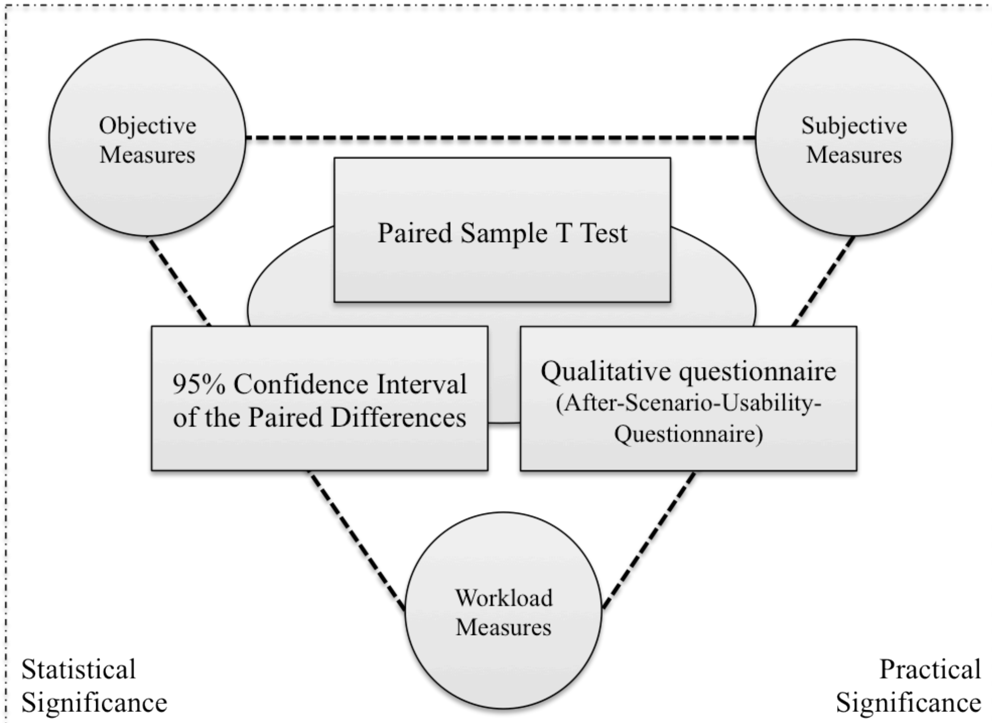


Figure 17: System evaluation and assessment

Following section will discuss the concept of Statistical Significance and then in the section afterwards the concept of Practical Significance and the reasons for deploying a practical approach together with the statistical one will be explained. Different statistical tools that would be used in this study for evaluation purposes and investigating Statistical and Practical Significance will be introduced (Table 5). Afterwards the concept of the Statistical Power as the state of correctly rejecting the null hypothesis will be discussed. Finally, different measures of operational level facility management practices in a BIM-MAR environment discussed and the ones that are of interest in this research will be introduced.

Statistical Significance

Two statisticians, Jerszy Newman and Egon Pearson (1933), provided a rubric that is used to determine whether or not a difference between two groups is statistically significant (Table 4). The very first step to test a hypothesis based on this concept is to build an assumption that there is no difference between two conditions. This assumption is called H_0. Generally the null hypothesis states, there is no difference between the control and experimental (treatment) group means. But researchers usually hope to reject or disprove the H_0. In the case of this research the null hypothesis is that there is no significant differences between the control and treatment conditions, in terms of subjective, objective, situation awareness and maintenance measures (Equation 1). Those conditions will be well-defined after system requirement and development phase but ideally they will be comparisons between Traditional Method (TM) and new Mobile Augmented Reality (MAR)-based approach or solely comparisons between different versions of the MAR-based system. H_0 happens when null hypothesis is true and H_A is the alternative hypothesis and happens when null hypothesis is not true.

$$H_0: \mu_{TM}=\mu_{MAR}$$
$$H_A: \text{Not } H_0$$

Equation 1: Specifying the Hypothesis

A statistical significance rubric should be viewed from two perspectives. First there are two (mutually exclusive and exhaustive) *states of the world*; (1) there is no difference between the control condition and the experimental (treatment) condition, which means the treatment had no effect on the dependent variable, and (2) there is a difference between the control condition and the experimental (treatment) condition.

Secondly there are two (mutually exclusive and exhaustive) *decisions that can be made*: (1) stating that there is a difference between the control condition and the experimental (treatment) condition which means rejecting the null hypothesis, and (2) stating that there is insufficient evidence to assert there is a difference between the control group and the experimental group, which means retaining the null hypothesis (retaining the null hypothesis is not the same thing as affirming the null hypothesis).

Table 4: Statistical decision making: four possible outcomes of a study comparing two conditions, X and Y, adopted from Goodwin (2009)

<table>
<tr><td></td><td></td><td colspan="2">The True State of Affairs</td></tr>
<tr><td></td><td></td><td>H_0 is true: There is no difference between X and Y</td><td>H_0 is false: There really is a difference between X and Y</td></tr>
<tr><td rowspan="2">Your Statistical Decision</td><td>Fail to reject the H_0: There is no significant difference between X and Y, so H_0 is not rejected.</td><td>Correct decision
$(1-\alpha)$</td><td>Type II error
(β)</td></tr>
<tr><td>Reject H_0: There is a significant difference between X and Y, So H_0 is rejected.</td><td>Type I error
α</td><td>Correct decision
$(1-\beta)$</td></tr>
</table>

Table 5 defines all the four possible outcomes of a Null Hypothesis Significance Testing (NHST) where there are two correct decisions (decisions matches truth) and two incorrect decisions (decisions does not matches truth). α is the probability of rejecting the null hypothesis when it is true while $(1-\alpha)$ is the probability of retaining the null hypothesis when it is true. Statistical power $(1-\beta)$ is the probability of rejecting the null hypothesis when it is false whereas β (miss) is the probability of retaining the null hypothesis when it is false. Ideal status is to reject the null hypothesis while H_0 is really false. Incorrect decisions are to reject the null hypothesis while it is really true (falling in type I error) or retain it while actually there is a difference between the conditions (falling in type II error). But only having a statistical significant difference between conditions in this research will not appropriately and adequately reveal the differences between conditions.

Table 5: Statistical decision making outcomes; definitions and lingos

		Truth, State of Nature, Situation in the Population	
		H_0 is true	**H_0 is false**
Your decision based on your sample	**Retain H_0**	Correct Decision: Decision Matches Truth P (retain H_0 | H_0 is True)= $1-\alpha$	Incorrect Decision: Decision Does Not Match Truth P (retain H_0 | H_0 is False)= β Type II error (Miss)
	Reject H_0	Incorrect Decision: Decision Does Not Match Truth P (reject H_0 | H_0 is True)= α Type I error (False Alarm)	Correct Decision: Decision Matches Truth P (reject H_0 | H_0 is False)= $1-\beta$ Power

What actually statistical significance testing does is to draw inferences about some characteristics of a population using some samples form that population. So a hypothesis is developed, samples are drawn from population, and a statistical test would be conducted on the subjects performing a facility management-related task to acquire a probability value and at the end if the value was below some criterion (.05, .01, or etc.) the population will not have the studied characteristics as hypothesized in the null, so happily our study would be successful. But there are some problems with statistical significance testing. This testing is inadequate for determining the importance of the results and the likelihood of obtaining similar results in the future. This testing methodology is unable to calculate the probability that the null hypothesis is true so we have to use some assumed numbers that have traditionally been used in the field. Also significance testing is unable to calculate the probability that the results are obtained by chance which means the sample might not be a true representative of the population or the results are atypical. Moreover, this test is also unable to calculate the probability that the same result will be found in any study that replicates the same methodology. The most important problem with the significance testing is that it doesn't show that studied effect is a true effect in the population. The calculated P value is showing the combination of effect size and sample size and does not directly measures the magnitude of observed differences. So statistical significance can be achieved due to a large effect, a large sample size or both. So situations might be faced that results are statistically significant due to a large sample size but there is small magnitude of observed differences between different conditions. This means that not only the statistical significance of results should be studies but also their practical significance should be investigated.

Practical Significance

Usually researchers want to answer three different questions (Kirk, 2001): (1) is an observed event real or it is due to a chance?, (2) how large is the effect, if it is true?, and (3) is this effect useful?. The significance test only answers the first question by telling us the probability of obtaining the effect if the null hypothesis is true. The significant test doesn't provide us with largeness of the effect or its importance or usefulness for us. Kirk (2001) says that focusing only on the statistical significance (obtaining a small *p* value) of an effect deviate us from he main business of science which is interpreting the outcome of research and theory development. Frank Yates (1951) has touched the same problem by stating that the null hypothesis significance test "has caused scientific research workers to pay undue attention to the results of the tests of significance they perform on their data, and too little to the estimates of the magnitude of the effects they are investigating. The emphasis on tests of significance, and the consideration of the results of each experiment in isolation, have had the unfortunate consequence that scientific workers have often regarded the execution of a test of significance on an experiment as the ultimate objective."

Consequently, for truly achieving the ideal result in this research, in addition to the statistical significance of results, two other characteristics of the effect were studied: (1) its magnitude (effect size) and (2) its meaningfulness (subjective and person dependent). An "ideal" practical significant status will not only be statistically significant but also would have a large-size and meaningful effect. The term practical significance implies "a research result that will be viewed as having importance for the practice of education or, in other words, it will be viewed as important by teachers, school administrators, policy makers, and others concerned about the day-to-day workings of education and efforts to improve it" (Gall, 2001). There is no specific statistics that directly measure the usefulness (practical significance) of a test. Confidence intervals as well as standardized measures of effect magnitude (e.g. effect size and strength of association) can be used for making decision on practical significance of the results (Kirk, 2001). Figure 18 illustrates the most common effect sizes tools and Table 6 shows some magnitudes of effect and Cohen's view (Cohen, 1988) about some of them in the social and behavioral sciences.

	Standardized Differences	Relationship Variance-Accounted-For
Uncorrected	Glass's g' Cohen's d	eta^2 (η^2; also called correlation ratio [not the correlation coefficient!])
"Corrected"	Thompson's "Corrected" d^*	Hays's omega^2 (ω^2) Adjusted R^2

Figure 18: A framework for conceptualizing the most common effect size indices (Measures of Association) (Thompson, 2002)

Table 6: Cohen's view (1988) about levels of effect size in the social and behavioral sciences

Index	small	medium	large
d	0.20	0.50	0.80
r	0.10	0.30	0.50
f	0.10	0.25	0.40
f^2	0.02	0.15	0.35
w	0.10	0.30	0.50

Focusing on the size of effects and their practical significance can serve the science much better. The APA board of Scientific Affairs requests to report the effect size together with the significant test result to see "briefly" whether the units of measurement are meaningful on practical level or not (Wilkinson, 1999). The word "briefly", means that even effect size is not a complete representation of the practical significance and does not reveal the meaningfulness of an effect completely. This happens due to two problems: (1) effect size treats all measurement scales alike and (2) it does not express the shape or variability of the score distributions of the two groups (Gall, 2001). Replication is another method for checking the practical significance. When possible, it would be beneficial to replicate findings by conducting another study or analyzing an unrelated dataset. A certain effect found repeatedly across multiple samples provides strong practical evidence.

In this research, a statistical significant test (paired-sample-T-test) was employed. For practical significance, 95% confidence limits for each of the dependent variables as well as conducting a qualitative research through After-Scenario Usability Questionnaire (ASUQ) with open-ended areas for comments were used. Confidence interval not only contains all the information that the significance test provides but also illustrates a range of values within which "the effect parameter is likely to lie" (Kirk, 2001). The qualitative research would provide us with better understanding about the phenomenon and might contribute to the practical concept through suggesting theoretical hypothesis or variables. Table 7 illustrates the tools that were used in this research for covering both statistical and practical significances. In this project, for each effect, the results of statistical significance together with confidence interval were used while using qualitative results to support them.

Table 7: Statistical tools used in this research

	Significance Type	
Statistical Concepts and Tools	Statistical Significance	Practical Significance
Statistical Significance Test Tool: paired-sample-T-test	✔	
95% Confidence Intervals of the paired differences	✔	✔
Qualitative Research Tools: ASUQ, Observing Subjects in a Thinking-aloud Process		✔

Statistical Power

As discussed previously, power is the state of correctly rejecting the null hypothesis or in other words, the ability to detect an effect if there is one (Equation 2).

$$P\ (\text{Reject } H_0 \mid H_0 \text{ is False}) = 1 - \beta$$

Equation 2: Statistical Power, H_0 is Null Hypothesis & β is Type II Error (Miss)

Power rather than being set is determined by:

1) Sample size; the power of the test increases as n increases.

2) α-level; as α increases (i.e. making the test more conservative), the power of the test decreases. Nonetheless an α-level of .05 is traditionally used.

3) 1-tailed tests are more powerful than 2-tailed tests. Nonetheless a 2-taled test should be used unless the mean difference that may occur in a particular direction is not within the interest of the researcher.

4) Effect size; larger difference between control and treatment groups lead to more powerful tests. In this case, the treatments should be made as strong as possible.

5) Error variances; smaller variances lead to more powerful tests. In this case, extraneous sources should be controlled as much as possible.

The power analysis can happen before or after the study: (1) post-hoc (retrospective) power analysis where the researcher has already analyzed the data and typically there is an effect of interest that was not statistically significant, and (2) a priori (prospective) power analysis where the researcher is planning a study and wants to determine the power that might be achieved with a given sample size if group differences and variability in the dependent measure were similar to the predictions. In a post-hoc study, an estimate of the difference in group means in the population can be obtained from the studied sample but in a priori study this should be done usually through research literature, pilot study, expert judgment and educated guessing. Also an estimate of the standard deviation of the dependent measure in the population (σ) should be provided for assessing the power (1−β). Usually the $(s^2_{pooled})^{.05}$ is considered as an estimated of the common σ.

Usually in a post-hoc power analysis, power would be calculated for given sample sizes, effect sizes, and α-levels. But in a priori power analyses, sample size would be calculated for given power values, effect sizes, and α-levels. There is no formal standard for the statistical power but researchers usually use a 4-to-1 trade off between β and α to get to a 80% power (β=0.2, α=0.05, and Power=1− β=0.8). But based on the context of the research, this weighting might be different. For most statistical tests, power is easily calculated from using statistical computer software such as G*Power, PASS, and nQuery (Thomas & Juanes, 1996) or Cohen's tables (Cohen, 1988).

In this research, just considering a within-subject approach for design the experiment would increase the statistical power. Studying multiple outcomes for each subject allows each subject to be his or her own control which leads to removing subject-to-subject variation from investigation of the relative effects of different conditions. This reduced variability directly increases power, often dramatically and indirectly reduces the number of subjects required for the study.

CHAPTER 6

PILOT STUDY- GDTA + INFOSPOT

In the preliminary stages of this research, the GDTA methodology was applied with facility managers (Gheisari & Irizarry, 2011). The outcomes were used as the foundation for the development of the InfoSPOT system, a Mobile Augmented Reality (MAR)-based tool integrated with BIM model of the facility (Gheisari, Williams, Irizarry, & Walker, 2012). A within-subject user participation experiment was performed to evaluate system usability considering some objective and subjective measures. This chapter provides a brief overview of this pilot study and lessons learned for enhancing the proposed stages of the research will be discussed.

Application of the GDTA to the General Facility Management Domain

Application of the GDTA involved structured interviews in which the interviewer asked each subject about his/her main goal as a facility manager. The interviewer continued to enquire about the sub goals, which are necessary to accomplish the main goal. These sub goals would serve to set the direction of the remainder of the interview and clarifying the information needs to accomplish the sub goals of a facility manager.

Results & Discussion: The GDTA-based interviews conducted with facility management SMEs provided the necessary information for developing the goal hierarchies and related SA requirements. By combining these hierarchies, a unique hierarchy of goals for the facility managers was achieved. This section explains the hierarchy of goals and SA requirements.

The main goal of a facility manager was identified as "proper care of existing facilities and manage the facility safety and productivity." The following figure illustrates the hierarchy of main goal and sub goals of a facility manager. As illustrated in Figure 19, for achieving this main goal, facility managers should accomplish three major subgoals. These three subgoals are (1) monitoring the activities within the facility, (2) determining facility needs, and (3) managing facility resources.

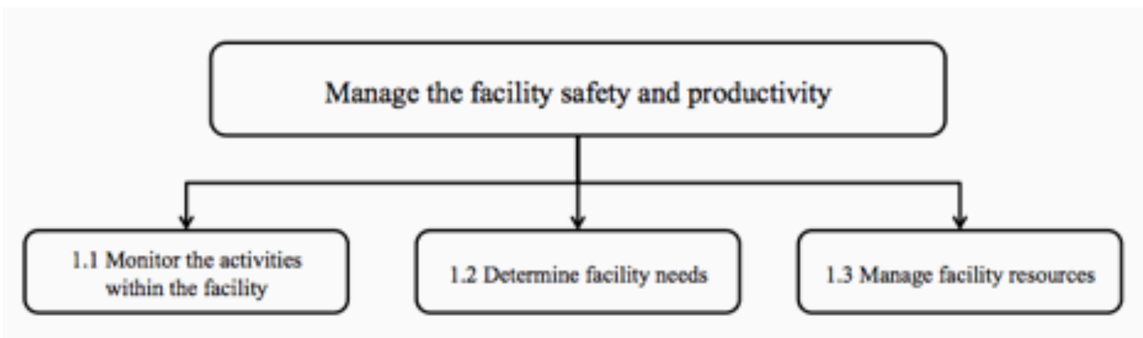


Figure 19: Goal hierarchy of facility managers

"Monitoring the activities within the facility" is the first subgoal, which was declared by SMEs for accomplishing the main goal of a facility manager. Based on Figure 20, for achieving this subgoal, facility managers should answer two questions:

1. Do facility managers understand the contracts to get the best values of the services, which they are contracting for?
2. What groups are using facility managers' data? Why are they using the data?

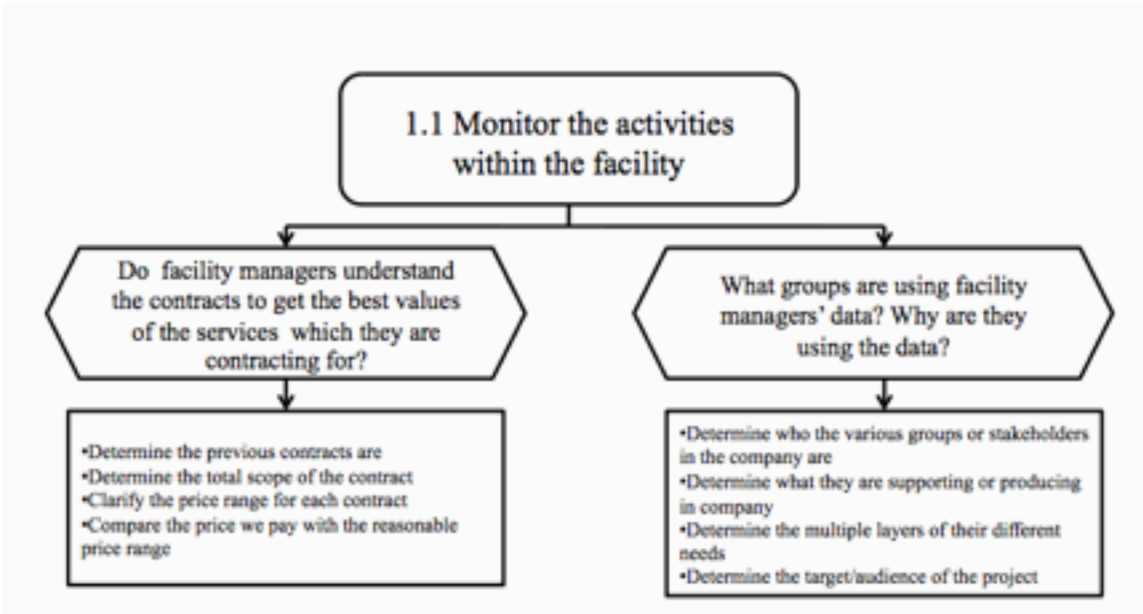


Figure 20: Decisions and SA requirements for first subgoal of facility managers

These questions show the decisions that facility managers should make to accomplish "monitoring the activities within the facility" (first subgoal). The bullet points in the figure 20 are the information and SA requirements that a facility manager needs in order to make these decisions. For knowing whether the facility managers have understood the contracts to get the best values of the services which they are contracting for, facility managers should for example consider previous contracts, the total scope of the contract or clarify the price range for each contract. For understanding what groups are using facility managers' data and why they are using this data, SMEs recommended that facility managers should for example determine who the various groups/stakeholders in the company are or should find out the target/audience of the project. A project here means a facility management project.

SMEs declared “determining facility needs” as the second subgoal for accomplishing the main goal of a facility manager. Figure 21 shows that for achieving this subgoal, a facility manager should answer two different questions:

1. What are the priorities for facility needs?
2. Have the workers been chosen based on the facility needs?

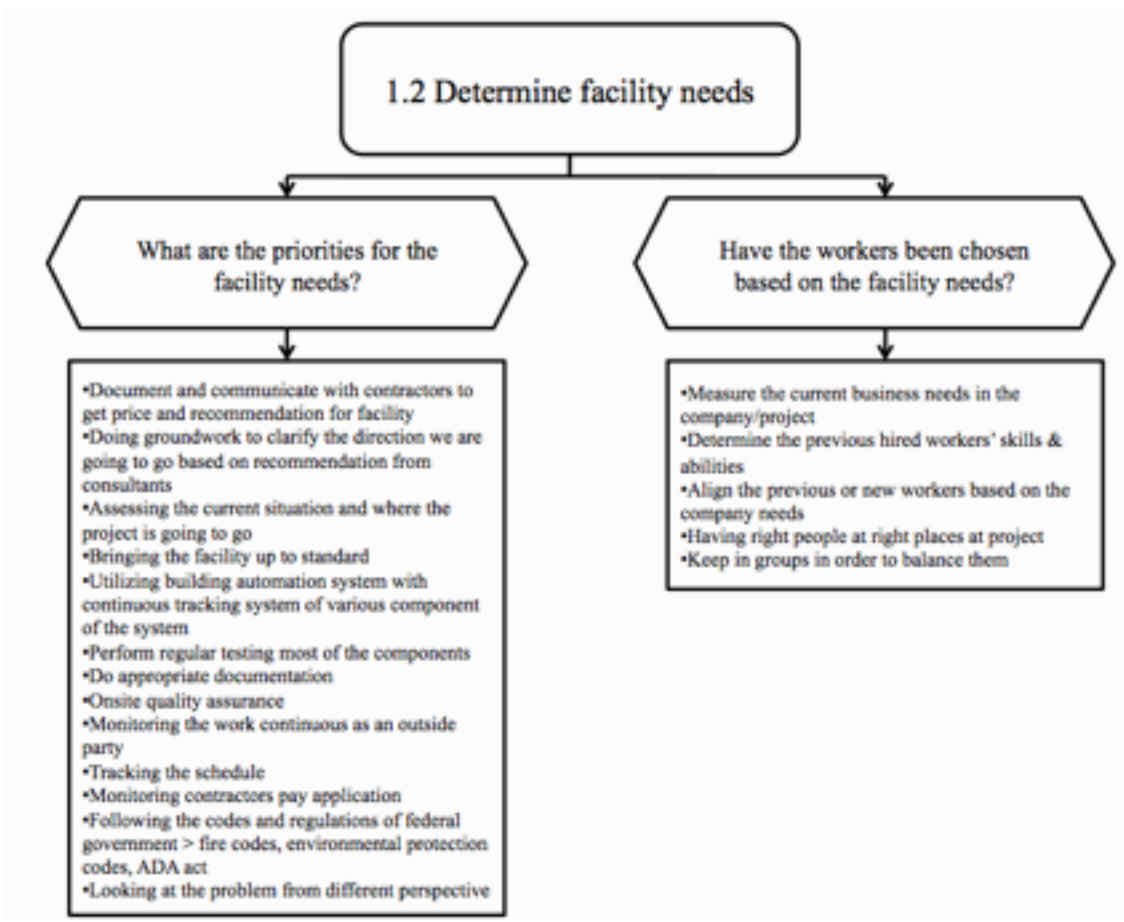


Figure 21: Decisions and SA requirements for second subgoal of facility managers

These questions show the decisions that facility managers should make to accomplish the second subgoal (determining facility needs). The bullet points in Figure 21 are the information and SA requirements that a facility manager needs in order to make these decisions. For knowing what the priorities for facility needs are, facility managers should for example consider document and communication with contractors or assess the current situation of the project and where it is going. For understanding whether the workers have been chosen based on the facility needs, SMEs recommended that facility managers should for example measure the current business needs in the company/project, and determine the previous hired workers' skills and abilities.

SMEs declared "clarifying the concerns/constraints of the business the work is done for" as the third subgoal, for accomplishing the main goal of a facility manager. Figure 22 shows that for achieving this subgoal, facility managers should answer following questions:

1. Have the economic issues of the project (budgeting concerns) been determined?
2. Have the safety issues of the project been determined?
3. Have the timing concerns of the project been determined?
4. Have the IT concerns of the project been determined?

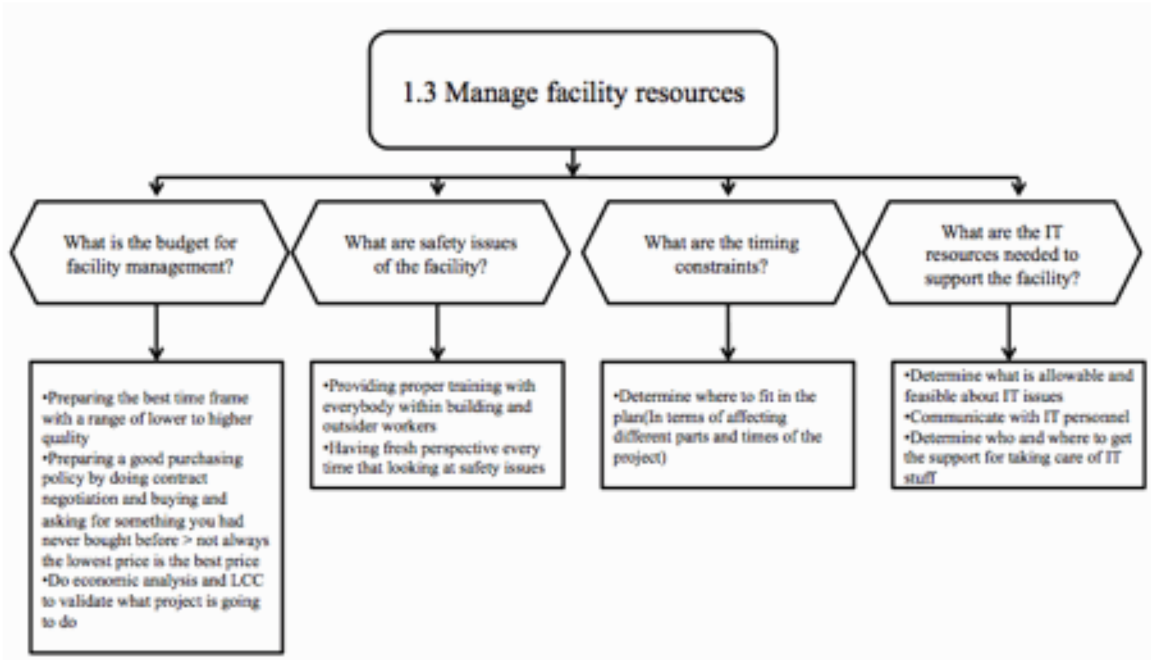


Figure 22: Decisions and SA requirements for third subgoal of facility managers

These questions show the decisions that facility managers should make to accomplish the third subgoal (clarifying the concerns/constraints of the business the work is done for). The bullet points in Figure 22 are the information and SA requirements, which a facility manager needs in order to make these decisions. This means that for making decisions related to determining the economic issues of the project (budgeting concerns), the facility managers should get requirements and information such as preparing a good purchasing policy or performing an economic analysis and life cycle costing. For determining the safety issues of the project, the facility managers should be provided with proper training and having fresh perspective toward safety issues. The timing constraints should be clarified in order to be determined where to fit in the plan. Furthermore, for understanding the IT resources to support the facility, all the allowable and feasible IT issues and the people in charge of them should be determined.

Lessons learned from application of GDTA to FM

One of the main challenges in this early stage of the research was applying the GDTA methodology in the facility management domain. An indication of this challenge was the discrepancy of SA goals or requirements between various facility management SMEs. Each interviewee had his/her own SA goals and requirements that were sometimes totally different from the other facility manager's goals and requirements. This can be due to three main reasons. Firstly, the facility managers interviewed were in charge of different types of buildings such as governmental offices, schools and private office buildings, which may demand different goals and requirements. Secondly, the interviewed facility managers had different backgrounds. Facility management is an area that employs individuals from varied disciplines. This also may influence their priorities, goals, and requirements as facility managers. To decrease this incompatibility between goals and requirements, the interviews should be conducted in a way that involves various experts or more experienced interviewees. The other problem was with the very large scope of the facility management domain which covers different issues such as real estate management, financial management, change management, human resources management, health and safety, contract management, building and engineering services maintenance, and domestic services (Atkin & Brooks, 2009). Not narrowing down the scope of the facility management in this pilot study led to very diverse and different set of goals and associated information and decisions which made the validation of the results very challenging. To address this challenge, a very detailed scope for the specific operational level of the healthcare facility management domain should be defined (section 5.1.1) and the SMEs from that specific domain should be used for the GDTA purpose. Furthermore, as another general challenge of applying GDTA, Ensley et al. (2003) indicates that, "not all interviews will go smoothly and result in optimal data collection." It is believed that this challenge is mostly related to interviewee's personality factors that sometimes negatively influence the interview. In addition, issues such as controlling for the experience of interviewees and pre-briefing them about the process of GDTA-based interviews can be useful strategies to overcoming this challenge.

Based on the SA-centric outcome of the GDTA, a human-computer application was developed to facilitate the decision making process of facility mangers. This human-computer application uses AR as a viable option to reduce data overload inefficiencies in facilities by adding interactive data to their real-world environment. Facility managers can use this application through their mobile devices.

Information Surveyed Point for Observation and Tracking (InfoSPOT)

As a pilot study, InfoSPOT (Information Surveyed Point for Observation and Tracking), was developed as a mobile Augmented Reality (AR) tool for facility managers to access information about the facilities they maintain. AR has been considered as a viable option to reduce inefficiencies of data overload by providing facility managers with a SA-based tool for visualizing their "real-world" environment with added interactive data. A prototype of the AR application was developed and a user participation experiment and analysis conducted to evaluate the features of the InfoSPOT (Figure 23). The following three approaches (conditions) were devised to mobile AR for facility management: (1) Augmented Reality I: Geo-referenced augmentation markers (InfoSPOTs) placed above a live video feed, (2) Augmented Reality II: InfoSPOTs placed above a 360 degree panorama of outlines of 3D object models above a live video feed, and (3) Virtual Model: Geo-referenced augmentation markers placed above a 360 degree panorama of a 3D model of object models and room architecture. The virtual model contains no video feed. The InfoSPOT system was considered as a prototype of a fully functioning facility management data-accessing tool. A within-subjects experiment was designed to test the InfoSPOT with real subjects while performing a facility-manager-related-task under different conditions. In this experiment, the subjects had to locate different objects in a room and then answered one question about each object under the said three different conditions. The time taken by experiment participants to perform the tasks as well as their responses to qualitative questions was used as dependent variables for comparing these three conditions. After performing the experiment, a repeated measures analysis of variance (ANOVA) was used to test whether there are statistically significant differences between these three conditions.

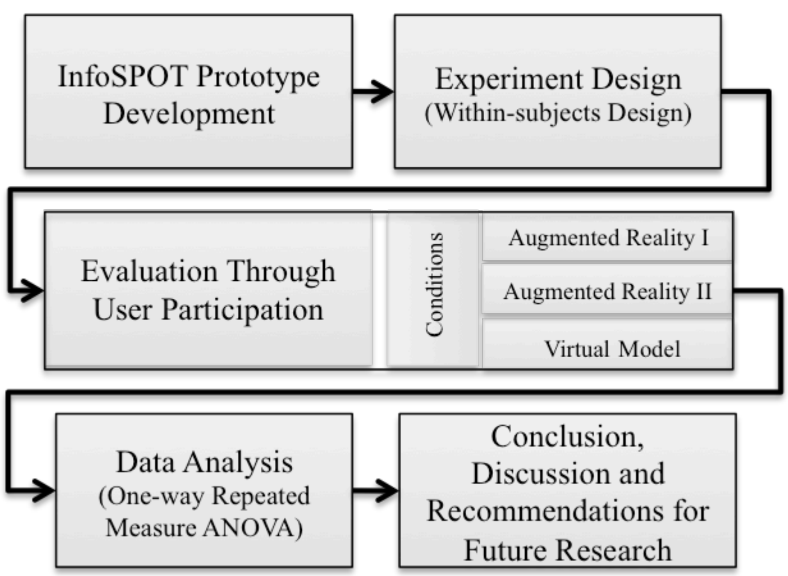


Figure 23: Overview of InfoSPOT pilot study

Challenges in InfoSPOT development

Working with a real world example of a BIM model, several unexpected issues changed the approach to creating the augmentations and visualizations for the InfoSPOT prototype. Early in the study, the contractor/architect's BIM model was obtained and checked for inconsistencies or errors. This process exposed the lack of pertinent database information embedded in the model. While architectural features, structural features, and furniture were all present in the BIM model, any useful information for facility managers was lacking. To try and ascertain if the models received were all that was used during the design/construction phases, several meetings were done with the contractors and architects which led to finding out that the BIM model was only used as a template for design. During the construction phase, the contractor and sub-contractor had generated their own working drawings in various other file formats and CAD software that were not available for performing this research.. These discussions led to questions regarding the accuracy of the BIM model therefore the surveys of the test area were conducted using total stations. Results of the survey indicated the BIM model was inconsistent with the built environment with architectural elements and furniture being off by several meters. Due to the amount of information in the BIM model and minimal control of how geometry topology is created in BIM modeling software, it was determined that the entire BIM model of our building was too complex to display in whole in a mobile device without geometry optimization. As a result of these issues, the 3D geometry was separated from the database information and optimized in modeling software (Autodesk 3Ds max) where geometry complexity was controlled. To further increase the efficiency and reduce errors in the prototype, the optimized 3D geometry was used to generate 3D panorama images that would load faster than 3D models in a mobile device with limited processing power.

Evaluation through user participation

The experiment consisted of using a tablet computer device (an Apple iPad was used in the experiment) as a mobile AR tool to access some inventory information about different objects in a test area (CONECTech lab at Georgia Tech). The user's task was to locate some objects in the room and then answer a question about each of them. Simultaneously the experimenter was measuring the time taken by the participants to perform each task. Based on the results from GDTA, having access to an inventory of different objects in a facility is one of the basic information needs of facility managers. Before starting the experiment, each subject was presented with an Informed Consent Form for him or her to read and sign in agreement to participate in the experiment. Georgia Tech's Institutional Review Board (IRB) evaluated and approved the study protocol. The subjects were also required to fill out a demographic information form before starting the experiment.

Pilot study design and methods

A within-subjects experimental design was employed, in which each subject participated in three "location finding + data extraction" conditions. The subject would sit on a chair over the InfoSPOT mat and was provided with a tablet device as an interaction tool to go through different scenarios and perform the required tasks (Figure 24).

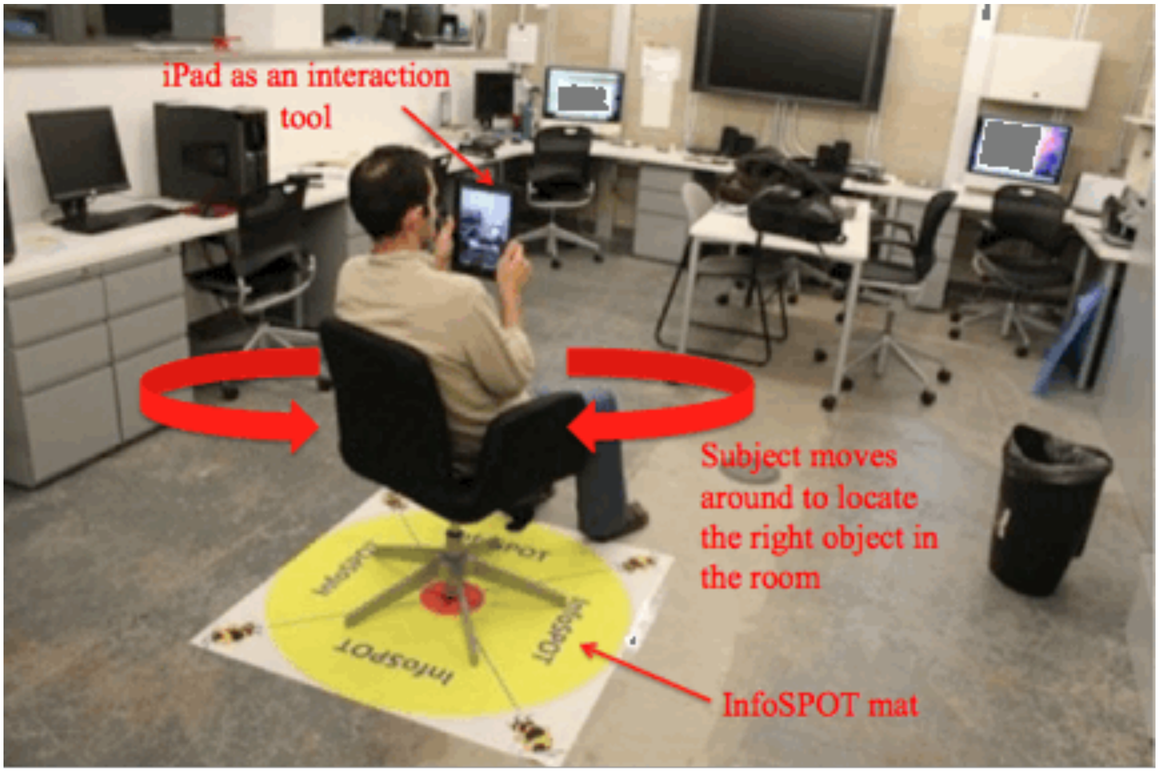
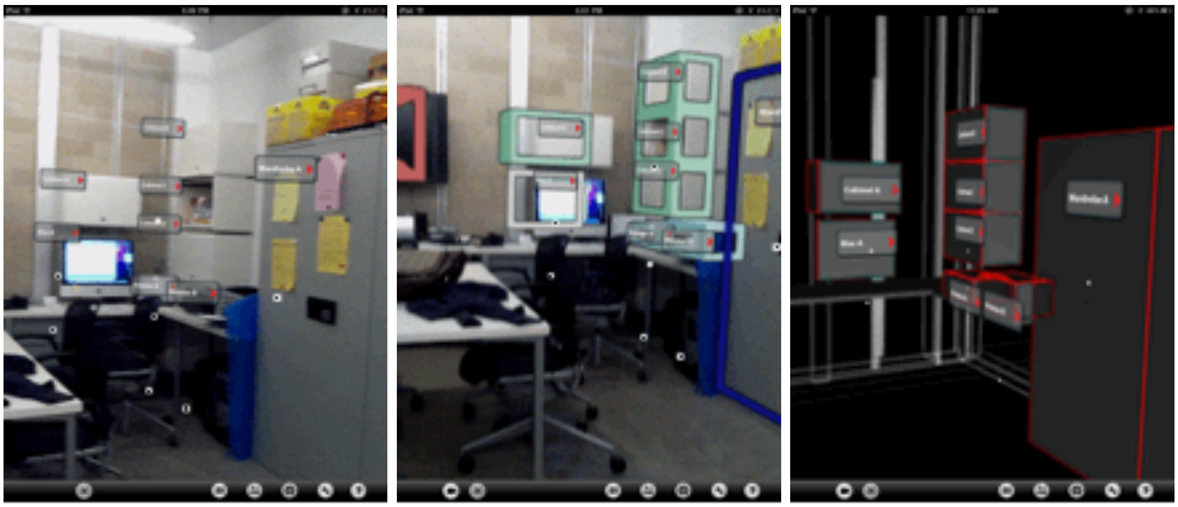


Figure 24: InfoSPOT experiment setup

There were three different scenarios (conditions) for performing the tasks. The conditions were different based on the models provided in the tablet device; Augmented Reality I (ARI), Augmented Reality II (ARII), and Virtual Model (VM). In the ARI condition, the participant had a real life view of the room while an augmented icon was tagged to each object in the room (Figure 25-a). In the ARII condition, the participant not only had the augmented icon used in the real life view of the room (ARI) but also the outline of each object was highlighted using augmented lines (Figure 25-b). It was assumed that having augmented outlines of each object could help the subjects to perform their locating-the-right-object task easier when they were faced with drift problem or information overloads/overlays in the object-congested-areas of the room. In the VM condition, the participant had a virtual model view of the room while an augmented icon was tagged to each object in the model (Figure 25-c). It was assumed that having the VM could be used as a non-location-based alternative providing the users with natural interactive experience of accessing the inventory data wherever they are.



(a) Augmented Reality I (b) Augmented Reality II (c) Virtual Model

Figure 25: Experiment Conditions

Each scenario included five different tasks. Each task considered one object in the lab and had two parts; (1) locating the correct object and (2) answering one question about the located object. Table 6 shows an example of one of the five tasks in each scenario. The experimenter asked the questions orally and also measured and wrote down the time taken on each task. Subjects were not required to write down any answer but they had to state them aloud so the experimenter could verify it. As soon as the experimenter said the word “START” at the end of each question, it meant the time measurement had started. Afterwards, if the subject stated aloud the right answer, the experimenter would say “STOP” as well as stopping the stopwatch. If the participant did not provide the right answer, the experimenter would say “NOT CORRECT” and the subject had to keep looking until finding the right answer. At the end of each condition, the experimenter would add up all the times for the five tasks to get the total time required for performing each scenario. This total time was used for the purpose of statistical analysis.

Table 8: An example of one of the five tasks in each scenario

Question	Answer	Time
Locate the printer with the following **support person in charge**: **Reza Chen**	B	--:--.--
What is the **last Inspection date for Printer B?**	10/08/10	--:--.--

By touching the augmented red icon tagged to each object, a table of information about that object would pop up (Figure 26). This table was the source from which the subjects could get the information to answer experimenter's questions. The list developed using the Gheisari and Irizarry (2011) research on SA-based data requirements for facility managers and consisted of information such as product manufacturer, support person in charge, installation date, anticipated life of the product, warranty expiration date, average replacement cost, and last inspection date. This information had been provided almost for all the objects in the lab but the questions in the scenarios were only about the ones that were illustrated in the schematic plan of CONECTech Lab (Figure 27): (1) two TVs, (2) four desktop Macs, (3) two PCs (Case + Monitor), (4) two wardrobes, and (5) two printers.

Before starting the experiment, the tablet had to be calibrated for the test location. To indicate that the tablet device was at a GeoSpot location, the researcher first placed the tablet device on a calibration marker (Figure 28). After placement, the researcher was prompted to enter several parameters to override sensor localization and select one of the three conditions of the experiment.

Mac A

Product Manufacturer	*Apple@Tech*
Support Person In-Charge	*Georgie Williams*
Installation Date	*04/04/09*
Anticipated Life of Product	*3 y 0 m*
Warranty Expiration Date	*10/08/11*
Average Replacement Cost	*$1420.00*
Last Inspection Date	*10/05/10*

Figure 26: An example of augmented table of information tagged to one object (Mac A)

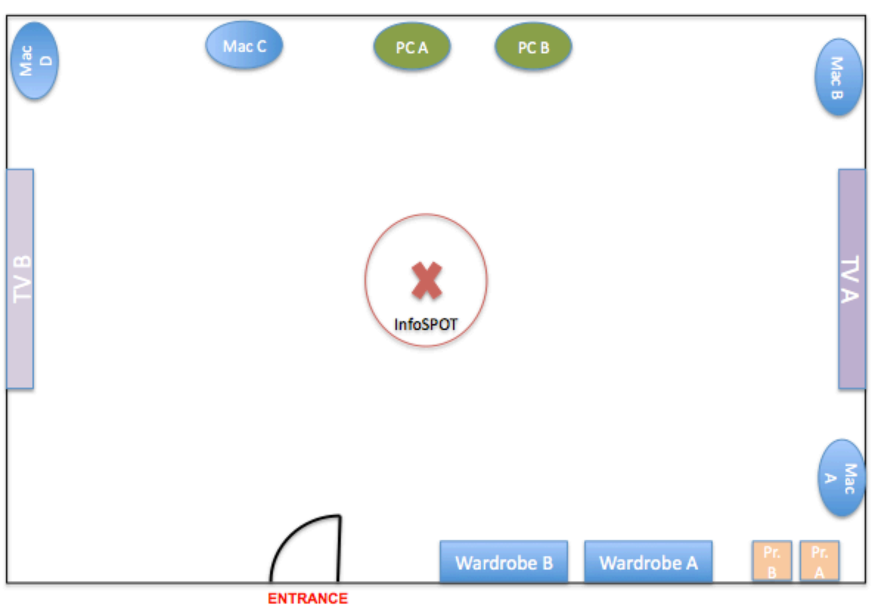


Figure 27: Schematic plan of CONECTech Lab

Figure 28: Calibration process

The experiment lasted approximately thirty minutes per participant. After performing the tasks under any specific condition, participants were asked to fill out a usability questionnaire to get their feedback and comments on each condition. A statistical analysis was performed on the outcome of the experiment as well as the questionnaires. The purpose of this experiment was to see whether there are statistically significant differences between these three conditions considering time and qualitative dependent variables.

Participants in the pilot study

Thirty participants (21 male and 9 female) took part in the experiment. All participants reported normal or corrected to normal vision. The majority of subjects (20) had heard about AR and only 9 had previously used any AR-based tool, device, or application. Argon, Yelp, Layar, and Junaio were the AR-based systems previously used by those subjects. Table 9 provides an overview of the collected demographic information. Due to limited access to the facility mangers and type of the experiment that was a simple scavenger-hunt-kind task, subjects with no facility management experience were also used for testing the system.

Table 9: Demographics of Participants

Variables		Frequency (Percentage) Total # of Subjects= 30
Age	19-25	11 (37%)
	26-30	11 (37%)
	31-40	8 (26%)
Gender	Male	21 (70%)
	Female	9 (30%)
Occupation	Student	27 (90%)
	Other	3 (10%)
Field of study for highest degree	Civil Eng.	8 (27%)
	Architecture	19 (63%)
	Other	3 (10%)
Academic Rank	Undergraduates	5 (17%)
	Master	6 (20%)
	PhD/Faculty	19 (63%)
Previous experience in the AECO Industry?	Yes	18 (60%)
	No	12 (40%)
Previously heard about AR?	Yes	20 (67%)
	No	10 (33%)
Previously used any AR-based tool, device, or application?	Yes	6 (20%)
	No	24 (80%)
Play videogame?	Yes	13 (43%)
	No	17 (57%)

Statistical analysis of InfoSPOT pilot study results

Analysis of the data collected includes reporting descriptive statistics as well as performing a one-way repeated measure ANOVA. Some parts of the IBM Post-Study System Usability Questionnaire (PSSUQ) (Lewis, 1995) were combined with other qualitative variables to develop a new After-Scenario Questionnaire (ASQ) for this experiment. The new questionnaire consisted of 18 questions while questions 1 to 12 were extracted from PSSUQ and questions 13 to 18 were based on some qualitative issues that were of interest to the research group. As same as the PSSUQ methodology (Lewis, 1995), the new ASQ requires combining different items in it to make three new overall items; Overall Usability (average of questions 1 to 12), System Usability (average of questions 1 to 8), and Interface Quality (average of questions 9 and 10). The items requested participants to express their level of agreement with the statements presented using the 7-point Likert Scale provided. Table 10 demonstrates the Means, Standard Deviations (SD), and different Likert scales of all the ASQ items based on the subjects' experiment conditions.

Table 10: Descriptive statistics for the After-Scenario Questionnaire

Question #	Variables	Likert Scale	Experiment Conditions: Augmented Reality I Mean (SD)	Augmented Reality II Mean (SD)	Virtual Model Mean (SD)
1 to 12	OVERALL (Overall Usability)	1=Strongly Agree to 7=Strongly Disagree	3.03 (.68)	3.10 (.78)	3.14 (.55)
1 to 8	SYSUSE (System Usability)	1=Strongly Agree to 7=Strongly Disagree	1.77 (1.04)	1.77 (1.22)	1.82 (.86)
9 and 10 *	INTERQUAL (Interface Quality)	1=Strongly Agree to 7=Strongly Disagree	2.07 (1.27)	2.30 (1.55)	2.81 (1.58)
13	How mentally demanding was the task?	1=Very Demanding to 7=Not Demanding	6.10 (1.18)	6.07 (1.38)	5.97 (1.40)
14 **	How physically demanding was the task?	1=Very Demanding to 7=Not Demanding	5.80 (1.73)	5.77 (1.70)	6.13 (1.48)
15	How hurried or rushed was the pace of the task?	1=Very Rushed to 7=Not Rushed	5.53 (1.70)	5.67 (1.60)	5.50 (1.70)
16	How successful were you in accomplishing what you were asked to do?	1=Very Successful to 7=Very Unsuccessful	1.93 (1.28)	1.90 (1.63)	1.77 (1.01)
17	How hard did you have to work to accomplish your level of performance?	1=Very Hard to 7=Not Hard	6.17 (1.34)	6.33 (.84)	6.17 (1.05)
18	I was insecure, discourage, irritated, stressed and annoyed with the task.	1=Strongly Agree to 7=Strongly Disagree	6.40 (1.22)	6.60 (.77)	6.40 (.93)

** Indicates marginally significant differences and ** indicates statistically significant differences.*

Table 11 also demonstrates the Means, Standard Deviations (SD), Minimums, and Maximums for the dependent variable of time based on subjects' experiment conditions.

Table 11: Descriptive statistics for the dependent variable of time

		Experiment Conditions		
Quantitative Variable		Augmented Reality I	Augmented Reality II	Virtual Model
Time (mm:ss.ss)	Mean	01:15.51	01:19.53	01:22.85
	Standard Deviation	00:19.88	00:27.66	00:20.39
	Minimum	00:33.90	00:39.30	00:44.80
	Maximum	01:53.10	02:36.60	02:08.00

Time and all different variables in the ASQ were analyzed using a one-way repeated measures ANOVA with Greenhouse-Geisser correction when necessary, and alpha level of $p = .05$. Greenhouse-Geisser correction is an index of deviation to sphericity to correct the number of degrees of freedom of the F distribution. Planned comparisons were used to compare condition means. Table 12 displays the results of the one-way repeated measures ANOVA. INTERQUAL and Question 14 were statistically significant between different conditions of InfoSPOT experiment. Mauchly's sphericity test was used to validate a repeated measures analysis of variance.

Table 12: One-Way Repeated Measures ANOVA results

Variables	Mauchly's Test Sig.	F	Sig.	Variables	Mauchly's Test Sig.	F	Sig.
Time	.42	1.50	.23	Question#14	.15	3.13	.05
OVERALL	$p < .01$ *	.33	.64	Question#15	.02 *	.36	.65
SYSUSE	$p < .01$ *	.04	.89	Question#16	.05 *	.18	.84
INTERQUAL	.03 *	2.78	.08	Question#17	.03 *	.41	.62
Question#13	.03 *	4.25	.66	Question#18	$p < .01$ *	.65	.47

**Mauchly's test statistic is significant ($p < 0.05$) so the condition of Sphericity has been violated. In this case, degrees of freedom for the reported F values have been corrected using Greenhouse-Geisser method.*

Discussion of InfoSPOT experiment

The results show that the general pattern is similar which means items were scored almost identically low or high in each of the three conditions. On average the subjects indicated a positive response to all the questions under three conditions of the InfoSPOT system. Individuals' comments in the ASQ also supported the findings.

In the case of Interface Quality (average of questions 9 and 10 in ASQ), the users liked the interface of InfoSPOT system under all three conditions while comparing those conditions they scaled the interface of ARI (2.07) and ARII (2.30) statistically better than VM (2.81). Having VM as least preferred interface comparing to AR ones was supported by comments such as "not pleasant User Interface [UI]", "not realistic interface", and "dark black and red [UI] is not very appealing". Also considering the question 14, the users agreed that using the InfoSPOT under any condition was not physically demanding and comparing those three conditions they statistically scaled VM (6.13) more physically demanding than ARI (5.80) and ARII (5.77). There were some negative comments on physical problems that were identical for some subjects. For example one user noted his physical problem that “my arms got a little tired by the end“. Some other subjects indicated the same problems in other words by saying “the tablet” was “heavy”, and “too wide” to be able to “hold [it] with one hand and manipulate the screen with the other [one] (safe clicking)” in an “awkward angle”.

Considering the total time for performing each scenario, on average it took more than a minute in all three conditions. Participants on average achieved the fastest time in ARI (01:15.51), followed by ARII (01:19.53) and VM (01:22.85) respectively. Participants indicated they somewhat agreed or liked the Overall Usability (average of questions 1 to 12 in ASQ) of InfoSPOT’s three scenarios. In this experiment, participants slightly liked the ARI (mean response out of 7, M = 3.03), more than ARII (3.10) and VM (3.14). In the case of System Usability (average of questions 1 to 8 in ASQ), participants were satisfied with easiness, simplicity, affectivity, efficiency, and comfortability of InfoSPOT under the three conditions. ARI and ARII both with 1.77, as their mean response, satisfied the subjects slightly more than VM (1.82). The users indicated their general positive interest on the InfoSPOT system using comments such as “I had a short, very short learning curve” or “very intuitive, everything was well labeled”. But comparing the three conditions, they had very different perspectives. For example, one individual noted, “I preferred the ARI setting” while on the other hand, one commented, “ARI is a little bit harder than the ARII”. Some users preferred AR systems to VM; “[VM] was easy, but AR was making it easier”, “[VM was] not as quick as the ones with the AR”, or “[VM was] slightly more difficult than the [AR] in my opinion”. Some others preferred the VM and supported their scaling by stating, “[VM] was simple and clear enough to perform well”, or “[VM] is easier to locate objects”. Interestingly one subject mentioned the intended purpose of having the augmented outline of each object in the ARII as a facilitator by stating, "[I] liked ARII the best! The outline for each product highlighted what exactly I was looking at". Also another user touched on the intended purpose of having VM as a non-location-based alternative by stating, "[In VM], it seems like you wouldn't have to be in the space and still accomplish the tasks".

Considering the questions 13, the scores indicated that the subjects did not believe that using InfoSPOT was mentally demanding under the three scenarios. In the case of question 15, although some subjects indicated that they "felt rushed because [they] were being timed" or "the START and GO [words for timing] put a bit of pressure [on them]" but the scores shows that participants believed that the pace of the task almost was not rushed while using InfoSPOT under three conditions. In the case of being successful in performing the required tasks (question 16) subjects on average believed that they were successful in accomplishing what they were asked to do and comparing the three conditions, they scaled augmented reality models (ARI (1.93), and ARII (1.90)) somewhat better than VM (1.77). Also they indicated that they didn't need to work hard to accomplish their level of performance (question 17). Moreover they were not insecure, discouraged, irritated, stressed, or annoyed with the tasks while using InfoSPOT (question 18). Interestingly under all these three qualitative statements, ARII was scaled somewhat better than ARI and VM.

Although the InfoSPOT system was scaled almost well under all three conditions it seems that "these three scenarios all [had] the drift problem". One subject stated, "[user interface] would be off its coordinates if I move too fast" and another one noted, "it seems that [all conditions] are susceptible to drift [problem]". Also another user declared that there is “less drift problem in VM”. The subjects also provided different recommendations such as embedding “voice function” in the system, “having search feature to filter out unnecessary objects”, “having an arrow that shows the amount of rotation we need to reach the object”, and testing the InfoSPOT under “different light conditions” or for “different viewing angles”.

Lessons learned from InfoSPOT experiment

On average the subjects indicated a positive response to all the questions under the three conditions (Augmented Reality I, Augmented Reality II, and Virtual Model). On average the results for overall usability, system usability and interface quality were positive. Furthermore, InfoSPOT almost was not physically or mentally demanding but there were some comments on facing physical problems while using the iPad tablet as an interaction tool. Also the subjects indicated that they were not supposed to really work hard to successfully accomplish the required level of performance, and they didn’t feel rushed, hurried, irritated, stressed and annoyed while using the InfoSPOT. Performing this experiment did provide us with valuable feedback and revealed real problems that should be considered in future stages of this research. The drift problem, choosing an appropriate interaction tool, and developing a user-friendly interface should be considered as major issues of developing a sophisticated AR-based facility management assistant tool. InfoSPOT serves as the first mobile AR solution for facility managers. It also supported that a “magic” lens approach to AR could be suitable for facility managers needs and database querying tasks. This pilot study was extremely helpful for developing the next stages of the research presented in this proposal showing that AR solutions can be easy to calibrate/setup and costly/timely hardware installations are not necessary for a successful AR application.

CHAPTER 7

RESULTS FROM INTERVIEWS AND SURVEYS

With the facility management industry adopting Building Information Modeling (BIM) technologies, there comes the need to investigate where this industry stands in the application process. Moreover, the studies on efficient and cost-effective solutions to integrate BIM and Mobile Augmented Reality (MAR) show promise for creating an environment where facility managers can experience an intuitive natural interaction with their mobile interfaces to efficiently access their required information. The industry's view on this new approach of accessing information from BIM models should also be investigated, and their feedback should be considered for future phases of this avenue of research. This part of research explores not only how BIM can benefit facility management practitioners, but also how its integration with MAR and making the data accessible through handheld mobile devices can enhance current facility management practices. An online survey and face-to-face interviews were conducted to assess professional facility managers' characteristics, technology use and working environment as well as the current status of BIM application in their practices. An online video scenario has also been used to illustrate to facility managers how a BIM-MAR-integrated environment can provide them with mobile access to their required information. Facility managers' feedback on the usability, applicability, and challenges of such an environment has also been investigated through a follow-up survey. With this study, industry practitioners as well as academic researchers will be able to understand the current status of BIM and mobile computing application in facility management along with the benefits and challenges of implementing these technologies in an augmented reality environment.

Semi-structured Expert Interviews

Eight professional facility managers in metropolitan Atlanta, GA, who are experts in HVAC-related practices were chosen as Subject Matter Experts (SMEs). Having easy access to these professionals was the main reason behind choosing them from metropolitan Atlanta. Four of the interviewees had more than 10 years of experience in facility management practices, and the other four had between five and 10 years of experience. Five of the interviewees had associate's degrees, and the other three had a high school diploma as their highest educational/training attainment. The GDTA Semi-structured Interviews conducted with these eight SMEs provided the necessary information for understanding their goal and information requirements. Their responses were combined, and a unique set of goals for the facility managers (HVAC technicians) was achieved. This section explains this set of goals and information requirements.

The main goal of an HVAC-related facility manager was identified as providing a safe and comfortable facility for patients, staff, and visitors through quick preventive maintenance and repair. The interviewees mentioned that, basically, they should deal with "comfort cooling and heating of people in facility," "make sure everything is working correctly," and "maintain all equipment and prevent major problems." For achieving this main goal, technicians mentioned that they should accomplish two major subgoals:

1. Monitor current status of all equipment: Preventive Maintenance (PM).

2. Fix/repair any problem that might occur in all equipment: Corrective Maintenance (CM).

A typical day for facility technicians usually starts by going through what happened over the course of the previous night and checking whether those problems have been fixed by the night crew. Communication between facility managers and technicians usually happens via cell phone or mobile two-way radios. Technicians usually do walkthroughs to check the general status of their designated zones in the facility and make sure nothing is wrong. If they do not have any CMs to do, they generally start on PM checklists. But if any CM emergency arises, it becomes the priority. This makes every day unique for technicians, as any unpredicted or unprecedented issues might happen in the facility that requires prompt attention of the facility group. There are usually three crews of technicians who are working consecutively in three daily periods of 7 a.m.–3 p.m. (day), 3 p.m.–11 p.m. (evening), and 11 p.m.–7 a.m. (night). Some facilities might have fewer crews or smaller crews for evening and night periods depending on the facility's working hours and complexity. Facility technicians are usually in charge of the very common and more frequent kind of PM/CM tasks such as checking the filters and belts, replacing the faulty ones, checking the temperature in different areas of the facility, or performing simple installation tasks (e.g. oven or valves). Third-party contractors are usually in charge of the more technical PM/CM tasks.

Preventive Maintenance (PM)

Preventive Maintenance (PM) means monitoring all equipment and facilities and making sure they are in satisfactory operating condition by performing regular inspections to proactively detect and correct the incipient problems. Generally, those PMs are based on checklists that technicians have to go through periodically to make sure everything is working perfectly. These checklists are step-by-step sets of tasks. Usually a technician in charge of the Computerized Maintenance Management System (CMMS) prints the PM checklists and provides them to the technicians to do their periodic PMs. Depending on the type of equipment that should be maintained, the PMs might occur on a daily basis, a yearly basis, or somewhere in between. The technicians would be assigned a specific number of PMs; when they have performed those maintenance tasks, they have to return the checklist to the facility management desk so the checked marks can be keyed into the CMMS.

As previously mentioned, one of the goals of HVAC technicians is to monitor the current status of all equipment within the facility to make sure it is working faultlessly. To achieve this goal, the technicians mentioned that they should know exactly what equipment they have to monitor as well as details of the required maintenance tasks. To fulfill this purpose, the technicians declared that they should be able to locate the target equipment in the facility through the shortest route, and also be provided with some required information such as average time to perform the maintenance task, the steps that should be followed to fully maintain the equipment, different related components in the equipment, and the due time/date for maintaining the target equipment.

Another issue that should be considered for achieving the goal of monitoring the current status of equipment within the facility is making sure that the technicians have the required knowledge to maintain the target equipment. To fulfill this purpose, the technicians should have not only the required training for fixing the equipment but also access to the history of all the maintenance tasks that have been performed on the equipment The technician should also have the contact information of the experts and lead technicians in the maintenance group or outside contractors, if there is a serious problem with the equipment that the assigned technician cannot fix.

Corrective Maintenance (CM)

Corrective Maintenance (CM) happens after a failure has occurred and means identifying a problem that has happened in a facility or its equipment and correcting that failure to bring the whole system back to in-service operations. One of the sources of CMs is the customers and occupants of the facility. Based on the technicians' comments in the GDTA interviews, those sources are patients, staff, and visitors in a healthcare facility who contact the customer service center to inform the facility group about a problem. The majority of CM calls that the maintenance group receives are for temperature-control problems (too-hot or too-cold situations). Typically there will be someone doing these hot/cold CMs who could call the duty mechanic to handle the problem. The duty mechanic would be one technician specifically designated to resolve general CMs (e.g. hot/cold calls, leaking, bad smell in the area, refrigerator breakdown). The technician would go through some predefined steps that he or she has been trained to do in order to troubleshoot and figure out what caused the system to fail and how to fix it. This position usually rotates between technicians. If this person cannot fix the CM, then other technicians—or in severe conditions, outside contractors—would help to resolve the issue.

As previously mentioned, another goal of HVAC technicians is to fix/repair any problem that might occur in any equipment within the facility. To achieve this goal, the technicians mentioned that they should know exactly who made the request and what the details of the problem are. To fulfill this purpose, the technicians declared that they should be able to firstly determine the source/person who requested the CM (e.g. name and contact information). The source can provide information about the details of the problem. Technicians also mentioned that they require other information such as severity of the problem, the location of the equipment or components inside it, the closest route in the facility to the target equipment, the history of maintenance tasks that have been conducted on the equipment, and where/from whom to get the problematic part.

Another issue that should be considered for achieving the goal of fixing/repairing equipment problems is to make sure that the technicians are capable of fixing the problem. To fulfill this requirement, it is beneficial to have information such as whether the designated technician has required/similar training in fixing that specific issue and has access to the contact information of the associated contractor and equipment supplier.

Figure 26 illustrates the goals and information requirements of HVAC-related facility managers in the areas of Preventive Maintenance (PM) and Corrective Maintenance (CM).

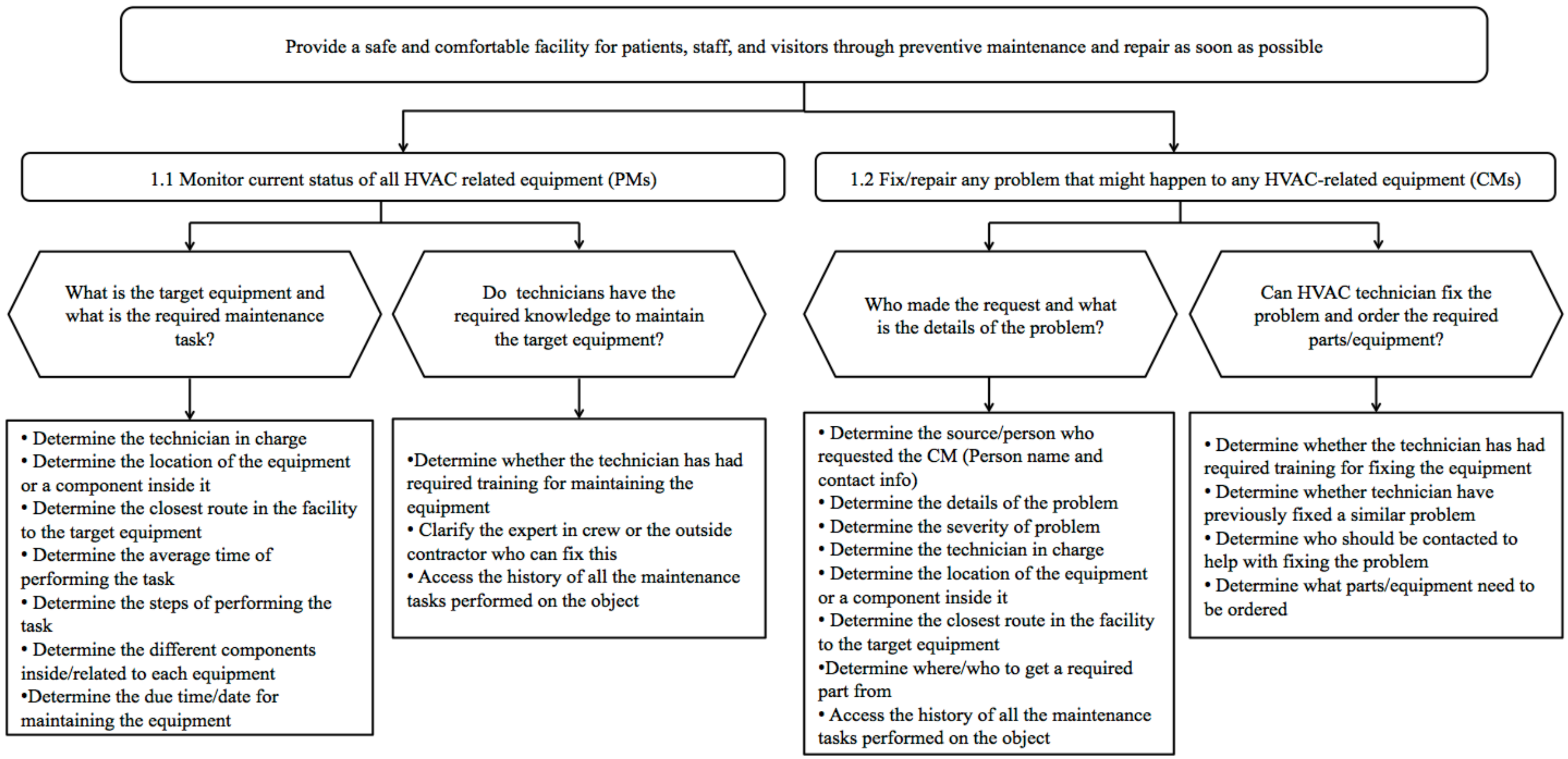


Figure 29: Goal Hierarchy of HVAC-related Facility Managers

The Online Survey and Scenario

The 32 survey questions were developed with information attained from a literature review and followed by six questions about the ARWindow Scenario (total of 38 questions). The survey was hosted on https://surveymonkey.com/ through an account funded by Georgia Tech's School of Building Construction. The paper format of the questionnaire has been provided in Appendix A. Distribution of the survey was directed through e-mail lists of facility management associations, including IFMA (International Facility Management Association) and ASHE (American Society for Healthcare Engineers). The survey was open between January 17, 2013 and March 9, 2013. During this period, 80 responses from facility managers were collected and included in the analysis.

Demographics and User Characteristics

The majority of the collected responses were from the U.S. (n=69), and there were five responses from Canada, four from Europe, and two from Asia. The majority of the respondents (77%) were male facility managers, while there were 18 responses (23%) from female facility managers. More than 40% of the respondents had more than 15 years of experience in facility management. The types of facilities they were managing were office buildings (42%), healthcare buildings (32%), industrial buildings (12%), education buildings (11%), and residential buildings (3%). Eighteen respondents (23%) mentioned other kinds of facilities such as churches, airports, and homeless shelters. Half of the respondents (n=40) had a bachelor's degree as their training/educational attainment; 31% held a master's degree. The following table shows the details of the respondents' demographic information.

Table 13: Demographics of Respondents

Variables	Responses	Percentage (Total # of Responses= 80)
Country	USA	86
	Canada	6
	Europe	5
	Asia	3
Gender	Male	77
	Female	23
Years of experience in facility management	Less than a year	10
	1 to 5 years	10
	6 to 10 years	23
	11 to 15 years	11
	More than 15 years	46
Type of facilities	Office Building	42
	Healthcare	32
	Industrial	12
	Education	11
	Residential	3
	Other (Church, Airport, Homeless shelter, etc.)	23
Educational/training attainment	High school diploma	5
	Associate's	13
	Bachelor's	50
	Master's	31
	Ph.D.	1

The majority of facility managers had good to excellent visual equity (84%) and hearing capability (95%) (Figure 30), and their preferred, fluent, and first language was English (95%).

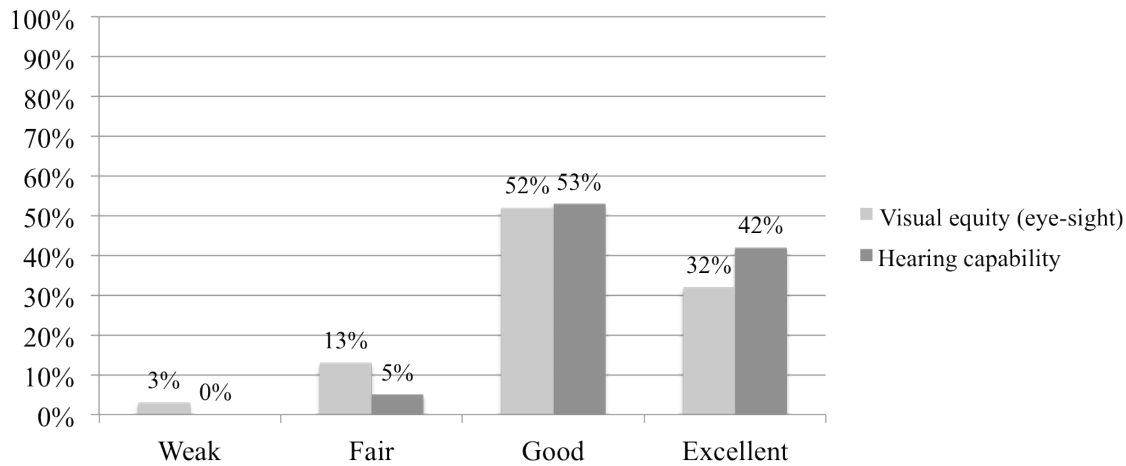


Figure 30: Visual and hearing capability of facility managers

Work Environment

The most common types of special clothing that respondents wear in their working environment are hardhat (61%), goggles (43%), earplugs/hearing protection (41%), gloves (35%), and mask (22%). Thirty-three percent of the respondents use gown and shoe covers, and 7% of them carry a backpack while working. On average they spend 87% of their time indoors and 23% outdoors. The majority of the respondents work in a regular/office environment in terms of loudness (87%) and brightness (90%). In terms of privacy in their working environment, the majority of time (63%), facility managers are working with their colleagues, and they spend the rest of the time (37%) working alone. These facility managers spend more than half (58%) of their working time sitting and the other time standing (21%) or walking around the facility (21%). Table 14 illustrates the details of the respondents' working environment.

Table 14: Working Environment of Respondents

Variables	Responses	Percentage (Total # of Subjects= 80)
What percentage of your time at work do you spend ……. ?	Indoors	87
	Outdoors	23
How loud is your working environment?	Quiet	5
	Regular/Office environment	87
	Loud	8
	Extreme	0
	Average: 2.03 (Regular/Office environment)*	
How bright is your working environment?	Dark	0
	Regular/Office environment	90
	Bright	10
	Extreme	0
	*Average**: 2.10 (Regular/Office environment)*	
How much privacy do you have at your working environment?	Usually working alone	37
	Usually working together with colleagues	63
	Usually working while there are clients around	0
What percentage of your time at work are you …….. ?	Sitting	58
	Standing	21
	Mobile	21

** Quiet=1, Regular/Office environment=2, Loud=3, and Extreme=4*
*** Dark=1, Regular/Office environment=2, Bright=3, and Extreme=4*

Technology Use

As illustrated in Figure 31, in terms of computer/technological tools for accessing facility managers' required data at their job, the respondents mainly use laptops (77%) and finger touch smartphones (71%), followed by desktop computers (50%), handheld tablet computers (33%), regular mobile phones (17%), and Personal Digital Assistants (4%). It is interesting that, when accessing their required information, facility managers more often use finger-touch smartphones than desktop computers and almost as much as they use laptop computers.

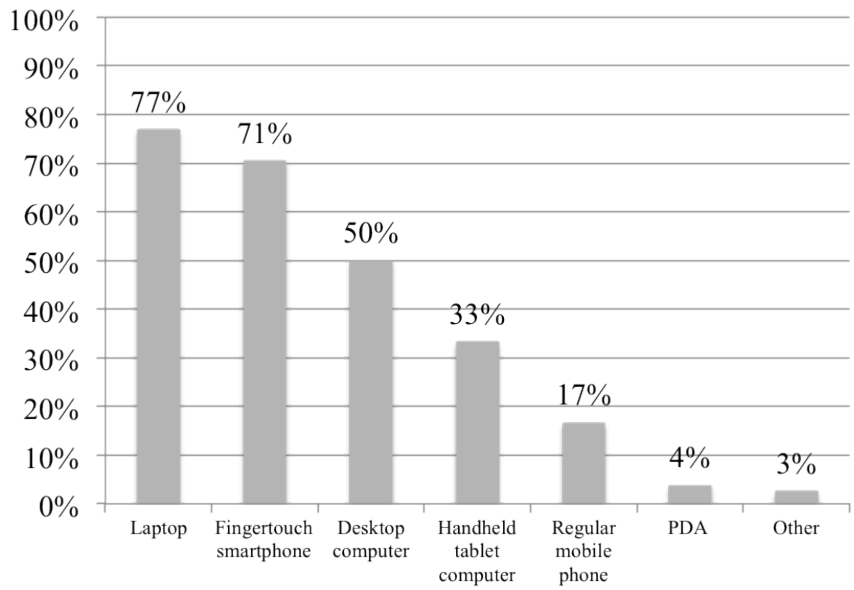


Figure 31: Computer/technological tools for accessing facility managers' required data at their job

Eighty-three percent of the respondents mentioned that they use touch-screen smartphones either at home or at work (Figure 32). Moreover, 68% of the respondents mentioned that they use some kind of handheld tablet computer (e.g. iPad, Nexus, Kindle) either at home or at work to access information.

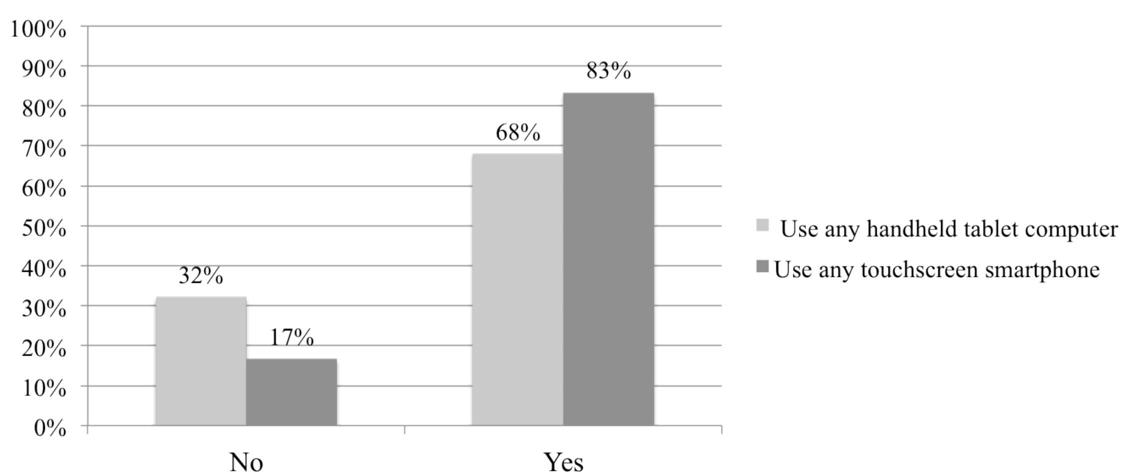


Figure 32: Use of Handheld Tablet Computers and Touch-screen Smartphone by Facility Managers

Considering information types, the majority of respondents (92%) usually use electronic format files (e.g. PDF, MS Word, MS Excel, MS Access, videos) to access the information required to perform tasks at their facilities (Figure 33). Electronic format types for accessing required information are followed by Internet searches using web browsers (71%), paper format files such as brochures, as-built plans (56%), and 2D/3D CAD/visualization files such as AutoCAD, Navisworks, Revit (39%).

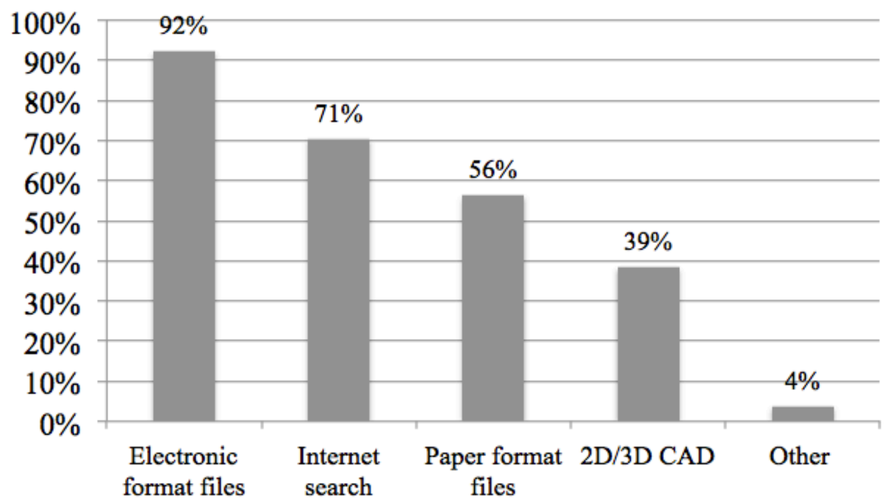


Figure 33: Information Types Used by Facility Managers at Their Jobs

Table 15 illustrates the environmental issues that might affect facility managers' use of tablet computers and touch-screen smartphones in indoor or outdoor environments. They rated all those issues in a scale of 1 (never) to 5 (always). In terms of environmental issues such as heat (2.01), cold (2.35), wind (1.99), snow (2.18), humidity (2.08), perspiration (2.06), and vibration (1.89), respondents rarely had any problem, while rain (2.64) was considered as the only environmental issue that “sometimes” might adversely affect the use of tablet computers or touch-screen smartphones.

Table 15: Environmental Issues Affecting Tablet Computers or Touch-screen Smartphones in Indoor or Outdoor Environments

Variables	Average	Variables	Average
Heat	2.01 (Rarely)	Snow	2.18 (Rarely)
Cold	2.35 (Rarely)	Humidity	2.08 (Rarely)
Wind	1.99 (Rarely)	Perspiration	2.06 (Rarely)
Rain	2.64 (Sometimes)	Vibration	1.89 (Rarely)

Never=1, Rarely=2, Sometimes=3, Often=4, and Always=5

Level of BIM Understanding in Facility Management Practices

This part of the survey started by asking the facility managers to rate their understanding of BIM on a scale of None=1, Some Knowledge of=2, Fair=3, and Competent=4. On average, their knowledge of BIM was 2.36, showing that they have some knowledge of BIM and its applicability in facility management practices. Moreover, almost 75% of the respondents mentioned that either their company doesn’t use any form of BIM for facility management purposes, or they are not aware of it (Table 16).

Table 16: Understanding of BIM and Its Application

Variables	Responses	Percentage (Total # of Respondents= 80)
Rate your understanding of *Building Information Modeling (BIM)*	None	12
	Some knowledge of	39
	Fair	29
	Competent	20
	Average*: 2.36	
Are you or your company using any form of BIM for facility management purposes?	No	60
	Not sure	14
	Yes	26

**None=1, Some Knowledge of=2, Fair=3, and Competent=4*

Respondents were also asked to rate the applicability of BIM for facility management purposes in 11 categories on a scale of Very Low=1 to Very High=5. The details of this rating are illustrated in Table 17.

Table 17: Applicability of BIM for Facility Management Practices in Different Areas

Areas of BIM applicability in facility management	Responses (Percentage)						Average*
	Don't know	Very Low	Low	Medium	High	Vey High	
Locating building components	10	3	3	28	35	21	3.37
Facilitating real-time data access	13	9	4	21	32	21	3.12
3D Visualization	16	3	3	19	29	29	3.31
Marketing	24	15	12	19	22	9	2.28
Checking maintainability	18	7	9	29	25	12	2.72
Creating and updating digital assets	16	4	7	28	28	16	2.96
Space management	12	6	7	28	26	21	3.13
Planning and feasibility studies for non-capital construction	19	7	10	19	31	12	2.72
Emergency management	15	9	15	24	25	13	2.75
Controlling and monitoring energy usage	18	9	6	26	21	21	2.85
Personnel training and development	15	9	12	35	19	10	2.66

**Don't Know=0, Very Low=1, Low=2, Medium=3, High=4, and Very High=5*

Respondents rated locating building components (3.37) and 3D visualization (3.31) as the highest categories and marketing (2.28) as the lowest category in which BIM is applicable in facility management practices (Figure 34).

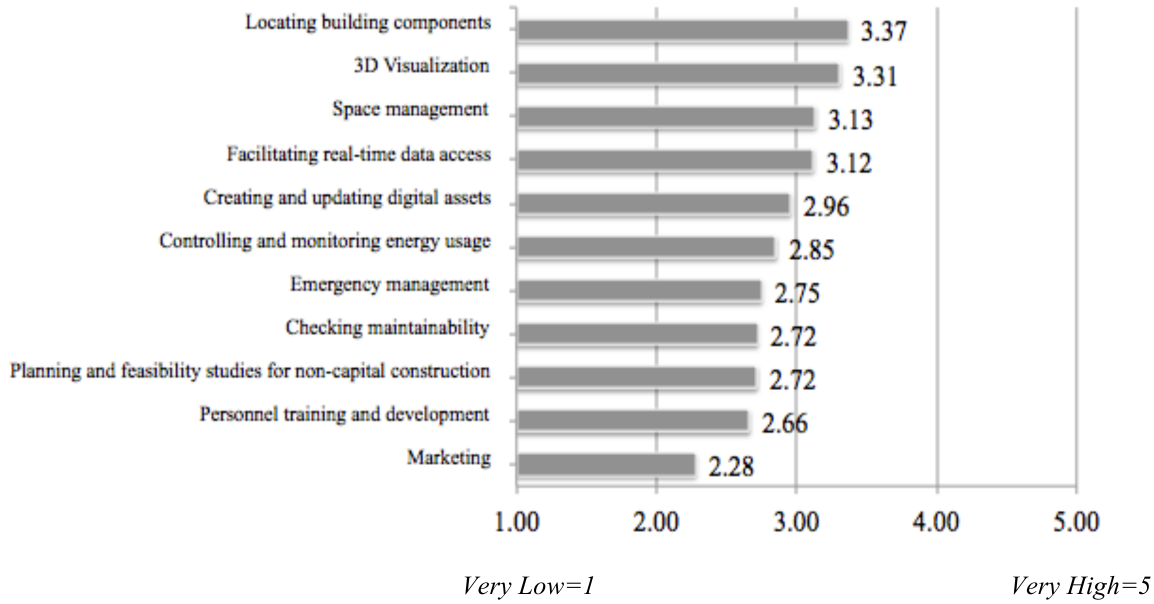


Figure 34: Different Categories of BIM Application in Facility Management Practices

In terms of challenges of implementing BIM in facility management practices, the respondents were asked to rate 12 issues on a scale of Very Low=1 to Very High=5. The details of this rating are illustrated in Table 18.

Table 18: Challenges of Implementing BIM for Facility Management Practices

Areas of BIM applicability in facility management	Responses (Percentage)						Average*
	Don't know	Not at all important	Low importance	Neutral	Moderately important	Very important	
Lack of understanding/knowledge of BIM	17	0	8	11	38	25	3.29
Lack of BIM models of the facility	17	2	5	11	30	36	3.42
Lack of BIM-trained personnel	22	2	6	6	25	39	3.28
Non-adaptive (reluctant to change) facility managers	19	5	5	23	25	23	3.02
Not receiving BIM models from other disciplines (e.g. design or construction groups)	21	3	10	15	24	27	3.00
Poor collaboration with other disciplines (e.g. design or construction groups)	22	0	9	13	28	28	3.09
Interoperability between different BIM-related software	25	0	5	16	22	33	3.08
Unclear responsibilities and liabilities when using BIM	22	2	5	24	30	17	2.90
Administrative costs	16	0	2	19	34	30	3.45
Education/training costs	17	0	5	17	33	27	3.30
Start-up/initial costs	16	0	2	14	27	42	3.63
Security concerns	20	6	23	20	23	6	2.39

**Don't Know=0, Not at all important=1, Low importance=2, Neutral=3, Moderately important=4, and Very important=5*

Start-up initial costs (3.63), administrative costs (3.45), and lack of BIM models of the facility were rated as the most important challenges while security concerns (2.39) were considered as the least important issue for implementing BIM in facility management practices (Figure 35).

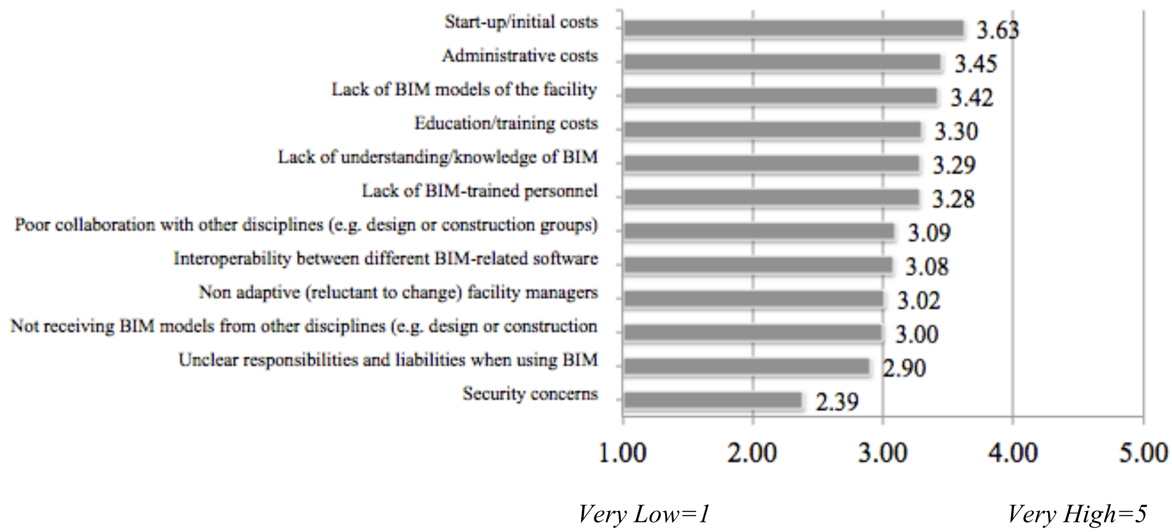


Figure 35: Information Types Used by Facility Managers

ARWindow Scenario

Interestingly, only one respondent had previously heard about AR and used an AR-based tool, device, application, or program, and almost 99% of those facility managers have either not heard anything about AR or have heard but not used any AR-based tool. The respondents were also able to watch the ARWindow scenario, which describes the ideal integration of BIM, MAR, and handheld mobile devices for performing an operational maintenance task, and provide their feedback. More than 80% mentioned that the proposed ARWindow system has some to substantial value (Average=3.29, None=1, and Substantial=4) for facility management practices. They also declared that ARWindow would be from some to substantially useful for facility management purposes (Average=3.26, None=1 and Substantial=4). Respondents also mentioned that they occasionally (Average=2.14, Not at all=1 and Frequently=3) would use such a system and believed that ARWindow would make their data access in facilities easy (Average=2.41, Very easy=1 and Very hard=5). They also supported these quantitative values by qualitative comments on how a system like ARWindow might help them perform their tasks. "[ARWindow] helps to locate and repair problems faster," "ARWindow brings all required information to [your] fingertips," "[it] can get another set of eyes on problem," "[it] provides additional technical data," and "[it] saves time, easier communication with key personnel [and there is] no paper [required]" are some examples of such comments provided by interviewees. In terms of the challenges of implementing the ARWindow system, the interviewees mentioned issues such as "it would require a lot of man-hours to develop the model and label everything within the facility," "price and getting everybody to use it," and "vast amount of equipment in the facilities."

Synopsis

This research has been conducted based on an idea that having a sophisticated and comprehensive BIM model, which embeds the required information as well as the 3D geometry of all the objects in the facility, could be used as a database that can be integrated with AR. Such an approach would provide an intelligent environment for facility managers in which they could access their required information easier and faster. For investigating this concept, first the current status of use and implementation of BIM and Mobile Augmented Reality (MAR) was explored. Feedback from professional facility managers was collected on how BIM integration with MAR as well as making data accessible through handheld mobile devices would benefit them. In this research, approaches such as online surveys and scenarios were used to investigate those issues for ideal and efficient facility management practices. Significant findings of this study are as follows:

- Facility managers use finger-touch smartphones to access their required information more than they use desktop computers and almost as much as they use laptop computers.
- More than 80% of the respondents have used touch-screen smartphones either at home or work.
- Sixty-eight percent of the respondents mentioned that they use some kind of handheld tablet computers either at home or at work to access information.
- The majority of facility managers usually use electronic format files (e.g. PDF, MS Word, MS Excel, MS Access, videos) to access information required to perform tasks at their facilities, and less than 40% of facility managers use 2D/3D CAD/visualization files such as AutoCAD, Navisworks, and Revit.
- Facility managers rated locating building components and 3D visualization as the highest issues for BIM application in facility management practices.
- Although most of the facility managers who responded to the survey did not have any previous knowledge about MAR, their feedback about the ARWindow scenario was positive.

These findings show that facility managers are increasingly using mobile technologies while not many of them are using 3D BIM tools. But the feedback provided by facility managers shows that they can understand the applicability of their required data associated with the objects in the facility while those objects are visualized in the real environment and can be accessible through their handheld mobile devices. Facility managers rated locating building components and 3D visualization as the highest issues for BIM application in facility management practices, and the hypothesis of this research is that integrating BIM with MAR can satisfy these needs for facility managers.

A huge practical challenge of a BIM-MAR system is that currently, augmenting information into the real world of facility management does not fit into a workflow that exists within AECO processes. For successful implementation of a BIM-MAR system, owners need to start asking for their requirements of BIM and avoid letting those requirements be postponed to the operations phase by designers or contactors. Another expedient of successful BIM-MAR integration will be the improvement of the technology and software, which will make AR easier to create and fit within a standard workflow, and also make it easier to use in the field and to integrate with BIM.

CHAPTER 8

BIM2MAR: BRINGING BIM TO MOBILE AR APPLICATIONS

Mobile Augmented Reality (MAR) provides an easy-to-learn and easy-to-use method of accessing information in an intuitive way by visually parsing the environment and relating information in the form of augmentations to specific objects in specific places through handheld mobile devices. With the Architecture, Engineering, Construction, and Operation (AECO) industry widely adopting Building Information Modeling (BIM) technologies, this section contributes an efficient and cost-effective solution to integrate BIM into MAR by developing a method and workflow that practitioners can use to consolidate, optimize, and visualize their data and models in an MAR environment. Moreover a real-world application of this method within facility management practices is described in this section that will consequently be used for a user-participation experiment (Description in Chapter 9).

BIM2MAR Workflow

A BIM2MAR exchange will require several activities to occur (Gheisari & Irizarry, 2011; Irizarry et al., 2012). First, it is necessary to generate new geo-spatial properties for each object. The MAR environments will be using geo-location to identify a user's position and subsequently only provide them with the information related to that particular location. Next, since the information displayed in MAR will relate to a user's position, several surveyed points within the BIM model also need to be identified. These points will represent where users can stand within a physical location and perform MAR tasks with sets of BIM data related to that location. And lastly, in order for BIM to be useable in an MAR environment, the geometry and property data set will need to be separated into two exchange formats. Figure 36 explains the BIM2MAR Architecture which has four phases: data, computing, tangible, and presentation (Chi, Kang, & Wang, 2013). In the data phase, two main types of files are generated: (1) geometry that is exported as a Collada file and (2) object attributes that are exported as an IFC file. The Collada file serves a dual purpose. It is first used for visualization of the geometry and also used in SketchUp to generate geo-locations of each object. In the computing phase, GPS, accelerometers, and gyroscopes sense the environment and capture data related to a mobile device's position, orientation, location, and context. The mobile device acts as the user's tangible tool aiding them in controlling the visual feedback they receive through the mobile device's screen. Users can also interact with the geometry and data through the Argon 2 platform utilizing the interactive surface and kinesthetic actions.

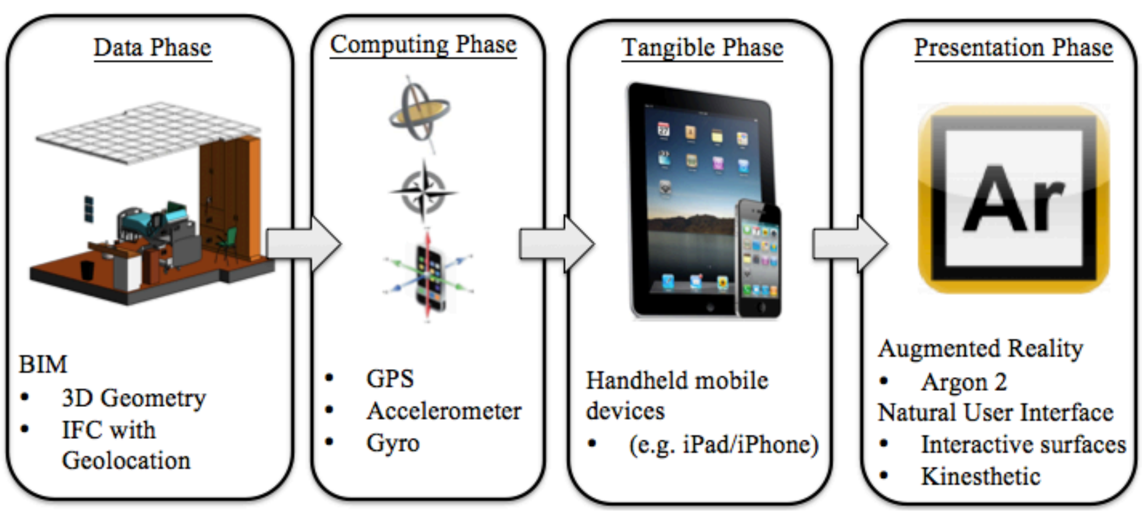


Figure 36: BIM2MAR architecture

Figure 37 illustrates the process of bringing BIM to an MAR environment. The developed method involves the integrated use of the different software applications. Autodesk Revit was used due to its widespread adoption in AECO and the ease of developing automation scripts using the Revit API. Google SketchUp was used due to its powerful Ruby API and integration with Google Earth. This project leverages SketchUp to automate the process of finding the geo-locations (latitude, longitude, elevation) of the BIM objects. Finally Argon 2, an Augmented Reality browser, which leverages Vuforia for vision-based tracking, Metaio for model-based tracking. THREE.js and WebGL, HTML5, and JavaScript, was utilized due to the ease of implementation and support from the developers of the project. Unlike Argon 1, Argon 2 allows efficient 3D rendering and manipulation. Argon 2 is currently under development at Georgia Tech's Augmented Environments Lab and is slated for public release in late 2013.

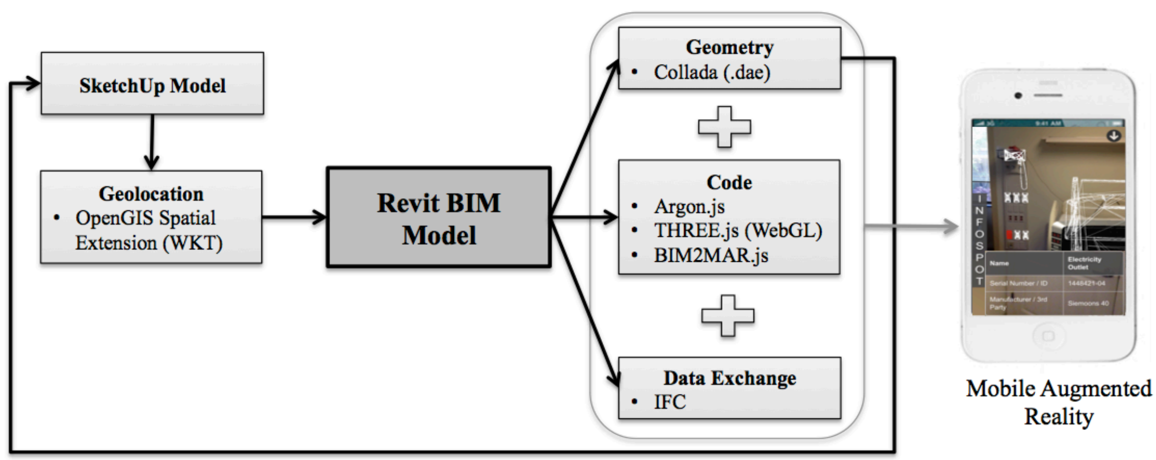


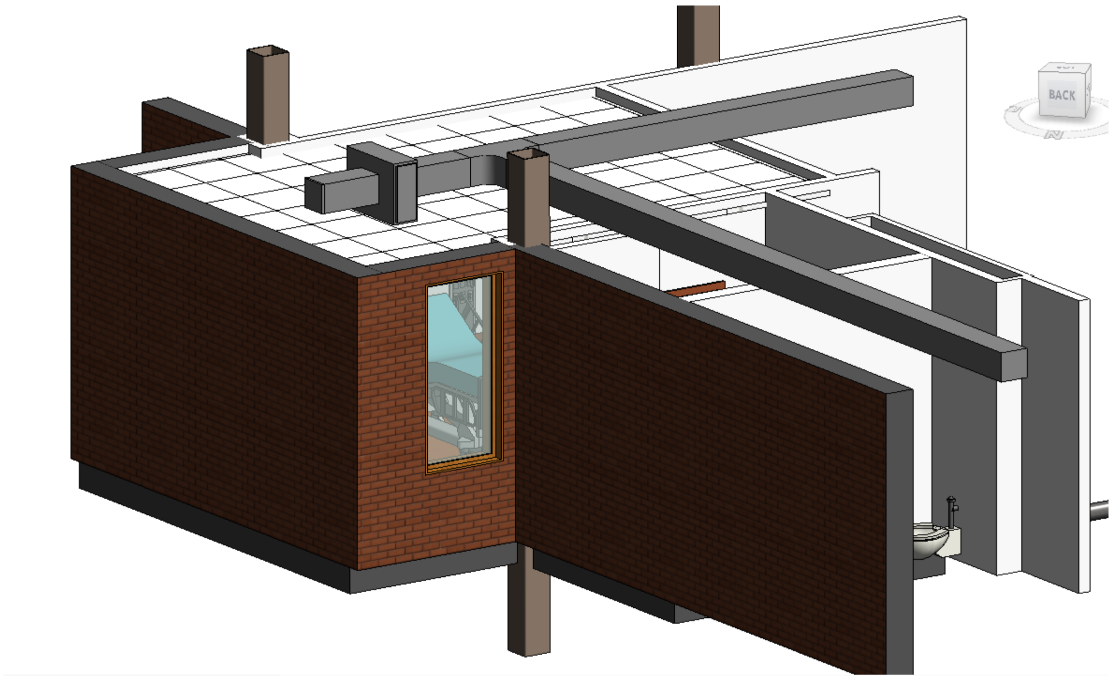
Figure 37: BIM2MAR workflow

The BIM2MAR process begins in Revit. First, A BIM model needs to be created or edited and based on the task that a user may perform; associated objects would be hidden/visible in augmentations. After a model has been generated and edited, a user will then need to export three types of files to be used in the MAR environment: geometry, code, and data. The geometry will be exported to Collada format, an XML-based schema that allows for easy transport between different software programs. Collada is compatible with both SketchUp where the geo-locations will be generated, and the Argon 2 browser, that utilizes WebGL/THREE.js. WebGL and THREE.js are JavaScript libraries/APIs for 3D graphics rendering on mobile/web browsers. The code for the MAR application will automatically be generated for the users via several Revit plugins that take into account the visible geometry, customized attributes of each object, surveyed points of observation, and textures/shading. The plugins will create several JavaScript and HTML files that include the Argon.js framework, the THREE.js library, and several BIM2MAR classes dealing with display and interaction. Finally the data/meta-data will be provided in an IFC schema format and accessed in the JavaScript code. All the exported files are placed on an Apache HTTP server in order to access them via the Argon 2 mobile web browser.

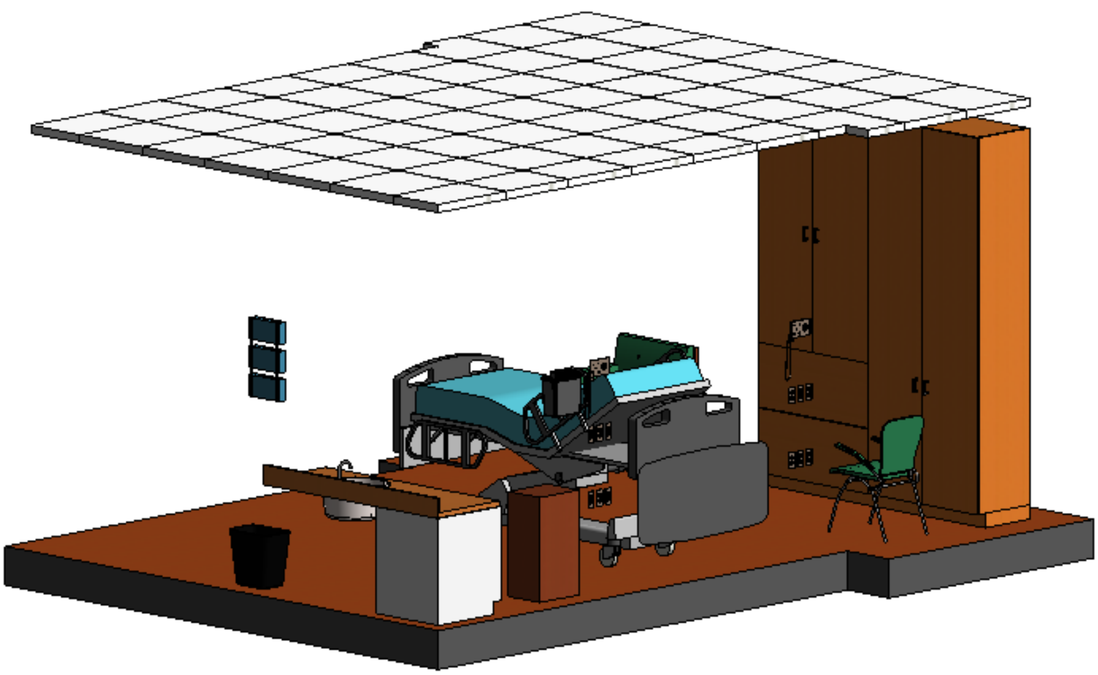
The BIM2MAR Revit plugins are at the core of the BIM2MAR process. The Autodesk Revit API requires the Microsoft .NET Framework v3.5 or v4.0. As Autodesk Revit only supports in-process Dynamic Link Libraries (DLLs) and single threaded access, the BIM2MAR workflow consists of multiple plugins to carry out multiple operations. For BIM2MAR, the External Commands deployment method was adopted which consists of two plugins. The first plugin is for translating BIM data for the Argon 2 environment that allows users to set the visibility of different objects according to tasks and generates the necessary files needed for 3D augmentation in Argon 2. To generate the files, the XMLTextWriter and StreamWriter classes were used, to write files that can be interpreted in Argon 2. The second plugin is for translating BIM geometry to the Collada format. A real-world application of this method within facility management practices is described in the following section.

Pilot Study, A Facility Management Environment

The BIM2MAR process was used in a living laboratory setting (Intille et al., 2005). A pilot study was conducted at the Shepherd Center in Atlanta GA, within a healthcare facility management context. Since there was no BIM model of this facility, building documentation (architectural, structural, mechanical, electrical, and plumbing construction drawings and photographs) was gathered to develop a BIM model in Revit. Since this was an active facility, the pilot study was restricted to one of the patient rooms (Room X). The BIM model of Room X was created and attributes were customized for each object based on a maintenance task (Figure 38.a). Since the task was facility management related, only the associated objects (Figure 38.b) were left visible for interaction within an augmented environment.



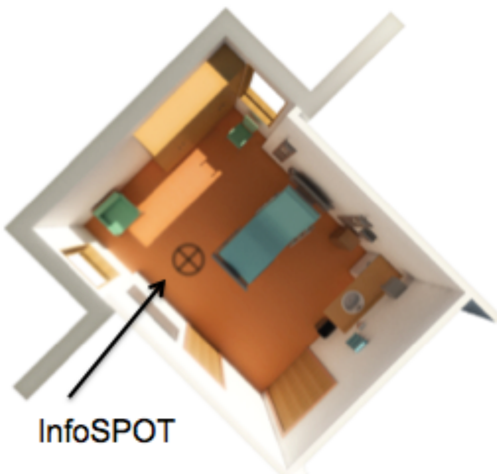
(a) All objects are visible



(b) Only task-associated objects are visible

Figure 38: BIM model of Room X

Additionally Information Surveyed Points for Observation and Tracking (InfoSPOTs) were selected to indicate where the users of the MAR system could access the properly registered geo-located augmentations (Figure 39.a). One InfoSPOT was chosen near the center of the room indicating where facility managers should stand (Figure 39.b) in order for the 3D geometry to be accurately registered with the real-world objects in a live view (Figure 40).



(a) InfoSPOT location at Room X

(b) User standing over the InfoSPOT

Figure 39: Location of InfoSPOT in Room X

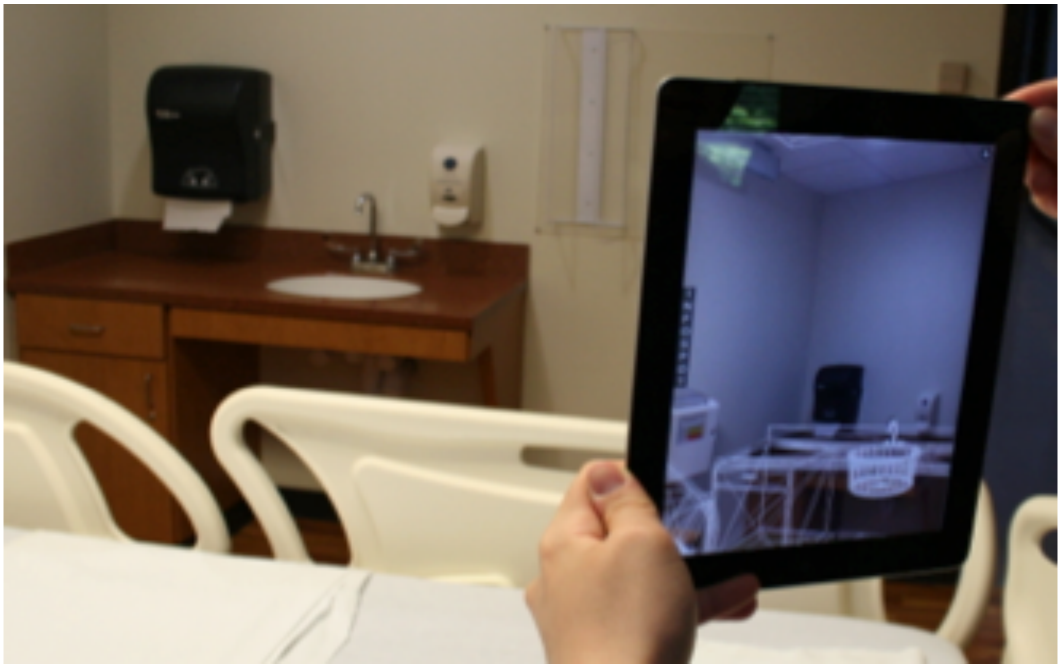


Figure 40: Augmentation on the user's mobile device

The BIM model of Room X was then used to generate geometry, code, and data files for the MAR environment. Collada Exporter for Revit (Lumion, 2012) was used to generate an XML file describing the 3D geometry and textures (Figure 41). Then, several JavaScript and HTML files were created via the BIM2MAR Revit API plugins (Figure 42) that provide the visualization and interaction framework for the MAR environment. Additionally, an IFC file was created that when paired with the exported code provides data related to 3D objects in the MAR environment.

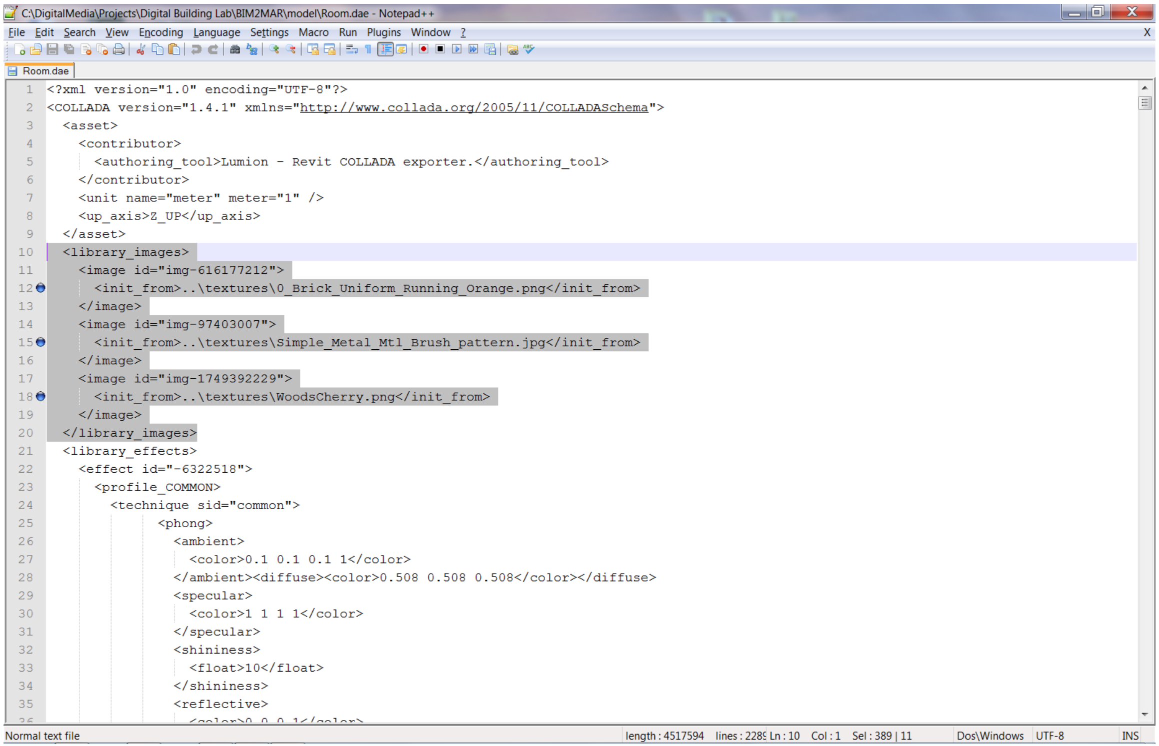


Figure 41: The XML file generated from Collada Exporter for Revit

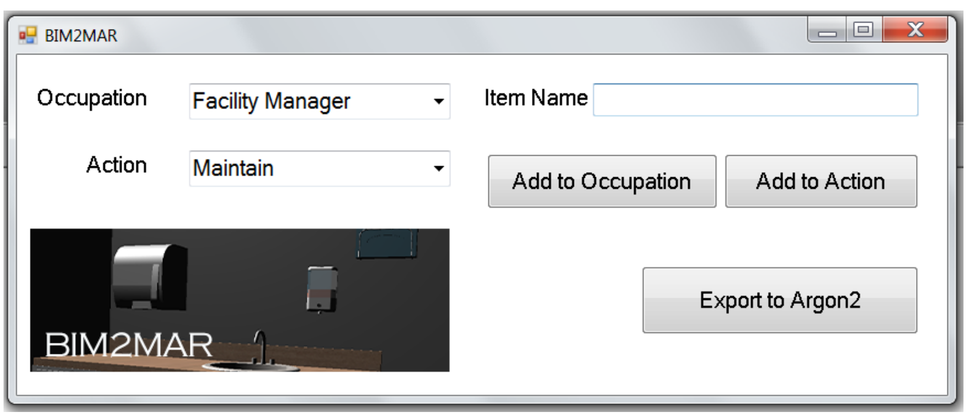


Figure 42: BIM2MAR Revit API plugin

After the files have been exported, they are uploaded to a web server and accessed via the Argon 2 browser. The interface provides users with an alternative to traditional paper-based work orders (Figure 43.a). In this interface, different tasks have been ordered based on priority and location of the facility manager within the building (Figure 43.b). Selecting the object would present the user with attributes associated with each object (Figure 43.c). Alternatively, a virtual model of the objects could also be accessed when users are not at InfoSPOT locations. The virtual model could be used as a non-location-based alternative providing the users with natural interactive experience of accessing the inventory data wherever they are (Figure 44.d).

(a) UI with AR on/off alternatives

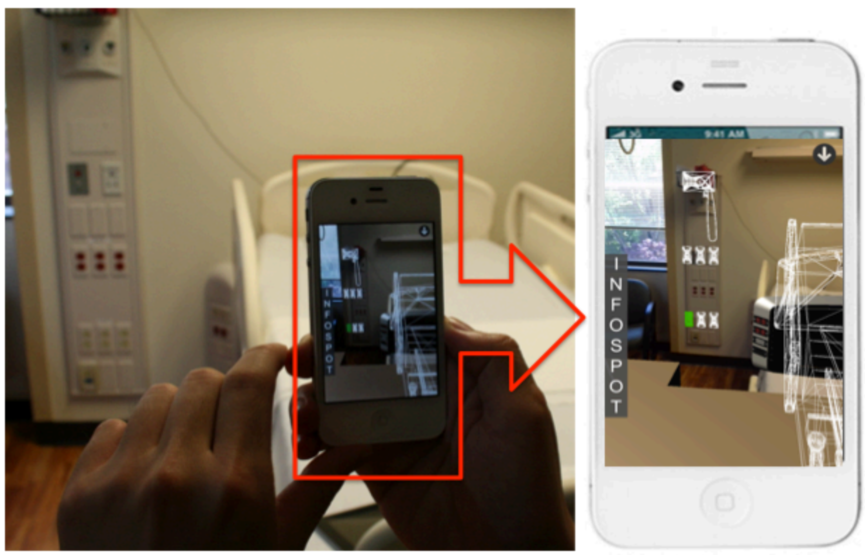
(b) UI with AR on and different tasks to be done

(c) Table of object attributes

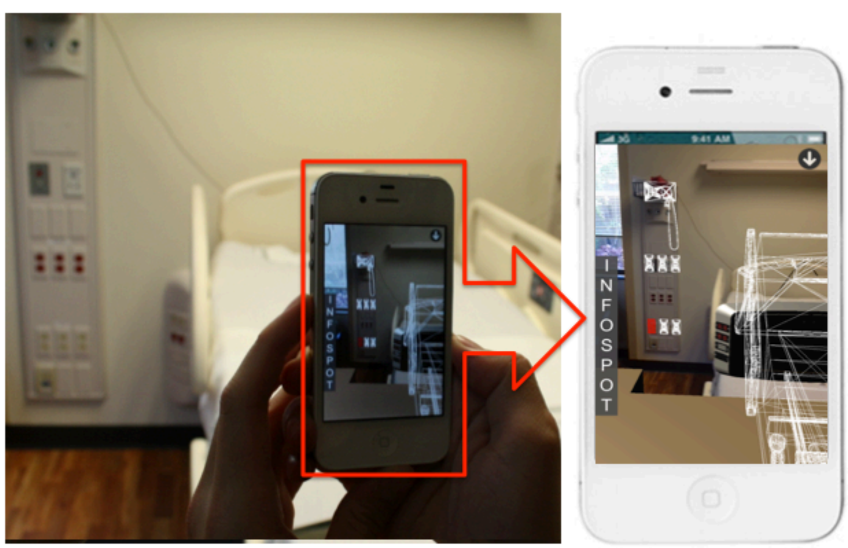
(d) Virtual model condition (location-independent alternative)

Figure 43: System User Interface (UI)

The facility manager could indicate through the user interface that a task has been completed. Objects associated with completed tasks are then displayed to the user with green shading (Figure 44.a) and the objects of the next task will subsequently appear shaded in red (Figure 44.b).



(a) Completed task-object highlighted in green



(b) Current task object highlighted in red

Figure 44: Augmented Reality views of objects

From our previous research (Irizarry et al., 2012), we discovered that drift and other registration issues were common in indoor MAR environments due to the use of sensor-based localization techniques with consumer-grade hardware. It was assumed that having wireframes of each object could help the subjects to perform their tasks easier when they were faced with drift problems or information overloads/overlays in the object-congested-areas of the room.

Discussion & Challenges

Implementing the BIM2MAR workflow posed several challenges, technically and logistically. Currently BIM is not a standard deliverable in many construction projects and is not maintained through the lifecycle of a building. Similar to other projects, only as-built CAD drawings (architectural, structural, mechanical) of the project site were available at the beginning of the project. From this documentation and photographs, a BIM model was created and required estimation of some of the building component dimensions. If a BIM model had been available, the workflow would have been more efficient and registration errors as the result of poor documentation would not have occurred.

There were numerous challenges that the authors faced during the creation of the BIM model itself. It was quickly realized that as-builts created by construction managers or architects of the site would likely be insufficient for daily facility management tasks. Facility managers are concerned with the components of building objects. Often, facility managers need to fix/maintain/replace one part of the system and not an entire system. The BIM software utilized, Revit, did not allow for sub-parts of a system to be individually tagged with unique properties. For instance, a facility manager might want to assign a corrective maintenance task to a particular wall socket on a wall panel. It is difficult to assign attributes/properties to that wall socket due to the Family structure in Revit. Due to this limitation, the authors had to approach creating the BIM model differently than construction managers or architects, keeping in mind what parts of an object a facility manager would want to operate on. Additionally, it is not possible to add custom instance properties to objects making it difficult to uniquely tag individual geometry with facility management related custom attributes like completion date, personnel assignment, and priority. To address these issues, the authors had to break down families (doors, ceilings, etc.) into smaller component families, which required significant effort and ultimately is not scalable.

One of the main focus areas for this project was to determine a method to provide complex geometry on a computationally simplified mobile platform. BIM models can be rather large file size and to visualize them on a mobile platform with limited processing power and graphics capability is a daunting task. Different options of displaying 3D graphics on mobile platforms were explored. Web Graphics Library (WebGL), which uses JavaScript with no additional software installation required, is quickly becoming the standard on a majority of both desktop and mobile browsers. There are several methods of displaying 3D geometry using WebGL, but a high level JavaScript library/API was found, THREE.js, which leveraged WebGL and had established pipelines for integrating complex geometry from traditional CAD programs like 3ds Max or Maya. Each established pipeline incorporated different 3D file formats including Wavefront OBJ (*.obj), JavaScript Object Notation (*.json), and Collada (*.dae). Each pipeline was tested and several problems with both OBJ and JSON formats were discovered. Both the

OBJ and JSON pipelines were time consuming, inaccessible, and the conversion process resulted in inconsistencies in geometry and loss of data. Conversion to the Collada format had several advantages including that a third-party, Lumion, had already developed an exporter plugin for Revit. The Collada files also maintained object hierarchies, properties, and textures that ultimately led to the adoption of this pipeline as part of the workflow.

Although, there was one significant drawback to using the Lumion plugin to generate Collada files. The BIM2MAR workflow relies on a backend relational database that stores the properties/attributes related to each piece of 3D geometry in the BIM model. In order to link the front-end geometry (*.dae) to the backend data (SQL), a method was initially conceived that would utilize the GUID (Globally Unique Identifier) of each 3D object as the primary key in our relational database. Unfortunately, the Collada files generated by the Lumion plugin did not maintain this GUID. Alternatively, another property that could be unique to each object was used, the object name. While this method worked for prototype purposes, this method is not scalable to larger projects where unique naming of thousands of objects would be time-consuming and require further development of taxonomies and naming conventions. Nonetheless, conversion to Collada was also beneficial because it allowed for easy import of the geometry into SketchUp, which has built-in access into Google Earth. A Ruby script was developed using the SketchUp API allowed gathering of the geo-locations for all objects for integration into the IFC schema. Although this method works, it is not the most efficient method for adding geo-location to the objects. In future work, the geo-location of objects will be established solely in the Revit platform.

After the geometry was ready for conversion, the next challenge was getting it to work in the Argon 2 environment, which is still in active development. To ensure stable results, we often communicated with the developers of the Argon 2 to help them debug issues with the incremental releases.

Ultimately, the BIM2MAR workflow required users to switch between several software applications and conduct numerous file type translations. Like other complex, multi-step workflows, this method is prone to error due to the many points in the process where users or software fails to accomplish a task sufficiently.

Pilot testing also revealed several more issues that had not been considered until on site at Shepherd Center. One of the main issues faced was matching the virtual camera with the physical camera on the mobile device. At first, the virtual geometry did not align accurately with the live camera feed. It was realized that the virtual camera did not have the same field of view, focal length, and depth of field as the physical camera. After adjusting accordingly, the wireframes of the virtual objects where visible over their real-world counterparts. But, further registration issues related to drift and accuracy similar to our first InfoSPOT prototype were encountered. Consumer grade accelerometers and gyroscopes caused the augmentations to be misaligned by several centimeters, and inaccurate CAD files resulted in the need to measure objects in the room and fix dimension errors in our BIM model.

BIM2MAR's main contribution is that it is a low-cost technical solution to transporting geometry and data from a BIM model to a Mobile Augmented Reality environment. BIM2MAR contributes to the AECO domain's body of knowledge in that it provides a better understanding of how inexpensively BIM and MAR can be integrated to facilitate access to information. WebGL and THREE.js, web standards used by most mobile browsers, are leveraged requiring no additional plugin installation or cost. Ultimately this is the first step in developing a fully automated BIM to MAR process for multiple AECO applications. In a fully automated BIM2MAR process all geometry and data would be accessible through a real-time input/output system and the AR environment would update automatically as changes are made to the BIM model.

CHAPTER 9

AR VS. PAPER: EVALUATION THROUGH A USER PARTICIPATION EXPERIMENT

The Architecture, Engineering, Construction, and Operations (AECO) industry, specifically the facility management domain, is searching for new methods of increasing maintenance efficiency and productivity in areas where constant critical decisions are made in order to maintain facilities. New digital technologies are capable of enhancing this decision-making process by providing better means of accessing required information. In this research, BIM, together with mobile Augmented Reality (AR), have been used for developing a system to access building information in facilities. AR is a viable option to replace the current approach of locating facility components using paper-based corrective/preventive maintenance work orders. The AR also reduces inefficiencies of data overload by providing facility managers with a BIM-based tool for visualizing their "real-world" environment with added interactive data. The hypothesis of this portion of the research is that bringing 3D BIM models of building components into an AR environment and making them accessible through handheld mobile devices would help the facility managers to locate those easier and faster components as compared to the facility managers' current approach of paper-based preventive/corrective maintenance work orders. A within-subjects user participation experiment and analysis was conducted to evaluate this hypothesis. The outcome of statistical analysis reveals that a mobile AR-based environment would significantly enhance the location of the correct object in the facility in terms of the required time and number of errors. Although there were drift and registration problems while conducting the experiment, participants significantly preferred the AR condition to the paper one.

Experiment Hypothesis

Locating building components in a facility was the main task in this experiment. Based on the results of the online survey and the feedback provided by the facility managers (Discussed in Chapter 7), locating building components and 3D visualization are the most important applications of BIM within facility management practices. The survey respondents also provided very positive feedback on accessing information in an AR environment. Considering these issues, the following hypothesis was developed:

> *"Bringing 3D BIM models of building components in an AR environment and making it accessible through handheld mobile devices would help the facility managers to locate those components easier and faster compared to facility managers' paper-based approach."*

In the current approach of locating facility components, facility managers are usually provided with preventive or corrective maintenance work orders in which the location of the target building component has been recorded based on the previous maintenance tasks (preventive) or the calls/reports provided by other parties (corrective maintenance). Figure 45 illustrates an example of the paper format explaining the location of a component in the facility (in red).

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448422 0224013- HVAC Tiles– Monthly

Schedule No: 5038
Sire/Bldg: Shepherd Center
Bldg/Floor: 3rd level
Floor/Wing: 3rd Level W. Wing
Location: Shepherded Center, Room 309, Left side of the room

Skill: Building Automation System
Priority: 1-High Priority
Status: Active
Sub-Status: Issued, Being worked on

Date Orig: 3/23/2013
Time Orig: 10:45
Date Avail: 3/25/2013

Figure 45: Location-related section of the work-order (highlighted in red)

Experiment Design and Methods

The within-subjects experiment consisted of using a tablet computer device (an Apple iPad) as a mobile AR tool versus using a paper format work order to locate problematic equipment in the test location. Simultaneously, the evaluator measured the time used and the number of errors made by the participants to successfully perform the tasks. The participants had to speak their thoughts aloud, and an observer made note of all critical accidents and participants' comments or concerns. Examples of evaluator and observer forms have been provided in Appendices B and C respectively. Before starting the experiment, each subject was presented with an Informed Consent Form (Appendix D) for him or her to read in agreement to participate in the experiment. Georgia Tech's Institutional Review Board (IRB) evaluated and approved the study protocol. The subjects were also required to fill out a demographic information form (Appendix E) before starting the experiment and a post-study questionnaire after the experiment (Appendix F).

Test location

The experiment was conducted in a living laboratory setting (Intille et al., 2005) at the Shepherd Center in Atlanta GA, within a healthcare facility management context (Figure 46.a). This test location was chosen as an example of a complex and dynamic healthcare facility where facility managers are required make critical decisions constantly. Since there was no BIM model of this facility, building documentation (architectural, structural, mechanical, electrical, and plumbing construction drawings and photographs) was gathered to develop a BIM model in Revit. Since this was an active facility, the pilot study was restricted to one patient room (Room X). The BIM model of Room X was created, and attributes were customized for each object based on the experiment task (Figure 46.b). As the experiment was facility management related, only the associated objects (Figure 46.c) were left visible for interaction within an augmented environment.

(a) The living laboratory test setting at Shepherd Center, Atlanta GA

(b) BIM model of Room X in Revit

(c) Experiment-associated objects in BIM model

Figure 46: Test Location

Objects in Experiment

All of the objects in Room X had been modeled, but the tasks in the experiment only applied to those illustrated in the Schematic plan of the test location (Figure 47): (1) electrical outlets on right and left side of the bed, (2) wood cabinets and shelves on left side of the bed, and (3) HVAC-tiles (roof tiles covering the HVAC-systems behind them) as illustrated in a grid format in Figure 47.

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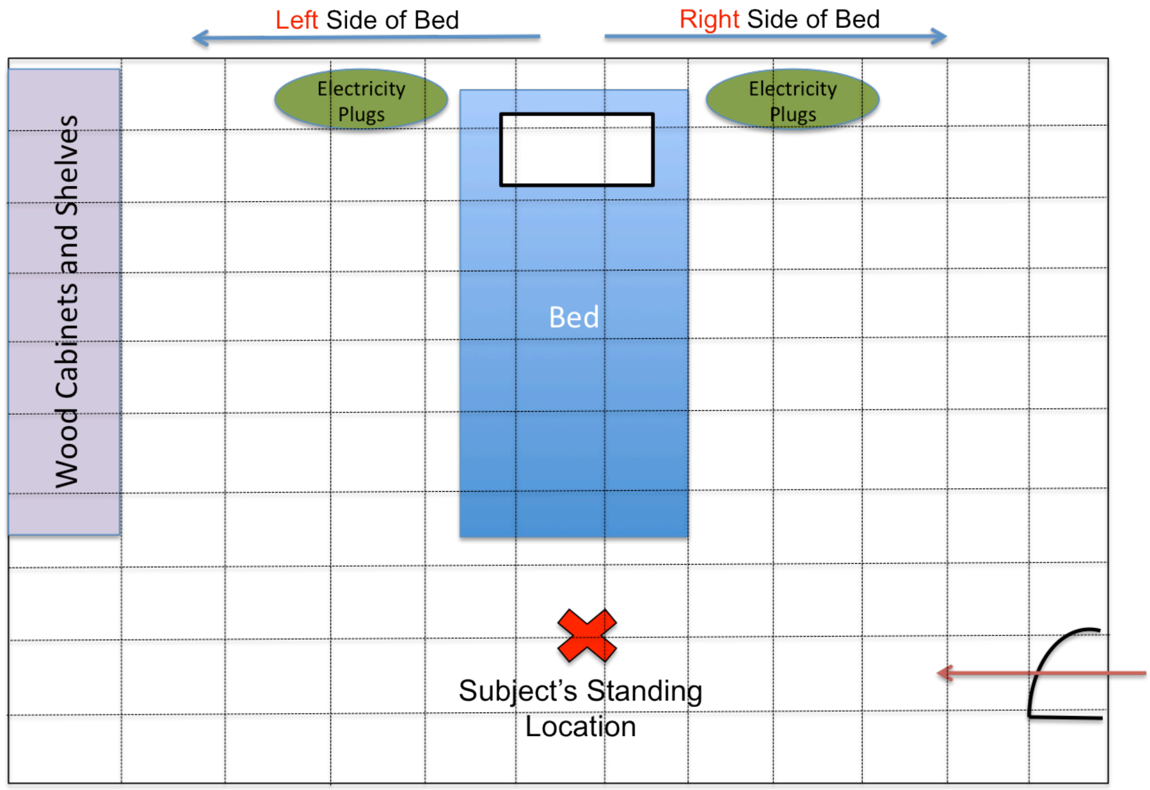
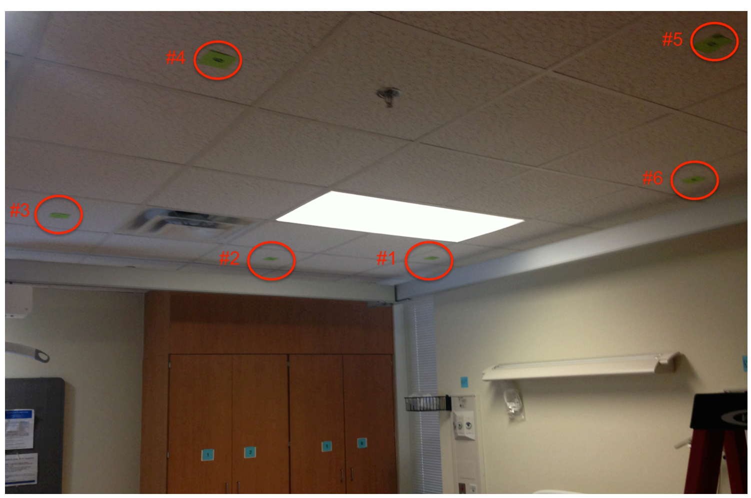


Figure 47: Schematic plan of test location (Room X)

The following specific group of objects was labeled and color-coded for use in the experiment: (1) six electrical outlets on right and six on left side of the bed were labeled in pink with numbers from 1 to 12 (Figure 48-a), (2) six wood cabinets and shelves on the left side of the bed were labeled in blue with numbers from 1 to 6 (Figure 48-b), and (3) the HVAC-tiles on the roof were labeled in green with numbers from 1 to 6 (Figure 48-c).

(a) Electrical outlets labeled from 1 to 12 on left and right side of the bed

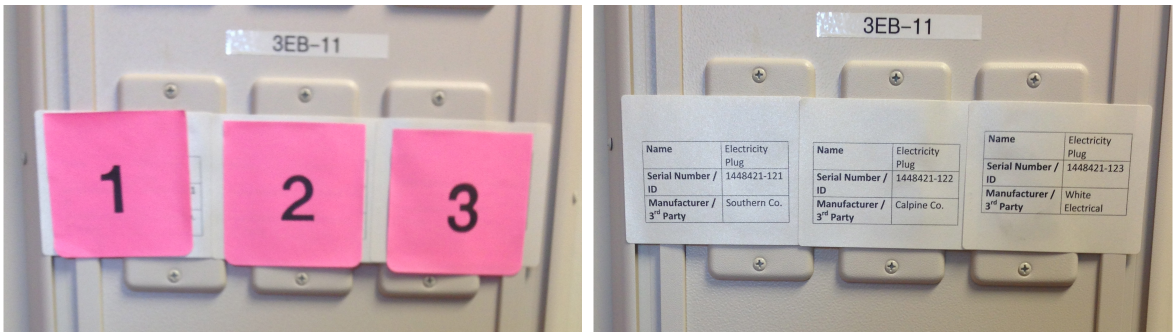
(b) Wood cabinets and shelves labeled from 1 to 6 on the left side of the bed



(c) HVAC-tiles labeled from 1 to 6 on the roof

Figure 48: Objects at Room X that were used in the experiment

Under each numbered label (Figure 49-a), a table of information (Figure 49-b) was provided indicating the serial number and product manufacturer unique to each experiment-target-object in the room (Appendix G).



(a) Electrical outlets labeled in pink numbers

(b) Tables of information under the number labels

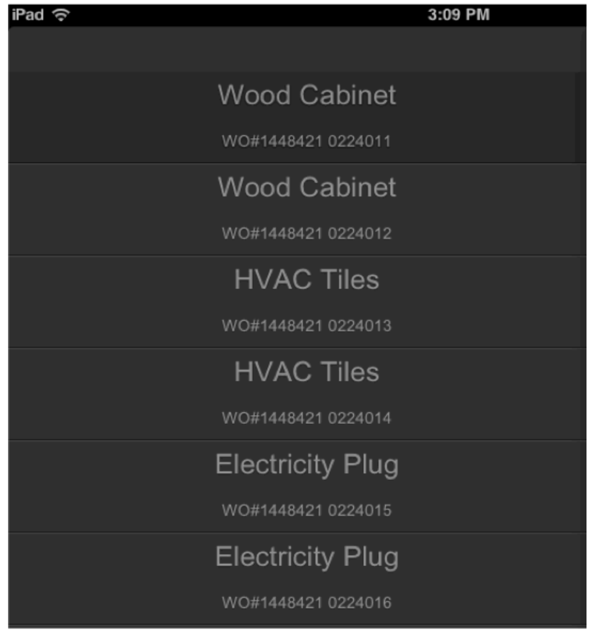
Figure 49: Number labels and table of information for the experiment target objects

Test Conditions and Experiment Task

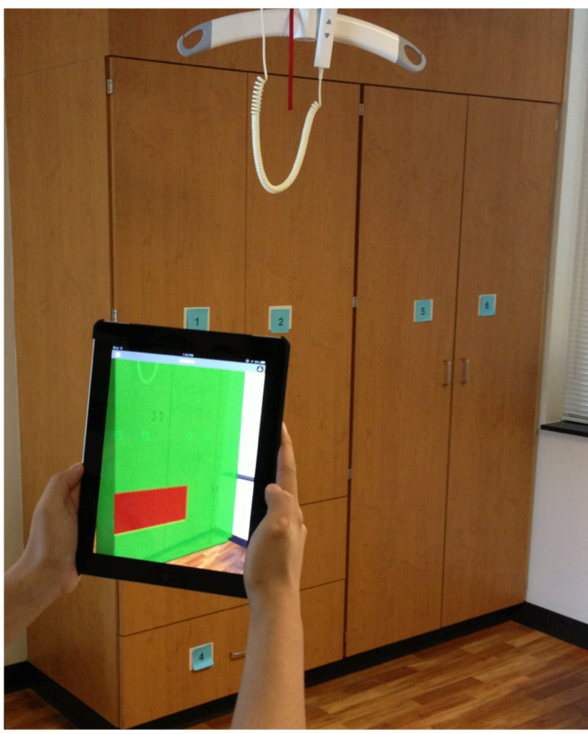
As previously mentioned in section 9.1, the experiment hypothesis was "bringing 3D BIM models of building components in an AR environment and making it accessible through handheld mobile devices would help the facility managers to locate those components easier and faster compared to facility managers' paper-based approach." Considering the hypothesis, there were two conditions in this experiment: (1) Augmented Reality (AR) and (2) paper format.

In the AR condition, subjects stood on a fixed geo-spot location previously defined in Room X (Figure 50-a) and were provided with an iPad to complete six different tasks (Figure 50-b). Each task indicated one object in the room that the subject should have located correctly. Two parts of the wood cabinets and shelves, two HVAC-tiles, and two electrical outlets were the targets of this experiment. Subjects could see the real-life view of the room through an iPad, but each object was highlighted using augmented 3D geometry of the same object from the BIM model (Figure 50-c and 50-d). On their iPads, the target component in the facility appeared in red, while other components from the same family appeared in green.

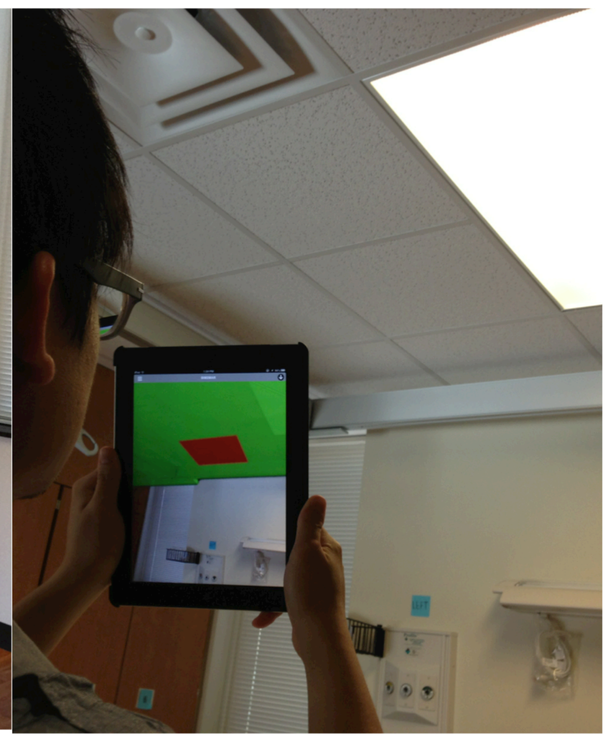
(a) Subject's standing location



(b) Six maintenance-related tasks



(c) Target wood cabinet in red with other cabinets and shelves in green



(d) Target HVAC-tile in red with other tiles in green

Figure 50: Augmented Reality (AR) Condition

In the paper-format condition, the subjects were provided with a very similar set of six preventive/corrective maintenance work orders but in the exact format that facility managers were using at the Shepherd Center. The subjects started the experiment at the starting location point (Figure 13-a), but unlike in the AR condition, they had to move about the room to find the correct objects. In the paper format-condition, the subjects had a paper work order of a target component in the facility. Appendices H and I show all the paper-format work orders that were used for the experiment. In this condition, the subjects were required to go through the work orders and, using the sections related to the location of the target building component, locate the right object in the facility. For locating the right object in the room, the subjects not only needed to focus on the location-related sections of the work order to approximately locate the area of the target object but they also had to check the serial number or manufacturer information on the work order using the table of information provided under the numbered labels to make sure they located the correct object (Figure 51). Those information-tables were unique, and each one was associated to only one work order. Figure 52 illustrates a subject in the paper-format condition checking the serial number and manufacturer information on his or her work order using the information tables under the number labels to locate the correct object in the test.

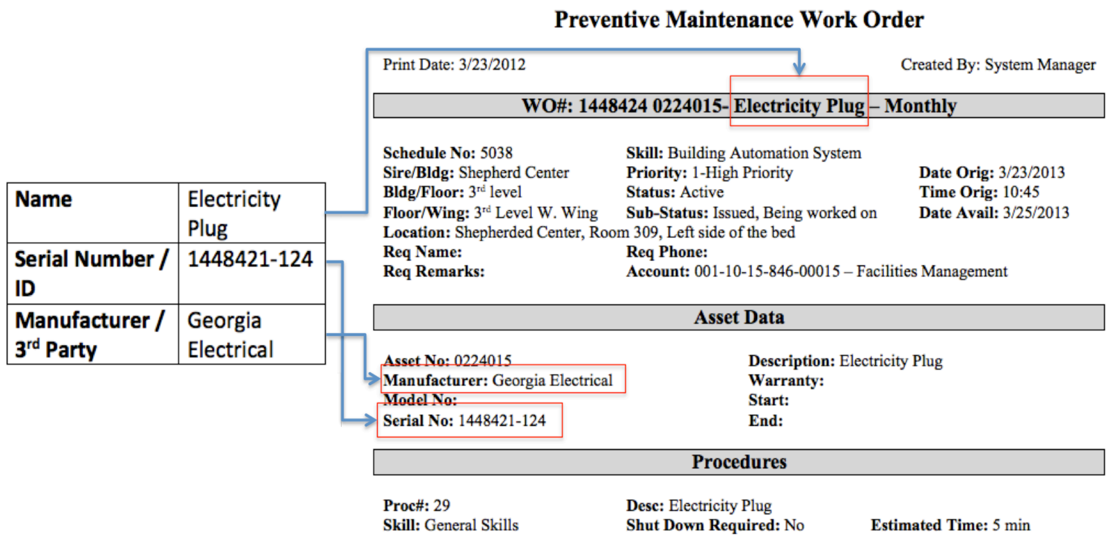


Figure 51: Matching the information on the table (left) and the work order (right)

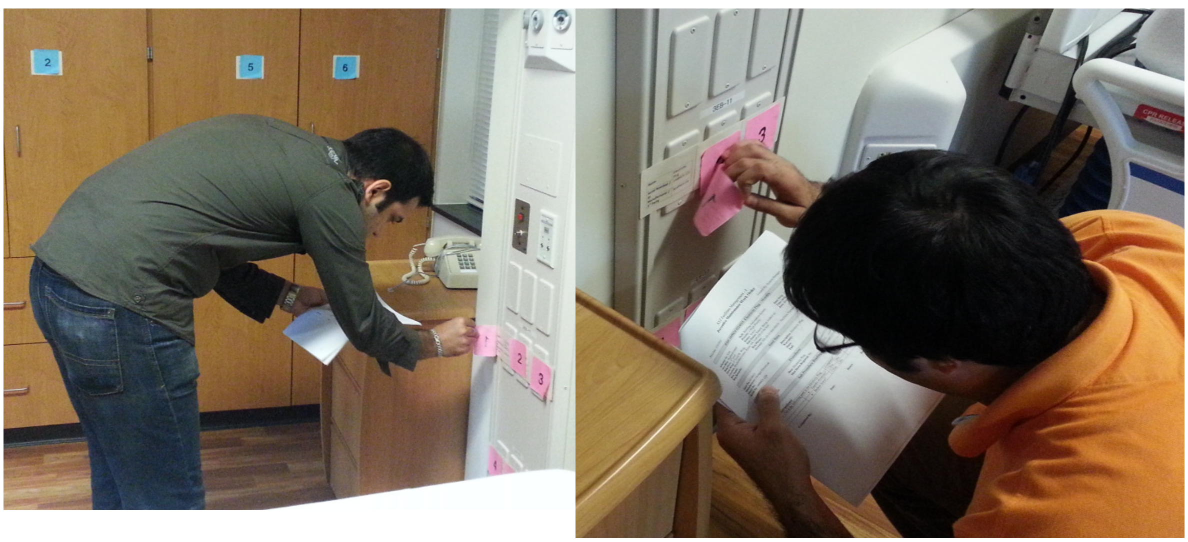


Figure 52: Subjects are checking the serial number and manufacturer information on their work order with information tables under the numbered labels

As previously mentioned, each condition included six different tasks. Each task considered one object in the room that each subject should have located correctly. Two parts of the wood cabinets and shelves, two HVAC-tiles, and two electrical outlets were the targets of this experiment. The experimenter measured and recorded the time used and the number of errors made on each task. Subjects were not required to write down an answer, but they had to state the number labeled on the target object aloud for the experimenter to verify. As soon as the experimenter said the word “START,” the time measurement began. Afterward, if the subject stated the correct object number aloud, the experimenter would say “NEXT,” indicating that the subject should move on to the next task. If the participant did not provide the right answer, the experimenter would say “NOT CORRECT,” and the subject kept looking until he or she found the correct object. At the end of each condition, the experimenter added up the times for each of the six tasks to get the total time required for performing each scenario. This total time was used for statistical analysis.

Participants in the Experiment

Eight participants (5 male and 3 female) took part in the experiment. All participants reported normal or corrected-to-normal vision. The majority of subjects (75%) had not heard of AR, and only 1 had previously used any AR-based tool, device, or application. Table 19 provides an overview of the collected demographic information.

Table 19: Demographics of Participants

Variables		Percentage (%) Total # of Subjects= 8
Age	19-25	12.5
	26-30	75.0
	31-40	12.5
Gender	Male	62.5
	Female	37.5
Occupation	Student	75.0
	Other	25.0
Field of study for highest degree	Construction & facility management	62.5
	Healthcare	37.5
Academic Rank	Undergraduates	25.0
	Master	75.0
Previously heard about AR?	Yes	25.0
	No	75.0
Previously used any AR-based tool, device, or application?	Yes	12.5
	No	87.5
Previously used any touch-screen mobile device?	Yes	100.0
	No	00.0
Play videogame?	Yes	25.0
	No	75.0

Results and Statistical Analysis

Analysis of the data collected includes reporting descriptive statistics as well as performing a paired-samples-T-test and a 95% confidence interval of the paired differences. Sections of the IBM Post-Study System Usability Questionnaire (PSSUQ) (Lewis, 1995) were combined with NASA Task Load Index (Hart & Staveland, 1988) to develop a new After-Scenario Questionnaire (ASQ) for this experiment. The new questionnaire consisted of 13 questions with questions 1 to 7 extracted from PSSUQ and questions 8 to 13 based on NASA Task Load Index. The items asked participants to express their levels of agreement with the statements presented using the 7-point Likert

Scale provided. Table 20 demonstrates the Means, Standard Deviations (SD), and different Likert scales of all the ASQ items based on the subjects' experiment conditions.

Table 20: Descriptive statistics for the After-Scenario Questionnaire

Q #	Variables	Likert Scale	Test Conditions: Augmented Reality Mean (SD)	Test Conditions: Paper Mean (SD)
1	Overall, I am satisfied with the ease of completing this task	1=Strongly Disagree to 7=Strongly Agree	6.50 (0.53)	3.63 (2.39)
2	It was simple and quick to use this approach	1=Strongly Disagree to 7=Strongly Agree	6.63 (0.52)	3.38 (2.56)
3	It was easy to learn to use this approach.	1=Strongly Disagree to 7=Strongly Agree	6.63 (0.74)	5.25 (1.39)
4	I believe I could become productive quickly using this approach	1=Strongly Disagree to 7=Strongly Agree	6.75 (0.46)	4.50 (2.14)
5	Whenever I make a mistake using the approach, I could recover easily and quickly	1=Strongly Disagree to 7=Strongly Agree	6.38 (1.06)	4.50 (1.77)
6	It was easy to find the information I needed	1=Strongly Disagree to 7=Strongly Agree	6.63 (0.74)	3.50 (2.27)
7	Overall, I am satisfied with this approach	1=Strongly Disagree to 7=Strongly Agree	6.50 (0.76)	3.63 (2.45)
8	How mentally demanding was the task?	1= Not Demanding to 7=Very Demanding	1.75 (1.49)	4.38 (2.13)
9	How physically demanding was the task?	1= Not Demanding to 7=Very Demanding	1.13 (0.35)	5.13 (2.64)
10	How hurried or rushed was the pace of the task?	1= Not Rushed to 7=Very Rushed	1.75 (1.75)	3.50 (1.60)
11	How successful were you in accomplishing what you were asked to do?	1=Very Unsuccessful to 7=Very Successful	6.75 (0.46)	5.50 (1.41)
12	How hard did you have to work to accomplish your level of performance?	1= Not Hard to 7= Very Hard	1.38 (0.52)	4.50 (2.07)
13	I was insecure, discourage, irritated, stressed and annoyed with the task	1=Strongly Disagree to 7=Strongly Agree	1.00 (0.00)	3.63 (2.50)

Table 21 also demonstrates the Means, Standard Deviations (SD), Minimums, and Maximums for the dependent variables of time and number of errors based on subjects' experiment conditions. Time was defined as the total amount of time that the subjects took to do the all of the tasks from start to finish for each condition, and the number of error was defined as total instances of calling or looking behind any wrong number in the test location.

Table 21: Descriptive statistics for the dependent variables of time and number of errors

Quantitative Variable		Test Conditions: Augmented Reality	Test Conditions: Paper
Time (h:mm:ss)	Mean	0:02:08	0:05:36
	Standard Deviation	0:00:52	0:01:23
	Minimum	0:01:09	0:04:00
	Maximum	0:03:21	0:07:50
Number of errors	Mean	1	19.38
	Standard Deviation	1.07	12.29
	Minimum	0	7
	Maximum	3	39

Time and all different variables in the ASQ were analyzed using a 2-tailed paired-samples-T-test, a 95% confidence interval of the paired differences, and an alpha level of $p = .05$. Table 22 displays the results of the paired-samples-T-test and the 95% confidence interval. As illustrated in this table, all results were statistically significant except those of Questions 3 and 10, which were marginally significant.

Table 22: Paired-samples-T-test and 95% confidence interval results

Variables	95% Confidence Interval of the Paired Difference		t	Sig.
	Lower	Upper		
Time (h:mm:ss)	-0:04:42	-0:02:13	-6.600	.000
Error	-29.062	-7.688	-4.066	.005
Q1: Overall, I am satisfied with the ease of completing this task	.956	4.794	3.543	.009
Q2: It was simple and quick to use this approach	1.119	5.381	3.606	.009
Q3: It was easy to learn to use this approach.	-.103	2.853	2.200	.064
Q4: I believe I could become productive quickly using this approach	.421	4.079	2.909	.023
Q5: Whenever I make a mistake using the approach, I could recover easily and quickly	.299	3.451	2.813	.026
Q6: It was easy to find the information I needed	1.487	4.763	4.511	.003
Q7: Overall, I am satisfied with this approach	.956	4.794	3.543	.009
Q8: How mentally demanding was the task?	-4.620	-.630	-3.111	.017
Q9: How physically demanding was the task?	-6.143	-1.857	-4.413	.003
Q10: How hurried or rushed was the pace of the task?	-3.881	.381	-1.941	.093
Q11: How successful were you in accomplishing what you were asked to do?	.089	2.411	2.546	.038
Q12: How hard did you have to work to accomplish your level of performance?	-4.991	-1.259	-3.960	.005
Q13: I was insecure, discourage, irritated, stressed and annoyed with the task	-4.718	-.532	-2.966	.021

Discussion of Results

The results indicate that the general pattern is similar, meaning items were scored significantly better in favor of the AR (Augmented Reality) condition. Individuals' comments in the after-scenario questionnaire, as well as issues declared by subjects in the thinking-aloud process during the experiment, also supported the findings.

Considering the total time for performing each condition, participants statistically completed the experiment task faster under the AR condition (Mean=0:02:08, Min=0:01:09, and Max=0:03:21) in comparison to the paper-format condition (Mean=0:05:36, Min=0:04:00, and Max=0:07:50). Another quantitative variable assessed in this experiment was number of errors. In this case, a significant difference occurred between two conditions, and the subjects in AR condition (Mean=1.00, Min=0, and Max=3) statistically had fewer errors in locating the correct object in the test room compared to subjects using paper-based preventive and corrective maintenance forms (Mean=19.38, Min=7, and Max=39). Subjects made similar comment in favor of the AR approach and against paper condition, supporting the result of time and number of errors. "[Paper approach] could lead to lots of errors easily", [Paper approach] was "confusing," "very unreliable," and "time consuming." One subject noted that "it was not easy to find the location [of right object in paper condition] because it was taking a lot of time to match information [between paper forms and objects' data table]."

In terms of the qualitative after-scenario questions, the users were significantly more satisfied with the ease of completing the experiment task under the AR condition (mean response out of 7, Mean=6.50) than the paper-based checklists (3.63). One subject stated, "even a kid can handle the task [using the AR system] as there was not much to do beside looking around [through the iPad] and find the right object [in the test room]". The subjects also believed that the AR approach was significantly simpler and quicker to use (6.63) than the paper-format (3.38). Subjects also indicated that difference between two systems in terms of easiness of learning was marginally significant and it easier for them to learn AR approach (6.63) as compared to the paper forms (5.25). They also believed that AR (6.75) made significant enhancement in terms of becoming productive quickly versus the paper condition (4.50). Using the AR system (6.38), when the subjects made a mistake, they could recover significantly easier and faster as opposed to the paper-based approach (4.50). In terms of finding the information, subjects indicated that it was significantly easier for them to find the information required to locate the correct object in the test room under AR condition (6.63) than in the paper-format (3.50). Overall, subjects were significantly more satisfied with AR condition (6.50) than the paper format (3.63).

Subjects' workload was measured using the NASA Task Load Index (Hart & Staveland, 1988) questions. The subjects rated the use of paper-format forms to locate the correct object in the test room significantly demanding for them mentally (1.75) and physically (1.13), in comparison to the AR approach (4.38 and 5.13 respectively). In support of these results, one subject stated, "I found this task [under AR condition] less demanding than actually having to read each individual paper [to locate the right object]." Subjects believed that the pace of the task was marginally significant and they were more hurried and rushed in paper condition (3.50) than with the AR system (1.75). Regarding success in performing the required tasks, subjects, on average, believed that they were successful in accomplishing what they were asked to do, and, comparing the two conditions, they scaled the AR condition (6.75) somewhat better than the paper-format (5.50). Subjects also believed that they had to work significantly harder in paper condition than with the AR approach (1.38) to accomplish their level of performance. Subjects strongly disagreed that they were insecure, discourage, irritated, stressed, and annoyed with the task under AR condition (1.00), while, considering the same criteria, they scaled paper condition significantly worse (3.63).

Although the AR system was scaled better than the paper condition, the majority of subjects made several comments about drift problem. One subject stated, "The [AR] system is very intuitive but sometime there is a mismatch between the objects and the augmentations," and another one noted that "[the augmentations] were not exactly matching [on the right object], but I could easily guess the right answer." As a part of the experiment under paper condition, the subjects were required to climb a ladder to check the information behind the HVAC tiles numbered labels. This led to several comments such as "AR is much more reliable and safer [than paper condition]," and "AR approach is easier and less risky than climbing ladders in a hospital and it has less try and error." The subjects also provided different recommendations/comments such as "I believe if the definition of the location was determined clearly, the performance could be better," "[AR] is simple and easy to locate the objects but just having green and red colors to represent right and wrong objects [in the test room] is not intuitive," and "I don't like touching objects in hospital and having AR system helped me not to do that."

There were some other issues observed while subjects were performing their tasks. In paper condition, most of the subjects were initially confused with the tasks but learned how to do so after completing the first. They made comments such as "I don't know what I am doing," or "I am not sure where I can find the right object in the room." In AR condition, the system crashed several times, and the most important comments made by users in their thinking aloud process was about the drift issue. They made comments such as "… It is difficult to find…align, please," "It is not matching," and "It is not totally matched, it is 1 meter away." Another issue observed several times in the AR condition was that subjects had to look at the iPad and the real world (switching the domains) to locate the right object. This issue might be due to the drift problem or the transparency and size of the augmented geometry of the object. Some other general observations in AR condition are as following: (1) some users were leaning back on their standing point to see some augmented information, (2) users were generally identifying the color first and then deducing from geometry, (3) after a short time, users would translate errors in drift and could begin to interpolate the correct answer, (4) due to drift, users felt as though they were guessing which object was the correct one, (5) some users were trying to align digital information before stating which object needed to be maintained, (6) some users moved their bodies extensively, and (7) some users has to look back and forth from the screen to call out the number.

CHAPTER 10

CONCLUSION

The SA-based methodology was not only an innovative user-centered approach in the facility management domain and was applied to this domain for the first time but also the outcome of it is an applicable source of all goals, information requirement and associated decisions for the facility managers at the operational level. This helped to understand the information needs of facility managers in goal-oriented positions that are critical to the decision-making process in dynamic and complex healthcare environments. The outcome provided the facility managers with a structured overview of their information requirements and would be of great benefits for not only the experienced facility mangers but also for novice ones who might work in the same position.

Second, the outcome of the survey and scenario stage helped to understand the status of BIM, MAR, handheld mobile computer and smartphone adoption, and even their integration in the facility management domain since there was little empirical data on these topics in the operational and maintenance stage.

Third, the BIM+MAR integrated prototype, as a low-cost solution that leverage current AR technology, showed that it is possible to take an idealized BIM model and integrate its data and 3D information in an MAR environment. This inexpensive solution would help facility managers with their routine tasks because their live view of a space could now be supplemented by needed information, all in one interface while there would be no need for distracting domain switching.

Fourth, the user participation experiment using the developed system in this research helped to quantify the effect of natural user interfaces on locating building components in an Ambient Intelligent environment through usability evaluation.

Finally, the whole process of (1) following a user-centered approach for understanding the user data needs for IT systems based on specific operational area, (2) converting those requirement to an IT tool using new and innovative technologies and then (3) asking the same people who have provided us with those system information requirement to use the system and evaluate it, was an innovative and Human-Computer-Interaction-based approach in the facility management domain. This is a paradigm shift for researchers and practitioners in the facility management domain from a technology-centered approach to a user-centered one that considers user requirements when adopting new technologies in this domain.

In summary, the contribution of this research to the body of knowledge were (1) understanding the information needs of operational level facility managers in dynamic and complex environment of hospitals, (2) understanding the current status of BIM, AR, and handheld mobile technology use in facility management practices, (3) developing a workflow for bringing a BIM model to an augmented reality environment, (4) quantifying the effect of natural user interfaces on information access in an augmented reality-based environment, and (5) identifying barriers to information access in such an environment.

One of the greatest challenges of the proposed ambient intelligent is that the whole AR system is built using a sophisticated BIM model that not only would play the role of the data repository but also would provide the geometry of different objects or components within the facility for augmentation purposes. Currently, augmenting information into the real world of facilities management does not fit into a workflow that exists within AECO processes. For a successful implementation of brining BIM to an AR environment owners need to start asking for their requirements of BIM and not let those requirements being pushed up to operations phase by the designers or contactors. Another expedient of successful BIM and AR integration will be the improvement of the technology and software, which will make AR both easier to create and fit within a standard workflow, and easier for AR to be used in the field and be integrated with BIM.

Another challenge of AR application for facility management practices is the drift problem meaning virtual augmentations would not exactly match on the real object. Solving this issue is a main avenue of research in the Computer Science domain. There are different approaches for reducing the drift issue to minimum amount but most of them are costly and not scalable for real applications in AECO practices. Through the user-participation experiment that was conducted, it was understood that even having the drift issue, significantly better outcomes were achieved under AR condition compared to the paper-condition. Accepting drift issues and investigating human computer interface requirements that would minimize the matching requirement and would enhance the user experience in an AR environment would be of great value for AR applications using the current technological infrastructure in the market (e.g. tablet computers and handheld mobile devices). Unfortunately there is no design guideline for AR for use in any handheld, projective, or head-worn tools. The next phases of this research should be investigating what would be the design requirements for AR application in AECO practices. Each phase of a building life cycle (design, construction, or facility management) might have its own requirement that should be studied in detail. The applicability of an AR environment within each of those phases of the building life cycle and comparing it to similar methods such as augmented panoramic views would be other issues that should be investigated as future steps of current research.

This research is the first rigorous study on bringing BIM to an AR environment while considering the users requirements in design, development, and evaluation phases. Systems have traditionally been designed and developed through a technology-centered perspective. In such a perspective the designers would accept the technology as is and would try to apply the very same technology in different domains without considering the very important element of the ultimate end-user (human). In a technology-centered perspective, the end user and all its requirements would be considered improperly identical in different domains. In this research, a user-centered approach was employed. In a user-center perspective the technology should be considered while investigating the real users' experience and their own requirements in any target specific domain. This user-centered usability-based step would provide a grounded base for understanding the requirements for practical application of the technology in a domain.

APPENDIX A

PAPER FORMAT OF THE ONLINE SURVEY AND SCENARIO

PAPER FORMAT   Date: ___/___/2012

Number: ________

The target of this questionnaire is facility managers or other professionals working in the area of facility management

This questionnaire (which starts on the following page) gives us an opportunity to collect some information about the status of the Building Information Modeling (BIM) and Handheld Tablet Computers (e.g. iPad or Galaxy tablets) application in the area of Facility Management (FM).

To as great a degree as possible, think about all the questions and provide accurate responses to them. **Whenever it is appropriate, please write comments to explain your answers.**

If you have any questions about this questionnaire you may contact us at +1-404-385-6779 or at masoud@gatech.edu

Thank you!
CONECTech Lab @ School of Building Construction, Georgia Tech

Demographic Questions

Q1. In which country do you work?

____

Q2. What is the job title of your current position?

____

Q3. Please briefly explain your role and responsibility at this job:

____
____
____

Q4. Years of experience in current job:

□ Less than 1 year
□ Between 1 and 5 years
□ Between 6 and 10 years
□ More than 10 years

Q5. Total years of experience in Facility management (FM):

□ Less than 1 year
□ Between 1 and 5 years
□ Between 6 and 10 years
□ More than 10 years

Q6. Type of facility you manage/work:

□ Healthcare
□ Residential
□ Industrial
□ Office Building
□ Other (please specify): ____

Q7. Educational/training background **(e.g. Civil Engineering, Finance, Architecture, …)**

____

Q8. Education/training attainment:

□ High school diploma
□ Bachelor
□ Masters
□ PhD

User Characteristics Questions

Q9. Gender: □ Male, □ Female

Q10. Age: ________________ yrs.

Q11. Visual equity (eye-sight): □ Weak, □ Fair, □ Good, □ Excellent

Q12. Hearing capability: □ Weak, □ Fair, □ Good, □ Excellent

Q13. Preferred/fluent/first language (Choose one):
□ English,
□ Spanish,
□ French,
□ Other:____________________

Q14. Which type of special clothing might you wear while working?
□ Hardhat
□ Earplugs/hearing protection
□ Gloves
□ Goggles
□ Mask
□ Backpack
□ Other (please specify): ____

Technology Analysis & Working Environment

Q15. Do you use any handheld tablet computer (e.g. iPad, Nexus, Kindle) either at home or work?

□ No
□ Yes, (If yes, how long have you been using it?): __________

Q16. Do you use any touchscreen smartphone (e.g. iPhone, Galaxy phones) either at home or work?

□ No
□ Yes, (If yes, how long have you been using it?): __________

Q17. If you did use a tablet computer or a touchscreen smartphone, how often would each of the following affect your use of it in either indoor or outdoor environments?

	Never	Rarely	Sometimes	Often	Always
Heat:	□	□	□	□	□
Cold:	□	□	□	□	□
Wind:	□	□	□	□	□
Rain:	□	□	□	□	□
Snow:	□	□	□	□	□
Humidity:	□	□	□	□	□
Perspiration:	□	□	□	□	□
Vibration:	□	□	□	□	□

Q18. Which computer/technological tools do you use for accessing data at your job?

□ Desktop computer
□ Laptop
□ Handheld tablet computer (e.g. iPad, Nexus, Kindle, etc.)
□ Finger touch smartphone (e.g. iPhone, Galaxy phones, etc.)
□ Regular mobile phone
□ PDA (Personal Digital Assistant)
□ Other (please specify): ____

Q19. How do you usually access the information required to perform your tasks at your job?

□ Paper format files (e.g. brochures, as-built plans)
□ Electronic format files (e.g. videos, PDF, MS Word, MS Excel, MS Access)
□ Internet search using web-browsers
□ 2D/3D CAD/visualization software (AutoCAD, Navisworks, Revit)
□ Other (please specify): ____

Q20. What percentage of your time at work do you spend ……. ?

Indoors (%): __________ Outdoors (%) __________

Q21. How loud is your working environment?

□ Quiet □ Regular/Office environment □ Loud □ Extreme

Q22. How bright is your working environment?

□ Dark □ Regular/Office environment □ Bright □ Extreme

Q23. How much privacy do you have at your working environment?

□ Usually working alone
□ Usually working together with colleagues
□ Usually workings while there are clients around,

Any comment? ____

Q24. What percentage of your time at work are you …….. ?

Sitting(%): _____ Standing(%):_____ While mobile(%):_____

Building Information Modeling

Q25. Rate your understanding of *Building Information Modeling (BIM)*:

□ None □ Some knowledge of □ Fair □ Competent

Q26. Briefly describe your own understanding and definition of BIM.

____

____

Q27. Are you or your company using any form of BIM for facility management purposes?

□ No
□ Not sure
□ Yes, (Please specify what BIM software you use):

____

Q28. Rate the applicability of BIM for facility management in the following areas:

	Don't know	Very Low	Low	Medium	High	Vey High
Locating building components	□	□	□	□	□	□
Facilitating real-time data access	□	□	□	□	□	□
3D Visualization	□	□	□	□	□	□
Marketing	□	□	□	□	□	□
Checking maintainability	□	□	□	□	□	□
Creating and updating digital assets	□	□	□	□	□	□
Space management	□	□	□	□	□	□
Planning and feasibility studies for non-capital construction	□	□	□	□	□	□
Emergency management	□	□	□	□	□	□
Controlling and monitoring energy usage	□	□	□	□	□	□
Personnel training and development	□	□	□	□	□	□

Q29. In what other particular areas are you or your company using BIM?

____

____

____

Q30. How important are the following as barriers of BIM adoption in facility management?

	Don't Know	Not at all important	Low importance	Neutral	Moderately important	Very important
Lack of understanding/knowledge of *BIM*	☐	☐	☐	☐	☐	☐
Lack of *BIM* models of the facility	☐	☐	☐	☐	☐	☐
Lack of *BIM*-trained personnel	☐	☐	☐	☐	☐	☐
Non adaptive (reluctant to change) facility managers	☐	☐	☐	☐	☐	☐
Not receiving *BIM* models from other disciplines (e.g. design or construction groups)	☐	☐	☐	☐	☐	☐
Poor collaboration with other disciplines (e.g. design or construction groups)	☐	☐	☐	☐	☐	☐
Interoperability between different *BIM*-related software	☐	☐	☐	☐	☐	☐
Unclear responsibilities and liabilities when using BIM	☐	☐	☐	☐	☐	☐
Administrative costs	☐	☐	☐	☐	☐	☐
Education/training costs	☐	☐	☐	☐	☐	☐
Start-up/initial costs	☐	☐	☐	☐	☐	☐
Security concerns	☐	☐	☐	☐	☐	☐

Q31. What other barriers of BIM adoption in facility management can you think of?

____

____

Q32. Have you previously heard about Augmented Reality (AR) or used any AR-based tool, device, application, or program??

☐ No
☐ Heard but not used
☐ Heard and used, (please specify the tool, device, application, or program:)

ARWindow Scenario

Please watch the following scenario and then provide your feedback on it. Turn your speaker on and watch the video on the Full Screen mode.

If you cannot watch the video, please copy and paste the following url into a new browser window: http://www.youtube.com/watch?v=RS24RpfatxY

Q33. Rate the value of ARWindow system:

☐ None ☐ Little ☐ Some ☐ Substantial

Q34. Rate the usefulness of ARWindow system:

☐ None ☐ Little ☐ Some ☐ Substantial

Q35. How likely would you be to use a system like ARWindow?

☐ Not at all ☐ Occasionally ☐ Frequently

Q36. How easy/hard would a system like ARWindow make your data access in facilities?

☐ Very Easy ☐ Easy ☐ No Change ☐ Hard ☐ Very Hard

Q37. Please briefly explain how a system like ARWindow might help you perform your tasks:

____

____

Q38. What do you think would be the challenges of implementing such a system in facility management or your job?

____

____

APPENDIX B

EVALUATOR FORMS

Evaluator: __________

Paper / ARWindow

Subject ID #: __________

DATE: __/ __/ 2013

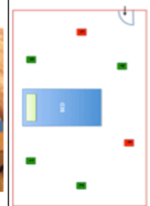
Step	Type	Correct Answer	Manufacturer	Time	# of errors	Figure
1	Wood Cabinet	**3**	Eternal Stone			
2	Wood Cabinet	**6**	DNR Woodworks			
3	HVAC Tiles	**3**	ACCA			
4	HVAC Tiles	**5**	HVAC USA			
5	Electricity Plug	**6**	TXU Co.			 
6	Electricity Plug	**8**	Southern Co.			
			Total:			

Figure 53: Evaluator Form – Scenario I

Evaluator: ____________

Paper / ARWindow

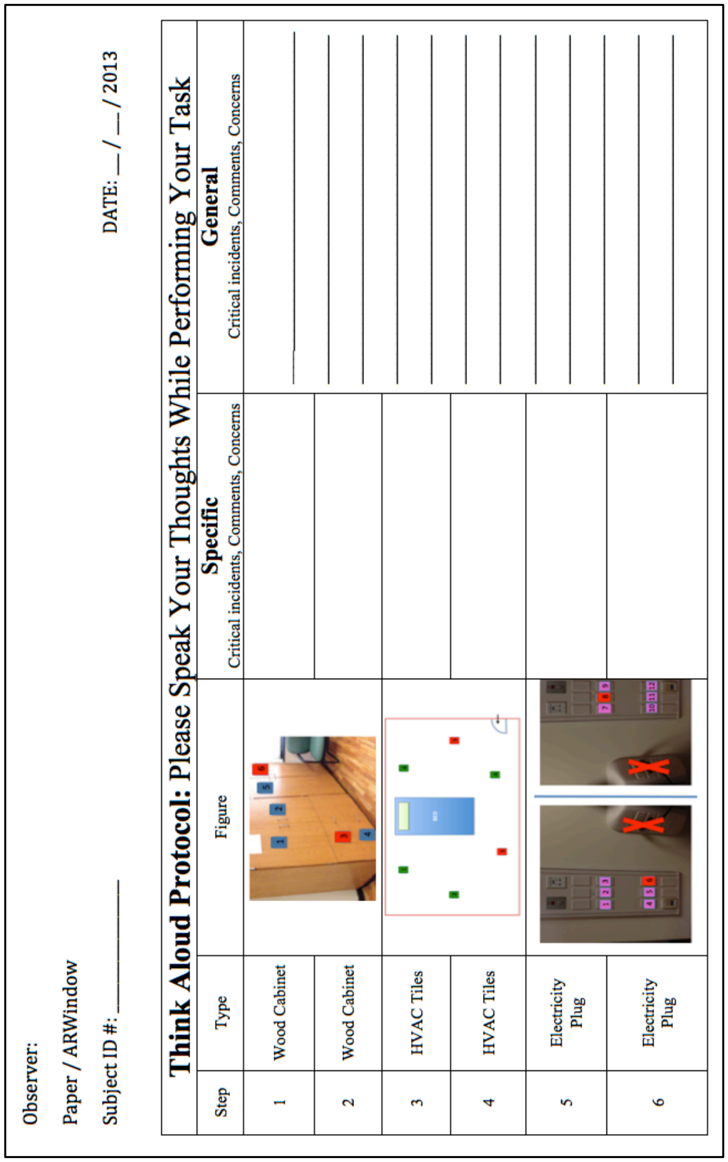
Subject ID #: ____________ DATE: __ / __ / 2013

Step	Type	Correct Answer	Manufacturer	Time	# of errors	Figure
1	Wood Cabinet	**2**	SanDino Furniture			
2	Wood Cabinet	**4**	Copper Sales			
3	HVAC Tiles	**2**	PEX Universe			
4	HVAC Tiles	**4**	AC Georgia			
5	Electricity Plug	**4**	Georgia Electrical			
6	Electricity Plug	**11**	Florida Co.			
			Total:			

Figure 54: Evaluator Form – Scenario II

APPENDIX C

OBSERVER FORMS



Observer:

Paper / ARWindow

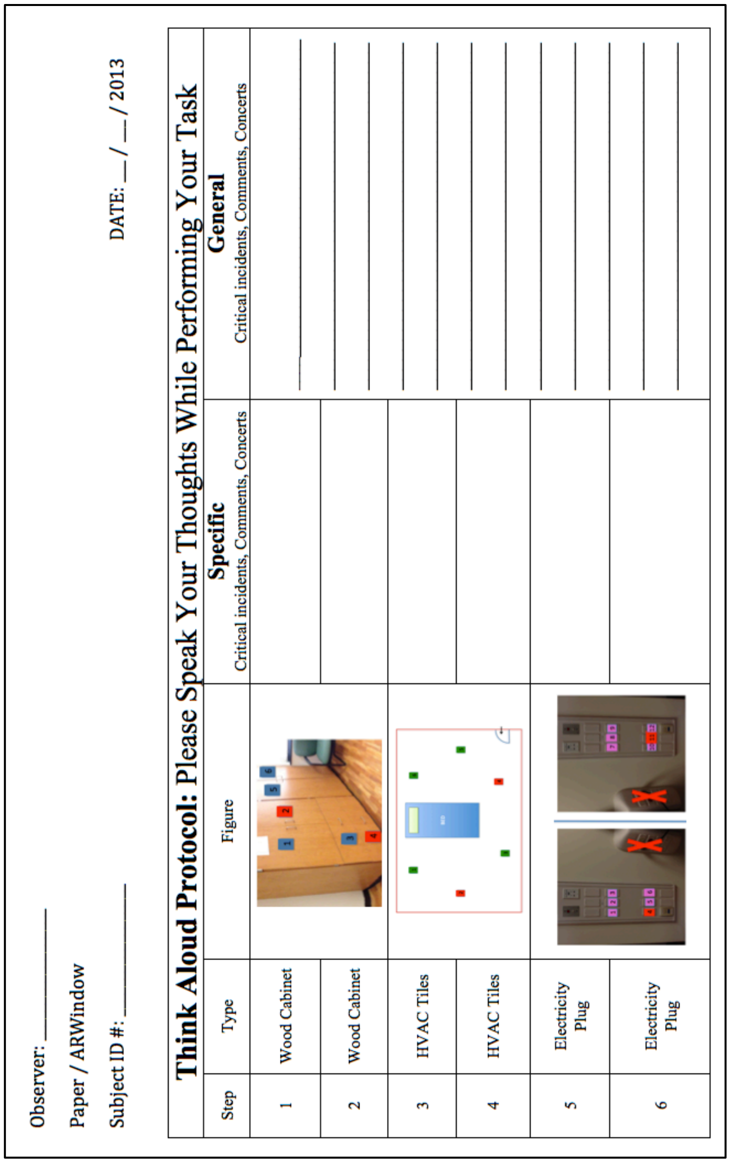
Subject ID #: ____________

DATE: __/ __/ 2013

Think Aloud Protocol: Please Speak Your Thoughts While Performing Your Task

Step	Type	Figure	**Specific** Critical incidents, Comments, Concerns	**General** Critical incidents, Comments, Concerns
1	Wood Cabinet			
2	Wood Cabinet			
3	HVAC Tiles			
4	HVAC Tiles			
5	Electricity Plug			
6	Electricity Plug			

Figure 55: Observer Form – Scenario I



Observer: ____________

Paper / ARWindow

Subject ID #: ____________

DATE: __ / __ / 2013

Think Aloud Protocol: Please Speak Your Thoughts While Performing Your Task

Step	Type	Figure	**Specific** Critical incidents, Comments, Concerts	**General** Critical incidents, Comments, Concerts
1	Wood Cabinet			
2	Wood Cabinet			
3	HVAC Tiles			
4	HVAC Tiles			
5	Electricity Plug			
6	Electricity Plug			

Figure 56: Observer Form – Scenario II

APPENDIX D

EXPERIMENT CONSENT FORM

Georgia Institute of Technology
STUDY INFORMATION SHEET

Consent to be a Research Participant
GA Tech College of Architecture and School of Psychology

Project: ARWindow: Accessing Building Information through Mobile Augmented Reality
Principal Investigator: Dr. Javier Irizarry (678-480-6035)
Co-Principal Investigators: Dr. Bruce N. Walker (404-894-2680), Graceline Williams (404-385-3308)
Student: Masoud Gheisari (404-385-6779)
Duration of Study: One hour
Total Compensation: None
Number of Participants: 40 volunteers (Facility Managers)
Participation limitations: Normal or corrected to normal vision and hearing.

General: You are being asked to volunteer for a research project studying human-computer interaction for facility managers.

Study Description: This research advances our study in AECO (Architecture, Engineering, Construction, and Owner) related to Augmented Reality (AR). Specifically, we are going to develop ARWindow, a low-cost mobile AR application that implements a market-ready solution to accurate indoor tracking while providing Facility Managers (FMs) with their required information for performing their tasks.

Procedures: Evaluation of ARWindow will be performed using a within-subjects experimental design in which each subject is tested under at least three different conditions: (1) ARWindow, (2) existing methods for Facility Management information access, and (3) Interactive Panoramic Visualizations (IPVs). For the ARWindow and IPV conditions, spot mats will be attached to the floor surface at different locations inside the building. The subjects would stand on these spot mats and will perform a pre-defined task. In general, the task will consist of a "scavenger hunt" type activity where FMs will find information related to objects in the environment adjacent to the SPOTs. This information would be related to items such as manufacturer data, performance data, maintenance records, equipment warranties, cost, inspection records, and energy efficiency. Performance of ARWindow will be measured against existing methods of information access used by FMs and an alternative method of information access through the use of IPVs.

Benefits: There is no direct benefit to you, however; your participation will help advance scientific knowledge in the area of using technology to improve facility management, as well as assisting researchers in learning about the practical aspects of conducting usability studies.

Compensation: You will not be compensated for participating in this study.

Costs: There are no costs to you by participating in this study.

Foreseeable Risks or Discomforts: There are no foreseeable risks to you by participating.

Confidentiality: The following procedures will be followed to keep your personal information confidential in this study: The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only the course teaching staff and the student researcher you worked with will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published. Note however that there is no intent to publish the results of this class project. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB will review the study records. The Office of Human Research Protections may also look over study records during required reviews.

APPROVED *Consent Form Approved by Georgia Tech IRB: November 16, 2012 - Indefinite*

Figure 57: Experiment Consent Form (Page 1)

Georgia Institute of Technology
STUDY INFORMATION SHEET

Injury/Adverse Reaction: If you are injured as a result of being in this study, please contact Dr. Javier Irizarry at telephone # (678) 480 6035. Neither the Principal Investigator nor Georgia Institute of Technology has made provisions for payment of costs associated with any injury resulting from participation in this study.

Contact: If you have any questions about this study or its procedures, please contact Dr. Bruce Walker at telephone # (404) 894-2680 or Dr. Javier Irizarry at telephone # (678) 480-6035.

Statement of Rights: You have certain rights as a research volunteer. Your participation in this study is voluntary. You do not have to be in this study if you don't want to be. You have the right to change your mind and leave the study at any time without giving any reason, and without penalty. If you have any questions about your rights as a research volunteer, call or write to: The Institutional Review Board, Office of Research Compliance, 505 Tenth Street, Atlanta, GA 30318. Phone: 404-385-2175; Fax: 404-385-2081.

Consent: I have read this form and received a copy of it. I have had all my questions answered to my satisfaction. I agree to take part in this study.

APPROVED *Consent Form Approved by Georgia Tech IRB: November 16, 2012 - Indefinite*

Figure 58: Experiment Consent Form (Page 2)

APPENDIX E

DEMOGRAPHIC INFORMATION FORM

Subject#: __________

Please provide the following information:

(1) Age: __________ Years

(2) Gender: Male ______ Female______

(3) Occupation: _________________________

(4) Field of study for highest degree: _________________________________

(5) Academic rank (circle one):

Freshman Sophomore Junior Senior MSc PhD/Faculty

(6) Have you previously heard about Augmented Reality (AR)? Yes No

(7) Have you ever used any AR-based tool/device/application? Yes No

(8) If Yes, what was its name? __________________________________

(9) Have you ever used any touchscreen smartphone or tablet computers?
Yes No

(10) If Yes, what was its name? __________________________________

(11) Have many hours per week do you play videogame? ____________________Hrs/week

(12) What platform/device/console do you play most often?
____

(13) What games do you play most often? ___________________________

____

____

Figure 59: Before Scenario Demographic Information Form

APPENDIX F

AFTER SCENARIO QUESTIONNAIRE

Subject#: __________ **Date:____/____/2013**

Experiment Condition:
ARWindow ☐ /
Paper Format ☐

Principal Investigator: Dr. Javier Irizarry (678-480-6035)
Co-Principal Investigators: Dr. Bruce N. Walker (404-894-2680), Graceline Williams (404-385-3308)
PhD Student: Masoud Gheisari (404-385-6779)

This questionnaire (which starts on the following page) gives you an opportunity to express your satisfaction with the usability of the experiment approach. Your responses will help us understand what aspects of this approach you are particularly concerned about and the aspects that satisfy you.

To as great a degree as possible, think about all the tasks that you have done with the system while you answer these questions.

Please read each statement and indicate how strongly you agree or disagree with the statement by circling a number on the scale.

Whenever it is appropriate, please write comments to explain your answers.

Thank you!

The Post-Study System Usability Questionnaire (PSSUQ):

For each of the statements below, circle the rating of your choice.

1. Overall, I am satisfied with the ease of completing this task.

Strongly Disagree	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Strongly Agree**

COMMENTS:

2. It was simple and quick to use this approach.

Strongly Disagree	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Strongly Agree**

COMMENTS:

3. It was easy to learn to use this approach.

Strongly Disagree	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Strongly Agree**

COMMENTS:

4. I believe I could become productive quickly using this approach.

Strongly Disagree	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Strongly Agree**

COMMENTS:

5. Whenever I make a mistake using the approach, I could recover easily and quickly.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

COMMENTS:

6. It was easy to find the information I needed.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

COMMENTS:

7. Overall, I am satisfied with this approach.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

COMMENTS:

8. How mentally demanding was the task?

Not Demanding	1	2	3	4	5	6	7	Very Demanding

COMMENTS:

9. How physically demanding was the task?

Not Demanding	1	2	3	4	5	6	7	Very Demanding

COMMENTS:

10. How hurried or rushed was the pace of the task?

Not Rushed	1	2	3	4	5	6	7	Vey Rushed

COMMENTS:

11. How successful were you in accomplishing what you were asked to do?

Very Unsuccessful	1	2	3	4	5	6	7	Very Successful

COMMENTS:

12. How hard did you have to work to accomplish your level of performance?

Not Hard	1	2	3	4	5	6	7	Very Hard

COMMENTS:

13. I was insecure, discouraged, irritated, stressed, and annoyed with the task!

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

COMMENTS:

General Comments:

APPENDIX G

EXPERIMENT TABLES OF INFORMATION ON STICKY PAPERS

Name	Wood Cabinet
Serial Number / ID	3227263-891
Manufacturer / 3rd Party	G&E Products

Name	Wood Cabinet
Serial Number / ID	3227263-892
Manufacturer / 3rd Party	SanDino Furniture

Name	Wood Cabinet
Serial Number / ID	3227263-893
Manufacturer / 3rd Party	Eternal Stone

Name	Wood Cabinet
Serial Number / ID	3227263-894
Manufacturer / 3rd Party	Copper Sales

Name	Wood Cabinet
Serial Number / ID	3227263-895
Manufacturer / 3rd Party	Cherry Cabinets

Name	Wood Cabinet
Serial Number / ID	3227263-896
Manufacturer / 3rd Party	DNR Woodworks

Figure 60:Experiment Wood Cabinets and Shelves information tables on sticky papers

Name	HVAC Tiles
Serial Number / ID	4785241-371
Manufacturer / 3rd Party	Air & Water

Name	HVAC Tiles
Serial Number / ID	4785241-372
Manufacturer / 3rd Party	PEX Universe

Name	HVAC Tiles
Serial Number / ID	4785241-373
Manufacturer / 3rd Party	ACCA

Name	HVAC Tiles
Serial Number / ID	4785241-374
Manufacturer / 3rd Party	AC Georgia

Name	HVAC Tiles
Serial Number / ID	4785241-375
Manufacturer / 3rd Party	HVAC USA

Name	HVAC Tiles
Serial Number / ID	4785241-376
Manufacturer / 3rd Party	AMCA

Figure 61: Experiment HVAC Tiles information tables on sticky papers

Name	Electricity Plug
Serial Number / ID	1448421-121
Manufacturer / 3rd Party	Southern Co.

Name	Electricity Plug
Serial Number / ID	1448421-122
Manufacturer / 3rd Party	Calpine Co.

Name	Electricity Plug
Serial Number / ID	1448421-123
Manufacturer / 3rd Party	White Electrical

Name	Electricity Plug
Serial Number / ID	1448421-124
Manufacturer / 3rd Party	Georgia Electrical

Name	Electricity Plug
Serial Number / ID	1448421-125
Manufacturer / 3rd Party	Edison Co.

Name	Electricity Plug
Serial Number / ID	1448421-126
Manufacturer / 3rd Party	TXU Co.

Figure 62: Experiment Electrical Outlets information tables (1-6) on sticky papers

Name	Electricity Plug
Serial Number / ID	1448421-127
Manufacturer / 3rd Party	Pacific Co.

Name	Electricity Plug
Serial Number / ID	1448421-128
Manufacturer / 3rd Party	Southern Co.

Name	Electricity Plug
Serial Number / ID	1448421-129
Manufacturer / 3rd Party	Detroit Electrical

Name	Electricity Plug
Serial Number / ID	1448421-130
Manufacturer / 3rd Party	DC Electrical

Name	Electricity Plug
Serial Number / ID	1448421-131
Manufacturer / 3rd Party	Florida Co.

Name	Electricity Plug
Serial Number / ID	1448421-132
Manufacturer / 3rd Party	American Electrical

Figure 63: Experiment Electrical Outlets information tables (7-12) on sticky papers

APPENDIX H

PREVENTIVE MAINTENANCE WORK ORDER – SCENARIO I

XYZ Facility Management - I
Preventive Maintenance Work Order

Print Date: 3/23/2012 | Created By: System Manager

WO#: 1448421 0224011- Wood Cabinet – Shelves – Monthly

Schedule No: 5038 | **Skill:** Building Automation System
Sire/Bldg: Shepherd Center | **Priority:** 2-Medium Priority | **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level | **Status:** Active | **Time Orig:** 12:30
Floor/Wing: 3rd Level W. Wing | **Sub-Status:** Issued, Being worked on | **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Left side of the bed on bottom
Req Name: | **Req Phone:**
Req Remarks: | **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 | **Description:** Wood Cabinet – Shelves
Manufacturer: Eternal Stone | **Warranty:**
Model No: | **Start:**
Serial No: 3227263-893 | **End:**

Procedures

Proc#: 29 | **Desc:** Wood Cabinet – Shelves
Skill: General Skills | **Shut Down Required:** No | **Estimated Time:** 7 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the cabinet/shelves:		Completed?	Problem?
	• Color	☐Yes ☐No	
	• Handle stiffness	☐Yes ☐No	
	• Crack	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 64: Preventive Maintenance Work Order –Wood Cabinets & Shelves– Scenario I (Page 1)

XYZ Facility Management - I
Preventive Maintenance Work Order

Print Date: 3/23/2012 | Created By: System Manager

WO#: 1448421 0224012- Wood Cabinet – Shelves – Monthly

Schedule No: 5038
Skill: Building Automation System
Sire/Bldg: Shepherd Center
Priority: 2-Medium Priority
Date Orig: 3/23/2013
Bldg/Floor: 3rd level
Status: Active
Time Orig: 12:30
Floor/Wing: 3rd Level W. Wing
Sub-Status: Issued, Being worked on
Date Avail: 3/25/2013
Location: Shepherded Center, Room 309, Left side of the bed, bigger one
Req Name:
Req Phone:
Req Remarks:
Account: 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015
Manufacturer: DNR Woodworks
Model No:
Serial No: 3227263-896
Description: Wood Cabinet – Shelves
Warranty:
Start:
End:

Procedures

Proc#: 29
Desc: Wood Cabinet – Shelves
Skill: General Skills
Shut Down Required: No
Estimated Time: 7 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the cabinet/shelves:		Completed?	Problem?
	• Color	☐Yes ☐No	
	• Handle stiffness	☐Yes ☐No	
	• Crack	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 65: Preventive Maintenance Work Order - Wood Cabinets & Shelves – Scenario I (Page 2)

XYZ Facility Management - I
Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448422 0224013- HVAC Tiles– Monthly

Schedule No: 5038
Skill: Building Automation System
Sire/Bldg: Shepherd Center
Priority: 1-High Priority
Date Orig: 3/23/2013
Bldg/Floor: 3rd level
Status: Active
Time Orig: 10:45
Floor/Wing: 3rd Level W. Wing
Sub-Status: Issued, Being worked on
Date Avail: 3/25/2013
Location: Shepherded Center, Room 309, Left side of the room
Req Name:
Req Phone:
Req Remarks:
Account: 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015
Description: HVAC Tiles
Manufacturer: ACCA
Warranty:
Model No:
Start:
Serial No: 4785241-373
End:

Procedures

Proc#: 29
Desc: Cabinet – Shelves
Skill: General Skills
Shut Down Required: No
Estimated Time: 15 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the Air handler:		Completed?	Problem?
	• Duct	☐Yes ☐No	
	• Pump	☐Yes ☐No	
	• Clean coil	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 66: Preventive Maintenance Work Order – HVAC Tiles – Scenario I (Page 1)

XYZ Facility Management - I

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448422 0224014- HVAC Tiles– Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 1-High Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 10:45
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Right side of the room
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** HVAC Tiles
Manufacturer: HVAC USA **Warranty:**
Model No: **Start:**
Serial No: 4785241-375 **End:**

Procedures

Proc#: 29 **Desc:** Cabinet – Shelves
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 15 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the Air handler:		Completed?	Problem?
	• Duct	☐Yes ☐No	
	• Pump	☐Yes ☐No	
	• Clean coil	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 67: Preventive Maintenance Work Order – HVAC Tiles – Scenario I (Page 2)

XYZ Facility Management - I

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448424 0224015- Electrical Outlet – Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 1-High Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 10:45
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Left side of the bed
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** Electrical Outlet
Manufacturer: TXU Co. **Warranty:**
Model No: **Start:**
Serial No: 1448421-126 **End:**

Procedures

Proc#: 29 **Desc:** Electrical Outlet
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 5 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the Electrical Outlet:		Completed?	Problem?
	• Transfer Electrical?	☐Yes ☐No	
	• Broken Screw?	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 68: Preventive Maintenance Work Order – Electrical Outlets – Scenario I (Page 1)

XYZ Facility Management - I

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448424 0224016- Electrical Outlet – Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 1-High Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 10:45
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Right side of the bed
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** Electrical Outlet
Manufacturer: Southern Co. **Warranty:**
Model No: **Start:**
Serial No: 1448421-128 **End:**

Procedures

Proc#: 29 **Desc:** Electrical Outlet
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 5 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the Electrical Outlet:		Completed?	Problem?
	• Transfer Electrical?	☐Yes ☐No	
	• Broken Screw?	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 69: Preventive Maintenance Work Order – Electrical Outlets – Scenario I (Page 2)

APPENDIX I

PREVENTIVE MAINTENANCE WORK ORDER – SCENARIO II

XYZ Facility Management - II

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448421 0224011- Wood Cabinet – Shelves – Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 2-Medium Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 12:30
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Left side of the bed, top ones
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** Wood Cabinet – Shelves
Manufacturer: SanDino Furniture **Warranty:**
Model No: **Start:**
Serial No: 3227263-892 **End:**

Procedures

Proc#: 29 **Desc:** Wood Cabinet – Shelves
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 7 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the cabinet/shelves:		Completed?	Problem?
	• Color	☐Yes ☐No	
	• Handle stiffness	☐Yes ☐No	
	• Crack	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 70: Preventive Maintenance Work Order –Wood Cabinets & Shelves– Scenario II (Page 1)

XYZ Facility Management - II

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448421 0224012- Wood Cabinet – Shelves – Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 2-Medium Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 12:30
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Left side of the bed, the bottom one
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** Wood Cabinet – Shelves
Manufacturer: Copper Sales **Warranty:**
Model No: **Start:**
Serial No: 3227263-894 **End:**

Procedures

Proc#: 29 **Desc:** Wood Cabinet – Shelves
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 7 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the cabinet/shelves:		Completed?	Problem?
	• Color	☐Yes ☐No	
	• Handle stiffness	☐Yes ☐No	
	• Crack	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 71: Preventive Maintenance Work Order –Wood Cabinets & Shelves– Scenario II (Page 2)

XYZ Facility Management - II

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448422 0224013- HVAC Tiles– Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 1-High Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 10:45
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Left side of the room
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** HVAC Tiles
Manufacturer: PEX Universe **Warranty:**
Model No: **Start:**
Serial No: 4785241-372 **End:**

Procedures

Proc#: 29 **Desc:** Cabinet – Shelves
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 15 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the Air handler:		Completed?	Problem?
	• Duct	☐Yes ☐No	
	• Pump	☐Yes ☐No	
	• Clean coil	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 72: Preventive Maintenance Work Order – HVAC Tiles – Scenario II (Page 1)

XYZ Facility Management - II

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448422 0224014- HVAC Tiles– Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 1-High Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 10:45
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Right side of the room
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** HVAC Tiles
Manufacturer: AC Georgia **Warranty:**
Model No: **Start:**
Serial No: 4785241-374 **End:**

Procedures

Proc#: 29 **Desc:** Cabinet – Shelves
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 15 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the Air handler:		Completed?	Problem?
	• Duct	☐Yes ☐No	
	• Pump	☐Yes ☐No	
	• Clean coil	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 73: Preventive Maintenance Work Order – HVAC Tiles – Scenario II (Page 2)

XYZ Facility Management - II

Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448424 0224015- Electrical Outlet – Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 1-High Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 10:45
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Left side of the bed
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** Electrical Outlet
Manufacturer: Georgia Electrical **Warranty:**
Model No: **Start:**
Serial No: 1448421-124 **End:**

Procedures

Proc#: 29 **Desc:** Electrical Outlet
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 5 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the Electrical Outlet:		Completed?	Problem?
	• Transfer Electrical?	☐Yes ☐No	
	• Broken Screw?	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 74: Preventive Maintenance Work Order – Electrical Outlets – Scenario II (Page 1)

XYZ Facility Management - II
Preventive Maintenance Work Order

Print Date: 3/23/2012 Created By: System Manager

WO#: 1448424 0224016- Electrical Outlet – Monthly

Schedule No: 5038 **Skill:** Building Automation System
Sire/Bldg: Shepherd Center **Priority:** 1-High Priority **Date Orig:** 3/23/2013
Bldg/Floor: 3rd level **Status:** Active **Time Orig:** 10:45
Floor/Wing: 3rd Level W. Wing **Sub-Status:** Issued, Being worked on **Date Avail:** 3/25/2013
Location: Shepherded Center, Room 309, Right side of the bed
Req Name: **Req Phone:**
Req Remarks: **Account:** 001-10-15-846-00015 – Facility Management

Asset Data

Asset No: 0224015 **Description:** Electrical Outlet
Manufacturer: Florida Co. **Warranty:**
Model No: **Start:**
Serial No: 1448421-131 **End:**

Procedures

Proc#: 29 **Desc:** Electrical Outlet
Skill: General Skills **Shut Down Required:** No **Estimated Time:** 5 min

Sub Procedure Readings

Instructions:

348- Check the following parts in the Electrical Outlet:		Completed?	Problem?
	• Transfer Electrical?	☐Yes ☐No	
	• Broken Screw?	☐Yes ☐No	

Completed By: **Date:** **Hours:** **Stop Time:**

Figure 75: Preventive Maintenance Work Order – Electrical Outlets – Scenario II (Page 2)

APPENDIX J

REVIT PLUGIN FOR ARGON2 SOURCE CODE

UI_Form.cs

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Windows.Forms;
using Autodesk.Revit.UI;
using System.Xml;
using System.IO;
using System.Resources;


namespace BIM2MAR
{
   public partial class UI_Form : Form
   {
      private String[] OccupationList = new String[4] {"Facility Manager", "Worker",
"Project Manager", "Executives"};
      private String[][] ActionList = new String[3][];
      // create a collection of all relevant data


      List<TaskData> data = new List<TaskData>();
```

```
public UI_Form()
{
    InitializeComponent();
    ActionList[0] = new String[5] { "Action1", "Action2", "Action3", "Action4",
"Action5" };
    ActionList[1] = new String[5] { "Occupation1", "Occupation2", "Occupation3",
"Occupation4", "Occupation5" };


}

private void button1_Click(object sender, EventArgs e)
{

    //Get Occupation and Action Text
    TaskData item = new TaskData(comboBox1.Text, comboBox2.Text);
    data.Add(item);

    //Create Directory
    String currentDir = Directory.GetCurrentDirectory();
    //Show Prompt Dialog
    TaskDialog.Show("Export", "Successfully Exported to " + currentDir);

    currentDir = /*YOUR DIRECTORY*/;
    DirectoryInfo d = new DirectoryInfo( currentDir );
    d.CreateSubdirectory("model");
    d.CreateSubdirectory("js");
    d.CreateSubdirectory("css");
```

```
d.CreateSubdirectory("img");


//Export to XML Format

XmlTextWriter w = new XmlTextWriter( currentDir+"/BIM2MAR_Tasks.xml",
Encoding.UTF8);

w.Formatting = Formatting.Indented;

w.WriteStartDocument();

w.WriteComment(string.Format(

  " BIM2MAR Exporting XML by Ray ",

   DateTime.Now));


w.WriteStartElement("Tasks");


foreach (TaskData i in data)

{

   w.WriteStartElement("Task");

   w.WriteElementString("Occupation", i.Occupation);

   w.WriteElementString("Action", i.Action);

   w.WriteEndElement();

}

w.WriteEndElement();

w.WriteEndDocument();

w.Close();


//Export to JavaScript Format

String mainJS = Properties.Resources.bim2mar;

StreamWriter s = new StreamWriter( currentDir+"/index.html", false,
Encoding.UTF8);
```

```
            s.WriteLine(/*UPPER HALF OF HTML SETUP*/);
            s.WriteLine( mainJS );
            s.WriteLine(/*LOWER HALF OF HTML SETUP*/);
            s.Close();

            //Export to JavaScript Format
            String colladaloaderJS = Properties.Resources.ColladaLoader;
            StreamWriter loader = new StreamWriter(currentDir + "/js/ColladaLoader.js",
false, Encoding.UTF8);
            loader.Write( colladaloaderJS );
            loader.Close();

            //Export to CSS Format
            String toggleswitch = Properties.Resources.toggle_switch;
            StreamWriter cssloader = new StreamWriter(currentDir + "/css/toggle-
switch.css", false, Encoding.UTF8);
            cssloader.Write( toggleswitch );
            cssloader.Close();
        }

        private void Form1_Load(object sender, EventArgs e)
        {
            //this.label_stime.Text = (DateTime.Now).ToString();
        }

        private void button2_Click(object sender, EventArgs e)
        {
            if (!this.comboBox1.Items.Contains(this.itemInput.Text))
```

```
        {
            this.comboBox1.Items.Add(this.itemInput.Text);
        }
        else
            TaskDialog.Show("Warning", this.itemInput.Text + " is already in the
Occupation List");


    }


    private void button3_Click(object sender, EventArgs e)
    {
        int NextItemIndex = 0;
        if (!this.comboBox2.Items.Contains(this.itemInput.Text))
        {
            for (int i = 0; i < ActionList[this.comboBox1.SelectedIndex].Length; i++)
            {
                if (ActionList[this.comboBox1.SelectedIndex][i] == "")
                {
                    NextItemIndex = i;
                    break;
                }
            }
            ActionList[this.comboBox1.SelectedIndex][NextItemIndex] =
this.itemInput.Text;
            this.comboBox2.Items.Add(this.itemInput.Text);
        }
        else
            TaskDialog.Show("Warning", this.itemInput.Text + " is already in the Action
```

```
List");
        }

        private void comboBox1_SelectedIndexChanged(object sender, EventArgs e)
        {
            this.comboBox2.Show();
            this.comboBox2.Text = "";
            this.comboBox2.Items.Clear();
            switch (this.comboBox1.SelectedIndex)
            {
                case 0:
                    for (int i = 0; i < ActionList[this.comboBox1.SelectedIndex].Length; i++)
                    {
                        if (ActionList[this.comboBox1.SelectedIndex][i] != "")

this.comboBox2.Items.Add(ActionList[this.comboBox1.SelectedIndex][i]);
                    }
                    //TaskDialog.Show("info", "choose:" + this.comboBox1.SelectedIndex);
                    break;
                case 1:
                    for (int i = 0; i < ActionList[this.comboBox1.SelectedIndex].Length; i++)
                    {
                        if (ActionList[this.comboBox1.SelectedIndex][i] != "")

this.comboBox2.Items.Add(ActionList[this.comboBox1.SelectedIndex][i]);
                    }
                    break;
                default:
```

```
                this.comboBox2.Hide();

                break;

            }


        }


        private void comboBox2_SelectedIndexChanged(object sender, EventArgs e)

        {

            TaskDialog.Show("info", OccupationList[this.comboBox1.SelectedIndex] + " will " + ActionList[this.comboBox1.SelectedIndex][this.comboBox2.SelectedIndex]);

        }


    }



}
```

APPENDIX K

BIM2MAR WEB PAGE FOR ARGON2 SOURCE CODE [MAIN JAVASCRIPT]

bim2mar.js

```
//Model
var dae = null;
var dae_object_material = [];

//Task
var Tasklist = [];         //Pre-Defined task array
var Tasks = [];

//AR Toggle Button
var isAR_ON = false;

//Task Assignment
for( var i = 1; i <= document.getElementById("tasks").children.length; i++){
        //get each task
        Tasklist[ i-1 ] = new
Array( document.getElementsByClassName("task"+i)[0].children.length );;
        for( var j = 1; j <=
document.getElementsByClassName("task"+i)[0].children.length; j++){
                //get each item in each task

        document.getElementById("task"+i+"_"+j).getElementsByClassName("taskname
")[0].addEventListener('click', TaskHandler, false);
```

```
document.getElementById("task"+i+"_"+j).getElementsByClassName("details")[
0].addEventListener('click', TaskDetailHandler, false);

        Tasklist[ i-1 ][ j-1 ] =
(document.getElementById("task"+i+"_"+j)).getElementsByClassName("objectname")[0
].innerHTML;

    }

    //Even handler for each task

    document.getElementById("display_button_task" + i).addEventListener("click",
TaskDisplayHandler, false);

}

//Task Object

function Task( taskid, targetname ) {

    this.taskid = taskid;

    this.targetName = targetname;

}

//Main Controller

var BIM2MAR_Controller =

{

    geoObject : null,

    createContent : function()

    {

        //Model

        var loader = new THREE.ColladaLoader();

        loader.options.convertUpAxis = true;
```

```
                loader.load( 'model/Room.dae', function ( collada ) {

                        dae = collada.scene;
                        dae.scale.x = dae.scale.y = dae.scale.z = 100;
                        dae.position.y = -200;
                        dae.updateMatrix();

                        for(var i = 0;i < dae.children.length;i++){

                                for(var a=0;a<Tasklist.length;a++){
                                        dae_object_material[a] = new
Array(Tasklist[a].length);
                                        for(var b=0;b<Tasklist[a].length;b++){
                                                if(dae.children[i].name == Tasklist[a][b]){
                                                        //Change Materials to semi-
transparent red
                                                        dae.children[i].material = new
THREE.MeshBasicMaterial({color: 0xff0000, wireframe: false, transparent: true,
opacity: 0.6});
                                                }
                                        }
                                }
                        }
                        ARGON.World.add( dae );
                });
        },

        removeContent : function(){
```

```
            var t = [];
            dae.getDescendants(t);
            for(var i=0;i<t.length;i++)
            t[i].visible = false;
        },

        animate : function(){
            BIM2MAR_Controller.render();
        },

        render : function(){
            //Perform Desired Task each loop
        },

        onArgonReady : function()
        {
            //After Argon is ready
        }
};

function ARmodeToggle(){
        MenuHandler();
        isAR_ON = !isAR_ON;
        if( isAR_ON ){
            if( dae ){
                var t = [];
                dae.getDescendants(t);
```

```
                for(var i=0;i<t.length;i++)
                t[i].visible = true;
            }
            else
                BIM2MAR_Controller.createContent();
        }
        else{
            BIM2MAR_Controller.removeContent();
        }
}

function MenuHandler(){
        var menu = document.getElementById("menu");

        if( menu.style.left != "0em")
            menu.style.left = "0em";
        else
            menu.style.left = "-18em";
}

function TaskDisplayHandler( event ){

        var tempTask = this.parentNode.getElementsByClassName(this.parentNode.id);
        if( tempTask[0].style.display == "block" ){
            tempTask[0].style.display = "none";}
        else{
            tempTask[0].style.display = "block";}
```

```
}

function TaskHandler( event ){

	// get toggle button
	var task_item = this.parentNode;
	task_item.getElementsByClassName("ckbox")[0].checked
= !task_item.getElementsByClassName("ckbox")[0].checked;
	var toggle = task_item.getElementsByClassName("ckbox")[0].checked;

	// change image if the item is fixed
	if( toggle ){
		task_item.getElementsByClassName("checkboxImg")[0].src =
"img/check.png";
		// change target color
		for(var i = 0;i < dae.children.length;i++){
			if(dae.children[i].name ==
Tasklist[ this.parentNode.parentNode.title-1 ][ (task_item.id).slice(6,7)-1 ]){
				//change material to original
				dae.children[i].material = new
THREE.MeshBasicMaterial({color: 0x00ff00, wireframe: false, transparent: true,
opacity: 0.6});
			}
		}
	}
	else{
		task_item.getElementsByClassName("checkboxImg")[0].src =
"img/cross.png";
```

```
                    // change target color

                    for(var i = 0;i < dae.children.length;i++){

                              if(dae.children[i].name ==
Tasklist[ this.parentNode.parentNode.title-1 ][ (task_item.id).slice(6,7)-1 ]){

                                        //change material to red

                                        dae.children[i].material = new
THREE.MeshBasicMaterial({color: 0xcc0000, wireframe: false, transparent: true,
opacity: 0.6});

                              }

                    }

          }




}


function TaskDetailHandler( event ){


          //change detail dialog

          if( this != window){    //if it is not triggered by close button

                    document.getElementById("detailTitle").innerHTML =
this.parentNode.getElementsByClassName("objectname")[0].innerHTML;

                    document.getElementById("detailParagraph").innerHTML = "detail
information about " + document.getElementById("detailTitle").innerHTML + " goes
here";

          }


          //Toggle on/off dialog box

          if( document.getElementsByClassName("modalDialog")[0].style.opacity == 1 ){

                    document.getElementsByClassName("modalDialog")[0].style.opacity = 0;
```

```
        document.getElementsByClassName("modalDialog")[0].style.pointerEvents =
"none";
        }
        else{
                document.getElementsByClassName("modalDialog")[0].style.opacity = 1;

        document.getElementsByClassName("modalDialog")[0].style.pointerEvents =
"auto";
        }


}


//Argon2 Events
document.addEventListener("AR.ArgonReadyEvent",
BIM2MAR_Controller.onArgonReady);


//UI Events
document.getElementById("slider").addEventListener("click", MenuHandler, false);
document.getElementById("paneltext").addEventListener("click", MenuHandler, false);
```

REFERENCES

Aarts, E. (2004). Ambient intelligence: a multimedia perspective. *Multimedia, IEEE, 11*(1), 12-19.

Aarts, E., Harwig, H., & Schuurmans, M. (2001). *"Ambient Intelligence," The Invisible Future*. New York: McGraw Hill.

Adam, E. C. (1993, 25-28 Oct 1993). *Fighter cockpits of the future.* Paper presented at the Digital Avionics Systems Conference, 1993. 12th DASC., AIAA/IEEE.

AHA. (2010). *Certified Healthcare Facility Manager, Candidate Hnadbook and Application*: American Hospital Association (AHA) Certification Center.

AHA. (2012). *AHA Hospital Statistics, 2012 Edition* (1 ed.): American Hospital Association.

Anumba, C., Ugwu, O., Newnham, L., & Thorpe, A. (2001). A multi-agent system for distributed collaborative design. *Logistics Information Management, 14*(5/6), 355-367.

Atkin, B., & Brooks, A. (2009). *Total facilities management*: Wiley-Blackwell.

Azhar, S., Hein, M., & Sketo, B. (2008, April 2-5). *Building information modeling (BIM): Benefits, risks and challenges.* Paper presented at the 44th ASC Annual Conference Auburn, Alabama.

Azuma, R. T. (1997). A survey of augmented reality. *Presence-Teleoperators and Virtual Environments, 6*(4), 355-385.

Bahl, P., & Padmanabhan, V. N. (2000, 2000). *RADAR: an in-building RF-based user location and tracking system.* Paper presented at the INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE.

Bajura, M., & Neumann, U. (1995). Dynamic registration correction in video-based augmented reality systems. *Computer Graphics and Applications, IEEE, 15*(5), 52-60. doi: 10.1109/38.403828

Bargh, M. S., & Groote, R. d. (2008). *Indoor localization based on response rate of bluetooth inquiries*. Paper presented at the Proceedings of the first ACM international workshop on Mobile entity localization and tracking in GPS-less environments, San Francisco, California, USA.

Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. (2011). Application areas and data requirements for BIM-enabled facilities management. *Journal of Construction Engineering and Management, 138*(3), 431-442.

Bedard, C. (2003). *Changes and the Unchangeable: Computers in Construction*, Nashville, Tennessee, USA.

Behzadan, A. H. (2008). *ARVISCOPE: Georeferenced visualization of dynamic construction processes in three-dimensional outdoor augmented reality*: ProQuest.

Behzadan, A. H., & Kamat, V. R. (2005). *Visualization of construction graphics in outdoor augmented reality*.

Behzadan, A. H., & Kamat, V. R. (2007). Georeferenced registration of construction graphics in mobile outdoor augmented reality. *Journal of Computing in Civil Engineering, 21*, 247.

Bell, B., Feiner, S., & Hollerer, T. (2001). *View management for virtual and augmented reality*. Paper presented at the Proceedings of the 14th annual ACM symposium on User interface software and technology, Orlando, Florida.

BIFM. (2012). Biritish Institute of Facilities Management. Retrieved 9 February 2012, from http://www.bifm.org.uk/bifm/about/facilities

BLS. (2011). Career Guide to Industries, 2010-11 Edition. Retrieved Feb 1st, 2012, from http://www.bls.gov/oco/cg/cgs035.htm

Bolstad, C. A., Riley, J. M., Jones, D. G., & Endsley, M. R. (2002). Using Goal Directed Task Analysis with Army Brigade Officer Teams. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 46*(3), 472-476. doi: 10.1177/154193120204600354

Calde, S., Goodwin, K., & Reimann, R. (2002). *SHS Orcas: the first integrated information system for long-term healthcare facility management*. Paper presented at the Case studies of the CHI2002\&\#124;AIGA Experience Design FORUM, Minneapolis, Minnesota.

CDC. (2008). National Hospital Ambulatory Medical Care Survey. Retrieved Feb. 1st, 2012, from http://www.cdc.gov/nchs/data/ahcd/nhamcs_outpatient/nhamcs0utpat2008.pdf

CDC. (2009). National Hospital Discharge Survey. Retrieved Feb 1st, 2012, from http://www.cdc.gov/nchs/data/nhds/1general/2009gen1_agesexalos.pdf

Chanter, B., & Swallow, P. (2007). *Building maintenance management* (2nd ed.): Blackwell Publishing.

Chen, H.-M., & Huang, P.-H. (2012). 3D AR-based modeling for discrete-event simulation of transport operations in construction. *Automation in Construction*.

Chi, H.-L., Kang, S.-C., & Wang, X. (2013). Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. *Automation in Construction*.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*: Lawrence Erlbaum.

Comport, A. I., Marchand, E., Pressigout, M., & Chaumette, F. (2006). Real-time markerless tracking for augmented reality: the virtual visual servoing framework. *Visualization and Computer Graphics, IEEE Transactions on, 12*(4), 615-628. doi: 10.1109/tvcg.2006.78

Cook, D. J., Augusto, J. C., & Jakkula, V. R. (2009). Ambient intelligence: Technologies, applications, and opportunities. *Pervasive and Mobile Computing, 5*(4), 277-298. doi: 10.1016/j.pmcj.2009.04.001

Deak, G., Curran, K., & Condell, J. A survey of active and passive indoor localisation systems. *Computer Communications*(0). doi: 10.1016/j.comcom.2012.06.004

Dunston, P., Wang, X., Billinghurst, M., & Hampson, B. (2003). Mixed Reality benefits for design perception. *NIST SPECIAL PUBLICATION SP*, 191-196.

Eastman, C. M., Teicholz, P., Sacks, R., & Liston, K. (2008). *BIM handbook*: Wiley Online Library.

Endsley, M. R. (1988). *Design and evaluation for situation awareness enhancement*.

Endsley, M. R. (1993). A Survey of Situation Awareness Requirements in Air-to-Air Combat Fighters. *The International Journal of Aviation Psychology, 3*(2), 157-168. doi: 10.1207/s15327108ijap0302_5

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*(1), 32-64. doi: 10.1518/001872095779049543

Endsley, M. R. (2000). Theoretical underpinnings of situation awareness: A critical review. *Situation awareness analysis and measurement*, 3-32.

Endsley, M. R., Bolte, B., & Jones, D. G. (2003). *Designing for Situation Awareness: An approach to human-centered design*: CRC Press; 1 edition

Endsley, M. R., Farley, T. C., Jones, W. M., Midkiff, A. H., & Hansman, R. J. (1998). Situation awareness information requirements for commercial airline pilots. Cambridge, MA: International Center for Air Transportation, Department of Aeronautics & Astronautics, Massachusetts Institute of Technology.

Endsley, M. R., & Garland, D. J. (2000). *Situation awareness: analysis and measurement*: CRC.

Endsley, M. R., & Kiris, E. O. (1995). The Out-of-the-Loop Performance Problem and Level of Control in Automation. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*(2), 381-394. doi: 10.1518/001872095779064555

Endsley, M. R., & Kiris, E. O. (1995). Situation awareness global assessment technique (SAGAT) TRACON air traffic control version user guide. *Lubbock, TX: Texas Tech University*.

Endsley, M. R., & Rodgers, M. D. (1994). Situation Awareness Information Requirements Analysis for En Route Air Traffic Control. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 38*(1), 71-75. doi: 10.1177/154193129403800113

Feiner, S., MacIntyre, B., Höllerer, T., & Webster, A. (1997). A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. *Personal and Ubiquitous Computing, 1*(4), 208-217.

Feng, Z., Duh, H. B. L., & Billinghurst, M. (2008, 15-18 Sept. 2008). *Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR.* Paper presented at the Mixed and Augmented Reality, 2008. ISMAR 2008. 7th IEEE/ACM International Symposium on.

Fuchs, C., Aschenbruck, N., Martini, P., & Wieneke, M. (2011). Indoor tracking for mission critical scenarios: A survey. *Pervasive and Mobile Computing, 7*(1), 1-15. doi: 10.1016/j.pmcj.2010.07.001

Furht, B. (2011). *Handbook of augmented reality*: Springer-Verlag New York Inc.

Gall, M. (2001). *Figuring out the importance of research results: Statistical significance versus practical significance.* Paper presented at the 2001 annual meeting of the American Educational Research Association.

Garrett, J. J. H. (2003). *From IT-Supported Offices Towards IT-Supported On-site Activity: Vision, Issues and Initial Directions*, Nashville, Tennessee, USA.

Gezici, S., Zhi, T., Giannakis, G. B., Kobayashi, H., Molisch, A. F., Poor, H. V., & Sahinoglu, Z. (2005). Localization via ultra-wideband radios: a look at positioning aspects for future sensor networks. *Signal Processing Magazine, IEEE, 22*(4), 70-84. doi: 10.1109/msp.2005.1458289

Gheisari, M., & Irizarry, J. (2011). Investigating Facility Managers' Decision Making Process through a Situation Awareness Approach. *International Journal of Facility Management, 2*(1).

Gheisari, M., Irizarry, J., & Horn, D. B. (2010, 6-8 September 2010). *Situation Awareness Approach to Construction Safety Management Improvement.* Paper presented at the 26th Annual ARCOM Conference, Leeds, UK.

Gheisari, M., Williams, G., Irizarry, J., & Walker, B. N. (2012). InfoSPOT: A Mobile Augmented Reality Method for Accessing Building Information through a Situation Awareness Approach. *AUTCON Journal of Automation in Construction*.

Golparvar-Fard, M., Pena-Mora, F., & Savarese, S. (2009). Application of D4AR,ÄìA 4-Dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication: ITcon.

Goodwin, C. J. (2009). *Research in psychology: Methods and design* (5th ed.): Wiley.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Human mental workload, 1*, 139-183.

Henrysson, A., Billinghurst, M., & Ollila, M. (2005, 5-8 Oct. 2005). *Face to face collaborative AR on mobile phones.* Paper presented at the Mixed and Augmented Reality, 2005. Proceedings. Fourth IEEE and ACM International Symposium on.

Henrysson, A., & Ollila, M. (2004). *UMAR: Ubiquitous mobile augmented reality*.

Hightower, J., Want, R., & Borriello, G. (2000). SpotON: An Indoor 3D Location Sensing Technology Based on RF Signal Strength *UW CSE Technical Report #2000-02-02*. Seattle, WA: University of Washington, Department of Computer Science and Engineering.

Hill, A., MacIntyre, B., Gandy, M., Davidson, B., & Rouzati, H. (2010, 13-16 Oct. 2010). *KHARMA: An open KML/HTML architecture for mobile augmented reality* *applications*. Paper presented at the Mixed and Augmented Reality (ISMAR), 2010 9th IEEE International Symposium on.

Hjelm, J. (2000). Research applications in the mobile environment. *Wireless Information Services*.

Hui, L., Darabi, H., Banerjee, P., & Jing, L. (2007). Survey of Wireless Indoor Positioning Techniques and Systems. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 37*(6), 1067-1080. doi: 10.1109/tsmcc.2007.905750

IFMA. (2009). Website of the International Facility Management Association (IFMA). Retrieved June 2009, 2009, from http://www.ifma.org

Innovation, C. R. C. C. (2007). Adopting BIM for facilities management: Solutions for managing the Sydney Opera House. *Cooperative Research Center for Construction Innovation, Brisbane, Australia*.

Intille, S. S., Larson, K., Beaudin, J. S., Nawyn, J., Tapia, E. M., & Kaushik, P. (2005). *A living laboratory for the design and evaluation of ubiquitous computing technologies*. Paper presented at the CHI '05 Extended Abstracts on Human Factors in Computing Systems, Portland, OR, USA.

Irizarry, J., Gheisari, M., Williams, G., & Roper, K. O. (2013). Ambient Intelligence Environments for Accessing Building Information: A Healthcare Facility Management Scenario (Under Review). *Emeral Journal of Facilities*.

Irizarry, J., Gheisari, M., Williams, G., & Walker, B. N. (2012). InfoSPOT: A Mobile Augmented Reality Method for Accessing Building Information through a Situation Awareness Approach. *Automation in Construction*(Special issue on "Applications of Augmented Reality in Architecture, Engineering and Construction"), in press.

Joyce, E. (2012). Augmenetd Reality for Facilities Management Edges Closer to Real-World Applications. Retrieved April 10, 2012, from https://enr.construction.com/engineering/subscription/LoginSubscribe.aspx?cid=22574

Karlekar, J., Zhou, S. Z., Nakayama, Y., Weiquan, L., Zhi Chang, L., & Hii, D. (2010, 19-23 July 2010). *Model-based localization and drift-free user tracking for outdoor augmented reality.* Paper presented at the Multimedia and Expo (ICME), 2010 IEEE International Conference on.

Kato, H., & Billinghurst, M. (1999, 1999). *Marker tracking and HMD calibration for a video-based augmented reality conferencing system.* Paper presented at the Augmented Reality, 1999. (IWAR '99) Proceedings. 2nd IEEE and ACM International Workshop on.

Khoury, H. M., & Kamat, V. R. (2009). Evaluation of position tracking technologies for user localization in indoor construction environments. *Automation in Construction, 18*(4), 444-457. doi: 10.1016/j.autcon.2008.10.011

Kirk, R. E. (2001). Promoting good statistical practices: Some suggestions. *Educational and Psychological Measurement, 61*(2), 213-218.

Kuo, C., Jeng, T., & Yang, I. (2012). An invisible head marker tracking system for indoor mobile augmented reality. *Automation in Construction*.

LaMarca, A., Chawathe, Y., Consolvo, S., Hightower, J., Smith, I., Scott, J., . . . Schilit, B. (2005a). Place Lab: Device Positioning Using Radio Beacons in the Wild

Pervasive Computing. In H. Gellersen, R. Want & A. Schmidt (Eds.), (Vol. 3468, pp. 301-306): Springer Berlin / Heidelberg.

LaMarca, A., Chawathe, Y., Consolvo, S., Hightower, J., Smith, I., Scott, J., . . . Schilit, B. (2005b). Place Lab: Device Positioning Using Radio Beacons in the Wild Pervasive Computing. In H. Gellersen, R. Want & A. Schmidt (Eds.), (Vol. 3468, pp. 301-306): Springer Berlin / Heidelberg.

Langston, C. A., & Lauge-Kristensen, R. (2002). *Strategic management of built facilities*. Oxford, U.K.: Butterworth-Heinemann.

Lavy, S., & Shohet, I. M. (2007). Computer-Aided Healthcare Facility Management. *Journal of Computing in Civil Engineering, 21*(5), 363-372.

Lewis, J. R. (1995). IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use. *International Journal of Human-Computer Interaction, 7*(1), 57-78. doi: 10.1080/10447319509526110

Lumion. (2012). Revit Collada Exporter. Retrieved from http://lumion3d.com/export-revit/

McHenry, K., & Bajcsy, P. (2008). An Overview of 3D Data Content, File Formats and Viewers.

Menzel, K., Eisenblatter, K., & Keller, M. (2004). *Issues of context sensitivity in mobile computing: restrictions and challenges in the construction sector.* Paper presented at the Proceedings of the European Conference on Products and Process Modeling (ECPPM 2004), eWork and eBusiness in Architecture, Engineering and Construction.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems, 77*(12), 1321-1329.

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). *Augmented reality: A class of displays on the reality-virtuality continuum*.

Mrawira, D., Rankin, J., & Nunoo, C. (2002). *Web-based tool in project quality management.* Paper presented at the Proceedings of the First International Conference on Construction in the 21st Century, Miami, Florida.

Neumann, U., & You, S. (1999). Natural feature tracking for augmented reality. *Multimedia, IEEE Transactions on, 1*(1), 53-64. doi: 10.1109/6046.748171

Neyman, J., & Pearson, E. S. (1933). On the problem of the most efficient tests of statistical hypotheses. *Philosophical Transactions of the Royal Society of London.*

Series A, Containing Papers of a Mathematical or Physical Character, 231, 289-337.

Ni, L. M., Liu, Y., Lau, Y. C., & Patil, A. P. (2004). LANDMARC: Indoor Location Sensing Using Active RFID. *Wireless Networks, 10*(6), 701-710. doi: 10.1023/B:WINE.0000044029.06344.dd

O'Brien, W., Issa, R. R. A., & Flood, I. (2003). *Moving from Information Tunnels to Configurable, User-Model Driven Environments: A Vision for Future Project Information Technologies.* Paper presented at the Fourth Joint International Symposium on Information Technology in Civil Engineering, Nashville, TN.

OSHA. (2012). Healthcare faciities.   Retrieved Feb 1st, 2012, from http://www.osha.gov/SLTC/healthcarefacilities/

Park, C.-S., Lee, D.-Y., Kwon, O.-S., & Wang, X. (2012). A Framework for Proactive Construction Defect Management using BIM, Augmented Reality and Ontology-based Data Collection Template. *Automation in Construction*.

Piekarski, W., & Thomas, B. H. (2001, 2001). *Tinmith-Metro: new outdoor techniques for creating city models with an augmented reality wearable computer.* Paper presented at the Wearable Computers, 2001. Proceedings. Fifth International Symposium on.

Popa, M., Ansari, J., Riihijarvi, J., & Mahonen, P. (2008, March 31 2008-April 3 2008). *Combining Cricket System and Inertial Navigation for Indoor Human Tracking.*

Paper presented at the Wireless Communications and Networking Conference, 2008. WCNC 2008. IEEE.

Pressigout, M., & Marchand, E. (2006). *Hybrid tracking algorithms for planar and non-planar structures subject to illumination changes*. Paper presented at the Proceedings of the 5th IEEE and ACM International Symposium on Mixed and Augmented Reality.

Reinhardt, J., Garrett, J. H., & Scherer, R. J. (2000). The preliminary design of a wearable computer for supporting Construction Progress Monitoring.

Reitmayr, G., & Drummond, T. W. (2006, 22-25 Oct. 2006). *Going out: robust model-based tracking for outdoor augmented reality.* Paper presented at the Mixed and Augmented Reality, 2006. ISMAR 2006. IEEE/ACM International Symposium on.

Riva, G. (2003). Ambient intelligence in health care. *CyberPsychology & Behavior, 6*(3), 295-300.

Rolland, J. P., Davis, L., & Baillot, Y. (2001). A survey of tracking technology for virtual environments. *In Fundamentals of Wearable Computers and Augmented Reality*(1), 67-112.

Sanchez, D., Tentori, M., & Favela, J. (2008). Activity recognition for the smart hospital. *IEEE Intelligent Systems 23,* 50–57.

Shin, D. H., & Dunston, P. S. (2008). Identification of application areas for augmented reality in industrial construction based on technology suitability. *Automation in Construction, 17*(7), 882-894.

Shohet, I. M., & Lavy, S. (2004). Healthcare facilities management: state of the art review. *Facilities, 22*(7/8), 210-220.

Son, J., Aziz, Z., & Pena-Mora, F. (2008). Supporting disaster response and recovery through improved situation awareness. *Structural Survey, 26*(5), 411-425.

Strater, L. D. E., Mica R. ; Pleban, Robert J. ; Matthews, Michael D. (2001). Measures of platoon leader situation awareness in virtual decision-making exercises: DTIC Document.

Takacs, G., El Choubassi, M., Yi, W., & Kozintsev, I. (2011, 11-15 July 2011). *3D mobile augmented reality in urban scenes.* Paper presented at the Multimedia and Expo (ICME), 2011 IEEE International Conference on.

Tang, A., Owen, C., Biocca, F., & Mou, W. (2003). *Comparative effectiveness of augmented reality in object assembly*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems, Ft. Lauderdale, Florida, USA.

Tang, L. C. M., Zhao, Y., Austin, S. A., Darlington, M., & Culley, S. (2007). *Knowledge and information evaluation practice-an exploratory study in a construction firm*. Paper presented at the Proceedings of the CIB W102 3rd International Conference, Stuttgart.

Then, D. S. S. (1999). An integrated resource management view of facilities management. *Facilities, 17*(12/13), 462-469.

Thomas, L., & Juanes, F. (1996). The importance of statistical power analysis: an example from Animal Behaviour. *Animal Behaviour, 52*(4), 856-859.

Thompson, B. (2002). " Statistical,"" Practical," and" Clinical": How Many Kinds of Significance Do Counselors Need to Consider? *Journal of Counseling & Development, 80*(1), 64-71.

Vacchetti, L., Lepetit, V., & Fua, P. (2004, 2-5 Nov. 2004). *Combining edge and texture information for real-time accurate 3D camera tracking.* Paper presented at the Mixed and Augmented Reality, 2004. ISMAR 2004. Third IEEE and ACM International Symposium on.

Wagner, D., & Schmalstieg, D. (2003, 18-21 Oct. 2005). *First steps towards handheld augmented reality.* Paper presented at the Wearable Computers, 2003. Proceedings. Seventh IEEE International Symposium on.

Wang, X., & Dunston, P. S. (2006). Compatibility issues in Augmented Reality systems for AEC: An experimental prototype study. *Automation in Construction, 15*(3), 314-326.

Want, R., Hopper, A., Falcao, V., & Gibbons, J. (1992). The active badge location system. *ACM Trans. Inf. Syst., 10*(1), 91-102. doi: 10.1145/128756.128759

Wilkinson, L. (1999). Statistical methods in psychology journals: Guidelines and explanations. *American psychologist, 54*(8), 594.

Wither, J., Tsai, Y.-T., & Azuma, R. (2011). Indirect augmented reality. *Computers & Graphics, 35*(4), 810-822. doi: 10.1016/j.cag.2011.04.010

Woo, S., Jeong, S., Mok, E., Xia, L., Choi, C., Pyeon, M., & Heo, J. (2011). Application of WiFi-based indoor positioning system for labor tracking at construction sites: A case study in Guangzhou MTR. *Automation in Construction, 20*(1), 3-13. doi: 10.1016/j.autcon.2010.07.009

Wu, Y., Choubassi, M. E., & Kozintsev, I. (2011, 26-29 Oct. 2011). *Augmenting 3D urban environment using mobile devices.* Paper presented at the Mixed and Augmented Reality (ISMAR), 2011 10th IEEE International Symposium on.

Yates, F. (1951). The influence of statistical methods for research workers on the development of the science of statistics. *Journal of the American Statistical Association, 46*(253), 19-34.

Youngmin, P., Lepetit, V., & Woontack, W. (2008, 15-18 Sept. 2008). *Multiple 3D Object tracking for augmented reality.* Paper presented at the Mixed and Augmented Reality, 2008. ISMAR 2008. 7th IEEE/ACM International Symposium on.