# Automated Data Acquisition for Tracking and Control of Construction Projects

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## ABSTRACT

**Automated Data Acquisition for Tracking and Control of Construction Projects**

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Controlling construction projects necessitates controlling their time and cost in an effort to meet the planned targets. Management needs timely data that represent the status of the project to take corrective actions, if needed. The earned value technique is widely used for periodic monitoring of actual expenditures and physical scope accomplishment and, accordingly, for generating period-by-period progress reports. These reports are commonly developed by essentially comparing the collected actual data pertinent to work performed on site to that planned. The objectives of this research thesis are to study and analyze the characteristics of automated data acquisition technologies in an effort to automate the process of data collection from construction sites for progress measurement. This includes their capabilities and limitations and their respective suitability to track various construction operations. Experiments were conducted to study the applications of different automated data acquisition technologies and explore the most suitable IT platform for integrating them in one tracking and control system. Current automated data acquisition technologies are described, and their suitability for use in tracking and controlling construction activities is assessed. This includes bar coding, Radio Frequency Identification (RFID) 3D laser scanning, photogrammetry, multimedia, and pen-based computers. Each automated technology, is used for a certain construction task on site. For example, 3D scanner or LADAR (laser distance and ranging) was integrated in this thesis together with photogrammetry to rapidly track changes of quantities of work accomplished such as excavation works. Integrating these two technologies alleviates limitations associated with each of them individually such as the number of scans required and the time needed for each scan to produce acceptable results during the 3D modeling process. It also overcomes limitations associated with photogrammetry when modeling 3D images of objects with unclear geometrical properties as in the case of earthmoving operations where modeling 3D images from digital photo images becomes difficult and the presence of a scanned image can be helpful. Bar coding and RFID are utilized for material and labor tracking. In the reporting stage, more photo images would be more desirable. Pen-based or tablet computer is utilized as the main interface tool with the user. The user can move with a tablet PC in the construction site and record, take snapshots and also hand written comments about activities on site. A proposed cost/schedule control model is presented that Integrates different automated data acquisition technologies, a planning and scheduling software system, a relational database, and AutoCAD to generate progress reports that can assist project management teams in decision making.

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# CHAPTER 1 INTRODUCTION

## 1.1 General

Tracking the progress of construction projects encompasses monitoring the time and cost of the work performed on site. Integrating time and cost is crucial to effectively control these two project management functions (Perera et al. 2004). The efficiency of that type of integration depends primarily on the accuracy, and timeliness collection of actual data that depicts work progress on site. Contractors need to manage the work so that they have good control over resource usage, including man-hours, equipment and material.

The Earned Value (EV) concept developed under the Cost/Schedule Control System Criteria (C/SCSC) by the US department of defense is considered a tool to keep an eye over project performance (Fleming et al 1997). EV analysis is performed using actual data collected from construction sites and comparing them to those planned in generated progress reports. Consequently, the process of actual data collection is vital in generating reliable progress reports. Emerging technologies have been the driving force behind taking initiatives to automate the process of data acquisition. Efforts have been made to automate the process of data acquisition in the construction industry (Akinci et al 2002, Perera et al 2004, Shashi et al 2007, Du et. al 2007, Jaselskis 2003 Echevery 1996, 1997, Flickinger 1995, Liu 1995, McCullouch et al 1993, Rasdorf et al 1990, 1991).

## 1.2 Project tracking and control

Project tracking and progress reporting are two essential management functions for the successful delivery of construction projects. These functions are critical to the application of the commonly used EV concept for monitoring and reporting on-site progress. Monitoring depends, to great extent, on timely and accurate on-site data collection. Traditionally, actual data pertinent to material usage, man-hours, and/or equipment utilization are collected manually by filling forms on site and then feeding the collected data into a computer in the office. In some cases, information is gathered through phone calls, by fax, or by mail (Li et al 1997). This process is not only time consuming, but is also susceptible to human error, and may lack consistency and reliability.

## 1.3 Scope and objectives

The scope of the research presented in this thesis is to study methods used in tracking and control of construction projects and likely efficient utilization of data acquisition technologies to improve the efficiency of such methods. A construction control model is developed to integrate automated data acquisition technologies and use them to assist in actual data collection from construction sites for tracking and control purposes. The model is designed to assist contractors in tracking project cost and time and to generate progress reports in a timely manner. The developed model will track cost and time at the lowest level, which is the activity level. It also provides flexibility to contractors to roll up the captured data from the activity level to the cost account and the work package levels.

The objectives of the research are to study and analyze the characteristics of automated data acquisition technologies. This includes their capabilities, limitations, and their respective suitability to track various construction operations. As such, it is intended to study and experiment with the applications of different automated data acquisition technologies and to explore the most suitable IT platform for integrating them in a control system. To fulfill these main objectives the research activities were organized in order to:

1. Evaluate the progress made in the field of automated data acquisition.
2. Explore the potential of applying different data acquisition technologies and study the best way to integrate them into one control system.
3. Design a centralized database to organize and store collected data.
4. Develop a prototype software application that acts as an interface with the user to enter actual data on site and store it in a centralized database.
5. Demonstrate how the developed methodology can be applied using a case example.

## 1.4 Thesis organization

Chapter two presents the earned value concept as a reliable tool to integrate time and cost control functions. Six major steps are briefly discussed to apply the earned value concept, and the importance of the monitoring stage is highlighted.

This Chapter also provides a background on current automated data acquisition technologies including bar coding, RFID (Radio Frequency Identification), pen-based computers, LADAR (Laser Distance and Ranging), photogrammetry, and multimedia.

Chapter three presents the proposed methodology, and describes its main components. The system integrates different automated data acquisition technologies to facilitate the process of actual data collection from construction sites that would help in generating earned value analysis and thereafter project progress reports.

The integration of laser scanning and photogrammetry has reduced the time required to scan an object and the number of scans and scan positions needed to get enough information on the scanned object. The PHIDIAS software package from RIEGL was acquired for this study. It is capable of modeling scanned 3D images with the help of digital photo images. Modeled 3D image is needed to calculate quantities of work performed. Chapter four examines the two technologies, 3D laser scanning and photogrammetry, and also presents the integration process through a comparison between using the LADAR equipment only and using both technologies together. Moreover, this chapter provides the results of a test performed on an actual construction project, which is the new John Molson School of Business building of Concordia University. Chapter five presents the developed relational database and the software designed to act as an interface with the user to store, organize, and retrieve data from the database.

Chapter six presents a summary of the study, concluding remarks, and some recommendations for future research.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 General

Construction projects encompass drawings, specification, construction schedule and cost estimate and subsequent updates to these documents including daily reports and photographs (Ganeshan et al 1994). Emerging technologies have been behind initiatives to automate the process of data acquisition needed to perform EV analysis. This include, bar-code technology (Tserng et al 2005, Li 2003, Abudayyeh 1991, Echevery 1996, 1997, Rasdorf et al 1990), RFID (Song et al 2006, Yagi et al 2005, Jaselskis 2003) pen-based computers (Elzarka et al 1997, Liu 1995, McCullouch et al 1993, Rusell 1993, 1995, Thabet 1997, Williams 2003, 1994), LADAR (Du et al 2007, Shih et al 2006, Cheok et al 1999, 2000, Jaselskis et al 2005, Shih 2002), Photogrammetry (Guarnieri, 2004 Styliadis 2007, Hirschberg et al 1996), and multimedia technology (Tsai 2007, Abeid et al 2002, Abudayyeh 1995, Abudayyeh 1996, Everett et al 1998, Liu et al 1995, Liu 1995). Researchers also developed web-based interface to facilitate the information flow between project participants during the control process (Moselhi et al. 2004, Yeung et al. 2003). This Chapter provides a literature review on the topic of integrated time and cost control and specifically the implementation of EV analysis as a tool to track and control construction projects. It also presents an overview on automated data acquisition technologies and their implementation into the construction industry. The following is a description of the earned value concept with highlight on the tracking and control process.

## 2.2 Integrated time and cost control

Controlling construction projects is not an easy task without a reliable and effective control system. Keeping the project on its planned duration and budget is the main objective of any control system. Traditionally time and cost control functions are done separately using the Work Breakdown Structure (WBS) and the Cost Breakdown Structure (CBS). Integrating these two functions is difficult due to the difference in level of detail used in each structure (Jung et al 2004, Abudayyeh 1991, Rasdorf et al 1991). As shown in Figure 2-1 (Abudayyeh 1991), the cost account to document the costs for the installation of the formworks of an 8" concrete wall is in the $6^{th}$ level of the cost breakdown structure. This represents the same activity in the work breakdown structure in the $8^{th}$ level and many other similar activities, which are in different floors and different areas of the project. To schedule the work, the project must be broken down into small work packages that will be assigned to contractors or superintendents to be responsible for their accomplishment. The challenge is to integrate these two functions so that controlling them becomes effective (Perera 2004, Abudayyeh 1991).

The Earned Value (EV) concept has proven to be the most reliable tool for tracking and control construction projects. It requires periodic monitoring of actual expenditures and physical scope accomplishments, and allows calculation of cost and schedule variances, along with the performance indices (Jung et al 2007, Anbari 2003). The earned Value concept establishes a relationship between the physical work being accomplished, and the costs of doing that same work (Flemming et al 1995). It involves the calculation of time and cost variances after determining the Budgeted Cost of Work Performed (BCWP). This is accomplished through acquiring project percent completion and comparing the Actual Cost of Work Performed (ACWP) with Budgeted Cost of Work Scheduled (BCWS). A survey was conducted to explore the application of the earned value technique for project control (McKim et al 2000) (see Table 2-1). The result of that survey indicated that few of the company's interviewed are applying it as a tool to control their projects. To apply the EV concept, the following steps have to be executed (Fleming et al 1997, Moselhi 1993, Tammo 1993). The most significant and critical step in performing EV analysis is to define the work using Work Breakdown Structure (WBS). The project must be broken down into small definable elements called Work Packages (WP) using WBS. A definition was given by James Dillworth (1989) for the WBS: "A WBS is a document similar to the bill of materials, divides the total work into major work packages to be accomplished. These work packages are divided into major elements, and the major elements are further subdivided to develop a list of all work items that must be accomplished to complete the project" (Mansuy 1991). This task has to be carefully performed because it will be the basis to relate cost and resources. In mega projects, the project is first divided into areas and the procedures continue at lower levels. The lowest level in the WBS is the work package. A WP has to have a well-defined scope of work, and start and end dates (Ho 1990). A work package also consists of a prescribed amount of work with an estimated value determined to be the responsibility of a specific individual (Kibler 1992).

Researchers have found that there is no particular size for a WP but it must have measurable and controllable units of work (Halpin et al. 1987).

Table 2-1 Most frequently used cost control technique (McKim et al. 2000)

| Technique | Frequency |
|---|---|
| Cost planning | |
| Budget base line | 22 |
| Cost breakdown structure | 19 |
| Control measurement/control | |
| Unit costing | 14 |
| Earned value | 5 |
| Cost variance | 21 |
| Cash flow analysis | 15 |
| Schedule of values | 23 |

A WP can represent an entire project or a very small activity in a project. However, it was recommended to use around 180 WP's for a $50 million contracts, 320 for a $100 million and 460 for a $150 million, but again it depends on the type of project and the values above are only averages (Moselhi 1993). After dividing the project into definable WP's, it must be planned and scheduled using the critical path method technique (CPM). Relationships will be determined between the work packages. This step will determine the sequence of the work, activity duration and specify its start and end dates, and accordingly the start and end dates for the entire project. Planning and scheduling depends mainly on the previous step, if the work was poorly defined; the result is a poor, and unreliable schedule, which in turns will lead to many delays (Fleming et al 1997, Moselhi 1991, Tammo 1993).

Resources will be allocated to each activity. This step has to be carefully performed. The challenge here is to minimize the use of resources or effectively utilize them to each activity with the aim of not having idle resources, or activity with lack of resources (Tammo 1993).

Each activity in the schedule is considered a cost account. Budget must be assigned to each cost account; this includes cost of material, equipment, and labor. The cost account will be assigned to a construction superintendent or a contractor to be responsible for its accomplishment (Fleming et al 1997, Tammo 1993).

A guide has to be available for the purpose of project progress measurement; this guide is the project baseline. It's done with summing all cost accounts throughout the duration of the project. This baseline should be approved from the management and saved for progress measurement and is subject to modification due to change orders. Figure 2-2 describes a schedule with the use of resources and the baseline (Moselhi 1993).

Monitoring project duration and the status of its expenditures provide early warning to management related to any delays or budget overrun. The budgeted cost of work performed (BCWP), known as the earned value, has to be calculated including time and cost variances (Fleming et al 1997, Moselhi et al.

2004, Yang et al 2007). The integrated cost/schedule performance curve provides actual accomplishment as compared to schedule performance in relation to work accomplishment of various slippages in the key control parameters including cost, time and performance (Stevens 1986). At the reporting period the actual cost of work performed (ACWP) is known and compared to the budgeted cost of work scheduled. The percent complete will be specified and the EV calculated. In Figure 2-3 (Moselhi 1993) at the reporting period, the ACWP exceeds the BCWS, whereas the value earned for the work accomplished or the BCWP is less than the BCWS. In this example the project is experiencing a cost overrun and is behind schedule, which will result in higher estimate at completion. Performing this concept in short periods will give the management the opportunity to respond early during the life of the project for corrective actions and to bring the project back in its planned track.

## 2.3 Automated data acquisition technologies

### 2.3.1 Bar coding

Bar-code technology is known in the manufacturing industry as a reliable tool for resource management. Applying it in the construction industry is tied with the rough condition of construction projects as bar code tags can likely be damaged (Abudayyeh 1996). The construction industry is still not very familiar with this technology, maybe only in material management but not in the whole process of cost and schedule control (Bell et al 1988). The construction industry institute (CII) had funded a research project in 1988 to explore the potential applications of bar code in the construction industry. During that research two categories of applications were found. In the first category bar code tags are applied to the material, equipment, and containers and/or paper work. In the second category, bar-coded menus are used for the purpose of improving the speed and accuracy of data that will be entered into the computer system (Bell et al 1988). Due to the harsh environment of construction projects, it was found that bar code labels can be best made of plastic or thin metal (Bernold 1990). Bar code system composed of bar code labels printed on paper and coded in a way to identify the product it represents. The *Universal Product Code* (UPC) is widely used as a product coding system. It was first adopted for the grocery industry and became the most widely used standard for product identification and today there are five versions of UPC (Shephard 2005). Other coding systems are available such as the *European Article Numbering* (EAN) system and the *Japanese Article Numbering* (OAN) system. There are two versions available of the EAN. The second component is the laser scanner, which is capable of reading information coded on the bar code label. Scanners are available in different types. There are hand held scanners, pen scanners (or wand scanners), wall- or table-mounted scanners that the barcode is passed under or beside, fixed position scanner (an industrial reader used to identify product during manufacture), and PDA scanners (a Personal Digital Assistant (PDA) with a built-in barcode reader). The last component is the printer to print bar code labels. During the control process, Bar-code labels are scanned and data is entered into the computer for related item. Bar-code labels can be applied to materials and equipment that are uniquely identified. Bulk material such as gravel can be stored in containers and issued a bar-code label. These labels are listed in menus (Abudayyeh 1991, Bell et al 1988). Figures 2-4 and 2-5 are examples of bar-code labels for construction materials like steel beams and bolts and for an activity on an activity sheet (Bell et al 1988). For labor control, each worker is issued an ID card with his personal information and the information of the project he is working on (Flickinger 1995). Researchers have studied the potential of developing a data acquisition, and storage model with the use of bar-code technology and then processing this data for the purpose of integrated control process (Abudayyeh 1991). Bar codes are divided into one-dimensional and two-dimensional. One-dimensional bar codes can hold 10 to 20 characters only while tow-dimensional contain file of information (Moselhi et al 2003). One-dimensional bar codes are more suitable for the construction industry due to the fact that the accepted standards governing one-dimensional codes, which can be adapted with other industries, make it the best choice for the construction industry (Moselhi et al 2003).

Researchers have studied the potential of applying the bar-code technology into the construction industry. Bar coding is used in the initial data collection to provide project managers with information needed to increase control over their projects. Using bar-code system, materials would be, ordered using bar-codes, delivered to the job site with bar-code tags attached to the material delivery, read by scanning device which could be integrated into the pen-based computer, and recorded and tracked on the job schedule (Colbe et al 1994). The following summarize the current application of bar code in the construction industry. (1)

Identify materials and build components on a construction job site; (2) Automate yard control to reduce loss and misidentification of material and equipment; (3) Track and manage both small and large equipment on the job site; (4) Track job-site workers; and (5) Identify documentation, drawings, material, equipment, and project activities (Tserng et al 2005).

A construction information management system (CIMS) was developed by Rasdorf and Herbert (1990). As shown Figure 2-6, this system had utilized the bar-code technology for the purpose of automated data acquisition for control needs of construction projects. The system integrated some construction management applications, among those were the DOS based scheduling program PLANTRAC. A cost control application was developed using LOTUS SYMPHONY. Actual data collected from construction sites, with bar-code hardware, to be used in an inventory control application that was written in R:Base. The basic component of that system was a centralized database, which was designed using R:Base under MS-DOS environment. In this system bar coding had the job of tracking materials and equipment. Bar-code labels were designed and applied on materials and equipment. This system had presented the need for a unified bar-code labeling system that could be designed by the participation of material suppliers to avoid designing bar-code labels for each construction project (Rasdorf et al 1990). The CIMS is a system that provides information to management through a centralized database about equipment and material utilization in the work. This system is an example of using bar coding for resource management including materials and equipment.

Tserng and Dzeng (2005) have integrated bar code technology and PDA "Personal Digital Assistant" as a way to facilitate the process of data collection and information sharing between project participants. Their system is called the mobile construction supply chain management (M-ConSCM) System. They identified problems associated with data collection and the solution for these problems with the use of PDA (Table 2-2). The M-ConSCM system is comprised of three components: PDA, bar code, and portal. Both thePDA and the bar code components are on the client side, whereas the portal component is on the server side (see Figure 2-7). Within the M-ConSCM system, all project related information acquired by on-site engineers is centralized in a supply chain system database (portal model database). Project participants (subcontractors and suppliers) in the supply chain may have access to all or some of this information through the portal, depending on their access privileges. The server of the M-ConSCM system has three types of layers, presentation, application, and database layers. In The presentation, the users can access information through web browsers. Administrators can control and manage information through the web browser as well as a separate server interface. The application layer defines various applications for information collection and management. These applications offer system security, information sharing, project control, project monitoring, and system administration functions. The database layer includes DB2 Everyplace, DB2 Universal, and SQL Server 2000. All the data are stored and organized in DB2 Everyplace for mobile devices.

Table 2-2 Problems on construction sites and their solutions with PDAs (Tserng et al 2005)

| *Function* | *Current status* | *Problem* | *Solution with PDAs* |
|---|---|---|---|
| Control | | | |
| Inventory control | | | Assist on-site engineers handle inventory management on the site |
| Maintenance control | Paper-based work | Time-consuming and ineffectively distributed | Assist on-site engineers handle asset maintenance management on the site |
| Schedule control | | | Assist on-site engineers to handle schedule control on the site |
| Quality control | | | Assist on-site engineers to handle quality control on the site |
| Record | | | |
| Experience record | | | Provide on-site engineers a portal tool to write down know-how tips on the site |
| Process record (voice) | Inconvenient & not handy | Inconvenient, no handy devices | Provide on-site engineers a portal tool to write down know-how tips on the site |
| Process record (photo) | | | Easy for on-site engineers to record construction process |
| Process record (video) | | | Easy for on-site engineers to record construction process |
| Communication | | | |
| E-Mail | N/A | N/A | Provide on-site engineers to send and read e-mail by PDA |
| Reference | | | |
| E-Drawing | | | Help on-site engineers refer to the construction drawings directly from PDA |
| E-specification | Paper-based work | Dreadful, inconvenient | Help on-site engineers refer to the specification directly from PDA |
| E-contract | | | Help on-site engineers refer to the contract directly from PDA |
| E-Manual | | | Help on-site engineers refer to the manual directly from PDA |

The data uploaded from mobile devices (client) are stored in DB2 Universal Database as a medium between the server and the client. Finally, SQLServer 2000 processes and manages the M-ConSCM system database. The M-ConSCM system is composed of a construction supply chain control portal integrated with mobile devices and bar code technology (bar-code-enabled PDA). The ConSCM portal is an information hub in the M-ConSCM system for general contractors. The ConSCM portal enables all the participants to log onto a single portal site and obtain the information they need to make their own plan. The portal gives suppliers information on the inventory levels of other portal users and allows them to manufacture products accordingly. The general contractor can access diverse information and services via a single front end on the Internet. For instance, a supplier can log onto the portal, enter an assigned security password, and gain access to real-time information about the production schedule. Two mobile device platforms, Palm OS and Windows CE, are selected as the bar-code-enabled PDA hardware systems. The M-ConSCM system uses Palm Scanner (SymbolSPT 1500) and iPAQ Scanner (Symbol SPS 3000). In the MConSCM system, bar code tags and labels are applied to the materials, equipment, and property, as well as to the item control list. All construction bar code applications in the M-ConSCM system use the Code 39 symbology, and bar code labels are printed using laser printers. Two types of bar code software are used in this system: bar code labeling software and bar code tracking software. Bar code labeling software provides the function for designing and printing quality labels. Bar code tracking software is applied to read and track the bar codes. Palm OS and Windows CE are the two platforms used to operate the M-ConSCM system. Visual Basic and embedded Visual Tools 3.0 are the programming language and tools used to develop the module. IBM DB2 Everyplace and Universal Database serve as the PDA database for the Palm OS-based PDA; SQL Server for CE serves as the PDA database for the Windows CE-based PDA. Additionally, on-site Viewer (http://www.autodesk.com) for Windows CE is installed on the Windows CE-based PDA to allow viewing, marking up, and measuring AutoCAD drawings on the PDA. In the PDA module, all the data files are first stored in the PDA database before being sent to the server through the Internet. After the application in the PDA is run, all the data files are sent, transformed, and saved in the server side database using open database connectivity (ODBC) and Java database connectivity (JDBC) technologies.

Using bar-code technology to collect actual data required for generating progress reports was the subject of a research done by Abudayyeh (1991). The system architecture is illustrated in Figure 2-8. Actual data was collected using bar-code hardware and stored in a centralized database that was designed using ORACLE. The database was linked with a commercial scheduling software to update the schedule and then generate progress reports using forms produced by the designed database. To collect data from construction site, a data acquisition module were designed and implemented on a portable device called the transition manager. Data was collected with a bar-code reader and then uploaded and stored in the relational database (Rasdorf et al 1991). Electronic forms combined with bar code data sheets were developed to be used by an operator (Abudayyeh 1991).

An automated labor and equipment card (ALEC) was developed by the United States army construction engineering research laboratories for collecting, processing, and uploading labor and equipment data using bar coding (Flickinger 1995) data is collected using bar-code reader (see Figure 2-9) called “micro wand”. Data is entered either by scanning the bar code label on the worker’s card or by using keys on bar-code wand. At the end of each working day, labor and equipment data are uploaded to the computer where they can be reviewed or edited.

Bar-code technology was applied as a way for automated data acquisition by Echvery and Beltran (1996, 1997). A stand-alone bare-code reader was placed at the site access (see Figure 2-10) to scan workers bar-code labels on their ID cards. Those ID cards were issued to them with information about their names and name of the project they are working on. By scanning bar-code label, data will be entered about their access and leave times and the place where they are going to be working. Material consumption were also controlled by placing the bar-code reader at the entrance of the storage. Data will be entered regarding quantities and the place where they will be used. That was later improved by using a portable bar-code module consists of Psion Organizer II with a microprocessor an, keypad, and RAM for bar-code data reading and storage. Data was entered manually regarding quantities of work executed corresponding to different activities.

### 2.3.2 Radio frequency identification (RFID)

RFID involves the use of miniature read/write transponders that are capable of storing data in harsh environment (Jaselskis et al 1995). It works in a maner similar to bar coding, whereas in RFID data can be stored in tags and retrieved with readers that can communicate with the tags using radio frequency waves instead of light waves as in bar coding. RFID system comprises tags, or transponders, and reader that include an antenna and a scanner. The tag contains a small circuit ship and an antenna that is encapsulated in a protective shell (Jaselskis 2003). There are two types of tags, active and passive tags. Active tags have a battery and more expensive than passive tags that can be charged from the reader. Tags can be read-only or read-write tags, and the read-write tags can be read-many write-once or read-many write-many. The read-only tags are programmed only once and can have memory from 8 to 128 bits (Jaselskis 2003). Examples of RFID tags and readers are shown in Figures 2-11 and 2-12. The cost of RFID depends primarily on the frequency used and on the type of tags, passive or active. Frequencies are divided into low, high, and ultra-high frequencies. Low frequency can be 124 KHz, 125 KHz, or 135 KHz and their range can vary from as low as few centimeters to 0.33 m. High frequency tags use 13.56 MHz and can read from up to 3.3 m. Ultra-high frequency use 860 to 960 MHz and read from a distance that ranges from 3.3 to 100 m (Roberti, 2005). RFID is a new technology and applying it into the construction industry is mainly tied with the high cost associated with the tags and the readers. Passive tags cost between $1.00 and $1.50 each while active tags can cost up to $250 each. Readers generally cost between $200 and $10,000 but generally cost around $4,000 each (Jaselskis et al 2003). The current price is now below those figures. This technology is advancing very rapidly. The following section explores the application of RFID in the construction industry, which is more concentrated in the field of construction material tracking. Some application was done in labor and equipment tracking.

The idea of using RFID lies in positioning fixed scanners on site and when an item passes near the reader its tag will be read to record the movement of that item. Jaselskis et al studied in 1995 the potential of applying RFID to ensure proper delivery, billing, and quality control for concrete. The process, as shown in Figure 2-13, starts when a contractor places an order with a concrete supplier. Contractor would send electronically to a supplier the quantity needed with material specifications. In the concrete plant the supervisor reviews the order and assign trucks and the trucks ID would be associated with the assignment. Trucks has RF tags to record information related to job site location, concrete mix, admixtures time of loading ...etc. With a read/write scanner that is placed at the loading, the scanner would scan the truck tag and transfer information from the plant computer, related to the concrete order, to the tag. When the truck departs, the supplier would send, electronically to the job site, information related to the truck ID, time of departure and mix specifications. When the truck arrives to the job site a scanner that is placed at the entrance would read the truck RFID tag. Information on the tag would be checked with the order placed and also to check the number of revolutions and delivery time with the specifications. When casting concrete, data related to the cylinder test would be associated with the truck ID. RFID tags would be placed on the concrete cylinder with information about casting time and location. When the truck departs, the scanner at the site entrance would read the truck RFID tag and information would be send to the supplier about truck departure time so that he can place another order related to that truck. RFID tags placed on the concrete cylinders would allow tracking their location in the storage area. As cylinders are transported to the lab, the scanner could read the cylinder's RFID tag for information related to the placement location and time. The results could be added to testing reports. Figure 2-14 shows a concrete truck being interrogated by a reader on the construction site.

Jaselskis et al (1995) suggested also that RFID card could be issued to construction workers on site to track their work. At the beginning of a working day, the cards would be scanned to record their arrival time to the job site and their working location. Information related to the cost code would be entered using hand held computers. When the worker enters a tool room, the worker's tag would be read to report the checking out of the tool.

RFID technology can be very successfully applied to control materials within the manufacturing process. An example for this type of application is the work done by Akinci et al (2002). There research was focused on precast concrete suppliers where different types of precast units are stored and has to be supplied to construction sites. Precast units are produced in a greater number that has to be delivered after manufacturing. Suppliers produce more pieces because they know that they have to deliver it in later time. After storing the later needed items, it's possible that when they are needed, it wouldn't be easy to find them and in some cases those items are produced again. Another problem is related to the quality of the item after storing it for a long time and moving it many times.

Information related to the quality of the item, are recorded manually. Applying RFID technology would help suppliers in controlling the precast units storing location and quality. Precast components vary from structural beams to columns, and curved sections. It was reported that a manufacturer's storage area is approximately 60 acres and the average number of precast elements stored at a given production facility is 3,500 pieces at a given time (Akinci et al 2002). After fabricating a precast item, passive R/W tag with unique ID is attached to the piece and information related to production are entered to the tag. A grid of transponders are embedded in the floor of the storage area as shown in Figure 2-15 to facilitate tracking the items movement and location at any time. When a piece passes through those transponders, its tag would be read and the location of the piece would be identified and transmitted to the supplier's material database. When a precast component is needed, it's easy to identify its location through the database and with a hand held RFID reader. Once the item is placed on the truck for transportation, the RFID tag of the truck would be scanned and information related to the precast items to be delivered are entered. The process includes controlling the arrival of the precast units to construction site and final placement of the component.

A similar research had been done by Jaselskis et al (2000) for tracking pipe supports from the time they enter the construction site to the time they are placed on their final location. In that research RFID tags were placed on the pipe supports items and were tracked with a hand held readers.

It was reported that construction materials and installed equipment may account for 50-60% of the total cost of a typical industrial project (Kini 1999). Many researchers explore the potentials to save cost on the tracking of construction materials and among those are Song et al (2006). The objective of their research was to examine the feasibility of applications of RFID technology to automate the tracking of materials on construction projects. Using RFID combined with global positioning system (PGS) technology, it was possible to determining the two-dimensional location of materials. They wanted not only to track the movement of the object with the use of RFID but to find the exact location of that object. Compared to the work done by Akinci et al (2002) explained earlier, the use of GPS would first identify the precise location of material and second there would be no need to install many readers to track the material's movement. A field supervisor or piece of materials handling equipment is equipped with an RFID reader and a GPS receiver, and serves as a "rover." The supervisor walks around the site and the position of the reader at any time is known since the rover _supervisor or materials handling equipment_ is equipped with a GPS receiver.

Goodrum et al (2006) used RFID technology to track tools on construction sites. According to CII (Construction Industry Institute), one of the methods for tool availability on job sites is to overstock the construction sites with hand tools because the cost of labor delays exceeds the cost of the extra tolls available (CII 2001). Goodrum et al developed a prototype tool tracking system to track tools in a mobile environment and to inventory hand tools that may be located in either mobile gang boxes or truck boxes. The research focused on the use of mobile RFID systems (see Figure 2-16). Active RFID tags were used in the prototype tool tracking system and they were equipped with 32 KB of memory. These were chosen based on their long read range, size, and ability to be read through metal under controlled settings. Operation and maintenance (O&M) data for the tagged tools was stored in the memory of the RFID tags. No modifications were made to the tags' antennae, memory chips or processors. A 3.6-V battery powered the active RFID tags with a capacity of 2.1 A h and a life of 5 years at 600 reads per day. The reader for the active RFID tag was employed on a Personal Computer Memory Card International Association (PCMCIA) card, which was installed on a personal data assistant (PDA) with a type II PCMCIA card slot. The Windows CE software on the PDA allowed the researchers to create spreadsheets describing maintenance history and service requirements of the tools to be stored on the active RFID tags. Tags were inserted within the tool handles (see Figure 2-17). Furthermore by installing the tags within the tool casing, they were protected by the casing itself. As shown in Figure 2-17, all of the tagged tools' handles were made of hard plastic.

### 2.3.3 Pen-based or tablet computers

Time is a very important factor when it comes to progress report. It has been reported that project engineers spend about four hours per day collecting data and processing the corresponding paper work (McCullouch et al 1993).

Pen-based computers are tools that support automated data collection. Other names for the pen-based computers are PC notebook, tablet, or slate. Pen-based computers were first introduced about a decade ago (McCullouch et al 1993). They are widely used in the healthcare, transportation, and utilities industry (Rojas et al 1999). They are becoming less costly and more powerfull and suite very much the construction industry (Williams 2003). The burden of move around in a construction site with many drawings and paper can be illuminated with the application of hand held computers. The user can access drawings, specifications, and bill of quantities on the spot without losing the time in going back to the office and looking for a particular document. Figure 2-18 shows an example of a pen-based computer (Fujitsu). This computer (Stylistic ST4121B) is one of the latest developments by Fujitsu electronics. Its capacity is 60 GB hard desk and it has a dimensions of 11.86"(h) x 8.66"(w) x .82-.88"(d). Their portability suit construction fields. Data entry is performed by writing on the screen with a pen, or by selecting the desired option from pop-up lists. With this way there is no need to fill up forms or to remember information and then enter them later into the computer. Data entry is done at the place where they are being collected. Current pen-based computers are operated with windows. Pen-window is an operating system that operates the pen-based computers. There is also the pen-point which is another operating system. They both have the handwriting recognition, which is the main feature in the pen-based computers (McCullouch et al 1993).

Pen-based computers application into the construction industry can be grouped into three categories. In the first category, they are used for inspection purposes in the field. The second is used for resource management and inventory, and the third category as part of a system for progress measurement. The following is a discussion of the application of pen-based computers in the construction industry.

A research was done by McCullouch and Gunn (1993) to design a system that automates the process of data acquisition from construction sites using pen-based computers. The system was designed to acquire information pertinent to material consumption and labor working hours. Three applications were developed to serve as an interface with the user. These applications were developed using a software called EasyTouch (McCulouch et al 1993). The first application was a time keeping application, the second is a material purchase order, and the third is a daily report form. With this software, electronic forms can be designed like the one shown in Figure 2-19 for time keeping where information was entered regarding working hours. After information was recorded in the electronic forms it can be transferred into other software system for further analysis.

Pen-based computer was the main component in designing a road inventory system by Multnomah county, Oregon (Newell 1994). A relational database was designed called Integrated Road Information System (IRIS). IRIS inventories road features and appurtenances such as signs, culverts, and guardrails (Newell 1994). Multnomah County investigated various procedures to automate the inventory process. They began to study the application of pen-based computers in 1991. In IRIS the user can make selections from lists or by checking boxes of described inventoried items simply by touching the screen with the pen.

A field inspection reporting system (FIRS) was developed and tested at the University of Colorado using pen-based computer to facilitate the process of facility inspection in mechanical, electrical, and architectural area's (Rojas et al 1999, 1996). A centralized database was developed to store data collected on site along with multimedia information taken with a digital camera. Figure 2-20 is an example of a FIRS screen, where information can be entered or retrieved through this screen.

Another project was done for bridge inspection for South Carolina department of transportation (Elzarka et al 1997). The automated bridge inspection system (ABIS) was developed using a software development tool called the pad base. Padbase enables developing software applications for the pen-based computers (Elzarka et al 1997). The development language for these applications is "Clipper", which is mainly used to develop dBase programs (Elzarka et al 1997). Inspection forms were designed using Padbase like the one shown in Figure 2-21. The database includes all the bridges within district 3 of the state. The pen-based computer enabled displaying forms needed to enter data related to a particular item.

An automated model for data acquisition was developed by Thabet (1997), which integrated a CAD model, where project drawings are stored, with the pen-based computer. An object-oriented database was designed to relate electronic forms, used with pen-based computer, with the drawing of each activity. A graphical object of CAD drawing will be called on the screen of the pen-based computer along with corresponding data form where information can be modified to represent current progress for each activity.

### 2.3.4 LADAR (Laser Distance and Ranging)

LADAR is a 3D laser scanner that is mainly used for spatial measurement. Other applications include surveying, earth moving operations, progress of concrete casting, highway alignment, paving operations and construction quality control (Gheok et al 1999). LADAR scanning yields the collection of 3D points or "point clouds" that are later displayed using software packages in useful images. Those images can be viewed at different angles (Witzgall et al 2004, 2006, Du et al 2007). Laser scanners can capture up to 2,000 data points per second (Jaselskis et al. 2005). Other scanners available like the Leica ScanStation 2 can capture up to 50,000 points per second. Figure 2-22 is a picture of a construction site and Figure 2-23 provide an example of scanning this construction site, which is a set of point cloud. The data points are given in *x, y, z,* coordinates. The concept of the LADAR technology works by sending illumination pulse to an object where the distance between that object and the LADAR called the "Range". The laser beam traverses a distance equal to 2d. The time needed to accomplish this operation can be expressed by the following Equation:

$$T = 2d/c$$

Where "c" is the speed of light and "T" is called "time of flight". It was reported that a clock time of 1ns represent a 300 mm round-trip flight or an absolute range "d" of 150 mm (Stone et al 2002). Every pulse will produce a pixel or a point in a point cloud that represent a range image. The limitations in applying LADAR are the long time required to do each scan and the high cost associated with the equipment. To have the best result, many scans should be taken from different locations to avoid objects that lie between the scanner and the range. A LPM 100 VHS LADAR scanner is illustrated Figure 2-24 from the company RIEGL.

As mention earlier, applying LADAR in the construction industry is tied manly with its high cost. Endeavors have been made to integrate this technology into construction. Of those endeavors is the project done by Cheok et al (2000) under the National Institute of Standards and Technology (NIST) to utilize LADAR for excavation measurement. To track changes made in terrain, scanned data (point cloud) were taken from two different locations at the end of a working day that involve new excavation. As mentioned earlier, taking different scans is essential for the accuracy and to avoid any obstacle could lie between the scanner and the scanned object. Photo images were taken with each scan. The terrain was first scanned from 5 different positions to obtain the initial reference surface. The surface was created from a combined point cloud from seven different scans (at two positions two sans were obtained from each position). After an excavation day, another surface was created and the volume between the two surfaces was calculated, which represent the excavated volume. Figure 2-25 provides an example of a surface model before and after excavation.

The research conducted by Su et al (2006) provide a good example for one of the major limitation of the laser scanning technology, namely the time required to scan an object to get enough information for later processing these information. Their work was focused on scanning construction at an urban excavation site in the Chicago metro area to acquire information about excavation geometry throughout construction to address issues related to geotechnical engineering, structures, and construction management. Issues include the actual volume excavated over a given period in order to assess pay items, excavated surface geometry, configuration of installed supports, and their relationship to measured movements using other instrumentation such as inclinometers and surface settlement points. A Cyrax 2500 laser scanner with a laptop with the Cyclone software (Leica GeoSystems) connected to scanner via a network crossover cable was utilized for scanning. The scanner was equipped with a built-in digital camera to capture the scan area before scanning and the operator can select a desired scanning area of any rectangular size based on this image. The density of the scan can be adjusted to get an image with 25 mm minimum point-to-point spacing at a distance of 50 m. The highest point resolution of the scanner is 1 million points with 1,000 points in both horizontal and vertical directions. The maximum resolution that can be obtained in a single scan is 1000 x 1000 points in a view field of 40° x 40°. A single scan with a 1 million-point resolution takes about 15 min to acquire. The intensity of the point could image is affected by the surface material, the angle of incidence, and the distance of the object surface to the scanner.

Table 2-3 Summary of Scan Sessions at Ford Center Excavation

| *Scan session* | *Date* | *Number of scans* | *Average daytime temperature (°C)* | *Weather condition* |
|---|---|---|---|---|
| 1 | January 30, 2004 | 8 | -17.0 | Sunny |
| 2 | February 4, 2004 | 14 | -6.5 | Sunny |
| 3 | February 11, 2004 | 17 | -4.0 | Cloudy |
| 4 | February 18, 2004 | 17 | -1.5 | Cloudy |
| 5 | February 27, 2004 | 16 | 2.5 | Sunny |
| 6 | March 3, 2004 | 11 | 5.5 | Cloudy |
| 7 | March 12, 2004 | 16 | -4.5 | Cloudy |
| 8 | March 26, 2004 | 15 | 13.0 | Sunny |
| 9 | April 2, 2004 | 15 | 7.0 | Sunny |
| 10 | April 9, 2004 | 17 | 7.0 | Sunny |
| 11 | April 14, 2004 | 14 | 9.0 | Sunny |
| 12 | May 3, 2004 | 8 | 5.5 | Cloudy |
| 13 | May 7, 2004 | 8 | 10.5 | Sunny |

The researchers indicated in their work that a single scan is insufficient for generating a three-dimensional model of an entire excavation which highlight the main limitation of the laser scanning technology and multiple scans at different locations must be conducted to capture the entire site. Scans must be overlapped to stitch individual scans together and form a complete 3D image of the site. A six-story building (two underground) was considered for the scanning activity. The floor area is 25,600 m2. and an approximate dimension of 44.4 m x 36.6 m and a maximum depth of 8 m below ground surface. The laser scanner was utilized weekly to perform 3D scanning. Scanning locations were chosen to provide views that are as unobstructed and as clear as possible while at the same time the scanner should be positioned in safe and nonconflicting areas so as not to interfere with ongoing construction. Figure 2-26 shows the main scanning position areas near the four corners of the excavation site and outside the excavated area. The four corners were adopted because they minimally interfered with the workflow, provided more personnel safety. A total of 13 scan sessions were conducted during a 4-month excavation period. Table 2-3 shows the scanning dates and the number of single scans in each scan session. The number of scans needed to cover the whole site varies between 8 and 17 for a single scan session. If the scanning time for one scan is 15 min then from the table it should take 2 hours in the case of the 8 scans and about 4 hours for the 17 scans this is excluding the setting up time between scans. This shows how time consuming the scanning process is to get better results.

LADAR was also utilized in a similar research project for the representation of construction sites. Works had been done in this area by Chaeok et al (1999) and Shih (2000). The concept was to scan the whole construction site and represent it in a model that could help in quantity surveying calculations as in cut and fill operations (see Figure 2-27)

Shih et al developed an internet-based three 3D scan information management system (3DSIMS) that can be used as an interface to input, display, and inspect design as-built construction information. The function of the 3DSIMS is to integrate the scan data collected before, during, and after a scan scheme that is designed to capture as-built 3D records. A long-range 3D laser scanner, *CYRAX* 2500 was used and *CYCLONE* software, as a survey device for continuous data retrieval. Measurements made to point clouds were used to check if any unexpected displacement or deformation occurred to construction members for vertical, longitude, or horizontal movement. Figure 2-28 depicts the gradual change over a period of time. Figure 2-29 shows a cloud and a corresponding foundation drawing placed together in the system. All related drawings, which are mainly in AutoCAD DWG format, are also included in that view.

Using only 3D scanning would not locate the global coordinate of an object and it requires the use of GPS to do so. Du et al (2007) introduced a method to integrate laser scanning and global position system (GPS) to acquire landslide data and to compute earthwork volume. GPS is used to obtain global geographic coordinates of the object to be scanned. Modeling 3D scanned images is suitable to compute earthwork volume in a danger-zone construction site such as debris flow and landslide area. One of the drawbacks of 3D laser scanning is that it just samples the earth's surface in some fixed pattern and it is not capable of pointing to particular objects or object features directly in exact global orientation (Ackermann 1999). Thus, to obtain the real geographic coordinates in this study, a GPS is introduced for this purpose. The procedure of this project is that the scanner is set up in front of landslide to scan the surface of landslide and the GPS assigned A1, A2, A3 and A4 as control points as shown in Figure 2-30. The volume of the landslide is then calculated using the scanned images

### 2.3.5 Photogrammetry

Photogrammetry is the extraction of geometrical properties of an object from photo images. The availability of high quality and precise still image cameras advanced the 3D modeling from photo images (Styliadis 2007). The process works by first placing targets on the objects needed to be photographed and identify the coordinates of those targets (see Figure 2-31). Several photo images of that object are then taken from different positions and angles. Nowadays there is an increasing demand for full three-dimensional data collection for planning, architecture, environmental analysis, tourism etc. (Shashi 2007). The advantage of photo images that it can extract information pertinent to object texture and color, which makes it better than laser scanning.

### 2.3.6 Multimedia

Information can be collected in the form of digital photographs, video clips, or sound and stored into the computer. In the reporting period multimedia information are very useful, in view of their visualization capabilities. Pictures and videos are important information tools and highlight problem areas (Tsai et al 2007, Abudayyeh 1995, 1996, Liu et al 1995). Pictorial information (pictures and videos) are captured on site and stored in a digital format. Collecting this data is performed with a video camera with time-laps capability (Everett et al 1998). Time-laps allow viewing long operations in short time. This happens by taking shots at selected time intervals and plays them back in a compressed form. Very big operations that have duration of months can, thus, be viewed in hours. Figure

2-32 illustrates the concept of recording in time-lapse mode (Everett et al 1998). This information, along with pictures and sound records, are stored in a data base model.

Multimedia information system refers to information systems that are capable of storing and displaying multiple media types, such as text, pictures, videos, and sound (Liu 1995). Researchers especially to support areas like as-built information, claim management, and inspection tested applying multimedia technology into the construction industry.

Photogrammetry is well used to represent historical buildings. Styliadis (2007) proposed a model for digital documentation with a 3D modeling functionality. The model was done for historical building representation the system layout is shown in Figure 2-33.

Abeid et al (2003) introduced an automated real-time monitoring system (PHOTO-NET II) for construction projects programmed in a Delphi environment. It accepts digital images taken from multiple cameras, stores them in chronological order and links them to a database that contains schedule information. The digital pictures taken from up to four cameras are placed on a website from where a remote computer(s) can capture and store the pictures in the database. The system layout is illustrated in Figure 2-34.

A multimedia project control and documentation system (MULTROL) was developed at the university of Illinois at Urbana-Champaign and USA-CERL (U.S. Army Corps of Engineers Construction Engineering Research Laboratory)

(Liu 1995). This system enables users to store and retrieve data in form of text, sound, image, and videos. This data was used later in the preparation of as-built information. With MULTROL, information are collected from site in form of text, sound, image and videos then stored, and attached to related project activities. MULTROL uses pop-up windows (see Figure 2-35). The main window has four boxes. The user can display an activity on one window and any information in form of multimedia format will be listed in the other boxes along with activity information. By clicking on any file like the sound file, the user will listen to comments that were recorded on site regarding problem areas. The user can also display an image or video file at the same time (see Figure 2-36).

Another system was developed called M-LOG (Liu et al 1995) that was similar to the previous one and had the job of storing and retrieving as-built information. Construction log reports document project information regarding weather, work accomplishment, resources on site including labor, equipment, and materials. They also document any events such as accidents or problems occurred during construction. M-LOG operates with a portable PC-486 with pen-based data input capability (Liu et al 1995). A M-LOG hardware is shown in Figure 2-37 where a digital camera is connected to the pen-based computer through a serial connection to transfer the digital images to the computer. The user will then store images into the database along with other information related to each activity on construction site. In the last two examples, multimedia was used to collect and store data needed for as-built information.

Contractors and owners tend to record almost everything in case they could be sued someday and the result is piles of documents (Liu 1995). Abudayyeh (1996) have developed an information management model that takes advantage of multimedia data to support decision making in delay and claim situations. To develop this model, data items, needed for that system, were first identified by specifying reasons of delay. Reasons of delay include, differing site conditions, interference by the owner with the contractor's work, weather-related delays or others. A conceptual data model was developed using NIAM (Nijssen's Information Analysis Technology). NIAM provides a conceptual schema design that can be mapped onto any database (Rasdorf et al 1992). After developing the conceptual modeling, a computational modeling that transforms the NIAM data model to a relational database were developed. In the last step of that system, the computer modeling develops an automated computer system solution to the problem (Abudayyeh 1996). The model was composed of a video camera, a microphone, a sound card and a 486-based workstation. The video camera had time-laps capabilities to allow displaying long operation in shorter time. Multimedia data is captured and stored into the database in a digital format. Video scene can be captured in a sequence of frames (video clip) or individual image (still picture) (Abudayyeh 1996). The Access relational database management system software was used for implementing that system. The system architecture that was designed to support delay management is shown in Figure 2-38.

Liu (1995) developed a digital data-collection device to support construction site documentation. This device is called the HardHat and contains an electronic notepad, microphone, headsets, video camera, and a heads-up display to transmit, receive or store multimedia data including text, audio, images, and videos. It uses a voice-activated control to allow users to walk hands-free while documenting site conditions (Liu 1995). Text input is performed with a pen-based computer. The digital HardHat allows communication in real-time between the operator and the local/remote experts as shown in Figure 2-39 to quickly solve construction problems. Figure 2-40 shows what the operator sees in the heads-up display.

Multimedia was also used by Rüppel (1995) for technical supervision of building. A system named "BestandManager" was developed for that purpose. The database of "BestandManager" is a catalogue of building components with associated methods for supervision, examination and documentation. For each construction element, there exist typical failures stored as pictures, and also typical examination methods that guide the inspector through examination. The system provides a decision support for possible reasons of failure (Rüppel 1995). Figure 2-41 illustrates two details of a typical failure from the failure multimedia catalogue and the advice to rehabilitate this failure from the multimedia catalogue of "BestandManager".

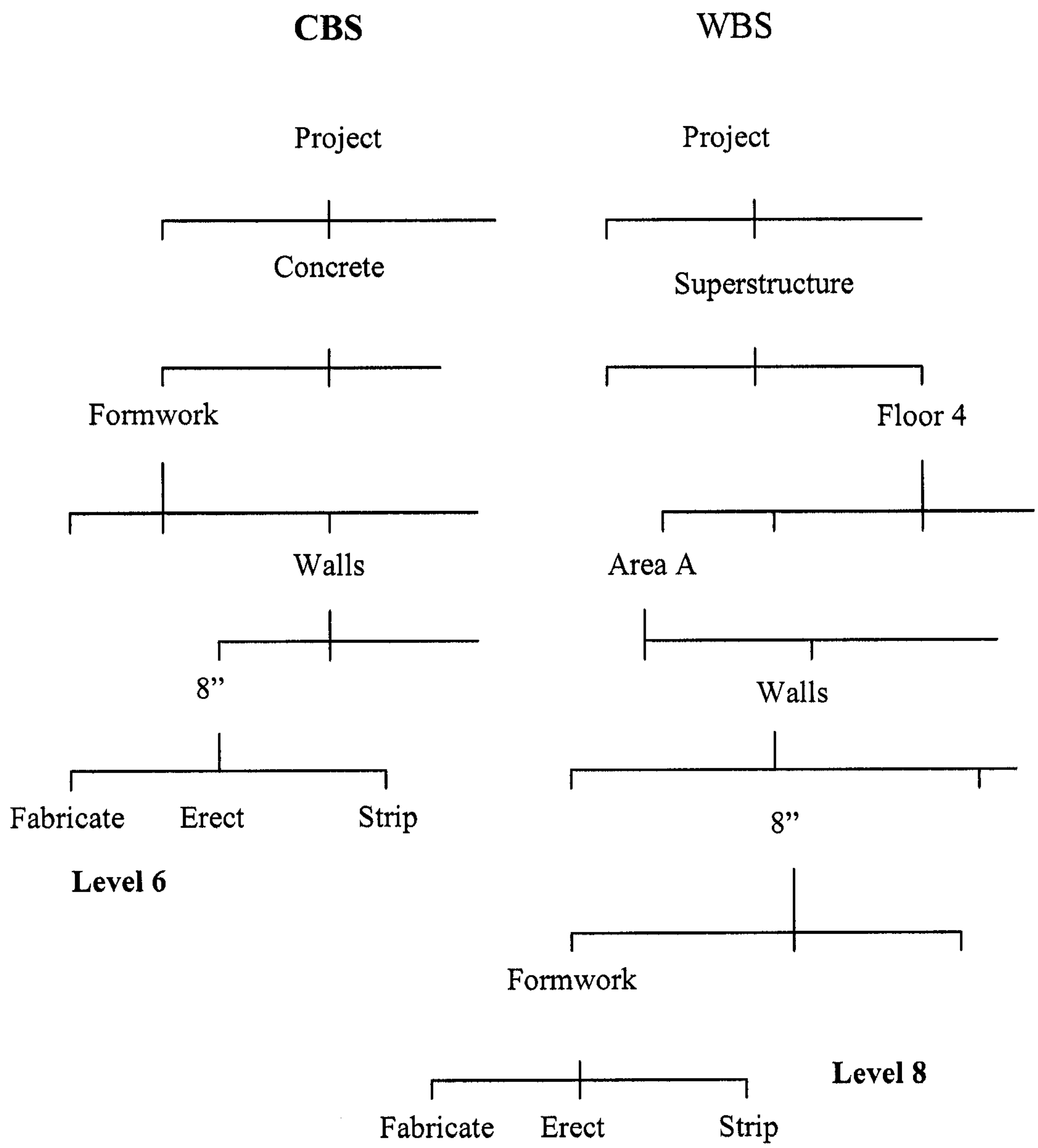



Figure 2-1 Difference in level of detail between CBS and WBS(Abudayyeh 1991)

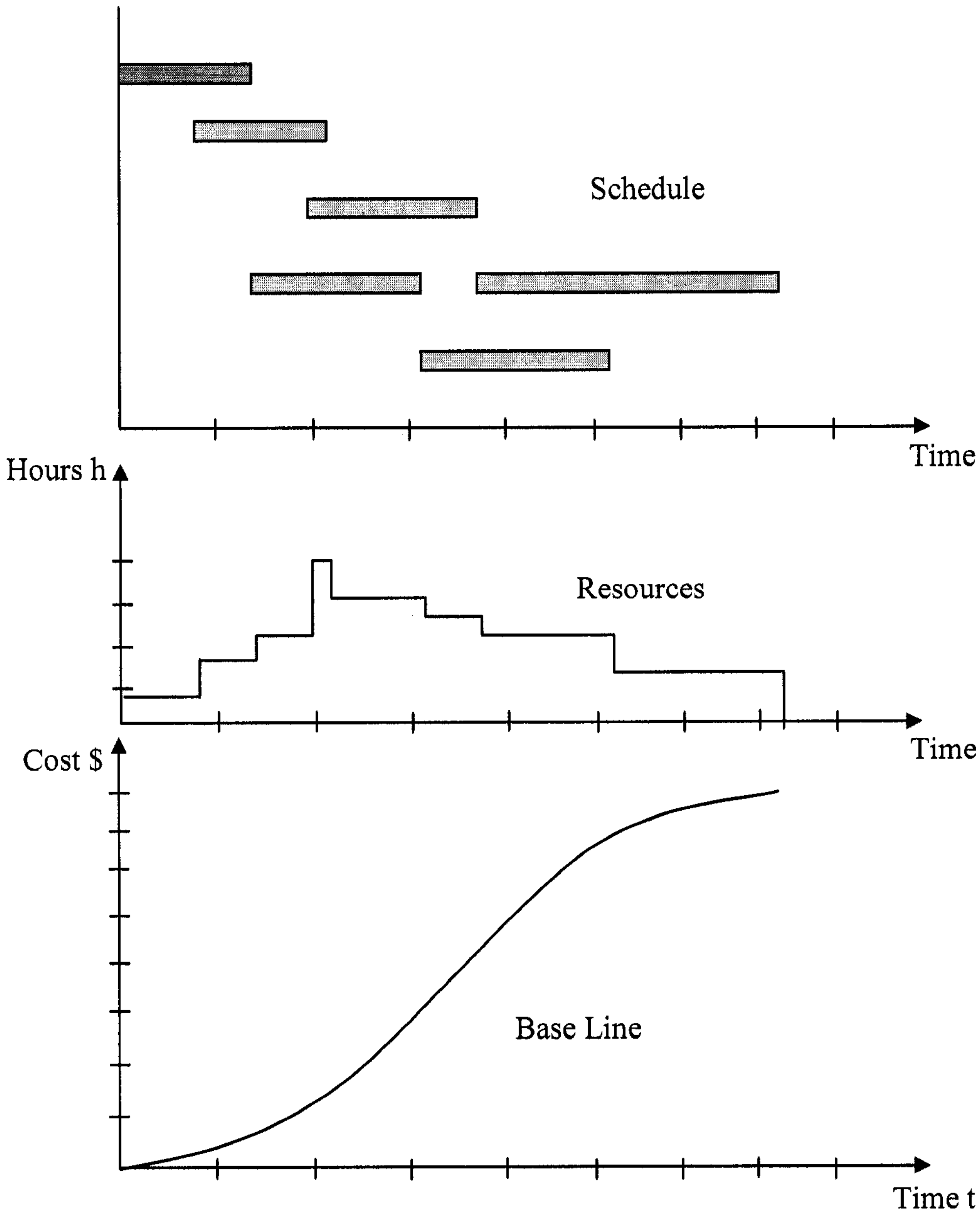



Figure 2-2 Base line generation (Moselhi 1993)

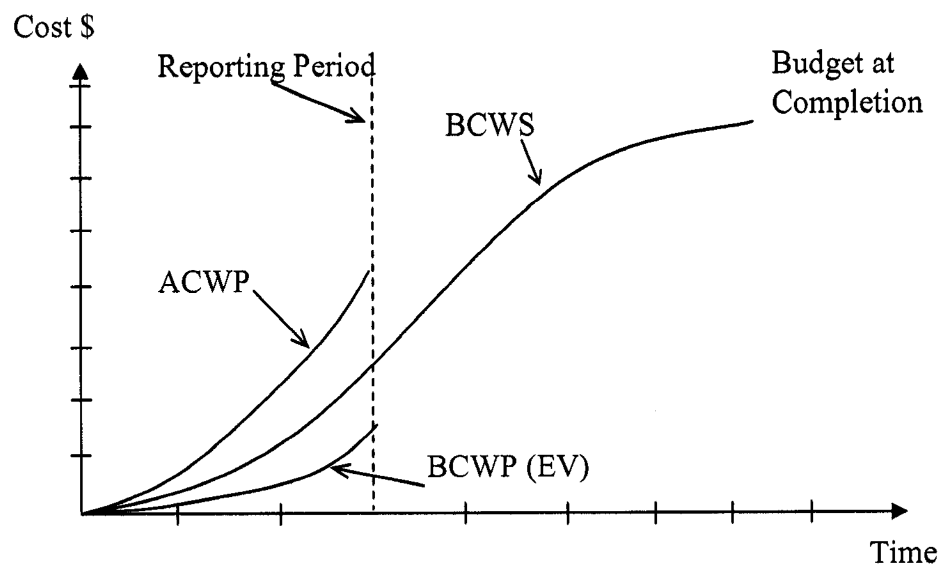



Figure 2-3 Project performance (Moselhi 1993)

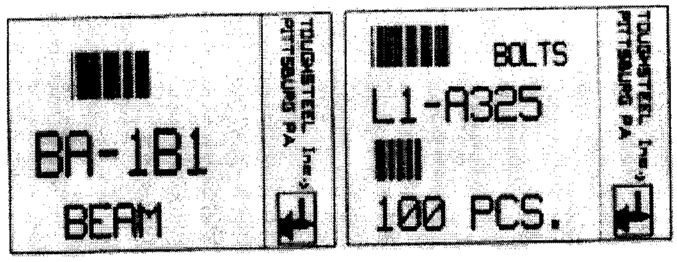



Figure 2-4 Bar-code label for structure steel beam and bolts (Rasdorf et al. 1990)

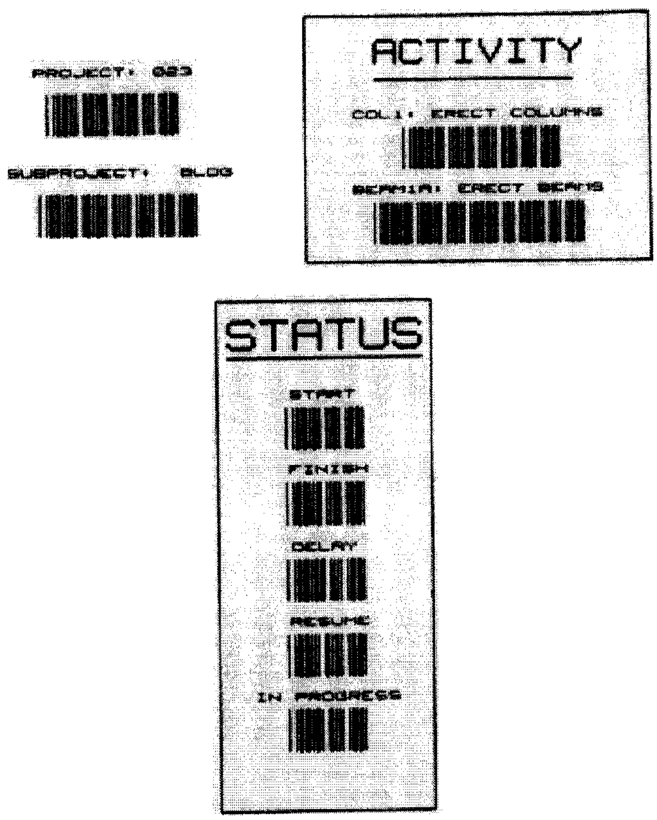



Figure 2-5 Bar code for an activity in an activity sheet (Rasdorf et al. 1990)

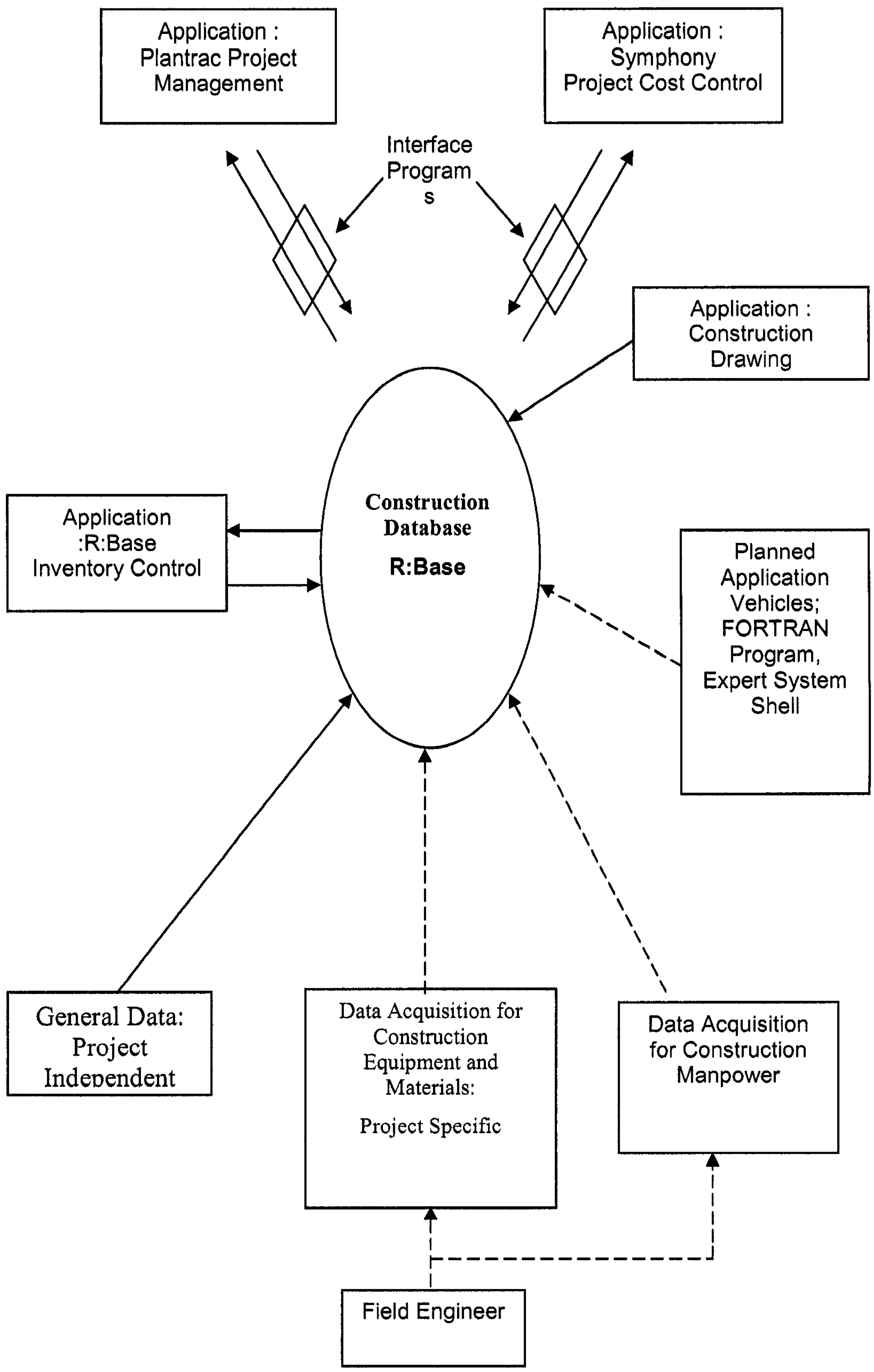



Figure 2-6 CIMS architecture (Rasdorf et al.1990)

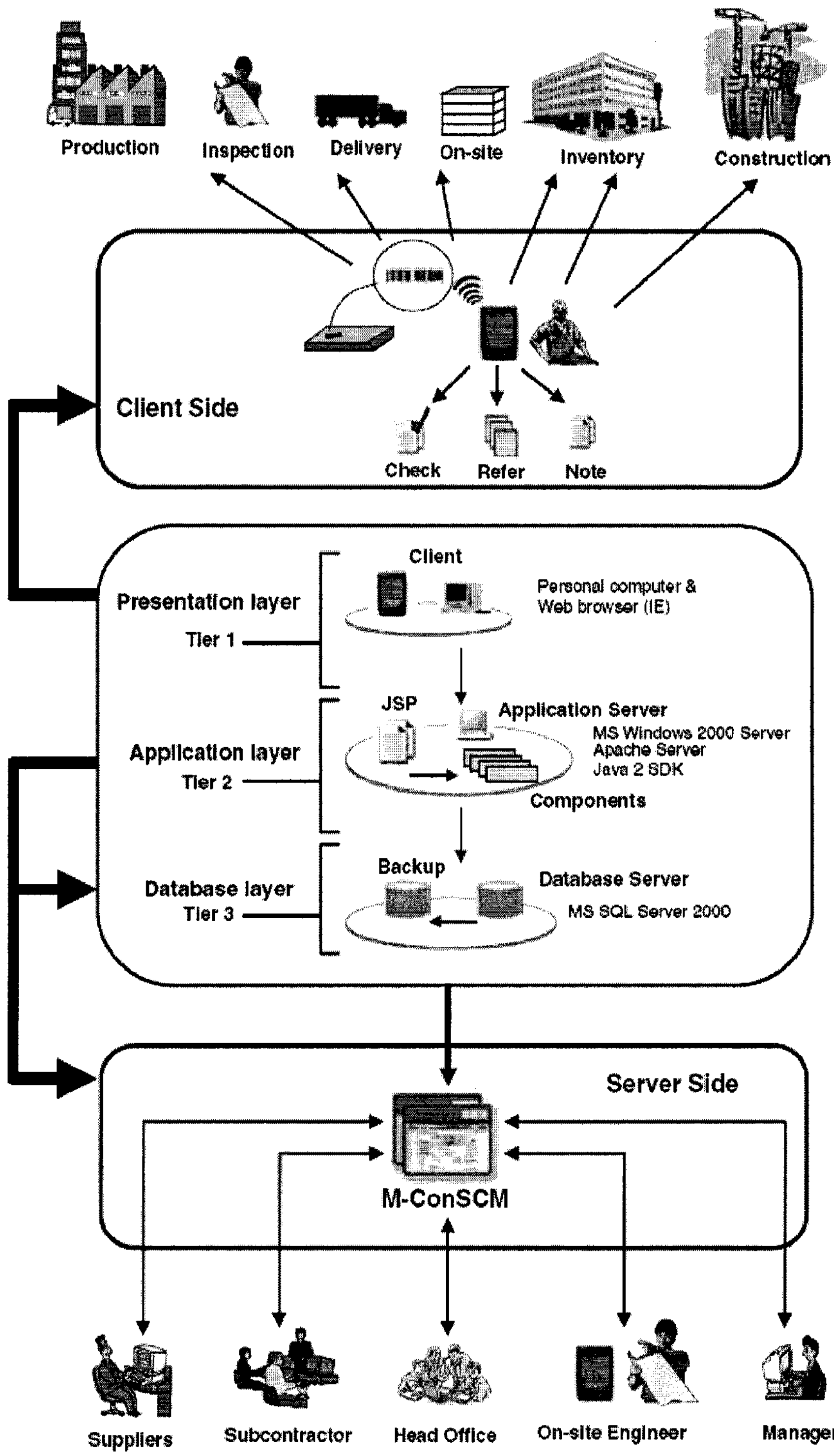



Figure 2-7 M-ConSCM system framework overview.(Tserng et al 2005)

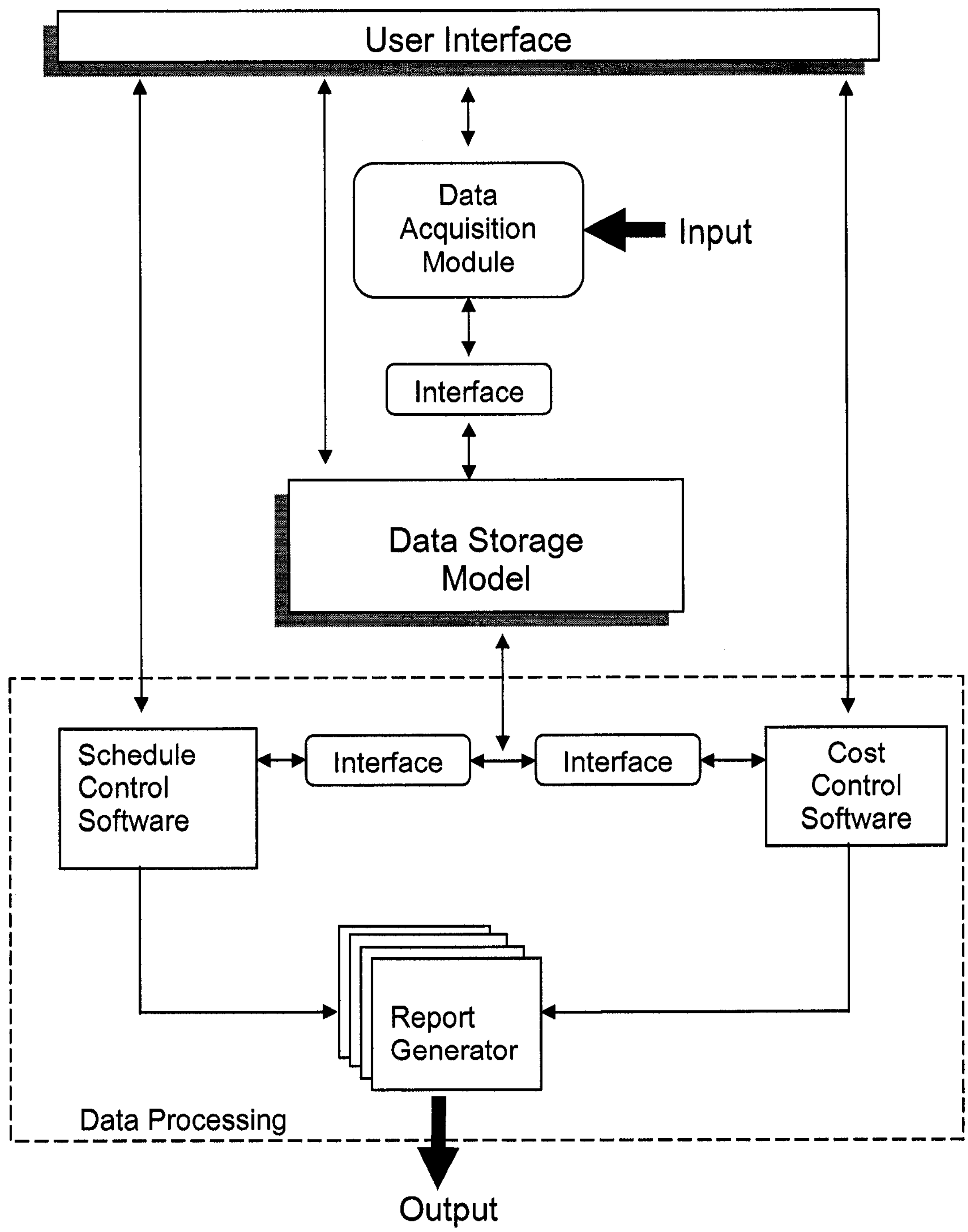



Figure 2-8 Conceptual system architecture (Abudayyeh 1991)

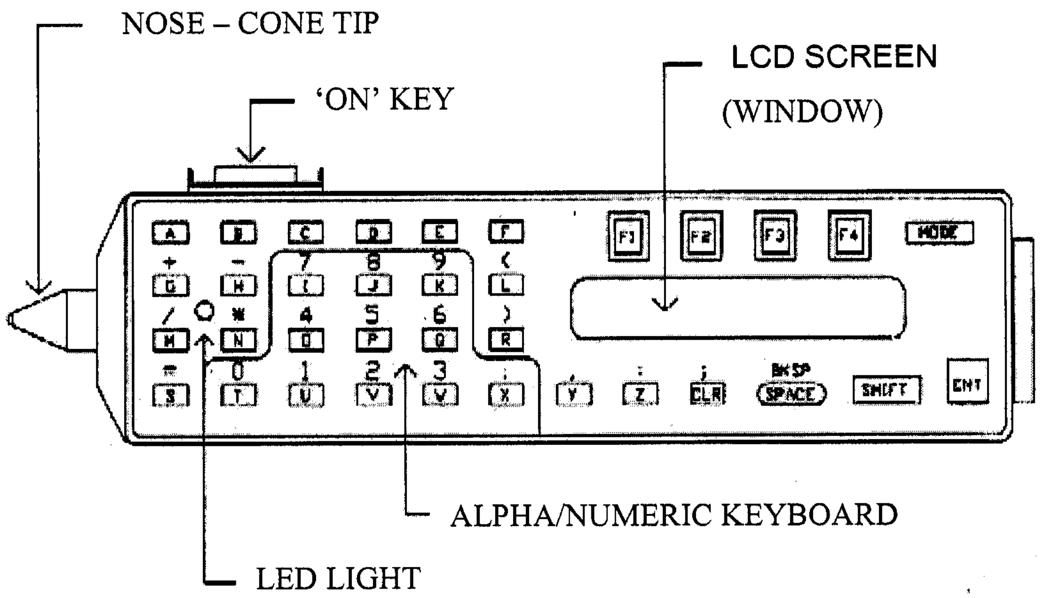


Figure 2-9 Bar code reader (Flickinger 1995)

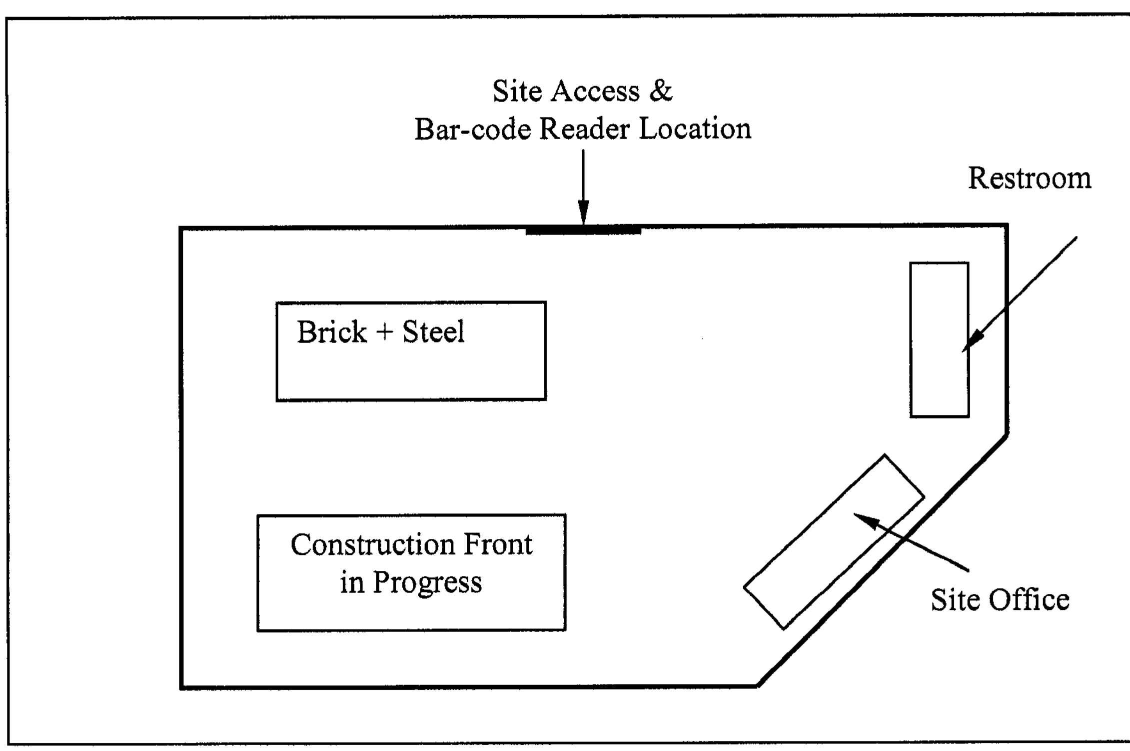
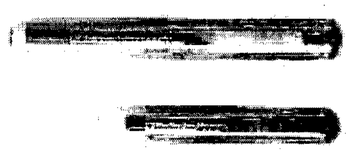



Figure 2-10 Lay out of a test site.(Echeverry 1996)



Small size, high robustness 100% waterproof used under extreme environmental conditions.

Read range upto 100cm for 3.85mm x 32mm tag

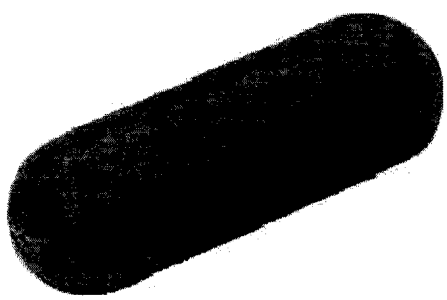
Read range upto 60cm for 3.85mm x 23mm tag

### Compact Wedge

Plastic encapsulation, very compact Robust, notch for secondary packaging.

Read range upto 20cm   Size 12mm x 6mm x 3mm

### Bulkhead Style



Designed for mounting on metal surfaces suitable for rugged outdoor environments

Read range upto 120cm

Size 102mm x 36mm x16mm

### Vehicle Style

Durable tag with enhanced read range, packaged to withstand harsh environments to allow it to be attached by means of non-metallic posts to trucks and containers.

Read range upto 200cm

Size 121mm x 21mm

Figure 2-11 Examples of RFID tags (www.rf-id.com)

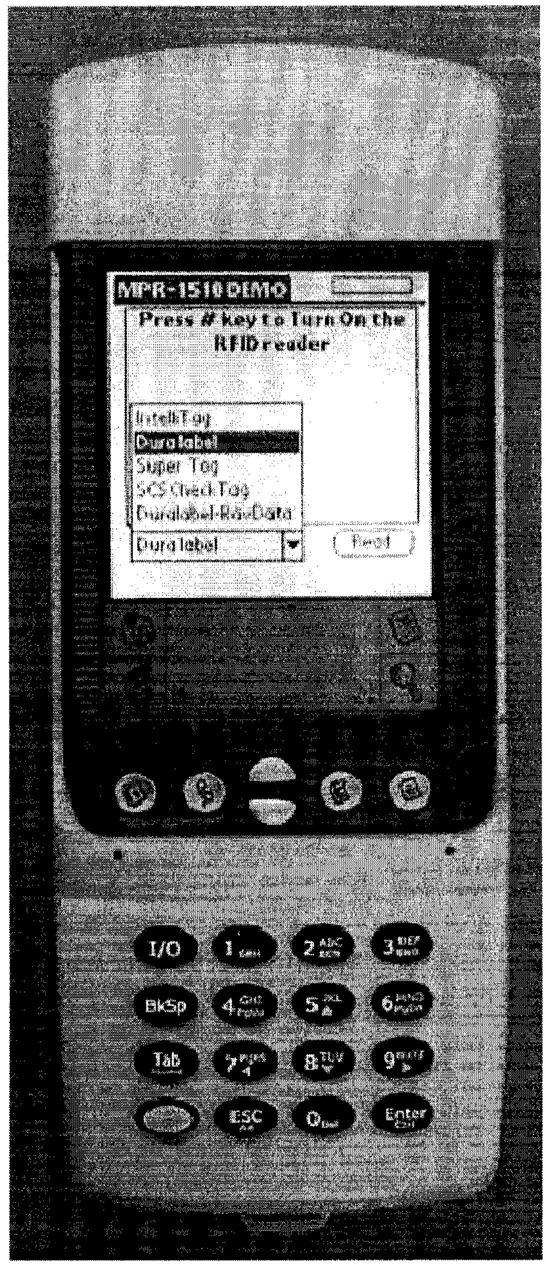



Figure 2-12 RFID Hand Held Reader (www.rf-id.com)

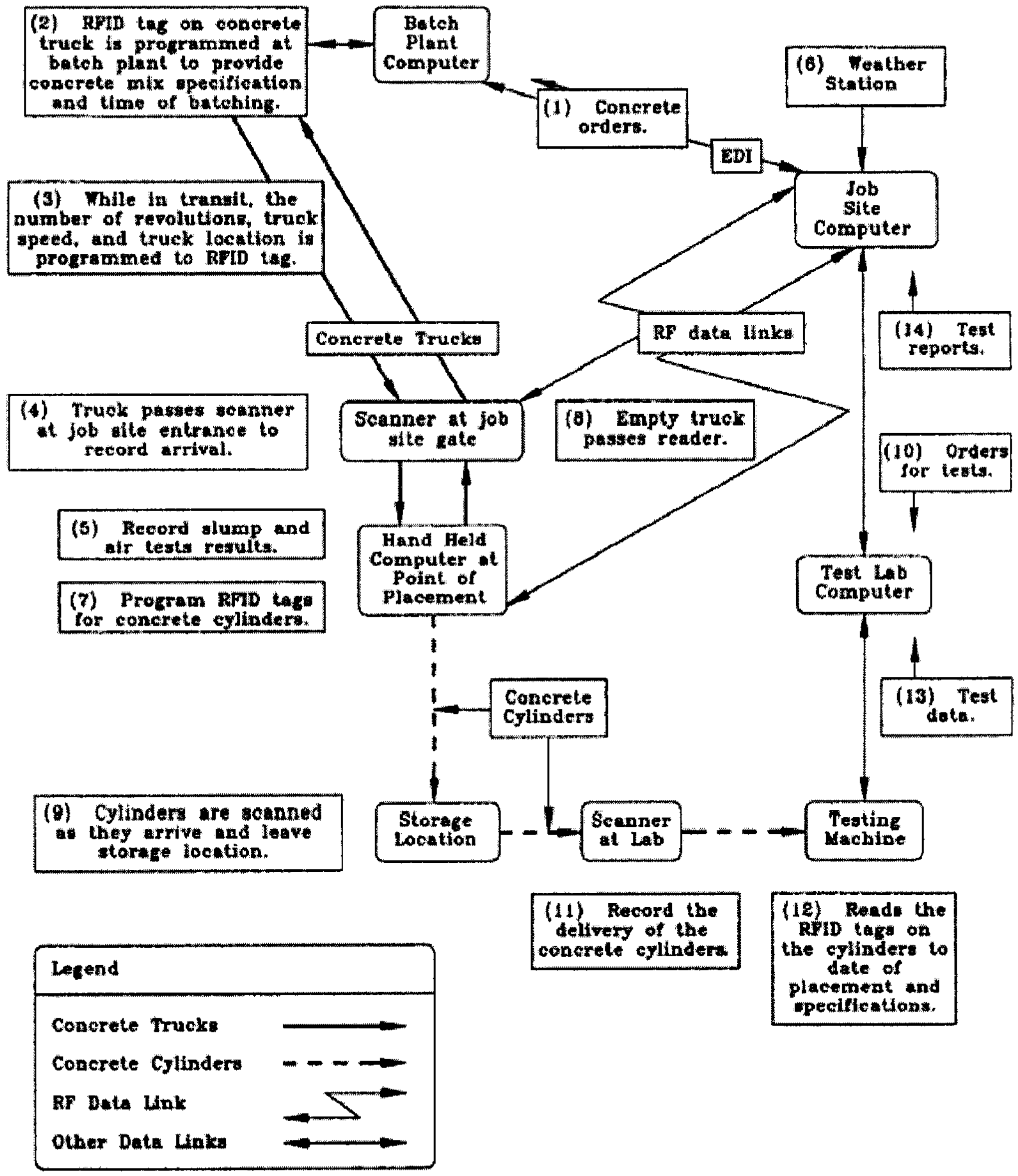



Figure 2-13 Concrete Operation Using RFID (Jaselskis et al. 1995)

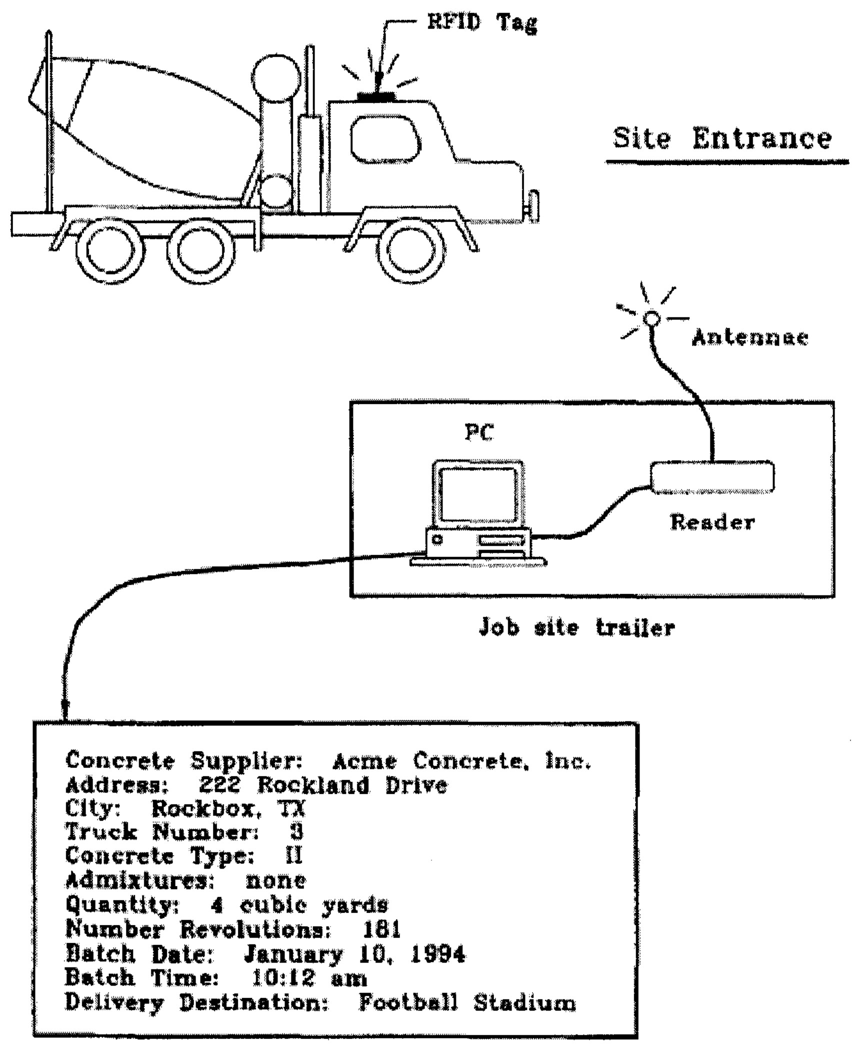



Figure 2-14 Concrete Truck Interrogated by RFID Reader (Jaselskis et al 1995)

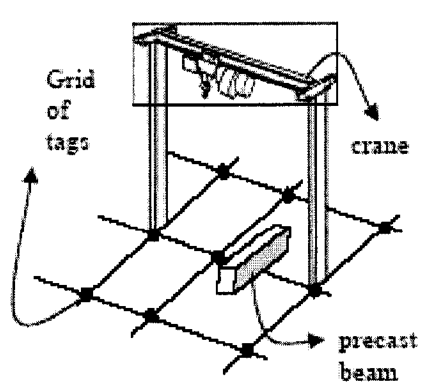



Figure 2-15 Grid of transponders in the storage area (Akinci et al 2002)

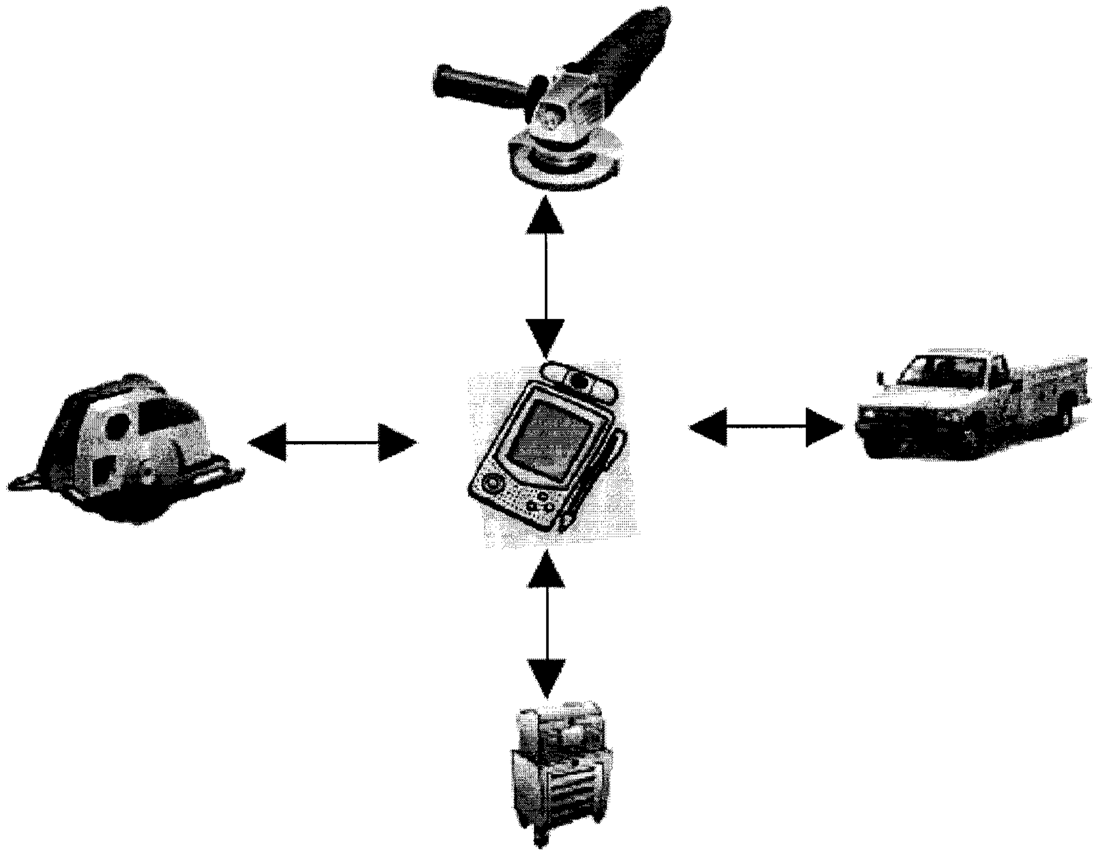


Figure 2-16 Mobile RFID tool inventory system (Goodrum et al 2006)

Figure 2-17 Tag installation within tool casings (Goodrum et al 2006)


Figure 2-18 Pen-Based computer (Fujitsu Stylistic ST4121B)

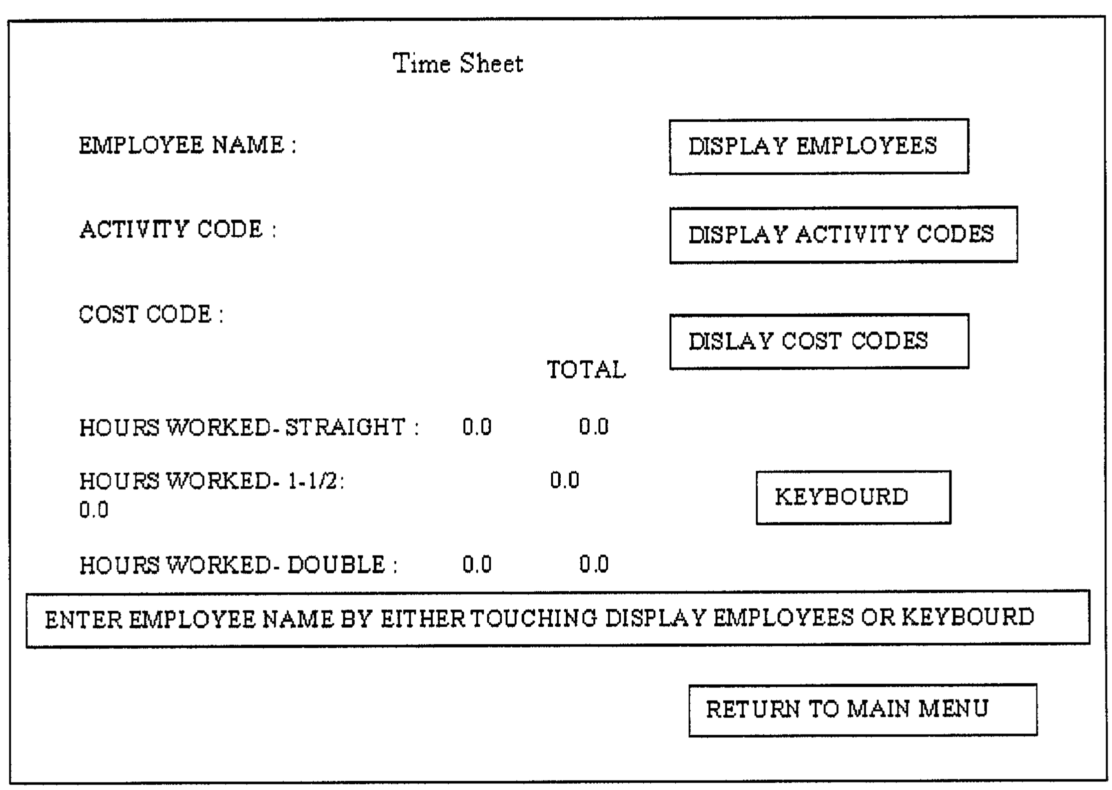



Figure 2-19 Time sheet form (McCulouch et al. 1993)

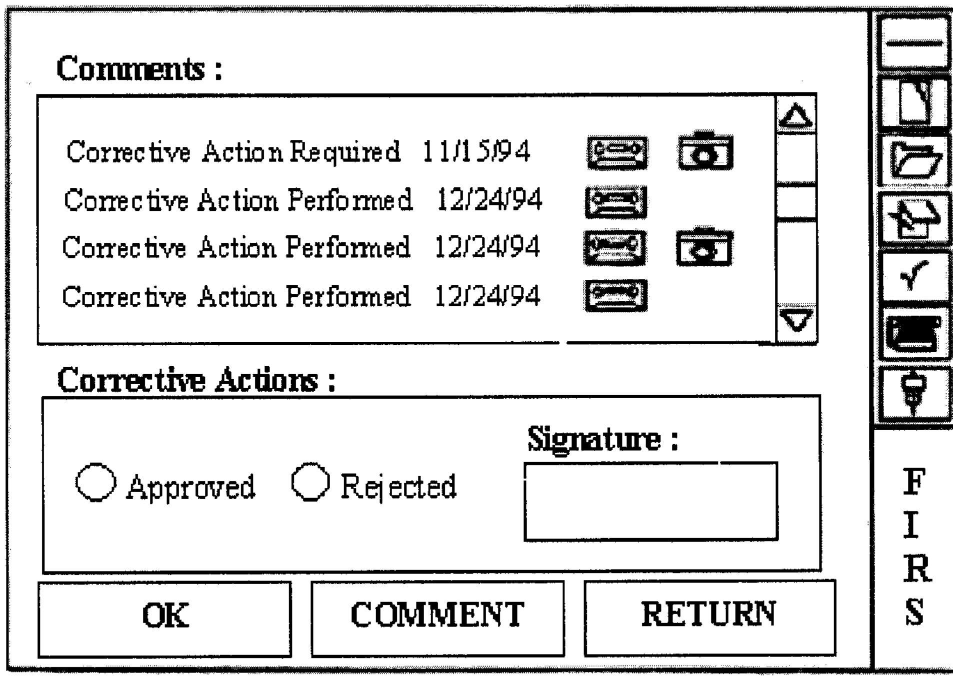



Figure 2-20 Item's status screen (Rojas et al. 1996)

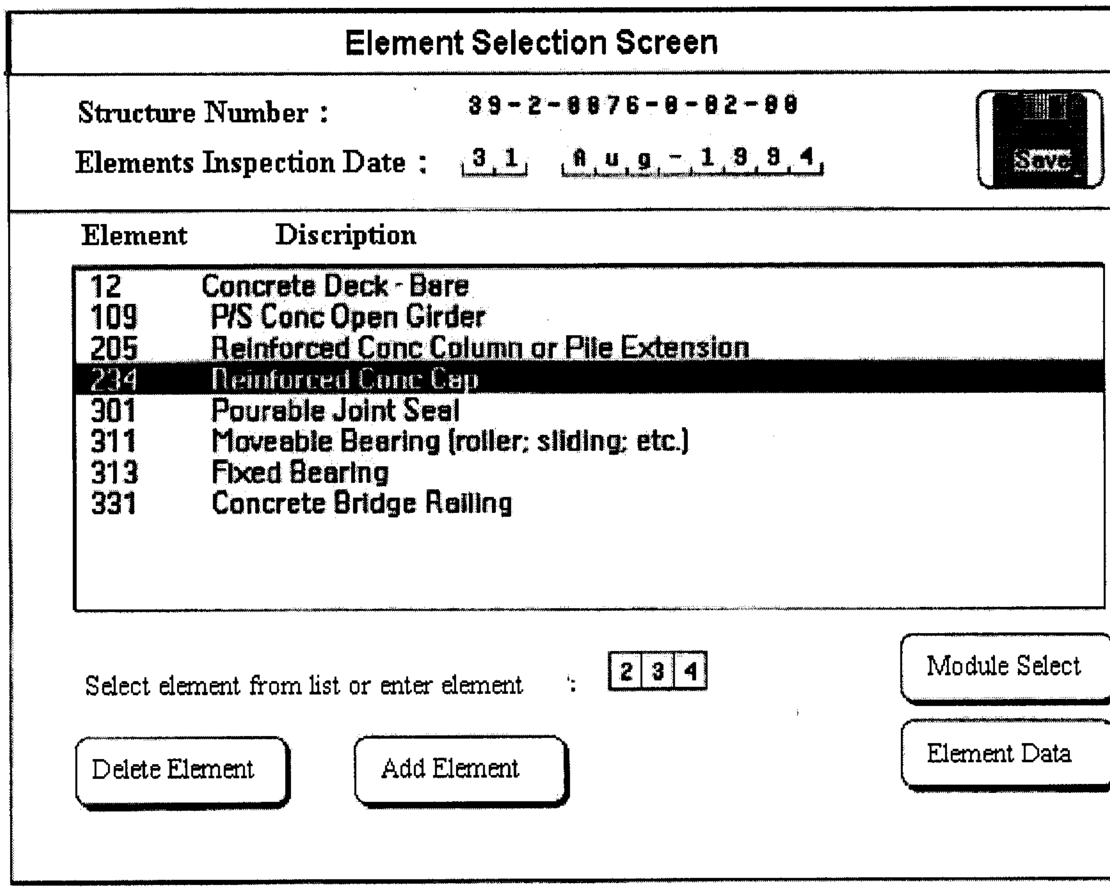



Figure 2-21 Form for element selection (Elzarka et al. 1997)

Figure 2-22 Initial terrain of construction site (Cheok et al 2000)

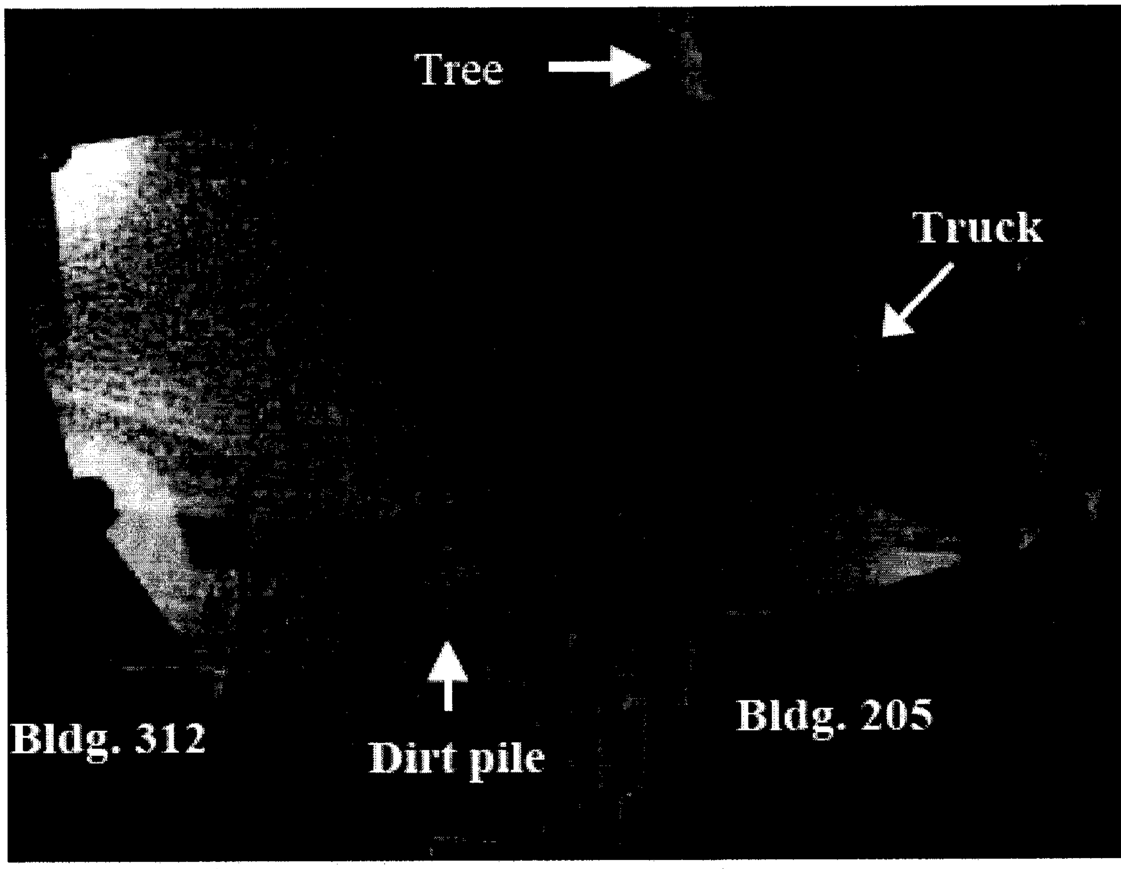
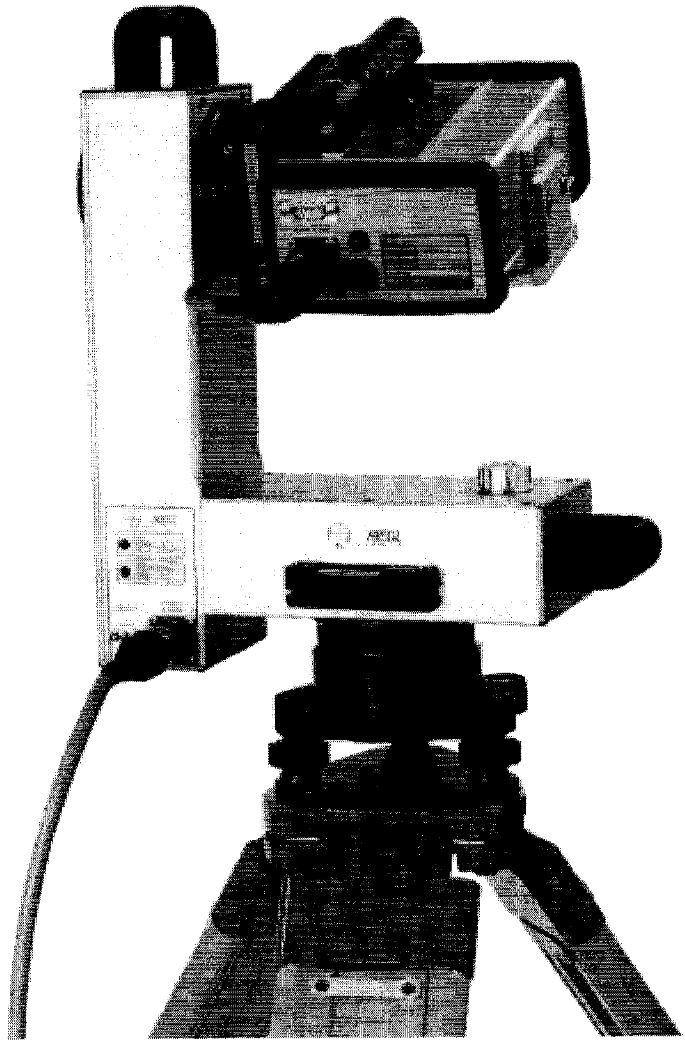
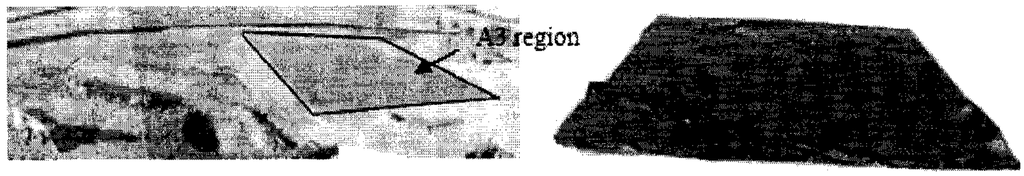



Figure 2-23 Point cloud of initial terrain produced by a LADAR equipment (Cheok et al 2000)

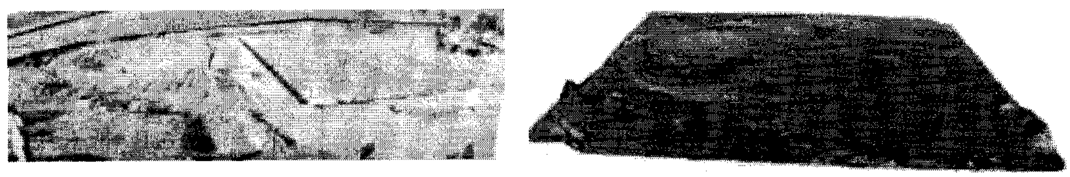


| | |
|---|---|
| Measurement range [1] | 2 m up to 200 m (diffusely reflecting targets) |
| Measurement accuracy [2] | ± 2 cm |
| Measuring rate | Up to 1000 Hz |
| Measurement resolution | 25 mm |
| Telescope | Magnification 1.5 - 4 x 16 (zoom telescope) |
| Laser wavelength | 0.9 µm (near infrared) |
| Beam divergence [3] | 3 mrad x 0.5 mra |

Figure 2-24 LADAR scanner LPM-100/300 VHS from RIEGL (www.riegl.com/scanner_menu_all.htm)




a. March 7, 2000



b. March 9, 2000

Figure 2-25 Terrain and Surface model for area before and after excavation (Cheok et al 2000)

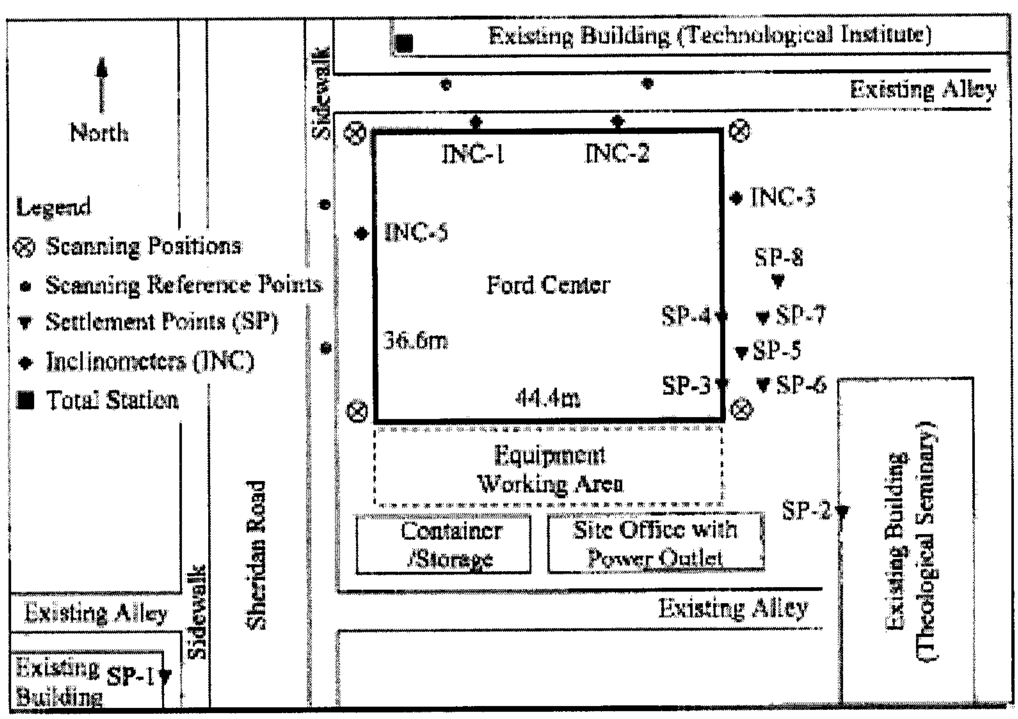



Figure 2-26 Scanning and surveying site layout (Su et al 2006)

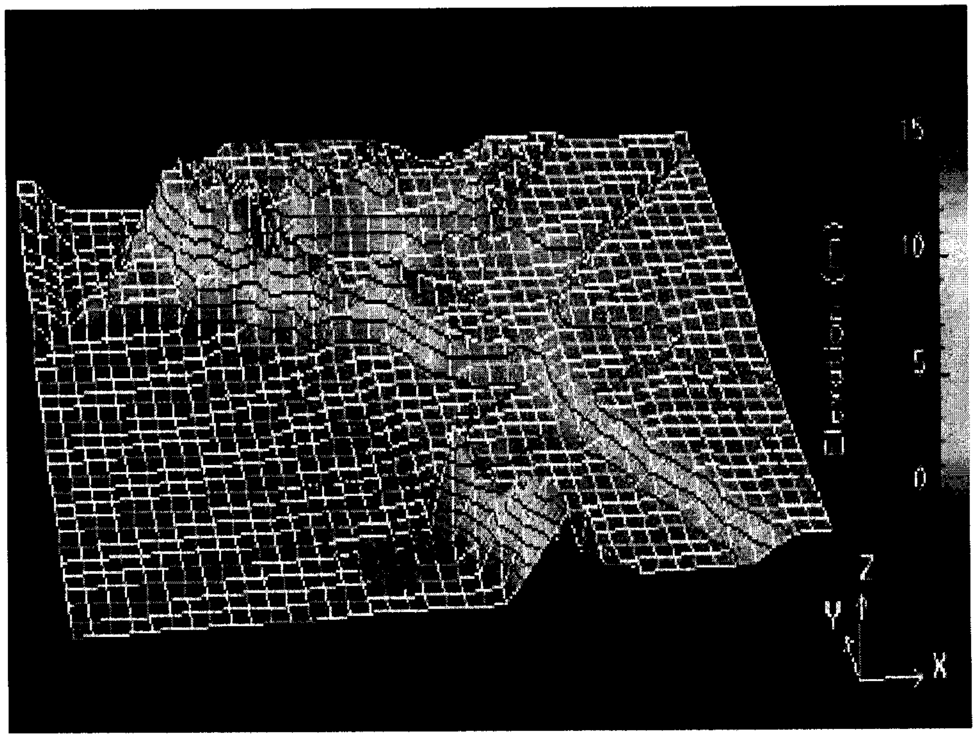



Figure 2-27 Meshed surface of scanned terrain (Cheok et al 1999)

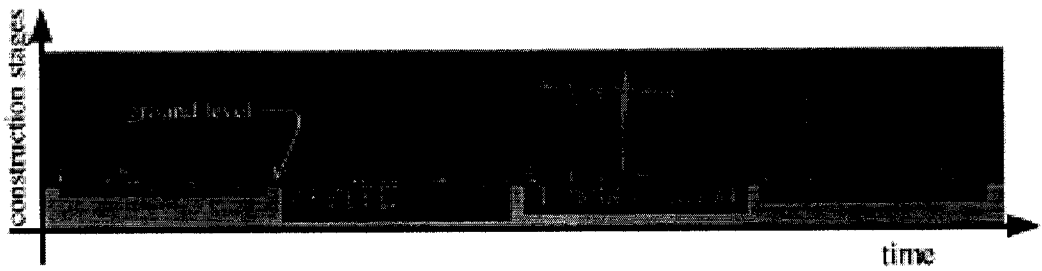



Figure 2-28 Chronological records of the construction of the campus building (Shih et al 2006)

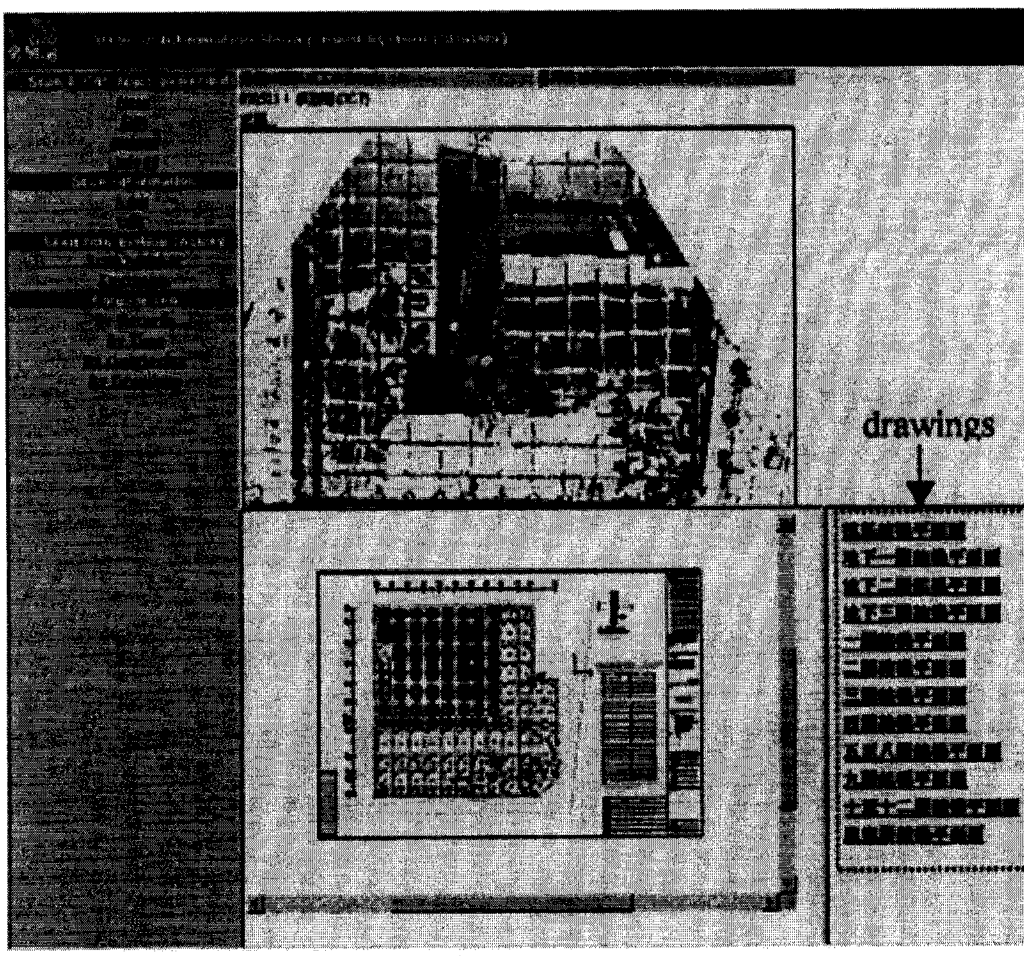



Figure 2-29 Scan and drawing are simultaneously referred (Shih et al 2006)

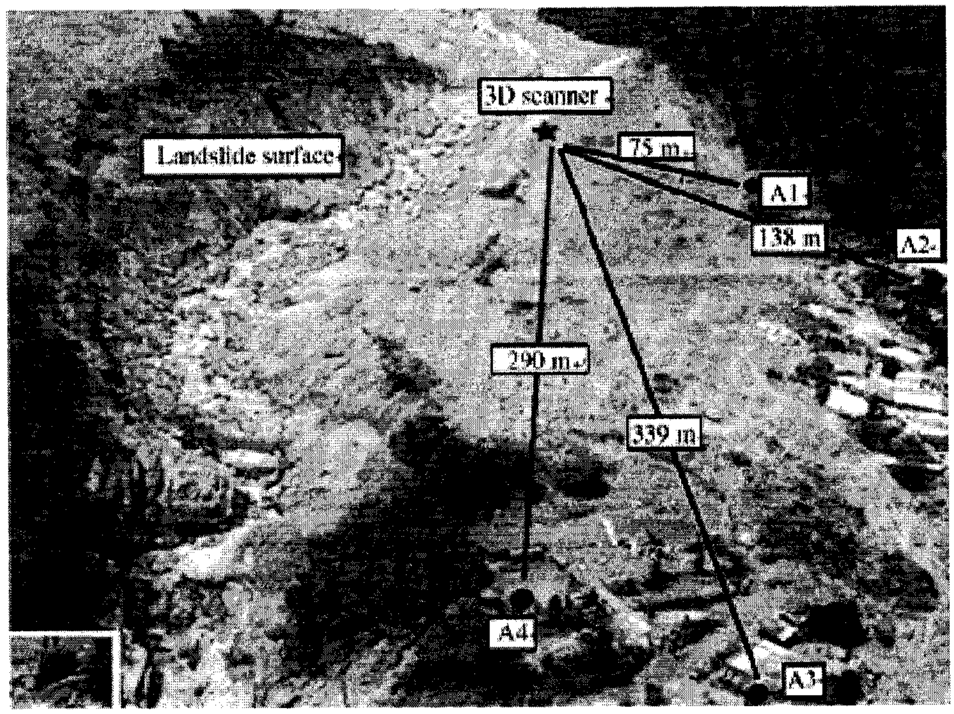



Figure 2-30 Location of 3D laser scanner and GPS (Du et al 2007)

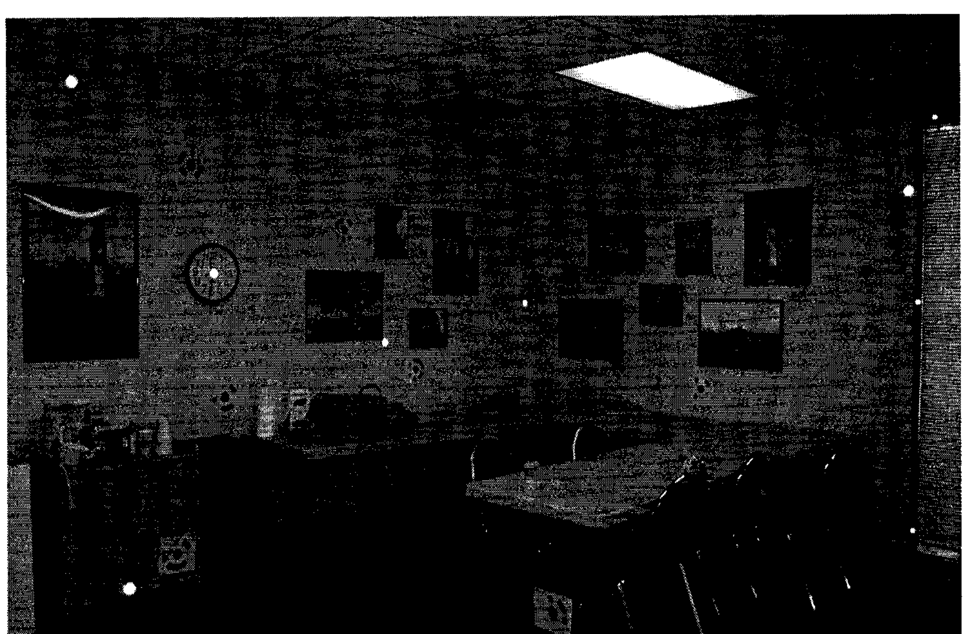


Figure 2-31 Targets Placement for 3D Modeling from Photo Images

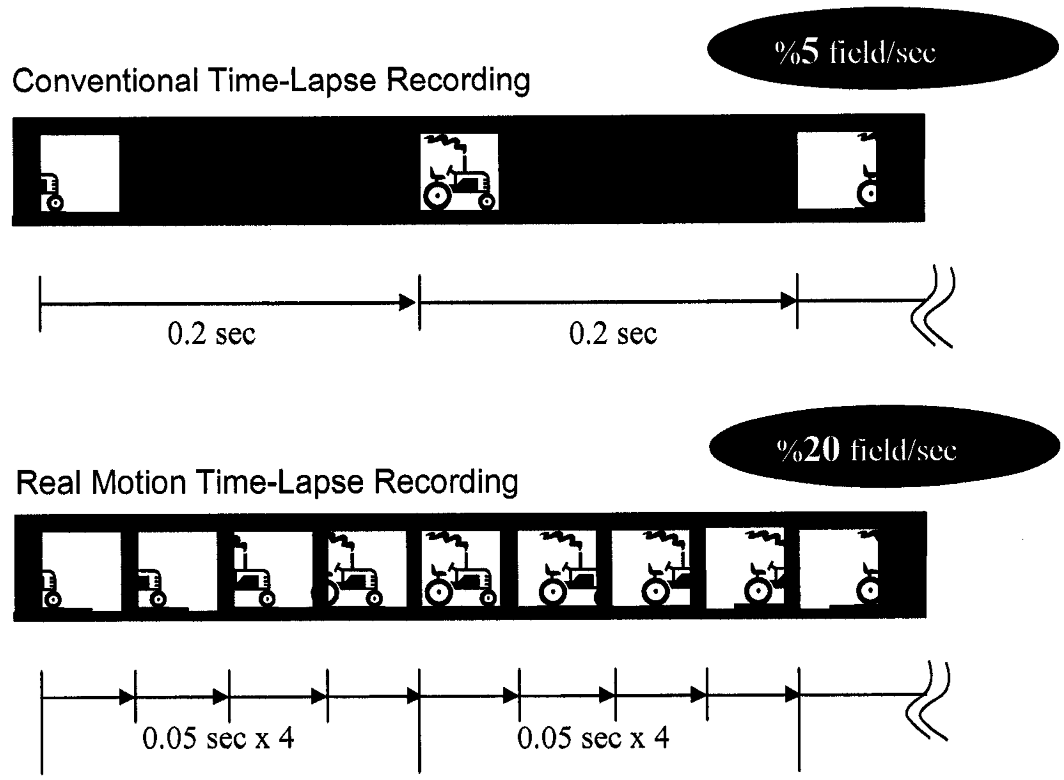



Figure 2-32 Conventional time-lapse versus real motion time-laps recording (Everet et al. 1997)

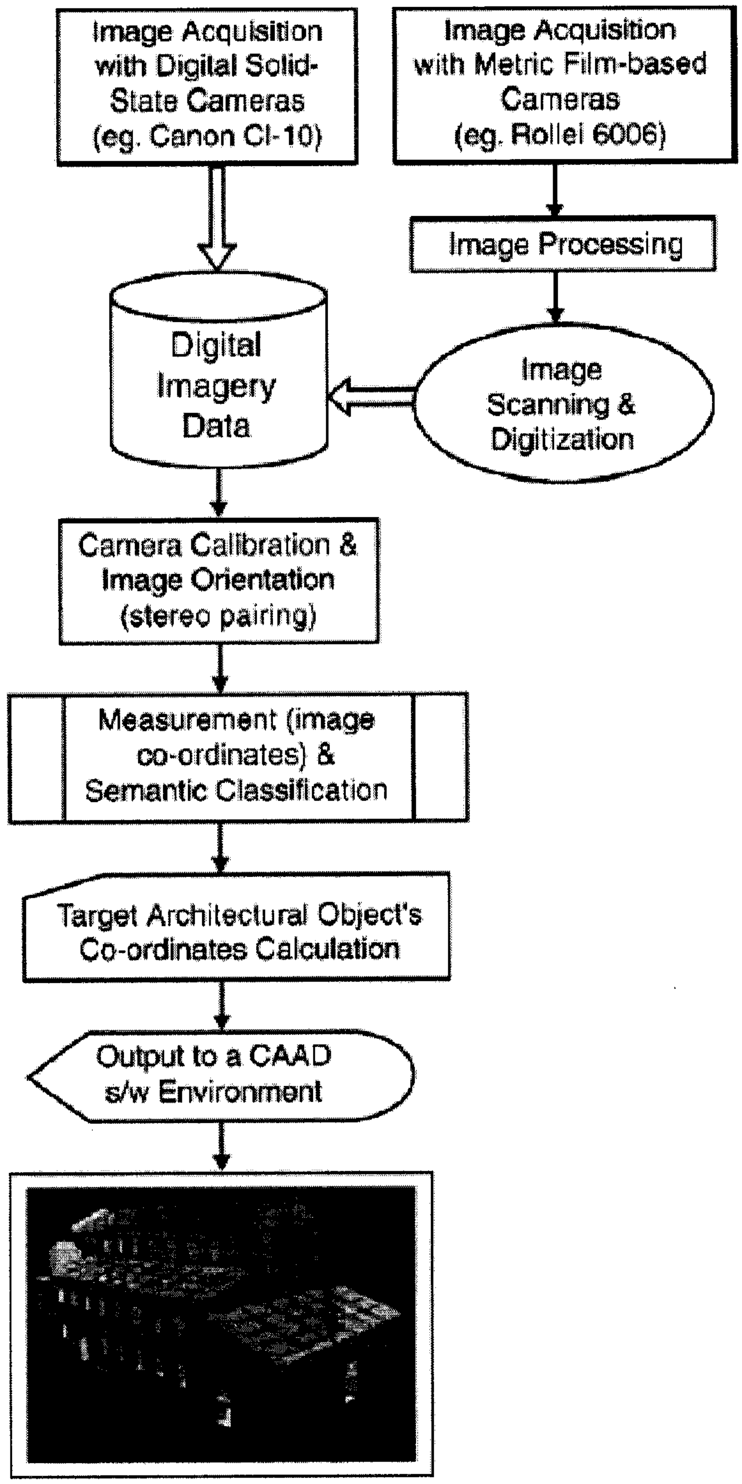



Figure 2-33 The processing steps for 3-d modeling using the digital architectural photogrammetry technique (Styliadis 2007)

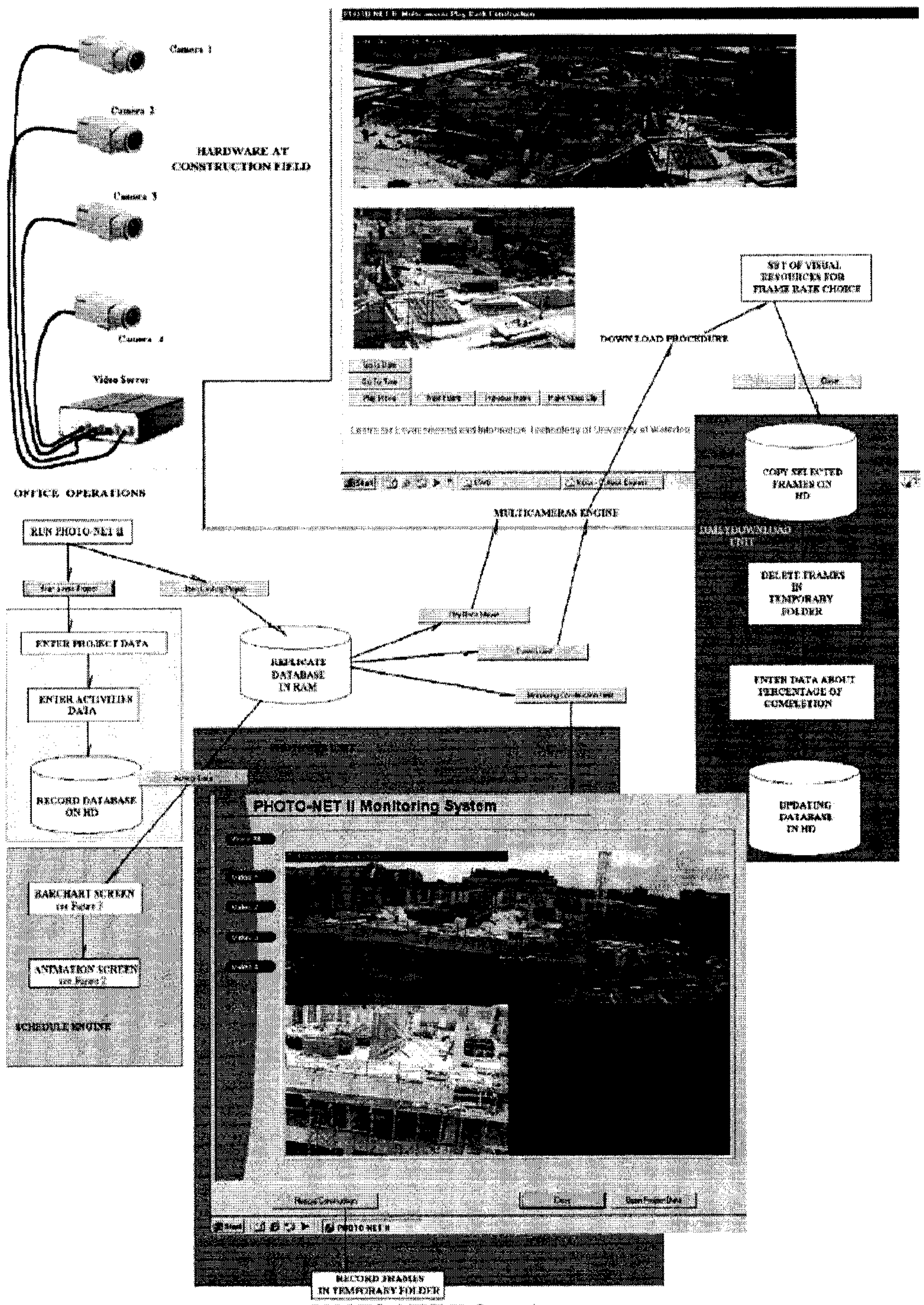



PHOTO-NET II Overview

Figure 2-34 System layout and hardware components (Abeid et al 2003)

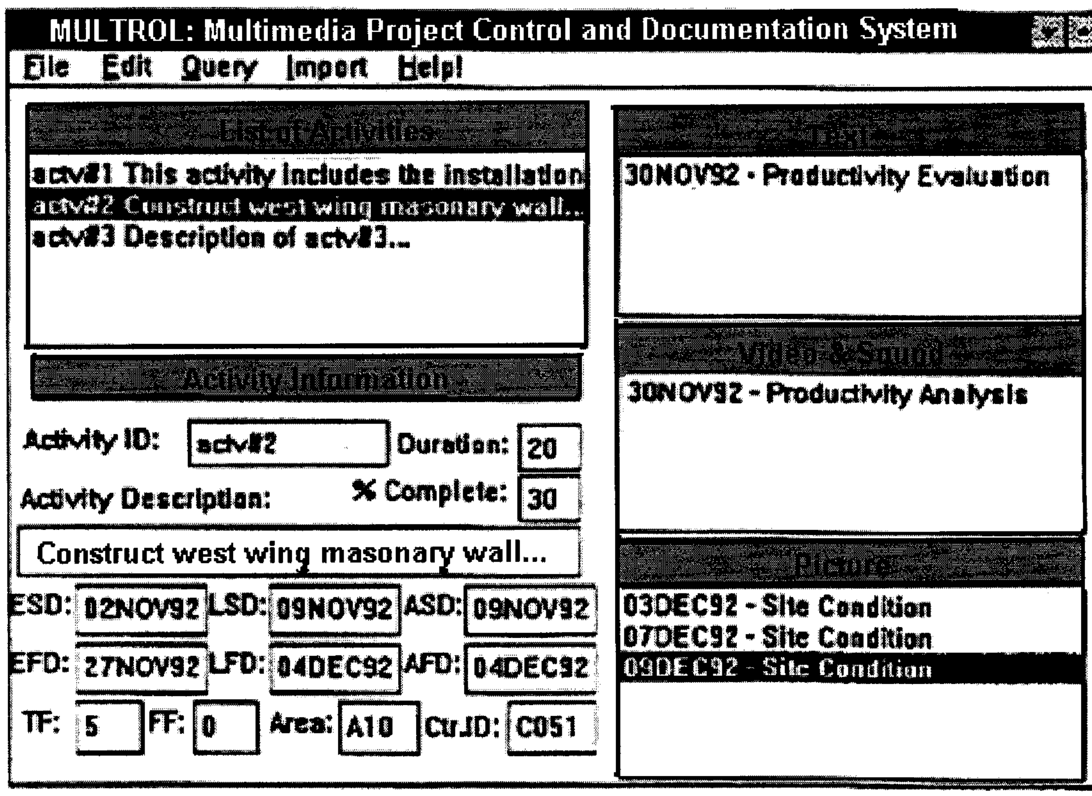



Figure 2-35 MULTROL main window activity (Liu 1995)

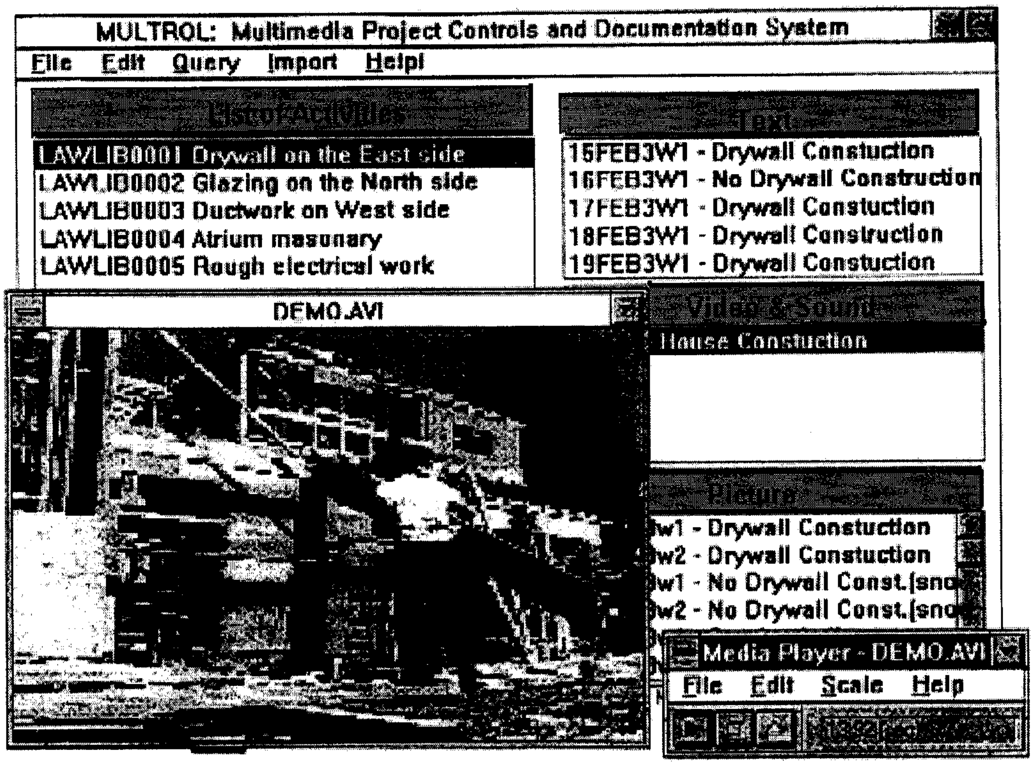



Figure 2-36 MULTROL information retrieval – Video and Sound (Liu 1995)

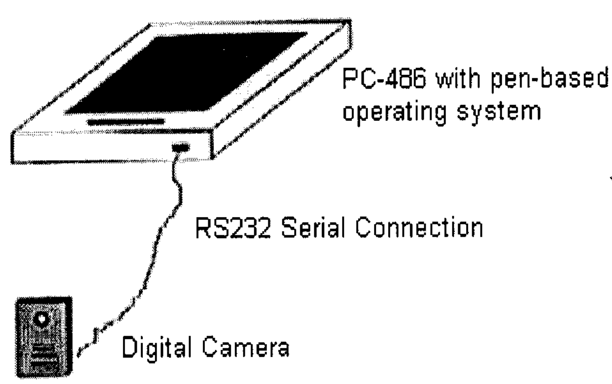



Figure 2-37 M-LOG Hardware Configuration (Liu et al. 1995)

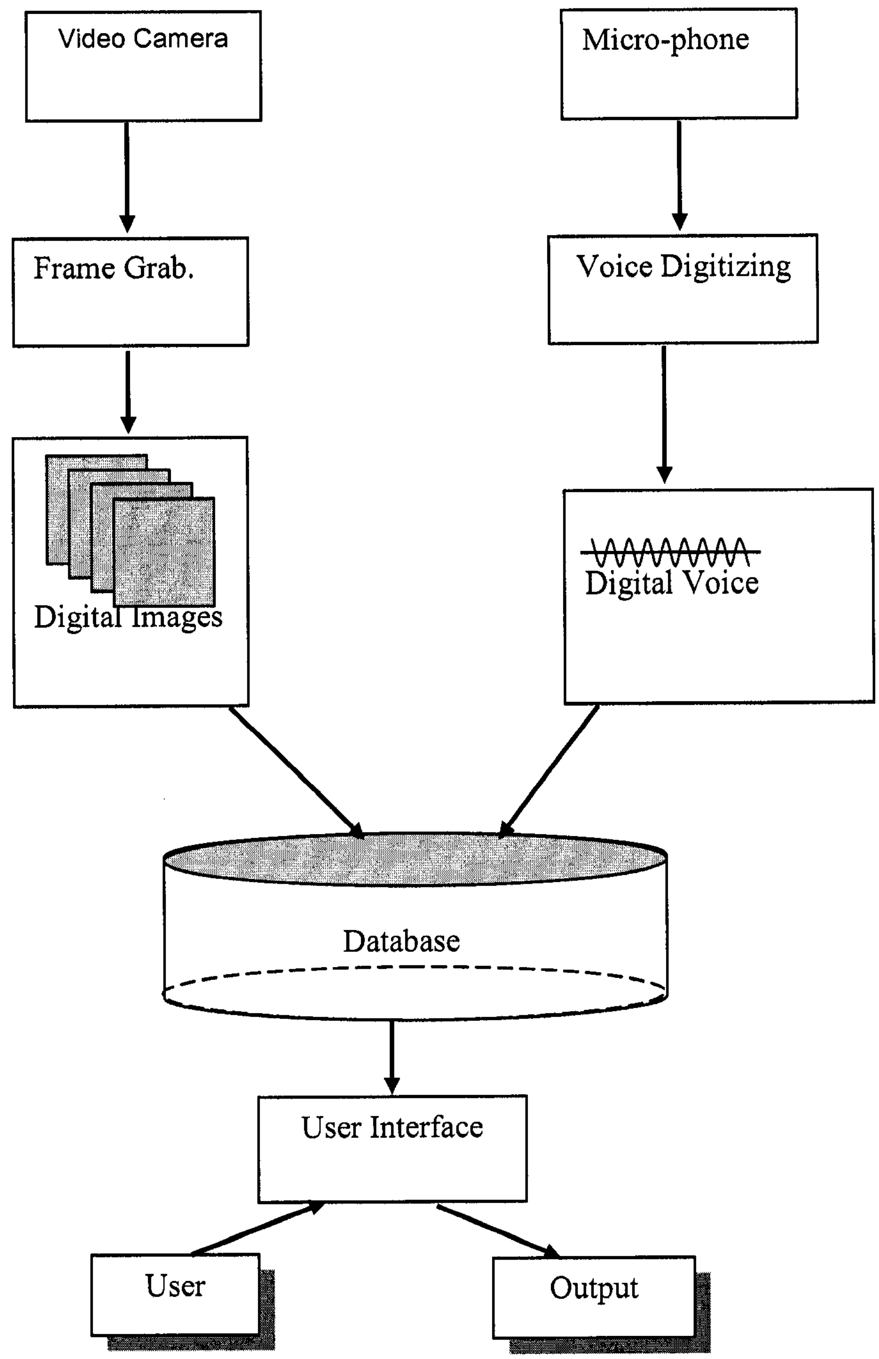



Figure 2-38 Prototype System to Support Delay Management (Abudayyeh 1996)

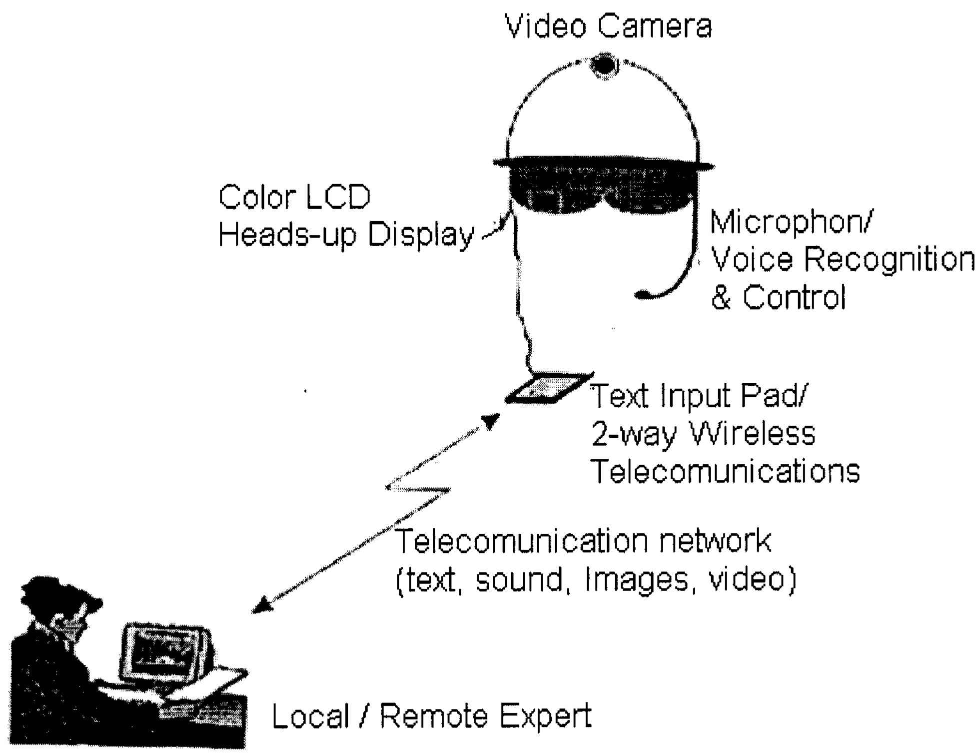



Figure 2-39 Components of the Digital Hard Hat (Liu 1995)

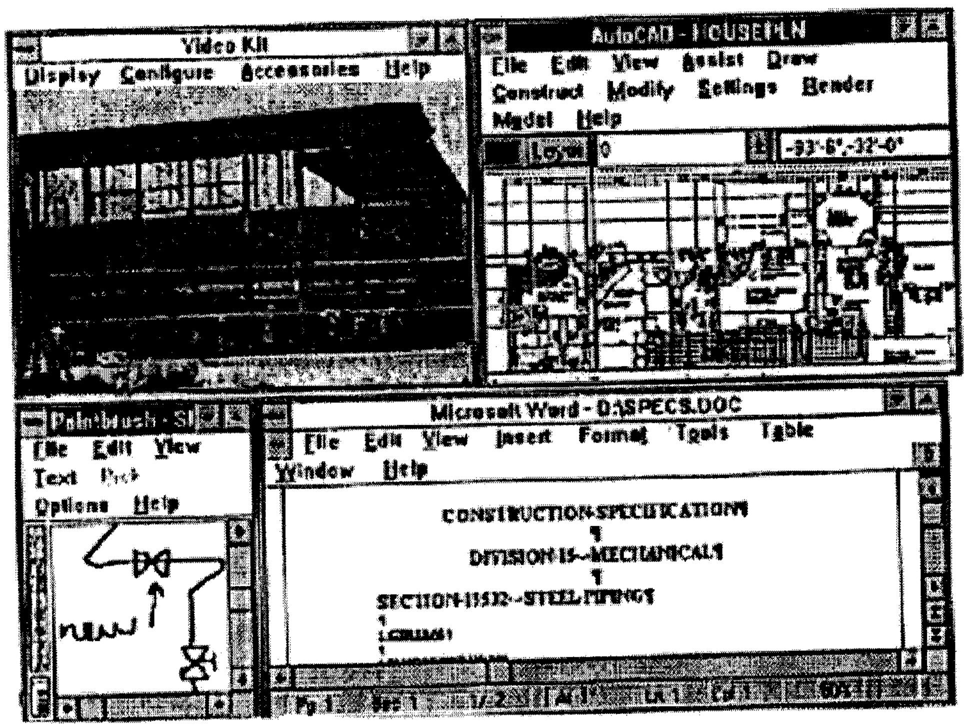



Figure 2-40 Information as Seen in the Heads-up Display by the Operator (Liu 1995)

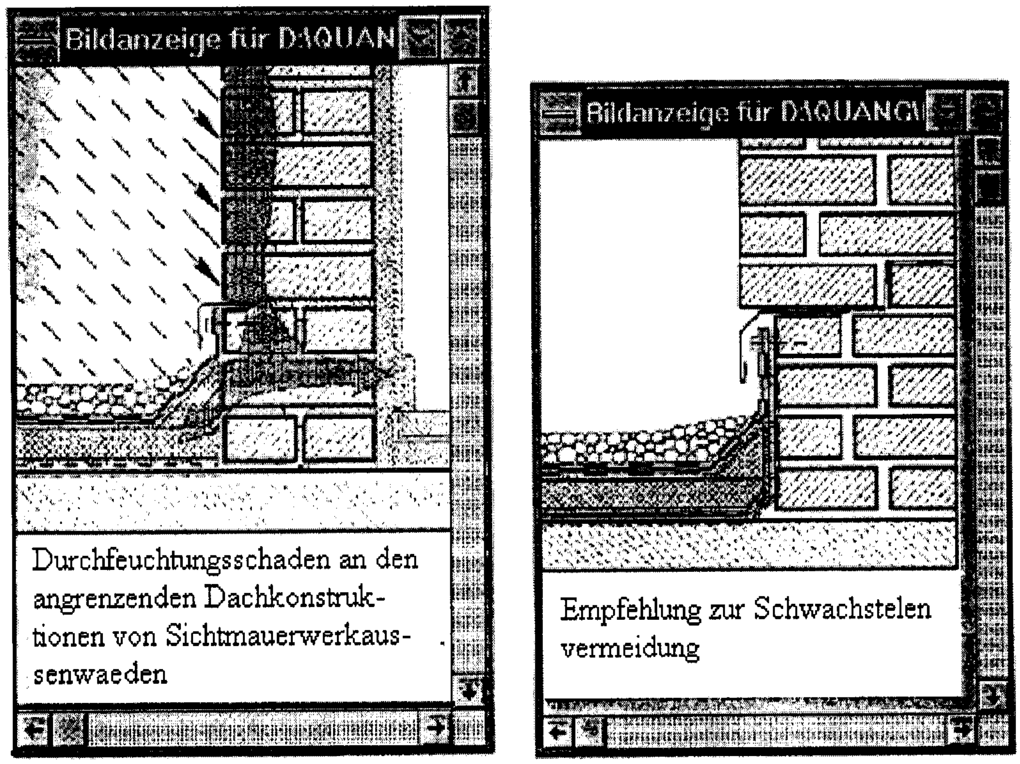



Figure 2-41 A typical failure and the advice for the rehabilitation of that failure from the multimedia catalogue of the BestandManager (Rüppel 1995)

# CHAPTER 3 PROPOSED METHODOLOGY

## 3.1 General

A project control system establishes guidelines for effective cost and schedule control. As mentioned earlier, data collection is a crucial step in the tracking control process. Considerable work has been carried out to utilize various automated data acquisition technologies for the purpose of data collection (Akinci et al 2002, Perera et al 2004, Shashi et al 2007, Du et al 2007, Jaselskis 2003 Echevery 1996, Flickinger 1995, Liu 1995). For example in Abudayyeh's model (1991), the bar code technology was used in acquiring construction data from site. In some other cases, these technologies were used for the purpose of inventory or inspection. The proposed system integrates different automated data acquisition technologies. Construction data is collected from site and stored into a centralized database for later use in generating progress reports. The system is designed from the contractors' point of view to help track their projects in a timely manner. It also allows owners to have a closer look over the project. Pen-based or tablet computer is utilized as a media of integration. An interface software application was developed using Microsoft Access. With this application, actual data related to each activity on the job site is collected using a pen-based computer, RFID, bar coding, LADAR, or multimedia information in form of voice records or video tapes.

## 3.2 Study and evaluation of site data acquisition technologies

This research study involved experimenting with different hardware and software systems. This section presents the work conducted on laser scanning, photogrammetry, and RFID to find the best combination that would provide the desired results. Comparisons with other available tested components are presented and the reasons behind the selection of the components used in the developed system are highlighted. Table 3-1 provides a comparison between the proposed system and other available integration models and systems. The comparison was carried out with respect to the purpose and essential characteristics of each model and system Included in the comparison are the Building Information Modeling (BIM), Documentum by EMC Corporation, Coreworx from Software Innovation Inc., and PM+ of SNC-Lavalin. BIM includes geometry, spatial relationships, geographic information, quantities and properties of building components. It extracts the information from design drawings and models it in 3D images to represent the site conditions and also calculate quantities of work performed. Future research could integrate features of the proposed system with BIM in regard to collecting actual information from the construction site (Lee et al 2006, Holness 2008, Estman et al 2008). RR, this is not clear. Documentum is document management software and it manages document content and attributes such as check-in, check-out, and version management. The purpose of proposed system isn't document control, but to assist in collecting and processing near real time data from construction sites such as labor or equipment hours to update the project schedule and generate progress reports. Coreworx is similar to Documentum, it automates document control functions, such as, version control, approval workflows, transmittal receipt/generation and built-in document reporting.

Table 3-1 Comparison between the proposed model and others

| | Proposed model | BIM | Documentum | Coreworx | PM+ |
|---|---|---|---|---|---|
| Main purpose | Integrating different data acquisition technologies to collect data from construction sites needed for progress measurements | 3D modeling from AutoCAD drawings for site representation and quantity measurements and help in developing as-built information | Primarily Document management | Primarily document management | Cost estimating, document control, and progress measurement of work packages |
| Level of integration | Activity level | 3D models that represent building components (e.g., beams, columns, walls) or assembly (e.g., floors, stairwells, facades) | | | Work package level |
| Document control | No | No | Yes | Yes | Yes, but doesn't store documents |
| Laser scanning | Yes, used for calculating actual quantities and site representation | No | No | No | No |
| Photogrammetry | Yes, used for calculating actual quantities and site representation | No | No | No | No |
| RFID / barcode | Yes, used to collect actual working hours | No | No | No | No |
| Modeling 3D from AutoCAD | No, AutoCAD is integrated but only for information purposes | Yes | No | No | No |
| Modeling from scanned and digital images | Yes | No | No | No | No |
| Site representation from design drawings | No | Yes | No | No | No |
| Integrating planning software | Yes, to import and update planned data | No | No | No | Yes |
| Automated collection actual working hours | Yes | No | No | No | No |
| Qalculating quantities from actual work | Yes | Quantities are calculated from the design drawings | No | No | No |

PM+ developed by SNC-Lavalin manages progress payments for suppliers and sub-contractors but it doesn't automate the process of data collection as in the case of the proposed control system. Data pertinent to material usage and labor and equipment hours are entered in PM+. PM+ also has a document control module but it doesn't store the documents in the software, it only provides information on the physical location of the document. From the comparison above, it can be noted that the proposed system utilizes different technologies for data collection needed to update the project schedule. This feature is not available in the other systems included in Table 3-1.

### 3.2.1 Laser scanning

Laser scanning operation components include a scanner, which is connected to a laptop computer through a serial connector type RS-232 or RS-422 depending on the scanner type or through a TCP/IP network cable. The scanner cannot operate without a scanning software installed on the laptop and that is the reason for the presence of the laptop. The scanning software can enhance the scanned image, such as removing destructing points caused by some obstacle from the point cloud image, before exporting it to the modeling software application, which is the last step in the 3D scanning operation. The triangulation based laser scanning technology was developed as early as 1978 and the National Research Council of Canada was among the first institutes to develop it (Mayer 1999). 3D scanning equipments evolve very rapidly. Scanner speed (how many points per second can it reads), range (distance from the scanner to the object to be scanned), and accuracy are important factors that are considered in new scanners. The scanner employed in this research was purchased in 2002 and it was one of the most advanced scanners at that time. Since then scanners have improved dramatically in their speed and accuracy but their prices remain a major limitation. The proposed control system utilized 3D scanners for progress measurement purposes. The following sections present the status of 3D scanning technology and explore available hardware and software. During the pace of the current research, some software systems were experimented with and it was decided to integrate photogrammetry to enhance the productivity and accuracy of 3D modeling for progress measurement purposes. **Table 3-2** provides information on some of the currently available 3D scanners.

Table 3-2 Laser scanners comparison

| | Company | Equipment | Range m | Accuracy mm | speed Points / Sec | Price 1000 $US | comments |
|---|---|---|---|---|---|---|---|
| 1 | Steinbichler Optotechnik | T-Scan 2 | 0.08 | 0.03 | 10,000 | 150 - 250 | Hand held |
| 2 | Leica Geosystems | Leicascanstation 2 | 300 | 6 | 50,000 | 120 | |
| 3 | Leica Geosystems | Leica HDS 6000 | 79 | 6 | 500,000 | 120 | |
| 4 | FARO Technologies | Faro Laser Scanner LS 840/880 | 79 | 3 at 25 m | 120,000 | 100 | |
| 5 | Datapixel | Optiscan H class | 0.1 | 0.006 | 60,000 | 100 | including arm |
| 6 | 3D Digital | Optix 400 | 0.3 - 0.9 | 0.0035 | 1,000,000 | 45 | |
| 7 | 3rdTech | Deltasphare-3000 | 15 | 7 | 24,000 | 30 | |
| 8 | CALLIDUS Systems | CALLIDUS CP 3200 | 80 | 5 | 1,750 | 120 | |
| 9 | RIEGL Systems | LPM-100VHS | 200 | 2 | 1,000 | 85 | |
| 10 | RIEGL Systems | LPM 321 | 6000 | 25 | 1,000 | 131 | |
| 11 | RIEGL Systems | LMS-Z420i | 1000 | 10 | 11,000 | 149 | |
| 12 | RIEGL Systems | LMS-Z390i | 400 | 6 | 11,000 | 125 | |

Laser scanners are divided into two categories, short- and long-range scanners. The T-scan 2 (see **Table 3-2**) from Steinbichler Optotechnik is a hand-held laser scanner used for the automotive industry and also in art restoration and archeology. The 8 cm range enables scanning with higher accuracy (Appendix I (a)). The scanning speed can reach up to 1 million points per second as in the case of the Optix 400 (see **Table 3-2**, Appendix I (b)) from 3D Digital. Another example of the short-range scanners is the Optiscan H class shown in Appendix I (c) (Datapixel). This scanner is used in the manufacturing industry for automation of inspection process. It has a very short range up to 10 cm and can capture 60,000 points per second at scanning as shown in **Table 3-2**. Deltasphare-3000 (3rdTech) is considered a short-range scanner but its 15 m range and low price (see **Table 3-2**) makes it ideal for indoor scanning in the construction industry (Appendix I (d)). The result is also a point-cloud image that can be imported to 3D modeling software system. The vertical range angle of the Deltasphare-3000 is 290°, which makes is advantageous over other available scanners for its ability to scan the ceiling without the need to scan at different scanning positions.

The advantage of long-range scanners lies in their ability to scan object that are in hundreds of meter distance from the scanner. The Leicascanstation 2 (see **Table 3-2**) from Leica Geosystems (Appendix I (E)) is considered one of the latest developments in 3D laser scanning. Its high scan rate that reaches the 50,000 points per seconds together with a range of 300 m, ranks it among the top of the currently available 3D laser scanners. FARO Technologies developed a long-range scanner that can reach 79 m distance (see **Table 3-2**). Their product, the LS 840/880 (Appendix I (F)) has a scanning rate of 120,000 point per second due to the low range distance compared to the Leicascanstation 2. The LMS-Z390i is the latest development (2008) of RIEGL systems (Appendix I

(G)) and can be mounted with a calibrated digital camera. This scanner has a range of 400 m while the LMS-Z420i (Appendix I (H)) has a range that reaches 1000 m. Both scanners have a maximum vertical and horizontal range angles that are also known as "field of view" of 80° x 360°. The scanner utilized in this research (Appendix I (I)), which is the LPM 100-VHS from RIEGL, is considered a long-range scanner with a range of 200 m (see **Table 3-2**). The scanner was acquired by Concordia University in 2002 and was one of the best scanners available in the market. Since then the 3D scanning equipments has evolved rapidly. The application of this scanner in the early stages of this research was examined and is more explained in Chapter four. Through this examination endeavors, the speed, number of scans required, and accuracy of that scanner were major limitations for the kind of application it was meant for. The scanner was utilized to scan construction sites at difference stages and compare quantities accomplished for progress measurement. Many scans had to be performed from different scan position to get enough information required for the 3D modeling process. A newer version of the LPM series developed by RIEGL systems, which is the LPM-321 (2006) is designed to be mounted with a digital camera as shown in Appendix I (J). The mounted camera is calibrated and takes images automatically during the scanning process. These images are on the same coordinate system as the point-cloud image captured by the scanner to facilitate the process of 3D modeling. This scanner has a very long rang that can reach up to 6000 m with a scanning rate of 1000 points per second (see **Table 3-2**).

Scanning software systems are different from those that are used to model 3D scanned point-cloud images. Each scanner is operated through a scanning software system installed on a laptop, which is connected to the scanner via TCP/IP network cable or serial connection. The scanner utilized in this research was working with RiPROFILE, A software package provided by RIEGL. Figures 3-1 and 3-2 are a 2D and 3D view mode of the scanned image of the construction site at Concordia University performed on June 2$^{nd}$ 2007. The Image represents the formwork and steel reinforcement of the basement slab and the formwork of the walls. The software saves the scanned image in two format, the first is in 3DD file format, which can be read by most modeling software packages and the other is as a Bitmap image as shown in Figures 3-3 and 3-4. RIEGL systems have developed another scanning application known as RiSCAN PRO that is more advanced than the RiPROFILE for the Z-series scanners (Appendix I (G)). The LPM-100VHS (Appendix I (I)) utilized in this research can only work with RiPROFILE.

Scanned point-cloud images are imported into 3D modeling software applications for further processing to create a 3D model and extract needed information from that model. Chapter 4 discuses the application of PolyWorks from InnovMetric at the early stages of this research. PolyWorks imports point-cloud image files for further processing. Other 3D modeling applications use photo images for 3D modeling as in the case of PhotoModler Pro from Eos Systems. One or more photographs of an object are taken and displayed on screen. The operator marks each photograph, tracing and tagging features of interest. PhotoModeler then combines the data and locates the marked points in three dimensions. These marks become accurately measured points, lines, curves, cylinders or surfaces in a 3D space. The result is a 3D model that can be transferred to any CAD program. A demo copy of PhotoModler Pro was acquired by the university for this research to examine the possibility of modeling 3D images from photo images. The demo had all capabilities of a full copy but working only with images available in its image library. Modeling 3D images require working with at least two images (see Figure 3-5). It is also possible to work with only one image but it's not possible to create 3D image of hidden information (e.g. back of a building not shown on the photo image). An important step when starting is referencing points in different images for orientation purposes. Figure 3-6 shows the points and lines drawn on building edges and corners where the points later are referenced to connect both images together. The lines drawn on the building edges are then shown in 3D view as in Figures 3-7 and 3-8. Other photo images can be added to the project even if they were taken with a different camera. Figure 3-9 shows the five camera positions for this project including two positions number 4 and 5 that were taken from different camera. Using the tools provided by the PhotoModler Pro including cylinders and curves, the building was then modeled and textures taken from the photos were added (see Figure 3-10). As this project demonstrated, finding common points of the building in different photo images is easy if it is possible to locate building corner or edges. In other cases, the use of coded targets as shown in Figure 3-11 facilitates the referencing process during 3D modeling. Coded Targets are circular targets that can be automatically recognized by PhotoModeler during the marking process. Targets should appear on at least three photographs to allow automatic referencing from different photographs. In cases like excavation, photogrammetry becomes difficult and the use of 3D scanning facilitate the process of 3D modeling. It was decided to integrate Phtogrammetry with 3D laser scanning for the purpose of quantity calculations as part of progress measurement to overcame limitations associated with each technology such as time required to perform many scans from different scanning position and the difficulty in modeling 3D photo image of earth moving operations. The integration process is explained in Chapter 4 with the application of PHIDIAS from RIEGL that is capable of modeling 3D images from Point-cloud and digital photo images.

### 3.2.2 Bar coding and RFID

The application of bar coding and RFID required thorough investigation of the available equipments in the market. RFID readers are either fixed readers, which are known as stand-alone readers, hand held readers and vehicle mounted readers. All three types of readers can be utilized for progress measurement through reading RFID tags of resources to update their working hours. The RFID technology grows fast and will soon replace bar-code technology when the price of utilizing it competes with bar coding technology. A Hand-held RFID reader was purchased for this research because it can read bar-code and RFID tags. The reader is from Intermec Inc. and composed of two parts, the mobile computer part that can read bar-code tags and used for user interface and the RFID reader part, which is attached to the mobile computer. Appendix I (K) is the mobile computer 751A,COLOR from Intermec that is capable of reading bar-code tags. The IP4 (Appendix I (L)) combines a RFID reader and the 751A mobile computer, which makes it capable of reading RFID and bar-code tags as well. The operating system for 751A is Microsoft Windows for pocket PC. Intermec readers use the basic reader interface (BRI) command-language that enable to read RFID tags and write information on them. The users must develop a user interface designed for their needs with programming languages like C#, C/C++, .NET or Java and use BRI command-language for tasks to be performed by the RFID reader. Figures 3-12 to 3-15 illustrate a demo application for reading and writing on RFID tags using the BRI command language. Intermec have recently developed mobile computer (CNe and CNe3, Appendix I (M)) with GPS capability that can be attached to the new IP30 (2008) RFID reader (Appendix I (N)). GPS RFID tags (Appendix I (O)) are now available in the market (IDENTEC SOLUTIONS).

## 3.3 Components and data flow of the developed model

The system integrates through its pen-based computer environment, RFID, bar coding, LADAR and multimedia technologies to automate data acquisition. At its core is a relational database, used to organize and store the collected data. An interface software application is developed in the pen-based computer environment (Fujitsu - Stylistic ST4121B). The developed interface integrates different construction management software applications such as Primavera Project Planner, Microsoft project, AutoCAD, Microstation and other software applications such as PHIDIAS, which is capable of integrating and modeling photo images together with scanned images acquired using the LADAR (LPM 100 VHS). In the proposed system, scanned images are modeled with the support of digital photo images to produce 3D images of the scanned object, which are then used to estimate quantities of work performed. The layout of the proposed control system is shown in Figure 3-16 (Moselhi et al. 2005). Data pertinent to equipment working hours, labor hours and material consumption are collected using the developed system. Table 3-3 depicts the capabilities of the automated data acquisition technologies used in the proposed system. Scanned and digital images are modeled to determine quantities of work performed and subsequently calculate percent of work complete. Percent (%) complete can also be determined through templates, which assign different weight to the sub-tasks involved in the activity being tracked (Moselhi 1993). Figure 3-17 highlights the system components. During the process of data acquisition, the user can access AutoCAD drawings related to the activity in-progress and record notes for any changes occurred to help in the preparation of as-built drawings. Information needed in the future about the performance of the project within a specified period can, accordingly, be retrieved for later use. Clearly, the EV concept works well if the data needed to generate that type of control are accurately collected in a timely manner. Traditionally, actual data pertinent to material use, man-hour, and/or equipment use, is collected manually by filling forms on site and then feeding the collected data into a computer in the office. This is not only time consuming but also is susceptible to human error, and may lack consistency and reliability. The proposed system aims at alleviating these shortcomings by incorporating the automated data acquisition technologies described in Chapter two (Moselhi et al. 2006, 2007, El-Omari et al 2005, 2008).

### 3.3.1 Data acquisition

Construction data collection are performed using the automated data acquisition technologies discussed earlier in Chapter two. The bar code / RFID hardware consists of the IP4 reader from Intermec Technologies Corporation that can read RFID as well as bar-code tags (Figure 3-18), PW 40 bar-code label printer, and RFID tags from the same hardware developer (see Figures 3-19 and 3-20).

Table 3-3 Construction Data Acquisition with different Technologies

| | Bar Code / RFID | LADAR | Pen-Based Computer | Multimedia | | |
|---|---|---|---|---|---|---|
| | | | | Photo Images | Video Images | Voice Records |
| Labor | ✓ | | ✓ | | | |
| Material | ✓ | | ✓ | | | |
| Equipment | ✓ | | ✓ | | | |
| Quantity | | ✓ | ✓ | | | |
| Task progress | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Weather conditions | | | ✓ | | | ✓ |
| Productivity | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Problem areas | | ✓ | ✓ | ✓ | ✓ | ✓ |

Integration of both technologies was necessary to overcome limitations associated with each technology. These limitations are described in detail in Chapter four. Traditionally, construction contractors use plastic or paper labels attached to the material as shown in Figures 3-21 and 3-22. Applying bar-code tags or RFID to the material would save time in collecting information regarding that material with a simple scan instead of hand recording the information from these tags to tables. Figure 3-23 depicts an image of reinforcement steel bars used in a project, which is utilized in this study. In this image, the use of hand written tags was required due to the loss of the original tag. Bar-code and RFID tags are also used for equipment and labor tracking. Information related to location and time are recorded on the tables that represent the activities for each equipment and labor to avoid misallocation of working hours on construction activities. This cost misallocation occurs when, for example, equipment or labor working hours are reported for activities other than the activity they are assigned to. Data collection is performed using a pen-based computer. The developed software application explained later in Chapter six serves as an interface to access project database and store, change or delete information pertinent to the various construction activities.

### 3.3.2 Modeling 3D scanned and photo images

LADAR is utilized with digital photo images so as to capture information regarding quantities of work performed at the end of a working day in a timely and cost effective manner. The captured information is used to estimate percent completion for the project. The scanner used in this study is the RIEGL LPM 100 VHS LADAR scanner. Figure 3-24 illustrates the scanner while connected to the tablet PC (Fujitsu - Stylistic ST4121B) via a serial cable during the scanning process. Integrating 3D scanned images with digital photo images is done to enhance the 3D modeling process by elevating the limitations associated with both technologies. Chapter four describes this integration process and discusses the limitations associated with both technologies and the methodology used in this study to overcome these limitations.

### 3.3.3 Multimedia

Multimedia information, including digital photo images, video images, and voice records, are acquired from site to represent the construction progress on site. Photo images and Video clips captured with a digital camera on a daily basis are stored into the database in their digital format. The use of video camera with time-laps capability, to allow capturing long time operations and display them in relatively short time, assists in productivity measurements. Recorded sound files associated with a particular activity are also stored into the database.

### 3.3.4 Data storage and analysis

Data needed for integrated cost/schedule control must be identified and stored in a relational database. Relational database management system is especially popular in construction because of its combination of power, simplicity, and ease of use (Kim et al. 1992, 1993). The database of the developed system was designed to organize and store data collected from construction sites that support the management function of the system. It was implemented in Microsoft Access to facilitate the interaction with scheduling software systems such as Microsoft Project and Primavera systems. The collected data is used to update the project schedule by first importing project files from the scheduling software, update it, then send files back to perform earned value analysis and generate project progress reports . The process is outlined in Figure 3-25. The proposed system's database is described later in Chapter five. The entity relationship diagram of the database is shown in Figure 3-26

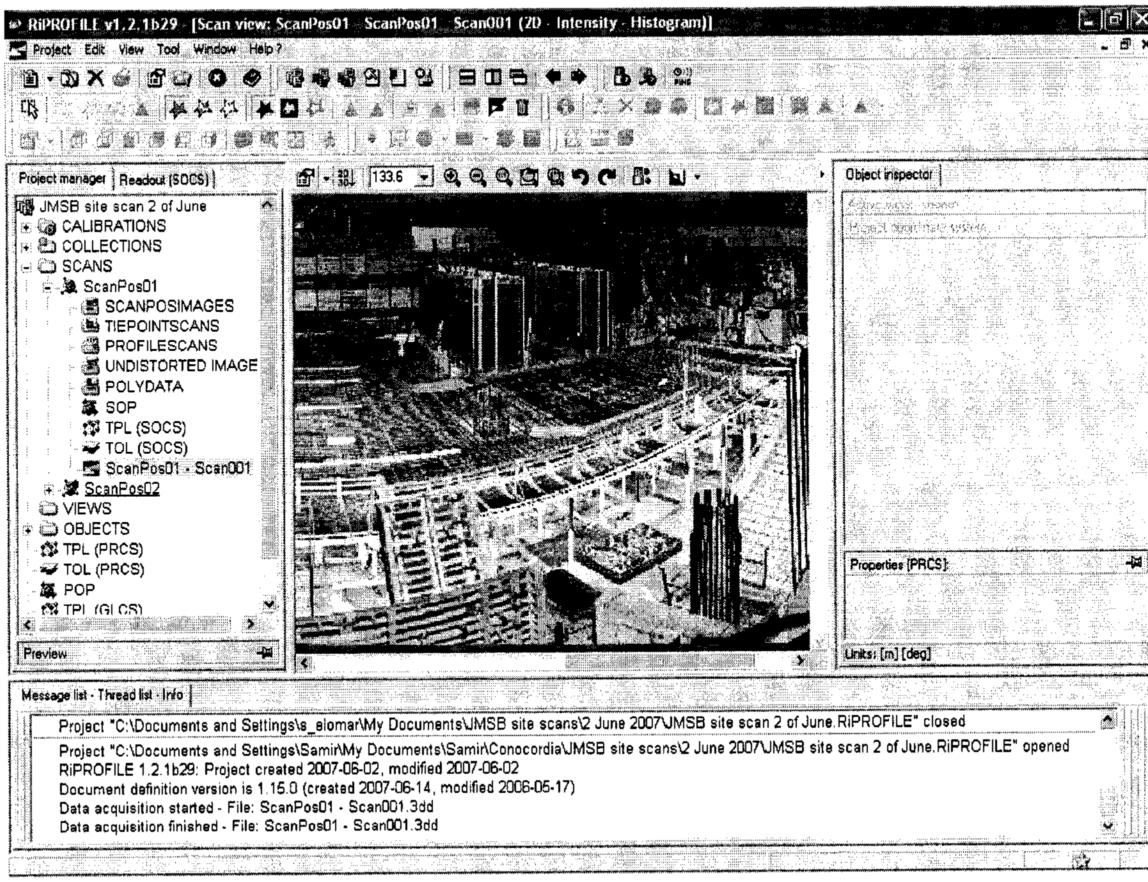



Figure 3-1 Construction site scan with RiPROFILE, 2D view (RIEGL)

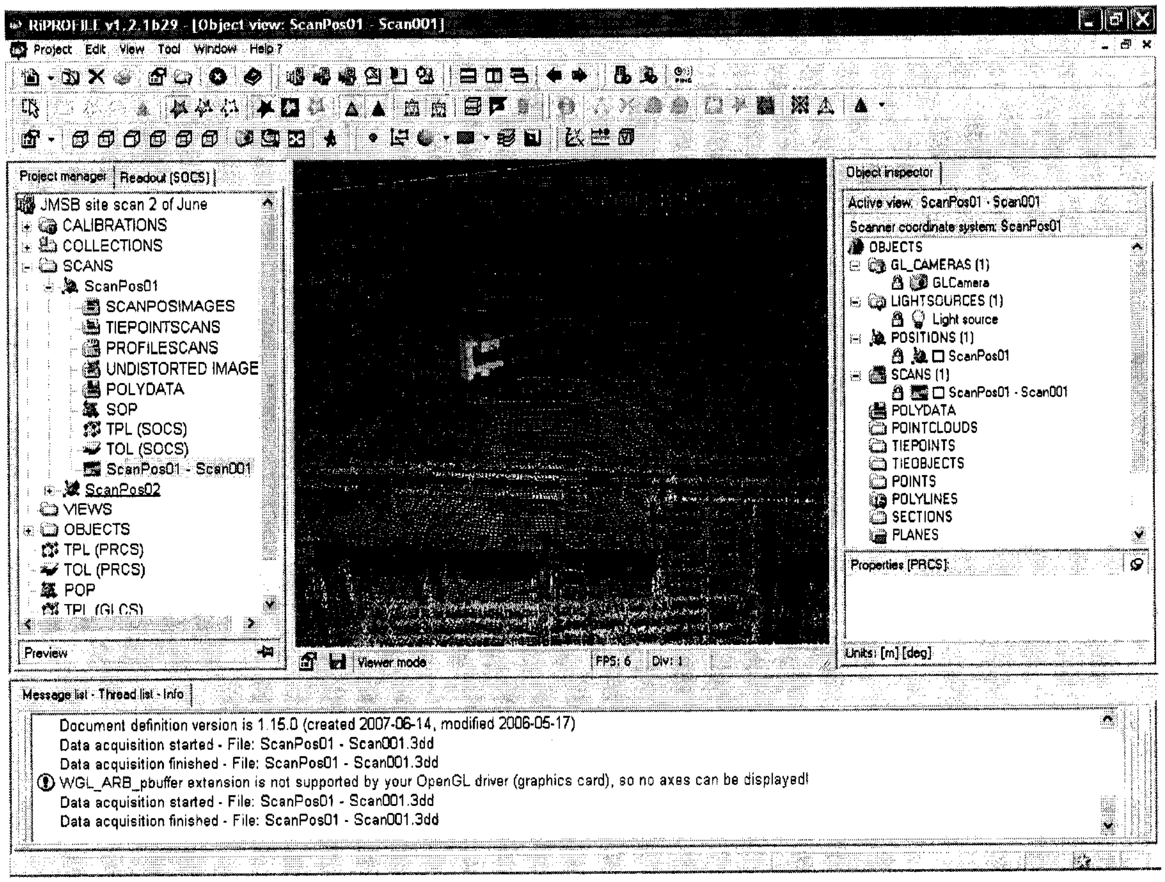



Figure 3-2 Construction site scan with RiPROFILE, 3D view (RIEGL)

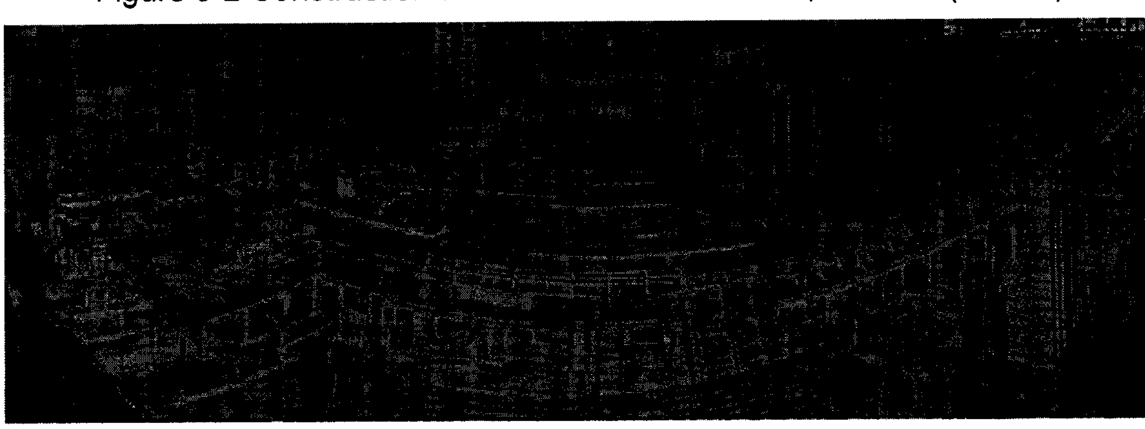


Figure 3-3 2D image of the construction site generated by the scanner LPM-100 VHS LADAR (RIEGL)

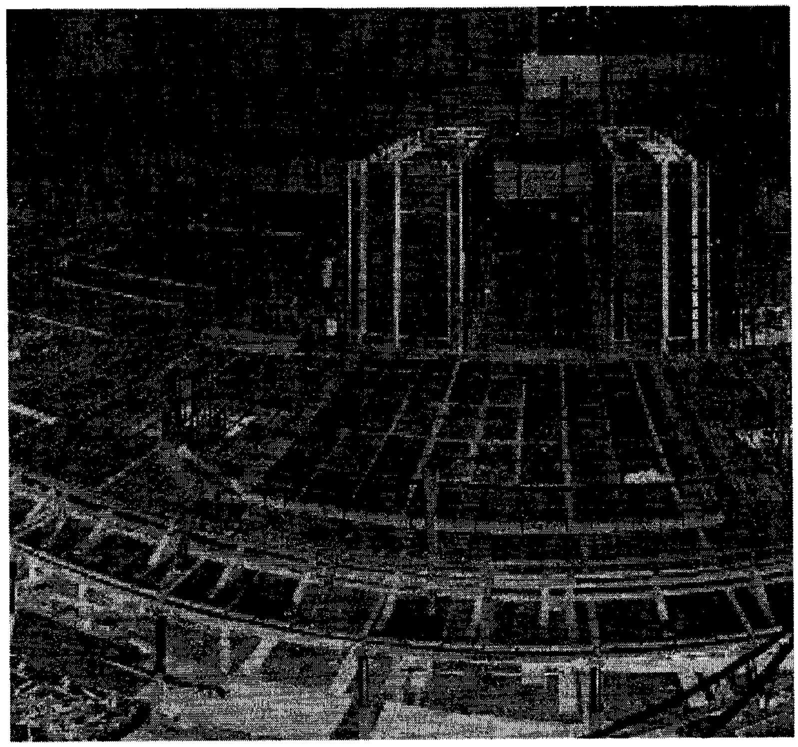


Figure 3-4 2D image of the construction site generated by the LPM-100 VHS LADAR (RIEGL) from different scanning position

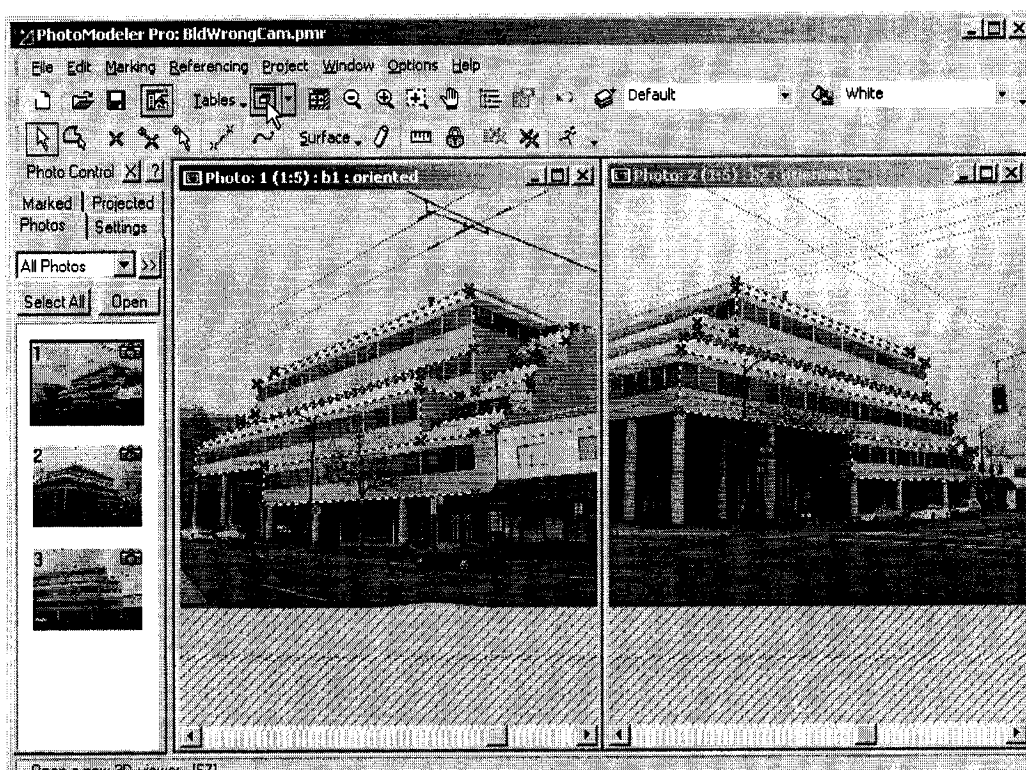



Figure 3-5 Modeling 3D image from digital images using PhotoModler Pro

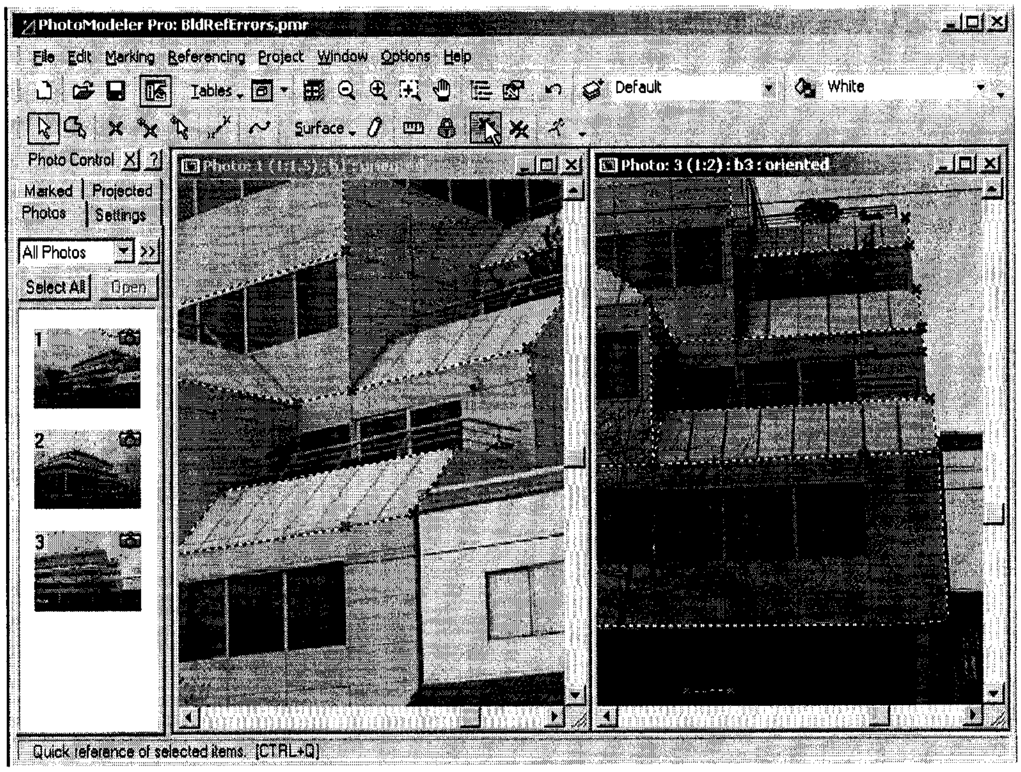



Figure 3-6 Referencing points on two images

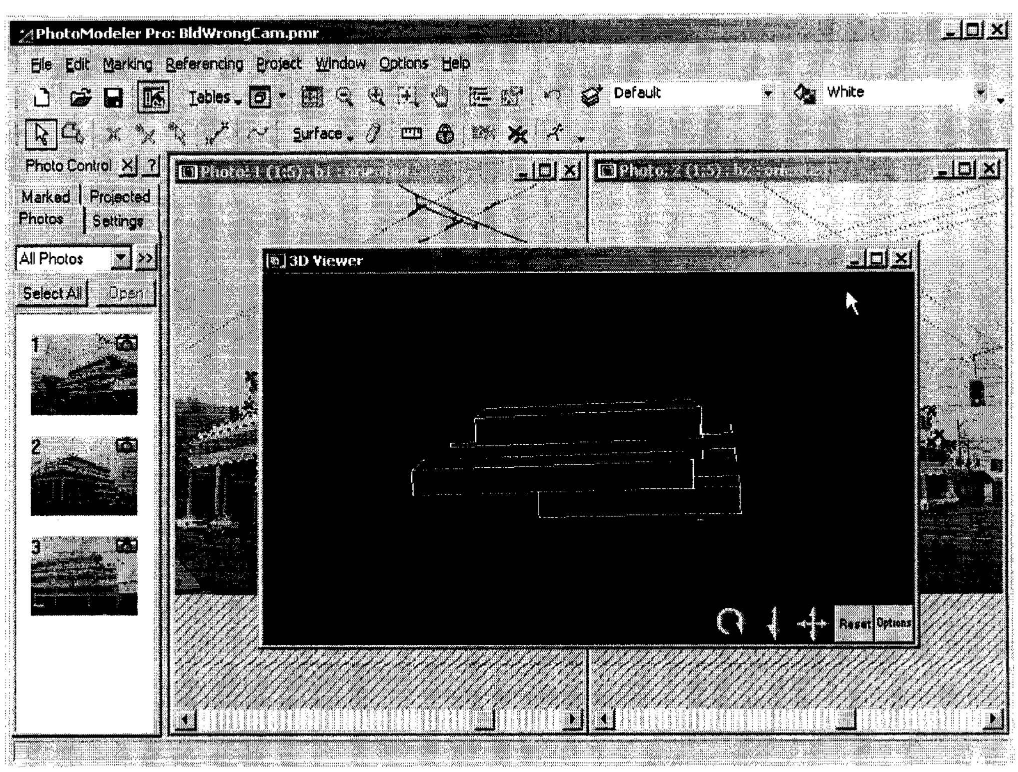



Figure 3-7 3D image view constructed from photo images

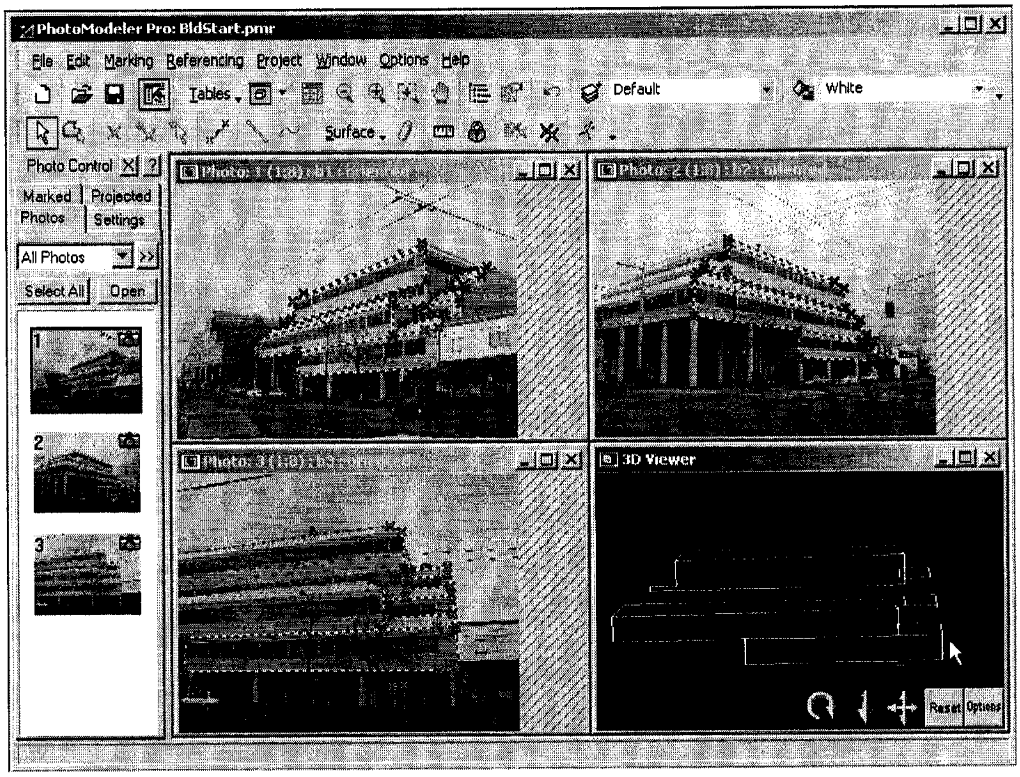



Figure 3-8 Photo images and lines in space

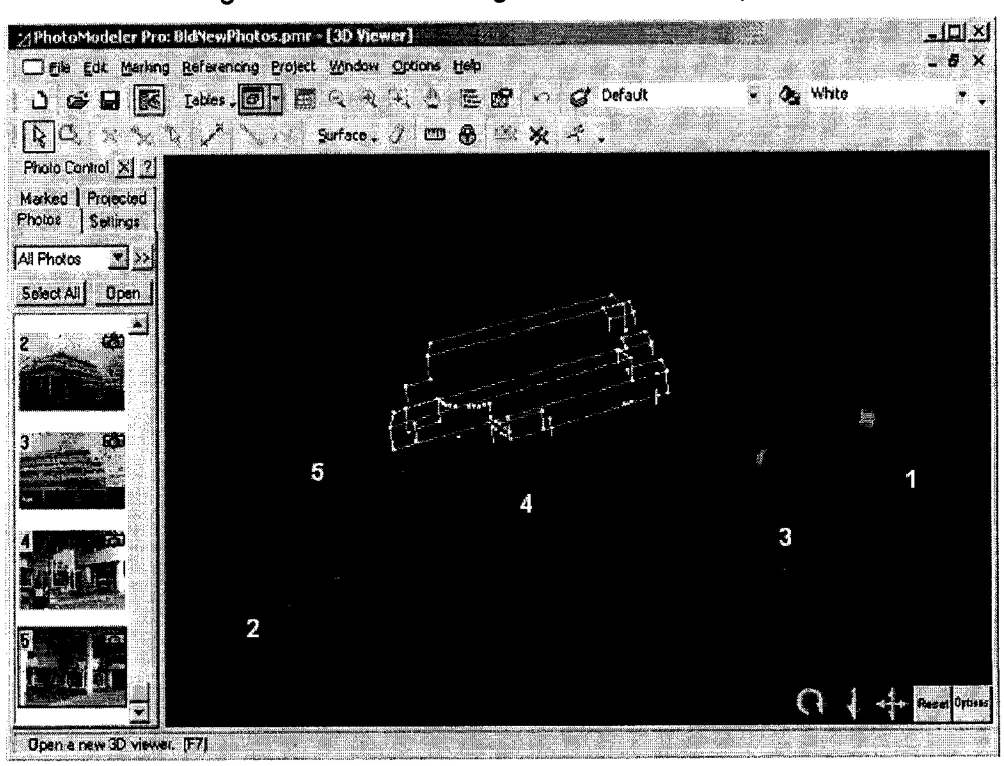



Figure 3-9 Camera positions

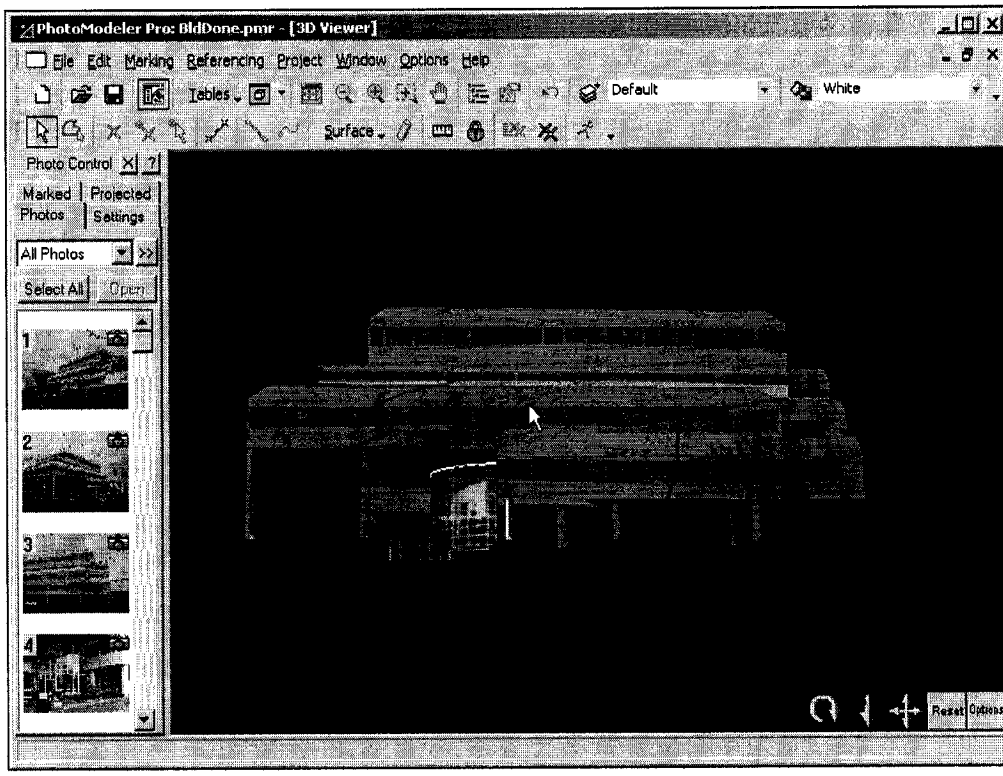



Figure 3-10 3D image with textures from photo image

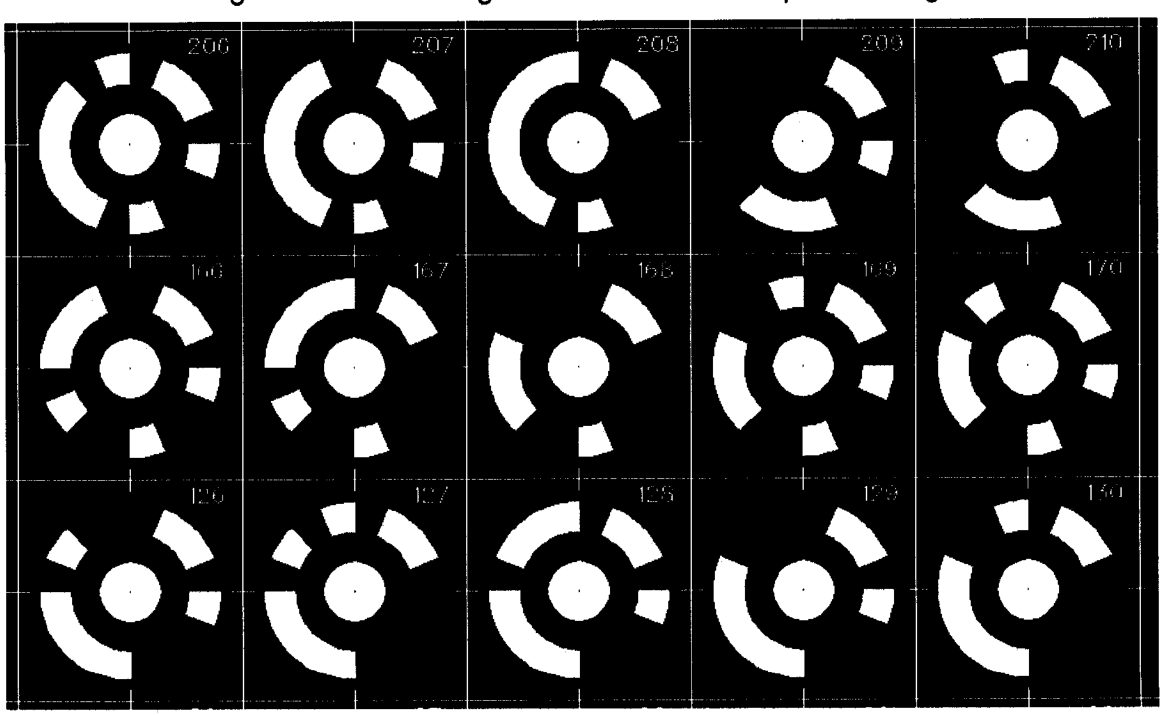



Figure 3-11 Coded targets (PHIDIAS)

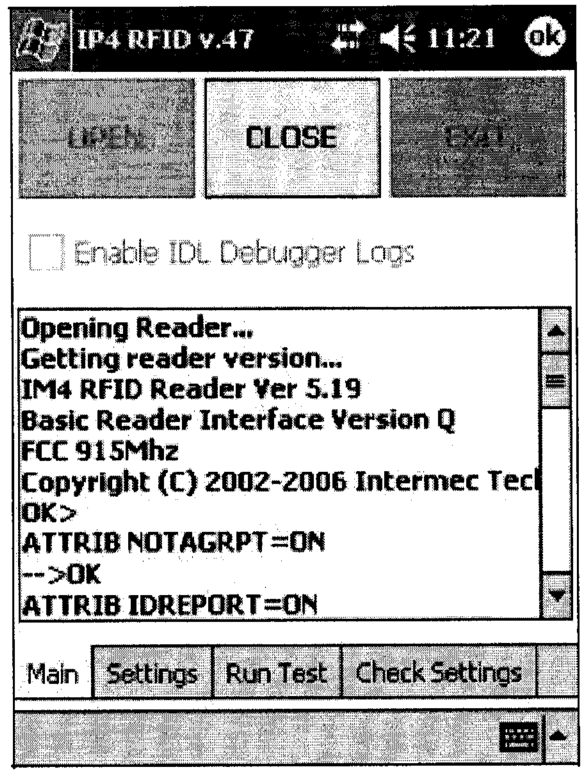


Figure 3-12 BRI demo from Intermec start screen

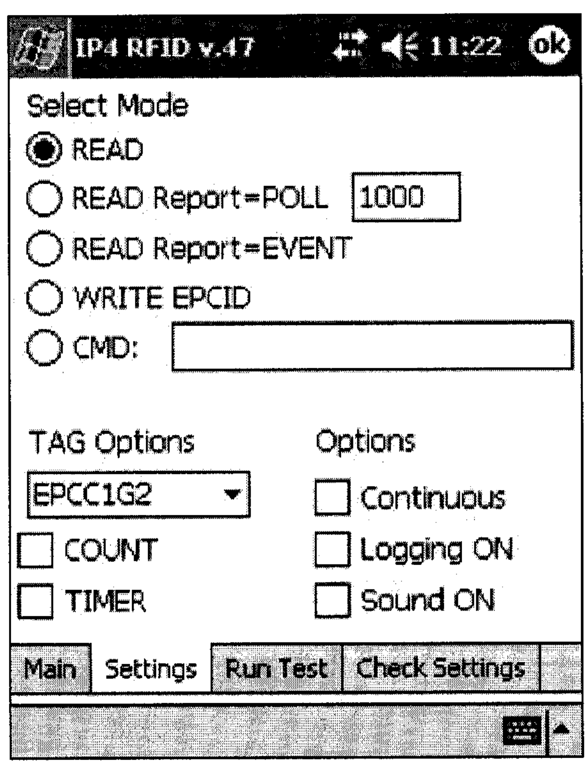


Figure 3-13 BRI demo setting screen

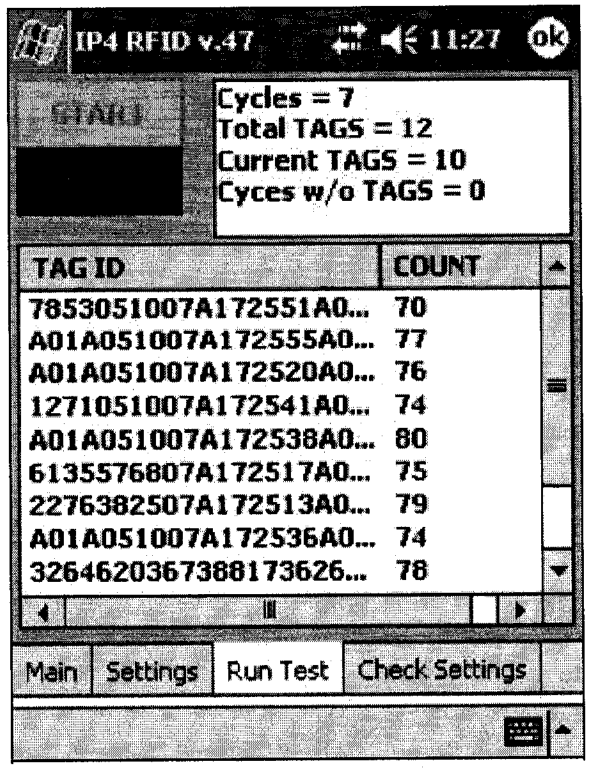


Figure 3-14 BRI demo RFID tag reading

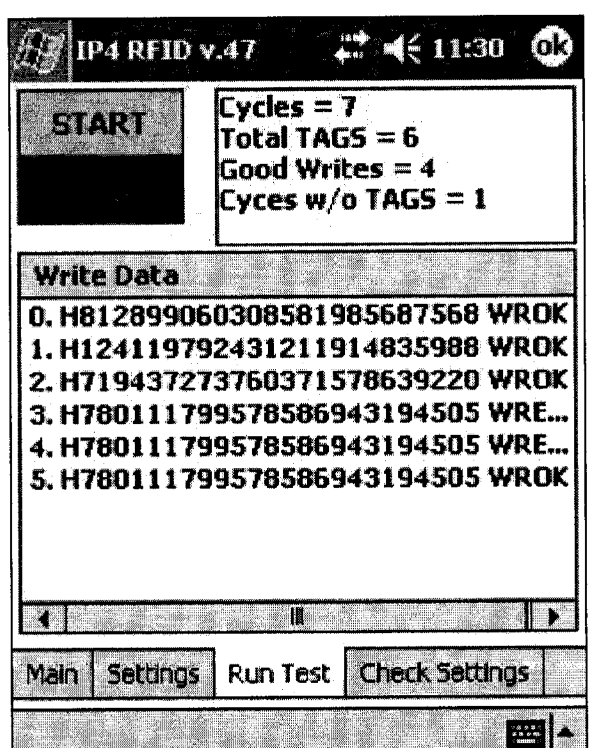


Figure 3-15 BRI demo write on RFID tags

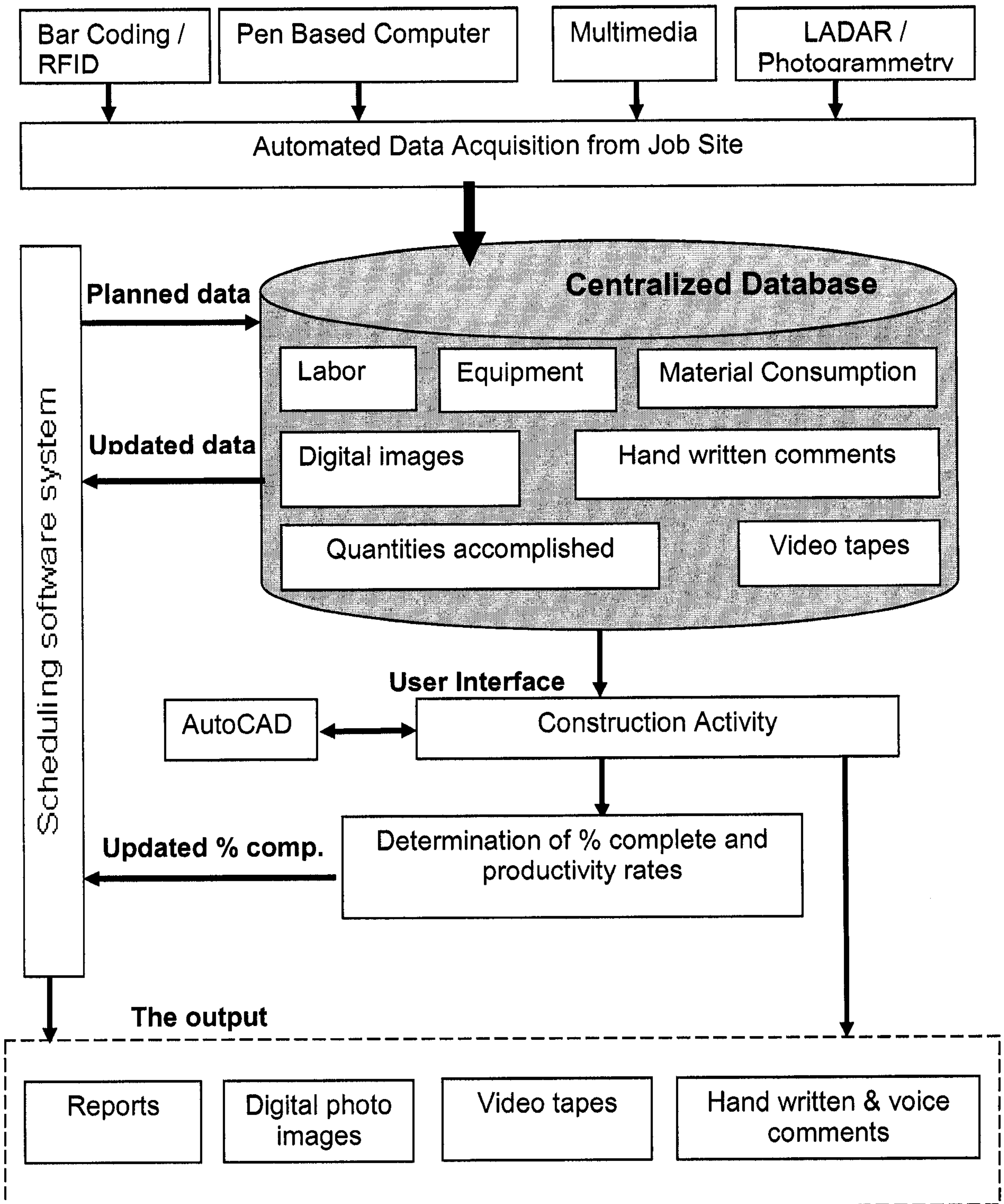



Figure 3-16 Proposed system architecture


Figure 3-17 Components of the proposed control system

Figure 3-18 IP4 RFID/Bar-code reader from INTERMEC

Figure 3-19 PW 40 bar-code label printer from INTERMEC

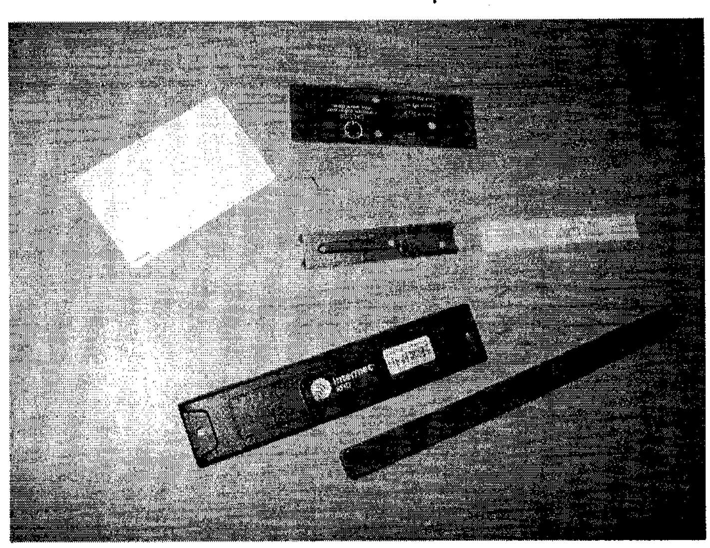


Figure 3-20 RFID tags from INTERMEC

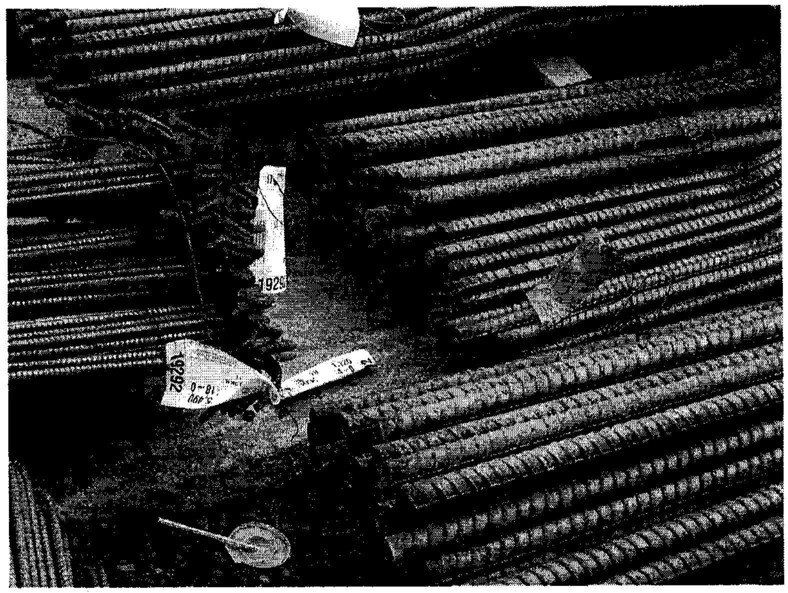


Figure 3-21 Steel reinforcement bars with plastic tags

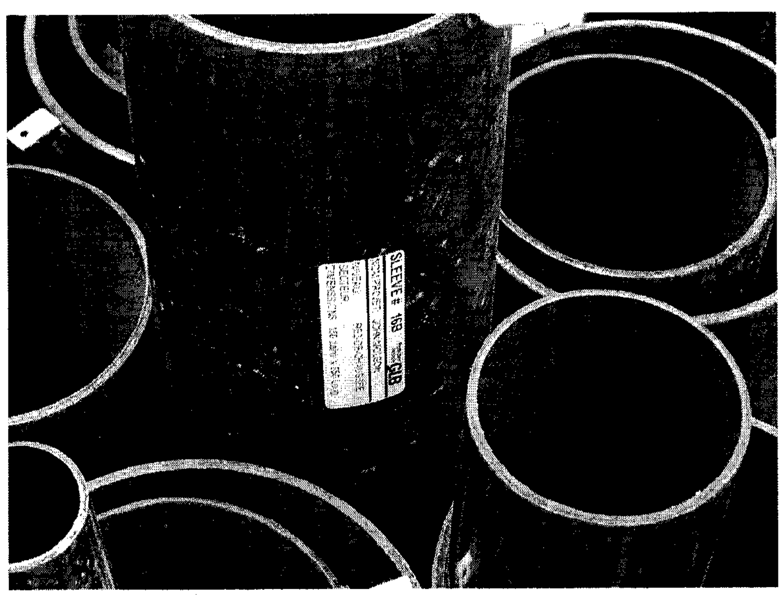


Figure 3-22 Pipe sleeves with paper tag

Figure 3-23 Hand written tags due to loss of original plastic tag

Figure 3-24 RIEGL LPM 100 VHS LADAR scanner

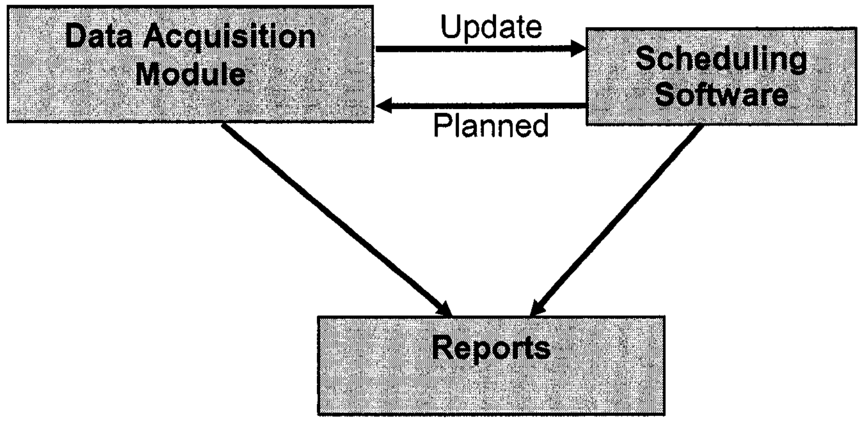



Figure 3-25 Data exchange and reporting

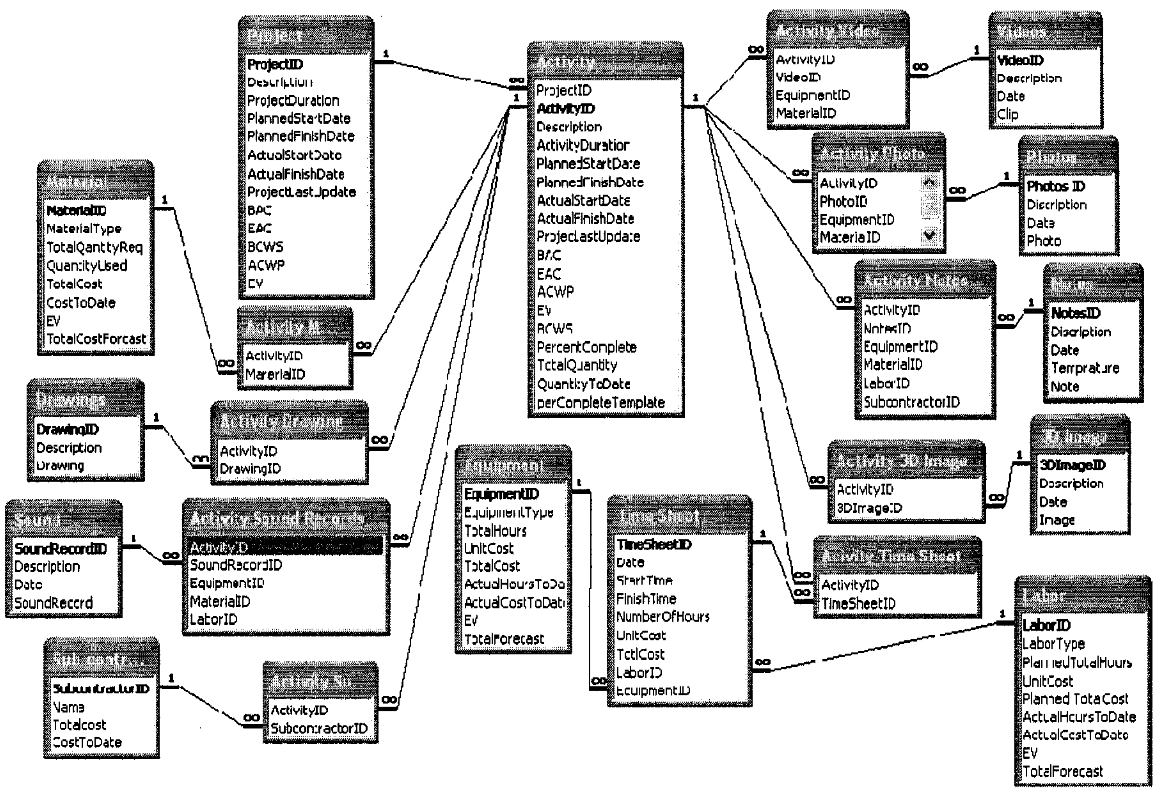



Figure 3-26 ER-Diagram of Developed Database

# CHAPTER 4 LADAR AND PHOTOGRAMMETRY

## 4.1 General

Modeling 3D point cloud images scanned with the LADAR (LAser Distance And Ranging) is a time consuming process that lacks the capability of capturing material type, texture, and color of scanned objects. To extract information from construction sites and update quantities of work completed as well as mapping as-built information with the use of 3D scanners, many scans must be done from different positions and with high accuracy. Although some scanners are available in the market (e.g. the Z-series scanners from RIEGL), which can scan a horizontal angel of 360° in a matter of 3 to 4 minutes, they are relatively expensive (around $ 160,000.00) and photo images are still required to capture the attributes of material, texture and color referred to above. On the other hand, modeling 3D images using photo images alone has its drawbacks such as, for example, the difficulty of locating excavation edges and the large number of targets required to generate sufficient information on object coordinates. Integrating 3D laser scanning with photogrammetry to enhance the 3D modeling process was introduced in this study to overcome limitations associated with the separate use of the two technologies. This Chapter introduces a method that integrates both technologies (i.e. LADAR scanning and Phtogrammetry) to demonstrate the time saved from that associated with the use of LADAR only. The results of test scans, performed in the laboratory, as well as the application of the proposed method to the new building of John Molson School of Business, currently under construction, are presented.

## 4.2 3D laser scanning

At the early stages of this study, the LADAR equipment was utilized without the use of digital photographs to scan objects and determine its geometrical characteristics after modeling scanned images. The laser scanner shown in Figure 4-1 was utilized in the proposed tracking and control system for scanning construction items to capture the data needed to calculate the percentage completion of work in-place. This LADAR model was acquired from the RIEGL Company, and has the technical specifications shown in Table 4-1. The LADAR is connected with USB/serial cable to a Tablet PC (ST4121B Fujitsu) that was purchased and has the specifications highlighted on Table 4-2.

Figure 4-2 illustrate the tablet PC, which also has a Dock with DVD/CD-RW drive, wireless Keyboard and mouse and they are provided so that it can work as laptop. The Tablet PC runs with windows XP tablet edition and has a capability of transforming handwriting and voice into computer characters. Using the LADAR model described above and a Tablet PC, enabled the capturing and processing of the data acquired from the scanning process. The scanning software RiPROFILE provided by RIEGL was installed on the Tablet PC and the software POLYWORKS was employed to model the scanned images and to extract information pertinent to the dimensions of construction items from the point cloud generated through the scanning process. Tests were carried out to determine the accuracy of results obtained by scanning well defined and known items in the department's lab and compare the scanned dimensions with the actual ones.

Table 4-1 LPM-100VHS LADAR Technical Specifications

| Attribute | Specification |
|---|---|
| Scanning range angle "α" | Horizontally: $\pm 180^{\circ}$ |
| | Vertically: $\pm 150^{\circ}$ |
| Positioning accuracy: | $\pm 0.01 gon$ |
| Scanning speed | 40 gon/sec (horizontal and vertical) |
| Range distance "d" | up to 200 m |
| Measurement accuracy | $\pm 2cm$ |

Figure 4-3 illustrates an image in the form of "point-cloud" of the lab door and Figure 4-4 shows the door dimensions after modeling the scanned image using the software POLYWORKS.

## 4.3 Scanning accuracy

Scans were taken from the department's lab. Figure 4-3 depicts an image in the form of point-cloud of the door from inside where details of the doorframe cannot be seen. Trial tests were made to get the best resolution so that small details could be seen. To increase the resolution, the angel that the scanner moves horizontally or vertically (to send a new laser pulse), which is called the resolution angle, had to be decreased. Figure 4-5 depicts the scanned image of the doorframe with incremental moving angel of 0.0015 degree and a horizontal rang angle of 2.7 degrees. The dimensions of the door were measured manually and compared to those generated using the scanned image and its subsequent data processing using POLYWORKS.

Table 4-2 Tablet PC specifications

| Attribute | Specification |
|---|---|
| Operating system | Intel PIII-M 933MHz ULV |
| Desk capacity | 60 Gb hard |
| Screen | 10.4" XG Reflective |
| Fax modem | 56K V.90 |
| RAM | 512 MB |
| Connectivity | Ethernet, & 802.11b Wireless LAN, Windows XP Tablet PC Edition English |

There was an error of approximately 1cm in the width of the door, about 0.5%. The measured actual width of the door is 180 cm and that obtained using the proposed automated scanning technology is 179 cm. This error resulted from the difficulty of choosing which point in the point cloud image that represent the door corner to take measurement. Figure 4-4 shows the door dimensions and Figure 4-6 depicts the point cloud at the upper left corner of the door. As the available LADAR will be used in determining percent complete, this error was deemed acceptable in the calculations of the quantities accomplished over each reporting period. During this experimental sessions it was observed that the scanning time was a function of horizontal and vertical resolution angles, which specify the point cloud density of the scanned image. Smaller resolution angle decrease the distance between two points in the point cloud image and accordingly increase the number of points. Figure 4-7 illustrates the vertical resolution angle. To overcome the scanning time constraints and number of scan positions, it was decided to incorporate photo images and utilize it to assist in the 3D modeling process. This proposed integration is explained more in detail in proceeding sections.

The new building for the Faculty of Engineering and Computer Science was considered for site tests. The building is 17 floors high with 2 floors below ground. The LADAR equipment was set to scan construction items like columns and HVAC ducts. Figure 4-8 is a scan that shows the part of a hall with a window and 2 columns. The scanned image was later processed using POLYWORKS to generate the objects representative of the scanned construction items. By selecting the object "Cylinder", a cylinder was drawn, to represent the column shown in Figure 4-8, through the selection of three points from the point cloud. The first two points represent the cross sectional area of the column in form of a circle, while the third point represents its height. To get the best result using the LADAR, many scans were acquired for the same item to avoid other objects between the scanner and the scanned item. Scans should be carried out at the end of a construction working day because of the long time one scan image can take and to avoid disruption of working crews and moving objects around the LADAR equipment. Figure 4-9 is the image of a HVAC ducts in the same construction site, where the ductwork is being monitored using the process described above.

## 4.4 Integrating 3D scanning and photogrammetry

Modeling 3D point cloud images scanned with the LADAR (LAser Distance And Ranging) is a time consuming process that lacks the capability of capturing material type, texture, and color of scanned objects. To extract information from construction sites and update quantities of work completed as well as mapping as-built information with the use of 3D scanners, many scans must be done from different positions and with high accuracy. Although some scanners are available in the market (e.g. the Z-series scanners from RIEGL, Figure 4-10), which can scan a horizontal angel of 360° in a matter of 3 to 4 minutes, they are relatively expensive and photo images are still required to capture the attributes of material, texture and color referred to above. On the other hand, modeling 3D images using photo images alone has its drawbacks such as, for example, the difficulty of locating excavation edges. This following sections introduce a method that integrates both technologies (i.e. LADAR scanning and Phtogrammetry) to collect data from construction sites pertinent to quantities of work accomplished, used subsequently for progress reporting. Integrating 3D scanned images with digital photo images to enhance the 3D modeling process allows the overcome of limitations associated with both technologies. One of these major limitations is the time required to scan the construction from different positions to get enough information needed for the modeling process. This method saves time related to the number of scans needed and enables the use of scanners with low accuracy, which saves cost and makes it feasible to the construction industry. The proposed method utilizes (1) a commercially available modeling software (PHIDIAS), which models both 3D point cloud images and photo images. (2) 3D scanner (LPM 100 VHS LADAR), (3) the software RiProfile, installed on a tablet PC (Fujitsu - Stylistic ST4121B) to generate 3D "point clouds" from different positions and (4) a Digital camera (Olympus C750). The process starts by scanning an object from different positions and capturing digital photo images of that object, not necessarily from the same scanning position. The resulting point cloud images and digital photo images are then merged using the software PHIDIAS to enhance the quality and accuracy of the geometric characteristics of the scanned objects, which in its processed digital form is used to estimate the quantities of work completed. The proposed method is used to report cumulative progress report.

### 4.4.1 Modeling 3D scanned and photo images

The modeling software PHIDIAS from RIEGL is an additional application to MicroStation, which must be first installed before the installation of PHIDIAS proceeds. When the point clouds are combined with digital photo images, then one may benefit from the advantages of both data sources. The determination of the depth (3rd dimension) works very well in the case of point clouds. The combined evaluation technique makes it possible to measure 3D coordinates directly even though much less images are used unlike in the case of photogrammetry alone. The three dimensional information of the point cloud, the accuracy in detail and the better feasibility for interpretation of the digital images complement each other very well. As an important precondition for the subsequent evaluation process the photo images and the point clouds has to be brought into a common coordinate system. The point clouds have been registered by the scanning software application RiProfile. At the end of the scanning procedure, all individual point clouds are available in a mostly local coordinate system. A training course was provided by RIEGL Laser Measurement Systems at their office in Orlando to demonstrate the software capabilities for modeling 3D images from point clouds and digital photo images. The following sections describe how photo images are oriented with point cloud images.

### 4.4.2 Photo image orientation

Digital photo images have to be oriented to the same coordinate system of the point cloud coordinates in order to make sure that image data and point cloud data coincide without fault during its common display on the computer monitor. There are two methods to initialize projects with point clouds and images. In the first, orientation data are imported in the case of laser scanners with a firmly mounted camera. In this case, the photo images are taken from the same angle and has the same distance to the object as the scanner. The second case is the orientation of images recorded by a separate camera. This case was adapted in this study because it allows taking more images and from different angle as the scanner to the object. It also enabled taking images with closer range than the scanner. Some special laser scanner instruments are equipped with a digital camera, which is mounted on the top of the scanner body (see Figure 4-10).

Accordingly, besides the point cloud data, the camera records additional photos at every scan station, which are oriented automatically with the point cloud coordinates. When the photos are recorded independent from the laser scanner, the images have to be oriented in a further step. In order to measure in photos, for each photo 6 external orientation parameters (position x,y,z and rotation omega, phi, kappa) and the internal camera parameters (focal length, coordinates of principal point and distortion parameters) are needed. Two methods are available in PHIDIAS for measuring from photo images taken separately from the scanner.

**a) Single image orientation with spatial resection.**

When digital photo images are recorded separate from the laser scanner, they have to be oriented in a further step. This is done in the same object coordinate system as the point clouds are given. In this case, common points are measured in photos and the 3D model (see Figure 4-11). The function used in PHIDIAS to perform this orientation process is called special resection. The accuracy of this method is not high as it relies on finding common points in the two images. This method was though applied to this study because the information needed is for progress measurement and the calculation of percent complete.

**b) Orientation with bundle adjustment program.**

In comparison to the single image orientation, the advantage of the bundle adjustment is that not so many control points are needed (only 3 for the whole project, not 4 in each photo), it is possible to calculate the camera parameters simultaneously, the accuracy is better and reliability is higher. The image coordinates of several common points (tie points) are measured in photos from different positions. The accuracy of the orientation parameters depends on the image scale and camera angles. It is important that not all photos are made from the same position because otherwise the intersection angles of the image rays are too small. When the photos and the point clouds are in the same coordinate system, then the measurement can be done in different ways:

4.4.2.b.1 Multi-Image-Measurement

The image coordinates of the same point is measured in 2 or more photos from different positions. The 2D image coordinates define image rays and the intersection of the rays is the 3D position. It is necessary to identify the same points in the photos.

4.4.2.b.2 Multi-Image-Measurement with help of epipolar lines

The epipolar lines are the visible image rays of the measurements in other photos and help to identify common points. The calculation of 3D coordinates is identical with the first method. Figure 4-12 (Hartley et al. 2003, Shapiro et al. 2001) depicts an object O that is being photographed from two camera positions, P1 and P2. The actual image planes I1 and I2 had to be placed behind the camera focal points P1 and P2 on a rotated image and for simplicity the planes were placed in front of the camera. O1 and O2 are the images of the object O on both image planes where E1 and E2 are the reflection of both camera focal points P1 and P2 on the other image planes and they are known as epipole points. Both epipoles E1 and E2 and both focal points P1 and P2 lie on a single line. The line P1-O is represented as a point on camera P2 image plane because it is directly in line with that camera's focal point. However, the right camera sees this line as a line in its image plane. That lines E1-P1 and E2 P2 are called epipolar lines and they are used in the modeling process of PHIDIAS software to determine the location of points in 3D space.

4.4.2.b.3 Stereo measurement.

With a special graphics card and stereo glasses it is possible to view 2 photos in stereo mode. In stereo mode it is much easier to measure irregular elements like terrain models because it is not necessary to identify exactly the same point in different photos. Stereo viewing is only possible if the camera directions are approximately parallel, otherwise it is difficult to get a good 3D impression.

4.4.2.b.4 3D-measurement in single photo with point cloud loaded.

Like in stereo mode, it is also possible to measure 3D coordinates directly without identifying common points in different photos, when point cloud surface lock is activated. In this case, two dimensions are measured in the photo and the third dimension, the distance, is defined by the point cloud. This method is not reliable if the measurement is too close to edges or if there is more than one intersection with the point cloud because of parallexes between scanner and camera.

## 4.5 Experimental laboratory work

The proposed system integrates 3D laser scanning and photogrammetry in modeling 3D images to overcome limitations associated with each technology such as number of scans required. To illustrate the importance of this integration a set of experiments were designed and carried out to study the scanner speed on the accuracy of modeling the geometry of the scanned object. The scanner used was the LPM 100 VHS LADAR from Rigel and the scanned objects were boxes placed at an average distance of about 4.3 m from the scanner (see Figure 4-13). The scanner was placed in front of the boxes and only that position was used to generate point cloud data. In the scanner configuration screen (see Figure 4-14) the following information was entered: horizontal start and end angles were set to 236° and 256°, which result in a horizontal range angle of 20°. The vertical range angle was set to 17°, with start and end angles of 95° and 112°, respectively. These angles were constant throughout the experiment.

A total of 17 experiments were conducted where the accuracy were depicted by the resolution measured in mm as shown in Table 4-3. The scanning speed represented by two parameters, the resolution angle and the scanning duration. The resolution angle was varied from 0.015° to 0.75°. As seen from the Table, the time required to scan the same horizontal and vertical ranges varies because the number of points in space generated each time the laser traverses to the object and back increases when the resolution angle decreases. The resolution, or the distance (mm) between points in the point could image, depends on the object's location relative to the scanner and the resolution angle (see Figures 4-

15 and 4-16). For example, the distance between two points in the point cloud image is equal to 7.5 mm for an angle of 0.1°, and a range of 4.3 m. When the scanned object is at a further distance, as in the case of a normal construction site (e.g. 30m), then the distance between the points will increase to 52 mm using the same 0.1 resolution angle. As such, all information within the 52 mm resolution limit is effectively lost. If the resolution angle is set to 0.015 then the average resolution based on Table 4-3 is about 1 mm, but for a 30 m distance between the scanner and the scanned object, an average resolution of 7mm would be expected.

Scanning time is also dependent on horizontal and vertical range angles. Since test angles were relatively small (20° and 17°), scanning times varied from 58 min, in the case of a 0.015° resolution angle, to 15 seconds in the case of 0.75° resolution angle (see Figure 4-15). In construction site applications, the range angles are normally larger and sometimes the horizontal range angles are set to about 160° to 180° to scan the entire construction site, which results in scanning duration of several hours. Two of the point cloud images of the test scans are shown in Figures 4-17 and 4-18. The resolution angle in Figure 4-17 is 0.015°, with a scanning duration close to one hour (see Table 4-3), while the resolution angle in Figure 4-18 is 0.2°, with a scanning duration of about 1 min. The difference in the point cloud intensity between the two scans is evident. The limitations associated with 3D scanning and digital photo imaging can be alleviated by integrating both technologies (El-Omari et al. 2008). Integrating 3D scanning and photo imaging can reduce the time required to obtain reliable construction project data. In addition, such integration reduces the cost involved as it allows for the use of less expensive, low accuracy scanners. To get enough information several scans must be conducted from different positions; however, using photographs can eliminate this need. Also, scanning with high resolution is no longer a necessity since information lost when scanning with low resolution can be obtained from the associated photo images.

Table 4-3 Scanning configurations

| Scanning Session | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Resolution Angle (Deg.) | 0.015 | 0.025 | 0.035 | 0.045 | 0.075 | 0.100 | 0.125 | 0.150 | 0.175 | 0.200 | 0.225 | 0.250 | 0.275 | 0.300 | 0.500 | 0.750 |
| Scanning Duration (Min.) | 58:24 | 35:16 | 21:02 | 13:31 | 04:53 | 02:34 | 01:37 | 01:09 | 01:01 | 00:52 | 00:46 | 00:40 | 00:39 | 00:38 | 00:23 | 00:15 |
| Resolution (mm) | 1.12 | 1.87 | 2.626 | 3.370 | 5.250 | 7.500 | 9.380 | 11.250 | 13.130 | 15.000 | 16.880 | 18.700 | 20.630 | 22.500 | 37.500 | 56.290 |
| number of points (Thousands) | 841.05 | 508.034 | 302.904 | 194.728 | 70.470 | 36.960 | 23.380 | 16.638 | 12.896 | 9.630 | 7.600 | 5.538 | 5.360 | 4.725 | 1.710 | 0.750 |

The proposed method utilizes: (1) commercially available modeling software (PHIDIAS), which models both 3D point cloud images and photo images, (2) 3D scanner (LPM 100 VHS LADAR), (3) the software RiPROFILE, installed on a tablet PC (Fujitsu - Stylistic ST4121B) to generate 3D "point clouds" from different positions, and (4) a digital camera (Olympus C750). The process includes scanning an object from different positions and capturing digital photo images of that object. The photo images did not necessarily coincide with scanning positions. The data resulting from point cloud images and digital photo images were then merged using the software PHIDIAS to enhance the quality and accuracy of the geometric characteristics of the scanned object. Figure 4-19 shows the photos with the scanned image, and the outcome of the merging process is shown in Figures 4-21 and 4-22. Figure 4-21 depicts the merging of the photo with the 0.2° resolution angle scan image and Figure 4-22 with the 0.015° resolution angle scan. Merging photo images with scanned images can be done either by assigning targets with known object coordinates or by finding common points on the scanned and photo images, like corner points on the boxes in the test example. The special resection method, described in pervious section, was used for the orientation process of photo images and point cloud images section

This proposed method would facilitate construction site scanning since it reduces the number of scans needed and also saves scanning time by utilizing large resolution angles. It also provides needed information on the material type and texture of the object to be scanned. For example, if unpainted wooden and steel doors are scanned, it will be hard to determine the type of door material from the scan image alone and a photo image is necessary to provide this information. The actual volume of the boxes where measured and found to be 0.36 $m^3$.

Table 4-4 Difference in volume with different scanning resolution angle

| Resolution angle | Vol. m3 | # of scans | Total scan time | error |
|---|---|---|---|---|
| 0.015 | 0.367 | 4 | 4 hr. | 2 % |
| 0.2 | 0.345 | 4 | 5 min | 4 % |

To calculate the volume using only the point cloud (Table 4-4), four scan position where performed from each side of the object. As shown in Figure 4-17 for the case of 0.015° resolution angle, it was hard to locate the borders of the boxes and accordingly the volume was found to be 0367$m^3$ with a error of about +2 %

not to mention the time needed to scan the 3 other positions which was about one hour each. In the case of 0.2° resolution angle, the volume was equal to 0.345 $m^3$ with about –4% error and this is because of the missing points due to the level of accuracy shown in Table 4-4. The volume was calculated using only the photo images for modeling. Four photographs were used to find the geometrical characteristics of the object (see Figure 4-20). The first step was to do the orientation using the special resection method explained in section 4.4.2. To do so, the corner points were identified in one image and the same point had to be identified and located in the second image. It is worth noting that finding common points in the experiment is much easier than in the case of earthmoving operations due to the difficulty in finding enough common points in the second case. The volume was calculated using the photographs to be 0.364 $m^3$ which is very close to the volume measured manually 0.36 $m^3$ with an error of about 1% (see Table 4-5).

Table 4-5 Comparison between modeling with scanned, photo images and after combining both technologies

| Modeling type | Number of scans or photographs | Volume in $m^3$ | Error in % |
|---|---|---|---|
| Laser scanning | 4 | 0.367 | 2 |
| Photogrammetry | 4 | 0.362 | 1 |
| Laser scanning & photogrammetry | 1 scan and 2 photographs | 0.359 | 0.27 |

After combining the photos with the scanned image it was found that the modeling process required only two photographs, which saves time during the orientation process as the scanned image helps in finding the 3D coordinates. It was also found that finding the edges of the object was easier than in the case of using only the scanned image due to the presence of the photo images. Another important observation was found during 3D modeling from photo images is that objects with undefined geometrical characteristics as in the case of excavation are difficult to model. Table 4-5 summarizes the findings of a comparison among the three methods. The last column of this table depicts the error associated with each method in calculating the volume. The process of merging photo images and the scanned images of the boxes is shown in Figures 4-21 to 4-24. Figures 4-23 and 4-24 illustrate the point cloud density in the cases of 0.015° and 0.2° resolution angels. Without the help of photo images, it would be difficult to locate the edges of the object used in this study. When calculating the volume after extracting the dimensions with the help of photos it was found to be $0.359m^3$ in both cases 0.015° and 0.2° resolution angles. This indicates that scanning with a large resolution angle of 0.2° does not reduce the accuracy. As well, the use photo images jointly with LADAR scanning saves the time of required scanning.

## 4.6 Data processing of scanned images

### 4.6.1 Site scanning

A new building under construction at Concordia University in Montreal was considered for scanning. The construction site is 60 m x 40 m and scans were performed along its length (see Figure 4-25). The number of scans and scan positions per day are shown in Table 4-6. The purpose was to model scanned images and estimate the quantity of work performed at the end of each working day. The time required for a single scan depends on the vertical and horizontal resolution angles, as previously discussed. For a construction site of that size it was necessary to scan with a wide horizontal angle of about 200° and vertical range angle of 59°. The vertical and horizontal resolutions angles were both set to 0.2°. The time required to scan this range was 26' 36", and the number of points in the point cloud image was 295,295. The second factor affecting resolution is the range or distance between the scanner and scanned object. The range used varied from 1 m to about 50, with an average of about 30 m. With a 30 m range the distance between two adjacent points in the point cloud image would be about 10cm.

Table 4-6 Construction site scan log

| No. | Date | Number of Scan positions | number of scans | Time 1st scan | Temperature |
|---|---|---|---|---|---|
| 1 | 23/Mar/07 | 1 | 6 | 18:00 | 4 |
| 2 | 27/Mar/07 | 1 | 2 | 19:00 | 7 |
| 3 | 30/Mar/07 | 2 | 3 | 18:20 | 4 |
| 4 | 2/Apr/07 | 1 | 1 | 15:00 | 7 |
| 5 | 3/Apr/07 | 2 | 3 | 17:30 | 9 |
| 6 | 5/Apr/07 | 1 | 2 | 17:00 | 6 |
| 7 | 9/Apr/07 | 1 | 1 | 18:00 | 8 |
| 8 | 10/Apr/07 | 1 | 1 | 17:15 | 5 |
| 9 | 13/Apr/07 | 1 | 1 | 11:30 | 1 |
| 10 | 17/Apr/07 | 1 | 1 | 17:00 | 5 |
| 11 | 19/Apr/07 | 2 | 3 | 18:00 | 9 |
| 12 | 25/Apr/07 | 2 | 4 | 17:20 | 6 |
| 13 | 1/May/07 | 1 | 1 | 17:00 | 14 |
| 14 | 12/May/07 | 2 | 4 | 14:00 | 11 |
| 15 | 14/May/07 | 2 | 2 | 17:30 | 21 |
| 16 | 18/May/07 | 3 | 13 | 17:15 | 12 |
| 17 | 22/May/07 | 1 | 2 | 17:00 | 19 |
| 18 | 29/May/07 | 1 | 2 | 17:00 | 22 |
| 19 | 2/Jun/07 | 2 | 2 | 14:00 | 23 |
| 20 | 8/Jun/07 | 1 | 1 | 17:00 | 30 |
| 21 | 11/Jun/07 | 1 | 1 | 17:00 | 29 |

This of course is considered low accuracy, and if the resolution angle was decreased to give a distance of about 5 mm between points, then resolution angle must set to 0.01°. The horizontal resolution angle was set to 0.01° and the scanner automatically set the vertical to 0.027°. This resulted in a scan time, for the same horizontal and vertical range, that approached 42 hours with about 37 million points in the point cloud image (see Figure 4-26). Since a number of scans must be taken at the end of each working day it was impossible to match scanner configurations with scanning requirements at this level of resolution.

Despite the fact that higher speed scanners are available, such as the Z-series from RIEGL (see Figure 4-10), it is clear that even after scanning with higher resolution the scanned image will lack information pertinent to texture and color, and a photo image must be used to aid the 3D modeling process. In addition, several scans must be taken from different positions to represent the site in a 3D image, and it was not possible to scan the construction site from its four sides due to obstructions (see Figure 4-25).

### 4.6.2 Photo images for 3D modeling

It was observed when working with the LPM 100 VHS LADAR that when the resolution angle was decreased the point cloud image would become very congested and point distributions were not in the same plane or level. Also, it is time consuming to model 3D images from digital images only since many targets with known coordinates must be positioned.

As illustrated in Figure 4-27, targets must be placed within an area to identify the coordinates of the different objects in the image. The process of taking photo images during the scanning process is achieved by installing a digital camera on top of the scanner, which is synchronized with the scanning procedure. The disadvantage of this method is that images are always taken from the same distance and the same angle as the scanner. Since the LPM 100 VHS LADAR could not be mounted with a digital camera it was decided to integrate photo images taken separately with scans later during the modeling process. This allowed for freedom in photo imaging angles and distances. Closer distances for photography, than the scanner distance, provided more information about the scanned object and minimized the number of scans required.

### 4.6.3 PHIDIAS 3D modeling

A scan was performed on the same construction site with scanner configurations set as follows: horizontal range angle 165 ° and vertical 55° with horizontal and vertical resolution angles set to 0.2°. These configurations resulted in a total of points 227,976 points in the point image and scanning time of 20'45". The scanned image was then exported to Phidais modeling software and the resulting image is shown in Figure 4-28. Digital photo images were also taken from different angles to support the 3D modeling process.

Due to the scanner position, some areas were not scanned due to obstructions and are represented as black or shaded areas (see Figure 4-28). The use of a digital camera enabled the gathering of information within these shaded areas (see Figure 4-29). Figure 4-30 Illustrate the shadowed area created in result of the LADAR position and range angle. After importing the scanned image from Riprofile to PHIDIAS and loading the photo images they must be oriented to link them together. The orientation process is done with the special resection method available in Phidais software.

Using this linking process, common points in the point cloud and photo images are selected and joined together (see Figure 4-31). Another way of connecting the images is by knowing the 3D coordinates of the same points. This is important in the case of modeling 3D images for as-built information purposes. As mentioned above the purposes for modeling is to estimate the quantities of work performed and therefore finding a common point in the scanned and digital image would be sufficient for that purpose. The result of using a common coordinate point is shown in Figures 4-32 and 4-33. For example, the corner of a wooden pallet was used as common point in both the scanned and photo image. The problems associated with low resolution, such as 10 cm between scan points in the point cloud, can now be solved and object dimensions can be extracted more accurately with only one scan and few digital images. The volume of the elevator shaft excavated pit was measured on site and found to be 887.5 $m^3$. The volume was measured from the scanned image and found to be 450 $m^3$ and the reason for that is that the scan was taken from only one position and two sides were missing information as in Figure 4-29. With the help of the photo images, these missing information were completed and the calculated volume was 850 $m^3$ with 5% error. As the excavation was measured with averages because the edges were not clear and that the result of the volume calculation was used to estimate % completed work, this result was acceptable. The process of integrating photogrammetry with 3D laser scanning to calculate the volume of the elevator foundation pit is explained in the following section.

## 4.7 Enhancing scanned point-cloud via photogrammetry

Concordia University's John Molson School of Business building site is located downtown Montreal, which made it difficult to move the LADAR equipment, due to its size and weight, freely to the site perimeter and perform scans needed for modeling 3D images. The only available side to position the LADAR was the west border of the construction site as shown in Figure 4-25. When the elevator shaft foundation was scanned, two sides of the shaft were represented as shaded or black area as in Figure 4-34. These shaded areas are created because the laser pulses of the LADAR can not reach these spots as illustrated in Figure 4-30. To get more information on these shaded areas, more scans had to be performed from the other side of the excavation pit, which was not possible due to the difficult site access. To solve this problem separate digital photo images were taken of the shaded area.

### 4.7.1 3D modeling using photo images

To have accurate results the camera parameters had to be known through a calibration process performed by the PHIDIAS software. The camera used was OLYMPUS C750. A file for this camera was opened in PHIDIAS where the camera parameters were recorded. The focal length were set to 6 mm with a resolution of 2288 pixels width and 1712 pixels height. If any of the parameters are changed or the camera model, a new file must be created for these parameters. All photo images used for modeling 3D images were taken with the same wide angle zoom and shortest focal length 6 mm. During the site scan on the 9$^{th}$ of April, the elevator foundation pit were scanned only from one position as shown in Figure 4-30, which created a shadow areas as depicted in Figure 4-34. After the scan few photo images were taken from the other side of the pit as in Figures 4-35 and 4-36. The process of creating point clouds from photo images is performed by first taking at least two photo images of the hidden part from different positions by measuring point elements or lines. These point elements are exported with its coordinate system that to be added to the point cloud of the original image (see Figure 4-38).

### 4.7.2 Image orientation

Images shown in Figures 4-35 and 4-36 are from the hidden part of the excavation pit. Using the epipolar lines explained in section 4.4.2.b.2, common point are identified from both images after turning on the epipolar lines method in PHIDIAS as highlighted in Figure 4-39. These common points are located on the hidden side of the excavation to construct lines used for modeling the 3D image of that side in form and transform it into point clouds (see Figures 4-40 and 4-41). The horizontal constructed lines are then connected with vertical lines as in Figures 4-42 and 4-43 where they are transported into point clouds and saved in a separate file with its coordinates (see Figures 4-44 and 4-45). After loading the point cloud image of the excavation pit (see Figure 4-46), the added point cloud was also loaded and saved with original point cloud adding the missed part of the foundation pit (see Figures 4-47 and 4-48). This process need to be performed with at lease two photo images for each missing part taken from different positions. Measuring foundation dimensions was performed on the elevator foundation before pouring concrete. The process of photo image orientation was performed to align the image with the 3D point cloud as in Figures 4-49 and 4-50. The foundation was measured as in Figure 4-51 and compared with data received from the contractor. The area measured from PHIDIAS was found to be 13.18m x 11.53m, while that from the contractor, which was calculated from the drawings, was 13.1m x 11.4. The developed method circumvents a set of limitations associated with the separate use of laser scanning and digital photo imaging. The proposed method enables cost effective and timely extracting of valuable information regarding quantities of work performed at the end of each working day. These quantities are then used to estimate percent completion and to report progress made on site.

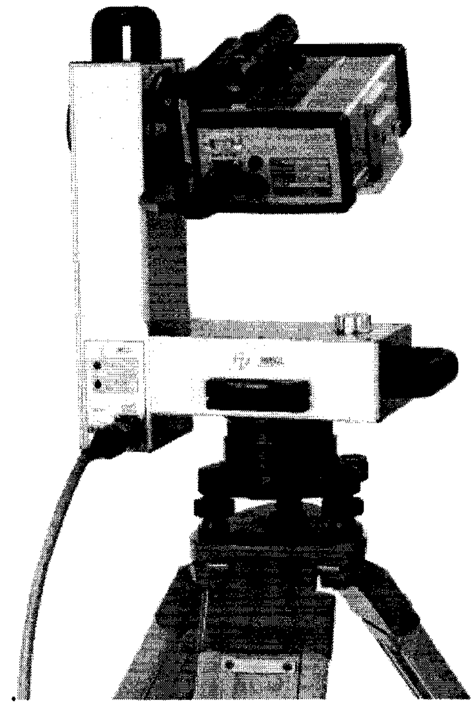


Figure 4-1 LPM-100 VHS LADAR (RIEGL)

Figure 4-2 Pen-Based computer (Fujitsu Stylistic ST4121B)

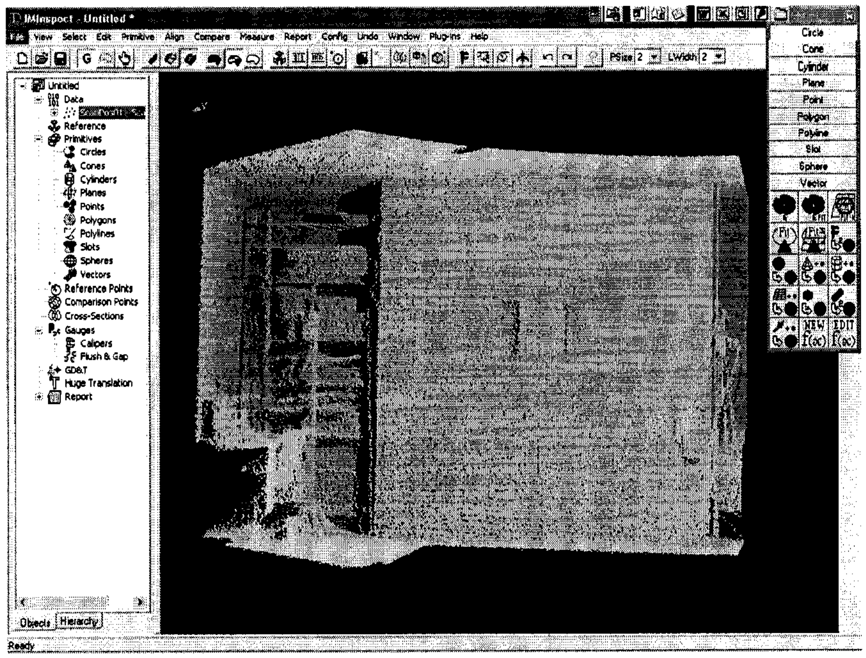


Figure 4-3 Scanned image

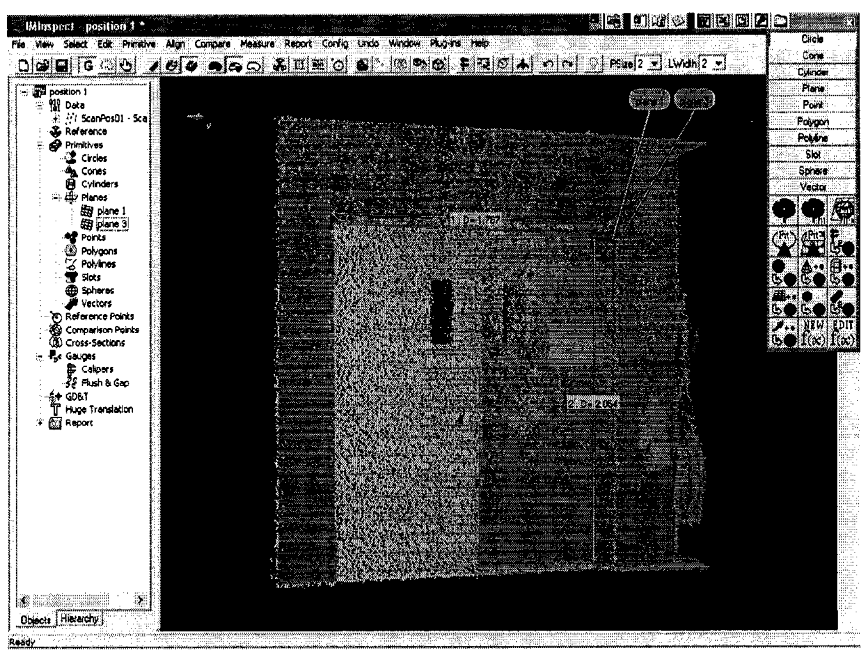


Figure 4-4 Processed image

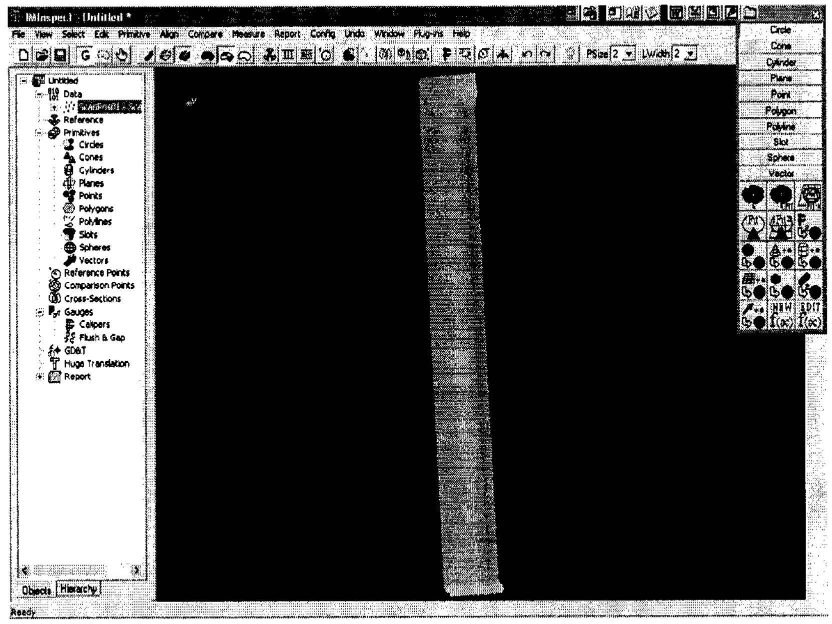


Figure 4-5 Scanned doorframe Image

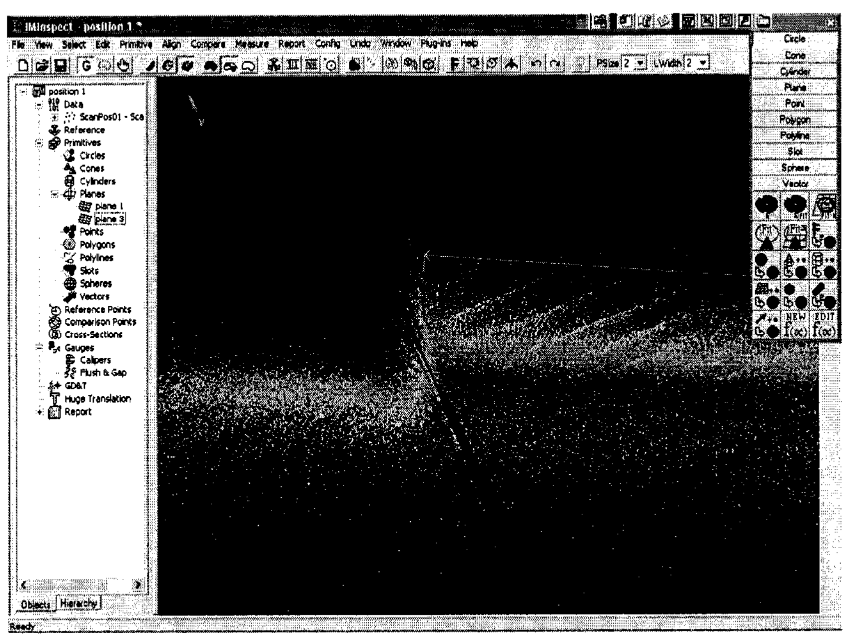


Figure 4-6 Identifying door dimensions

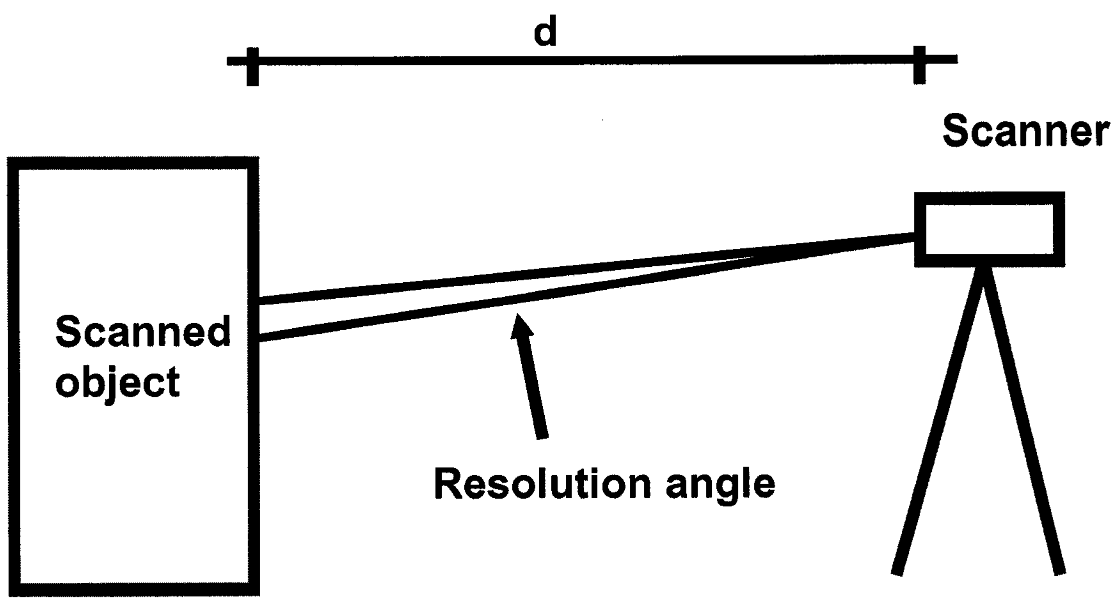



Figure 4-7 Resolution angle

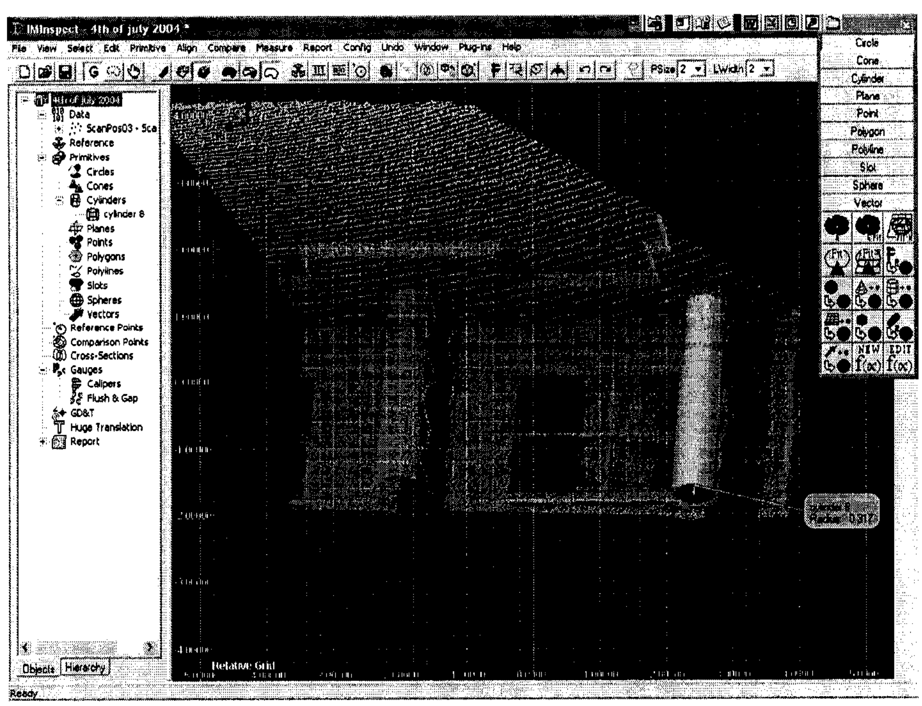


Figure 4-8 Modeling scanned image with Polyworks

Figure 4-9 Scanned Image of HVAC duct

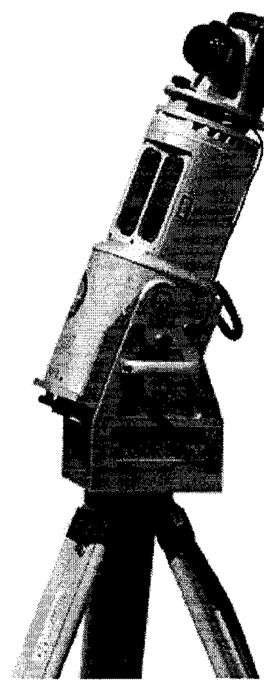


Figure 4-10 LMS-Z420i from RIEGL

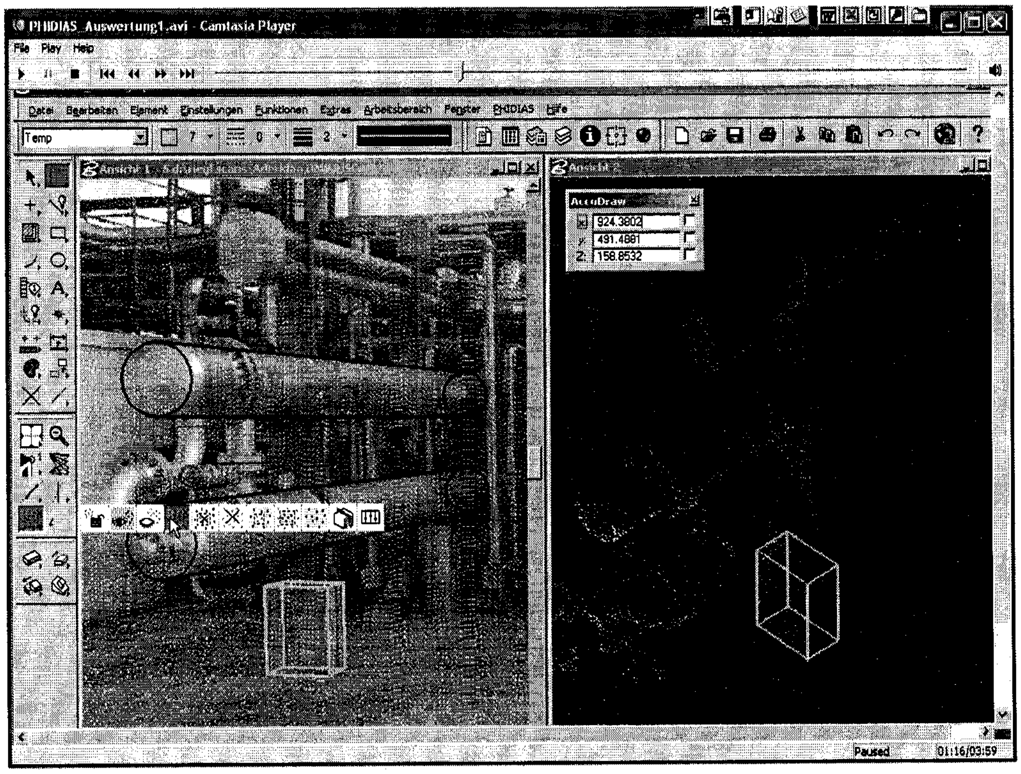



Figure 4-11 Point cloud and photogrammetry

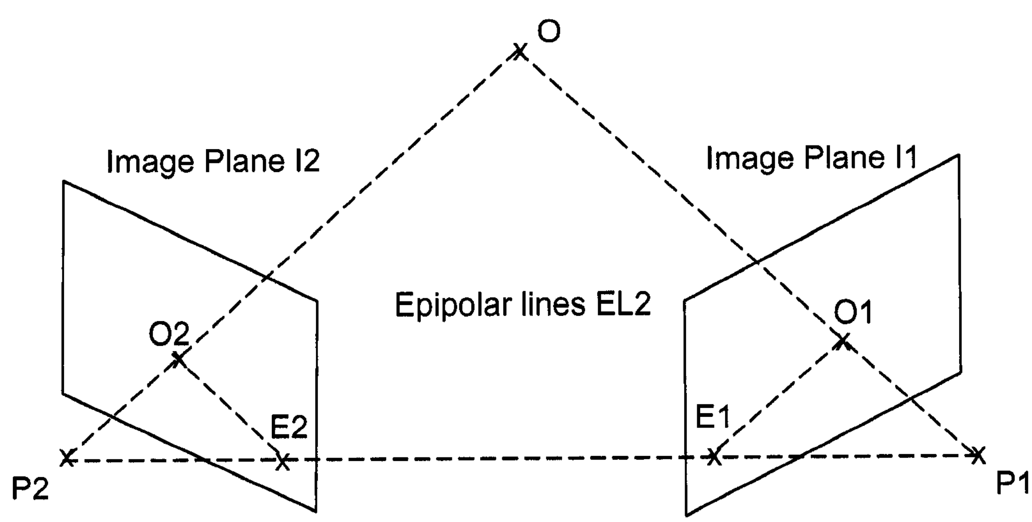
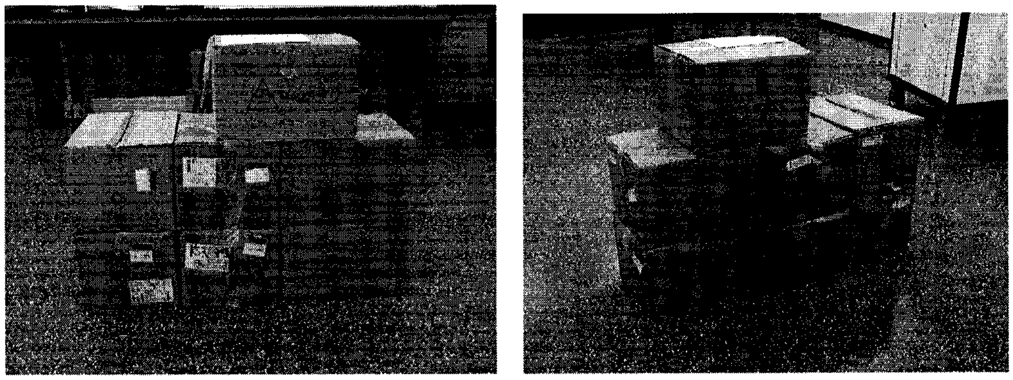



Figure 4-12 Epipolar lines



(a) (b)

Figure 4-13 Test object a) front b) back

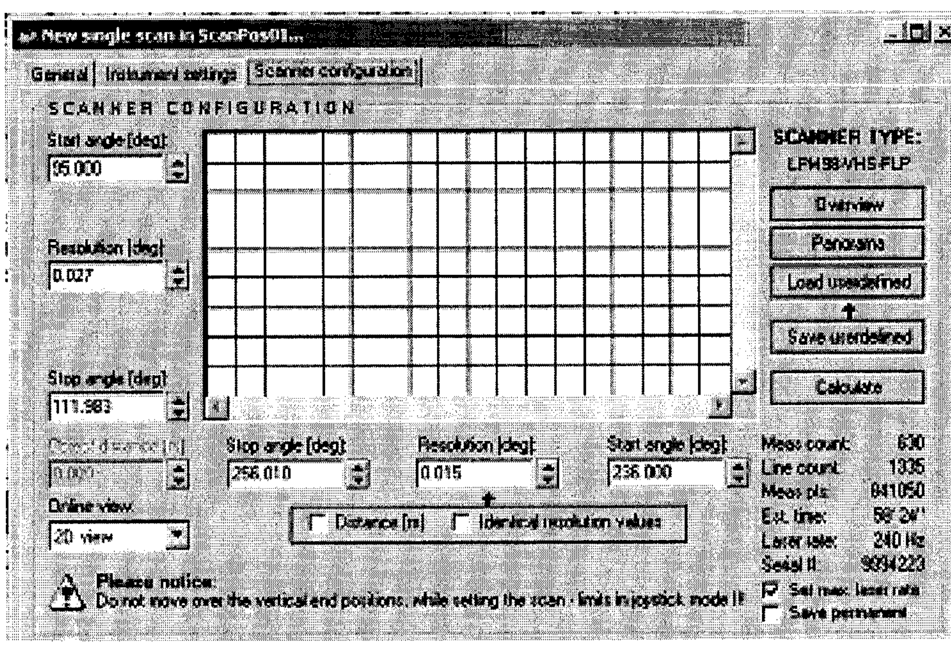



Figure 4-14 Scanner configuration

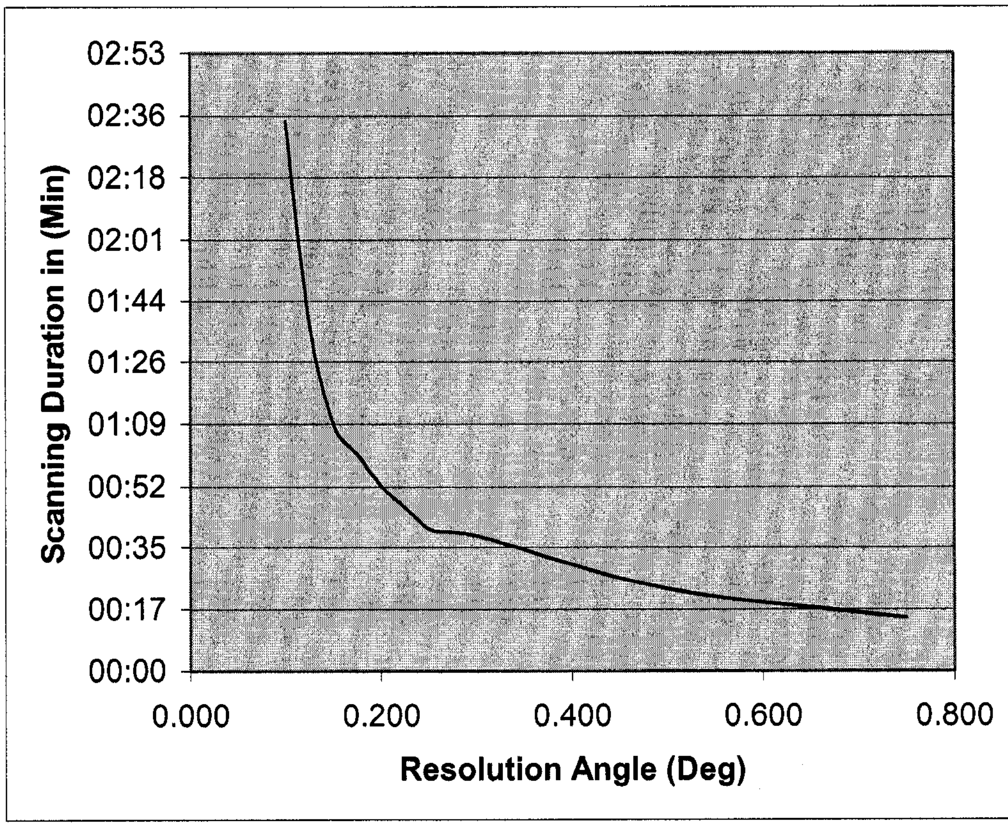



Figure 4-15 Resolution versus scanning duration

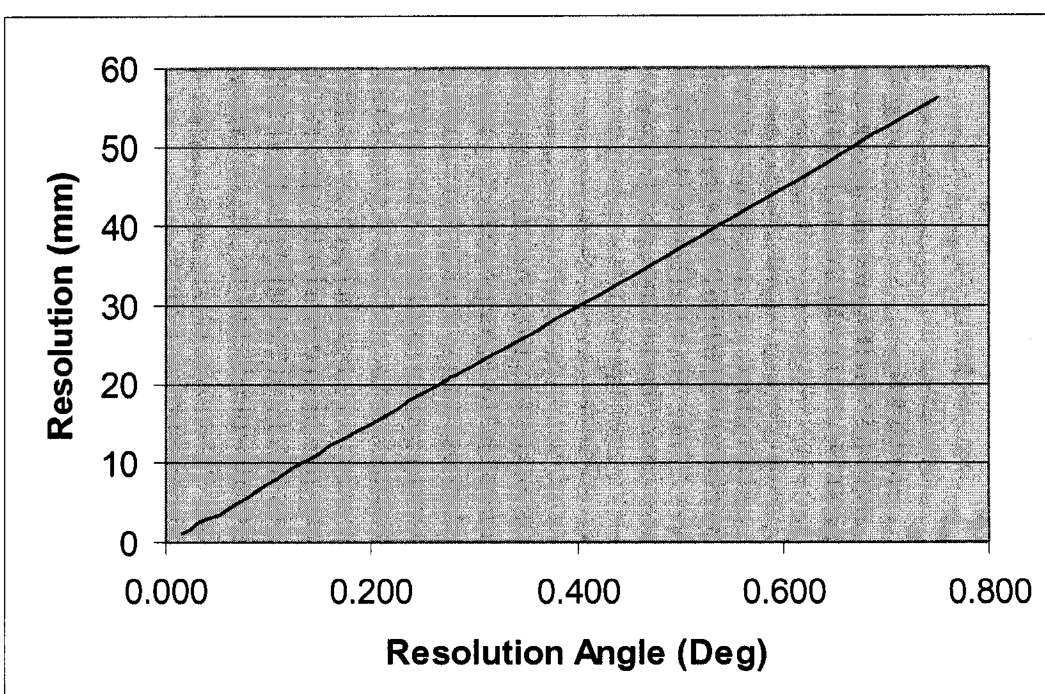



Figure 4-16 Resolution versus resolution angle

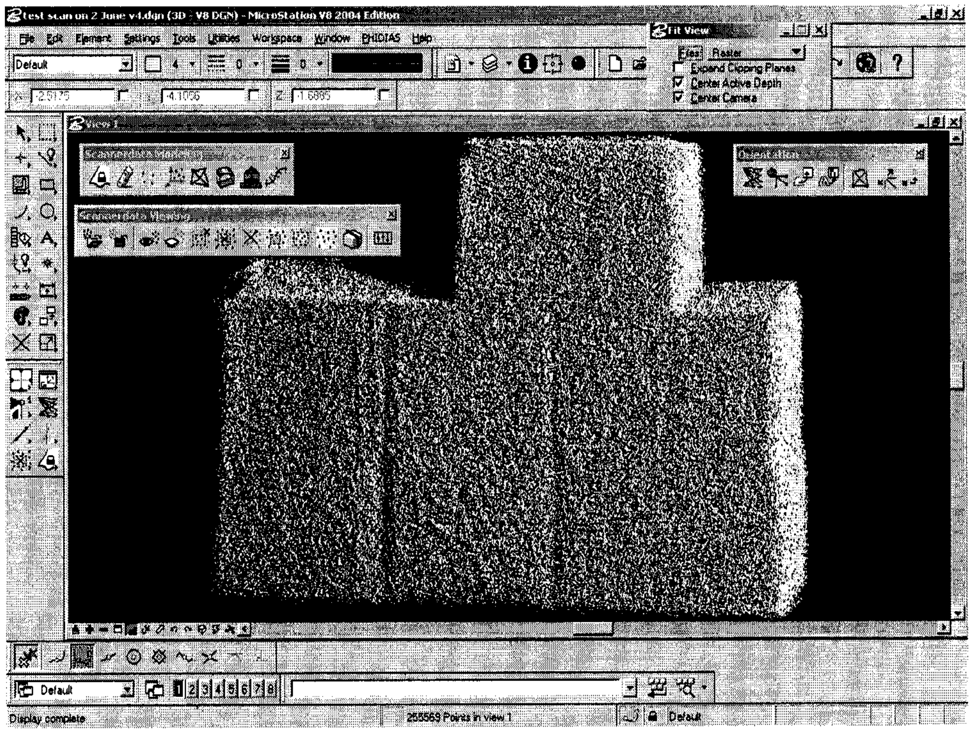


Figure 4-17 Point cloud image with 0.015° resolution angle

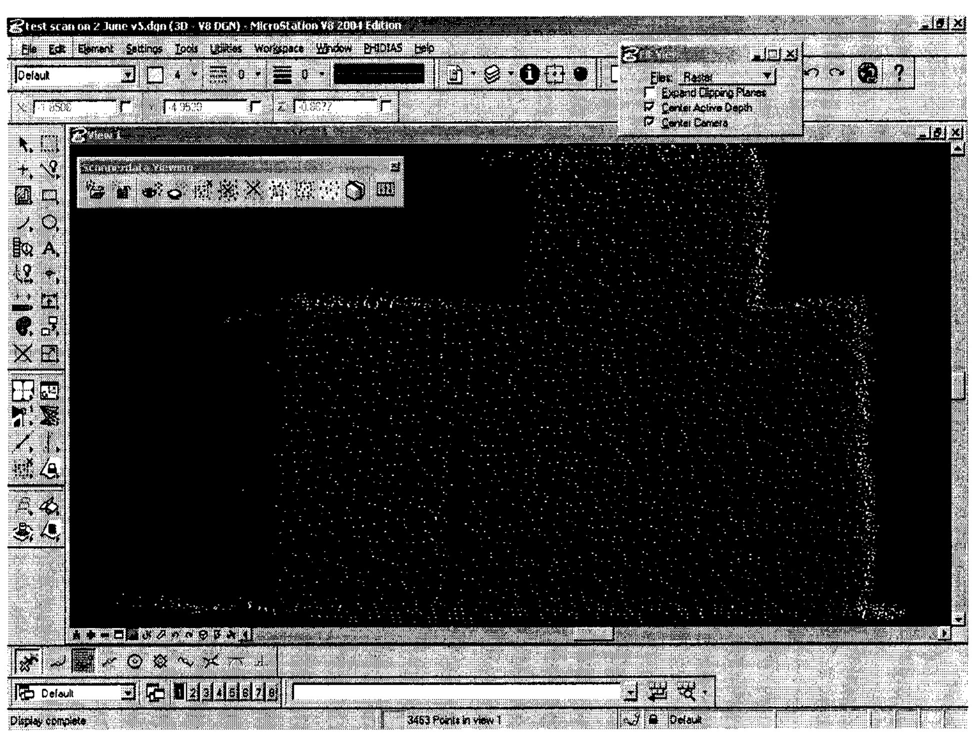


Figure 4-18 Point cloud image with 0.2° resolution angle

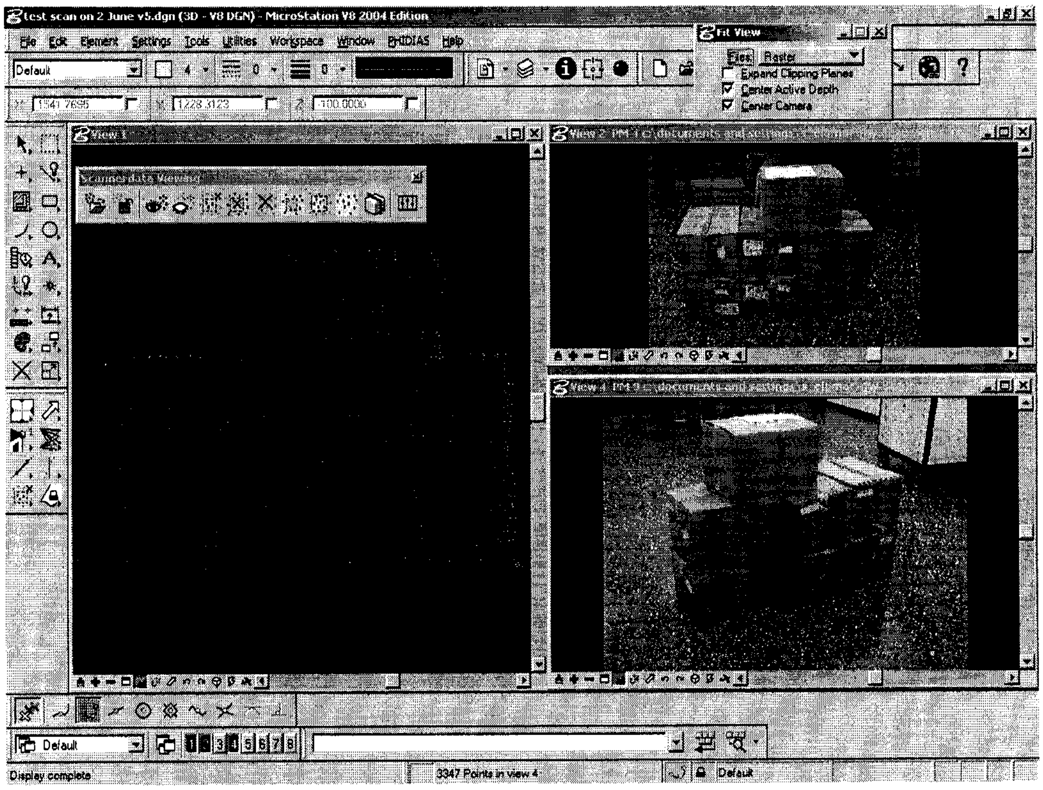



Figure 4-19 Point cloud and digital photo images

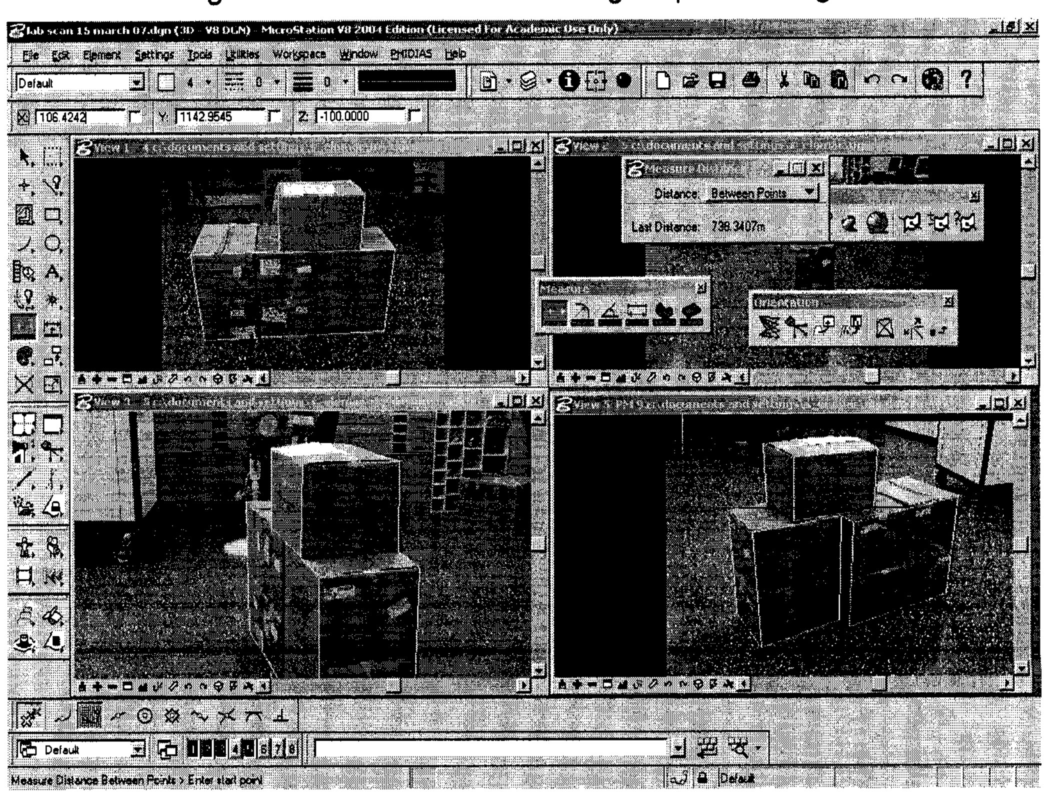



Figure 4-20 3D Modeling from photo images

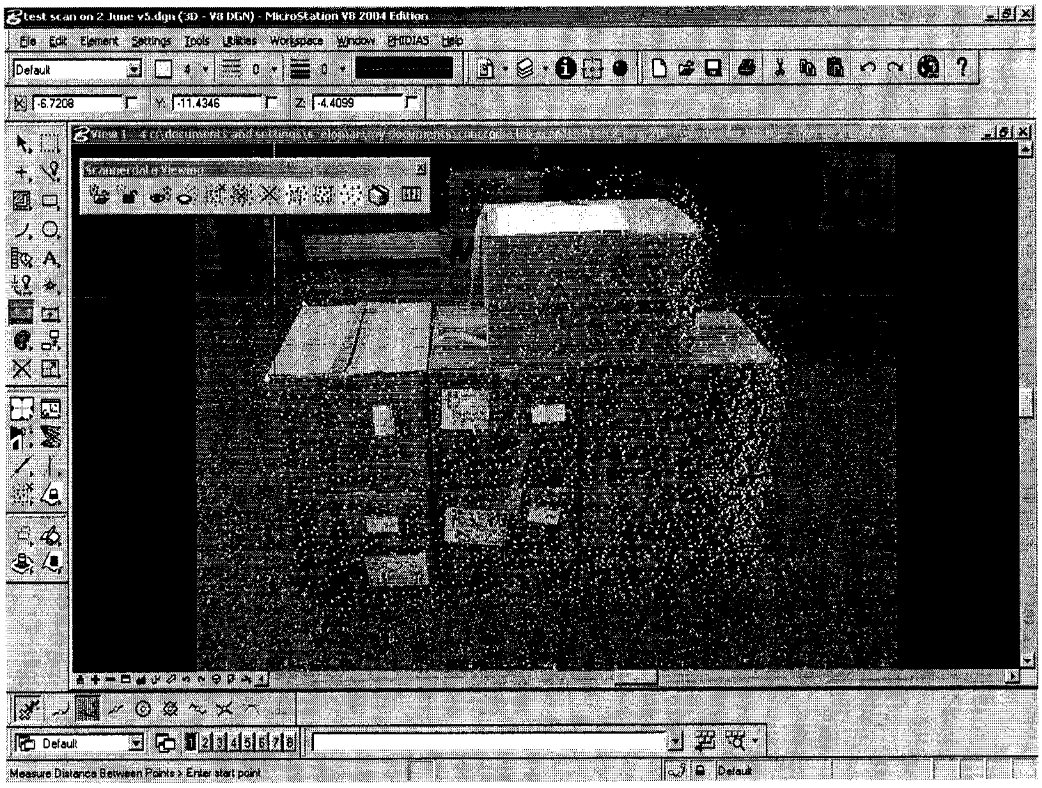



Figure 4-21 Merging photo and 0.2° resolution angle point cloud images

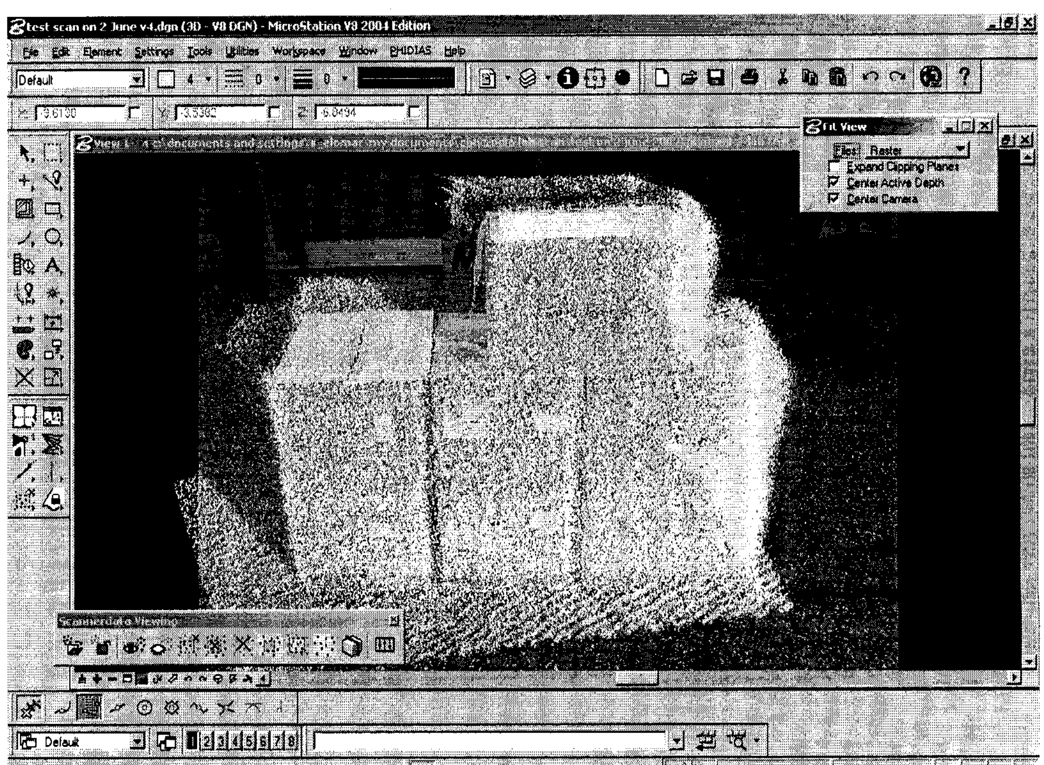



Figure 4-22 Merging photo and 0.015° resolution angle point cloud images

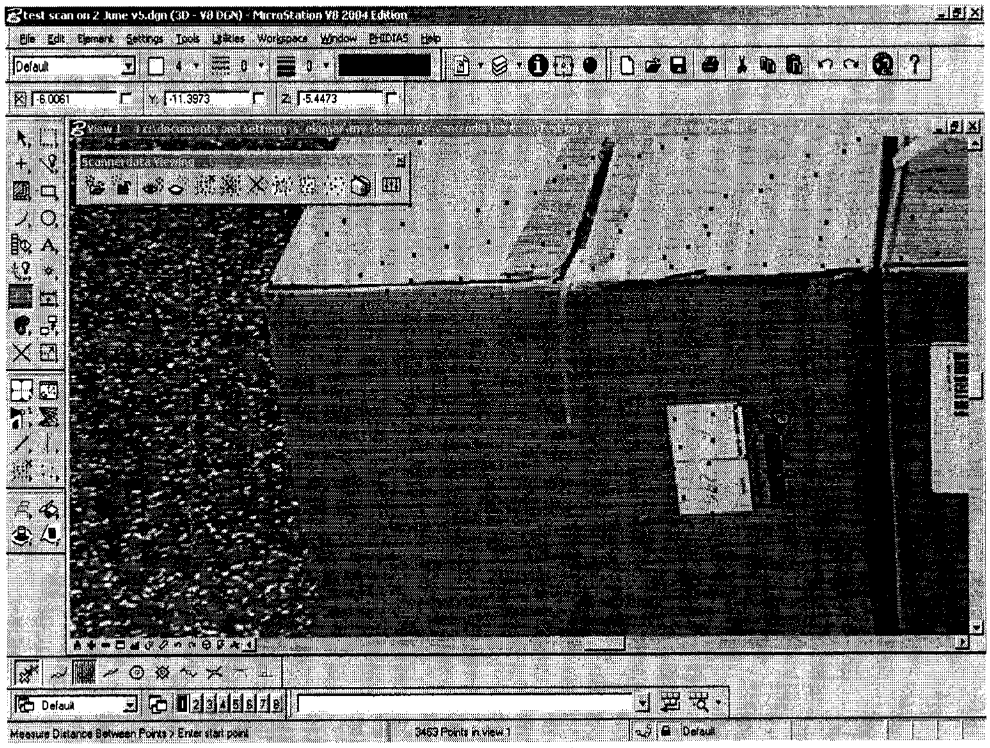



Figure 4-23 Point cloud density for resolution angle 0.2°

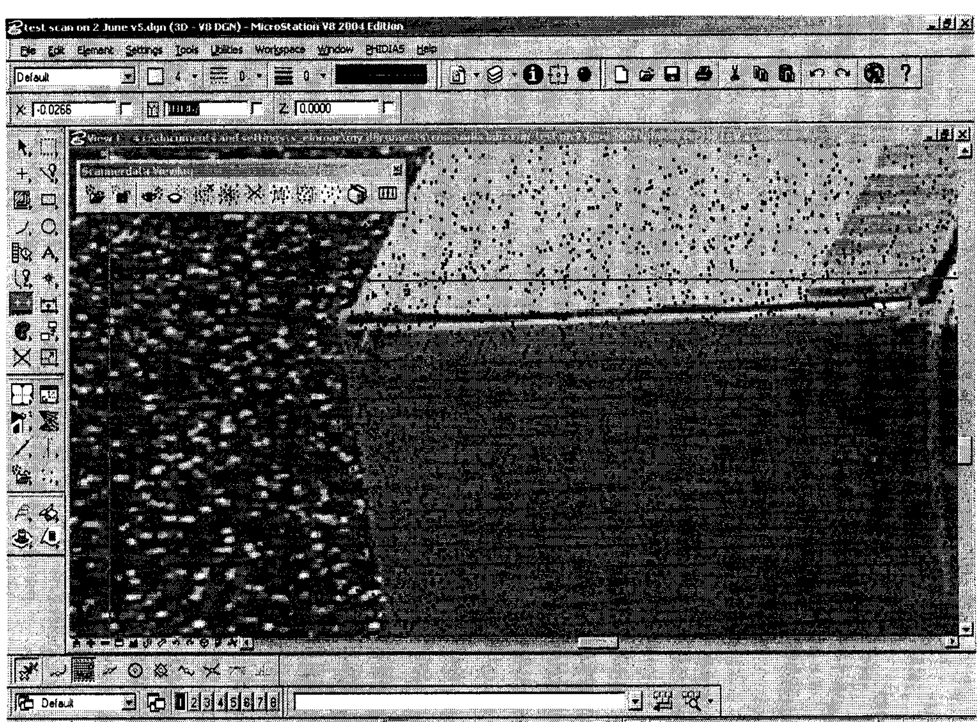



Figure 4-24 Point cloud density for resolution angle 0.015°

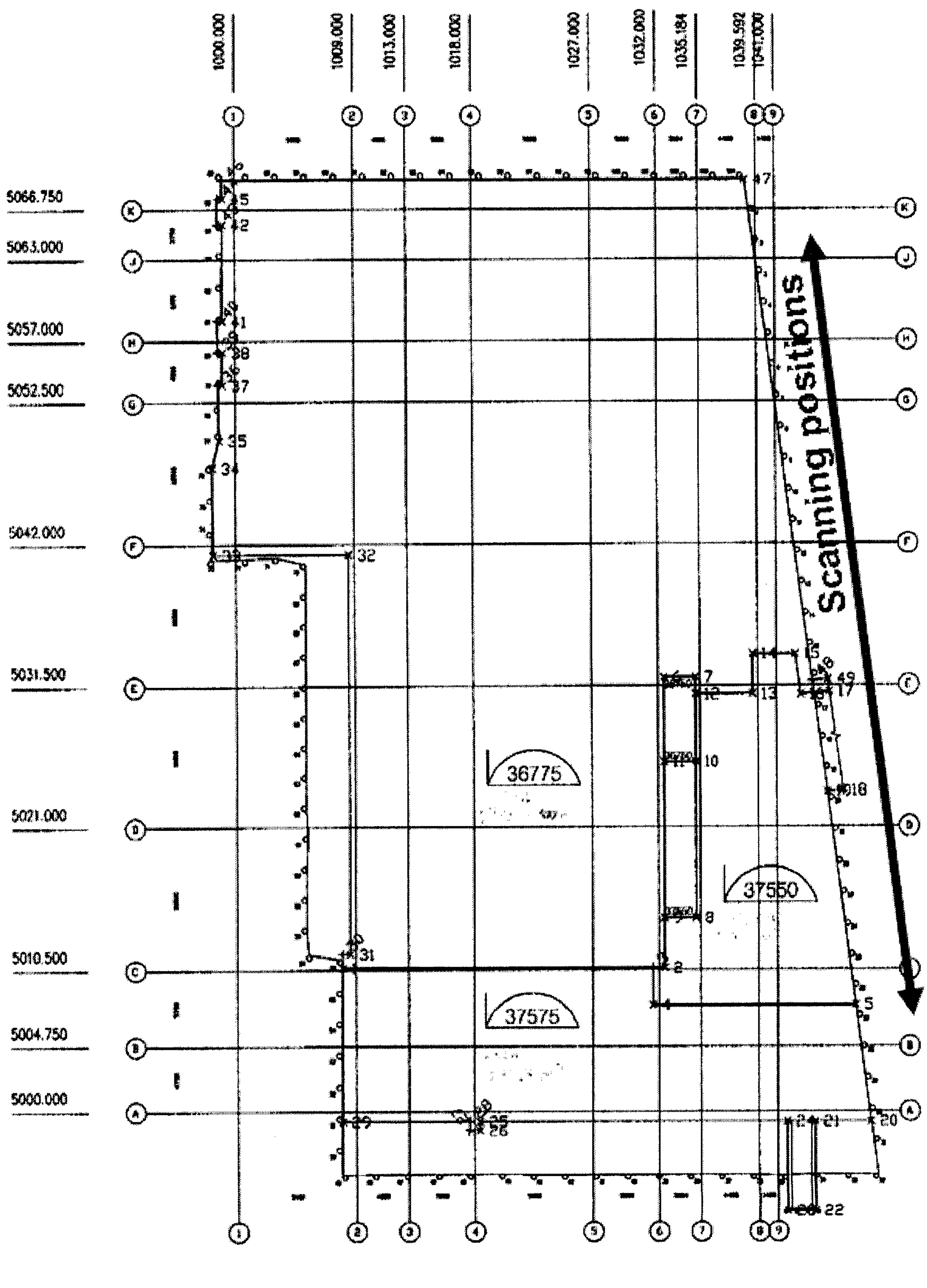



Figure 4-24 Construction site scanning positions

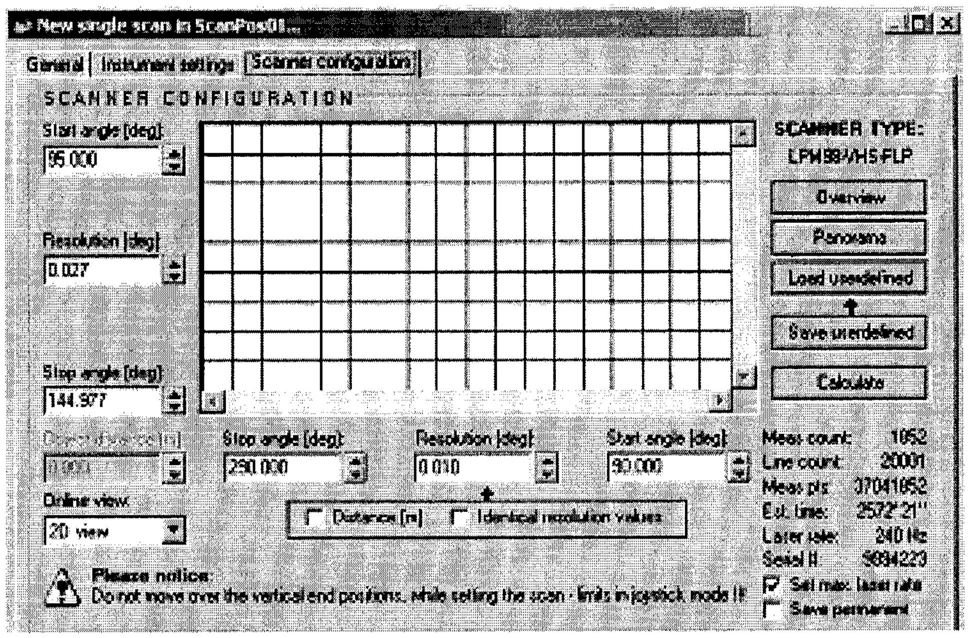



Figure 4-26 Scanner configurations with 50 hours scanning duration

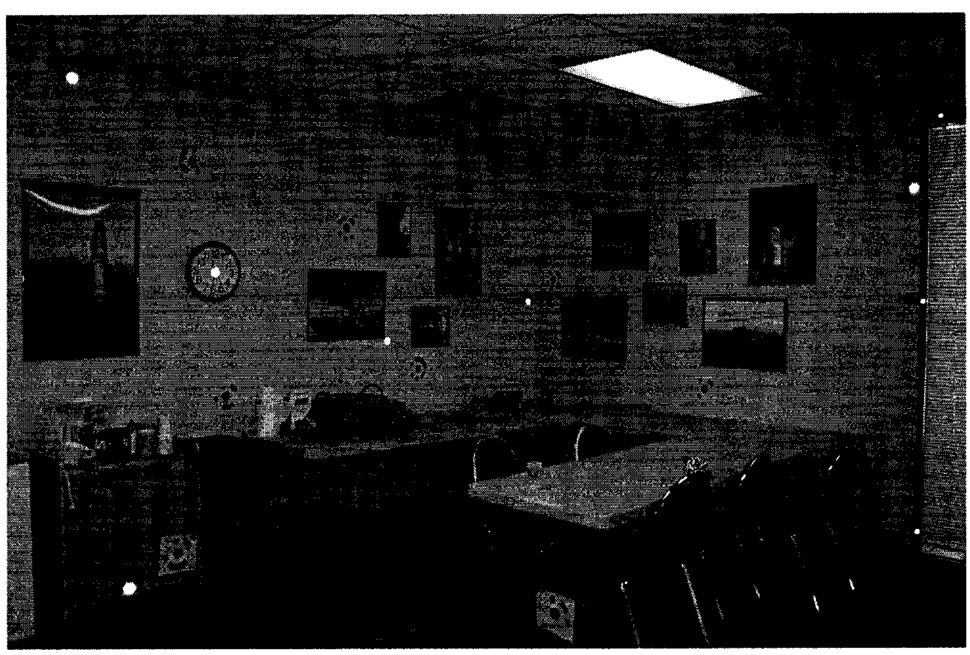


Figure 4-27 Targets Placement for 3D Modeling from Photo Images


Figure 4-28 Scanned and Digital Images

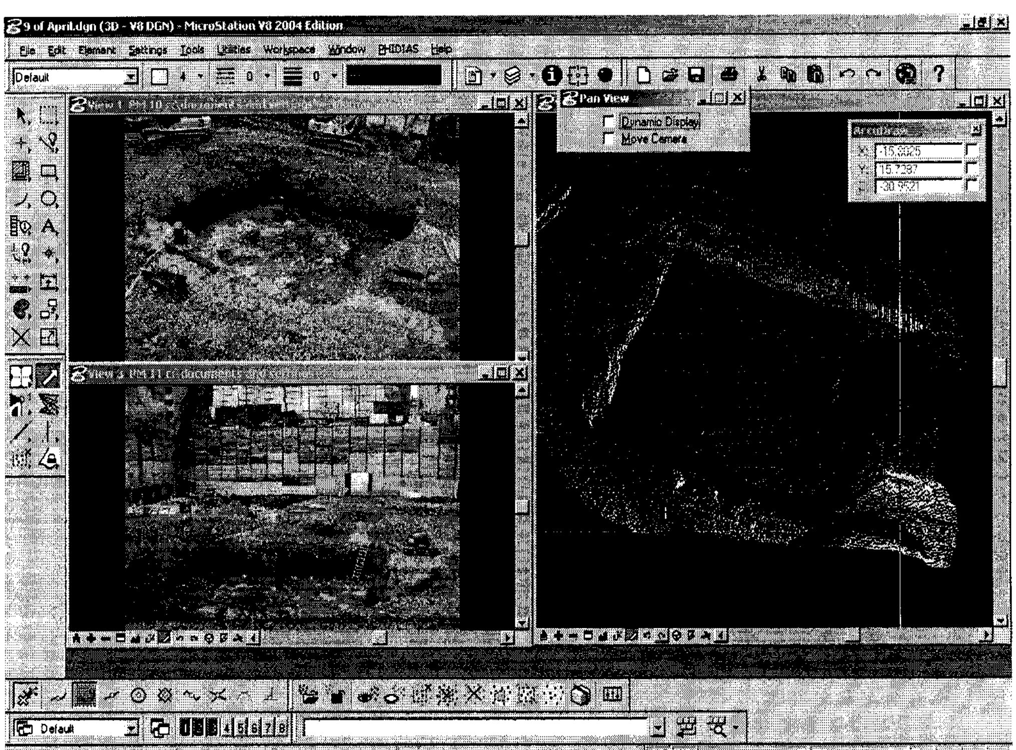



Figure 4-29 3D Modeling with Scanned and Digital Images

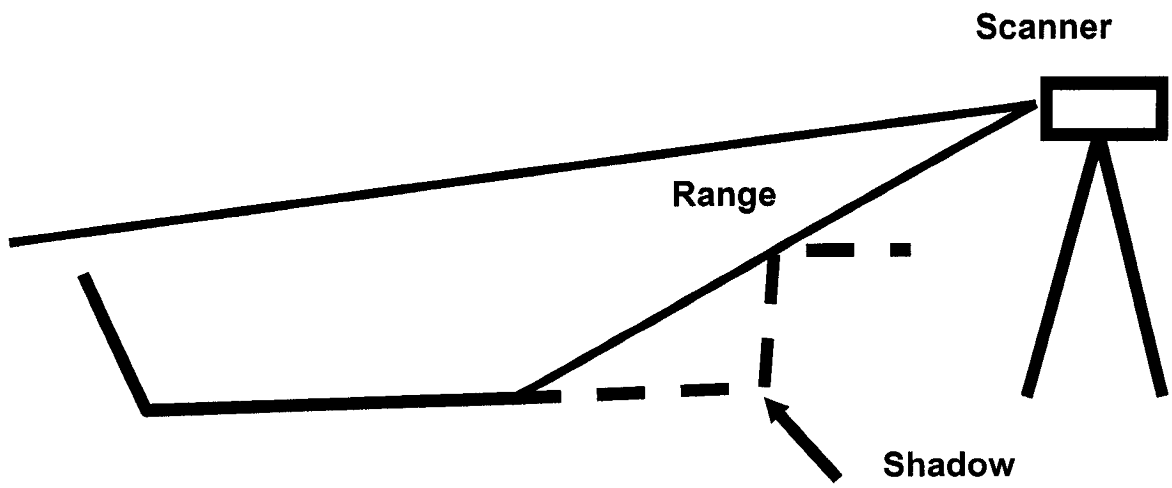



Figure 4-30 Scanner Range and shadow area

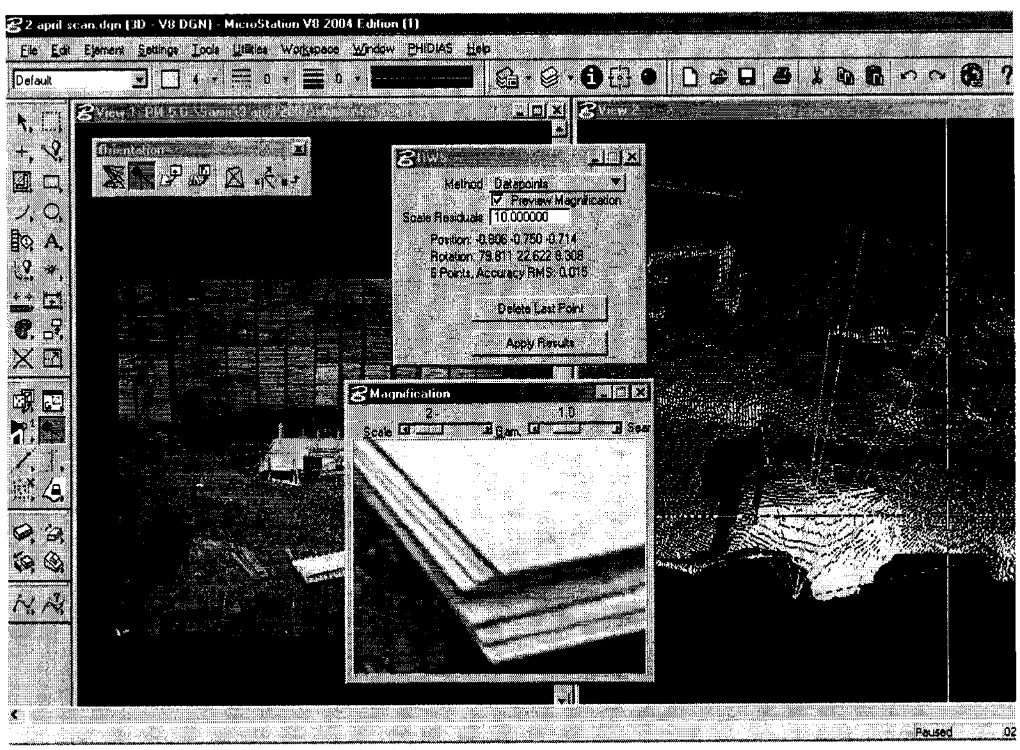



Figure 4-31. Connecting Point Cloud with Digital Images

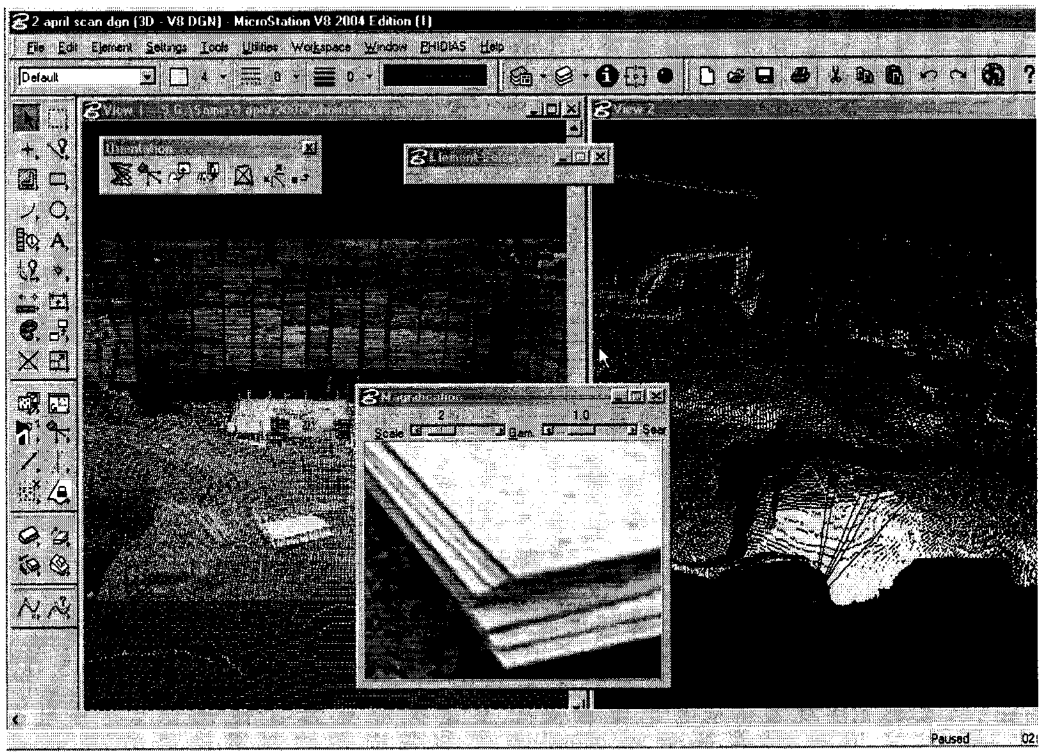



Figure 4-32. 3D Modeling

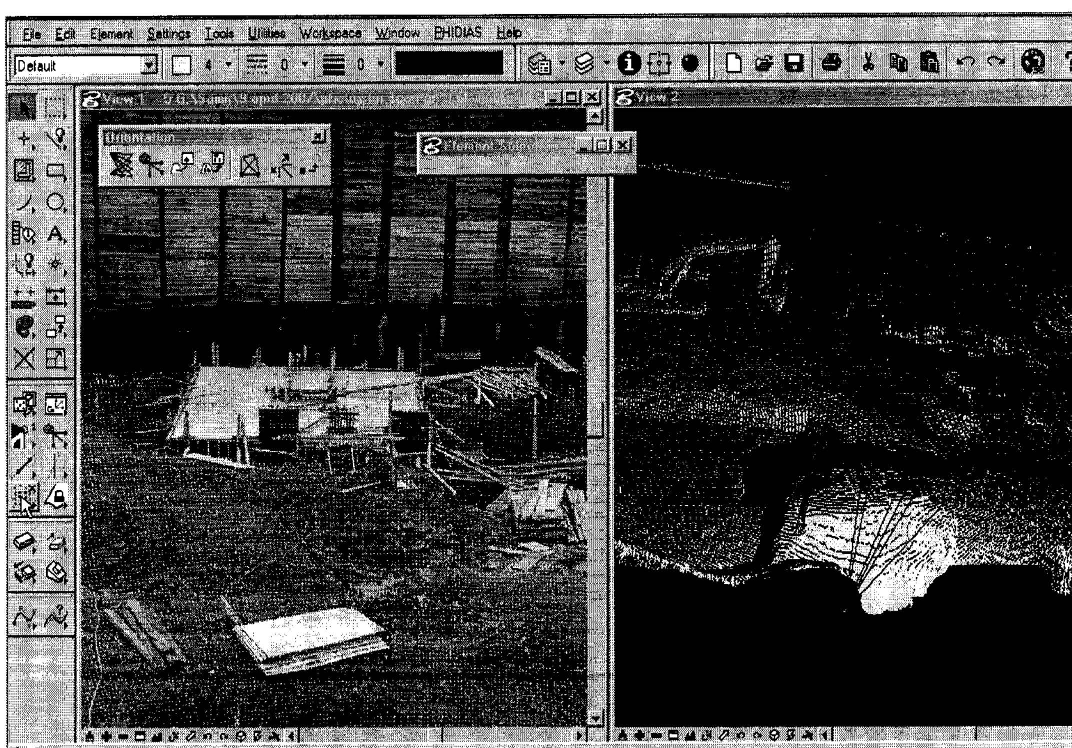



Figure 4-33. Results of connecting digital images and point cloud

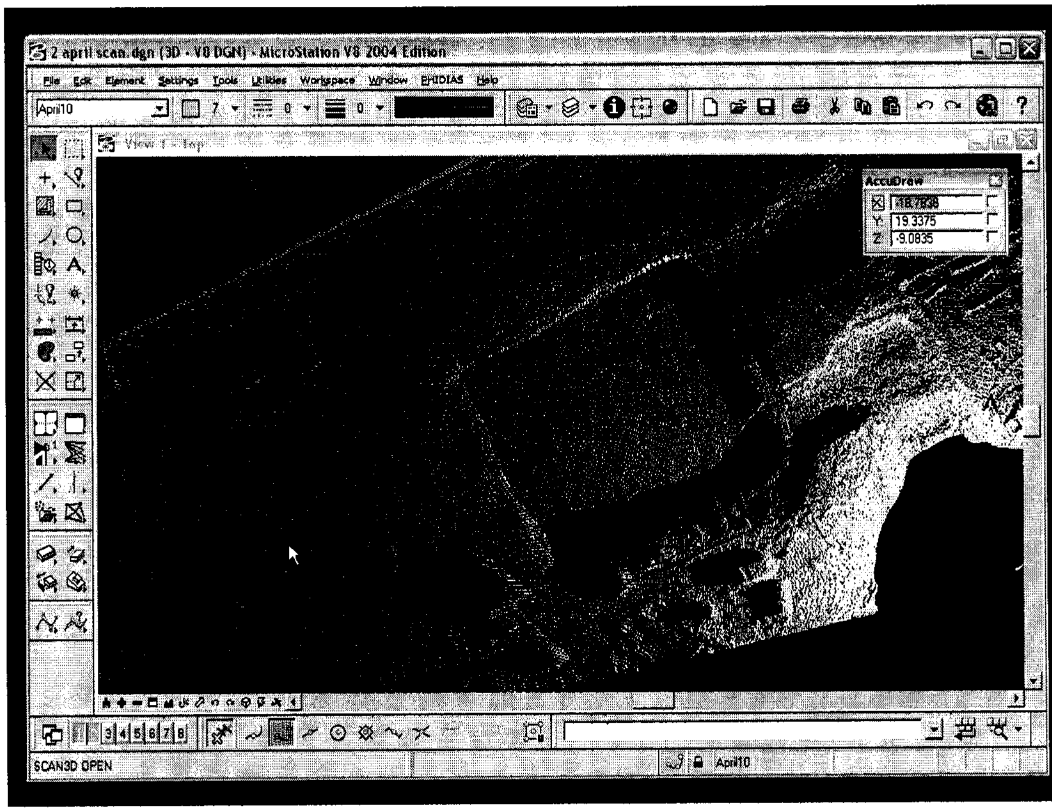



Figure 4-34 Elevator shaft foundation with shaded area

Figure 4-35 Elevator foundation pit position 1

Figure 4-36 Elevator foundation pit position 2


Figure 4-37 Photo image orientation

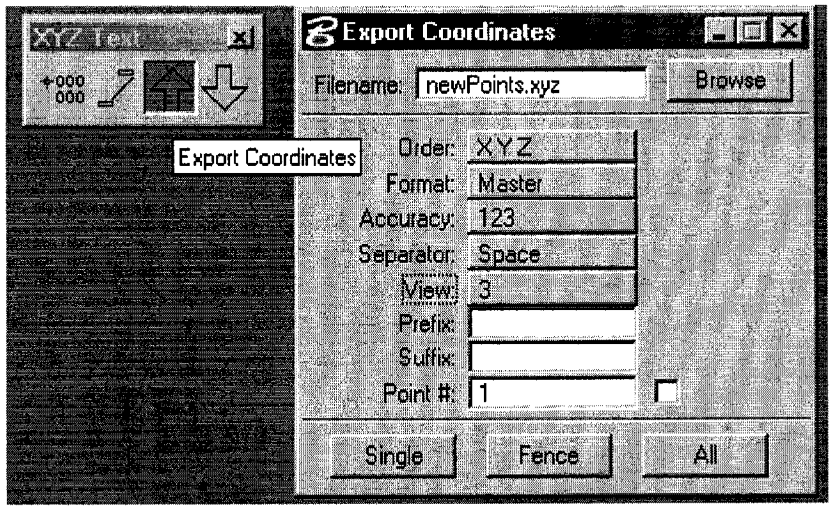



Figure 4-38 Saving new points

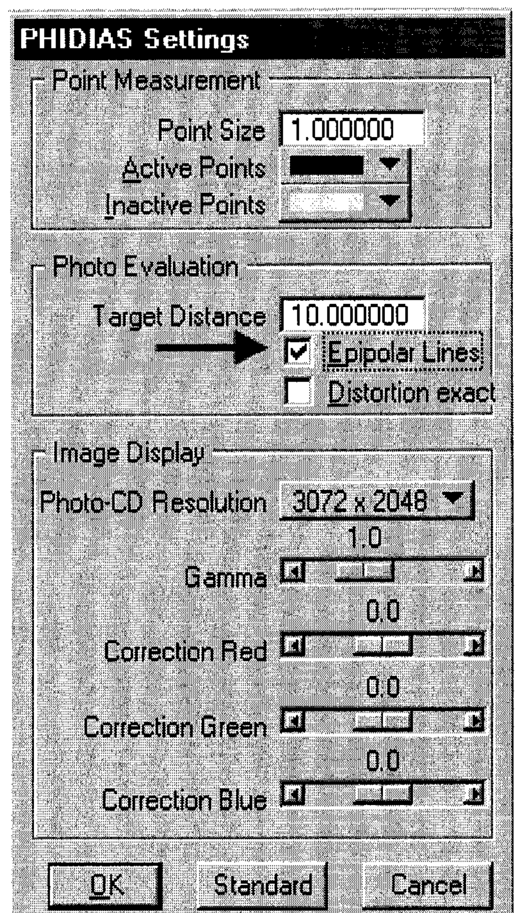



Figure 4-39 turning on epipolar lines in PHIDIAS

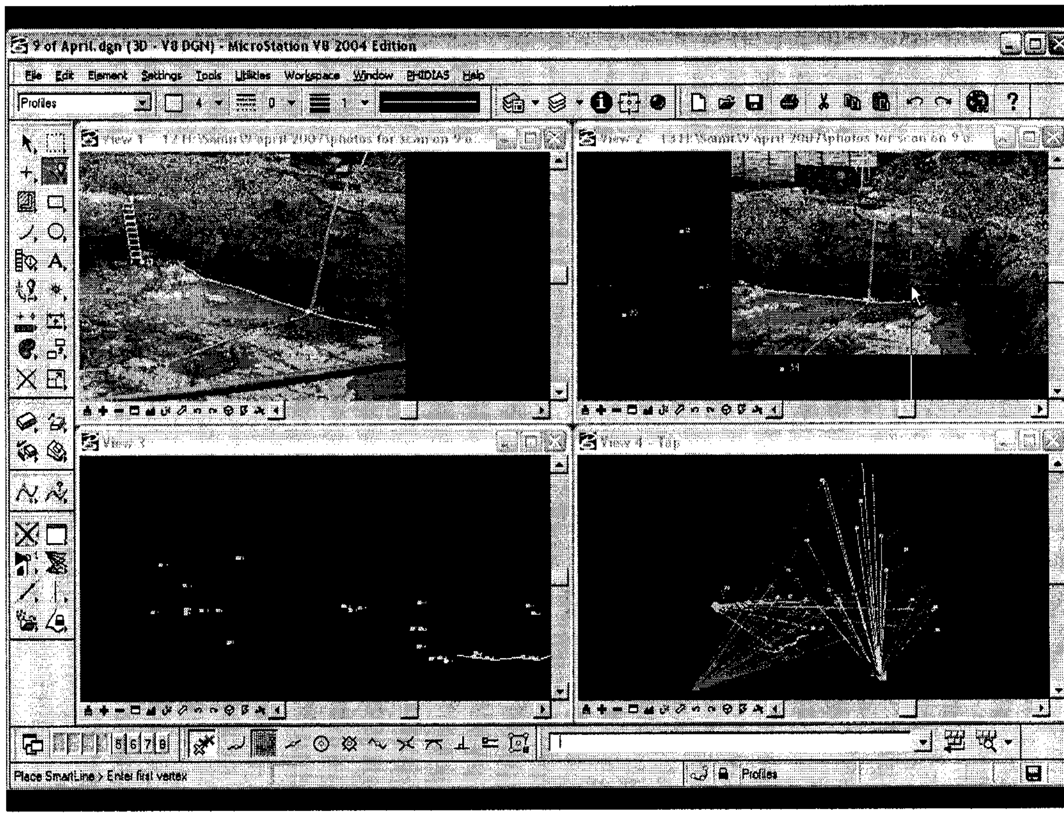



Figure 4-40 Finding common points in two images

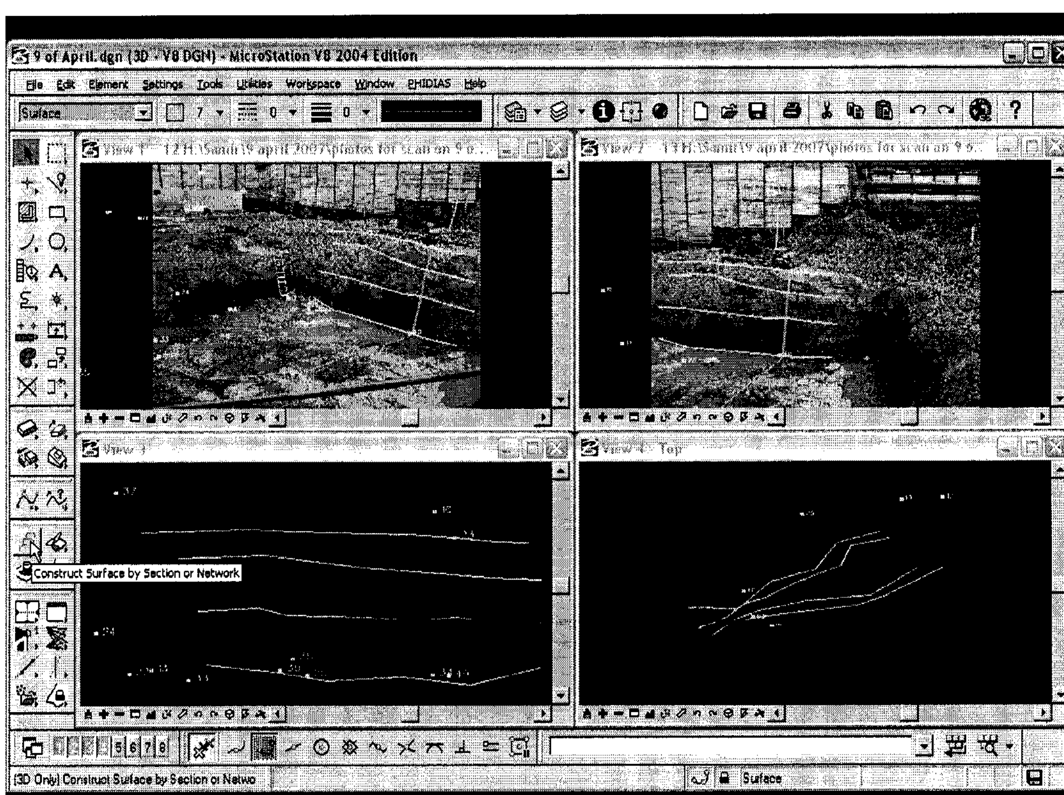



Figure 4-41 Modeling 3D image of excavation side


Figure 4-42 Mesh representing side of excavation


Figure 4-43 Excavation side

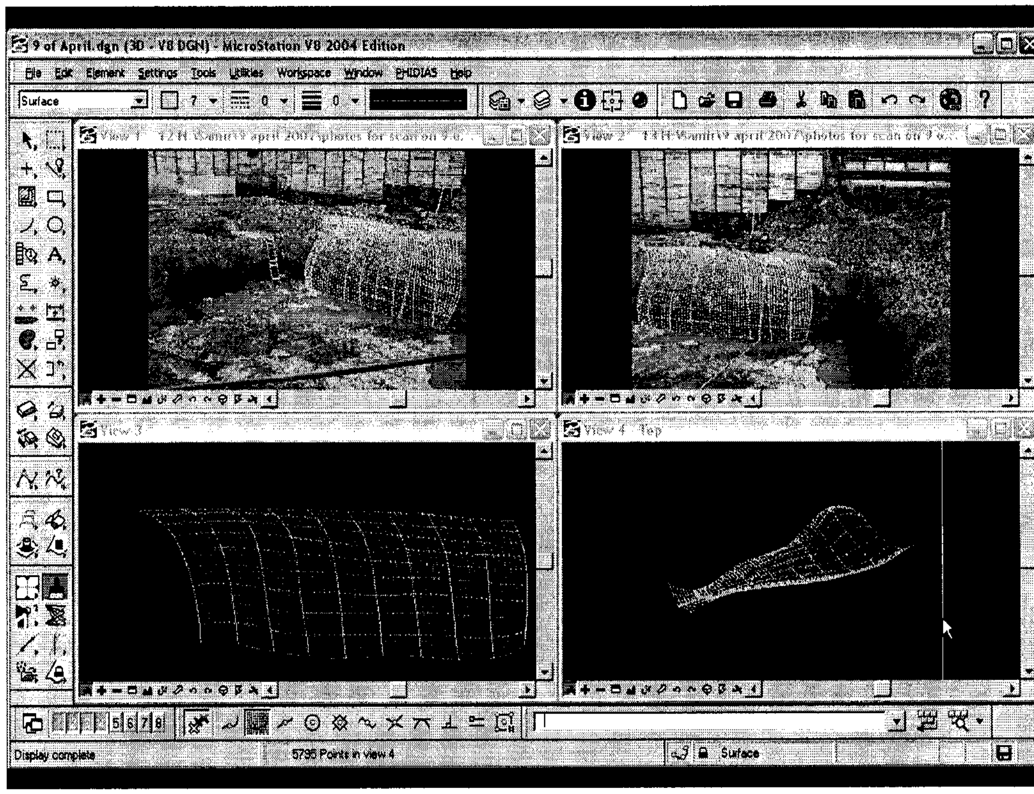



Figure 4-44 Transforming 3D mesh into point cloud

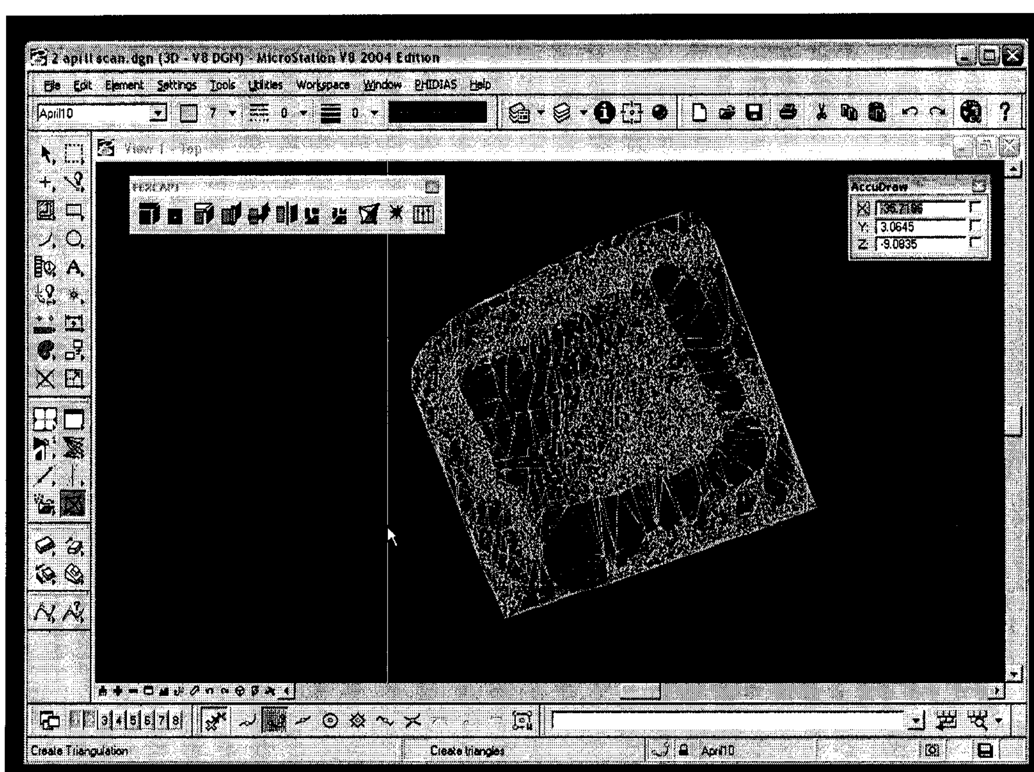


Figure 4-45 Excavation pit

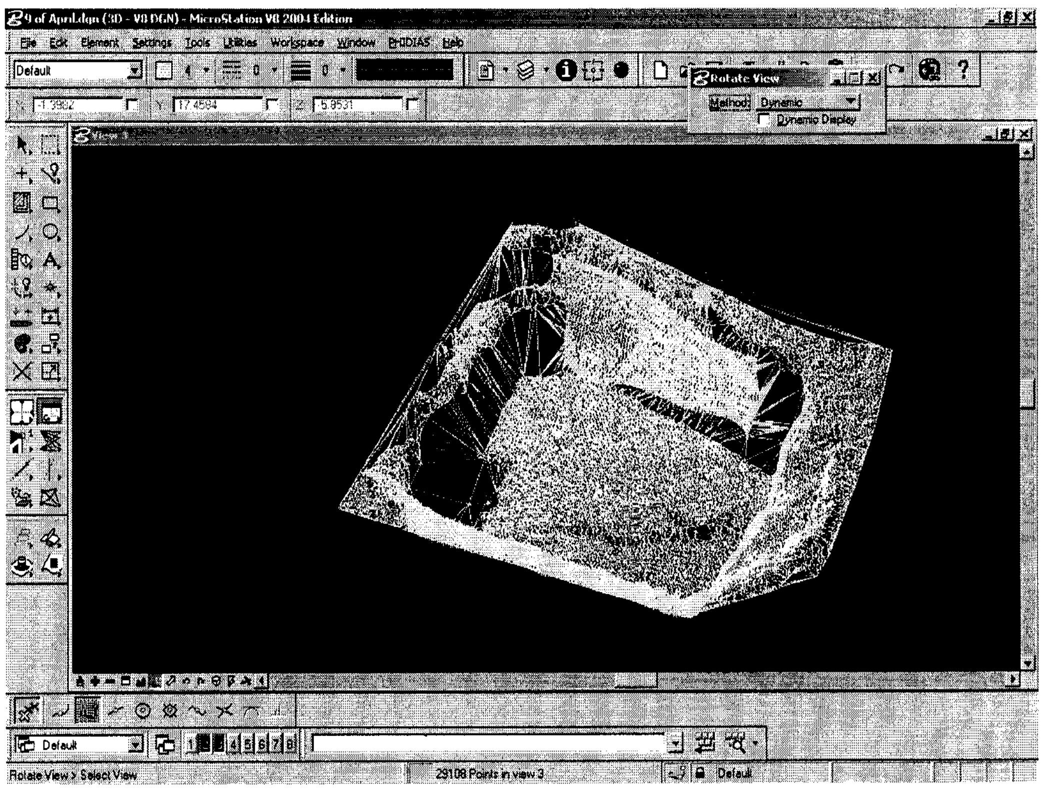



Figure 4-46 Adding modeled point cloud to scanned image


Figure 4-47 Scanned image with added information

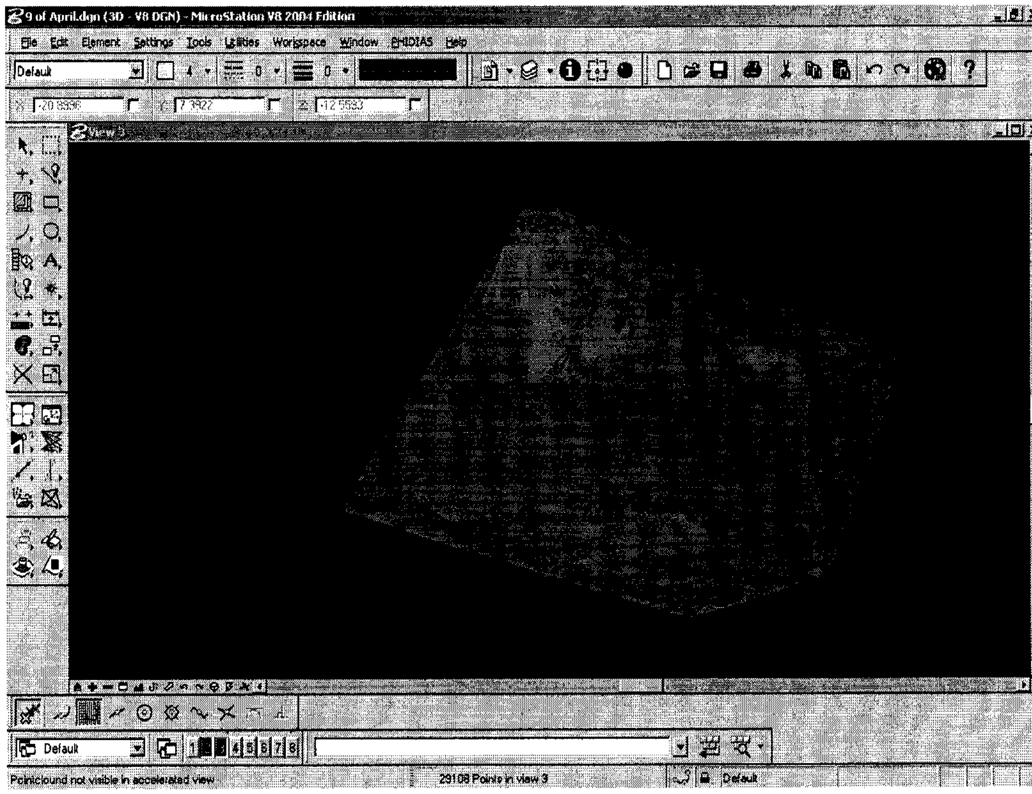



Figure 4-48 Enhanced excavation pit


Figure 4-49 Elevator's shaft foundation image and point cloud

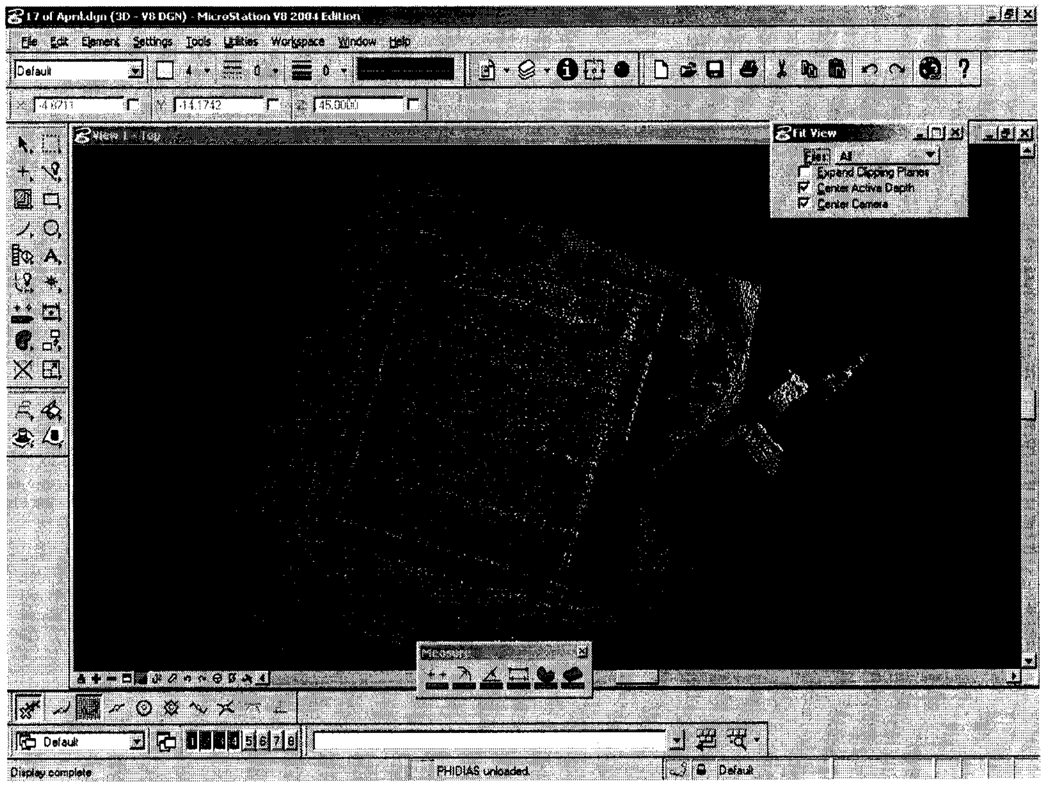



Figure 4-50 Point cloud image of foundation

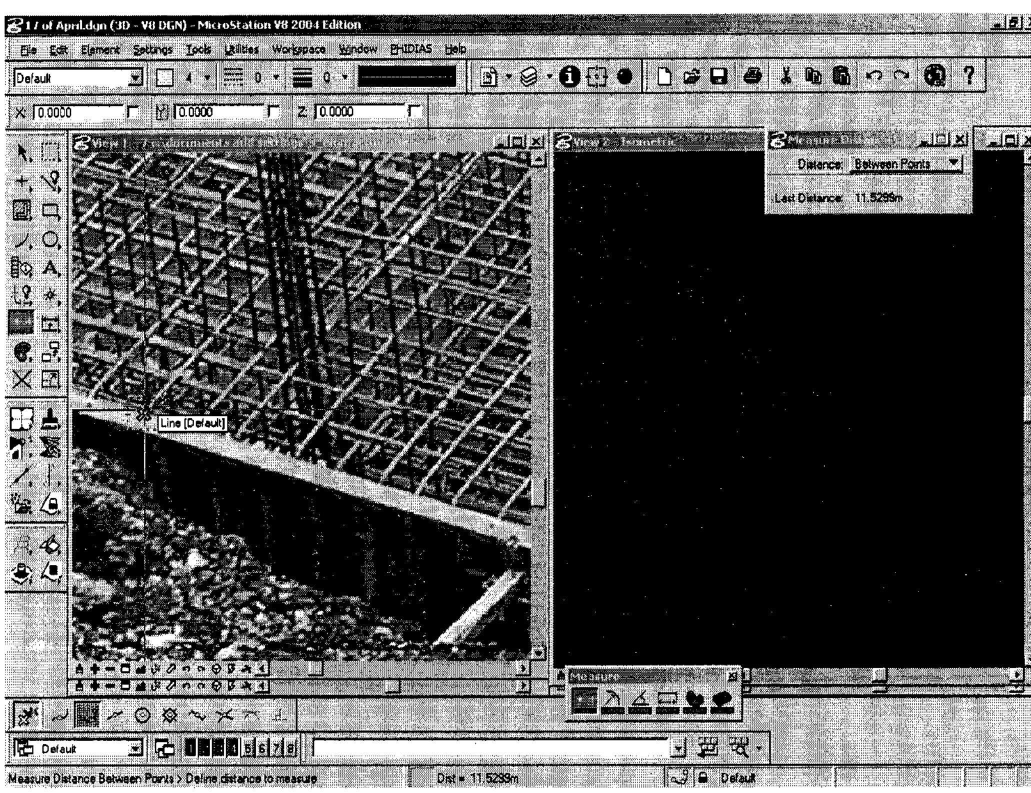



Figure 4-51 Getting foundation dimensions

# CHAPTER 5 DATABASE AND USER INTERFACE

## 5.1 General

Data collection is an important step in project tracking and control. Available planning and scheduling software packages, such as Primavera or Microsoft project, rely on data collected from construction job sites to generate progress reports that depict the project time and cost status at the end of each reporting period. Traditionally, data are collected manually by filling forms on site then feeding it into software systems for processing and for ultimately generating progress reports. Organizing collected data is a very important step and it facilitates future retrieval of this data, which can help not only in progress reporting but also in management of claims and in the production of as-built drawings. The developed centralized database is at the core of a proposed system that is designed to organize and store data collected from construction sites. Data needed for the tracking and control process is first identified. The collected data is divided into two major groups; (1) input data, which needed to produce deliverables such as labor man-hours, equipment usage and material consumption, and (2) output data, which depict the quantities of work completed. This Chapter presents the control system's database. It highlights its entity relationships and also describes the user interface, which is designed to enable the user to collect and store data from construction sites using pen-based computer.

## 5.2 Input Data

The misallocation of labor working hours to construction activities results in inaccurate cost reports at the activity level. This requires a close control of hours spent for the accomplishment of the scope of work of the activities being considered. The same applies to equipment hours and material consumption. Table 5-1 illustrates the distribution of working hours on construction activities where the working hours of worker number 3 were divided between activities A and B. The wrong allocation of working hours to individual activities affects the accuracy of the reported cost of the activities involved.

Table 5-1 Working hours allocation on construction activities

| Name | Activity A | Activity B | Total hours |
|---|---|---|---|
| Worker 1 | 8 | | 8 |
| Worker 2 | | 8 | 8 |
| Worker 3 | 3 | 5 | 8 |
| Total | 11 | 21 | 32 |

The proposed control system collects data pertinent to labor hours through the utilization of RFID and bar coding. To understand the need and type of the database required, it is important first to go through the proposed system data flow diagram highlighted in Figure 5-1. As seen in the flow chart, the system has two main modules, the 3D modeling and the resource management modules. If the data type is resource related then the RFID/bar-code reader is used to collect data pertinent to labor working hours, equipment hours or material usage. The application of RFID or bar-code tags depends on the need to change the stored information and on the site conditions where the tag will be exposed to, as bar-code tags can be damaged due to harsh site conditions and could be difficult to read information from them (Moselhi et al 2006, 2008). Information can first be stored on the reader during the process of data collection from the job site then transferred to computer through synchronization process performed using Microsoft Sync function. The workers ID card include next to his personal data, the activity he is currently working on. If he, happened to work on another activity, the activity ID on his RFID tag will be changed and the user will record the start time on his time sheet available in the developed database. To control allocation of working hours on activities, each supervisor will have an RFID/bar-code reader to record the workers start and end time related to each activity. After the synchronization process data are stored in the main database (see Figure 5-1). The 3D modeling module is composed of the LADAR equipment that scans the construction site for later processing of the scanned point cloud images. The 3D modeling module incorporates data collected from the LADAR equipment placed on site in the form of point cloud images and that captured from digital cameras. The integration of point-cloud and photo images was utilized to save time in the scanning and 3D data processing (El-Omari et al 2008). Planned data are imported directly from scheduling software systems, such as Primavera or Microsoft project, in database format. The final step of the data flow (see Figure 5-1) is reporting. The files of the scheduling software are first updated and then sent back to the scheduling software package. Reports are generated by the system and by the scheduling software package.

## 5.3 Relational Database system

The proposed system focuses on entering data collected from site into a database and providing queries to later retrieve the data needed for reporting the project time and cost-status. Because this type of application contains relatively simple data relationships and schema design, consequently, relational database management systems (RDBMs) are better suited for these applications. Relational database management system is commonly used in construction because of its efficiency, simplicity, and ease of use (Kim et al. 1992). The relational database model was designed to allow files to be related by means of a common field. This was established by generating common fields among these files (Gilfillan 2002). For example tables "Project" and "Activity" shown in Figures 5-2 and 5-3 are related through the project ID field in the activity table. The project ID field specifies to what project an activity belongs. Table 5-2 explains how data are collected and with which file format.

## 5.4 Organization and storage of information

The database consists of 37 entities or tables (see Figure 5-4). The entity relationship diagram is illustrated in Figure 5-5. The database was implemented in Microsoft Access to facilitate the interaction with commonly used scheduling software systems such as Microsoft Project and Primavera. The main entities of the database are Project, Activity, Labor, Equipment, Material, Photos, Sound, Videos, 3D Image and Drawings. The attributes of these entities are listed in Figure 5-5. A "Time Sheet" entity was constructed to store daily start and finish time of labors and equipments. The "Labor" and "Equipment" entities have a one-to-many relationship with the "Time Sheet" entity (see Figures 5-6 and 5-7).

Table 5-2 Data collection and storage

| Data acquisition technology | Method of capturing data | File format | Storage location in the systems' database | Use in the developed model |
|---|---|---|---|---|
| Laser scanning | LADAR<br>Directly via cable connection to the tablet PC | .3dd using first RiPROFILE from RIEGL and exported later to PHIDIAS for 3D modeling to calculate actual quantities | The modeled image is stored in the database entity "3D Image" in .dgn format | For quantity calculation and site representation |
| Photo images | 2D camera<br>No direct link to the PC tablet, images are stored first on the memory card of the camera and are transferred later to the tablet PC | Commonly used image formats such as .gpeg, .jpg, etc. | Digital photo images are stored in the database entity "Photos" | For quantity calculation after 3D modeling and for site representation |
| Video | Video camera<br>No direct link to the PC tablet, images are stored first on the memory card of the camera and are transferred later to the tablet PC | Commonly used video formats such as .mpeg, .mpg, etc. | Video files are stored in the database entity "Videos" | For site representation |
| barcode | RFID/barcode reader<br>No direct link to the tablet PC | Stored in excel sheet and the table is imported to the database | Stored in the database entities "Time Sheet", "Material", "Labor", "Equipment". | To track working hours and material usage |
| RFID | RFID/barcode reader<br>No direct link to the tablet PC | Stored in excel sheet and the table is imported to the database | Stored in the database entities "Time Sheet", "Material", "Labor", "Equipment". | To track working hours and material usage |
| Hand written notes | Tablet PC<br>Notes are written on the tablet PC screen and stored as a word file | Word document format | Stored as word file in the entity "Notes" and linked to the related activity, labor or equipment | To report on activity, labor or equipment |
| Voice records | Tablet PC<br>Stored directly on the tablet PC | Audio file format like .wav, .wma, .ram | Stored in the database entity "Sound" and linked to the related activity, labor or equipment | To report on activity, labor or equipment |

This relationship was created on the basis that a labor can have many time sheet entries. To relate his time to the activities he is working on, a many-to-many relationship was constructed between the "Activity" and the "Time Sheet" entities. To build this many-to-many relationship, a new entity was built with the name "Activity time sheet", which has the activity ID and the time sheet ID as attributes as shown in (see Figure 5-8). For example, the insulation worker, who has an ID of 10 (see Figure 5-7) has time sheet entries 10 and 20, which are then connected to activity ID 102 "Insulation and wall membrane" as shown in Figure 5-6. The "Activity time sheet" entity holds the primary keys of "Activity" and "Time sheet" entities so that a worker can be assigned to the correct activity. The "Activity Drawings" entity holds the primary keys of "Activity" and "Drawings" entities to establish the many-to-may relationship between the two entities. The many-to-many relationship was set because a drawing can belong to many activities and an activity can have many drawings. All drawings of the project under consideration are stored in the "Drawings" entity and are related to the project's activities. During the data collection process, hand written notes are entered on the tablet PC screen directly. Notes are saved in word format files, which are then stored in the "Notes" entity along with the description and date of each note (see Figure 5-9). As notes can be related to a particular activity, labor, equipment, or material, a many-to-many relationship had to be established between the primary keys of the "Notes" entity and the "Activity", "Labor", "Equipments", and "Materials" entities. The "activity Notes" entity has the primary keys for the many-to-many relationship feature. Other types of relationships that exist beside many-to-many is the one-to-many as in the case of "Project" and "Activity" entities because a project can have many activities and an activity belongs only to one project. To update planned information, data had to be first imported from the output of the scheduling software such as Microsoft Project. Microsoft Project can export data in Access MDB file format. An example was performed using an actual case of a project under construction in the Montreal are. The project is an institutional multi-story building for the business school (JMSB) of Concordia University. The data files of the project were used to export planned data, update it, and send it back to Microsoft Project. The imported table (JMSB Activities) is shown in Figures 5-4 and 5-10. To update the proposed system's database with information imported from the scheduling software, a number of queries were developed using SQL language such as the one shown in Appendix II. links were also constructed between photograph, video clips, drawings, and 3D modeled images and their respective "Photos", "Videos", "Drawings" and "3D Images" entities. The "Quantity to Date" attribute of the "Activity" entity is to update quantity of work performed. The 3D image entity includes 3D modeled images that are linked with different activities to illustrate the current project status. After all data are updated during a reporting period the database of the scheduling software package is then updated using update queries in a reverse order to that performed at the beginning and used to export time data to the project schedule. EV analyses are then performed in the scheduling software package using processed data generated from the developed system and progress reports are subsequently generated. Additional reports, such as notes, and photographs are also generated using the proposed system to highlight critical issues.

## 5.5 Design of queries

Queries are designed to retrieve the stored data using structured query language (SQL). Access database management system converts a query into its own Access SQL to constructs this required request for data retrieval (Mata-Toledo 2000). Queries were used in the proposed system to update tables imported from the scheduling software package and organized to match the database design as shown in Appendix II (a). This query updates the fields: "Description", "Duration", "Start Date", and "Finish Date" in the "Activity" table with those imported from the project's schedule where the activity ID attribute was set as a criteria. Queries also were used to request data from different tables and represent it in a new query table such as the one shown in Figure 5-11, which provides drawings pertinent to each activity. Figure 5-12 highlights the list of queries in the system's database.

## 5.6 Actual cost of work performed

The proposed system updates the Actual Cost of Work Performed, known as ACWP, at the activity level using collected site data. ACWP of an activity is calculated based on labor and equipment hours spent to complete the work represented by this activity as well as quantities of material used to perform that work. If all or parts of the activity is/are sub-contracted out, then the ACWP is the sub-contractor's payment for the work being reported. Therefore, the ACWP of an activity in the database include these factors as shown in Equation 1

$ACWP = L + E + M + S$ Equation 1

Where L and E are the cost of labor and equipment hours respectively, M is the cost of material used, and S is the payment made to the sub-contractors. The hours spent on any activity are reported in the "Time sheet" table and then the actual cost spent is calculated using the query "Labor, equipment and material cost-to-date calculations" as shown in Appendix II (b). This query calculates also the material actual cost based on quantities consumed. The difference in start and finish times is calculated for each labor and equipment and multiplied with by unit cost per hour to determine their cost-to-date. For material cost, the quantity consumed is multiplied by its unit cost and the material cost-to-date is determined. The total cost for each labor, equipment and/or material spent on each activity is calculated with the queries shown in Appendix II (c), (d) and (e) and subsequently represented on tables such as the one shown in Figure 5-13. The sub-contractor cost per activity is also calculated with the query shown in Appendix II (f). To update the ACWP of each activity, new queries were designed to find the sum of all resource-costs for each activity and list them in tables ( Appendix II (g) – (j)). Finally, the ACWP field in the activity table is updated with the sum of ACWP of all resources as shown in Appendix II (k). This is performed by setting the activity ACWP equals to the ACWP from the labor then adding this new value to the subsequent resource. The last step performed in the control system is to update the scheduling software table with the data in the "Activity" table.

## 5.7 User interface and data retrieval

A list of forms was designed to facilitate the interaction process with the user. The user starts by a validation process of his username and password. Authorized users are listed in the "Employees" table shown in Figure 5-4. Upon granting access, the user is prompted with the main screen shown in (see Figure 5-15) that includes the list of forms available is prompt so that the user can start first by selecting the project he wants to invoke. The project form, shown in Figure 5-16, includes project information such as its duration, and start and finish time. A list of projects is available to choose from in the project dropdown menu. The user then can access the project's activity by selecting the activity command button in the project form or from the main screen. The control process is performed on the activity level where hours spent on that activity such as labor hours has to be reported. This can help in integrating cost and time reporting. Clearly, once the data becomes available at that detailed level, it could be rolled up at the cost account or work package level. The activity form, shown in Figure 5-17, includes, aside from the activity information, command buttons to invoke different forms and queries. Figures 5-18 to 5-20 highlight some forms that can be accessed from the activity form that represent stored multimedia information such as photo images as in Figure 5-18 where the user can double-click to open the image file. The code to access these forms is written in visual basic and is similar to the one shown in Appendix III (a), which accesses the activity form from the project form. The combo box that represents the activity type is needed to select the various activities (Appendix III (b)). Invoking queries through command buttons is important to update fields while the user is for example in the time sheet form mode shown in Figure 5-21, which he can access from the activity form (see Figure 5-17). The user can also get the total cost of the resource per activity, and calculate the ACWP of the activity that include this resource by running the relevant queries as shown in Appendix (c). The same procedure is also applied to the material form (see Figure 5-22) and the sub-contractor form (see Figure 5-23). The activity form includes a command button that update the ACWP field in the activity table by running the queries in Appendix II (k). The four queries will run simultaneously upon activating the "Update Activity ACWP" command. The code to do that is shown in Appendix III (d). The user can access different database tables through forms such as the notes form (see Figure 5-24), which can be accessed from the activity form or the main screen of the database. Reports are generated from the scheduling software and from the database. The reports form is invoked from the main screen shown in Figure 5-25. The reports available in the database are listed in Figure 5-26. Example reports are shown in Figures 5-27 and 5-28. The visual basic code to access the reports from the reports form is demonstrated in Appendix III (f). The developed database, explained in this chapter, has a number of interesting features. It allows for capturing data from construction sites using a set of automated data acquisition technologies. This includes laser scanners, photogrammetry, RFID, bar coding. Hand-written notes are stored in the database in the form of word file and linked to the related activities. 3D modeled images developed with the use of laser scanner and photogrammetry are also stored in the database that can represent the project activities and also help in estimating quantities of work performed. The data was structured such that it enable tracking cost and time at the activity level, which can support integrated time and cost control. It also provides flexibility to the user to roll up the captured data from the activity level to the cost account and the work package levels. Microsoft Access was used in the development of the database as it allows the interaction with the most commonly used scheduling software systems such as Microsoft Project and Primavera. The database was designed to retrieve planned data from the scheduling software systems, update it then send it back to generate reports.

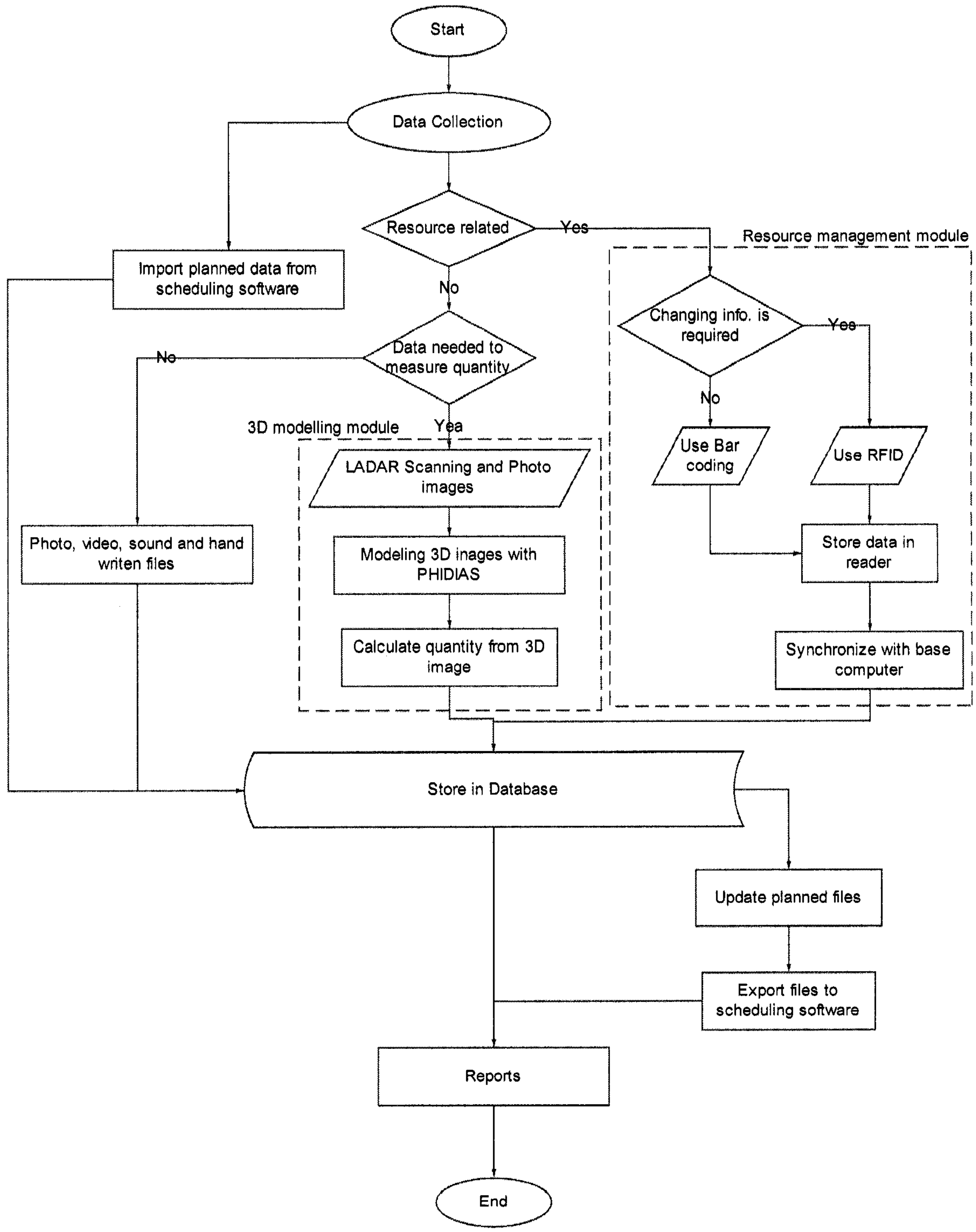
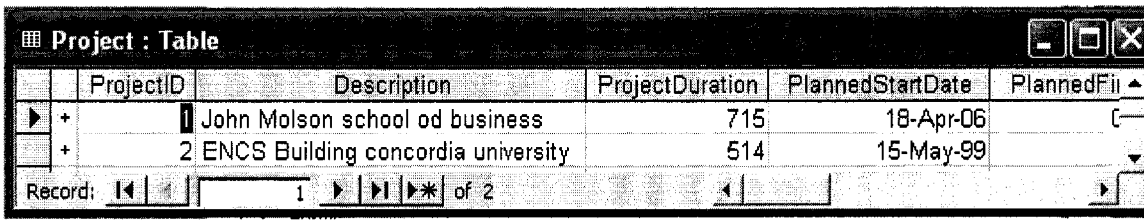



Figure 5-1 Data collection flow

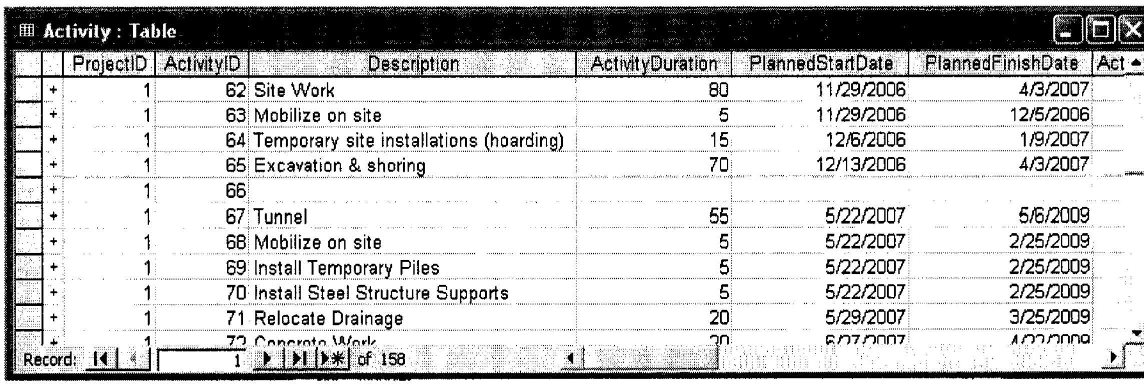


Project : Table

| ProjectID | Description | ProjectDuration | PlannedStartDate | PlannedFi |
|---|---|---|---|---|
| 1 | John Molson school od business | 715 | 18-Apr-06 | |
| 2 | ENCS Building concordia university | 514 | 15-May-99 | |

Record: 1 of 2

Figure 5-2 Project table



Activity : Table

| ProjectID | ActivityID | Description | ActivityDuration | PlannedStartDate | PlannedFinishDate | Act |
|---|---|---|---|---|---|---|
| 1 | 62 | Site Work | 80 | 11/29/2006 | 4/3/2007 | |
| 1 | 63 | Mobilize on site | 5 | 11/29/2006 | 12/5/2006 | |
| 1 | 64 | Temporary site installations (hoarding) | 15 | 12/6/2006 | 1/9/2007 | |
| 1 | 65 | Excavation & shoring | 70 | 12/13/2006 | 4/3/2007 | |
| 1 | 66 | | | | | |
| 1 | 67 | Tunnel | 55 | 5/22/2007 | 5/6/2009 | |
| 1 | 68 | Mobilize on site | 5 | 5/22/2007 | 2/25/2009 | |
| 1 | 69 | Install Temporary Piles | 5 | 5/22/2007 | 2/25/2009 | |
| 1 | 70 | Install Steel Structure Supports | 5 | 5/22/2007 | 2/25/2009 | |
| 1 | 71 | Relocate Drainage | 20 | 5/29/2007 | 3/25/2009 | |

Record: 1 of 158

Figure 5-3 Activity table

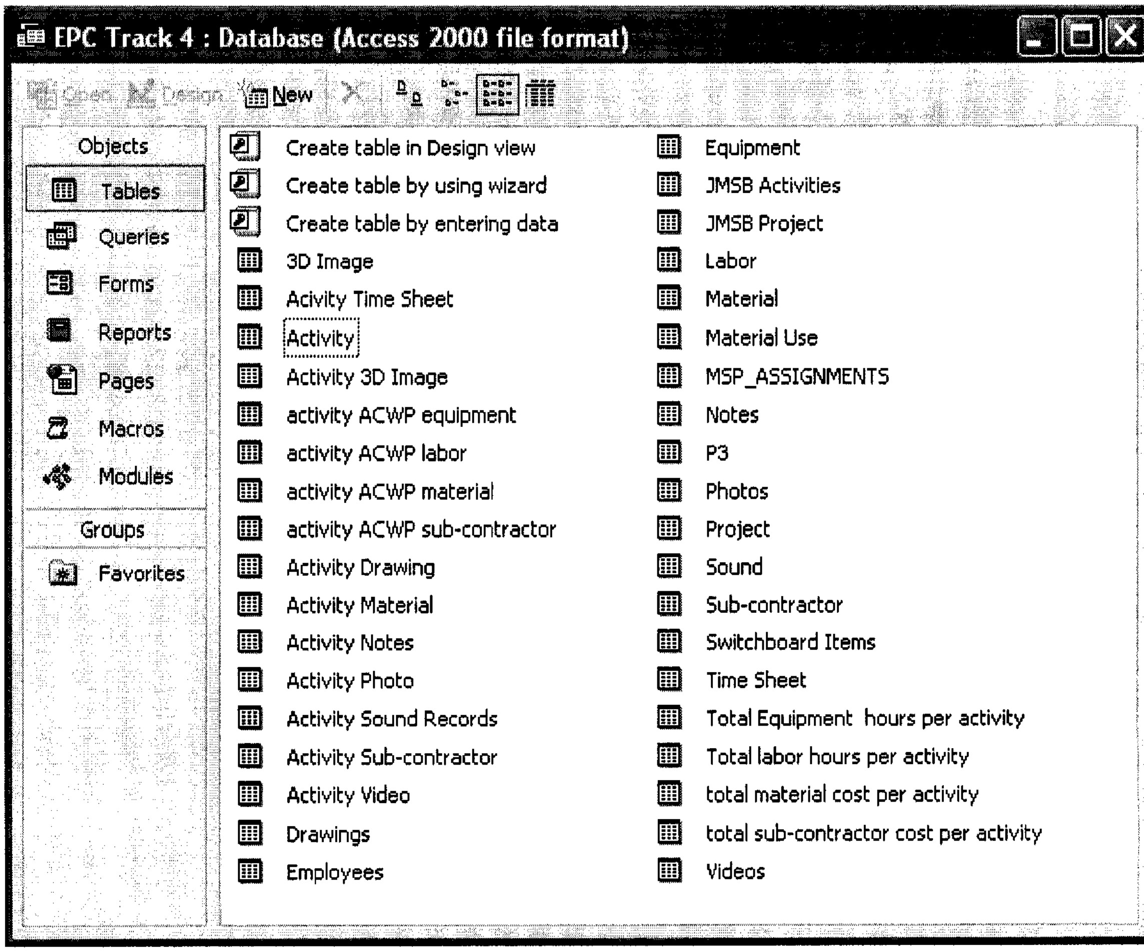



Figure 5-4 EPC Track list of tables

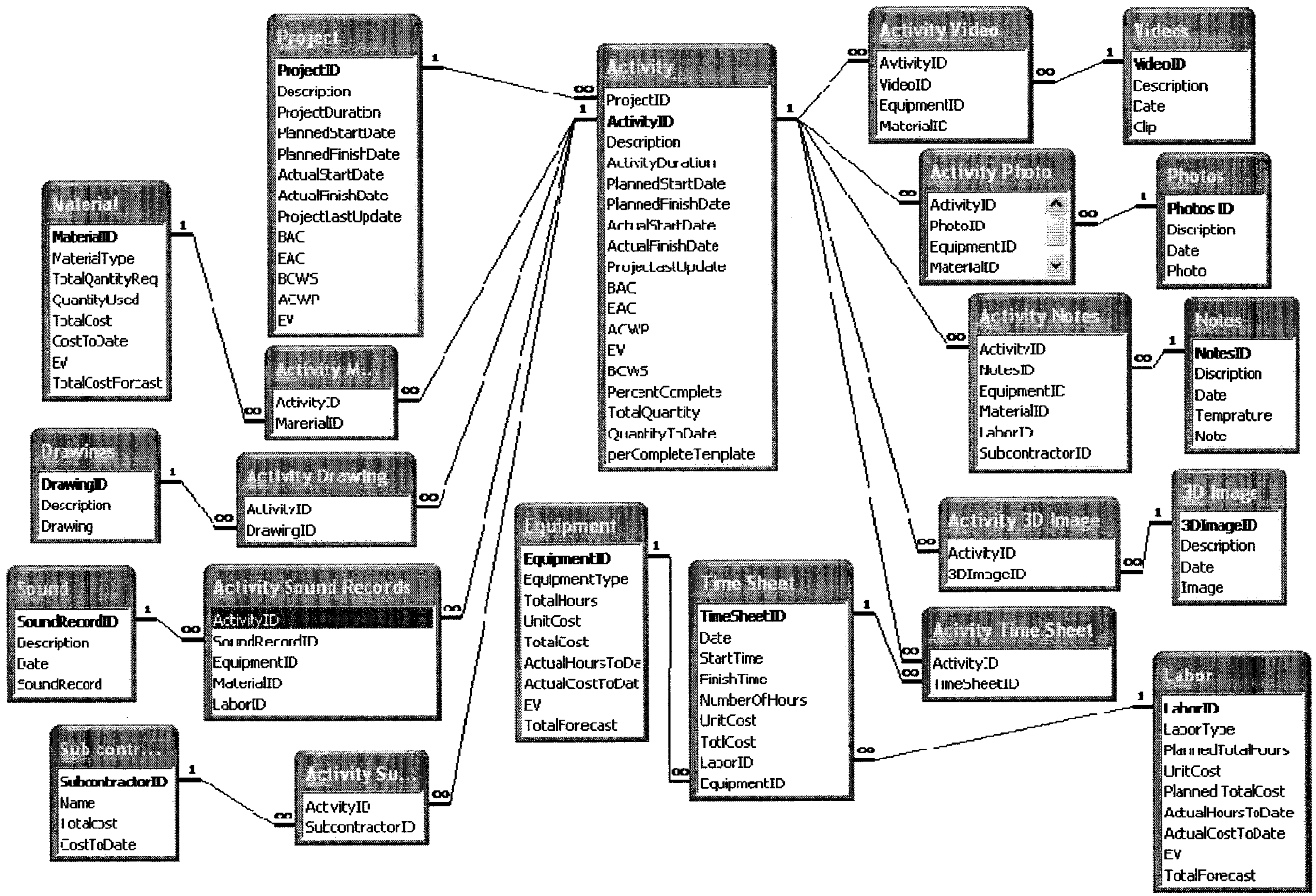
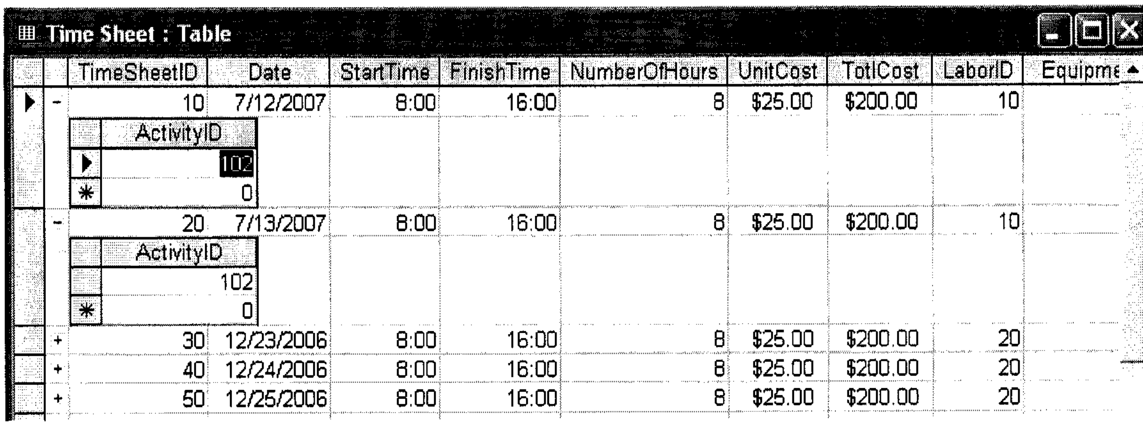


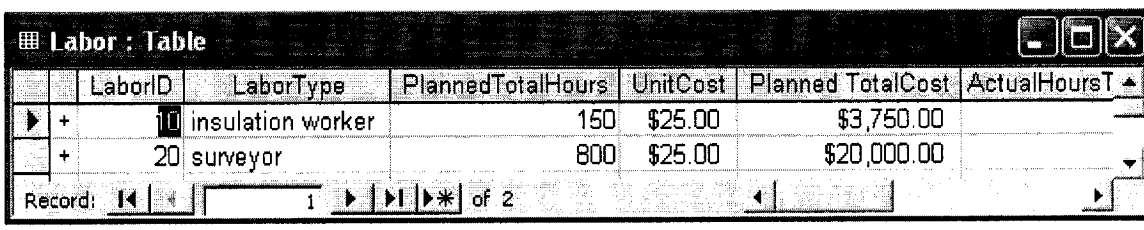
Figure 5-5 Entity relationship



Time Sheet : Table

| TimeSheetID | Date | StartTime | FinishTime | NumberOfHours | UnitCost | TotlCost | LaborID | Equipme |
|---|---|---|---|---|---|---|---|---|
| 10 | 7/12/2007 | 8:00 | 16:00 | 8 | $25.00 | $200.00 | 10 | |
| ActivityID: 102, 0 | | | | | | | | |
| 20 | 7/13/2007 | 8:00 | 16:00 | 8 | $25.00 | $200.00 | 10 | |
| ActivityID: 102, 0 | | | | | | | | |
| 30 | 12/23/2006 | 8:00 | 16:00 | 8 | $25.00 | $200.00 | 20 | |
| 40 | 12/24/2006 | 8:00 | 16:00 | 8 | $25.00 | $200.00 | 20 | |
| 50 | 12/25/2006 | 8:00 | 16:00 | 8 | $25.00 | $200.00 | 20 | |

Figure 5-6 Time sheet table

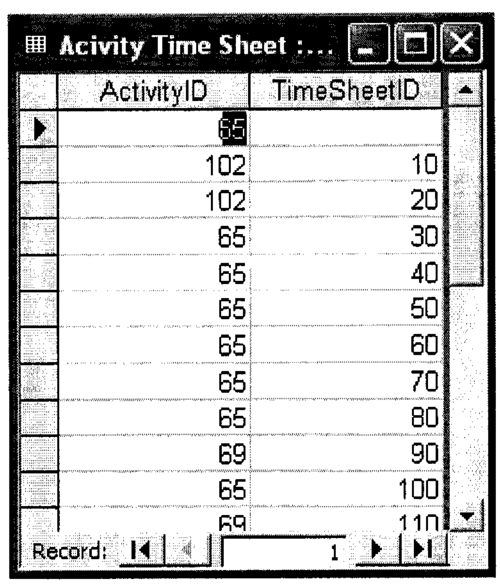


Labor : Table

| LaborID | LaborType | PlannedTotalHours | UnitCost | Planned TotalCost | ActualHoursT |
|---|---|---|---|---|---|
| 10 | insulation worker | 150 | $25.00 | $3,750.00 | |
| 20 | surveyor | 800 | $25.00 | $20,000.00 | |

Record: 1 of 2

Figure 5-7 Table of labors

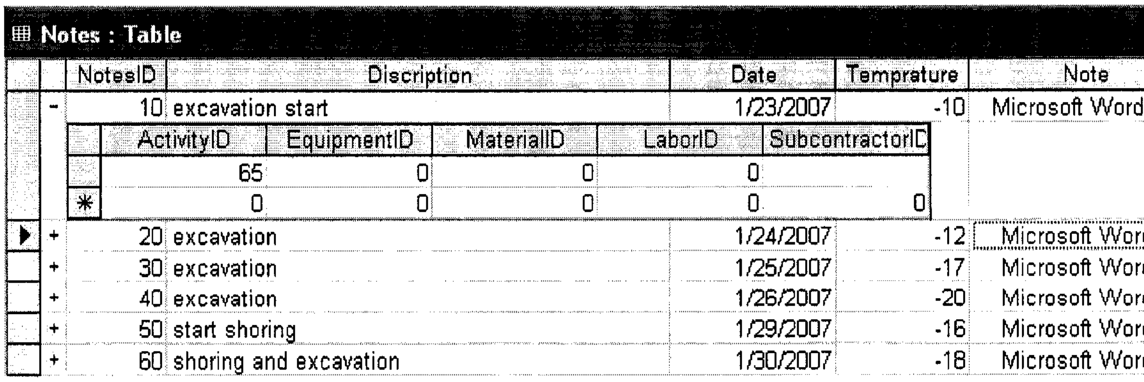


Acivity Time Sheet :...

| ActivityID | TimeSheetID |
|---|---|
| 65 | |
| 102 | 10 |
| 102 | 20 |
| 65 | 30 |
| 65 | 40 |
| 65 | 50 |
| 65 | 60 |
| 65 | 70 |
| 65 | 80 |
| 69 | 90 |
| 65 | 100 |
| 69 | 110 |

Record: 1

Figure 5-8 Activity time sheet table

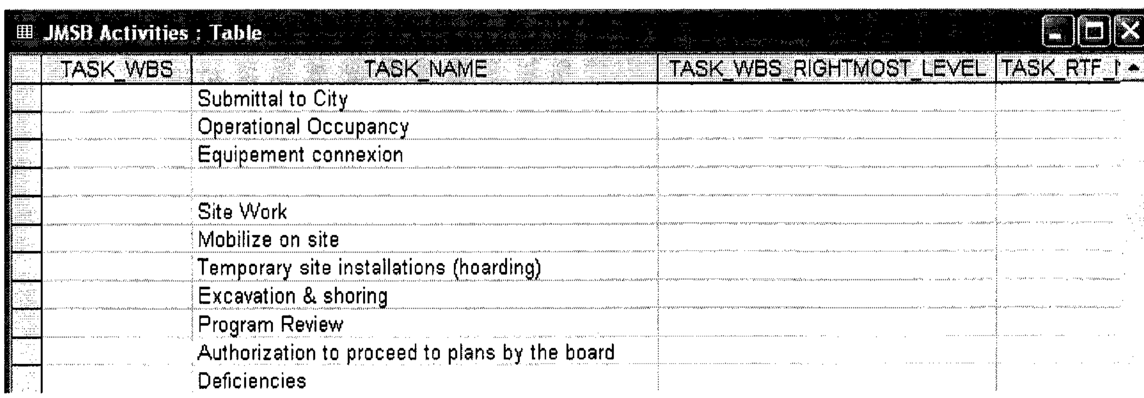


Notes : Table

| NotesID | Discription | Date | Temprature | Note |
|---|---|---|---|---|
| 10 | excavation start | 1/23/2007 | -10 | Microsoft Word |
| 20 | excavation | 1/24/2007 | -12 | Microsoft Word |
| 30 | excavation | 1/25/2007 | -17 | Microsoft Word |
| 40 | excavation | 1/26/2007 | -20 | Microsoft Word |
| 50 | start shoring | 1/29/2007 | -16 | Microsoft Word |
| 60 | shoring and excavation | 1/30/2007 | -18 | Microsoft Word |

| ActivityID | EquipmentID | MaterialID | LaborID | SubcontractorID |
|---|---|---|---|---|
| 65 | 0 | 0 | 0 | |
| 0 | 0 | 0 | 0 | 0 |

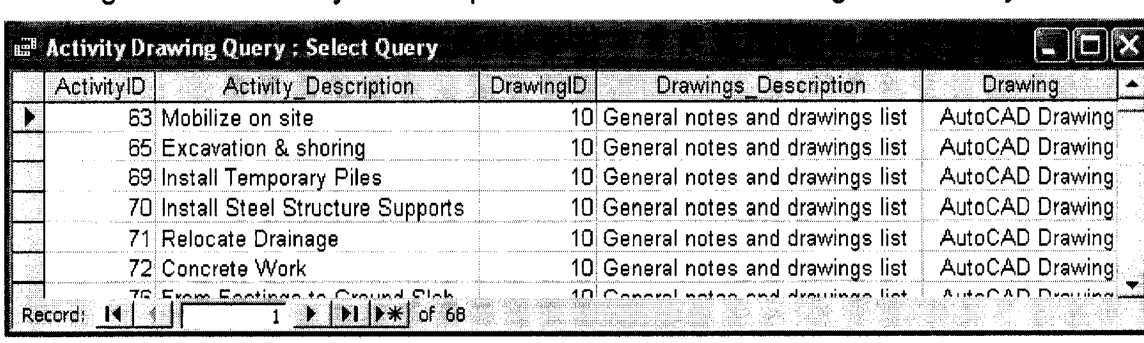
Figure 5-9 Notes table



JMSB Activities : Table

| TASK_WBS | TASK_NAME | TASK_WBS_RIGHTMOST_LEVEL | TASK_RTF_I |
|---|---|---|---|
| | Submittal to City | | |
| | Operational Occupancy | | |
| | Equipement connexion | | |
| | | | |
| | Site Work | | |
| | Mobilize on site | | |
| | Temporary site installations (hoarding) | | |
| | Excavation & shoring | | |
| | Program Review | | |
| | Authorization to proceed to plans by the board | | |
| | Deficiencies | | |

Figure 5-10 Activity table imported from the scheduling software system



Activity Drawing Query : Select Query

| ActivityID | Activity_Description | DrawingID | Drawings_Description | Drawing |
|---|---|---|---|---|
| 63 | Mobilize on site | 10 | General notes and drawings list | AutoCAD Drawing |
| 65 | Excavation & shoring | 10 | General notes and drawings list | AutoCAD Drawing |
| 69 | Install Temporary Piles | 10 | General notes and drawings list | AutoCAD Drawing |
| 70 | Install Steel Structure Supports | 10 | General notes and drawings list | AutoCAD Drawing |
| 71 | Relocate Drainage | 10 | General notes and drawings list | AutoCAD Drawing |
| 72 | Concrete Work | 10 | General notes and drawings list | AutoCAD Drawing |
| 76 | From Footings to Ground Slab | 10 | General notes and drawings list | AutoCAD Drawing |

Record: 1 of 68

Figure 5-11 Query for activity drawings

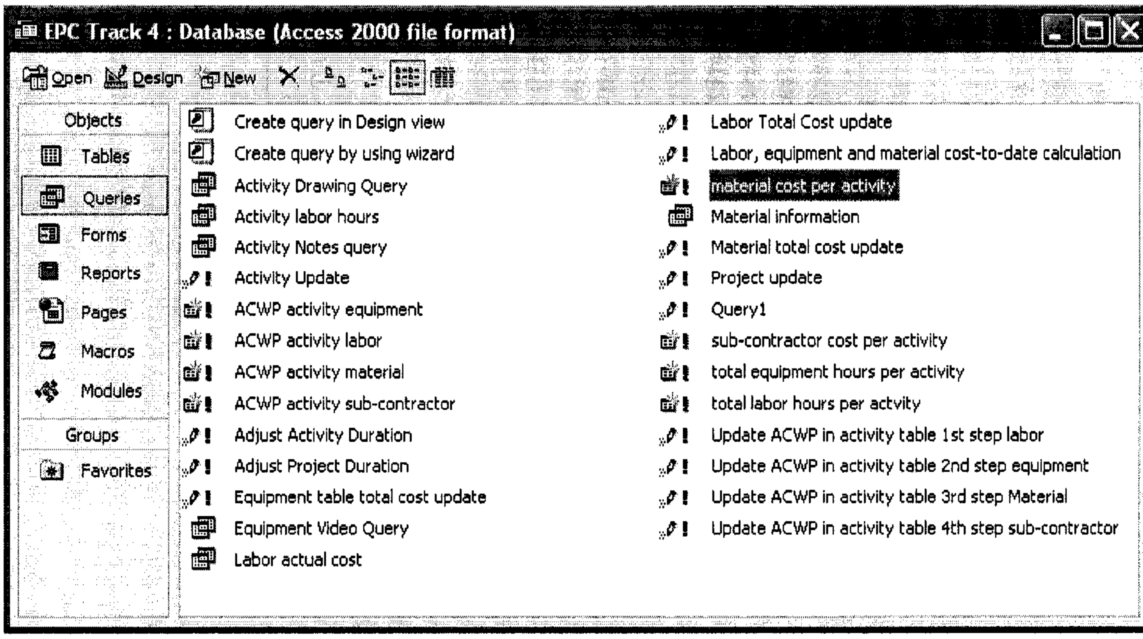
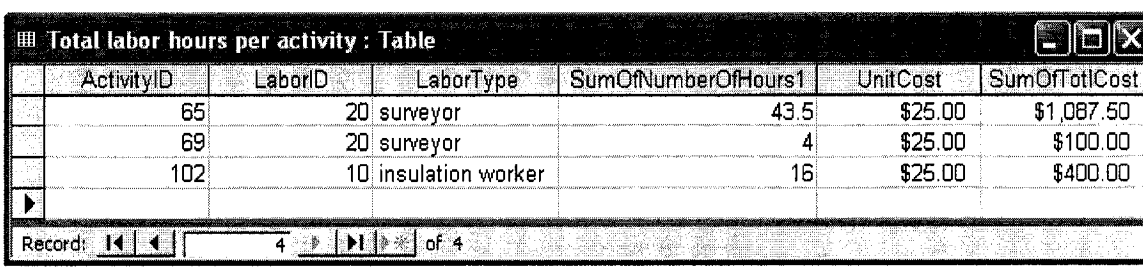



Figure 5-12 List of queries



Total labor hours per activity : Table

| ActivityID | LaborID | LaborType | SumOfNumberOfHours1 | UnitCost | SumOfTotlCost |
|---|---|---|---|---|---|
| 65 | 20 | surveyor | 43.5 | $25.00 | $1,087.50 |
| 69 | 20 | surveyor | 4 | $25.00 | $100.00 |
| 102 | 10 | insulation worker | 16 | $25.00 | $400.00 |

Record: 4 of 4

Figure 5-13 Total labor hours per activity

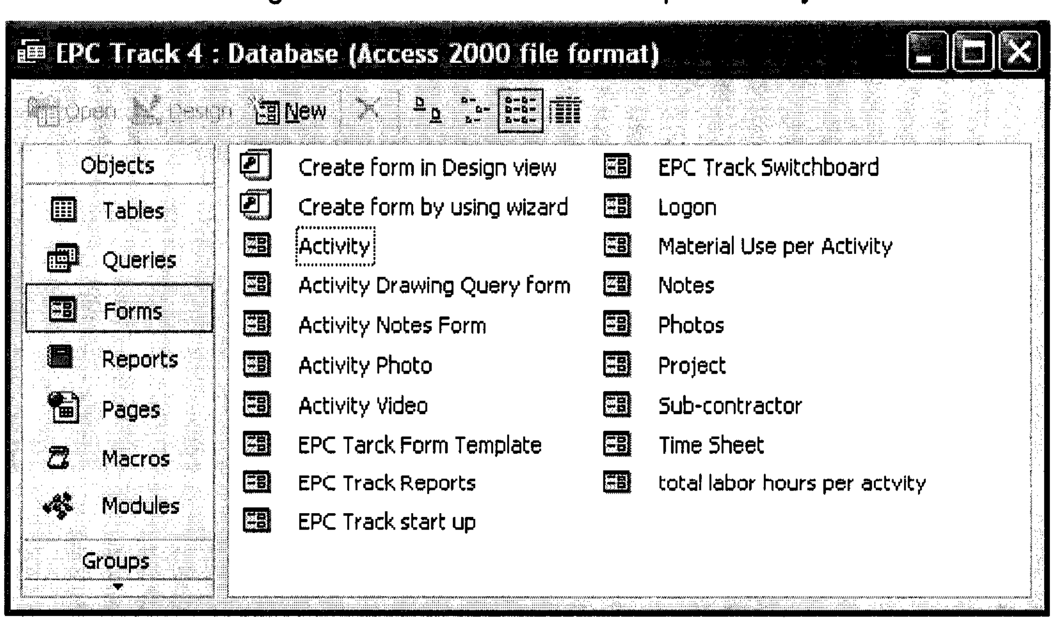



Figure 5-14 List of forms

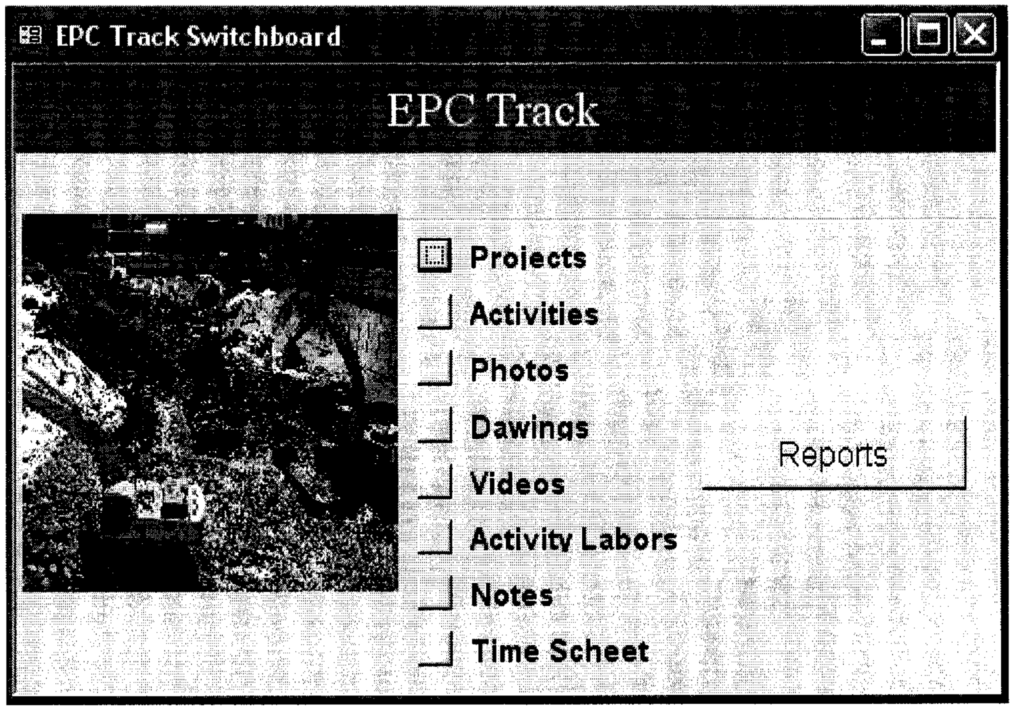



Figure 5-15 EPC Track switchboard

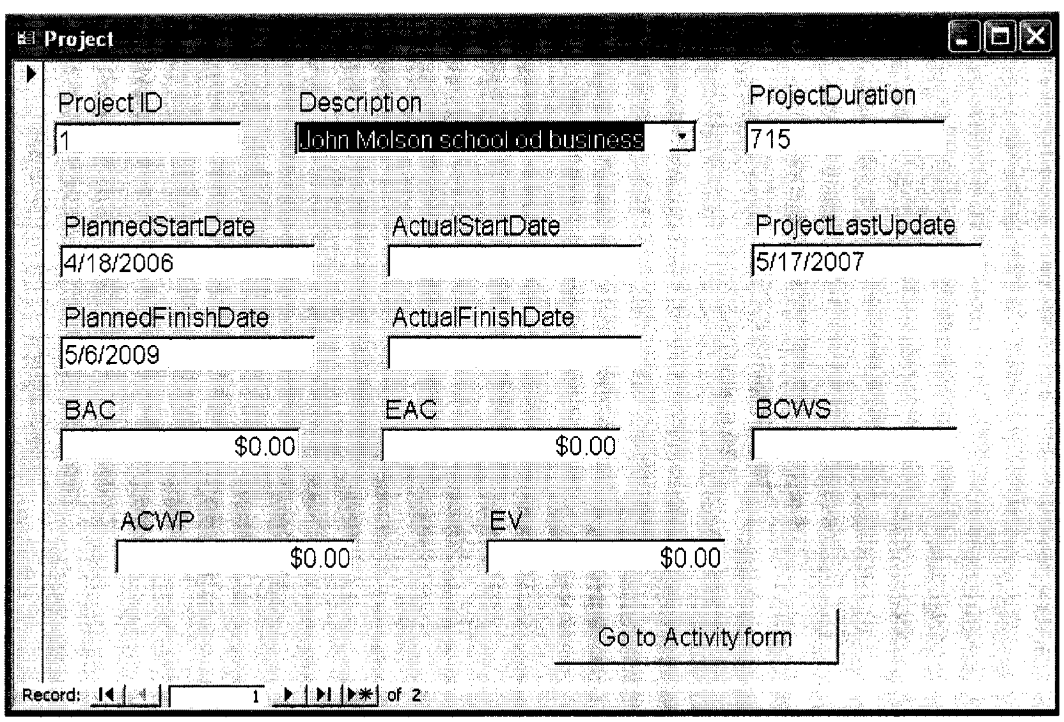



Figure 5-16 Projects form

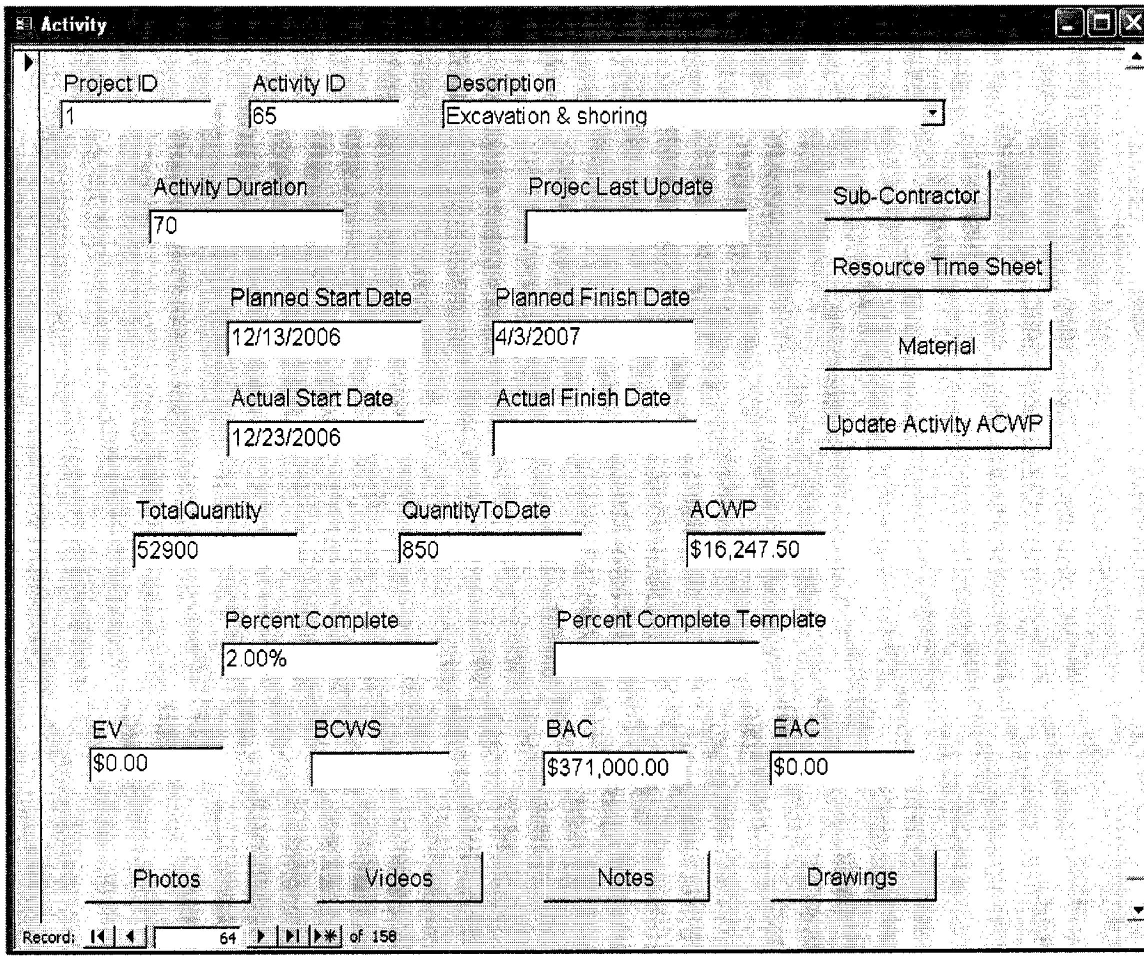



Figure 5-17 Activity form

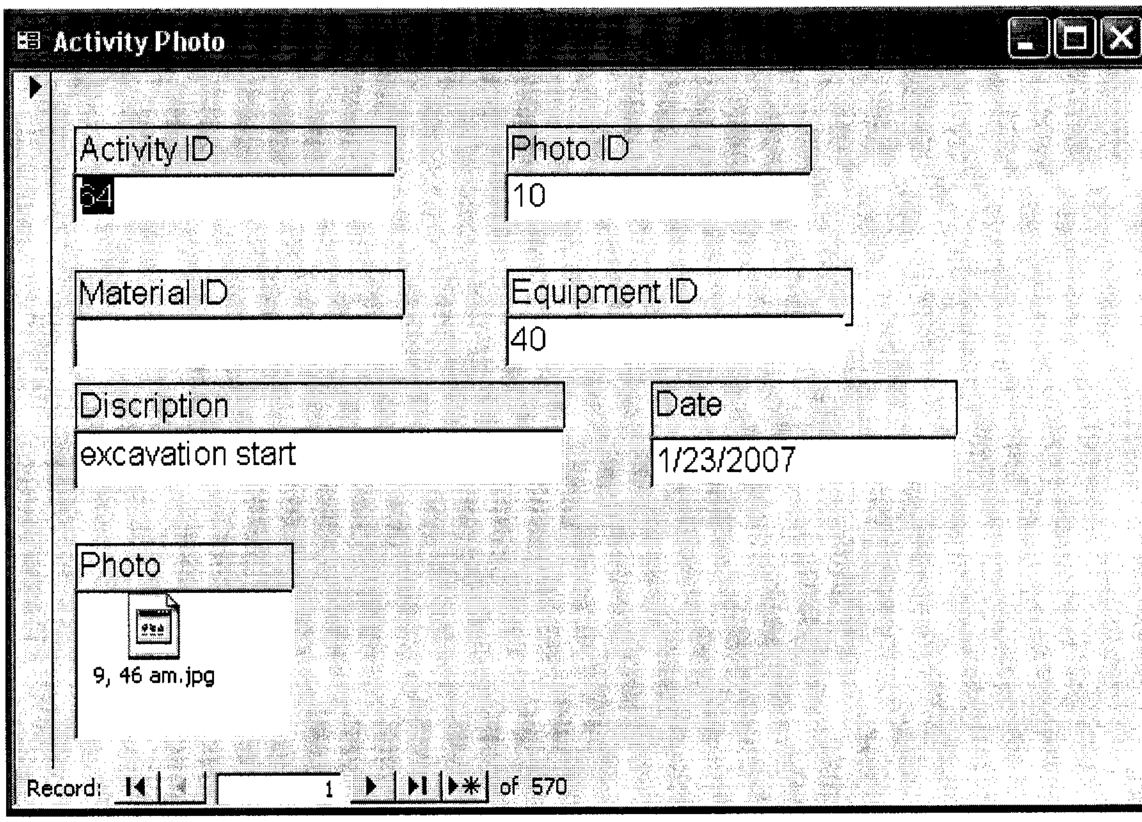



Figure 5-18 Activity photos

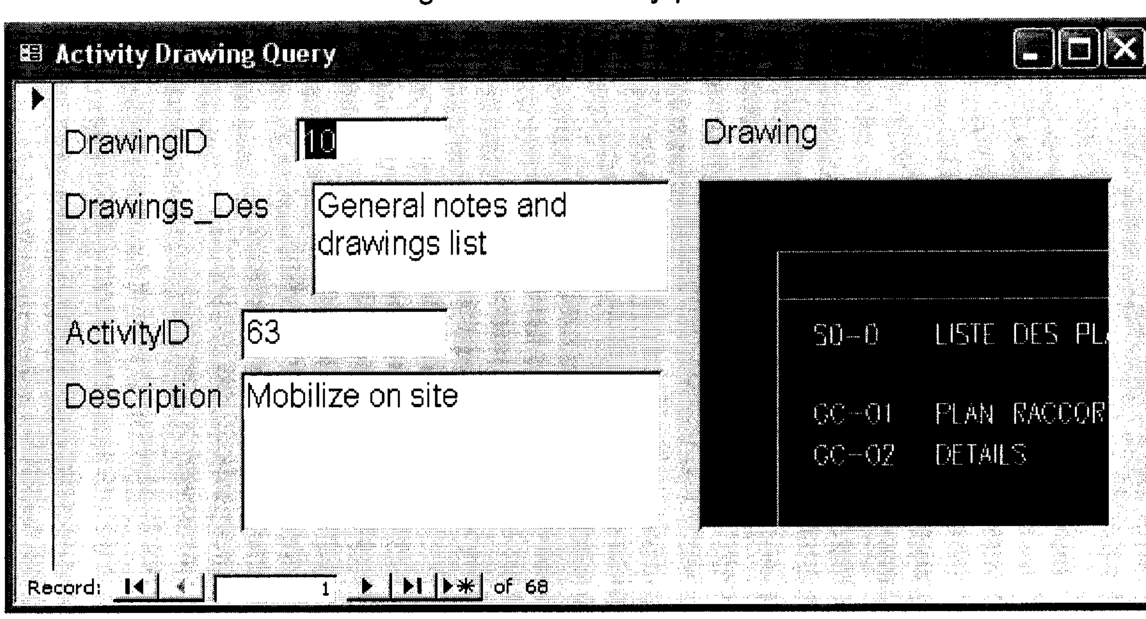



Figure 5-19 Activity drawings

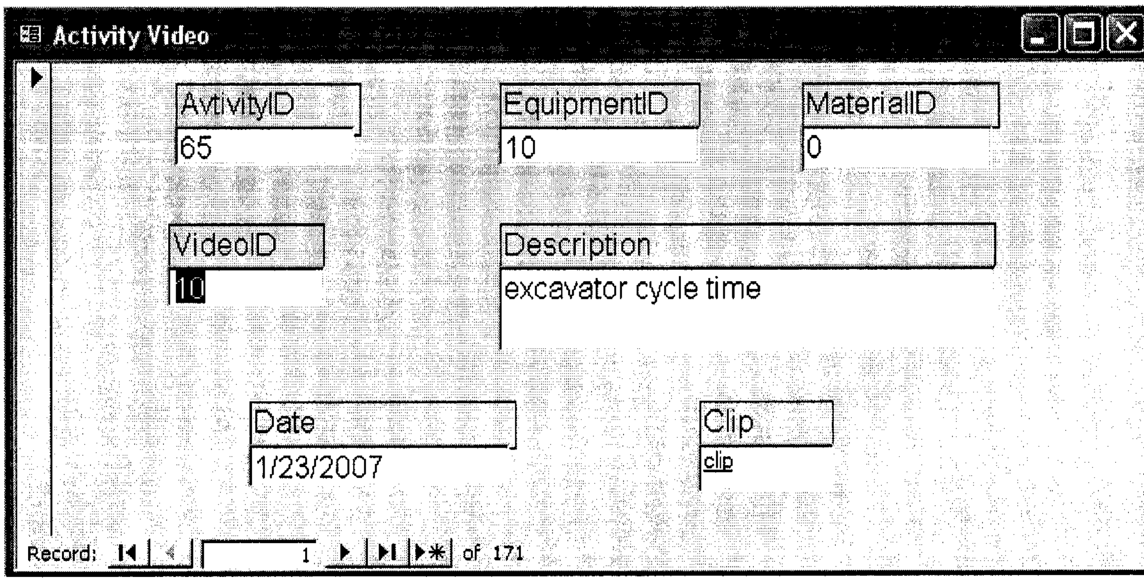



Figure 5-20 Activity video

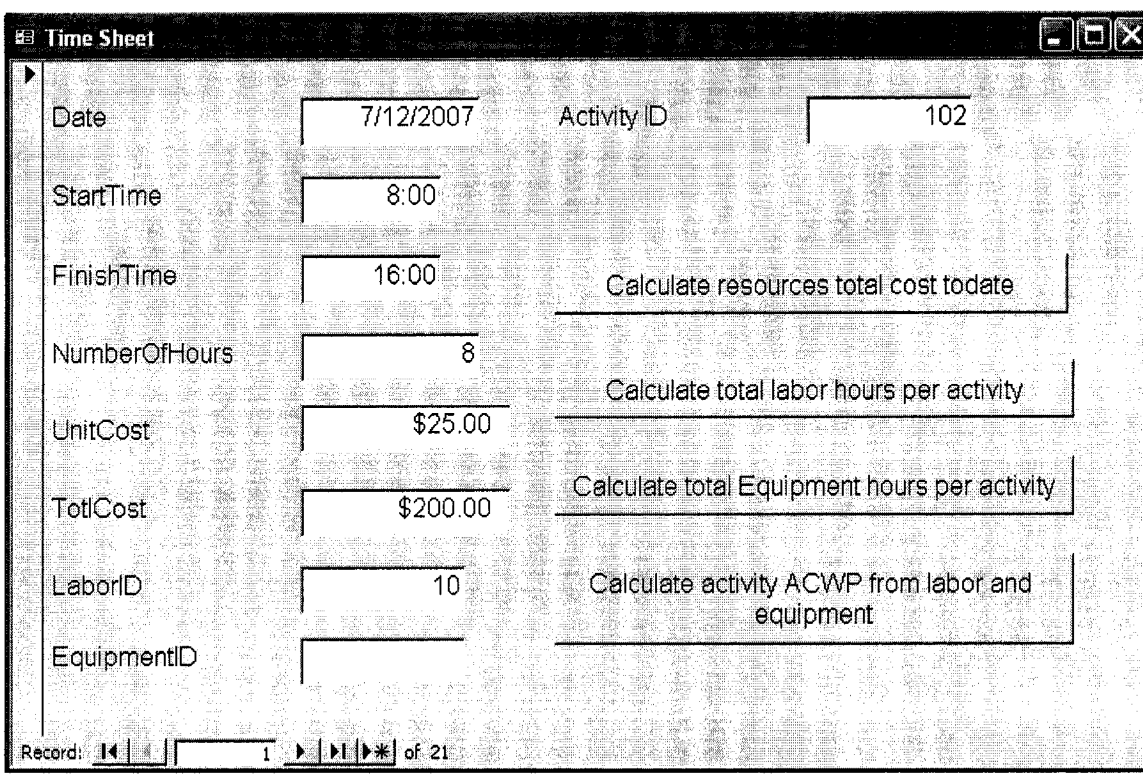



Figure 5-21 Time sheet form

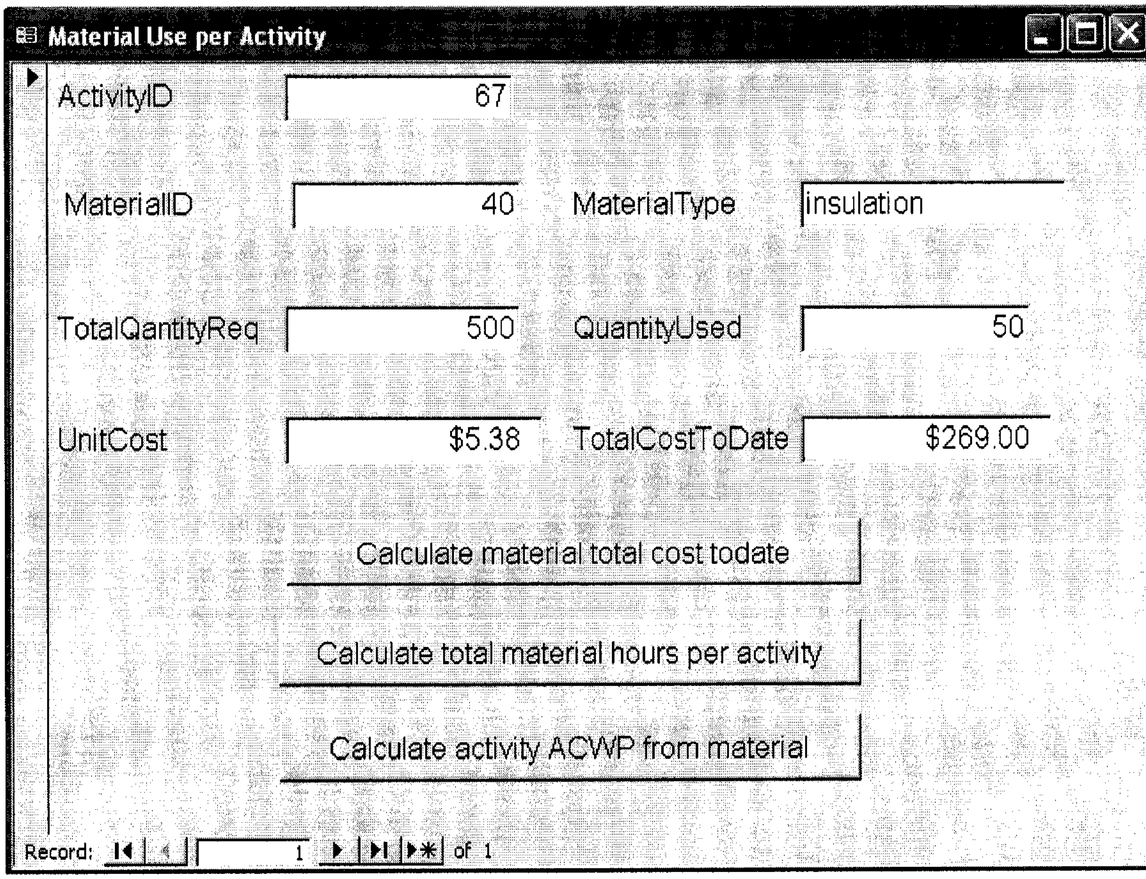



Figure 5-22 Material form

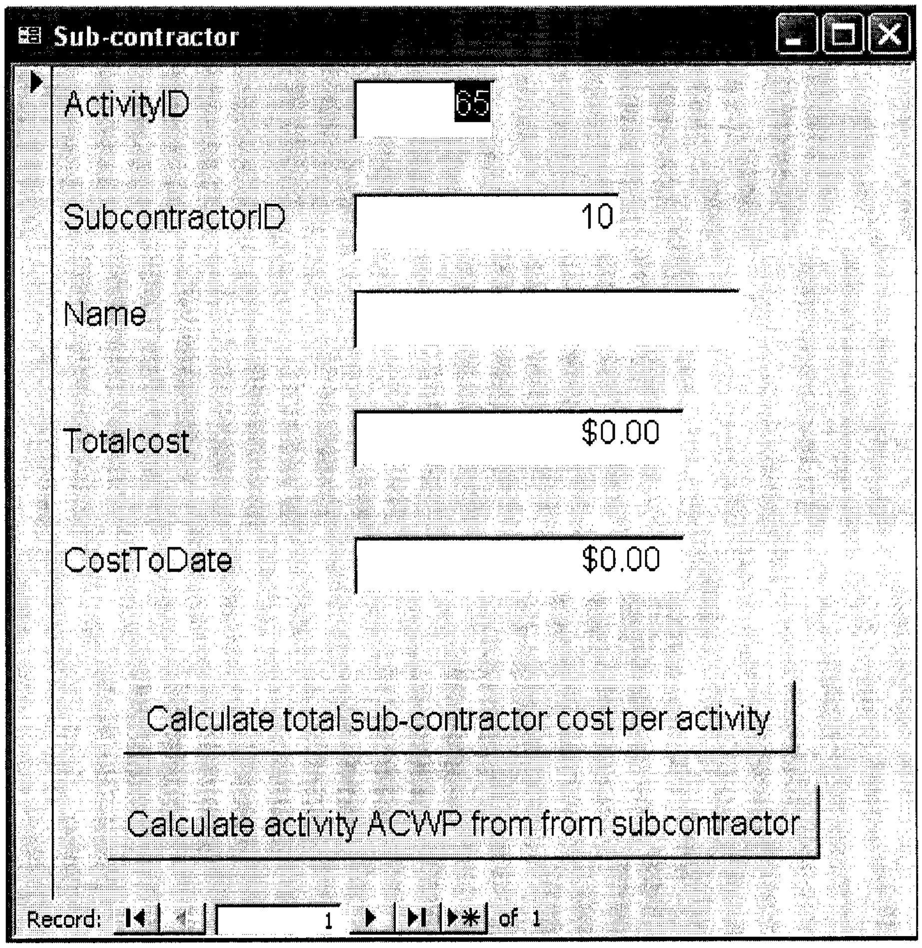



Figure 5-23 Sub-contractor form

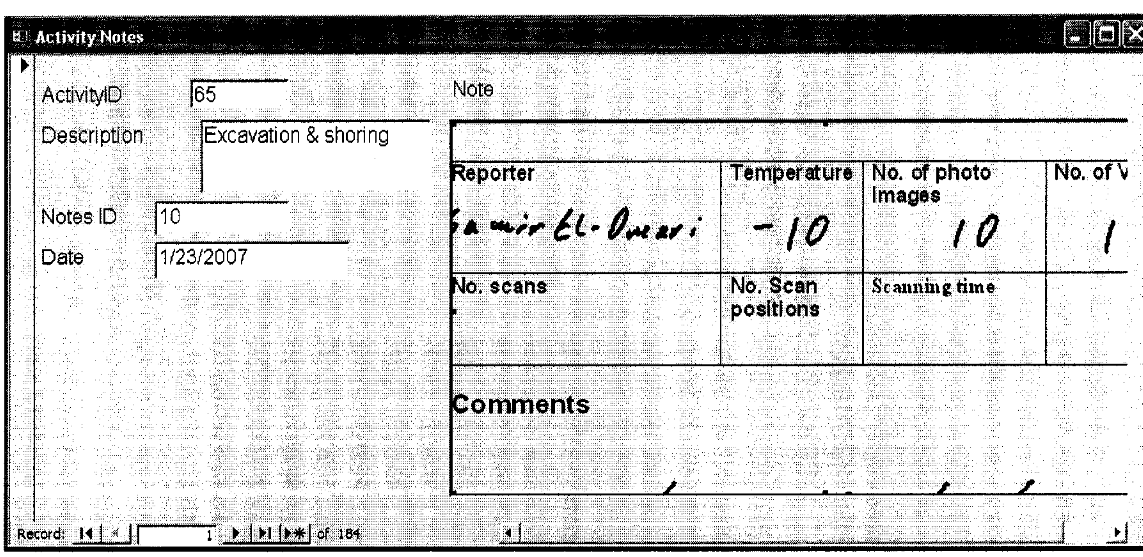



Figure 5-24 Notes form

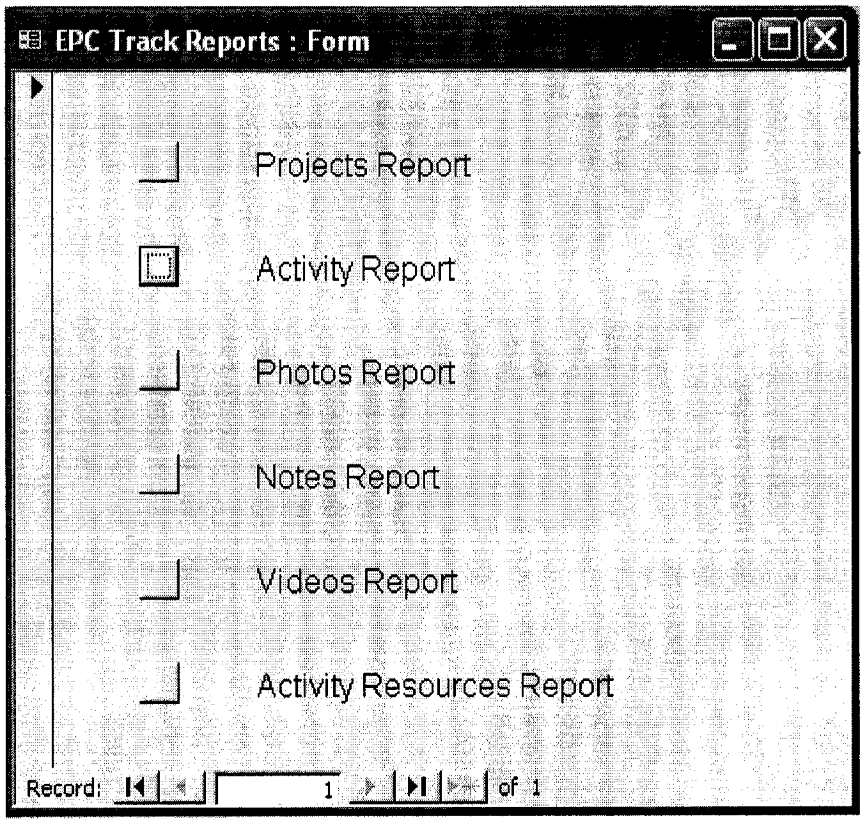



Figure 5-25 Reports


Figure 5-26 EPC track reports

# Activity Notes

# EPC Track

| ProjectID | ActivityID | Description | NotesID | Discription | Date | Temprature | EquipmentID | MaterialID | LaborID |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | |
| | 65 | Excavation & shoring | 660 | B1 FW and excavation | 5/4/2007 | 10 | 0 | 0 | 0 |
| | 65 | Excavation & shoring | 410 | excavation | /26/2007 | 2 | 0 | 0 | 0 |
| | 72 | Concrete Work | 920 | B2 slab and GF slab FW and Tunnel base FW | /14/2007 | 20 | 0 | 0 | 0 |
| | 71 | Relocate Drainage | 940 | no work week end some photos | /17/2007 | 24 | 0 | 0 | 0 |
| | 71 | Relocate Drainage | 340 | tunnel excavation | /15/2007 | 0 | 0 | 0 | 0 |
| | 71 | Relocate Drainage | 330 | start tunnel work, shoring pile driving | /14/2007 | 6 | 0 | 0 | 0 |
| | 70 | Install Steel Structure Supp | 940 | no work week end some photos | /17/2007 | 24 | 0 | 0 | 0 |
| | 70 | Install Steel Structure Supp | 340 | tunnel excavation | /15/2007 | 0 | 0 | 0 | 0 |
| | 70 | Install Steel Structure Supp | 330 | start tunnel work, shoring pile driving | /14/2007 | 6 | 0 | 0 | 0 |
| | 65 | Excavation & shoring | 810 | B2 slab and tunnel excavation | /28/2007 | 15 | 0 | 0 | 0 |
| | 72 | Concrete Work | 940 | no work week end some photos | /17/2007 | 24 | 0 | 0 | 0 |
| | 65 | Excavation & shoring | 790 | B2 slab and tunnel excavation | /24/2007 | 14 | 0 | 0 | 0 |
| | 72 | Concrete Work | 950 | tunnel wall formwork started | /19/2007 | 26 | 0 | 0 | 0 |
| | 65 | Excavation & shoring | 650 | B1 Walls FW and Backfilling | 5/3/2007 | 9 | 0 | 0 | 0 |
| | 65 | Excavation & shoring | 560 | backfilling | /19/2007 | 9 | 0 | 0 | 0 |
| | 65 | Excavation & shoring | 480 | excavation | 4/9/2007 | 2 | 0 | 0 | 0 |

*Tuesday, June 03, 2008*

Figure 5-27 Activity notes report

*Page 1 of 11*

| ProjectID | ActivityID | Description | BAC | EAC | ACWP | EV | BCWS | PercentComplete | TotalQuantity | QuantityToDate |
|---|---|---|---|---|---|---|---|---|---|---|
| | 64 | Temporary site inst | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 65 | Excavation & shori | $371,000.00 | $388,800.00 | 6,247.50 | 5,961.00 | | 2.00% | 52,900.00 | 850 |
| | 66 | | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 67 | Tunnel | $0.00 | $0.00 | 269.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 68 | Mobilize on site | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 69 | Install Temporary P | $0.00 | $0.00 | 100.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 70 | Install Steel Structu | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 71 | Relocate Drainage | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 72 | Concrete Work | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 73 | Electrical Tunnel In | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 74 | | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 75 | Structure | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 76 | From Footings to G | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 77 | Footings | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 78 | Level B2 fnd. Wall | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 79 | Level B1 slab & fdn | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 80 | Ground floor slab | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 81 | Above Ground Stru | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 82 | Level 2 slab | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 83 | Level 3 slab | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 84 | Level 4 slab | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |
| | 85 | Level 5 slab | $0.00 | $0.00 | 0.00 | 0.00 | | 0.00% | 0.00 | 0 |

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Figure 5-28 Activity report

# CHAPTER 6 SUMMARY AND CONCLUDING REMARKS

## 6.1 Summary

This research thesis presented the layout of a construction control model developed to assist in the process of data collection from construction sites to support efficient time and cost tracking and control of construction projects. This model enables contractors to track cost and time not only at the activity level but also at the cost account and the work package levels. The integration of 3D laser scanning and photogrammetry as a method to overcome limitations associated with the application of each individual technology was examined and presented. Experimental work was conducted on each technology separately, which led to the identification of limitations associated with each technology and exploration of the likely advantage of integrating these two technologies and using them to estimate quantities of work performed on construction sites. Other automated data acquisition technologies where tested including bar coding, RFID, and pen-based computers and utilized in the proposed construction control model. At the core of developed model lies a data management model that organizes, stores, retrieves and processes the data collected from construction sites to support project tracking and control. The database was implemented using Microsoft Access to facilitate the interaction with other scheduling software systems such as Microsoft Project and Primavera systems.

## 6.2 Research Contributions

Integrating time and cost control functions depends primarily on the timeliness and accuracy of data needed for the tracking process. The objectives of the research were to study and analyze the characteristics of automated data acquisition technologies including 3D laser scanning, photogrammetry, bar coding, RFID, and pen-based computers. This includes their capabilities and limitations and their respective suitability to track various construction operations. The applications of different automated data acquisition technologies were studied and analyzed to explore the most sui- IT platform for integrating them into one control model. To fulfill these objectives, the following steps were performed:

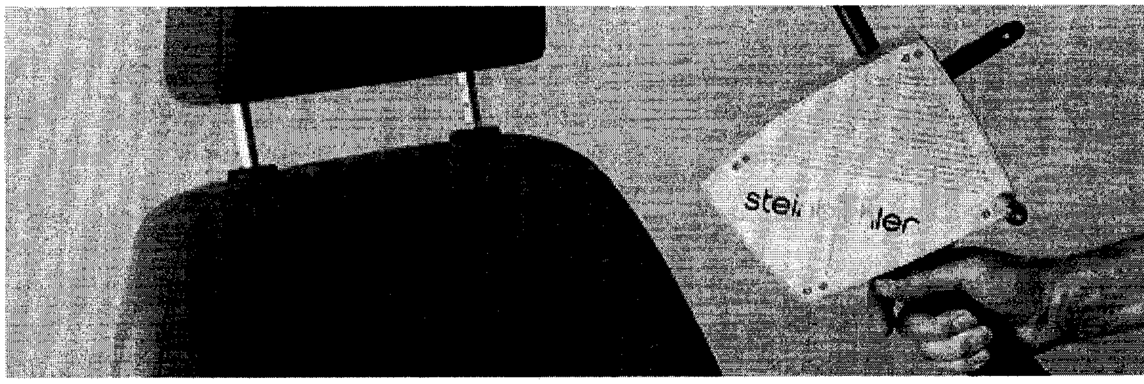
a. Evaluating the progress made in the field of automated data acquisition.
b. Exploring the benefits of applying different data acquisition technologies and integrating them into one control model.
c. Designing a centralized database to store collected data.
d. Developing a software application that acts as an interface with the user to enter actual data on site and store them in a centralized database.

## 6.3 Recommendations for Future Research

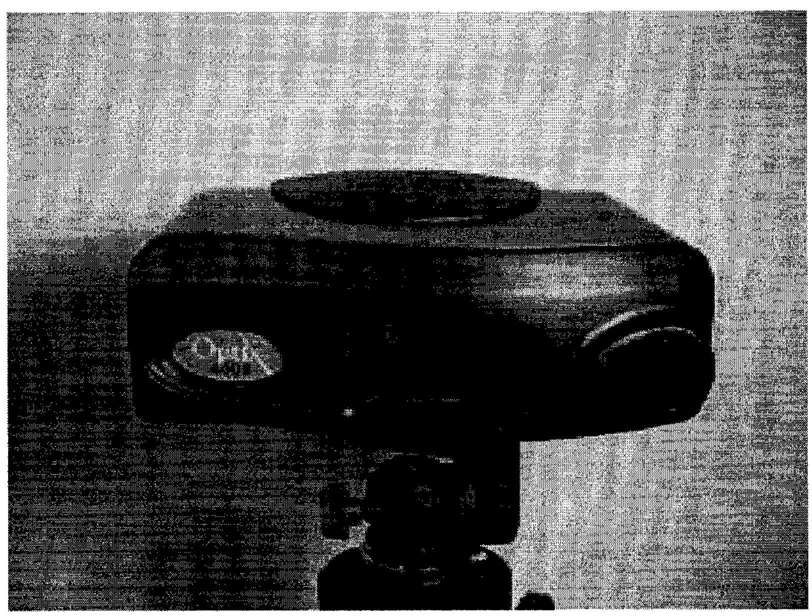
Automated data acquisition technologies are rapidly evolving and more research needs to be done on available technologies. The following are some recommendations for future research based on the analysis conducted in the current study:

1. Studying the potential of utilizing GPS (Geographical positioning system) together with RFID to identify the location of the scanned item, particularly in equipments used in high way construction.
2. Applying different RFID readers including vehicle mounted, stand-alone, and hand-held readers and integrating them into one control model for resource management in construction projects and studying the possibility of replacing bar-code technology with RFID based on the cost of RFID tags, which is the main limitation in the replacement process.
3. Performing cost analysis for the automation of data collection process through comparing the cost of non-automated with automated control systems. This is important to provide the construction industry with cost analysis that would help in the decision making process regarding the application of automated data acquisition technologies and the time and cost it can save when the system is utilized. This includes estimating the costs of unforeseen expenses that might arise as a result of delays and lack of accuracy of the data collected as a result of using traditional data collection methods.

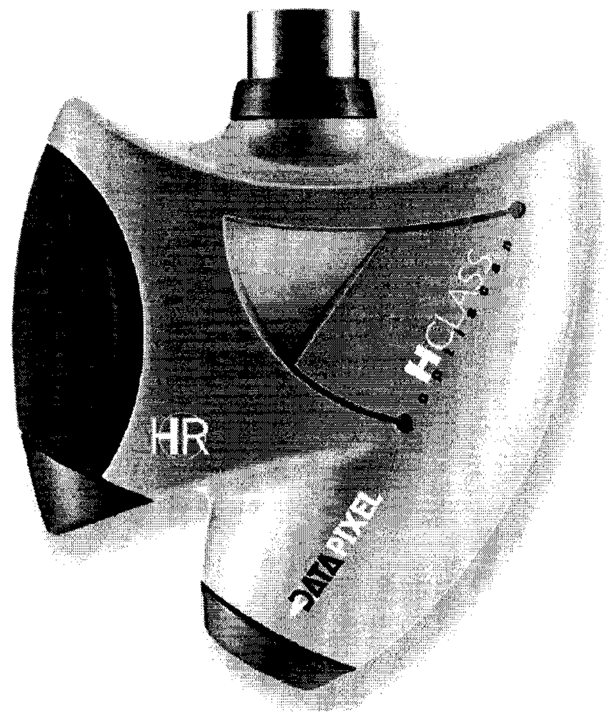
# Appendix I
# Automated data acquisition equipments



(A) T-Scan 2 short range laser scanner (Steinbichler)

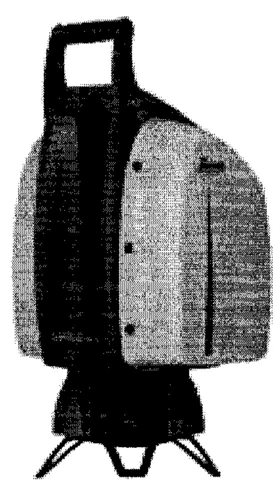



(B) Optix 400 L (3D Digital)

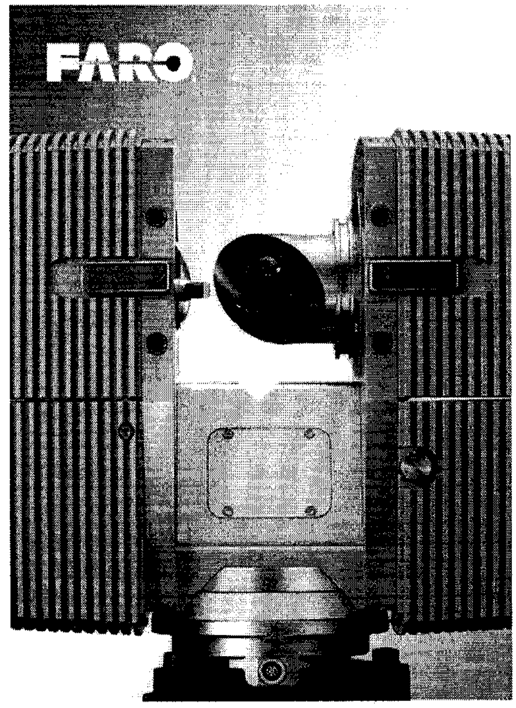



(C) Optiscan H class (Datapixel)

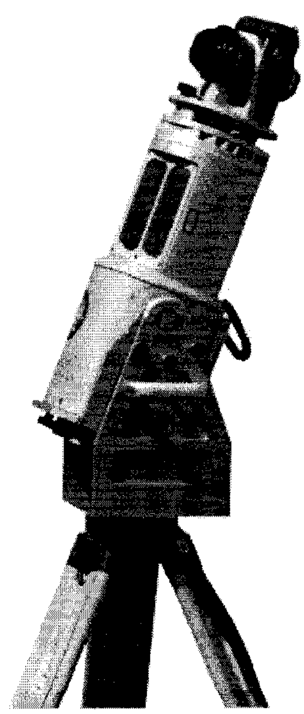
(D) Deltashare 3000 (3rdTech)

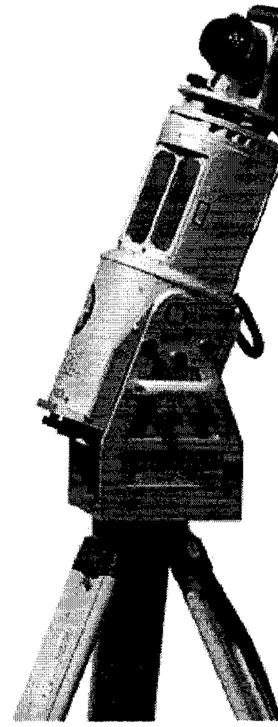


(E) Leicascanstation 2 (Leica Geosystems)

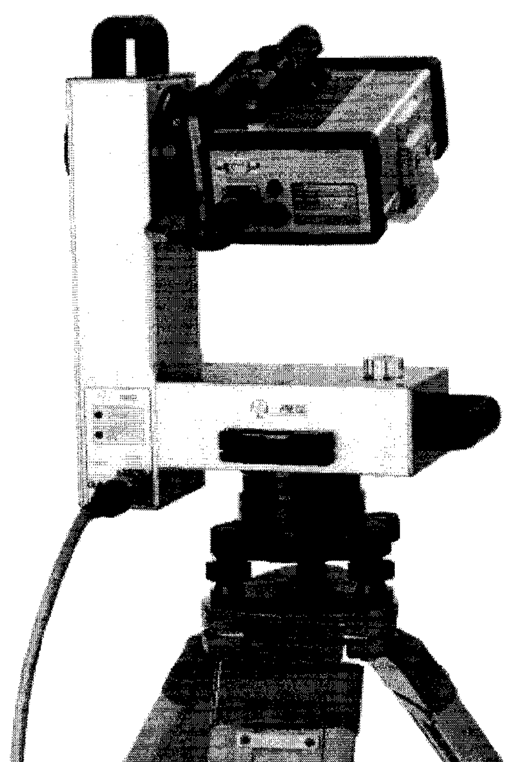


(F) Faro Laser Scanner LS 840/880 (Faro)


(G) LMS Z390i (RIEGL)

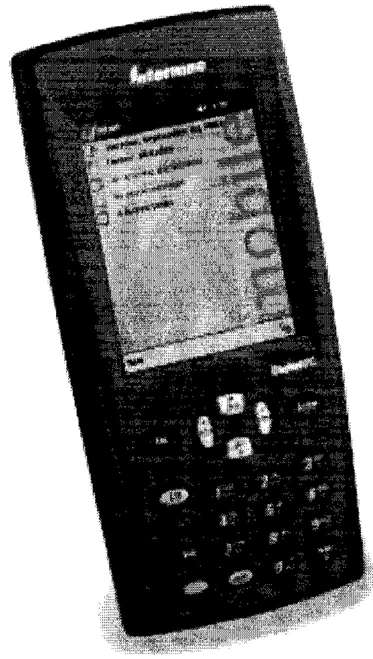


(H) LMS-Z420i (RIEGL)



(I) LPM-100VHS (RIEGL)

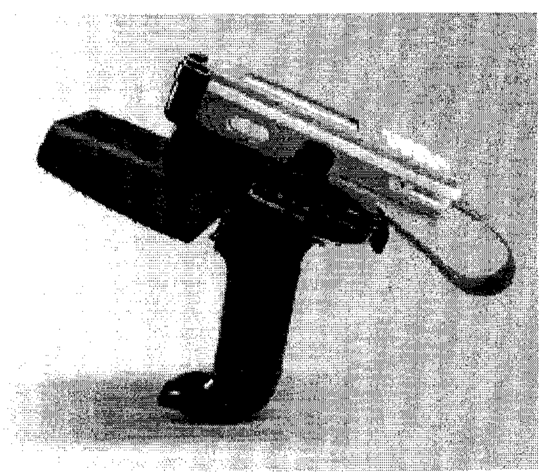
(J) LPM 321 (RIEGL)



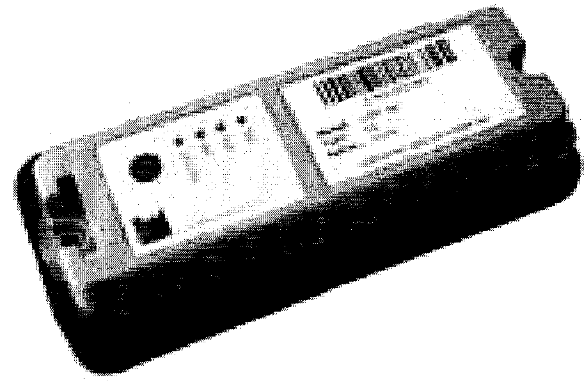
(K) 751A,COLOR mobile computer from Intermec

(L) IP4 INTELLITAG PORTABLE RFID READER (UHF) from Intermec


(M) CN3e mobile computer from Intermec



(N) IP30 RFID reader from Intermec



(O) GPS RFID tag from IDENTEC SOLUTIONS

# Appendix II
# Queries

a) Update Activity data with those imported from the scheduling software application

```
UPDATE Activity, [JMSB Activities] SET Activity.Description = [JMSB Activities]![TASK_NAME], Activity.ActivityDuration = [JMSB Activities]![TASK_DUR], Activity.PlannedStartDate = [JMSB Activities]![TASK_EARLY_START], Activity.PlannedFinishDate = [JMSB Activities]![TASK_LATE_FINISH] WHERE (((Activity.[Activity ID])=[JMSB Activities]![TASK_ID]));
```

b) Labor, equipment and material cost-to-date calculation

```
UPDATE [Time Sheet], [Material Use] SET [Time Sheet].NumberOfHours = ([Time Sheet]![FinishTime]-[Time Sheet]![StartTime])*1440/60, [Time Sheet].TotlCost = [Time Sheet]![NumberOfHours]*[Time Sheet]![UnitCost], [Material Use].TotalCostToDate = [Material Use]![QuantityUsed]*[Material Use]![UnitCost];
```

c) Total labor hours per activity

```
SELECT [Acivity Time Sheet].ActivityID, Labor.LaborID, Labor.LaborType, Sum([Time Sheet].NumberOfHours) AS SumOfNumberOfHours1, Labor.UnitCost, Sum([Time Sheet].TotlCost) AS SumOfTotlCost INTO [Total labor hours per activity]

FROM (Labor INNER JOIN [Time Sheet] ON Labor.LaborID = [Time Sheet].LaborID) INNER JOIN [Acivity Time Sheet] ON [Time Sheet].TimeSheetID = [Acivity Time Sheet].TimeSheetID

GROUP BY [Acivity Time Sheet].ActivityID, Labor.LaborID, Labor.LaborType, Labor.UnitCost;
```

d) Total equipment hours per activity

```
SELECT [Acivity Time Sheet].ActivityID, Equipment.EquipmentID, Equipment.EquipmentType, Sum([Time Sheet].NumberOfHours) AS SumOfNumberOfHours, Equipment.UnitCost, Sum([Time Sheet].TotlCost) AS SumOfTotlCost INTO [Total Equipment  hours per activity]

FROM (Equipment INNER JOIN [Time Sheet] ON Equipment.EquipmentID = [Time Sheet].EquipmentID) INNER JOIN [Acivity Time Sheet] ON [Time Sheet].TimeSheetID = [Acivity Time Sheet].TimeSheetID

GROUP BY [Acivity Time Sheet].ActivityID, Equipment.EquipmentID, Equipment.EquipmentType, Equipment.UnitCost;
```

e) Sub-contractor cost per activity

SELECT [Activity Sub-contractor].ActivityID, [Activity Sub-contractor].SubcontractorID, [Sub-contractor].Name, Sum([Sub-contractor].CostToDate) AS SumOfCostToDate INTO [total sub-contractor cost per activity]

FROM [Sub-contractor] INNER JOIN [Activity Sub-contractor] ON [Sub-contractor].SubcontractorID = [Activity Sub-contractor].SubcontractorID

GROUP BY [Activity Sub-contractor].ActivityID, [Activity Sub-contractor].SubcontractorID, [Sub-contractor].Name;

f) ACWP activity labor

SELECT [Total labor hours per activity].ActivityID, Sum([Total labor hours per activity].SumOfTotlCost) AS SumOfSumOfTotlCost INTO [activity ACWP labor]

FROM [Total labor hours per activity]

GROUP BY [Total labor hours per activity].ActivityID;

g) ACWP activity equipment

SELECT [Total Equipment  hours per activity].ActivityID, Sum([Total Equipment hours per activity].SumOfTotlCost) AS SumOfSumOfTotlCost INTO [activity ACWP equipment]

FROM [Total Equipment  hours per activity]

GROUP BY [Total Equipment  hours per activity].ActivityID;

h) ACWP activity material

SELECT [total material cost per activity].ActivityID, Sum([total material cost per activity].SumOfTotalCostToDate) AS SumOfSumOfTotalCostToDate INTO [activity ACWP material]

FROM [total material cost per activity]

GROUP BY [total material cost per activity].ActivityID;

i) ACWP activity sub-contractor

SELECT [total sub-contractor cost per activity].ActivityID, Sum([total sub-contractor cost per activity].SumOfCostToDate) AS SumOfSumOfCostToDate INTO [activity ACWP sub-contractor]

FROM [total sub-contractor cost per activity]

GROUP BY [total sub-contractor cost per activity].ActivityID;

j) Update ACWP in activity table

1st step labor

```
UPDATE [activity ACWP labor], Activity SET Activity.ACWP = [activity ACWP labor]![SumOfSumOfTotlCost]
WHERE ((([Activity]![ActivityID])=[activity ACWP labor]![ActivityID]));
```

2nd step equipment

```
UPDATE Activity, [activity ACWP equipment] SET Activity.ACWP = [Activity]![ACWP]+[activity ACWP equipment]![SumOfSumOfTotlCost]
WHERE ((([Activity]![ActivityID])=[activity ACWP equipment]![ActivityID]));
```

3rd step Material

```
UPDATE Activity, [activity ACWP material] SET Activity.ACWP = [Activity]![ACWP]+[activity ACWP material]![SumOfSumOfTotalCostToDate]
WHERE ((([Activity]![ActivityID])=[activity ACWP material]![ActivityID]));
```

4th step sub-contractor

```
UPDATE Activity, [activity ACWP sub-contractor] SET Activity.ACWP = [Activity]![ACWP]+[activity ACWP sub-contractor]![SumOfSumOfCostToDate]
WHERE ((([Activity]![ActivityID])=[activity ACWP sub-contractor]![ActivityID]));
```

# Appendix III
# Visual basic code

a) Accessing activity form from the project form through a command button

```
Option Compare Database
Option Explicit

Private Sub cmdGoToActivityForm_Click()
'open Activity form

    DoCmd.OpenForm "Activity"
End Sub
```

b) Selecting activity from dropdown box in combo box

```
Private Sub Description_AfterUpdate()
Dim rs As DAO.Recordset

  If Not IsNull(Me.Description) Then
    'Save before move.
    If Me.Dirty Then
      Me.Dirty = False
    End If
    'Search in the clone set.
    Set rs = Me.RecordsetClone
    rs.FindFirst "[ActivityID] = " & Me.Description
    If rs.NoMatch Then
      MsgBox "Not found: filtered?"
    Else
      'Display the found record in the form.
      Me.Bookmark = rs.Bookmark
    End If
    Set rs = Nothing
  End If
End Sub

Private Sub ProjectDescription_AfterUpdate()
Dim rs As DAO.Recordset

  If Not IsNull(Me.ProjectDescription) Then
    'Save before move.
    If Me.Dirty Then
      Me.Dirty = False
    End If
    'Search in the clone set.
    Set rs = Me.RecordsetClone
    rs.FindFirst "[ProjectID] = " & Me.ProjectDescription
```

```
        If rs.NoMatch Then
            MsgBox "Not found: filtered?"
        Else
            'Display the found record in the form.
            Me.Bookmark = rs.Bookmark
        End If
        Set rs = Nothing
    End If
End Sub
```

c) Invoking queries from the time sheet from

```
Private Sub cmdActivityACWPfromLaborAndEquipment_Click()
'Run query (ACWP activity labor) & (ACWP activity equipment)


        DoCmd.OpenQuery "ACWP activity labor"
        DoCmd.OpenQuery "ACWP activity equipment"
End Sub

Private Sub cmdResourceTotalCostTodate_Click()
'Run query (Labor, equipment and material cost-to-date calculation)


        DoCmd.OpenQuery "Labor, equipment and material cost-to-date
calculation"
End Sub

Private Sub cmdTotalEquipmentHoursPerActivity_Click()
'Run query (total labor hours per actvity)


        DoCmd.OpenQuery "total equipment hours per activity"
        DoCmd.OpenTable "Total Equipment  hours per activity"

End Sub

Private Sub cmdTotalLaborPerActivity_Click()
'Run query (total labor hours per actvity)

        DoCmd.OpenQuery "total labor hours per actvity"
        DoCmd.OpenTable "Total labor hours per activity"

End Sub
```

d) Update ACWP field in activity table

```
Private Sub cmdUpdateACWP_Click()
'Run query (Update ACWP in activity table)

    DoCmd.OpenQuery "Update ACWP in activity table 1st step labor"
    DoCmd.OpenQuery "Update ACWP in activity table 2nd step equipment"
    DoCmd.OpenQuery "Update ACWP in activity table 3rd step Material"
    DoCmd.OpenQuery "Update ACWP in activity table 4th step sub-contractor"
```

e) EPC track switchboard

```
Private Sub FillOptions()
' Fill in the options for this switchboard page.

  ' The number of buttons on the form.
  Const conNumButtons = 8

  Dim con As Object
  Dim rs As Object
  Dim stSql As String
  Dim intOption As Integer

  ' Set the focus to the first button on the form,
  ' and then hide all of the buttons on the form
  ' but the first.  You can't hide the field with the focus.
  Me![Option1].SetFocus
  For intOption = 2 To conNumButtons
    Me("Option" & intOption).Visible = False
    Me("OptionLabel" & intOption).Visible = False
  Next intOption

  ' Open the table of Switchboard Items, and find
  ' the first item for this Switchboard Page.
  Set con = Application.CurrentProject.Connection
  stSql = "SELECT * FROM [Switchboard Items]"
  stSql = stSql & " WHERE [ItemNumber] > 0 AND [SwitchboardID]=" &
Me![SwitchboardID]
  stSql = stSql & " ORDER BY [ItemNumber];"
  Set rs = CreateObject("ADODB.Recordset")
  rs.Open stSql, con, 1   ' 1 = adOpenKeyset

  ' If there are no options for this Switchboard Page,
```

```
    ' display a message.  Otherwise, fill the page with the items.
    If (rs.EOF) Then
        Me![OptionLabel1].Caption = "There are no items for this switchboard page"
    Else
        While (Not (rs.EOF))
            Me("Option" & rs![ItemNumber]).Visible = True
            Me("OptionLabel" & rs![ItemNumber]).Visible = True
            Me("OptionLabel" & rs![ItemNumber]).Caption = rs![ItemText]
            rs.MoveNext
        Wend
    End If

    ' Close the recordset and the database.
    rs.Close
    Set rs = Nothing
    Set con = Nothing

End Sub

Private Function HandleButtonClick(intBtn As Integer)
' This function is called when a button is clicked.
' intBtn indicates which button was clicked.

    ' Constants for the commands that can be executed.
    Const conCmdGotoSwitchboard = 1
    Const conCmdOpenFormAdd = 2
    Const conCmdOpenFormBrowse = 3
    Const conCmdOpenReport = 4
    Const conCmdCustomizeSwitchboard = 5
    Const conCmdExitApplication = 6
    Const conCmdRunMacro = 7
    Const conCmdRunCode = 8
    Const conCmdOpenPage = 9

    ' An error that is special cased.
    Const conErrDoCmdCancelled = 2501

    Dim con As Object
    Dim rs As Object
    Dim stSql As String

On Error GoTo HandleButtonClick_Err

    ' Find the item in the Switchboard Items table
    ' that corresponds to the button that was clicked.
    Set con = Application.CurrentProject.Connection
```

```
   Set rs = CreateObject("ADODB.Recordset")
   stSql = "SELECT * FROM [Switchboard Items] "
   stSql = stSql & "WHERE [SwitchboardID]=" & Me![SwitchboardID] & " AND
[ItemNumber]=" & intBtn
   rs.Open stSql, con, 1    ' 1 = adOpenKeyset

   ' If no item matches, report the error and exit the function.
   If (rs.EOF) Then
      MsgBox "There was an error reading the Switchboard Items table."
      rs.Close
      Set rs = Nothing
      Set con = Nothing
      Exit Function
   End If
```

f) Accessing reports from the report form

```
Private Sub cmdActivityReport_Click()
'open Activity Report


      DoCmd.OpenReport "Activity Report", acPreview
End Sub

Private Sub cmdActivityResourcesReport_Click()
'open Activity labor hours Report


      DoCmd.OpenReport "Activity labor hours", acPreview
End Sub

Private Sub cmdNotesReports_Click()
'open Activity Notes Report


      DoCmd.OpenReport "Activity Notes", acPreview
                                                  End Sub
```

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