COMPUTER AIDED DESIGN–BASED PROJECT MANAGEMENT MODEL

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ABSTRACT

CAD-Based Project Management Model

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The construction industry is one that is fragmented by nature. In current practice, information is exchanged between the designers and contractors in the form of paper documents such as drawings, bills of material and specifications. Information is lost and errors are made during the forward and backward exchange of the design-construction information and constructability knowledge between the design professionals, cost estimators and contractors. Despite the technological developments in IT, the industry has been slow in adopting change in its processes. Computer Integrated Construction (CIC) strives to bridge the gaps of information by integrating the tools and processes within the Architecture, Engineering and Construction industries. This thesis proposes an integrated methodology across the design and construction functions supported by available CAD technologies. The proposed methodology has been implemented in a prototype software application named "CAD-B PM" that allows the user to integrate the CAD design with a central database that is a repository of project information. Productivity and cost estimates are generated within the database and are further integrated to a scheduling application for project planning and control. The prototype system provides a unique solution where the project information is openly shared between the applications in a dynamic environment through the use of Open Database Connectivity (ODBC).

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Integrated Project Management Functions

The functions of planning, scheduling and cost estimating make-up some of the core mandates of project management. Traditional construction techniques, widely used in the industry, perform these functions under separate processes with little if any interactions between them. Construction scheduling, planning and cost estimating require large amounts of work that is time consuming and often redundant. The current planning methods rely on manual manipulation of data that is provided by planners in an unstructured manner with considerable reliance on intuition and judgment.

A construction schedule organizes a detailed plan including the activities, tasks required, sequence, duration, and at times the required resources [PMBOK, 1996]. The schedule serves the following functions:

1. Modeling Function: model of installation approach for all required components and assemblies.
2. Communication and Trade Coordination Function.

3. Support Procurement and Financial Management Function.
4. Progress Control Function.
5. Data Recording Function.

To produce a schedule and to achieve the above functions, information from several sources must be made readily available. The design affects the schedule in terms of the scope of work, quantities, and production method used. This in turn determines the type of resources required, given a commitment to a delivery date. The information about the resource productivity is required to calculate the activity duration. Both duration and resource data impact the cost tag attached to the scheduled activities.

Therefore, data is required to plan and generate a schedule, and this data that is collected and applied, in turn generates new information. The communication of this information between the involved parties is often incomplete, inconsistent and inefficient. The main limitation is the fact that several systems are usually implemented to perform the above functions. Currently, several systems are implemented to track the above information under separate processes, resulting in inconsistencies and inaccuracies. Project Managers require an integrated set of project management tools that exchange information avoiding the redundancies and inconsistencies in the process. Despite Technological advancements, design, cost, and schedule information continue to be generated and maintained using separate processes producing inconsistent information that is often redundant.

Staub and Fisher [1999] refer to the data generated under the umbrella of the above-mentioned tools as " Islands of Information". At present, the construction phases are developed and planned individually with almost no electric exchange of the data generated at the different phases of construction. This information generated with each process is incomplete if standing on its own. The information should be enriched as the construction planning process advances. Due to the lack of integration at each phase of the process of design and management that are supported by different applications, information is usually re-keyed manually leading to an opportunity for error and/ or omissions of data integral to both the product and process. An integrated information management strategy is needed to make efficient the transfer of construction information among the phases of planning and design, construction and operation/ maintenance phases. Such a need stems from the fact that information generated during design can be used during the construction planning, scheduling and estimating phases. The productivity enhancement is directly related to the ability of reusing information and not having to recreate it.

1.2 Computer Integrated Construction

There is a demand for integration of construction project information, and technology continues to move forward introducing new applications and network improvements in Computer Integrated Construction, CIC. CIC strives to replace the traditional work process within architecture/engineering/construction, AEC, where documents are exchanged back and forth in the form of hard copies with the electronic sharing of project information [Russell and Froese, 1997]. Benefits of electronic sharing of project information include the minimization of errors, secured data integrity across the functional applications, as well as improved process efficiency particularly as related to accelerated communication between project team players involved in the facility design and construction.

Researchers have addressed the concept of construction integration through several efforts and developments varying from: integration at the application level (i.e. communicating between software), integration through a central database (i.e. project repository of information), geometrical integration at level of CAD packages, knowledge-based integration between applications, and databases, and object-oriented models integrating product and process information to promote collaboration among AEC agents. Researchers in this field have recognized that construction information integration is a very important task and yet difficult at both the practical and research levels. Many core process models have been presented in an effort to provide solutions to the problem of integration for construction. However, the challenge is not in modeling the information but in establishing a standard that enables the translation of information among different models for different applications through a common data structure, supporting project management data.

The International Organization for Standards' (ISO) is developing a standard for computer interpretable representation and exchange of project data. The Standard for Exchange of Product Model Data (STEP) focuses mainly on developing individual application models. Another effort at integration standardization is that of the Industry Alliance for Interoperability (IAI). The standards under development are in the form of Industry Foundation Classes (IFC's) for the exchange of data between computer systems within the AEC industry. IFC's introduce a global common system for defining physical attributes of construction objects, and at identifying a language not limited to any one software vendor or system. These efforts are a result of an evident need for standards establishing common data structures that would provide the methods for handling information generated throughout the life cycle of a project, through CIC [Rusell and Froese, 1997; Rezgui, et al., 1998; Froese et al., 1999; Froese and Yu, 1999; Kiviniem, 1999; Udaipurwala and Russell, 1999].

1.3 Scope and Objectives

This thesis studies the integration of a number of project management functions with an objective to minimize redundancy and errors typically encountered in the preparation of cost estimates, schedule development, and data exchange among the participants within the different phases of the construction project. The research presented in this thesis proposes a methodology to integrate a project design with the related construction management functions, thereby circumventing some of the limitations imposed by current practice in the AEC industry. The framework of this methodology is based on the concept of data sharing supported by a relational database. This methodology proposes to automate a number of the construction management functions through computer aided design, CAD media. An interactive prototype system has been developed for integrating CAD with construction related applications in an effort to circumvent the limitations posed by design fragmentation in the construction industry. It can be realized that scheduling and cost planning are directly related to the facility design, and that any changes on the design level will translate into a change in the schedule in terms of duration and task relationships. Design information logically impacts the cost estimate of the project where traditionally the practice continues to have contractors use the paper drawings to produce a cost estimate based on quantity take-off that are manually calculated.

Integration is synonymous with information sharing and is defined in this context as the continuous and interdisciplinary sharing of knowledge and data among all project participants, in support of the project objectives. The effort presented in this thesis proposes a CAD database model that provides comprehensive support for the project management functions that include planning, scheduling, as well as labor and material cost estimating. A methodology has been put forward demonstrating design-cost integration with cost-schedule integration via a central database system. This research establishes the fundamentals for developing an integrated project management system by defining what information must be captured and modeling the relationships between the sets of data. The development of the prototype has been limited to serve as a proof of concept for the proposed methodology outlined within this dissertation.

Specifically, the objectives of this study are:

1. Study the existing AEC processes for the delivery of Engineering/ Construction projects and identify any associated inadequacies.
2. Present the barriers to integration and discuss the requirements for an open information system spanning the lifecycle of a building project from design to construction.
3. Highlight the research efforts and developments as related to CIC.
4. Propose a methodology for integration in AEC based on the concept of relational data.
5. Implement the developed methodology in a “proof of concept” prototype; CAD-based integrated system utilizing commonly used software in the AEC industry.
6. Present a case example to demonstrate the use of the developed prototype system and to illustrate its capabilities.

1.4 Methodology

The first stage of the research approach is to study the current practice within AEC organizations and the state of information technology in the industry. The process analysis is conducted by means of interviewing the three organizations representing the AEC firms on a given building construction project in the Montreal area. Issues related to current practice in document and information exchange, intra-organizational practice versus inter-organizational practice, information technology tools adopted in the industry, aspects of design and construction integration, and various barriers to integration were examined and analyzed.

The research methodology embraces an in depth literature review of the research areas that make up CIC, including the integration of construction product and process models. The concept of an integration standard in an AEC framework is emphasized by highlighting the current developments within the realms of the International Standards Organization (ISO) and the International Alliance for Interoperability (IAI) [Rusell and Froese, 1997, Debras et al., 1998; Rezgui, et al., 1998; Froese et al., 1999; Froese and Yu, 1999; Kziviniemi, 1999; Udaipurwala and Russell, 1999]. The major development steps of recognition of the end-user needs for business improvement and the developments to fulfill those needs are outlined. Emphasis is put on the modeling of business processes, the integration of functional requirements within an integrated information model, and the methodologies and architectures adopted by each of the related research work.

The second stage of the research proposes the author's strategy for CIC. This phase is fundamental to the research effort. Following the exploratory investigation of the first stage, the requirements for integration of AEC functions are highlighted and a methodology to achieve information integration between each phase is presented. Through reviewing proposed models of information integration and existing applications that are available to perform the required functions, the information required to be captured are defined and the conceptual relationships between the sets of data are modeled. The solution proposed is based on a central relational database, (i.e. a central repository of building project information). The implementation of the methodology takes on a modular approach interfacing software applications commonly available and used in the industry as well as adopting an open system approach. Computer tools common to the AEC industry support the proof of concept prototype, and a system is developed by both interfacing and integrating specific computer applications. The core and central repository is populated with data from The Means® Cost Catalogue [1999], with productivity rates, labor and material costs. Given the academic nature of this study, efforts are concentrated on developing the data and workflow model and implementing it in a working system that could be easily expanded, rather than on increasing the size of the database.

The final stage involves the application of the proposed strategy in a case example. This case based approach allows for the validation and evaluation of the proposed model and the developed prototype. The general integration concept is specialized to the case construction project and the input information is gathered from AEC participants in a medium rise building project on the island of Montreal. The judgement of the strategy is based on an evaluation of the process involved by following the proposed methodology via the prototype computer system versus the practice implemented by AEC organizations involved in the project.

1.5 Organization of the Thesis

The tedious processes involved in the current practice of information exchange in AEC are discussed and the need for information and process integration is emphasized in Chapter two. Furthermore, this chapter analyzes information generated by participants and the overlapping areas between the domains of design-management. This chapter also includes an extensive review of the current approaches to integrated design-management processes and of the many research efforts and proposed models and/ or systems for construction information integration.

A conceptual data flow model of the proposed methodology for integrated process approach is presented in Chapter three. This chapter details the entities and relationships that make up the database as well as highlighting the functionality of the proposed model. The user needs to improve the AEC processes are specified and emphasized in the development of the proposed methodology. This chapter further describes the developed proof of concept prototype, CAD-B PM, along with the structure, system components and architecture.

An example application, presented in Chapter four, both illustrates the features and capabilities of CAD-B PM and validates the solution strategy adopted in this thesis.

Based on the findings of the thesis and their evaluation, the conclusion in Chapter five includes a summary of the identified advantages of the proposed system and re-emphasizes the need for computer integrated construction, CIC. Within this chapter a conclusion is drawn on the value of the proposed methodology for its implementation in the AEC industry. Recommendations for future work and development are noted.

CHAPTER TWO

2.0 LITERA TURE REVIEW

2.1 Need for Integration in AEC

2.1.1 Challenges for the Building Industry

The construction industry has been slow and rather timid in embracing the new and emerging information technology (IT) that is constantly advancing and in so doing, it is placing new demands on the AEC industry. The demand for changes within the industry comes from both the technological advancements as well as different groups in the society. Markets are expanding and opening up to global competition. Clients ask for higher quality at a lower price and with a shorter lead-time. The scale of building continues to grow and the trend for customization is ever present, requiring flexible building systems. In order for organizations within the building industry to try and adapt to these changes, they have to evolve and change their current processes and information communication. The construction industry is quickly becoming more industrialized by the increased mechanization present on site and by making use of pre-fabrication of building elements. Collaboration among project participants is improving with the concepts of partnering, building teams, Total Quality Management, and design-build contracts. However, these changes are not sufficient. There is a need for a greater optimization of the building process as a whole to bridge the growing gap between society's demands and the building industry's supply. The issue of integration of the various stages involved in the process of construction has become more critical than ever [Ahmad, Russell, & Abou-Zeid, 1995].

In the construction industry, integration has become the key word in computing systems developed for the industry. The industry has used IT to improve the capability and efficiency of the many aspects of the construction process. This technology is vast for applications that are specific to sub-process activities. Integration of the construction process as a whole is not widespread and presents a major area of opportunity for research and development [Construct IT, 1995].

Information transfer throughout the construction process between functional groups, project life cycle stages, and between the engineering disciplines, is a primary research area for the field of Information Technology in Construction (ITC), [Björk, 1999]. As a consequence, researchers have given particular attention in recent years to Computer Integrated Construction and the methods of describing a building in digital form, i.e. Building Product Modeling. The keen interest in this field of research is exhibited by the various conceptual models that have been introduced to enable more efficient information sharing and exchange within the construction industry.

The following three categories group the current and emerging IT capabilities: communications, data accessibility, and common systems. Communication technologies continue to contribute to the tremendous improvements in the industry's operations. The concept of data accessibility is manifested in the technology of Electronic Data Interchange (EDI), computer processing, as well as document imaging. At the higher level, IT contributes to decision making in the form of knowledge-based expert systems (KBES) and decision support systems (DSS).

The ever-changing business environments coupled with the increased technological capabilities are translating into a more defined need and drive towards integration. Integration between planning and design, and design and construction has gained increased attention from both researchers and the industry alike. The needs are primarily focused on integration of the functions of planning, design, procurement, and construction. This concept of integrating functions has a profound need for uniform and standardized information exchange.

There are several features of the industry, which inhibit an integrated approach to IT. In its nature the building industry is one that is fragmented. It has many diverse players with many more clients and building proprietors. All these players represent a diffuse network of information flows and requirements [Mitchell, 1999]. Other inhibitors to IT use in the industry are lack of client focus, too many dispersed clients with little power to influence the industry, and the lack of IT standards. In addition, the uniqueness of building projects makes the process of automating design and construction a more difficult task [Construct IT, 1995].

Information flows within the building industry are inhibited by the complexity of the construction process. The following points summarize the existing barriers to information exchange and the effective use of IT to support the construction industry:

- Fragmented clients impose little pressure on the industry to change in spite of a perception of poor service.
- Fragmentation of the construction industry and the lack of collaboration resulting in the inability to set-up information exchange protocols.
- The unique nature of each building project leads to the view that there is little benefit in automating the process.
- Difficulty in establishing IT standards for effective information exchange.
- The complexity of the construction process itself poses as a barrier.

Figure 2.1 illustrates the above points.

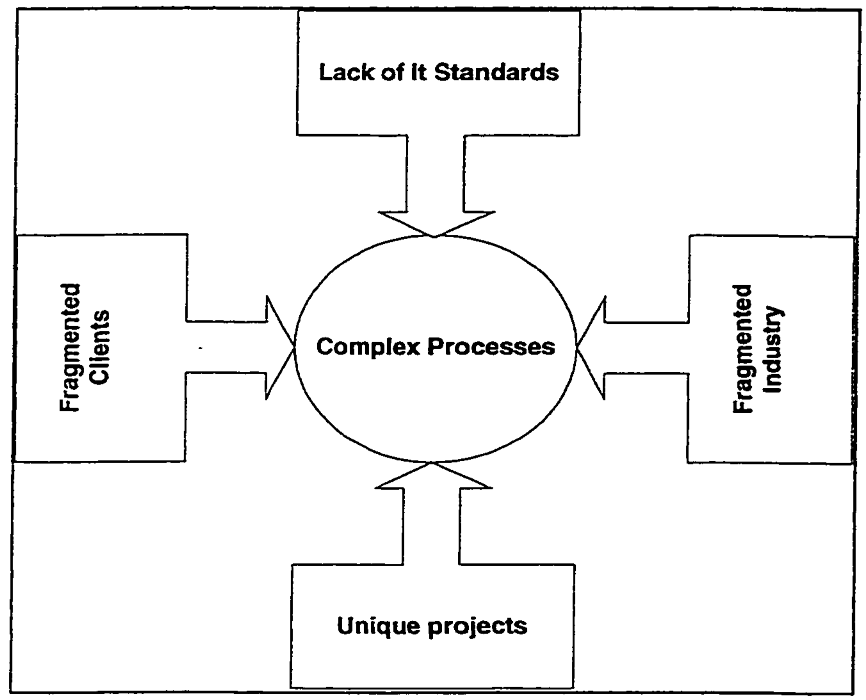


Figure 2.1 Characteristics of the Construction Industry Inhibiting IT Use.

2.1.2 Design for Construction

Design for Construction (DfC) as presented in Luiten's Ph.D. dissertation [1994] deals with the integration of two main building processes, i.e. design and construction. The term DfC is rather new, however, the notion of integrating design and construction is certainly not. Software applications developed for design, scheduling, and cost estimations continue to flood the market. However, most of these applications deal with activities within a sub-process and the information produced is particular to the application and does not support open exchange of data.

In its current state, different companies with different and often conflicting goals perform design and construction. The exchange of information has not really changed despite the ever-growing technologies. The industry continues to exchange paper documents, and these drawings resulting from the design require human interpretation before construction management can use them. Luiten [1994] continues to propose a bottom-up approach to integration; i.e. start with the sharing of information, then knowledge, and finally goals.

The integration of design and construction supported by computers is referred to as Computer Aided Design for Construction (CA DfC). The integration of processes appears on three related levels; organization level, computer application level, and information and knowledge level which require standards on structuring and information exchange.

2.1.2.1 Analysis of the design-management process

The following process analysis focuses on DfC, i.e. only design and construction processes are considered. The process analysis presents the information and knowledge flows that relate design to construction processes.

The graphical process analysis technique, IDEF0 [Kimbler, 1997], is used to present the process analysis. Figure 2.2 shows the realization of a building with inputs to the process coming in from the left, outputs to the right, controls from above, and mechanisms from below. The realization of the building has both general and projects specific input. Information on the client requirements and on the site is project specific. The product and building method information, on the other hand, are general. The designers and constructors are the mechanisms behind the building realization. The execution is controlled by project management information, building regulations, and realization knowledge. The process generates designs, construction schedules, as well as feed back information such as progress. During the realization process the designers and constructors gain experience, i.e. realization knowledge.

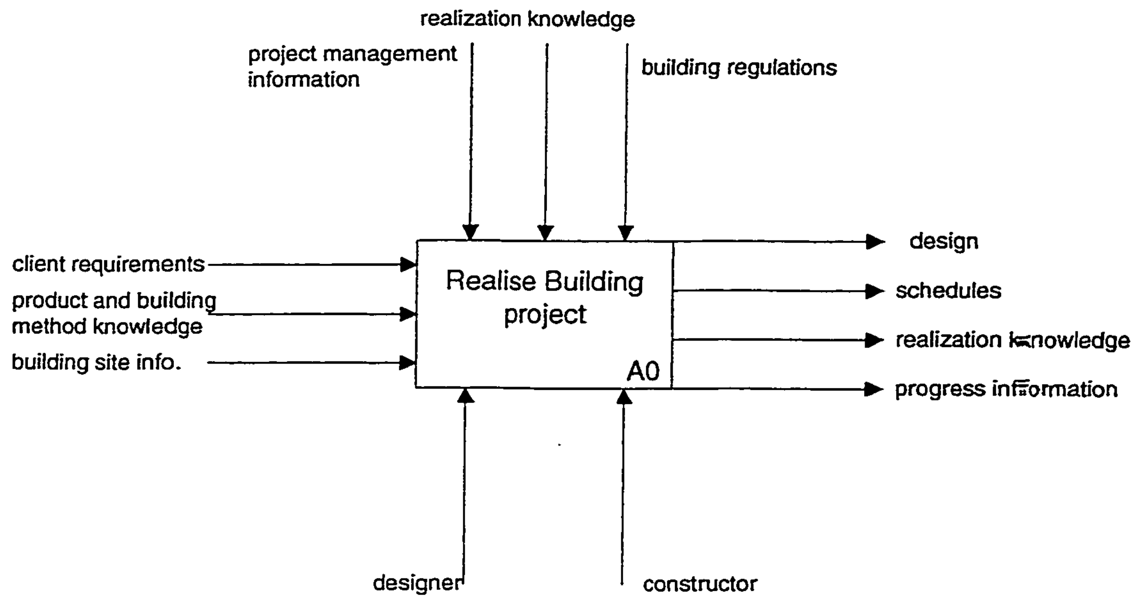


Figure 2.2 Realization of a Building Project Represented in IDEF0.

Adapted from [Luiten, 1994].

A similar representation can be done in the analysis of design management processes. The co-ordination and communication of information in design-management is complex. Figure 2.3 shows the disciplines involved in design management as well as the overlapping areas in the processes, graphically manifesting the interactions between design and construction [Thompson, Tah, and Howes, 1996]. As indicated by the diagram, the realization of a building project is broken down into three activities, with the second activity consisting of two sub-processes. This indicates that the knowledge areas to be integrated are design knowledge, construction management knowledge (i.e. estimating and planning), and constructability knowledge.

A building project starts with the design by the designer, i.e. architect firm. The feasibility study, conceptual study, preliminary design, final and detailed design are part of this activity. As presented by the IDEF0 diagram, the inputs to this activity are the client requirements in addition to the available product information. The resulting output from this activity is the building design, which functions as the key controlling constraint for downstream activities.

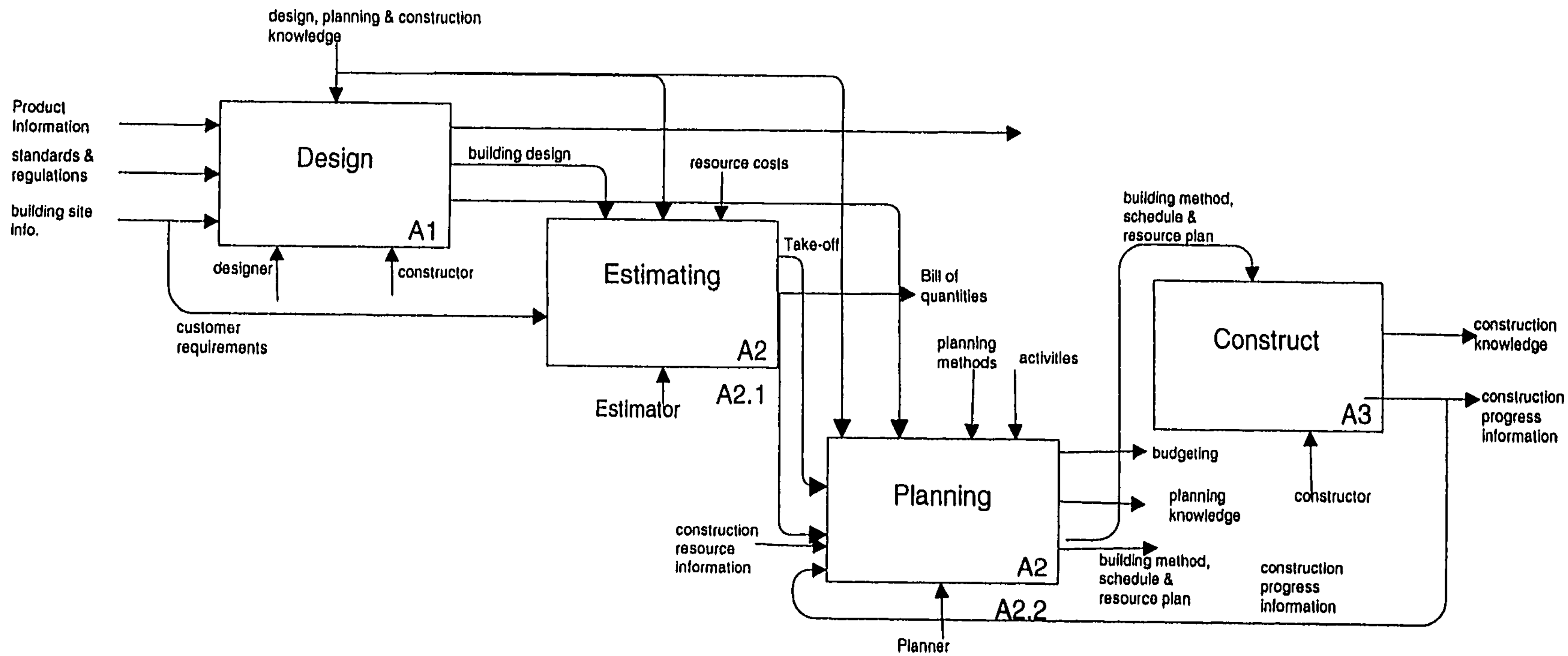


Figure 2.3 Activity and Information Flows for Modeling Design-Management Processes.

Adapted from [Luiten, 1994].

The construction management activity is broken down into two sub-activities: estimating and planning. Inputs to generating cost estimates, schedules, and resource plans are information on the building site, customer requirements and general information on the building methods. Both of the sub-activities depend on the building design and on general design, planning and construction knowledge. The estimating activity generates a project take-off and bills of quantities. The planning activity generates information such as the building method, schedules, budgets, and resource plans. These two activities are performed by the estimator and planner, respectively working within one organization, i.e. construction management company.

The constructor performs the last activity. Both design and construction management outputs control the building construction activity. There is a feedback loop to construction management with the construction progress information. The resulting output is the construction knowledge that can be used in future projects.

The three $IDEF_0$ mechanisms in figure 2.3 demonstrate six interactions between the functions of design and construction. These interactions are characterized by the exchange and overlapping of information and knowledge between AEC entities. The interactions as relevant to design for construction DfC are outlined by Luiten [1994] as follows:

1) Forward exchange of the building design.

2) Feedback on the building design from construction,

3) Backward exchange of constructors' information,

4) Backward exchange of general constructability knowledge,

5) Upstream shift of construction management tasks, and

6) Downstream shift of design tasks.

2.1.2.2 Required Interactions

The following elaborates on the six interactions outlined above. These interactions are a result of the process analysis discussed in the previous section. An understanding of the current situation and the technical barriers that hinder better integration will prove to be valuable information to proposing a solution that would improve the process.

1. Forward exchange of the building design

The designer who produces detailed plans and drawings develops the building design. This same design becomes the instruction manual during construction. The product information is detailed in the specifications and drawings. These drawings are generated by Computer Aided Drafting systems such as the popularly used AutoCAD from Autodesk. This allows for the exchange of the electronic drawings. Although the CAD applications supports the design process and allows for the exchange of documentation in a digital format, this information must be interpreted by an end-user before it can be used further in any other application.

Another technical barrier that stands in the way of digital information exchange is the reluctance of the construction industry to embark on the inter-corporate electronic networks. In current practice, paper document exchange is predominant. The forward communication of a building design from the architect firm to the constructor is generally achieved by the exchange of 2-dimensional building plans that need to be further interpreted by the constructor firm to establish the required plan for material, resources, budget, etc.

2. Feedback on the building design from the constructor

At this stage where construction management and construction are taking place, feedback information is generated on the building design. Issues of constructability are addressed and building alternatives loop back to the designer for approval. This exchange of comments or suggestions currently takes place in a informal manner. This may lead to change management whereby the design may have to be revised and the information exchanged once again. This non-integrated process is costly, inefficient and a cause for the time consuming process redundancy.

3. Backward exchange of constructors' information

Ideally, constructor knowledge and information should be exchanged before the design is completed and the design choices made. The information of concern is related to building site conditions, the availability and the cost of resources. Unfortunately, this type of information exchange only takes place in design build situations where both functions on the project are performed by one organization. The main barrier to the lack of communication at this stage is that the constructor is usually not selected prior to the completion of the design. Yet another barrier is the reluctance of companies to share information with other companies, i.e. competition.

4. Backward exchange of general constructability knowledge

General constructability knowledge for the design of specific types of products should be exchanged for use during the design. This type of knowledge originates from experiences in earlier projects and is part of a long feedback loop. The exchange of constructability knowledge is informal and conveyed mainly through the media of education and technical texts. However, constructability mainly exists with experienced personnel.

5. Upstream shift of construction tasks

This type of interaction proposes an alternate way to integrate the two processes of design and construction by shifting tasks between participants. That is, when the designer performs part of the constriction management tasks, an appreciation and deeper understanding of the construction consequences of the design would be attained. The designer in such a situation would be involved in scheduling and cost estimating and therefore attain an understanding of the time and financial aspects of the design.

In order to achieve this shifting of tasks, the designer requires that construction applications be integrated with those used for design. In current practice, the design produced by computer aided drafting tools does not integrate with the applications used for estimating and scheduling by the constructor. The barriers to this integration are two folds; both the lack of integrated applications and the fragmented nature of the industry prevent the concept of upstream shifting of construction tasks.

6. Downstream shift of design tasks

Similarly to the fifth interaction, design tasks can be shifted to constructors. In such a case the designer would prescribe solutions and requirements that would best suit the construction capabilities. Generally, designers are reluctant to share tasks and responsibilities with constructors due to issues control coordination and liability.

As analyzed above, the technical possibilities along with the organizational barriers imposed in current practice limit the integration of design and construction. However, the need for interaction and information exchange between the two tasks is evident from the outlined mechanisms that emphasize the overlapping of both knowledge and information. The analysis goes to prove that there is a need for integration in the AEC industry. Current practice implements several industry tools, however, communication among the computer-aided processes has not changed; i.e. humans continue to perform the communication by interpreting paper documents. The aim is to improve the integration of design and construction by implementing a method for application specific integration.

2.1.3 Computer Integrated Construction

Computer Integrated Construction (CIC), as defined by Teicholz and Fischer [1994] is a business process that links project participants through all phases of a project in a collaborative environment. The use of technology to facilitate the sharing of the required data is integral to CIC. A primary goal of CIC is to achieve rapid production of quality designs. Quality can be measured by fewer field changes. The use of 3D models permits more accurate designs, minimizing the field changes caused by design errors and omissions. Therefore, CIC aims at a fast and cost effective construction. The largest gain from CIC systems is the ability to use data and models developed during the process for facility management.

CIC is dependent on a number of technologies required to support the creation, updating, and sharing of project information. Relational databases (RDBs) allow the storage of component data where relationships among the data are less complex than those relationships requiring object-oriented approaches. A number of Artificial Intelligence (AI) techniques support the reasoning necessary for CIC models, such as rule-based and case-based reasoning. Dynamic simulation and robotics are technologies that can further support CIC requirements.

As stated above, the interactions that govern design and construction clearly highlight the requirement for information integration between the two functions. At this point it is important to distinguish between the concepts of horizontal and vertical integration. A construction project development generally involves several phases from pre-construction and planning, to construction, operation, and maintenance. The integration of computer applications within one of the phases is referred to as “horizontal integration”, whereas “vertical integration” refers to integration across two or more phases [Fischer, and Kunz, 1995]. The purpose of horizontal integration of applications used within a phase of the building project is to make the process more efficient by increasing the speed and quality of its performance.

Research efforts for construction have addresses the concept of computer integration in a number of ways [Rezgui et. al, 1998]:

1. Integration of *specific computer applications* (i.e. software developed to integrate chosen and invariant applications).
2. Integration achieved through *geometry* (i.e. integration based on geometrical information in CAD packages).
3. Integration achieved through *knowledge-based interfaces* that communicate between multiple applications and databases.
4. Integration through a *central database* that holds information relating applications to a standardized common model (i.e. a model defining the structure of shared information).
5. *Component-based* approach to integration (i.e. frameworks which define semantic relationships between the interfaces of separate components).

This dissertation addresses the concept of computer integrated construction through the central database approach.

2.1.3.1 Models of Integration

Fischer and Kunz [1995] have distinguished between the two types of integration that constitute the concept of "technical integration", i.e. linking software applications.

1) *"Multi-point integration"* is based on the concept of a central controller that receives information from individual applications and dispatches the relevant information to other applications that constitute the relevant parameters. The link is achieved in a manner that allows any application to obtain data from any relevant source and that the output from a given application is available to interested destinations. The results from each application are reported to a central controller, which typically includes at least one database. The technologies that support multi-point integration vary from neutral file exchange, data translation through a central data repository, to object oriented technologies. The benefits of this type of integration are rapid data transfer and feedback.

2) *"Circle integration"* link applications, each to a single predecessor and a single successor. This type of architecture involves passing the

information around a circle of applications. Some of the data received by an application are not processed, but simply passed on to the successor application. Other data is processed and the values assigned to parameters that are passed on to the next application. The analysis through such a process utilizes complete global data and not only single discipline data. The circle integration iteration is well structured and defined, and must be accessible by all team members.

The main difference between the two types of integration is that in a multi-point integration the controller determines what information to distribute to each application for an efficient propagation of information. The drawback is the organizational integration problems identified in current practice involving data consistency. Circle integration, on the other hand, re-computes the entire design and construction plans for each set of changes entered into the system. Although this strategy may seem inefficiently repetitive, it ensures data completeness and consistency. Therefore, the trade-off between multi-point integration and circle integration is system complexity with computational efficiency.

2.1.3.2 Integrated Database Systems

Information sharing and data transfer can be further classified as falling into one of two categories; external and internal. External data transfer refers to the computer to computer transfer by performing format modifications on the data allowing transfer to a dissimilar hardware or software environment. Electronic data transfer (EDI) is one of the technologies improving external data transfer. On the other hand, central databases are at the core of internal data transfer. The data captured are managed by an integrated database system (IDS). The concept of IDS as researched by Gibson and Bell [1992] for the Construction Industry institute, links CAD data with traditional non-graphic data processed in the functions of estimating, scheduling, material management, and other construction/ project management functions. [Collaboration in the Building Industry; Kalay, 1998; Marir, Aouad and Cooper, 1998; Veeramani, Tserng and Russell, 1998; Voeller, 1996].

2.1.3.3 Integrated CAD Systems

The proposed model is based on the premise of integrating CAD applications with construction management tools. Before embarking on the description of the system architecture and data flow, it is necessary to describe the levels of integration as originally proposed by Richen and further modified by Atkin and Gill [1986]. Today, computer applications specific to AEC have flooded the market, each addressing one or more functions (i.e. CAD systems, scheduling software, estimating software, costing applications, etc.). The information generated by each of the applications is separate. The range of integration possible with this software are classified as follows:

- Level 0: Tools.

  The system is non-integrated, however offers the potential for sharing data. Configuration of the tools is required to suit the individual requirements.

- Level 1: Inter-connected tools.

  Such tools offer a degree of integration where information can be moved across the applications, (i.e. cutting and pasting).

- Level 2: Shared data.

  A layered approach to integration where a greater amount of data transfer is possible in a multi-user environment.

- Level 3: Total design database.

  System integration relies on large-scale databases. Such systems are based on the idea of integrating computer-aided design and relational database management systems.

The difficulty of exchanging data between computer systems has been largely due to the lack of standards required for the successful implementation of linked computer systems. The need for graphical data-exchange standards have been recognized early on and supported by the National Institute of Standards and Technology. The Initial Graphics Exchange Specification (IGES) has been used to demonstrate the exchange of graphical and the related non-graphical data between dissimilar computer systems. DXF is another CAD standard for graphical data exchange. Rather than exchanging paper documents, the proceeding allows for the communication of the relevant portions of a CAD database in an efficient and productive manner. [Voeller, 1996; Tavakoli and Klika, 1991]

2.2 Current IT-Based Models for Integration in AEC

Much of the current ongoing research in the field of generating Information Technology, IT, tools for the construction industry center around the concepts of automation and integration. Computer Integrated Construction, or CIC, has the objective of achieving information exchange among design and management software allowing for effectiveness and efficiency throughout the construction processes. Researchers have addressed the need for information automation and integration in construction in a variety of different ways ranging from information modeling to knowledge based interfaces linking several applications and multiple databases.

Over the past few years, many CIC projects have been carried out that deal with core AEC process or project models. The following section will present an objective analysis of core process models for AEC. Many of the core process models have been used for prototype implementation. [Hampson and Tatum, 1999; Kim, Kim and Ahn, 1999; Ihsan and Alshawi, 1999; Kalay, Khelmani and Choi, 1998; Sadonio and Tommelein, 1998; Laptali, Bouchlaghem and Wild, 1997]

2.2.1 Formation Models

There are many categorizations for data models. "Type" models define data representation constructs for capturing domain information and are created using a modeling language, e.g. EXPRESS [Froese, 1996].

Core models, or sometimes referred to as reference models, are a higher level reference for more detailed application models to be constructed on top of them. These models do not represent actual data, but may be used for the exchange of information between different application areas.

Conceptual models provide domain particular information, defining basic entities and relationships. Aspect, or property models, on the other hand provide all the specific attribute and relationship information on a more detailed level, supporting specific implementations.

Classification models are based on simple conceptual models for representing entities, and they develop a breakdown categorization of elements within a domain. An example of classification models is AEC's MASTERFORMAT [CSI] categorizing and numbering system. An important classification organization is the International Organization for Standardization [ISO, 1989]. The classification is done per hierarchical categories or classes which enable the communication of standardized and computer interpretable project information.

Product data gives information about the physical characteristics of a product regardless of the processes used to build it. A Product Model proposes an organized structure to communicate building product information among the participants within a project team, describing product data information such as: dimensions, size, orientation, finishing etc. Examples of product oriented models are RATAS, STEP standards, and IFCs [Björk, 1999; Ghanbari and Froese, 1999; Kunz et al., 1999; Alami and Fischer, 1998; Froese, Yu and Shahid, 1996; Parfitt et al. 1993].

On the other hand, Process Data is information about the actions taken to construct a product. Process models present information on the process methods, resources, organization, etc; indicating the important steps in a project's life cycle. Examples of proposed process models are: IRMA [Luiten et al. 1993] and ICON [Stumpf et al. 1996].

The need for the integration of product models with process models gave rise to the concept of project models [Aalami and Fischer, 1998; Fischer and Froese, 1996]. The link between the product models and process models is evident in the evolution of the product; from the initial concept to the phase of implementation, data about the product at each stage of its development becomes a reference to subsequent processes to come.

2.2.2 Product Models

Product modeling has been adopted in many past and current research in the field of construction integration. The potential offered through the feature of high-level standardized open communication predisposes product modeling to form the basis for CIC.

Product modeling evolved from a history that started with the concepts of geometric modeling. In the seventies and eighties, CAD systems were promoted to be central for integration. However, it was realized that the exchange of shape information could not be relied on as the central point for information integration because:

- The shape of a product evolves during the process of design.
- Project information is often available before the shape is specified.
- Different project participants use different shape representations.

As described by Luiten [1994], geometric modeling concepts eventually gave way to the concept of product modeling. As stated previously, product models contain product information for all the life cycle phases of a building process. The geometric information became one of the properties of product modeling.

Such models separate between three semantic levels of information, namely *definition, representation, and presentation.* Product information on shape, dimensions, material used etc. is offered by the definition in a format that is application independent; e.g. a steel beam is defined as IPE400 with a length of 3m. The representation derives itself from the definition in a format that enables computer manipulation; e.g. within a CAD system the shape of the beam is represented as lines with edges, faces, volume, etc. The presentation, derived from both the definition and the representation, manifests the product information in a human interpretable fashion; e.g. a 3D CAD interpretation or a set of 2D drawings. It can be realized from the above concept of inheritance that integration can be achieved through the exchange of the definition alone and as a consequence both the computer manipulation and human interpretation can be derived.

2.2.2.1 STandard for the Exchange of Product model data - STEP

STEP, also referred to as ISO-10303 [ISO, 1989]b, is an international standardization effort which started in 1984 and is being developed under the direction of ISO to support computer based representation and exchange of product data [Debras, et. al, 1998; Rezgui et al., 1998]. The objective of this international effort is to develop and promote a standard for a neutral, i.e. independent of any operating system or hardware, and unambiguous means for the exchange of interpretable product information between software applications throughout the life cycle of a product.

The STEP approach builds on the Product Data Exchange Specification (PDES) architecture, a development of the American National Standards Institute (ANSI). This architecture consists of three layers [Luiten, 1994]:

- Application layer, i.e.-internal schemata, representing information the way it is stored and manipulated by the computer.
- Logical Layer, i.e. conceptual schemata, defines information independently of the user view.
- Physical Layer, i.e. external schemata, defines information in the way that the user views it.

The logical layer is the one that is most important for STEP, given that it is view and application independent. The main results of STEP is the EXPRESS modeling language that has been developed for specifying data structures for the unambiguous description of information though an object oriented approach. EXPRESS schemata are system independent and offer a standardized format for information exchange, by means of defining entities and their attributes. A database can be structured denoting sets of objects with common properties. Information within the database can be exchanged with a file. STEP offers a Physical File Format. Further to that, STEP specifies the Standard Data Interface (SDAI) for standardized data access through a dedicated application-programming interface.

STEP supports sector specific conceptual models (i.e. specification of an information structure) referred to as Application Protocols (AP). The following are some of the APs addressing the building sector [Debras, 1998]:

- AP 225: Structural Building Elements Using Explicit Shape Representations.
- AP 228: Building Services.
- AP 230: Building Structural Frame.
- Part 106: Building Construction Core Models.

STEP modeling languages offer a great value to the field of CIC. It transcends the barriers that face the construction industry at the level of application integration by offering standardization at an international level (ISO) that would be widely implemented by vendors.

2.2.2.2 Industry Foundation Classes - IFC

The product data technologies that are constantly evolving are making gains into the building sector at the industry level as demonstrated by the existence of the International Alliance for Interoperability (IAI). IAI is an international industry-based consortium for the architecture, engineering, construction, and facilities management (AEC/FM) industry, gathering over 300 members that is developing data standards for the building industry [Froese & Yu, 1999; Froese, Rankin and

Yu, 1997]. IAI members come from AEC/FM industry organizations, software vendors, research institutes, and professional organizations as well as government agencies. Within the organization, domain committees are established to represent specialized industry sectors providing information requirements for the IFCs. Domain committees include architecture, structure, codes, standards, building services, project management, etc. IAI devotes its mission to the development and promotion of interoperability among industry processes by allowing computer applications used by the project participants, during the life cycle of a project, to share and exchange information. The primary goal of IAI is to define a common semantic model for the building industry referred to as the Industry Foundation Classes (IFC), for sharing data throughout the project life cycle, across disciplines and technical applications. As stated by a team of industry specialists convened for a roundtable discussion in October 1998; a common standard is needed to be used throughout the whole of the construction process before the industry is inundated with software vendor-specific object definitions, such as Autodesk-defined objects and Bentley-defined objects. The concept of interoperability has three prospective gainers. First, the clients who will have better efficiency from interoperable project models. Second, the software vendors will gain, as there will be an immense opportunity for software revisions. Third, product suppliers who design the product data to be web-enabled will provide designers with information in a format that can be directly plugged into a project model [Bunn and Roderic, 1998].

Similar to STEP, the IFCs architecture is based on layers containing model schemas [Froese & Yu, 1999]:

- Resource layer; describes geometry, units, measures, etc.
- Core layer; defines a kernel meta-model (i.e. projects, products, processes, etc.)
- Interoperability layer; defines data that is used across multiple domain areas (i.e. building elements, structural components, etc.)
- Domain layer; defines data used with specific application areas (i.e. space layout, property management, etc.)

Several IFC projects being undertaken focus on the domain of project management. These include the North American Project Management Committee's Cost Estimating Project (project ES-1 for IFC release 2.0), and Construction Scheduling Project (PM-1 for IFC release 3.0) which includes initializing a project schedule from a cost estimate.

Software vendors are expected to develop object-oriented applications that will instantiate objects based on IFC specifications. For example, a window identified as an IFC object will contain information pertaining to what type of window it is, its dimensions, design, material, what components it is constituted of, and how it operates. The information contained within this IFC object is useful for both cost estimating and scheduling purposes. As a result of carrying this extensive object specific, task, and resource use information, applications specific to CAD, estimating, databases, scheduling, and procurement would all be able to manage the same objects, i.e. sharing and exchange of information.

2.2.3 Total Project Systems

The total-project systems research program, sponsored by the University of British Columbia's Construction Management and Engineering department, focuses on the development of new, integrated, computer-based tools to increase the efficiency of construction management functions. The term total-project systems or TOPS defines a class of construction management applications with the following characteristics:

- *Comprehensiveness* – tools that support a broad range of construction management functions.
- *Integration* – information exchange and sharing amongst the tools.
- *Flexibility* – modular and open framework of operation, rather than a restrictive environment.

The combination of the three characteristics describes a system that is currently not in existence. The effort displayed by TOPS is an attempt to push computer applications for construction management past the point of "critical mass", where broadly-applicable computational models become the primary vehicle for practicing CM [Froese, Rankin, and Yu, 1997]. TOPS drives at extensive information sharing amongst computer applications, requiring a common data structure for meaningful interpretation of this information. As previously mentioned, no single model can accommodate all the requirements defined by

TOPS, and therefore a successful implementations relies on a layered approach consisting of core models unifying the more detailed application-area models. The TOPS approach is not independent from the ongoing research efforts in the areas of product and process modeling; rather, it builds on the developed standards for AEC common data models.

2.2.4 Collaborative Construction Planning Models

Cross-functional data acquisition and sharing are important to the concept of collaboration in construction. Cost estimating, scheduling and cost control are closely related in that the data is not particular to one of the functional areas but rather each functional area is required to feed data into the next in order to derive functional specific information. An example to illustrate this point; calculating the cost of a task produced by a crew in cost estimating, and estimating the duration of the task for scheduling are both based on the crews productivity rate.

Research to improve the information sharing and integration for construction cost estimating, scheduling, and cost control can be divided into the following categories [Kim,Kim & Ahn, 1999]:

- Data exchange achieved through direct mapping. This method attempts to model relationships among primary construction data (i.e. design components, activities, costs, & control budgets).

* Data exchange using a global data model which relies on developing a common denominator for data exchange (i.e. WBS provide a unified project view by means of Work Packages).
* Data exchange using basic interface elements to achieve sharing of information among separate functional systems. This method of exchange was utilized by Grobler where he achieved cost/schedule integration with PEC's (Primitive Elements for Construction) as basic interface units.

2.2.4.1 Primitive Elements for Construction - PEC

Grobler [1988] introduced the idea that the only real construction takes place when labor (including equipment) resource executes a task consuming material in the process and resulting in a constructed object fitting in time and space. He further suggested that a key to enable information systems to correctly model real project events is for them to be able to account for task and resource union in time and space. Refer to Figure 2.1 for a graphical representation of this union.

As suggested above, data integration within a project system can be achieved via an interfacing unit, i.e. a unifying element. This unifying element serves as a common denominator between aspects of projects to be unified. It can also be used to map project information and various views (project schedule, cost control, etc.). Unification, therefore, is equivalent to the concept of integration. A Primitive Element for Construction, as defined by Grobler [1988] in his doctoral thesis, "is an object describing a task to be performed by one crew type, which fits entirely into one scheduling activity, and can be associated with at least one identifiable physical object".

2.2.4.2 Data Acquisition and Sharing

The Collaborative Construction Planning Data Model [Kim, Kim and Anh, 1999] is based on the concept of construction assemblies, combining design components with a location attribute from the project Area Breakdown Structure (ABS). Each assembly is associated with a Work Package that uses the same design component, and this in turn is associated with the assembly's PECs. Therefore, the model in discussion builds on Grobler's [1988] data representation scheme where data sharing for systems across functional areas is achieved by means of the basic interfacing units' approach to data sharing. The assembly (association between design component and work zone) provides for data sharing with the design, where attributes of an assembly include material type, construction method, and quantity. On the other hand, PECs allow for data sharing with the project cost estimate, schedule, and cost control scheme. Attributes of PECs include, crew, crew productivity, material cost, labor and equipment cost, and task precedence. The quantity of each PEC is passed from the design interface and the unit prices are data shared with the resource pool.

CHAPTER THREE

3.0 PROPOSED MODEL

3.1 Overview

As expressed in Chapter two, the concept of Computer Integrated Construction can offer many benefits such that it has been a source of motivation for researchers and practitioners alike to work and develop more efficient solutions. The developments and research efforts differ in their approach, however they all depend on extensive computer use throughout the project. Many of the proposed systems make use of information exchange among advanced computer aided design and management software systems utilizing approaches based on object oriented data modeling and artificial intelligence technology [Ghanbari and Froese, 1999; Ihsan and Alshawi, 1999; Kiviniemi, 1999; Tah, Howes, and Iosifidis, 1999; Aalami and Fischer 1998; Kalay, Khelmani and Choi, 1998; Mohamed and Celik, 1998; Rezgui et al., 1998; Tarandi, 1998; Thompson, Tah and Howes, 1997]. The construction industry, however, remains apprehensive and reluctant to embrace the high-end computer integrated systems [Bunn and Roderic, 1998; Mitchell, 1997; Russell and Froese, 1997; Construct IT, 1995; Howard et al., 1989]. These barriers to computer integration have been previously enumerated and discussed in Chapter two.

This chapter specifically presents a framework for addressing Computer Integrated Construction (CIC) in a practical and efficient manner. The model addresses the various functions performed by project management teams, specifically identifying the areas where information overlaps and is shared across the full Architecture/ Engineering/ and Construction (AEC) functions including the computer applications that support them. The methodology pursued utilizes Computer Aided Design (CAD) systems to integrate construction project information through a commonly accessible design-oriented relational database. This model is based on the premise that the technology necessary for information integration in construction is available. However, the fragmented and reserved nature of the construction industry impedes innovation.

3.2 Requirements for Model Design

A database-CAD system is proposed to provide comprehensive support for project management functions for a typical building construction project. Some of the project management functions referred to include cost estimating, planning, scheduling, and resource allocation. It can be realized that planning and scheduling are directly related to the project design and that any changes on the design level may translate into a change in schedule, both in terms of duration and task relationships. Design information logically impact the project cost estimate through material and construction methodology selected at the design stage [Zahnan and Moselhi, 1999]. The concept of integrating design with construction management is supported by the following two premises:

1) The construction activities are partly governed by design. For instance, if the design specifies certain materials to be used, this would impact the selected construction technology and hence the activities scheduled. It would also define the impacted activities' sequencing logic. The construction sequence and scheduling of the activities are therefore dependent on the design and how the project is broken down into work packages as well as on the selection construction technologies and methods to be carried through on each particular project. This relationship between design and construction highlights the fact that information provided at the time of design may have a direct impact on the procurement pursued as well as on the activity planning and sequencing.

2) Procurement of material and cost estimating are governed by design. At the time of design, quantities are known and the designer may determine the material that constitutes the design entity. Once the material is part of the design, its cost is committed to since it becomes part of the CAD object which has a known quantity and dimensions [Sadonio and Tommeleïn, 1998].

The innovation in the proposed model is that it takes advantage of the concept that proposes productivity enhancement which is directly related to the ability of reusing information and not having to recreate it [Parfitt et al., 1993]. From a project management perspective, the implications on project cost and schedule will be able to be seen at the time the design is generated. The key behind the CAD-database model is capturing relevant information from the design phase and sharing it with the project/construction management phase. In current practice, cost estimating is a time consuming and tedious process. This process is further classified by its inefficiency given that quantity take-off is performed manually from paper documents and hard copies of technical drawings that are exchanged from the design / architect firm to the construction management firm. Information that is part of the design function is re-created during the construction management function due to the lack of integration in the construction management process. This chapter proposes a methodology that integrates design functions with construction functions by means of efficient information exchange via a central database residing within an open system architecture solution, where information sharing and exchange can take place regardless of the specific applications selected.

3.3 Data Flow

The proposed model is composed of a system that constitutes a central database application, CAD application and design procedures, a CAD-database interface, and a scheduling application. The functional applications that make up this system are representative of those used by many of the organizations within the AEC industry. The data flow within the system is represented by Figure 3.1 which shows how the flow is divided between four quadrants representing the flow of information between the processes of design, to material and resource allocation, from there to cost estimating, and finally to scheduling.

The design quadrant of the Figure 3.1 represents the initial process of identifying a construction project and developing the Work Breakdown Structure for the project. A key to integration, as identified by Rasdorf and Abudayyeh [1991], is a common denominator control account defined at a sufficient level of detail for cost and time data. Identifying the work packages is the next step in the flow of data. The Project Management Body of Knowledge, as developed by the Project Management Institute [PMBOK, 1996] defines a work package (WP) as a well-defined scope of work that terminates in a deliverable product. The work package is usually a functional division of an element of the lowest level in the Work Breakdown Structure (WBS). The concept established for the data flow here is based on the Work-Packaging model, as developed by the National Aeronautics and Space Administration (NASA) and by the Department of Defense (DOD) [Forsberg, Mooz, and Cotterman, 1996]. This Work-Packaging model achieves true integration by providing a unified view of project cost and schedule control data using the WBS as a common denominator [Choo et al., 1998; Syal et al. 1992; Moselhi and Ho, 1994].

Figure 3.2 shows the detailed workflow within the design quadrant as identified in Figure 3.1. The design element is created within the CAD (Computer Aided Design) application either by inserting a Block Object that already exists in the

Block Library or by creating a new object, which is stored in the Block library for later use. Definitions of Block Objects and Attributes are included subsequently in section 3.4.1. Upon inserting a block into the project design, the designer is prompted to attach attributes that are associated with each design block, including the project work package (WP) reference. The WBS should be developed early in the project life cycle. However, as the logic flow of Figure 3.2 suggests, if the WP reference is not available at the time of design within the CAD application, then the WP identification attribute can be assigned at a later stage outside the design application and within the database.

One or more design objects are associated with each WP as defined by the WBS. The concept of Block Objects is explained in section 3.4.1. The key element that must be stressed is that each design object created within the CAD application captures both the geometrical CAD data as well as non-graphical information that is known at the design stage. The conceptual model presides on the idea that design information known at the early stages of design should be captured within the project and associated with the relevant design component. These attributes (design component non-graphical information), are extracted as tuples into the project database (see Figure 3.3). Each Block Object comprising a design component is captured with its associated data within the database. This database stores the design information into project schemas. As Figure 3.3 suggests, attributes that were not identified during the design stage can be assigned outside the design application and within the project database. The central database stores construction cost data that has been divided into 16 divisions according to the MasterFormat classification and numbering system, as developed by the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) [CSI]. The central database carries the structure of and is populated with data from the RSMeans® Building Construction Cost Data [1999]. Information that can be obtained from this construction data repository include material costs, labor costs, equipment costs, crew cost/day as well as productivity rates. As identified by Figure 3.4, each design component Block Object is assigned material and labor attributes from the central database. The database holds construction cost data based on national averages. However, if the material and labor information are available for actual costs assessments as opposed to a project estimate, they can be captured and added into the database. Furthermore, the material and resource data can be accessed from within the CAD application allowing designers to select materials and validate costs. The objective of the proposed flow of information is to capture design data associated with each design element at the time that this information is known. Structuring the project database in a manner where each design element is identified with a project work package and associated with data entries that identify the types of material, quantities, and costs required allows for an efficient process of cost estimating and project planning.

The cost estimating process (refer to Figure 3.1 Cost Estimating quadrant) is performed by identifying the objects assigned to each work package, calculating the quantities of materials and resources assigned and hence aggregating the associated costs. As stated by Björk [1992], the cost of an activity is a direct result of the consumption of resources (i.e. labor, material, and equipment). The activity duration is derived from productivity data available with the assigned crew. Finally, the scheduling functions, refer to Figure 3.1 Scheduling Quadrant, are fulfilled by exporting the work packages to a scheduling application. The information attached to each WP assigns data to the required fields of task name, resources, duration, and cost.

The data flow described is within one system made up of integrated AEC applications. The integration of the previously mentioned four processes allows for an efficient and productive method for capturing project information for the purpose of construction management. The block objects created within the CAD application can be saved in a library accessible to the designers, allowing designers to save time where applicable in creating new designs. The CAD design captures attributes of the design element. The model proposes to capture the data identified at the design stage allowing for an automated quantity take-off and cost estimating. The process seeks to minimize if not eliminate errors and omissions that often occur during traditional cost estimating. The database is depicted as the central repository of project information. Each selected material is assigned to a graphical design element represented by an object instance in the database and assigned a primary key. The data flow logic is simple and is based on the concept of the transfer of low level data generated between the

AEC processes with the objective of bridging the islands of information produced at each level within each function.

The above is a brief description of the proposed information flow within the suggested model. The emphasis is to clearly identify the design/ construction functional areas of information generation and how they are related in such a way that information generated in one phase becomes input that is processed in another phase. These relations highlight the integration requirements within the construction industry to achieve greater efficiency and productivity by means of data sharing and transfer across planning/design, cost estimating, and construction project phases. The information flow diagram shown in Figure 3.1 presents a strategy to eliminate data re-entering and to develop a coherent design-construction information management system.

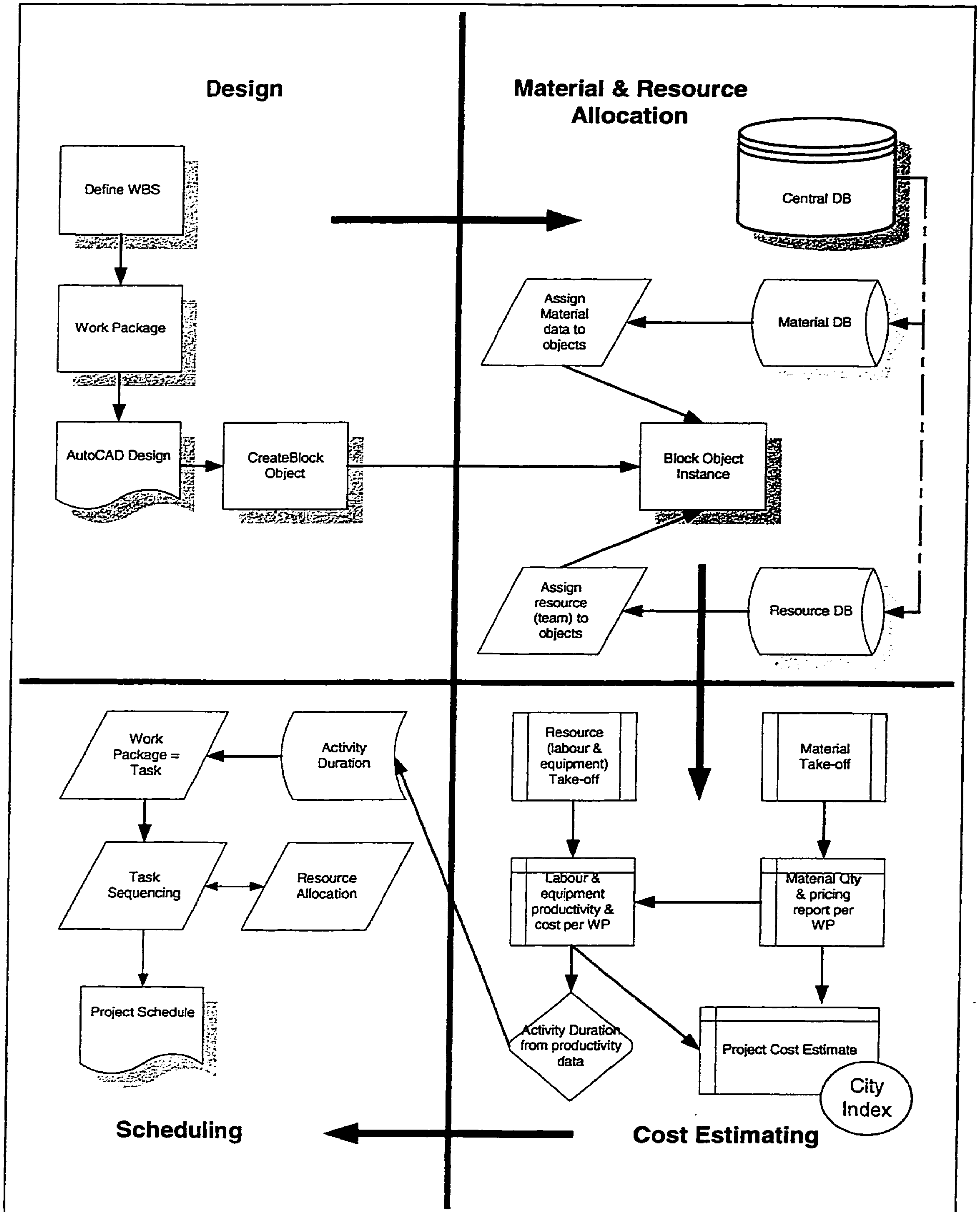


Figure 3.1 Data Flow

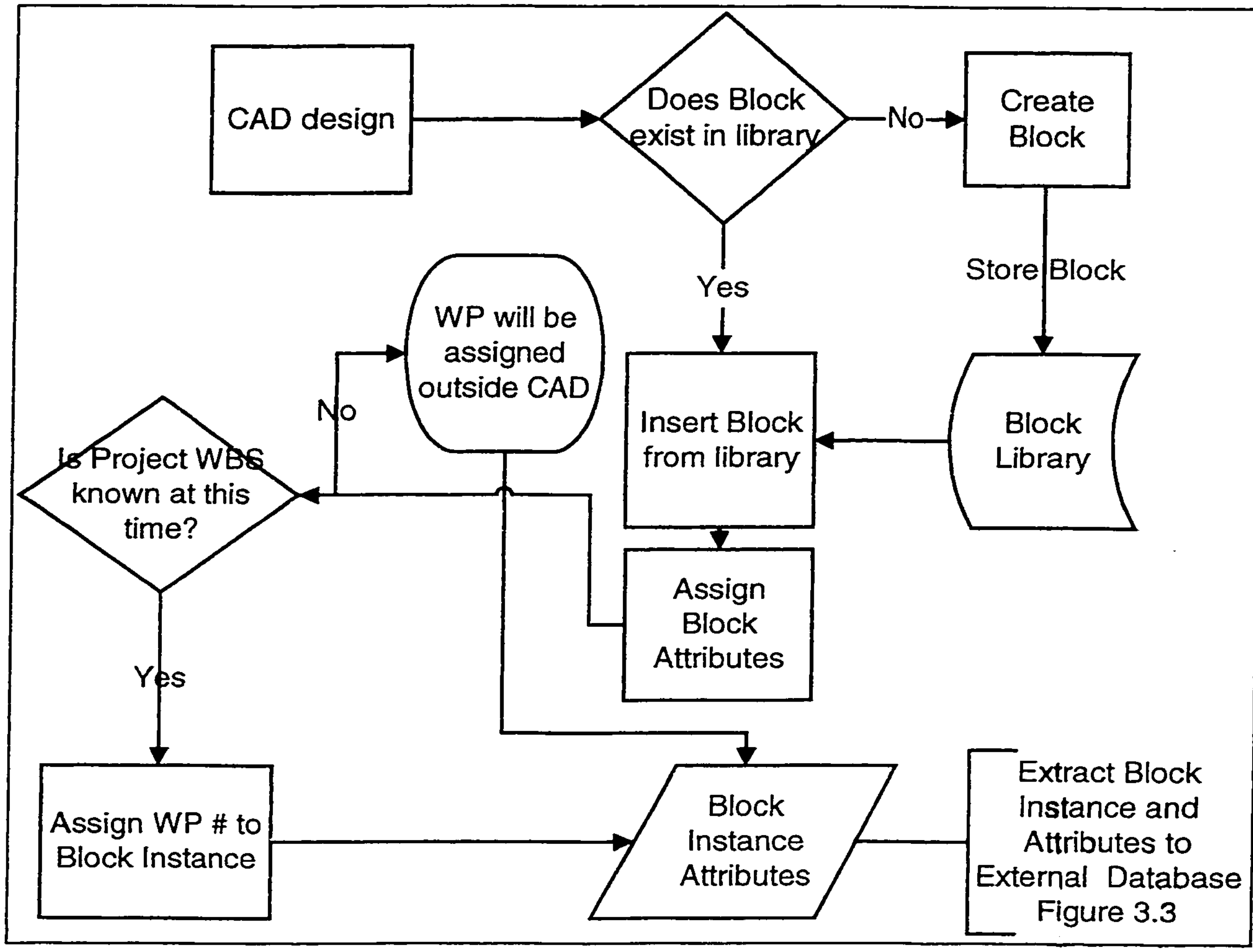


Figure 3.2 Data Flow within the Design Quadrant

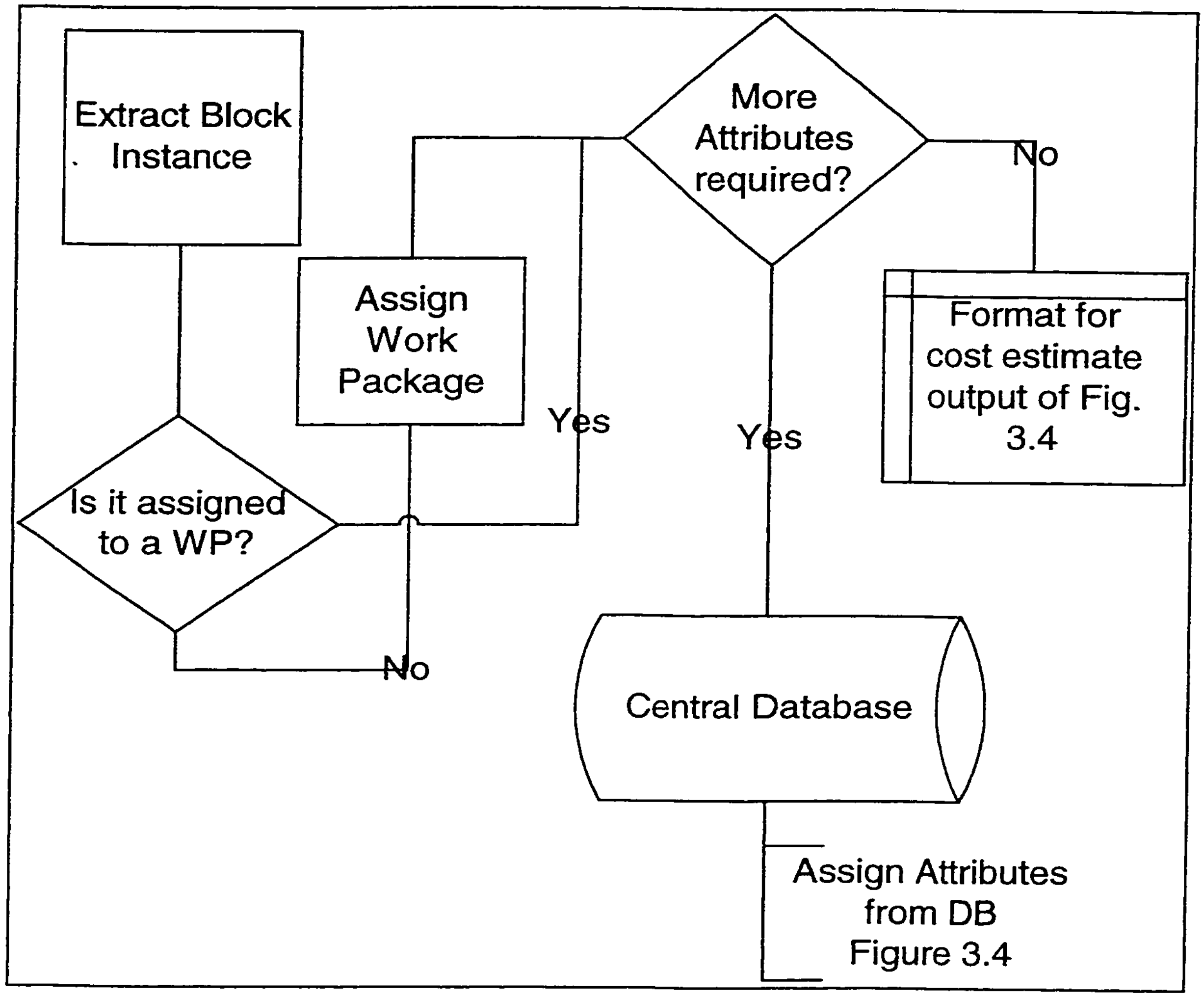


Figure 3.3 Extracting Attributes from the Design Application.

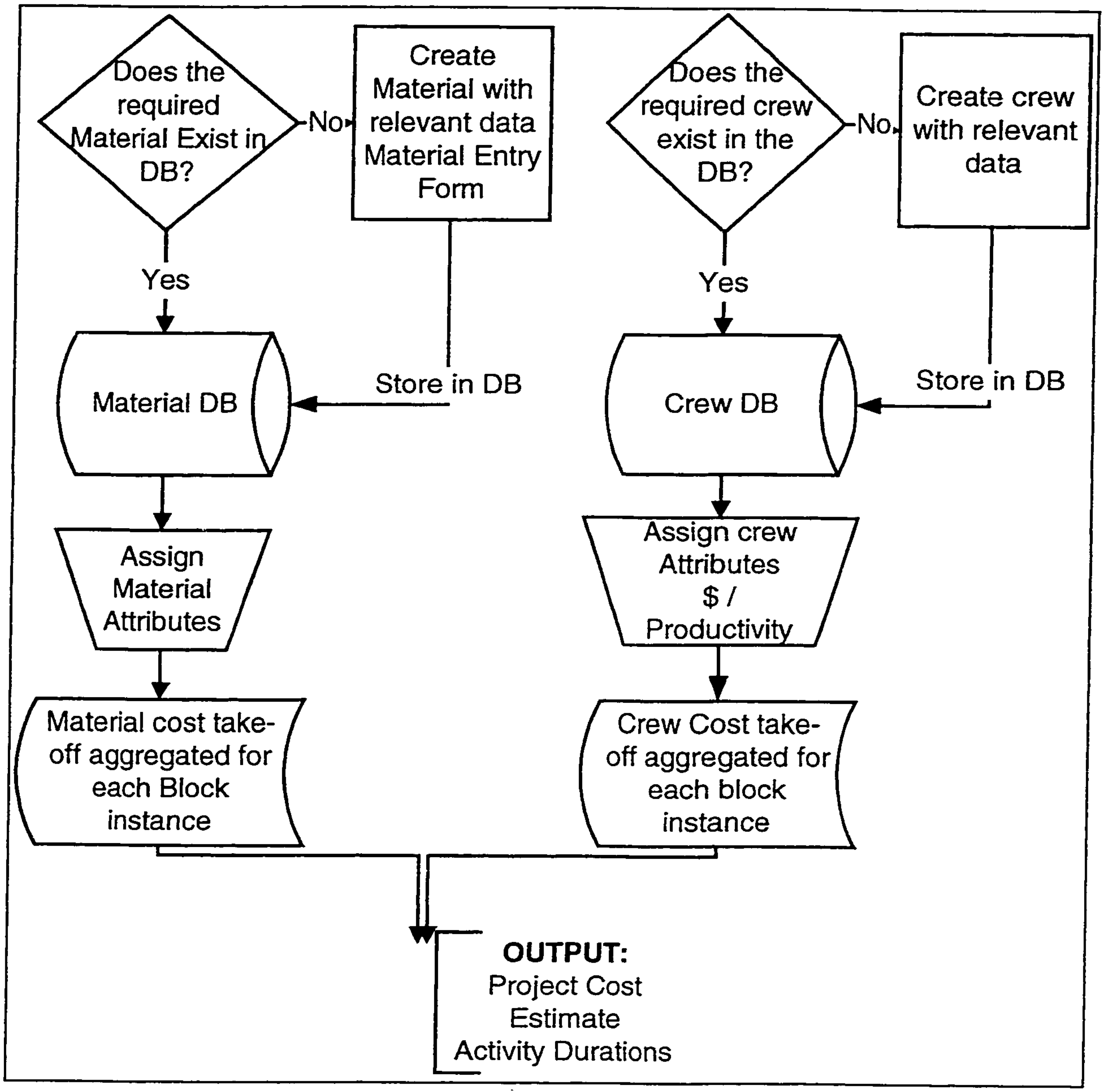


Figure 3.4 Central Database Processing.

3.4 CAD Data Model

To properly define the system that is proposed in this research, it is best to start by defining the methodology that has been adopted. The integration is based on AutoCAD's concepts of Blocks and attributes and the AutoCAD 2000 user interface [Autodesk]. While the CAD geometric representation of the project is based on 2-D or 3-D models, non-graphical information may be added to the design elements generated, such as text descriptions, quantities, dimensions, and more. These non-graphical attributes are assigned to CAD objects within a design and they may be extracted to external databases to be treated as project data. The advantage of such a methodology rests on the fact that CAD models have added value when they are produced from an assembly of objects whose positions and relationships within the CAD model is a representation of the case at site.

3.4.1 Block Objects

AutoCAD offers the possibility of utilizing Blocks in any design. Blocks are graphical objects that contain groups of other objects that are saved and named so that they can be inserted in a drawing at any time [Finkelstein, 1997]. Blocks have the possibility to have non-graphical, user-defined attributes or labels attached to them. The main characteristic of block objects is that they can be saved and inserted in a drawing whenever required and because each Block is in effect one object, they can be easily copied, scaled, rotated, etc. Block Objects reduce the size of a drawing file whereby AutoCAD stores the composition of a Block only once, as part of a Block Collection, along with a simple reference to the block each time it is inserted. This method is efficient rather than storing each individual drawing element within each block in a drawing database. Each insertion of a Block in a drawing is an instance of the Block created and saved in the Block Library.

Using attributes, non-graphical text data can be attached to blocks. These attributes may be visible or invisible (i.e. hidden when the block is inserted within a design drawing), and constant or variable (i.e. the attributes may vary for each insertion of a block object). Defining attributes essentially creates a template into which values can be attached when a block is inserted. When a block is inserted, AutoCAD prompts the user for the tag (equivalent to a field in a database) values. Attributes are useful in that the same data that is attached to blocks in a design can be extracted and imported into a database. This feature allows the user to work directly with data that is part of the objects in the design drawing. . Each instance generated has a unique ID attached to it and for each instance the block information are captured as attributes which are easily extracted to a central project database, where the data is aggregated and handled to produce a project cost estimate and project schedule. One limitation of attributes is that they can only be attached to blocks. Therefore, the model proposed within this thesis is based on the premise that main design components are developed within a project design based on Block Objects.

Designers can create object blocks to represent design components within a building project, or otherwise use an existing block from the Block Library. The object blocks within the proposed model have a specific set of attributes attached to them. Each block created within the proposed model must have a uniform set of tag names in order for the system to correctly extract the component data for cost estimating and scheduling purposes.

Each block has an attribute that identifies the work package number to which the object design component belongs. The association of each block object instance with a work package allows for a structure into which material and labor costs and schedule can be aggregated. Additional attributes associated with each object generated within the CAD model include; Block ID, Block Description, Unit of measure, Quantity, Dimensions, Material ID, as well as additional fields for additional materials that comprise a design component block. An example to illustrate the above is Block C12 which represents a 12" diameter column where the unit of measure is inches. The column dimensions are geometrical attributes that can be extracted directly from the CAD design. The material ID 033-130-1120 is inserted from the material database referencing cast in place concrete including forms and reinforcing steel for average reinforced round tied columns. The attribute tag names and descriptions are summarized in Table 3.1.

Table 3.1 Definitions of Block Object Attributes

Attribute Tag Name	*Description*	*Data Example*
Block ID	Unique Block Object Identifier	C12
Block Instance ID	Unique Block Instance identifier – captures block insertions in drawing	C12.1
Description	Description of design component represented by Block	12" Round Column
Unit of Measure	Unit of measure of the dimensions of the design component	inches
Quantity	Number of units of objects	NA
Dimensions	Height; Width; Length; Diameter Dimension information can be captured from CAD object geometrical information	120", NA, NA, 12"
Material ID	Unique Material Identification retrieved from material database	033-130-1120
Additional Material ID	Material identification for attached or complementary material on the same object block. (i.e. paint finish)	NA
WP#	Work Package Number to which the design component belongs	100020-1-1

3.4.2 Linking Objects to the Database

As stated previously in this chapter, the material database holds a repository of resource information that is structured as per RSMeans® [1999], Building Construction Cost Data. The advantage of such a structure is that for each design object that has a designated material, a material unit cost as well as labor information are associated with that object. The construction data can be retrieved from within the design application. Designers can associate material information to each design component generated by consulting the database and inserting the appropriate data. The database structure allows the designers to validate the material selection and costs prior to establishing a link between the design component and the existing information within the database.

The proposed model makes use of the AutoCAD 2000 feature that allows for managing data from external database management systems within the CAD application. Furthermore, objects generated within AutoCAD can be linked to the information present in external databases. By linking external data to AutoCAD objects, data can be manipulated in a faster and more efficient fashion by selecting the AutoCAD objects linked to that data. However, the most promising advantage is by storing links to the external database, one can avoid storing data in the drawing thereby reducing the size of drawings. More than one design drawing can share the data available in the database.

3.5 Prototype Design

A great part of Chapter two was devoted to explaining the flow of information between the key players within the AEC industry and the need to capture this information in such a way that it flows seamlessly from one phase to another and between the project stakeholders. The construction industry relies heavily on information collection, information processing and interpretation. Therefore, database management solutions is proposed to help capture AEC data, transfer, and integrate the information across other AEC applications including scheduling.

The prototype developed for the purpose of this research, CAD-B PM (Computer Aided Design-Based Project Management), is structured around a database application designed to integrate a number of design and construction management functions. The application is based on a relational database supported by and interfaced to both a design application and a scheduling application. The Entity Relationship Diagram (ERD), shown in Figure 3.5, represents the structure of the CAD-B PM database.

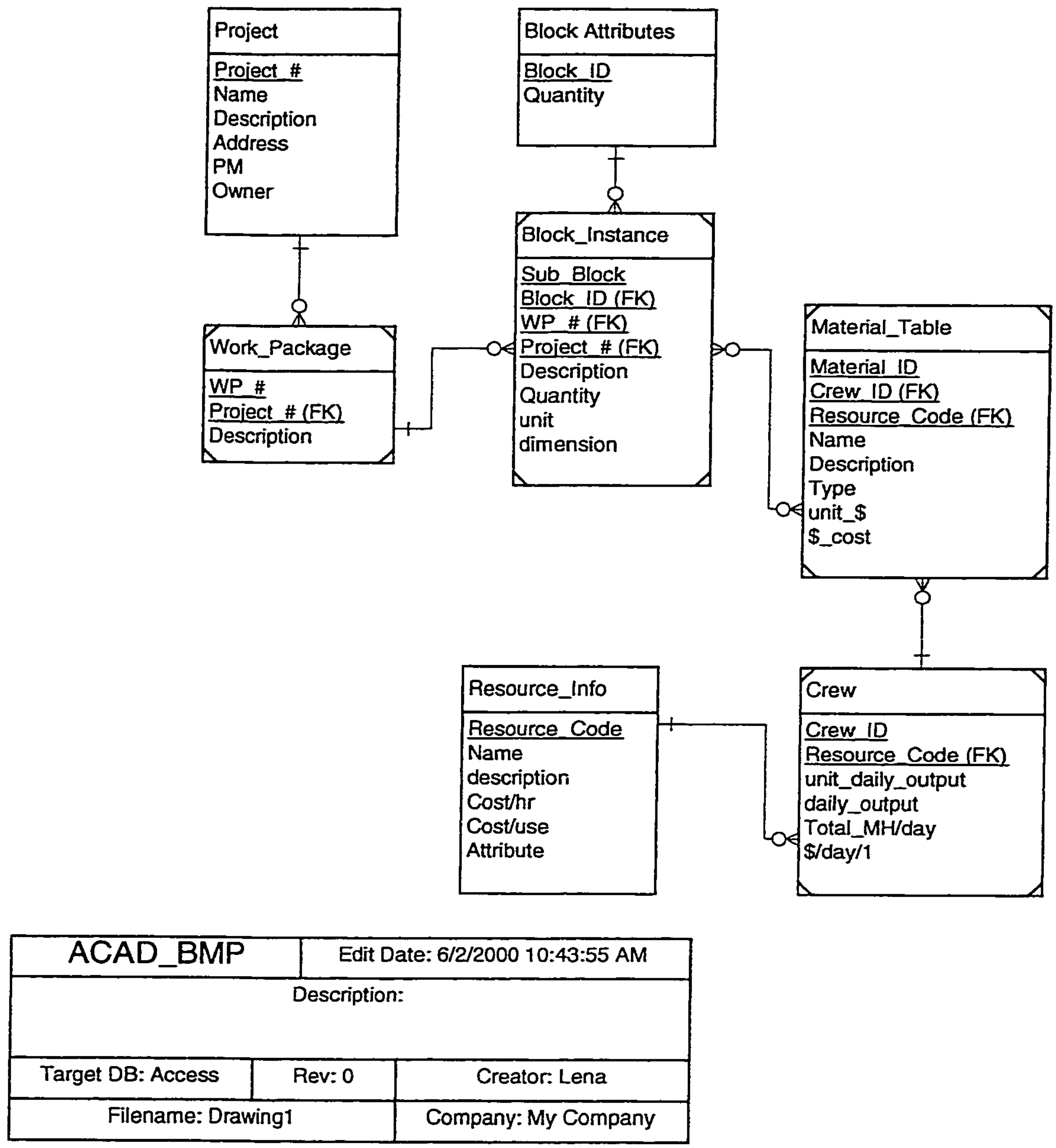


Figure 3.5 CAD-B PM Entity Relationship Diagram

The proposed database consists of seven entities: 1) projects, 2) work packages attached to the projects, 3) deign elements represented by block objects, 4) Block instances, 5) materials along with their descriptions and types, 6) construction resources, and 7) crews responsible for specific tasks. The relationships between these entities is representative of the information flow on an AEC industry project. The Entity Relationship Diagram (ERD) in Figure 3.5 attempts to capture all the relevant attributes that are related to the design-management information transfer (refer to section 2.1.4, Analysis of the Design Management Process). The objective of the proposed model is to provide an integration interface between the project deign and the project management phases as represented by their respective applications. The seven entities that the model outlines are the key points of information integration. These entities along with their respective attributes and attribute relationships are the subject of further detailed discussion in the subsequent paragraphs.

As per the definition presented earlier in Section 3.4.1, Block Objects are a collection of CAD objects developed in the design application to represent a design component. For each Block created in AutoCAD a unique identification number is assigned to it. Each time the Block is inserted within an AutoCAD drawing, a Block Instance identification number, Sub_Block_ID is created and serves as the unique identifier for each instance of a specific Block Object. Therefore, the parent Block ID is the foreign key to the Block Instance entity, as represented in the ERD shown in Figure 3.5. The Sub_Block_ID serves as the partial key that uniquely identifies the weak entity, Block_Instance, related in turn to the parent entity Block_Object. Apart from the identifier number, each Block Instance entity includes the following attributes: a description of the block instance, unit of measure (i.e. meter, foot, etc.), dimensions (i.e. length, height, width, radius, diameter, etc.), and quantity. These attributes are transferred from the design element inserted in the CAD file into the database.

The WP_ ID attribute serves as the foreign key that relates the Block_Instance entity to the Work Package entity. While there is no standard definition for a work package, the definition provided by Burke [1996] is used in this thesis. As such, it is considered as a well-defined scope of work that usually terminates in a deliverable product. The PMBOK Guide [1996] further defines a work package as the deliverable at the lowest level of the Work Breakdown Structure (WBS). The relationship described above associates each block instance inserted throughout the project design phase to a project deliverable in the construction or execution phase identified within the project's hierarchical WBS. The methodology adopted is an attempt to simplify the relationship between design components and deliverables described within a work package constituting part of the project's WBS. It is therefore evident that multiple Block Instances may belong to the same work package number. A one to many relationship exists between the two entities, Work_Package and Block_Instance, where each work package may have one or more design elements attached to it. The advantage of assigning each instance of a given design element to a work package is that the element is directly associated with a deliverable that is clearly identified within the work breakdown hierarchy of the project. The WBS is mandatory in project planning because it is the basis for work assignments, budgeting, scheduling, risk assessment, cost aggregation, and performance status [Kim, Kim and Ahn, 1999; PMBOK, 1996; Burke, 1996; Forsberg, Mooz, and Cotterman, 1996; Coles and Reinschmidt, 1994; Moselhi and Ho, 1994; Rasdorf and Abudayyeh, 1991; Moselhi and Nicholas, 1990]. The association of the design elements, block instances, with particular work packages within the project's WBS identifies the work that should be done to produce individual system/ project components. The WBS structure also provides a useful tool for cost roll-up, i.e. summating upwards the cost or man-hours associated with multiple activities belonging to a work package within the WBS for a project.

Within this database system, the work package is the cost center (i.e. code of accounts) where the cost of design elements within a functional division is rolled up. Furthermore, we hold one assumption within this model and that is: the deliverable as described within the project's WBS work package serves as the activity that is utilized for schedule planning and control. Therefore, the design components associated with each deliverable as prescribed within the work package are rolled up to obtain a total quantity and thereby a cost estimate. The same work package is the high level activity mapped to the project schedule. For simplicity, the model utilizes the defined project work packages as the designated activities, which are further sequenced for schedule development. One important consideration to remain within the scope described in the proposed model is that the project work packages are not further developed into activities. The restraint to be taken into consideration is that the activities associated with the deliverables are implied within the description of the work package. For example, column C12.1 in Table 3.1 is associated with Work Package #100020-1-1 which could represent the WBS deliverable with the description; first floor corner columns. As illustrated in the ERD, this work package description is the activity that is mapped into the scheduling application. All the Sub_Blocks that are associated with this work package are rolled up to obtain a total quantity along with a total cost estimate that includes both the required labor and material.

The repository of block materials data is the "Material" schema that carries the following attributes: 1) Material_ID (primary key), 2) Name, 3) Material Description, 4) Unit, 5) Cost of Material per Unit, 6) Crew required to install the item, 7) Cost of Labor per Unit, 8) Cost of Equipment per Unit, 9) Total Bare Cost, and 10) Cost including Overhead and Profit. The material table is populated with data from the RSMeans® Building, Construction Cost Data [1999]. The material attributes are formatted within the material database to resemble the structure of data as presented by the RSMeans®. The advantage of such an information structure is that it provides the most current information that can be directly uploaded into the system database from the RSMeans® CD-ROM. The cost data is divided into the 16 divisions according to the MasterFormat system of classification and numbering as developed by both the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) [CSI]. The cost estimating information as provided by RSMeans® Building Construction Cost Data is based on a "national average" normalized to account for 930 City Cost Indexes for North America. Each material within the material schema of the system is assigned a unique ten-digit code Material_ID that is based on the 5-digit CSI MasterFormat classification. The material database is structured and formatted as per the RSMeans® Building Construction Cost Data, thereby facilitating the process of populating the database with the most current estimating data as published by the annual edition of the RSMeans®. The database also allows for the creation of new material entries, allowing the user to populate the database with actual project data for more realistic estimates.

Each block object instance (design element) generated within the AutoCAD design may have one or more relationships to the material entity. For example, a floor slab composed of cast in place concrete has the following material; 3.3-140-4650 representing a 4" thick cast in place ground slab, including the required forms for holding the concrete in place and average reinforcing steel. This concrete floor is finished with dusted on floor coloring (0.5 psf). Therefore, a second material is attached to the block object representing the floor slab; namely Material_ID 3.3-260-3000. The material database as stated earlier contains the reference to construction material data and the designer has access to this database during the process of selecting the appropriate material that comprise the design object. The material attribute can be identified at the time of design, i.e. within the AutoCAD environment, or selected as an entry from the material database. If the material is new, or the AEC firm has specific cost information pertaining to a specific material, the material data entry form may be used to create a material entry into the material database.

The structure of the database further associates the material entity with the crew entity. A typical crew is composed of workers and the required equipment. For each material there is a reference to the typical crew installing the given material. For each of the material entries in the material database, a productivity daily output and required labor hours per unit of work is given based on a designated crew working a normal eight-hour day. Given the productivity information and the required quantity of work, the estimated duration for the work associated with installing the material can be derived. Therefore, duration is a derived attribute stemming from the relationship between the block material and the crew entities (see Figure 3.4). The crew entity is an association of a group of resources (including equipment) that are listed in the resource database. Attributes of resources include, the Resource_ID (primary key), name, bare cost per man hour, bare daily cost, bare cost per use (reference to equipment), as well as the daily and hourly cost with overhead and profit factored in. The crews assigned by default to each material in the database may be rejected and a new crew re-assigned. The crew entry form allows the user of the database to create new crews by aggregating a group of resources from the resource database along with their specified productivity rates. The database structure also allows the user to create a resource profile with the associated cost information; if the specific resource required is not already an entry in the database.

The database captures and stores historical project information as those pertaining to the cost of material, labor, and equipment. It further provides a list of alternatives to assist designers and contractors in the selection of materials and crew requirements. The database has a built in report generator that issues reports including the project Bill of Material, the resources required completion, and a list of the project work packages with its respective labor and material cost.

The process of material quantity take-off is automatically generated within the database based on the attribute information associated with each block instance that is stored as an entry within the database. Each insertion of a design block within the CAD design has a unique ID number attached to it and becomes an instance of the template block stored in the Block Library. For each block instance, the composite material's quantity and cost are rolled up. The system further aggregates the composite material of the instances of the same block producing a quantity take-off. The material list can be further rolled up to the level of the work package. For example, the work package #100020-1-2-2 represents the foundation columns. The column blocks that fall under this work package include, square (12") columns as well as circular columns (radius = 12"). The material with the same Material_ID reference that make up the two columns previously described are rolled up to the work package level and aggregated to obtain a cost estimate for the objects of interest. The process aggregates the costs based on groups of similar materials and their required quantities.

It can be noted that although simple, the seven database entities hold all the information related to a project according to the pre-established conceptual model. The entity relationships represent the actual relationships as encountered during the processes that make up AEC functions. The entity relationships represent the core processes as related to material and labor cost estimating as well as deliverable oriented schedule planning, including the activity definitions and sequencing.

3.6 CAD-B PM

CAD-B PM, or Computer Aided Design-Based Project Management, is a database application developed as a prototype implementation of the database described in the previous section. CAD-B PM is a proof of concept prototype software system developed for the project management methodology outlined within this thesis. Therefore, the application described in the following pages is limited in scope to only a few database entries supported by user-friendly interface screens.

CAD-B PM incorporates the central database that facilitates the integration of both the design (CAD) and scheduling applications. This database application includes the database model as described in section 3.5; the code developed to retrieve, calculate and update the required data; user friendly forms that allow the end user to enter data; as well as reports that can be customized to meet various management needs. Section 3.6 presents the following: a) established design requirements, b) the proposed functions of the application, c) the system architecture, d) hardware and software requirements, e) the components constituting the proposed application. To facilitate comprehension of the features within the application, a series of captured screens are used to illustrate the developed modules within the proposed database system.

3.6.1 Established Design Requirements

The need for integration of construction project information has been identified and discussed earlier in Chapter two. The efforts in developing the system "proof of concept" prototype were keyed to the requirements within the AEC industry for project information integration. The basic components and features within the application are based on requirements that emerge from traditional processes of design development, quantity take--off, cost estimating, and schedule generation within the AEC industry. Although limited in scope, CAD-B PM is based on a data model that meets core processes integration requirements. The need to capture and store pertinent project information at the design stage was taken into consideration when developing the data model. The main problems associated with the separation of design information from project management information are redundancy, errors, and omissions. The need to capture project data as it is created within an open and integrated system eliminates the problem of data redundancy. The concept of integration promotes the process of building on to existing information. Furthermore, the integration of multiple applications emulates a fusion into one system thereby eliminating the often-incurred problem as identified by Fischer and Froese [1996], "islands of information".

Another design requirement is a central database that holds a repository of material and labor information. Such a database stems from the need to automate the quantity take-off and cost estimating within one interface. This is addressed in the proposed model where CAD-B PM has a material table formatted in such a way that it can be populated and updated with estimating information as found within the RSMeans® Building Construction Cost Data [1999]. The innovation of the database application is that it is structured in such a way that it is open to receiving the attributes associated with the design objects and identified at the time of project design within the CAD application. The proposed data model identifies the schema structure so that information retrieved from the CAD application is inserted in the appropriate field and further used for cost estimating and schedule development.

3.6.2 Application Functionality

The system functions are directly derived from the design criteria discussed in the previous section. The CAD-B PM application supports and automates the following functions:

1) Automates Quantity Take-Off. The CAD application is linked to the external database enabling the retrieval of the Block Objects embedded in the design along with their attributes. CAD-B PM generates a list of blocks with their associated materials and consolidates similar bock materials to obtain total quantities. The list produced is in essence a bill of material (BOM).

2) Material Management. The material table stores construction material information as found in the RSMeans® Building Construction Cost Data [1999]. The database contains information about types of materials, units of measure, crew requirement for erecting and/ or placing a given material, crew productivity (i.e. units/ man-hour), as well as unit price information. This information is accessible from within the CAD application, via a link to an external database, or directly from within CAD-B PM. Although the material information is stored within the material repository the end user may update existing material information or generate new material entries. The material management tasks can be performed using the material form within CAD-B

PM. The material database allows the user to refer to the list of existing material types and to select the one that is required for a given block object within the design.

3) Resource Management. Both the resource and crew databases within CAD-B PM support the resource allocation process and hence the cost estimating process. Resource types and productivity within a crew are tabulated along with their daily and hourly cost. Both labor and equipment are covered under the umbrella of "resources". For each type of material a default crew required to install the selected material is assigned. However, the user may over-ride the default crew assigned and create a new crew entry by selecting a group from within the existing table of individual resources, and or generating new entries of individual resources required for the project. The information within the assigned crew schema pertains to both cost estimating and activity duration calculations as derived from the resource productivity rates.

4) Automated Cost Estimating. The proposed system identifies the blocks within a design project and quantifies the required material and resources as associated with each block object. The total material and resource requirements are consolidated for each material type utilized on the project. An internal calculator within CAD-B PM calculates total costs as rolled up to the material type level. The cost estimating process is automated within the material, resource and crew schema. CAD-B PM automatically generates a

cost estimate for each bock object inserted in the design and assigned a material type. The automated cost estimating function allows the user to compare different design solutions without necessitating time-consuming re-work associated with varying the design and associated material requirements. As such, it supports naturally Value Engineering Analysis.

5) Project Task Definition and Sequencing. CAD-B PM prompts the user to identify the Work Package to which each design element belongs. This requires some planning on the user's part. This function of CAD-B PM is based on the notion that the Work Breakdown Structure for a project is generally well defined well into the design stage. Each block object inserted in the design is assigned to a Work Package by identifying the appropriate WP# within the dialog box prompting for the attributes of a given block. The materials and cost estimates associated with each block are consolidated and rolled up to the level of the work packages within the WBS. These work packages identify the project's key deliverables and are used as tasks for the project schedule development. The sequence or logic may be identified within the proposed CAD-B PM system, where the user may select the identified tasks and impose relationship constraints as well as any identified lags that may need to be imposed for certain tasks. The interface to perform this function is a user-friendly table within the WBS module of the prototype.

3.6.3 System Layout

The layout of the system is based on a central database that allows the open communication between the design and project management applications. It is important to note that the proposed conceptual data model is application independent and targets the re-engineering of the AEC process to suit the needs of data integration. The model is driven from within the CAD application where the design elements are created by means of Blocks, and it takes advantage of the applications capability to attach non-graphical attributes to the Block Objects within the CAD design. The proposed system links the graphical objects within a CAD design to one or more instances of the database repository by means of an external database link. This database is a central repository holding construction project material and labor information. The relational database is capable of extracting, generating, updating, storing, and retrieving project specific data. This central database is the heart of the system. Design information is retrieved from the CAD application and then processed within the database. The list of project tasks associated cost, task duration, as well as assigned resources are mapped into the project management application to produce a project schedule. The management functions of schedule detailing, resource and material allocation as well as cost tracking and control are performed from within the scheduling application.

The objective is to have an open system that allows for efficient flow of information so that effective project control can eventually be achieved [Rasdorf and Abudayyeh, 1991]. As described within this context, "open" refers to the proposed system architecture and flow of information where the flow is non-application specific. Furthermore, the communication between the three main applications; namely the CAD tool, central database management system (DBMS), and the scheduling tool is achieved via an ODBC link that ensures feedback loops for a dynamic exchange of information. The Open Database Connectivity, or ODBC, is a widely accepted Application Programming Interface (API) for database access, which utilizes Structured Query Language (SQL), as a database access language. ODBC allows maximum interoperability allowing a single application access to various DBMSs that share the same source code. Most applications have database specific modules referred to as drivers that store ODBC interface functions. ODBC offers two distinct functionalities that proved to be of use within this research: 1) a way to merge data from different DBMSs in a single application, and 2) a way to have a single application that is independent of any specific DBMS, and hence the "Open". Detailed information on ODBC can be found in Appendix A. Within the proposed model ODBC provides the links between the applications in such a way that they openly share information. Specifically, any updates to the data from within any of the applications will be reflected in the original source of the data. Refer to Figure 3.5.

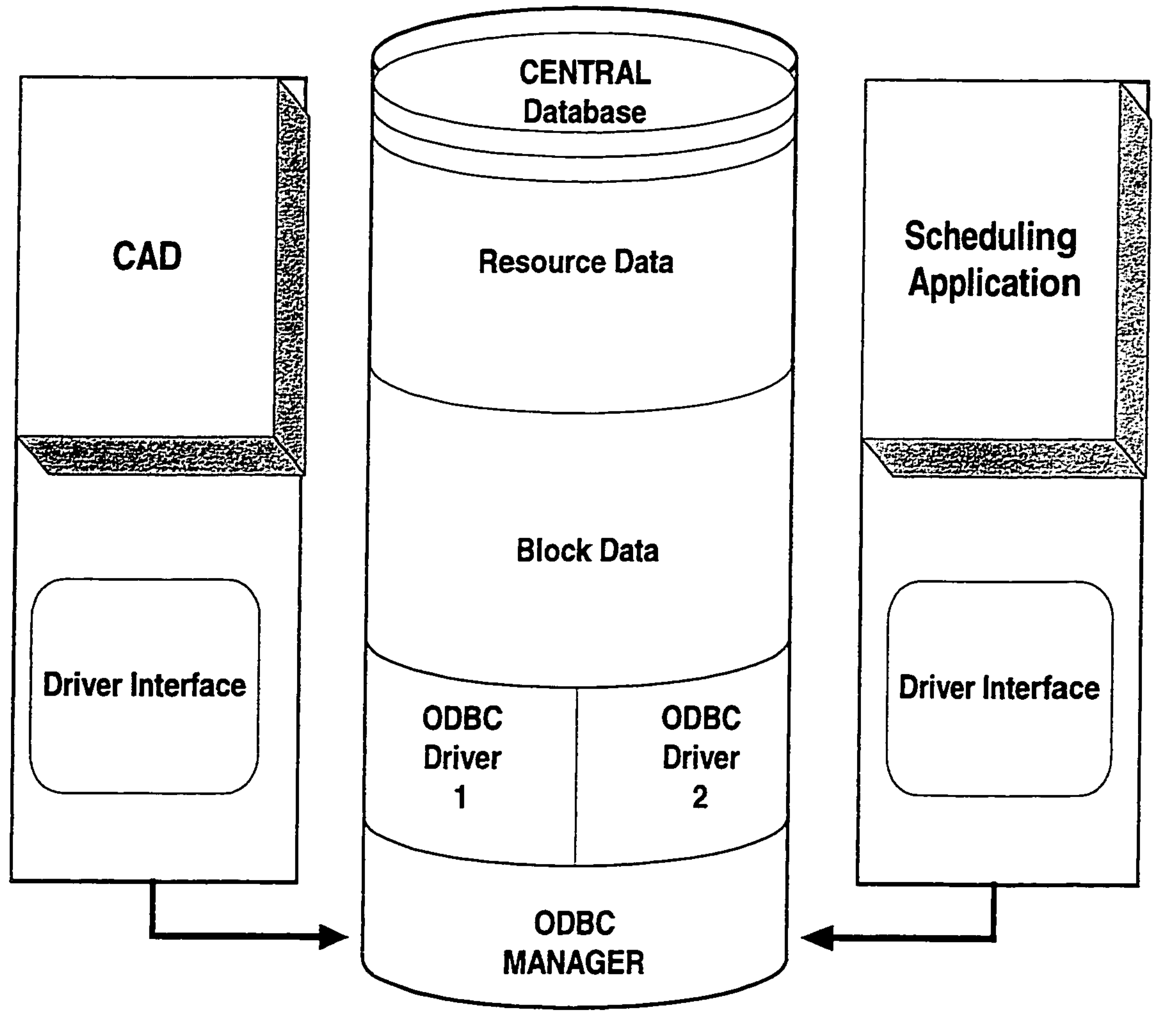


Figure 3.6 Proposed System Layout

The system operational layout presented in Figure 3.6 illustrates the following functions:

1) CAD system: The information flow starts here with the design elements via blocks and attribute definitions. These block attributes are extracted to the external database via:

CAD interface to the database application specific ODBC driver. This interface allows the CAD application to access tables from within the central database and through a managed security access routine allows the CAD user to dynamically manipulate the database entities (i.e. Block Objects, material data, cost data, etc.). The definition of this dynamic interface resides in the fact that any data manipulated from within the CAD application is automatically reflected in the central database.

2) Central Database Management System: The DBMS is populated with construction estimating information. The DBMS stores the design element information assigned from within the CAD system and it calculates the material cost and duration for completing the task for each design object. The PM application uploads the project tasks and associated fields using:

PM application interface to DBMS ODBC driver Input/ Output Interface with Project Management Application: This is the interface that maps the project information processed within the DBMS into the specified PM tool.

3) Project Management Application: Once the information processed from CAD into the DBMS is mapped into the PM tool it can be handled from within this interface for project plan detailing, tracking and control.

Figure 3.7 summarizes the proposed integration process between the three core applications required for the conceptual data model presented within this research. The figure presents the integration process including the interface points among the software applications developed and based according to standard industry practice.

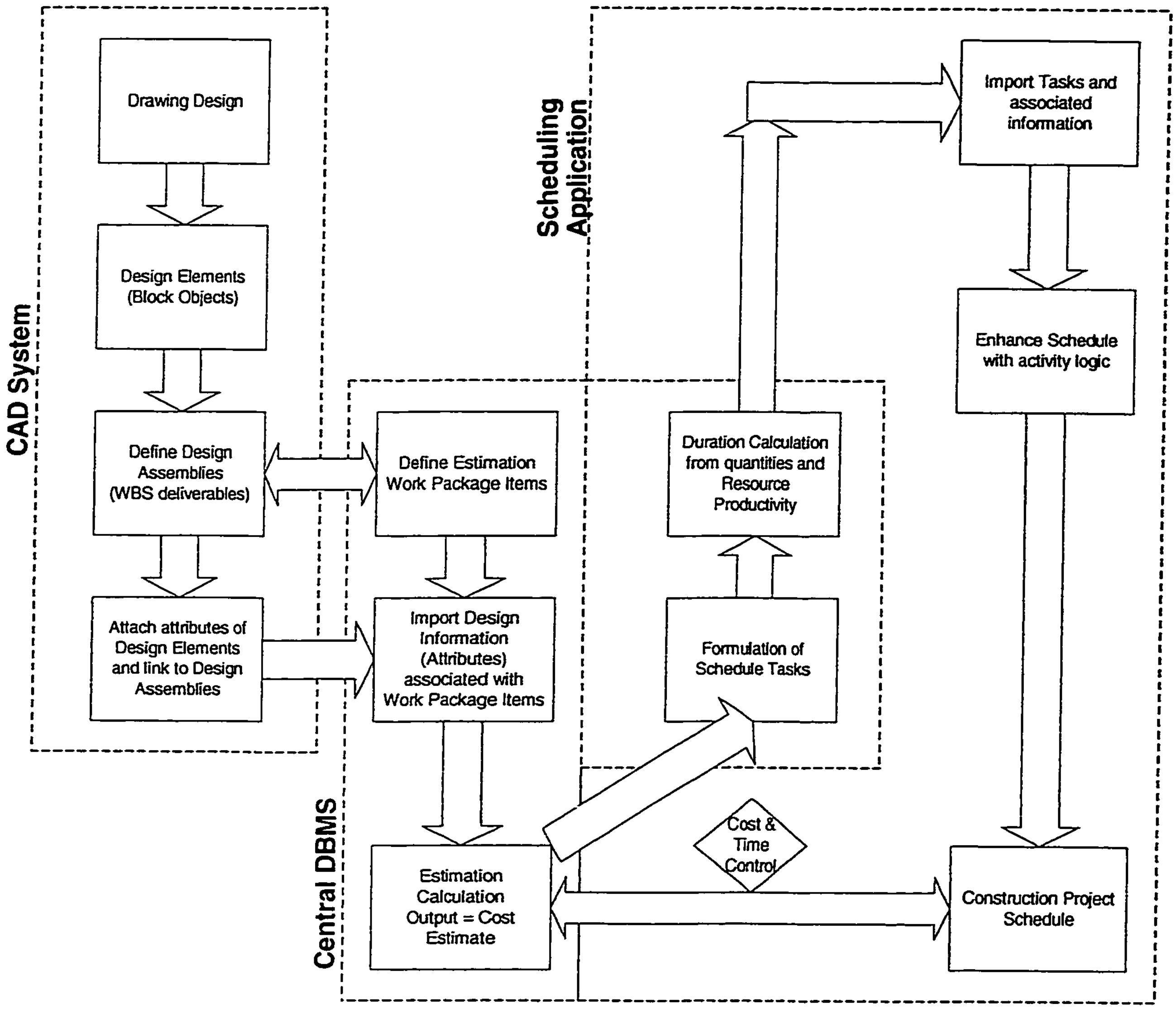


Figure 3.7 Proposed Integration Process Across Three Applications [Adapted from Parfitt et. al,, 1993].

3.6.4 Hardware and Software Requirements

The implementation of the system in the proof of concept prototype utilizes the following specific software applications: AutoCAD 2000 (AutoDesk 2000), 4D Server (4th Dimension, ACI SA 1998), and MS Project (Microsoft 1998). The choice of the specific applications for the implementation phase was one of a strategic nature. The intention was to choose the most commonly used software within the AEC industry. Autodesk's AutoCAD is by far the most popular software utilized within the industry and accessible to small contracting firms as confirmed by the author's interviews with AEC firms local to Montreal. Furthermore, MS Project is compatible with all Windows based desktops, by far the most popular and hence require minimum if any hardware requirements. The main objective of the application choice was to choose specific applications that are most readily available within small contracting firms because the nature of information integration requires that all the stakeholders within a project be on the same infrastructure to allow for the required flow of data. It should be noted that the choice of DBMS in this implementation is 4D and although a powerful and strongly popular tool within the software industry it is rarely found in AEC offices. A preferable choice would have been MS Access. The DBMS 4D was chosen for this prototype implementation in view of its availability and the many features it offers, including its ability to run in a cross-functional environment (i.e. Mac and PC). A main feature of 4D is its ability to run in a client-server environment, hence providing efficiency for data storage and processing. In light of the previous statement, it is important to note the point that has been stressed within the previous sections highlighting the openness of the proposed data model and system architecture. In other words, the choice of application is not a restraining factor within the implementation [Tah, Howes and Iosifidis, 1999] (i.e. The source of data could be any ODBC compliant application.)

The prototype system runs under Windows 95 Operating System (OS). For satisfactory operation the following specifications are required:

- Pentium processor or compatible.
- 128 MB of RAM.
- Approximately 500 MB of hard disk space in addition to space required for storing files in the system folder.
- Minimum of 640 x 480 VGA display.
- CD-ROM drive for application installation.
- Windows 95 / NT or Macintosh OS

The system deployment requires Windows NT or Macintosh functional environment with a central server (NT or Appleshare) for optimal client-server processing.

3.6.5 CAD-B PM System Components

CAD-B PM is a Project Management system supported by the relational database model presented earlier in this chapter and makes use of commercial software interface integration. The application platform for the database development is 4D. The entities and entity relationships within the database's conceptual model were developed into tables that store information within the DBMS. Although accessible to the users, the user does not access the tables directly, but uses the various forms for data entry, updating and manipulating. In addition to the user-friendly forms, the end-user has access to both queries and reports allowing him/ her to display, generate and print relevant information to the specific project phase. CAD-B PM is linked to both AutoCAD 2000 and MS Project via an ODBC (refer to Appendix A) interface, providing material and estimating information to designers and partially automating the project planning and scheduling processes. Figure 3.8 shows CAD-B PM's opening screen. There are eight Menu options developed for the user interface: 1) File, 2) Edit, 3) Block Attributes, 4) Material, 5) WBS, 6) Resources, 7) Tools, and 8) Help. Each menu has a host of sub-menus that call up entry forms, queries, reports, and tables.

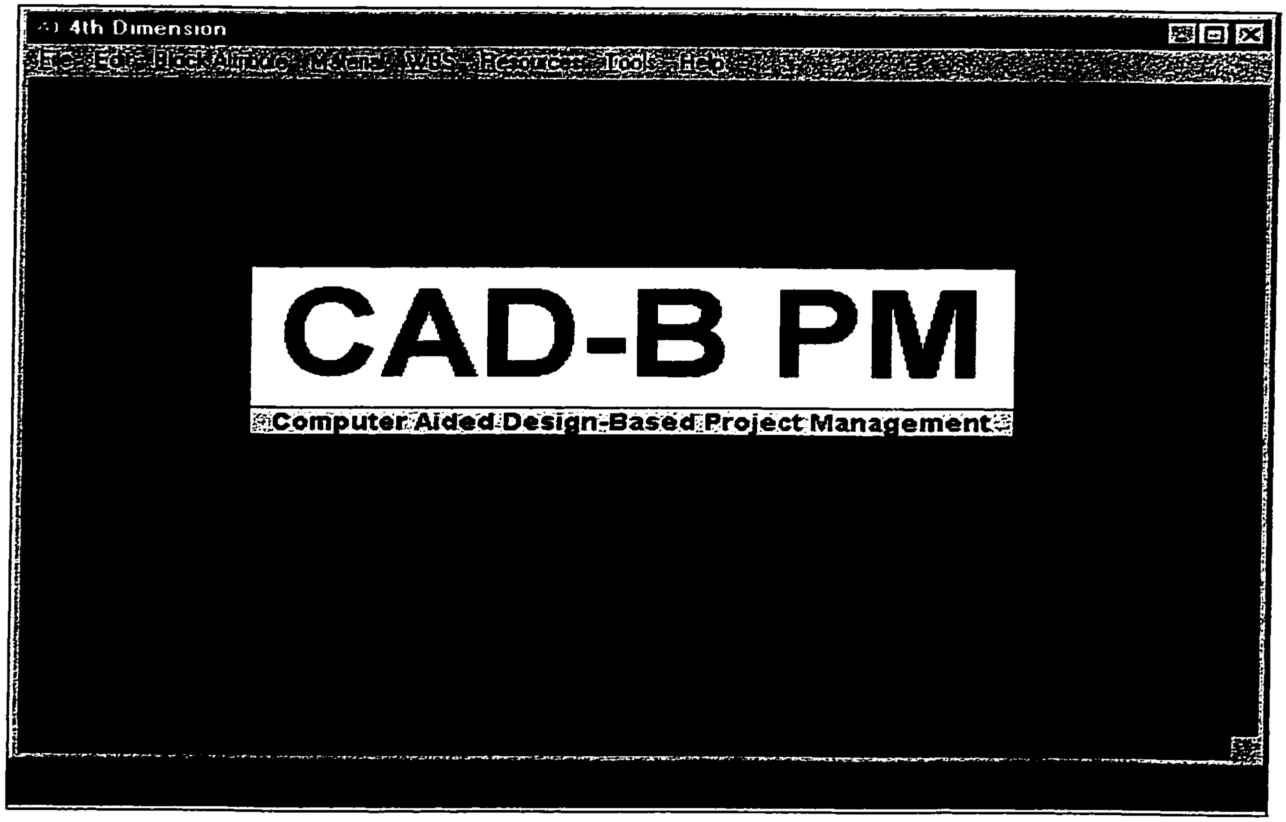


Figure 3.8 CAD-B PM Opening Screen

3.6.5.1 Tables

The proposed data model as presented in the ERD supports seven main entities and their relationships. In the implementation phase some of the relationships are translated into tables within the database. Figure 3.9 shows part of the ERD as implemented in 4D.

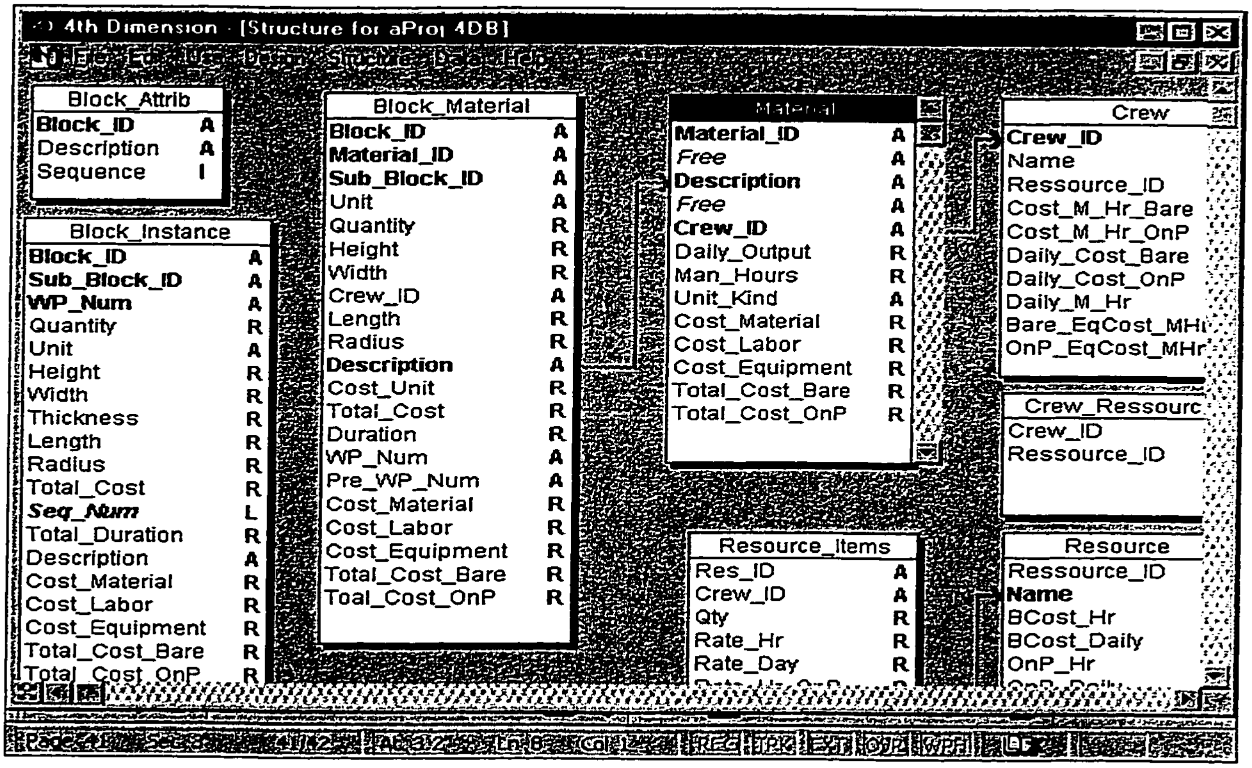


Figure 3.9 Captured Screen of the ERD.

As mentioned earlier, these tables are accessible to the system designer but hidden from the end-user. The tables store the following groups of entities: 1) Project Information, 2) Design Element Information as retrieved from AutoCAD, 3) Material information including material blocks, quantities and prices, 4) Resource information including assimilation of resources into crews, productivity per material type, and price per man/hour and 5) Work Package information as related to design assemblies for schedule development, sequencing, and established level for project activity cost and duration roll-up.

The tables store information that is further processed by the DBMS through a developed code that applied to certain attributes of the defined entities. For example, the DBMS retrieves the design information such as block type and quantity from the CAD application. Once related to a material type within the database, a procedure automates the process of calculating the total cost (product of quantity and unit price) as well as the duration for producing the design element based on the assigned resource productivity and the quantity of material. The code also has the ability to convert units of measure in order to comply with the units of measure stored for each material information. For example, a square column produced within AutoCAD may have both height and width in inches. The information is extracted into the appropriate table and based on the link to a specific material with the cost designated as $\$/ft^{3}$. the DBMS converts the inches into feet and calculates the volume in order to determine the total cost of a given square column. The source code within the application may be refined to a detailed level with multiple functionalities, however the limited scope of the prototype allows for only a demonstration of a few of the features that may be further enhanced in a fully operational development.

3.6.5.2 Forms

The forms are the user interface to the CAD-B PM system. These forms allow the user to call up data and generate new entries. Furthermore, the user may query the system and produce management reports through these forms. The Forms combine fields that are retrieved from more than one table allowing for ease of use and operation efficiency.

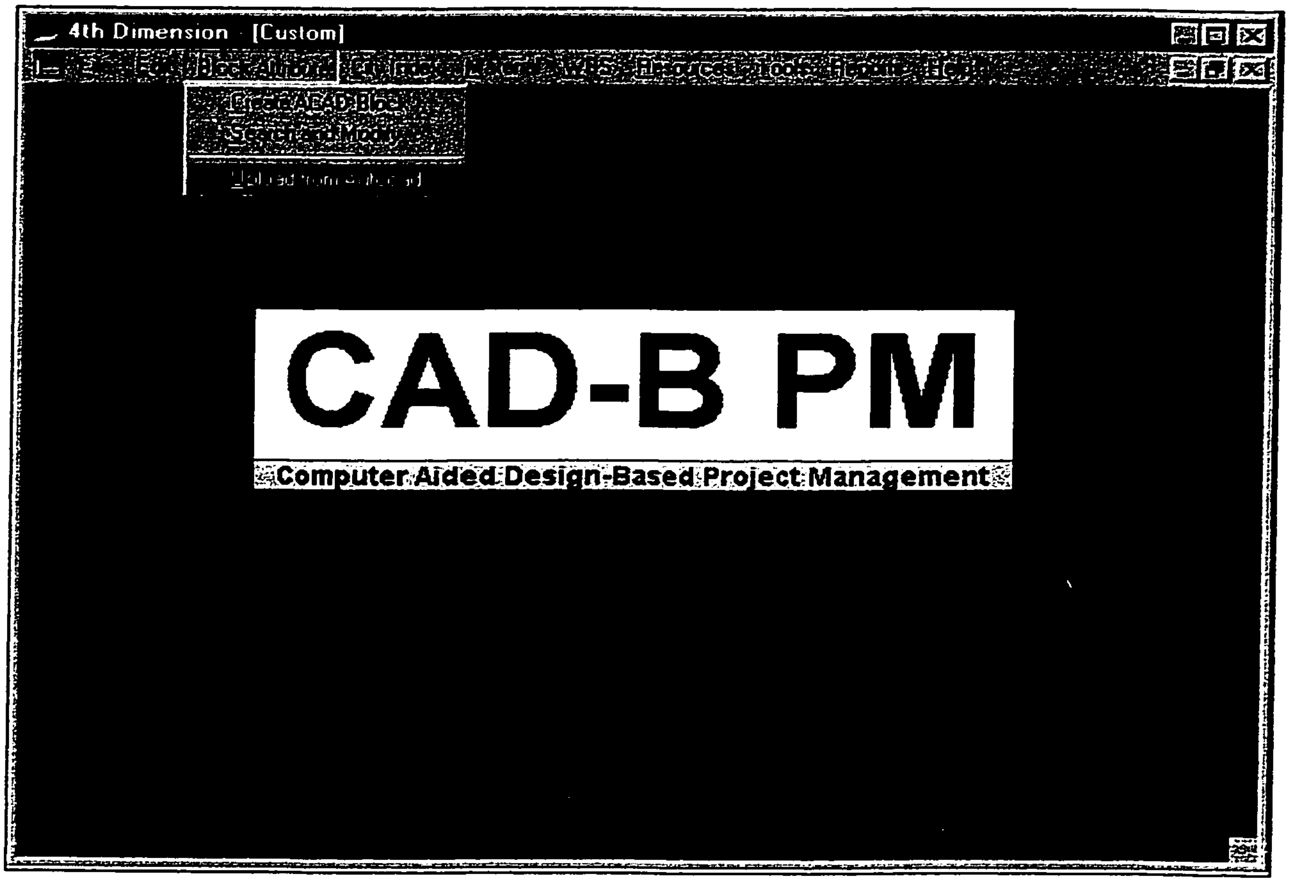


Figure 3.10 Search and Modify sub-Menu of Block Attribute Men

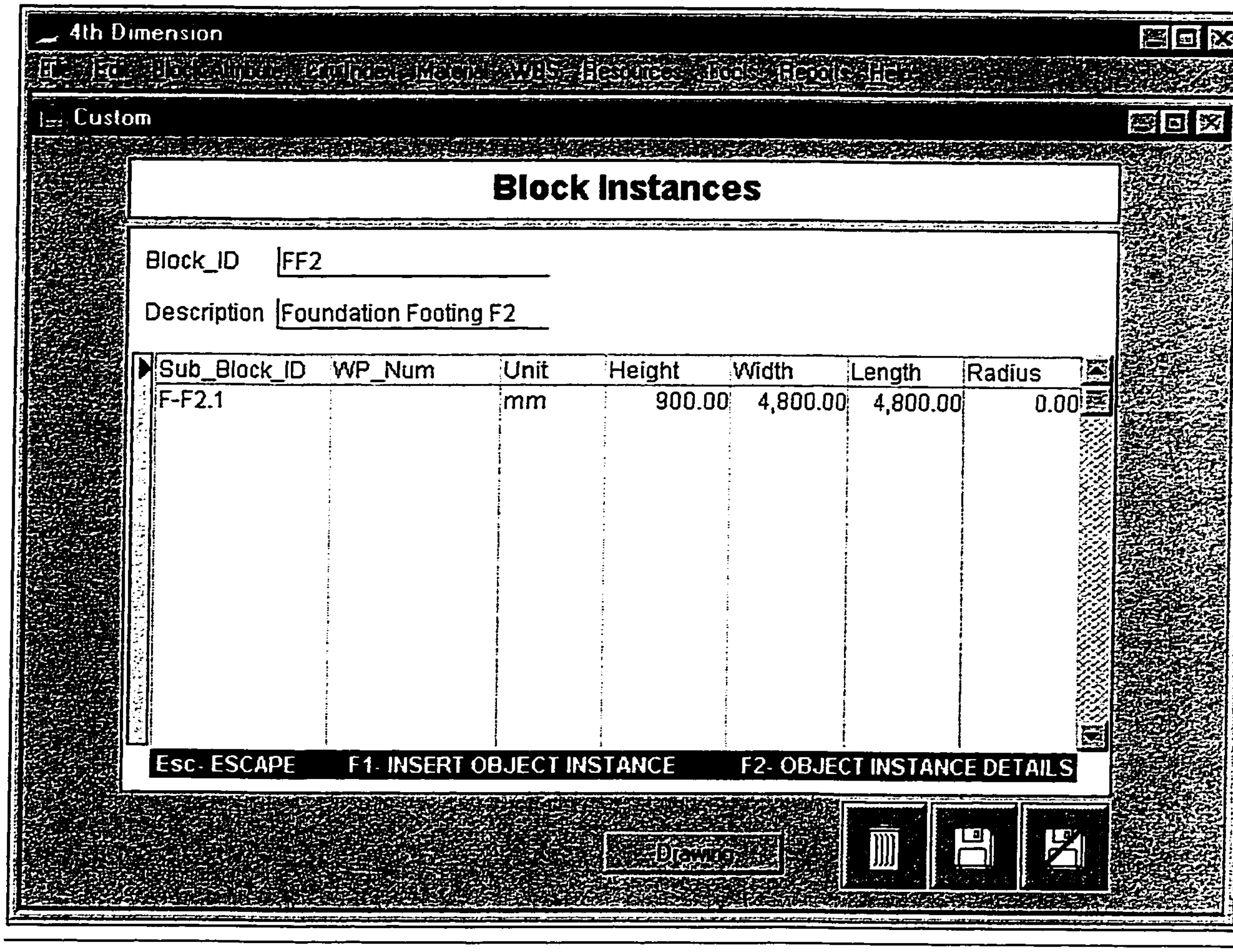


Figure 3.11 Block Instance Entry Form.

When the user selects the sub-menu of the Block Attribute menu, Search and Modify as shown in Figure 3.10, a table of project related blocks is displayed. The user may then select a given block and the Block Instance form is opened. Figure 3.11 shows a captured screen from CAD-B PM for the Block Instance Form. The information found within this form include the master block reference and description as well as a table listing all the instances of the main block inserted in the project design. These block instances are generated automatically with each block insertion within the AutoCAD design. Therefore, when called up, this particular form shows the block instances of each particular block (referred to as sub-blocks) with the relevant dimension information as retrieved from the CAD design. The entries within this form also include a reference to the Work Package number to which each block instance belongs. Most of the fields within this form are retrieved from the block instance attributes that are assigned within AutoCAD by the designer. Figure 3.12 is a captured screen of the Work Package entry form where the user can create the WBS structure for a given project. The database user may fill in any blanks that may have been unknown during the design phase. Here is where the ODBC link plays an important role. Any insertions to the database that are related to the design block attributes are dynamically translated back into the AutoCAD design to update the relevant attribute changes. Such a dynamic process ensures system compatibility and conformance, eliminating any errors that manual entries and updates may generate.

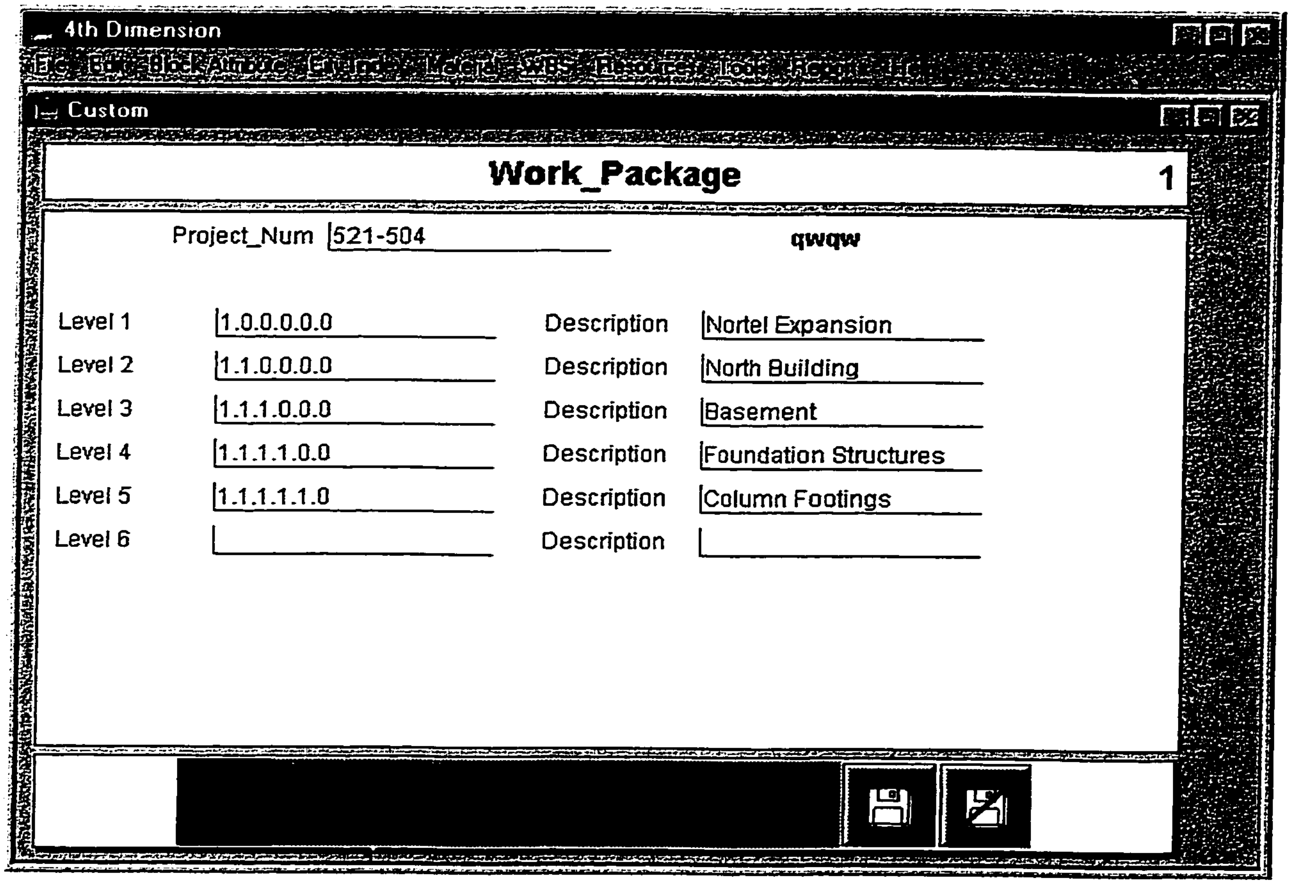


Figure 3.12 Work Package Entry Form.

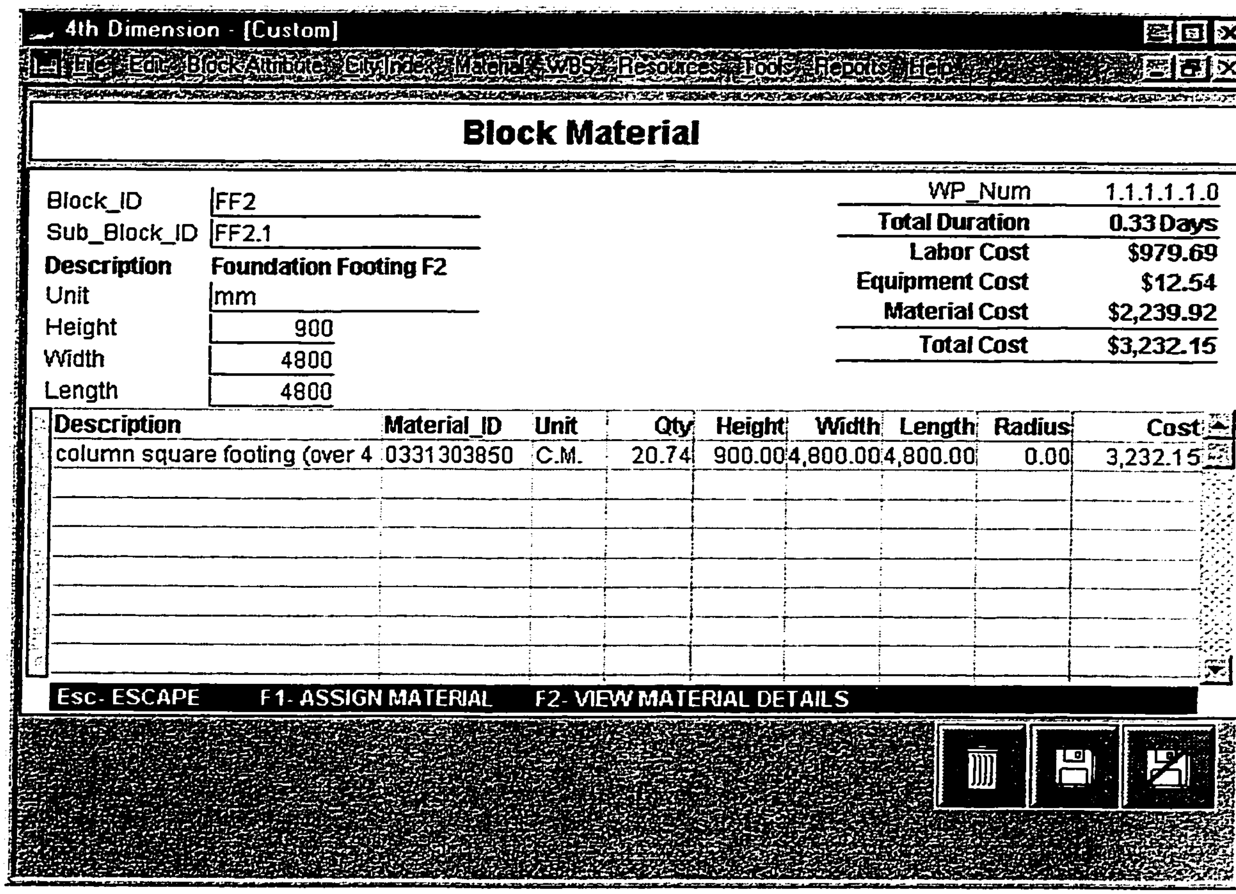


Figure 3.13 Block Material Screen.

Pressing the F2 key in the Block Instance screen, when the cursor is resting on a particular block instance, will call up the Block Material entry form as shown in Figure 3.13. This form allows the user to specify the block instance component materials if they were not specified or known at the time of design. The form shows the referenced block instance and dimensions. The table in the lower portion of the form lists the material description and reference ID, unit of measure and quantities or dimensions. This allows the user to specify the amount of material that make up the block if it is not completely composed of one type of material. The dimensions are necessary so that the system may calculate the quantity of required material for a cost estimate. The last column in the lower table is a derived field that is calculated by the DBMS to show the cost of each material attached to a specific block instance. By pressing the F1 key the user can attach the selected material to each block instance. The material database may be called at this time if the user is not familiar with the material description or needs to consult the choices of material within the database. Figure 3.14 is a captured screen of the table of material that may be consulted from within the Block Material entry form. The material list within the database is a complete listing of the information available within the RS Means® Building Construction Cost Data [1999]. Should the user not find the appropriate material or wish to generate a new material entry within the material database, he/ she can use the Add Material form as shown in Figure 3.15. The Add Material form can be accessed from the Material Menu, within the Add sub-menu. To generate a new material entry the user must input the description and assign a material ID number. The default crew required to install the material should also be specified, as well as the crew's productivity in performing the tasks associated with the specified material. Furthermore, the user should specify the unit of measure as applied to the productivity and material unit cost. The fields for man hours, labor and equipment costs, as well as the total bare cost are calculated automatically by the system. The new material entry generated is then stored within the Material table for future reference when needed.

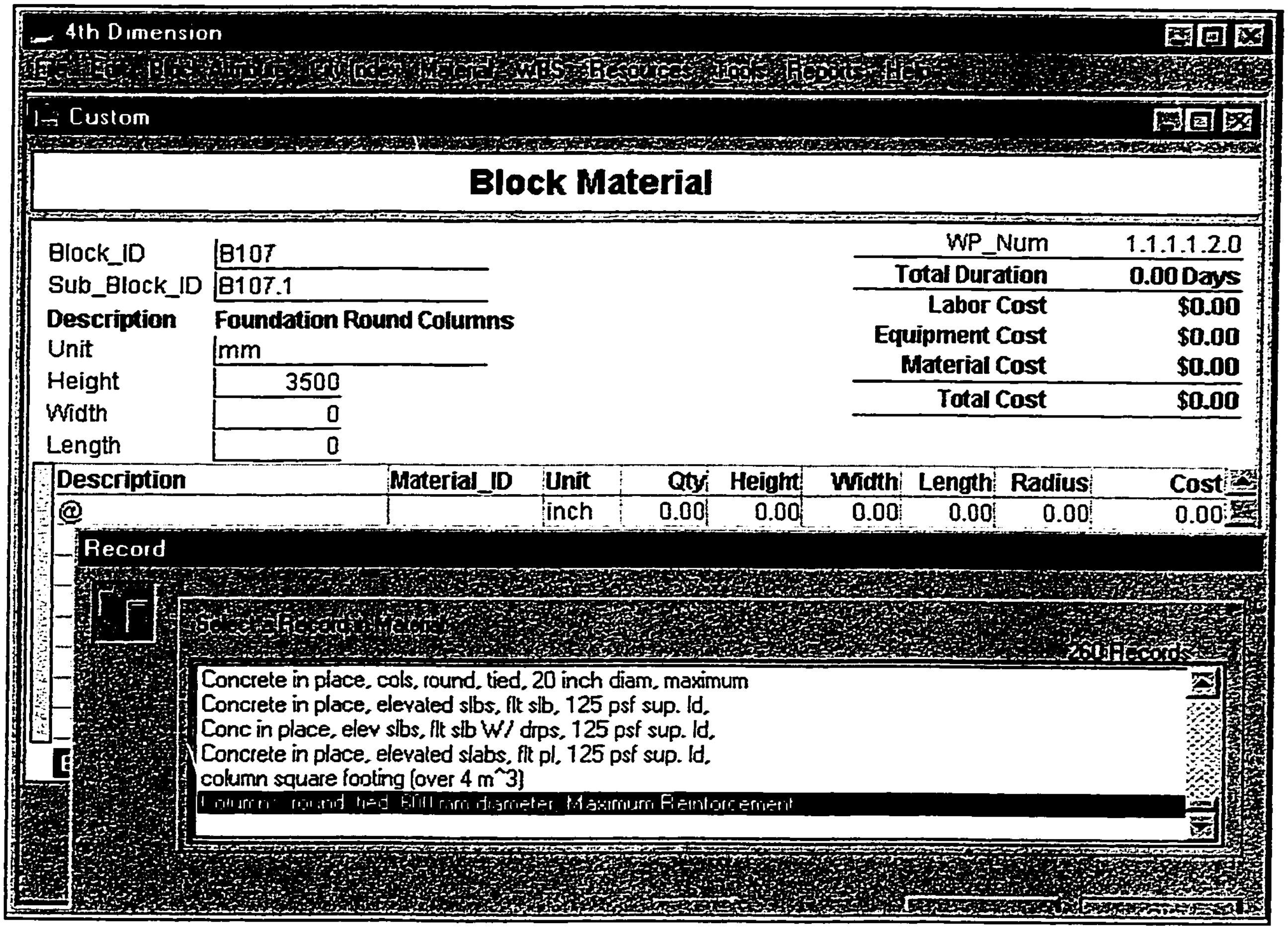


Figure 3.14 Material Table for Reference.

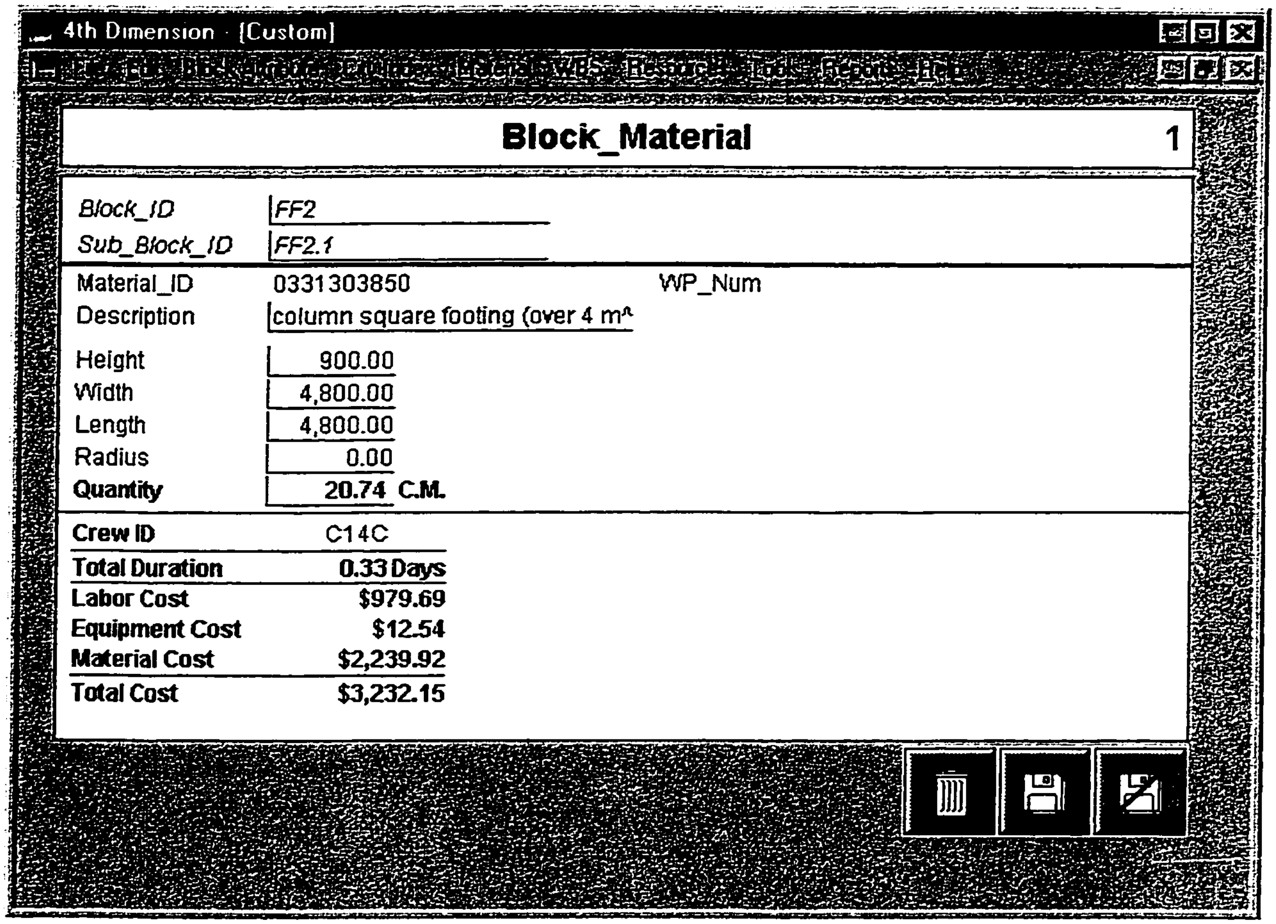


Figure 3.15 Material Entry Form.

The Resource Menu gives the end user the option to specify resource and crew allocations as applicable to project deliverables. The Add Resource selection within the Resource menu option allows the user to add specific resources not available in the Resource table. The resource table may be consulted from the Resource menu by choosing the option Search and Modify immediately under the Add Resource Option. Figure 3.16 is a captured screen of the Add Resource form.

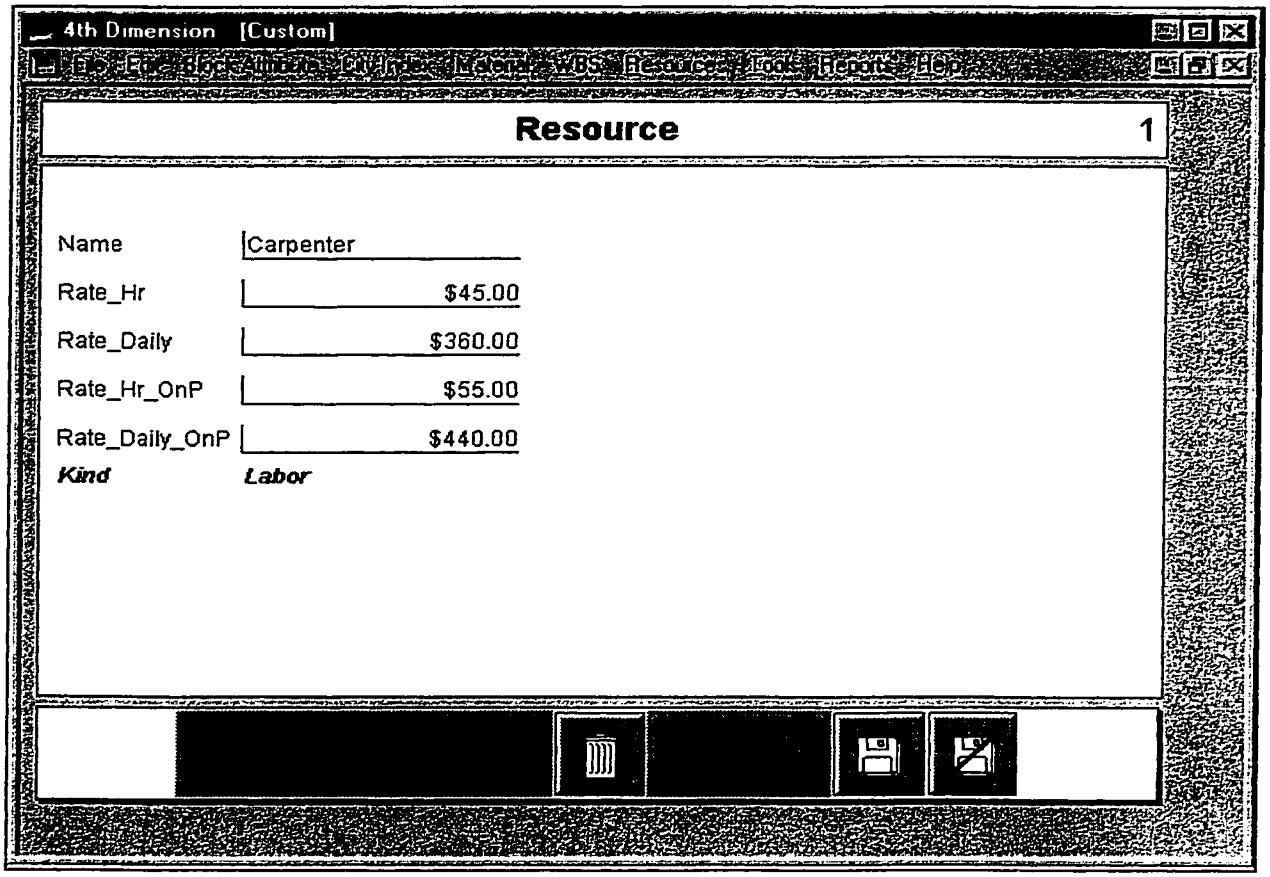
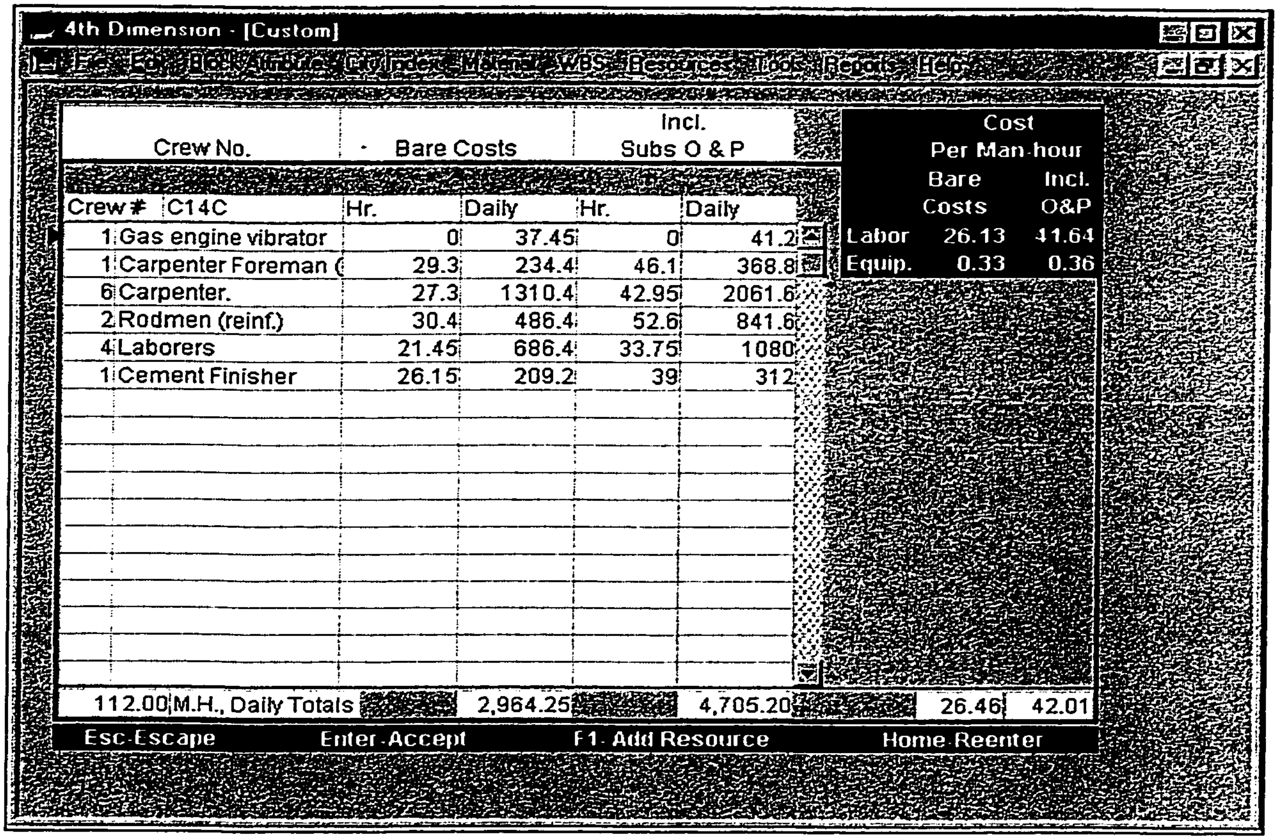


Figure 3.16 Add Resource Form.

Should a particular resource not be available in the resource database, the user may create a new resource entry by completing the required information within the Add Resource form. A resource name should be identified along with the associated hourly rate as well as the hourly rate including the Overhead and Profit. The database will then derive the respective daily rates. The user must specify the "kind" of resource, i.e. labor or equipment. The "kind" designation is important since it allows the system to distinguish between cost that is pro-rated per hour and that which is accrued on a daily basis. In general the cost of material is a one time cost per day whether the equipment is used during the full 8 hour day or for only a few hours within a given day.

The resources within the resource database are assimilated together into crews and stored within the crew table. The standard crew ID numbers and compositions are stored within the crew table and are defined as per the RS Means® catalogue [1999]. Each material type within the material table is related to a default crew that is considered as standard requirement in the installation or placement of a given material. Figure 3.17 shows the resources that compose crew number C14C, namely 1 carpenter foreman, 6 carpenters, 1 cement finisher, 4 laborers, 2 rodmen and 1 gas engine vibrator. The crew form shows both the bare costs as well as the costs plus overhead and profit for each of the resources that make up the given crew. Each type of cost is listed as both per man-hour cost and a daily cost rate. Based on the total numbers of resources, the daily total bare cost and the daily total cost plus profit and overhead are totaled at the bottom row. The upper right hand corner of the form tabulates the aggregated cost per man-hour for the given crew. The aggregated cost per man-hour is listed as both bare and cost plus profit and overhead. This table also separates the cost of labor from the cost of equipment. The user to amend the crew compositions or to create a new crew entry may utilize the crew entry form. The crew creation constitutes of assigning a crew name and then identifying the quantities of each selected resource. By typing "@" in the field for resource name, the user may consult the resource table. If the required resource is not within the resource table, the user is prompted to create a new entry for the desired resource and the form in figure 3.16 allows the user to create a new resource profile. Once created, the new resource may be selected to be part of the composition of the crew entry. The cumulative costs are automatically calculated within the form and these costs are used as part of the project cost estimate.



4th Dimension - [Custom]

File Edit Block Attributes City Index Materials WBS Resources Tools Reports Help

Crew No.		Bare Costs		Incl. Subs O & P		Cost Per Man-hour	
						Bare Costs	Incl. O&P
Crew #	C14C	Hr.	Daily	Hr.	Daily		
1	Gas engine vibrator	0	37.45	0	41.2	Labor 26.13	41.64
1	Carpenter Foreman (	29.3	234.4	46.1	368.8	Equip. 0.33	0.36
6	Carpenter.	27.3	1310.4	42.95	2061.6		
2	Rodmen (reinf.)	30.4	486.4	52.6	841.6		
4	Laborers	21.45	686.4	33.75	1080		
1	Cement Finisher	26.15	209.2	39	312		
112.00	M.H., Daily Totals		2,964.25		4,705.20	26.46	42.01

Esc-Escape Enter-Accept F1-Add Resource Home-Reenter

Figure 3.17 Example Form for Crew C14C.

3.6.5.3 Task Definition and Sequencing

CAD-B PM supports construction data integration in that it captures, sorts, and generates design information including quantities, labor and material requirements, and cost estimates. This information is aggregated for the design elements and rolled up to the WBS level to which the design elements belong. As previously stated, the user must identify the work package number to which each block instance in the design belongs. Therefore, a correct assumption, within this context, is that both the project WBS is defined and the level to which the project information will be rolled up is previously established. It is very important to establish the level within the WBS that the project costs will be collected and rolled-up to. The description assigned to each of the elements within the WBS will hold as the activity name imported into the project management software tool. The cumulative cost attached to each work package is the sum of the aggregated costs of labor and material for each of the block objects associated with a given work package.

The work packages provide control accounts and assembly based structures for each of the project design components. The project WBS is the basis of the project plan and provides the premises from which the project activities are defined, the material and labor requirements are determined, and the project cost estimates are generated. CAD-B PM generates the WBS structure for the project in an outline form and based on the numbering system as well as the definitions defined by the user. The WBS outline structure can be displayed on the screen, as shown in Figure 3.18, by selecting WBS from the menu and then selecting "Display", screen.

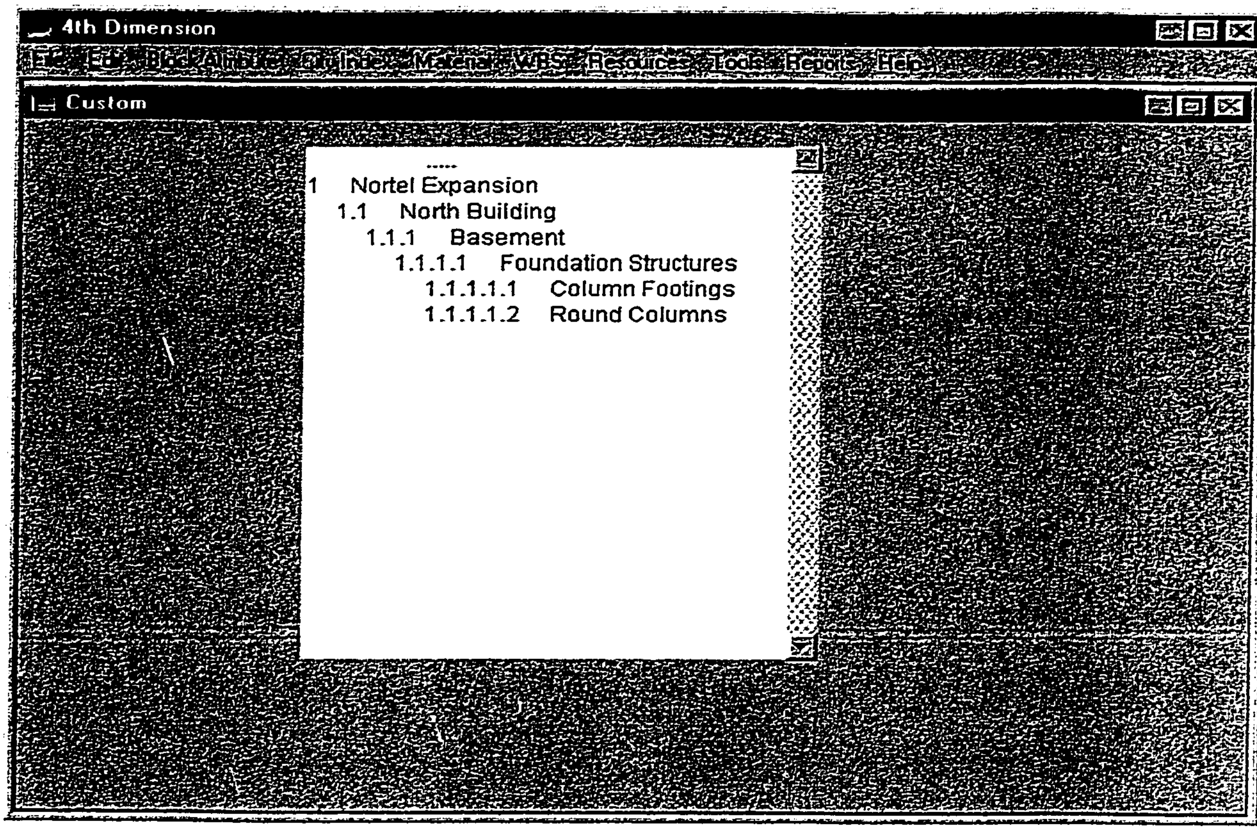


Figure 3.18 Project WBS: Outline Format.

As stated earlier, each block object inserted within the design must be assigned to a work package within the project WBS. Within the proposed model, the work packages serve as activities and they are imported into the scheduling tool for the purposes of project planning and control. CAD-B PM allows the user to perform a preliminary activity sequencing from within the interface of the database. The objective is to identify any known logic constraints at this point. Figure 3.19 shows the screen the user works with to identify the activity sequencing and known activity relationships and constraints (i.e. lag time). The Task Sequencing screen maybe accessed by choosing the WBS menu and then selecting "Organize". The system retrieves all the levels as defined within the WBS with 3 columns that allow the user to identify the predecessor task, the lag time if any (negative for lead), as well as the relationship type (i.e. FS, SS, FF. SF).

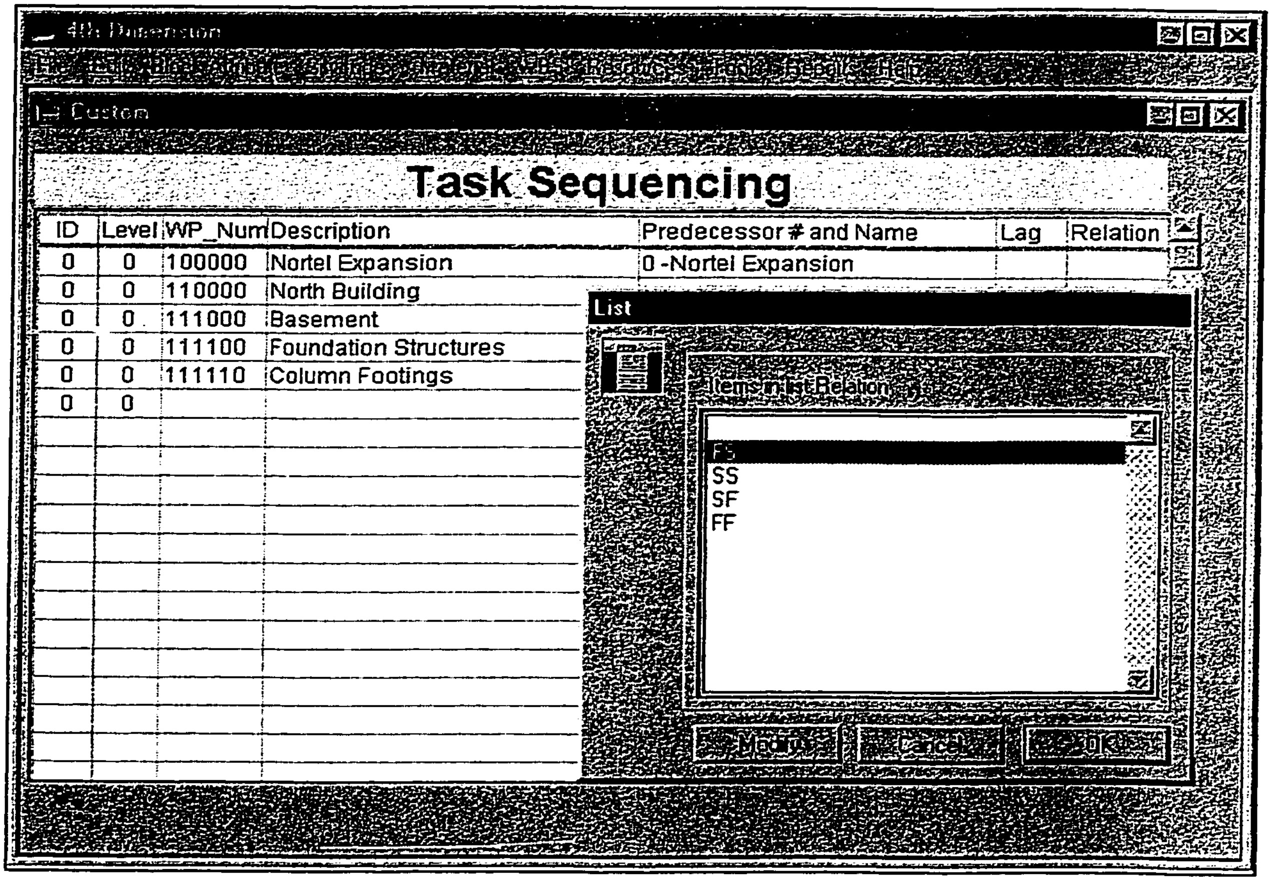


Figure 3.19 Activity Sequencing and Relationships

The use of this feature within CAD-B PM is not mandatory. The Task Sequencing option has been incorporated to allow for early task planning where certain constraints and relationships maybe known during the design phase and prior to the active process of project management. For example, a specific construction method may be known at the time of design where it is necessary to complete phase A tasks prior to phase B due to known constraints (i.e. availability of resources, curing, etc.)

The user may identify the task predecessor by clicking on the column "Predecessor # and name" of the appropriate task with the left key of the mouse. A dialogue box is displayed, as shown in Figure 3.20, with a drop-down list of all the possible selection of tasks and ID numbers. The user can then select the appropriate task predecessor while designating the type of relationship (i.e. Finish to Start (FS), Start to Start (SS), Start to Finish (SF), or Finish to Finish (FF)), in the relationship column. Furthermore, the database allows the user to assign the appropriate lead/ lag time for the task in question, if known when the relationship is flagged.

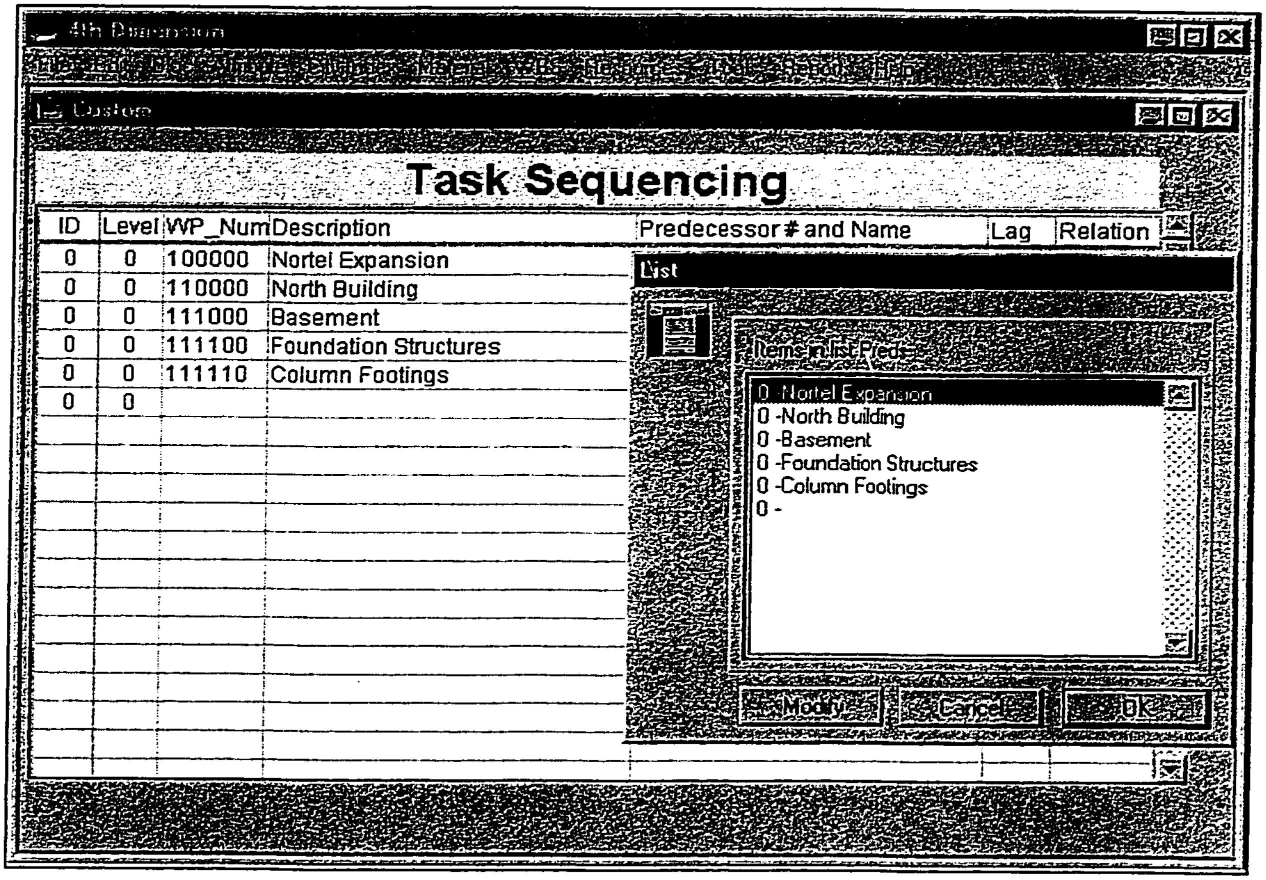


Figure 3.20 Task Predecessor Selection

3.6.5.4 Exporting Project Data into the Scheduling Tool

The project information collected within the CAD-B PM database is further destined to the planning and scheduling application to which the system is integrated. The objective is to automate the process of developing the preliminary project schedule. That is, the list of activities and associated costs as collected within the CAD-B PM database. The proposed system prototype integrates with MS Project. The relevant fields within the central project database are mapped to MS Project, the scheduling application, for the automated generation of the project schedule. The activity sequencing and relationships are also mapped into the scheduling application given that this information has been defined earlier within the CAD-B PM database.

The data related to the AutoCAD objects that was extracted to the external project central database and used in task definition, material cost estimation, and resource productivity calculation for activity duration estimation, is linked to the MS Project application through the use of the DBMS's ODBC (Open Database Connectivity) driver. The required data are mapped into the scheduling application by identifying the required data fields from the tables within the central database. This is accomplished by defining an import/export map to select these tables and fields to be imported to the specified destination within the project data file. Figure 3.21 is a captured screen of the mapping set-up for the date field within MS Project. Both task and resource maps are pre-defined and the open link to the central database is automated to import the information directly to MS Project by clicking an IMPORT macro button. Therefore, the project baseline data is not only automatically imported from the central database, it is also mapped into the proper fields within the scheduling application creating a project baseline.

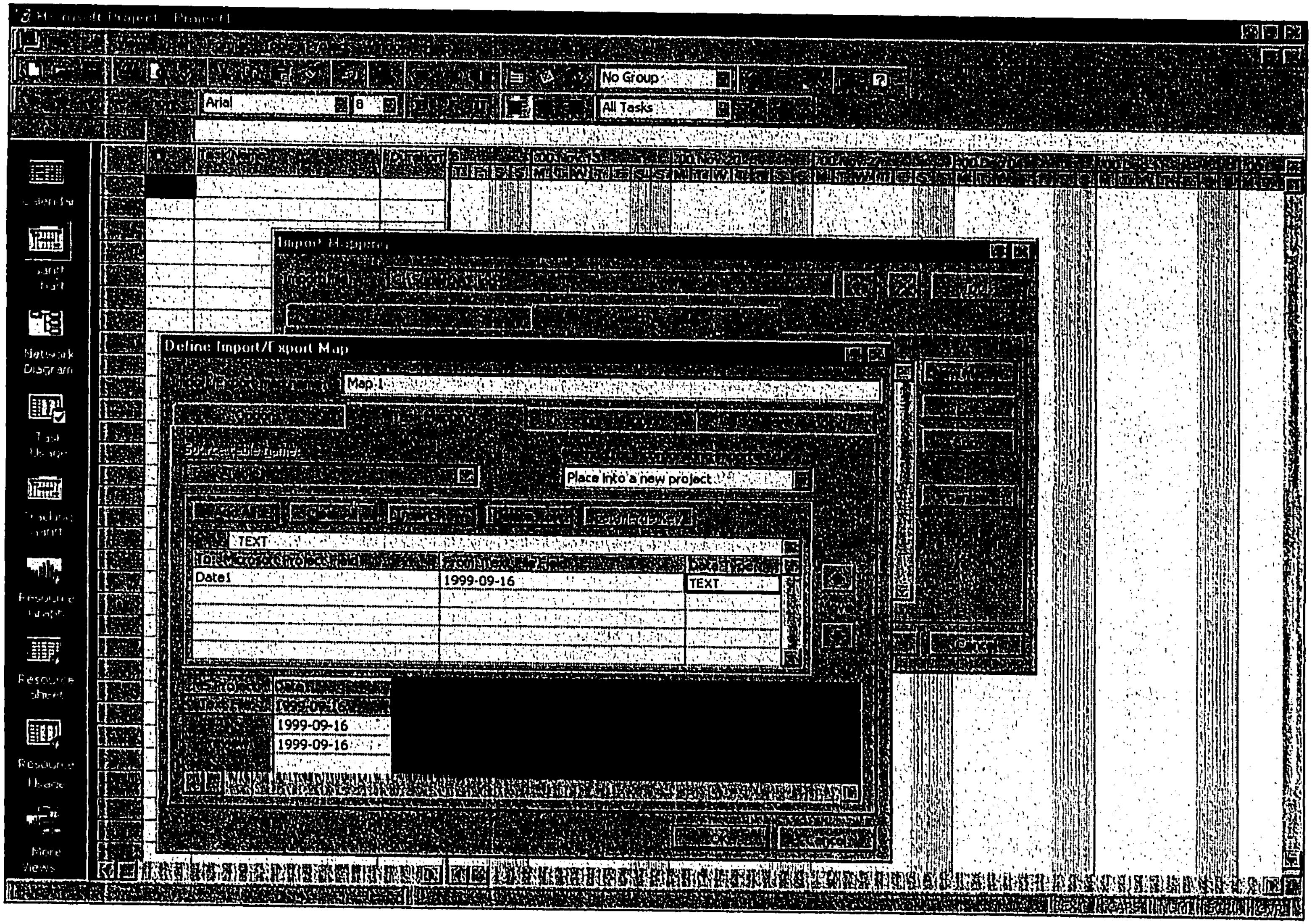


Figure 3.21 Import/Export Maps Specified within MS Project.

3.6.6 System Advantages and Limitations

The proposed conceptual model features an open system architecture solution for Engineering, Procurement and Construction (EPC) management. The central database was developed using a client-server database management system (DBMS) and features a number of advantages:

1) Open system layout: The conceptual model is developed in such a way that it is application independent and may be implemented with any ODBC compliant software [Tah, Howes and Iosifidis, 1999]. The very fact that it is open suggests a means to revise and enhance the solution [Kawasaki and Moreno, 2000].

2) Client-server processing: The 4D DBMS allows for client-server processing where the central database is the server storing all the relevant data entities and processing the user requirements. The client machines can access required data and call on the server for processing. The advantage offered by such an environment is two-fold: 1) reduce system size requirements whereby client machines do not need the capacity for storing and processing the central data, and 2) allows for a ready and available method to give project stakeholders access to available project data without the need of investing in localized project databases.

3) Open database connectivity providing a dynamic processing environment: By means of the interface to the ODBC driver, AutoCAD can access and manipulate the records in the central database without opening the DBMS. Furthermore, any entries, changes and data processing are dynamically updated in the database. This is an advantage that is particularly interesting to the architects and engineers that primarily utilize the CAD application.

4) Integration of readily available commercial applications: The proposed system is based on an application independent solution. However, the prototype implementation is an integration of the most prominent and economical industry application solutions (i.e. AutoCAD and MS Project). The DBMS of choice in the proof of concept implementation was 4th Dimension. However, any other ODBC compliant DBMS can be selected; such as MS Access.

5) RS Means® Building Construction Cost Data populated database: The central database is structured in such a way that the material cost data and related resource selection and productivity are based on the RS Means® [1999] reference for building cost estimating. The structure provides for the ability to upload current annual cost lists published by the RS Means® Company Inc.

6) CAD-B PM provides for a natural way to perform Value Engineering: The fact that the user can access the central database and utilize the material

selection, resource information and other design specific requirements allows for on-line and dynamic alternative comparisons. As such supports the performance of Value Engineering analysis. The user has the ability to select from the provided records or to incorporate new record entries that may be project specific. This is both an efficient and economical method to perform Value Engineering.

7) City Cost Indexes. The system further incorporates Means® City Cost Indexes (CCI) allowing the user to specify the city or region for which the costs in the database will be adjusted. This proves to be very useful as a tool for cost comparisons between cities within the US and Canada. The AEC industry can further make use of this feature in scenarios where a building was constructed in one city and the cost for a similar construction is required for another.

8) Bridges the gaps between the stakeholders of a construction project: the proposed model addresses the key barrier in the field of construction, namely collaboration and integration. The model allows for a continuous flow and capture of project information as it arises across the project functions. This reduces if not eliminates process redundancy and allows for an efficient flow of information that is required across the project functions as described in Chapter two.

Objects and the extraction of the Block instance data to the central database for processing and price roll-up. Therefore, to capture all the design elements that are created within AutoCAD, it is necessary to define them as Blocks. Although this appears as a limitation, design employing Block Objects is being widely used in a number of leading industries (e.g. the use of CAEE for design within ABB Inc.) [ABB, 2000].

3) The methodology developed calls for the work packages within the project WBS to represent the scheduling activities. A meaningful and direct time and cost control can be done by rolling up the project costs to the work package level. This is the level to which objects are attached and progress is monitored. It is therefore important to work with a clear and concise project plan with a well-defined WBS.

4) MS Project is not an ODBC server. This is a technology limitation, and therefore, this scheduling software does not allow for a dynamic integration of data with the central database. The project tasks with their associated data are imported in batch from within the central database and processed from within MS Project. Unlike AutoCAD, this scheduling tool cannot directly access the central database for dynamic extraction of the entries. Hence, a mapping macro was developed within the scheduling application to circumvent this limitation.

5) City Indexes are accounted for using the weighted average rather than those associated with each of the 16 divisions of the Master Format. However, the developed prototype allows for entering the city cost indexes at the division level. Additional programming is required for the association of each Block cost element with its appropriate division index.

CHAPTER FOUR

4.0 SYSTEM APPLICATION IN A CASE EXAMPLE

4.1 Introduction

Validation of a system is the process of applying formal methods to ensure that the system design is achieving its intended functions correctly within pre-established conditions. The objective of this chapter is to demonstrate the verification and validation of the proposed collaborative design-construction integrated system, CAD-B PM. The validation process of the developed system started from inception to completion, testing and validating its individual components against their intended purpose. Data processing through the various algorithms and sub-routines have also been verified individually against the expected output. In addition, an illustrative case example is used as an effort to manifest the various functions of the prototype and to verify its intended purpose.

The following functions have been validated and / or verified:

1) Open Database Connectivity between AutoCAD and 4th Dimension Central database.
2) Automated Block attributes extraction to 4th Dimension Central database.

3) Correct processing within the central database in terms of schemas and logic relationships.
4) Correct numerical calculations and metric conversions.
5) Database Queries.
6) Data import and mapping to scheduling tool.
7) Project reporting.
8) Overall system integration.

4.2 Case Example

The following project has been chosen to both illustrate the essential features and the operation of CAD-B PM and to be used as one of the validation examples ensuring the required functionality of the proposed integrated system.

4.2.1 Project Description:

This case has been extracted from an actual project referenced as the NORTEL (Northern Telecom) expansion in the West Island of Montreal, Quebec. The project consisted of two buildings. Each building has four floors with a fifth floor for the mechanical room and a total area of 400,000 square feet consisting mainly of office space. The two buildings, north and south wings are connected by an atrium. Refer to the basement floor plan in Figure 4.1. The buildings are concrete structures with the exterior constructed from masonry brick and curtain wall and the Mechanical Rooms are of steel structures. The total cost of the project including land acquisition, design and construction was approximately $60 million Canadian. Appendix C contains the floor plan in a larger format.

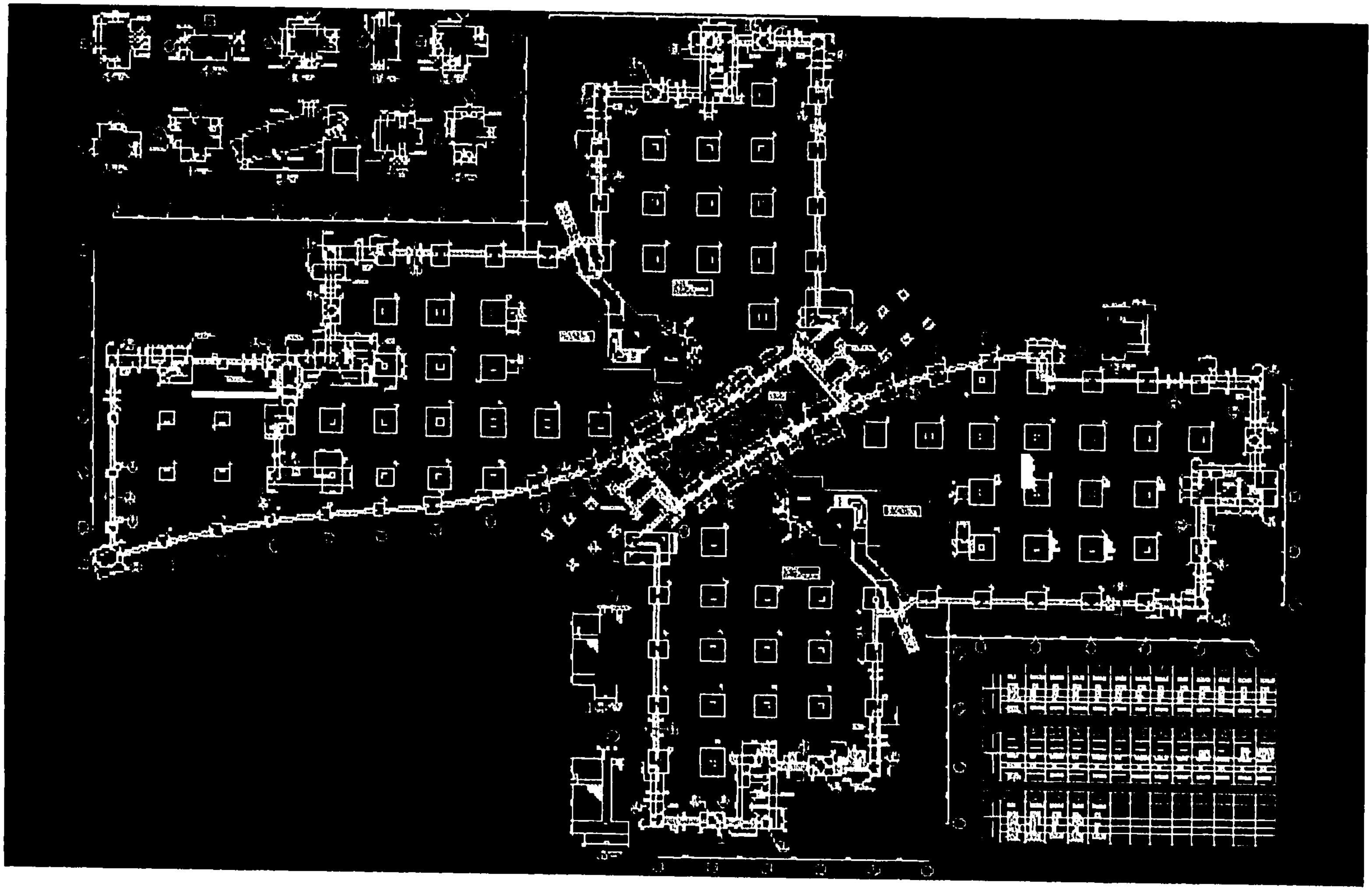


Figure 4.1 Nortel expansion Project Basement Floor Plan.
(Courtesy of MSD and Magil Construction Inc. 1999)

The construction management firm for this project was MAGIL Construction Inc. It is important to note that the conceptual development of CAD-B PM commenced after a thorough interview was conducted with the Project Manager and Site Manager for the Nortel expansion project. The interviews consisted of reviewing the project requirements, deliverables, processes and involvement between the stakeholders in terms of information sharing and exchange. The processes identified with this project confirmed the conservative and traditional functions associated information exchange within AEC industry as described in chapter two. Therefore, the need for an integrated system was confirmed first hand during the site meetings and interviews with the construction management responsible at the Nortel expansion site.

The architect design firm was Menkès Shooner Dagenais (MSD) with HOK Ontario Limited. Quinn Dressel and Associates performed the structural engineering for the project. BPA Inc. completed the mechanical design; MCW Consultants Limited completed the electrical design; and CIMA performed the civil engineering work. Prior to the design completion, Nortel employed MAGIL Construction Inc. as the Construction Management (CM) firm for a fixed price. The potential sub-contractors for the project were pre-qualified by the owner based on a list of desirable contractors submitted by MAGIL Construction Inc.

MAGIL Construction Inc. produced standard bid documents to be completed by each sub-contractor when submitting a proposal for a work package. The competing sub-contractors obtained hard copies of the lot number drawings for their trade (i.e. indicating the items that are part of the scope of work for a particular trade). The contractors referenced the drawings to produce a manual quantity take-off that formulated the basis of their estimates. The prices submitted by the various contractors were then recorded in an Excel spreadsheet. This spreadsheet was also used by MAGIL Construction Inc. to incorporate the final bid-price, cost to date, as well as any changes as applicable to the work-package also referred to as lot number.

MAGIL Construction Inc. using Primavera scheduling software completed the project scheduling. Refer to Appendix C for the Nortel project high level schedule. The planning and scheduling processes as performed by the CM organization followed a paper trail where the duplication of effort is clear. The scheduling was based on bills of material as produced by the sub-contractors based on manual quantity take-off from hard copies of design drawings. Furthermore, the costing information was submitted by the contractors in the form of hard copies which were later inputted into an excel spreadsheet for cost tracking and control.

The workflow as described above proves to follow the traditional construction industries conservative process, allowing for duplication of efforts and information and increasing the risk of errors and omissions. The idea of a dynamically integrated system was based on the requirements for process improvements as assessed from the case study described in this chapter. The need for process integration correlates to the need of application integration where information is created once and carries forward as it evolves. The proposed system, CAD-B PM, addresses a number of issues as related to information sharing and process integration within the AEC industries. The following sections describe a numerical example as obtained from the above case. It demonstrates the essential features of CAD-B PM, its use and capabilities. Figure 4.2 illustrates the flow of information on this project.

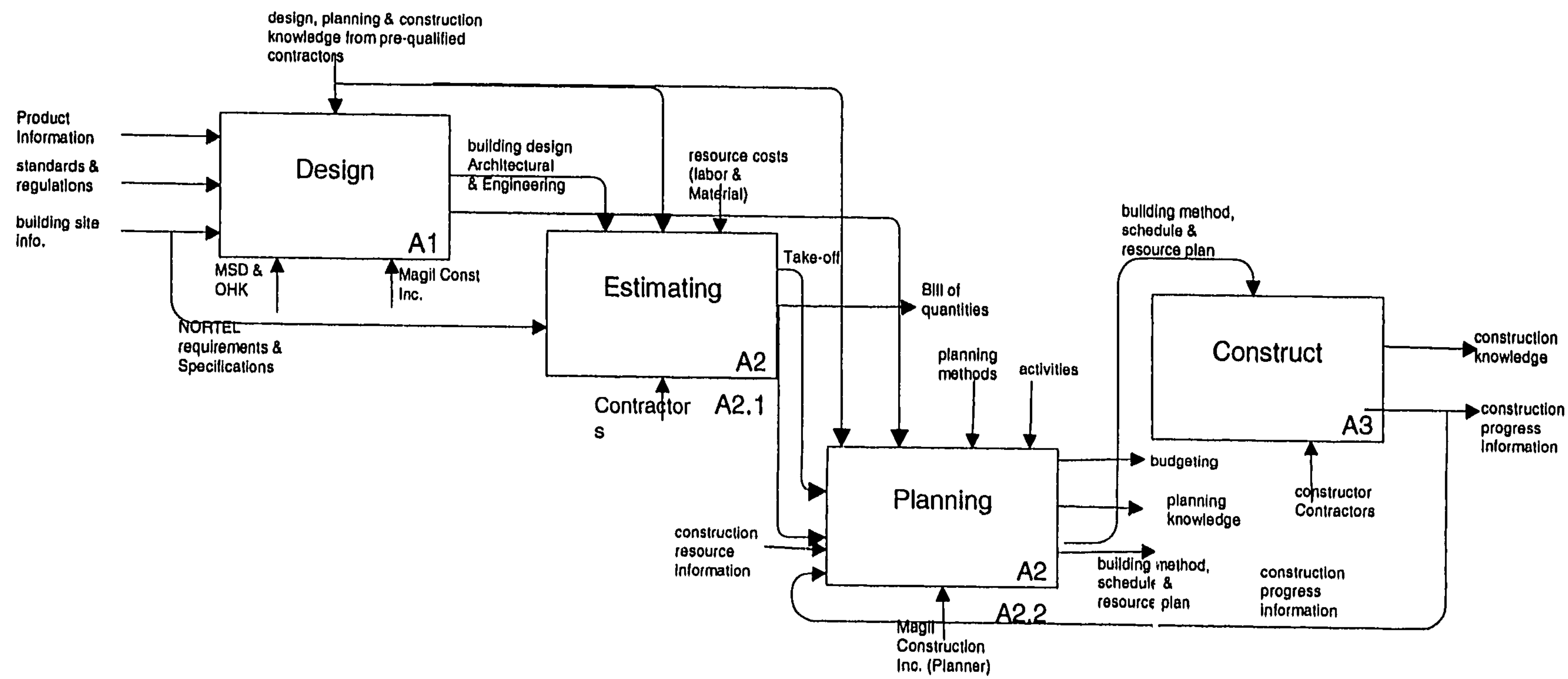


Figure 4.2 Workflow on Nortel Project.

4.2.2 Numerical Example

The column square footings as seen in the basement layout, Figure 4.1, was chosen as a good illustrative example for processing the design element data through the CAD-B PM system.

COLONNE	[illegible]	6-MR25 13	6-MR25 19	6-MR25 1[illegible]	6-MR25
	DIMENSION	600⌀	600⌀	600⌀	600⌀
EMPATTEMENT	DIMENSION	5000	4800	4800	4200
	PROFONDEUR	950	900	800	800
	ARMATURE RAS CH. DIR	18-MR30@2	17-MR30@3	15-MR30@4	13-MR30[illegible]

Table 4.1 Table of Column Foundation Specifications.
(Extracted from basement Layout – Nortel Expansion Project)

Table 4.1 shows a portion of the column and foundation column footing specifications for dimensions, height and reinforcement based on the foundation type. For demonstration purposes, column foundation footing type F2 will be carried through the system as an illustrative example. The foundation square footing type F2 has a width and length of 4,800 mm each and a height of 900 mm. The column F2 that sits on this foundation footing is a round tied column with a diameter of 600 mm. Both design elements are composed of concrete; fc' = 30 Mpa.

4.2.3 Integration Process with CAD-B PM

The dynamic connection from AutoCAD to the project central database is established through the definition of the environment through the Connectivity program within AutoCAD 2000. This program allows the user to choose the DBMS to which he/ she needs to connect to, thereby accessing the required project catalogs (i.e. collection of tables) and schemas (i.e. database tables). Figure 4.3 is a capture screen of the connectivity established between the AutoCAD design document and the project Central database catalog represented as folders within the 4D directory on the left hand side of the screen. This ODBC connectivity allows the designer within the AutoCAD application to open project tables residing in the central database (i.e 4^{th} Dimension). The advantages of such a feature are two fold: 1) the designer may consult the tables for refernce when it comes to assigninig material types and considering the cost impact and 2) the designer may link the design objects directly to rows within the project tables. Figure 4.4 is a capture screen of the linked project material table that is being accessed from within AutoCAD directly without the necessity of opening the central database.

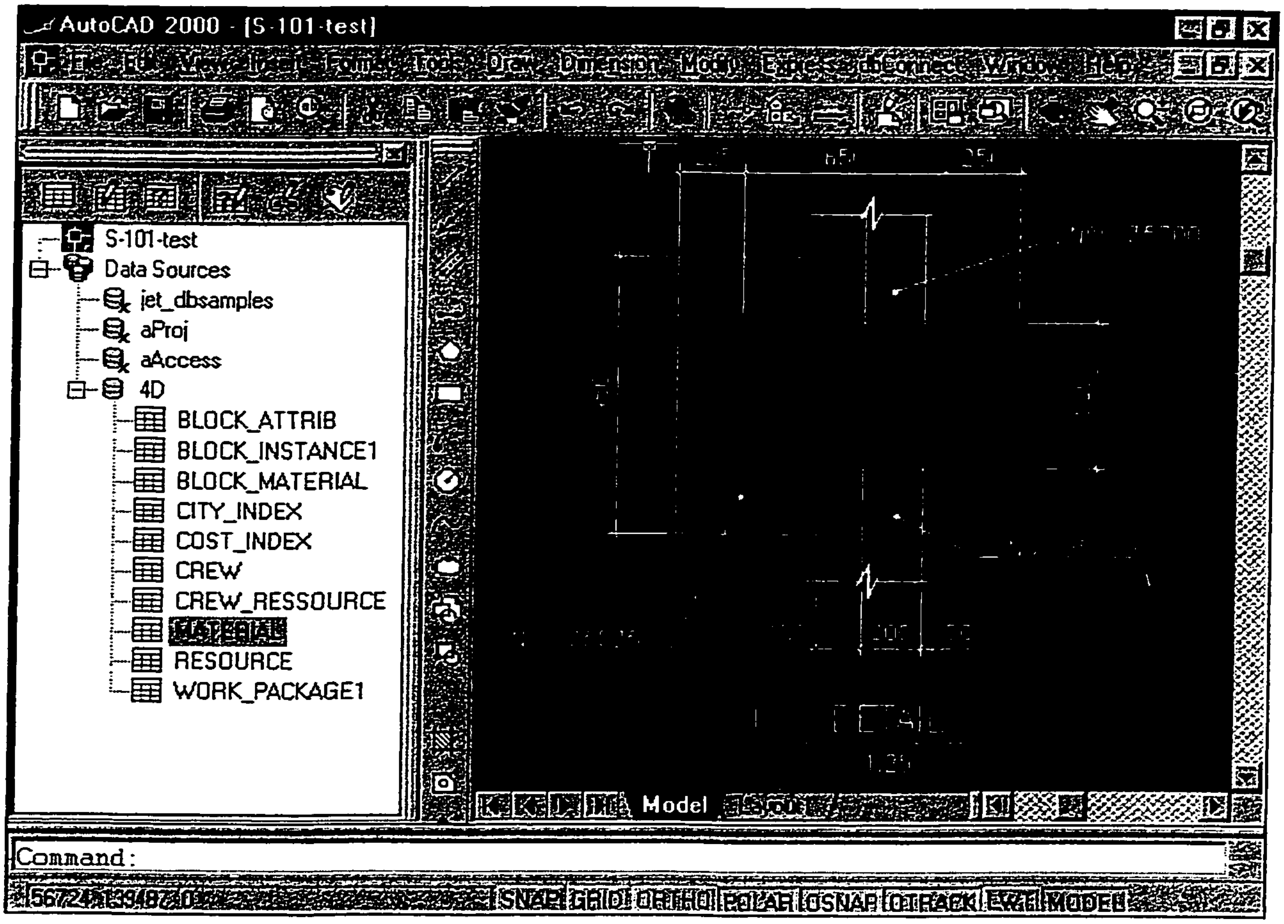


Figure 4.3 Dynamic Linking of External Database to AutoCAD 2000.

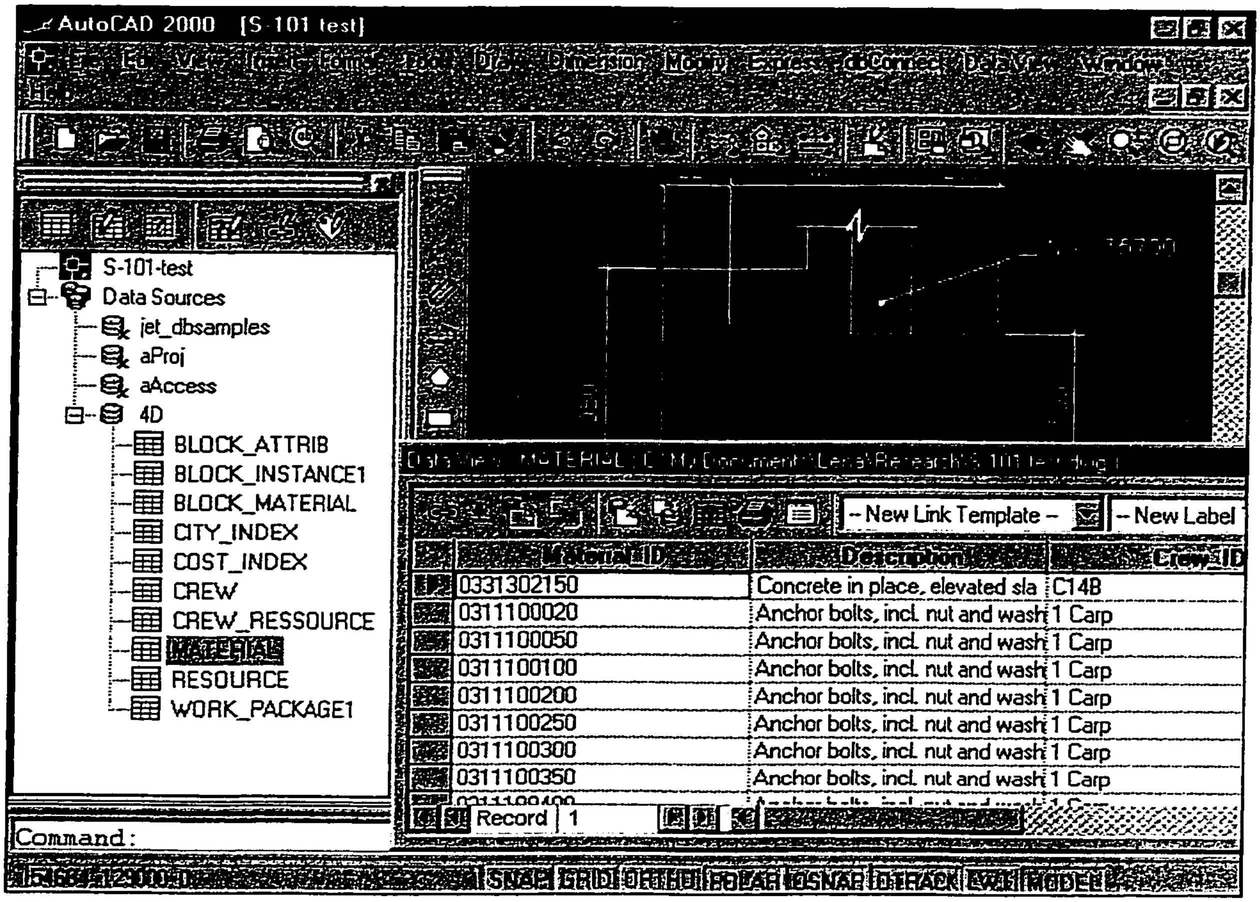


Figure 4.4 AutoCAD ODBC Access to Central Material Table.

The example utilized in this section takes into consideration the column type F2 with the square foundation footing type F2. To proceed with the integrated system CAD-B PM the Block Object for each of the design elements above was created and stored in the Block Library. Figure 4.5 is a capture screen of inserting a Block Object named Foundation Footing Type F2.

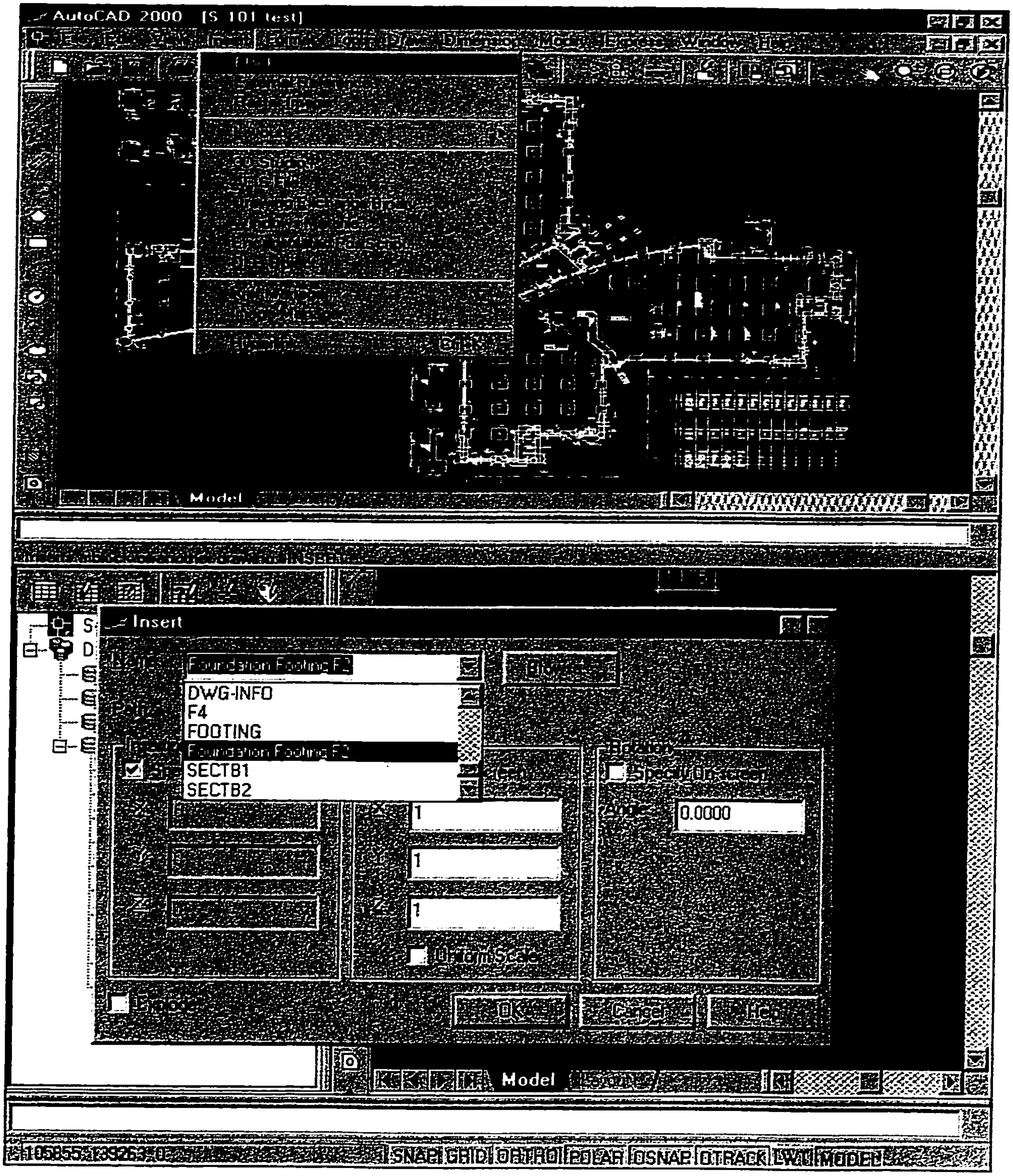


Figure 4.5 Insert of Block: Foundation Footing F2 within AutoCAD.

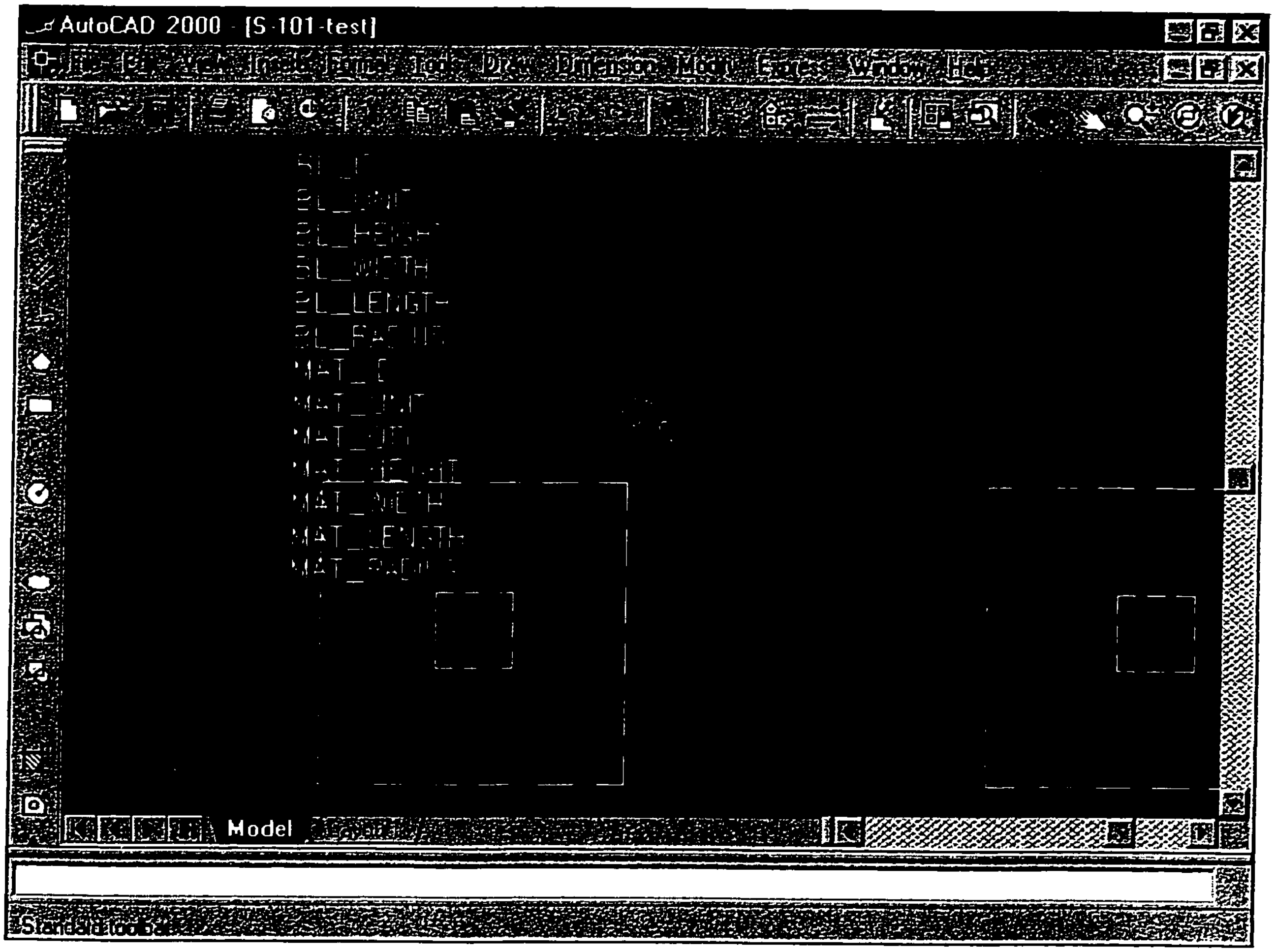


Figure 4.6 Foundation Square Column Footing with Attributes.

As was previously discussed in Chapter three, Block Objects have attributes attached to them. The user can assign the design element attributes per insertion of each block. These attributes are the non-graphical text that adds value to the design element. In the case used here one of the attributes is the block name and reference. These attributes are then extracted to the 4th Dimension central DBMS where they fall into the appropriate tables allowing the flow of information to continue through the process. Refer to Figure 4.6 for a capture screen of Block

Object F2 with unhidden attributes. Figure 4.7 is a capture screen of the extraction of attributes dialog box that appears in AutoCAD.

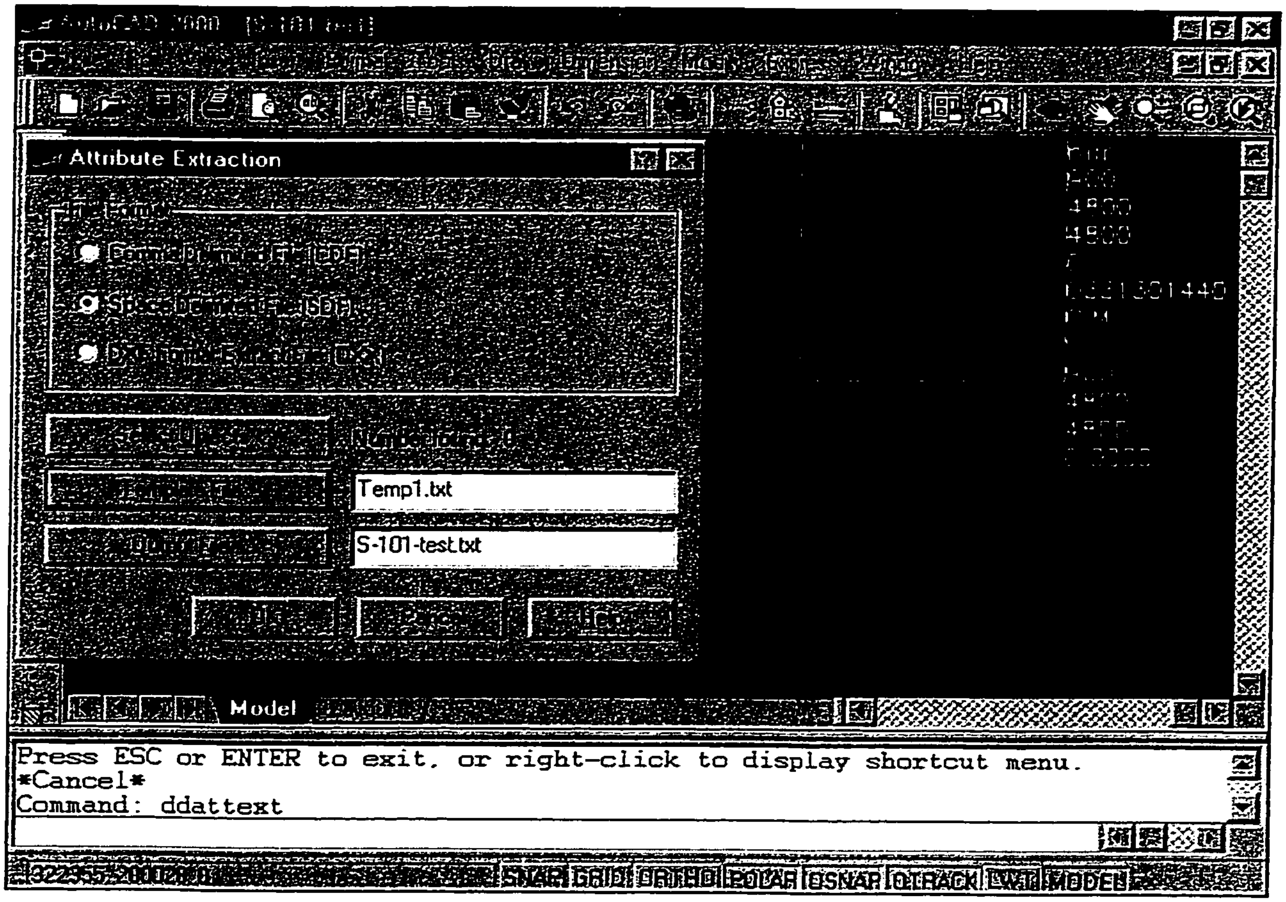


Figure 4.7 Attribute Extraction.

Depending on the number of Block Objects selected for extraction to the central database, CAD-B PM will generate unique instances for each insertion of the Design Block type. In the current example one Block Object type, Foundation Footing F2, was inserted in the design and selected for attribute extraction. This Block type is assigned a unique ID number, namely FF2. The one particular instance that is extracted has the Sub_Block-ID FF2.1 as shown in Chapter three Figure 3.11 which is a capture screen of the Block Instance entry Form. The extracted data populates the field in the tables that are linked to this form. The dimensions of the square foundation footings are automatically extracted from AutoCAD and appear correctly under the columns; Height, Width and Length. The unit of measure is in mm as was assigned in the attribute field for the Block Object. Furthermore, given that the footing is a square the radius appears as zero. Within the same Figure 3.11, the Block Instance entry form has a field with the name WP_Num (i.e. Work Package Number). The work package number simply refers to the item to which the design element belongs within the project Work Breakdown Structure. Refer to Figure 3.12 for the high level outline of the WBS for the Nortel Project. You will note that the column footings belong to WP number 1.1.1.1.1.0 which consequently falls under 1.1.1.1.0.0; foundation structures. All the other WBS levels consequently belong to the highest level 1.0.0.0.0.0; Nortel Expansion. As discussed earlier in Chapter three, establishing a clear and specific WBS is essential for proper project cost roll-up.

Refer to Figure 4.8, Block Material Screen. The data on this screen belong to the Block Instance FF2.1 that was defined earlier. This screen allows the user to identify the material that makes up the Block Object if it was not already defined within AutoCAD. The end user can reference the existing Material table within the DBMS in order to select one or multiple materials that constitute the Block Object. Figure 3.14 shows the material table that can be referenced from within the Block Material entry screen. If a material does not exist in the database, CAD-B PM will prompt the user to create a new material within the Material entry form as shown in Figure 3.15. Here, the Block ID and Sub_Block_ID (FF2 and FF2.1 respectively) are automated field that are captured from the Block instance. The user needs to define the Material_ID and enter a description. In this case the description refers to the section three (i.e. concrete) entry in the RS Means® Building Catalogue, column square footing over $4m^3$. The user is required to further enter the material cost per defined unit of measure and a recommended crew is defined with their associated productivity for that given material. Figure 4.8 shows the calculated value of the quantity of material in cubic meters for the example of the square column footing. CAD-B PM has several algorithms that take unit conversion into consideration to allow for an automated costing calculation based on the price per unit type as defined in the Material table. The system converted the dimensions in mm to meters and recognized that the volume must be calculated in order to calculate the cost of the material and labor as shown in the summary table in the upper right hand corner of the Block Material form.

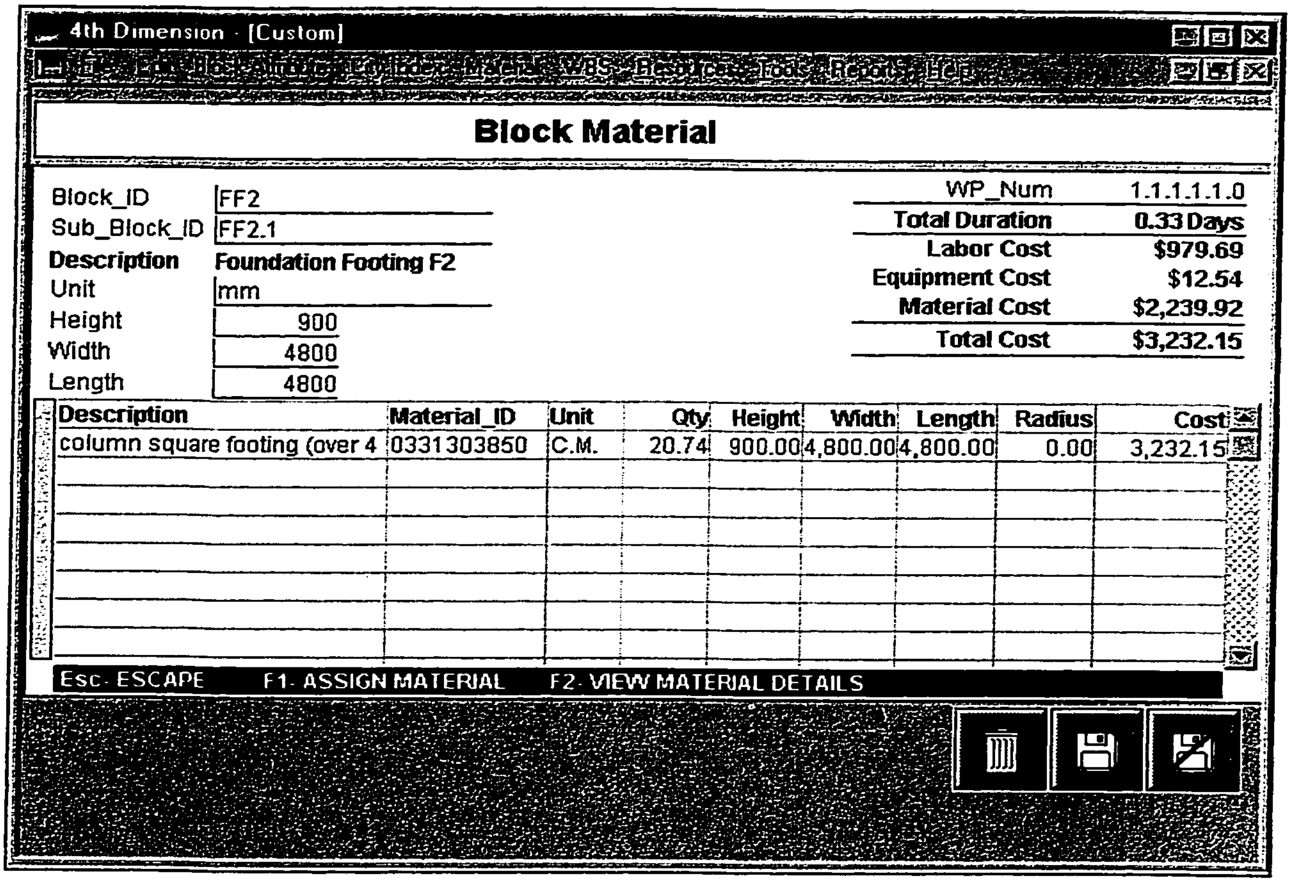


Figure 4.8 Block Material of Block Instance FF2.1.

The crew identified with Material_ID 033130850 is crew C14C. Figure 3.17 lists the resources that makes up this crew as they appear in the Crew Form of CAD-B PM. The hourly rate for this crew, which is comprised of both labor and equipment, appear in a separate column from the daily rate. The crew table further totals the daily costs and lists the cost per man-hour as calculated for that crew. The data from this form and related table are linked to the material table where crews are associated with the material types. The association between the crew productivity for a given material type and the crew cost per hour are taken into consideration by CAD-B PM when it calculates the activity duration for the tasks that fall under this Block Instance. The system takes the above data into consideration when it further calculates the Total Cost that is broken down into labor cost, material cost and equipment cost.

Figure 4.8 demonstrates the conversion of units by CAD-B PM for volume from unit mm^3 to C.M. (cubic meters). The volume of concrete that is required for this foundation column footing is 20.74 C.M. (Volume = .9m x 4.8m x 4.8m). The Material cost for one foundation column square footing is $3,232.15 and it would take crew C14-C 0.33 days to complete one such foundation.

The cost of the foundation was calculated based on the normalized National average cost in US dollars. CAD-B PM takes city indexing into account to adjust the price to a particular city as selected in Figure 4.9. Once a city is selected from the list of various North American main cities, the system multiplies all the costs by the designated factor to allow for city cost adjustment. This adjustment is uploaded to the scheduling application when the costing is exported for tracking and control.

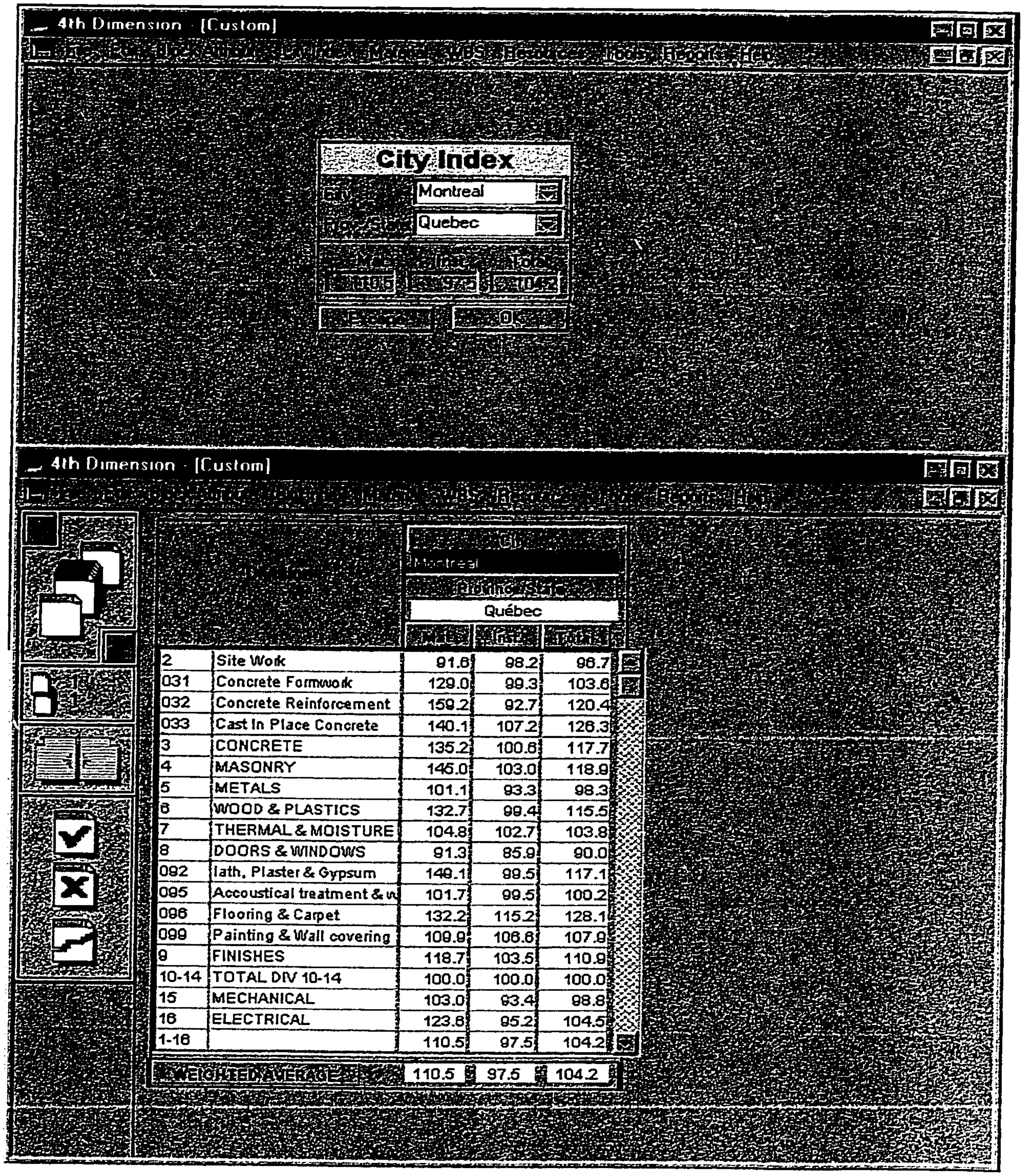


Figure 4.9 City Index selection for Montreal.

Once all the Block design elements are processed within the database, then the user will have a complete project estimate as rolled up from the particular block instance materials to the defines work packages. These work packages can be processed from within the database to identify known job logic at the time of design. Refer to Figures 3.18 and 3.19 for the Nortel project high-level structure relationship and constraint definitions. This project plan along with the costs is then integrated to the scheduling application, MS Project. Figure 4.10 shows the WBS structure and work packages as defined in this example for the Nortel project. Both the rolled up costs and activity duration are mapped into the scheduling application allowing the project manager to base his or her planning on actual data as linked to the design in a dynamic fashion.

The cost column in the scheduling Gantt chart reflects the adjusted prices based on the selected City Index for Montreal. The example in Figure 4.10 illustrates two level five work-packages that fall under the level four foundation structures. The cost and duration attached to these work packages (Column Footings and Round Columns, respectively) are rolled up from the Block instances attached to these work packages.

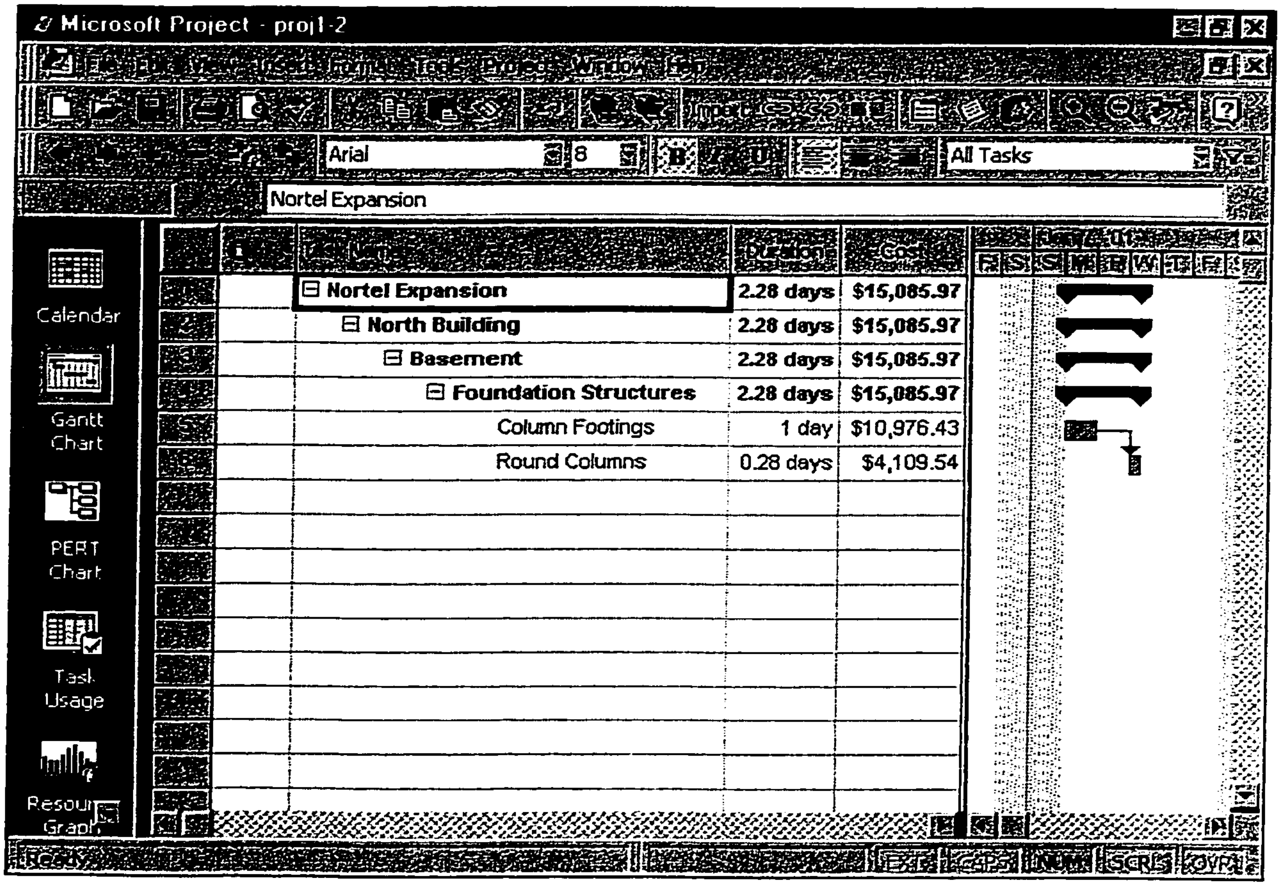


Figure 4.10 Nortel Project Schedule.

4.2.4 Reporting

CAD-B PM has a built in reporting module that allows the user to generate standard reports or to customize their required fields to produce a specialized report. Figure 4.11 shows the CAD-B PM main menu screen with the Reports, BOM sub-menu selected. This Bill of Material Report (BOM) sorts all the Block elements in the project with their associated material description and quantity. The user may add the fields for material pricing if required. This report is very useful especially for the estimating function and can further be explored for procurement. Refer to Figure 4.12 for a capture screen of the BOM report. Other reports that have been standardized with CAD-B PM include a costing report (i.e. breaks down project cost into detail by Material, labor, equipment block instances) and the resource report (i.e. a listing of required resources on the project).

The reporting function is an essential requirement for all stakeholders of the AEC industry. Given that CAD-B PM integrates the various functions and processes allowing for enhanced and fluid like information sharing, the reporting capacity can be made available for all client machines (i.e. designers, constructors, CM, owner and contractors). Based on client-server security measures access to some confidential information, such as mark-up factors, may be restricted. Refer to the Appendix B for sample reports.

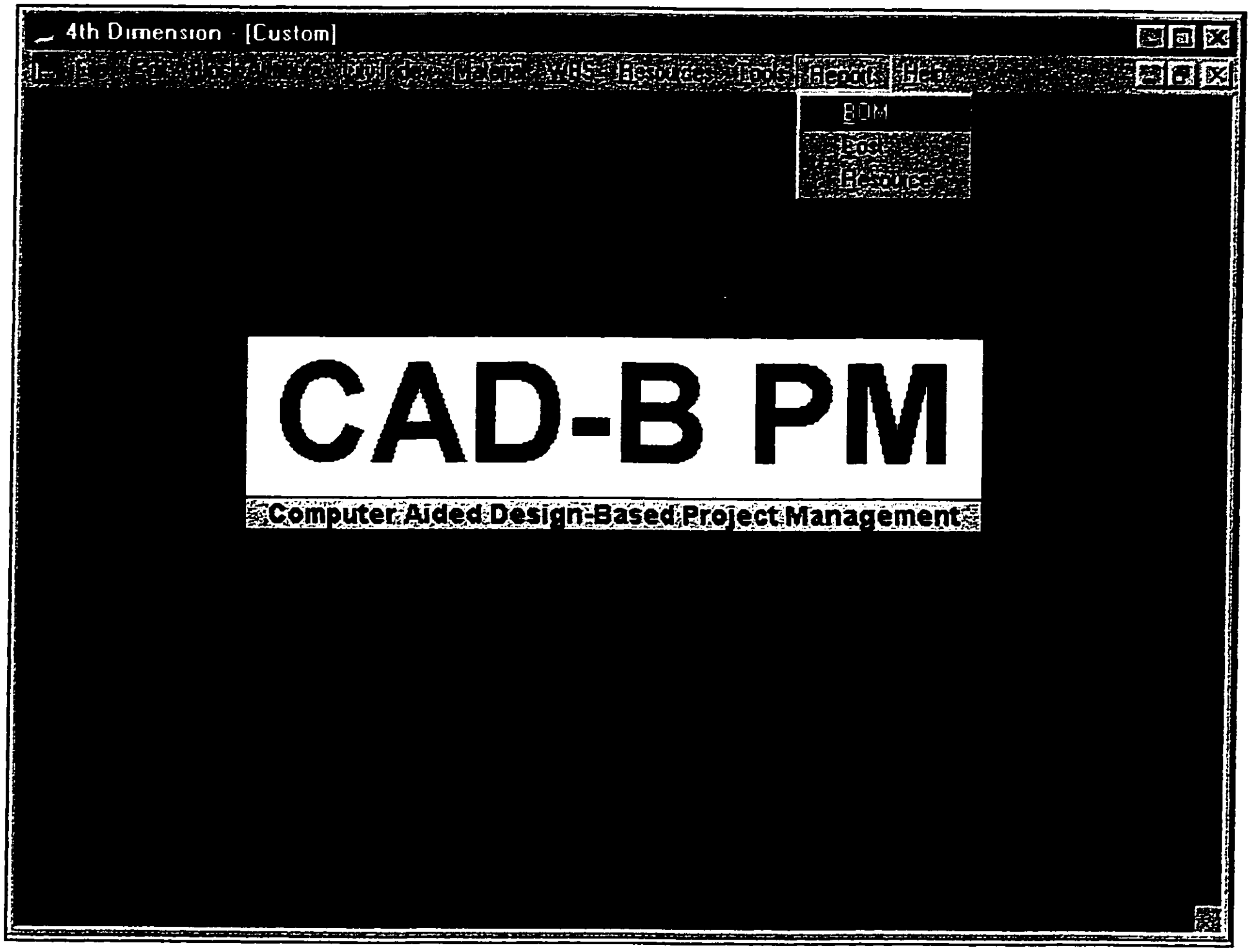


Figure 4.11 Reporting Menu Selection.

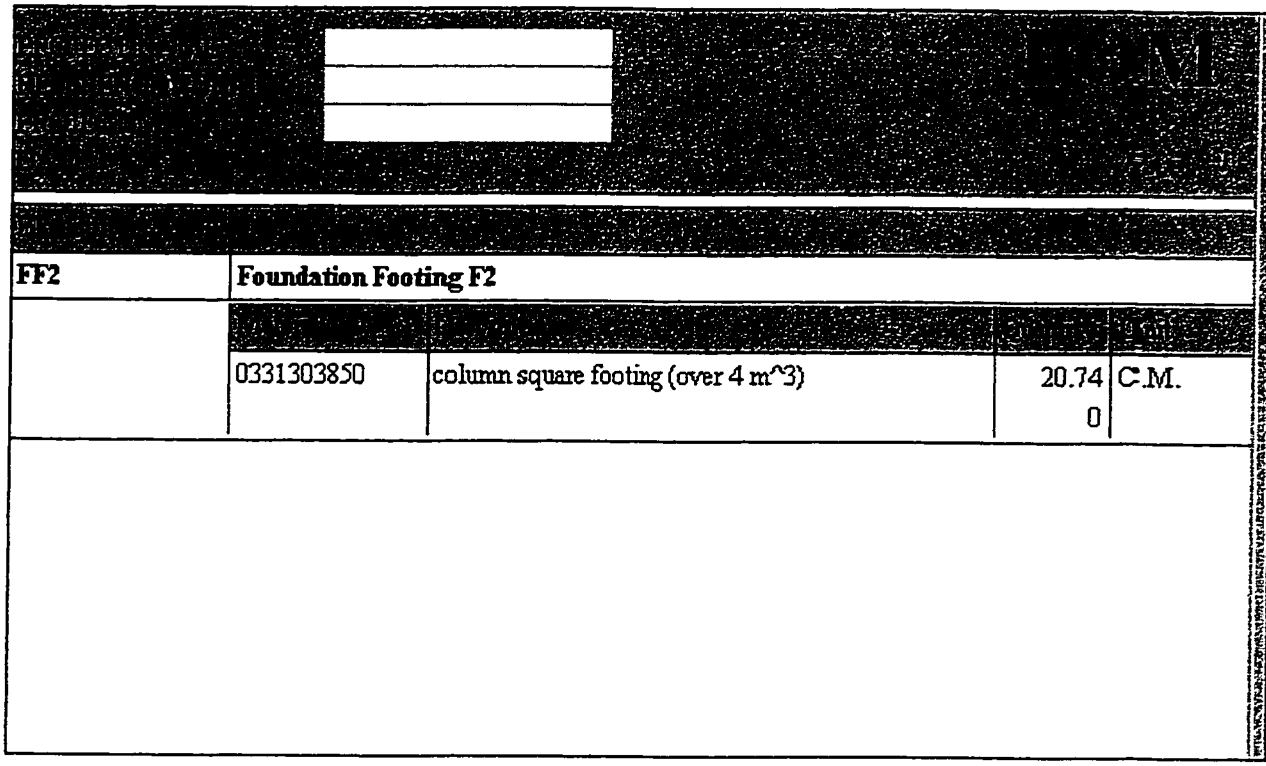


Figure 4.12 BOM Report.

4.3 Summary and Comments

The validation of CAD-B PM was performed with many examples and testing sessions. The above illustrative case example exposed the functionality of the system as well as its user-friendly interface. The objective at the onset of this thesis was to develop a comprehensive integrated system for AEC process application. The interviews conducted with MAGIL Construction and the engineering and architectural firms retained for the Nortel expansion project further confirmed the requirement for a streamlined system that can be immediately adopted by firms and small contractors alike. The proposed process emphasizes the use of electronic documentation and automates the exchange of information as well as the tasks associated with cost and duration estimating. The mapping to the scheduling application further adds value to the system by allowing the capture of the most up-front information and tying it to the preliminary schedule that maybe further enhanced by the project manager. By far the biggest advantage of CAD-B PM is its ability to dynamically integrate the AEC applications for an on-line information exchange and updating process. One can look at this feature as a form of revision control, where changes in the design are correlated automatically to the design database. Hence, errors and omissions are avoided by eliminating the AEC linear processes that involve data redundancy and reproduction.

CHAPTER FIVE

5.0 CONCLUSION

5.1 Summary

CAD-B PM is a prototype system that supports AEC functional information management. It provides a tool for storing architectural/ engineering design information in a relational database that is shared across a number of construction computer based applications. The objective as presented in the onset of this thesis is to develop a methodology and a framework for implementing Computer Integrated Construction (CIC) to reduce design fragmentation and to bridge the gaps between the AEC disciplines that generate separate islands of information. In designing the system, the use of ODBC proved to be useful in implementing an open and dynamic data-sharing environment.

The development of CAD-B PM addresses the need for integration in the construction industry and offers an integrated solution on a readily available commercial software platform. The methodology proposed behind the system development allows the user to separate the design data from the specific CAD package that is used to process it. Furthermore, it creates a rich information framework by integrating the CAD elements (i.e. product) with its respective tasks (i.e. process) thereby developing a project model. The approach emphasizes the capture of graphical and textual information about the building project and directly storing them in a central relational database on the server. Given that the methodology revolves around working with objects, the developed prototype further promotes the concept of re-use. The designer and construction management industry can save valuable time where object libraries are updated and used in the process. This promotes the concept of re-use where objects are created once and updated from within the central library, avoiding the inefficient and expensive generation of "islands of information" [Fischer and Froese, 1996].

CAD-B PM contributes to the improvement of quality on construction projects and to the ability of meeting the owner's needs. The main contribution of such system integration is through the improved design and better open communications between the design and construction stages. CAD-B PM is a solution for sharing project information among the project stakeholders and across the various project stages, in an open and dynamic environment As a consequence, the proposed model reduces the AEC industry fragmentation and is expected to increase efficiency, hence competitiveness.

5.2 Future Work

The developments achieved within this thesis have been based on a modularized yet integrated approach. Therefore, any limitations that have been outlined within Chapter four may be addressed and easily incorporated into the model prototype as future work. The following is a list of recommended future endeavors:

1) Model uncertainty into the system: the current prototype addresses cost and duration estimating in terms of material cost, equipment cost, labor cost, labor productivity based on crew assignments and design elements. The data that has been used to populate the 4th Dimension database was extracted from the RS Means® catalogue and does not take uncertainty of the costs or labor productivity into consideration.

2) Transfer of the database development into MS Access: the prototype central database has been developed in 4th Dimension, which is a powerful client-server DBMS. However, the ERD can also be implemented in MS Access to allow access for users such as small contractors who may not have the ability to purchase the required licenses for the 4D implementation.

3) Further enhance the system to incorporate Procurement: the current prototype addresses the design-construction integration by capturing design elements and their attributes within a central database. These attributes include the material and labor requirements. A module can be developed that attaches itself to both the material database which automates the process of selecting the required suppliers for the project. This feature will further enhance the automation of the project cycle by addressing Construction Procurement.

4) Incorporate Project Reporting as a function: to further utilize the integration of time and cost control within the scheduling application as linked to the design elements through the proposed model. Currently the system captures the construction cost information and calculates the project duration based on the productivity values for the crews assigned to each design element. The module can be further developed to address the earned value for the project implementation within the PM application.

5) Change Management Interface: to track project changes and update both the central database as well as the scheduling application's cost table to reflect as sold vs. actual costing and margin impact.

6) Web-enabled system: the current prototype integrates software that has the capability to be web-enabled and therefore accessible on the Internet. A future endeavor would be to capitalize on this capacity and allow for on-line processes where the design, engineering and construction management stakeholders can access the project information on-line and in real time. Such an implementation would further promote information sharing, collaboration, as well as globalization. The data within the database could not only be accessed on the web, but the user would have the ability to download prices from the manufacturers' websites in real-time. Contractors would also have the capability of generating material and labor estimates as well as submitting

their proposals on-line. The current technologies provide for such communications and the proposed methodology within this thesis provides the framework to allow for e-business implementation.

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APPENDIX A

OPEN DATABASE CONNECTIVITY

Source: www.microsoft.com/data/

Introduction to ODBC:

Open Database Connectivity (ODBC) is a widely accepted application-programming interface, otherwise known as API, for database access. Based on the Call-Level Interface (CLI) specifications from ISO/ IEC, it uses Structured Query Language (SQL) as its database access language.

ODBC is designed for maximum interoperability; allowing a singe application to access more than one database management system (DBMS) with the same code. In a nutshell, database applications call functions in the ODBC interface and these functions are implemented in data-specific modules referred to as drivers. These drivers are what isolate applications from database specific commands. To present an analogy; these drivers act much in the same way as does printer drivers when they isolate word processing applications from printer specific commands.

ODBC created out of a need:

ODBC was created out of a need for companies to acquire and have access to multiple databases. Historically, companies worked with only one DBMS and all database access was done either through the front end of the system or through applications written to work exclusively with that system.

Accessing various DBMSs grew even more complex with the advent of personal computers that brought with them many querying tools, analytical tools and even more databases.

A bigger challenge was the advent of client/server technologies. The inexpensive personal computers (clients) provide a graphical interface for the user while the mainframe computers (servers) host the DBMSs. The question was, how can the front-end software applications connect to the back-end databases?

The need determined is two fold:

1. Need to merge data from different DBMSs in a single application.
2. Need for writing a single application that is independent of any one DBMS.

The above two are summarized by the term, open database connectivity (ODBC) to achieve an interoperable way of accessing data.

Overview of ODBC:

ODBC is a specification for a database application-programming interface (API), where the API is independent of any particular DBMS or operating system (OS). The ODBC API is language independent and is based on Call-level Interface (CLI) specifications.

The ODBC API functions are implemented by developers of DBMS specific drivers. Applications can access data in a DBMS-independent manner by means of the drivers. In short, ODBC is designed to expose the capabilities of a given database and by no means does it supplement the database.

The creation of ODBC provided a uniform method for users to store, accesses, and modify data in an efficient manner. Structured Query Language (SQL), developed by IBM in the 1970s, is both an ANSI and ISO standard; and it is used by many DBMSs.

ODBC Architecture:

Composed of four components:

1. Application; which performs all the processing and calls ODBC functions to submit SQL statements and retrieve results.

2. Driver Manager; loads and removes drivers on behalf of the applications and processes ODBS function calls by passing them to the driver.

3. Driver; processes ODBC function calls, submits SQL requests, and returns the query results to the applications. Furthermore, the driver may modify the request to conform to the syntax supported by the DBMS.

4. Data source; consists of the data accessible by the user along with its associated operating system, DBMS, and network platform.

APPENDIX B

SAMPLE REPORT FORMATS

FROM CAD-B PM 4D DATABASE

[illegible]	column square footing (over 4 m^3)	20.74	C.M.

[illegible]	Foundation Round Columns	$1,552.61	$193.48	$2,197.80	$3,943.90	$3,943.90
FF2.1	Foundation Footing F2	$0.00	$0.00	$0.00	$0.00	$0.00
FF2.1	Foundation Footing F2	$0.00	$0.00	$0.00	$0.00	$0.00
FF2.2	Foundation Footing F2	$979.69	$12.54	$2,239.92	$3,232.15	$3,232.15
FF2.3	Foundation Footing F2	$979.69	$12.54	$2,239.92	$3,232.15	$3,232.15

	Foundation Round Columns

Crew ID
C14A

Resources
1 Carpenter Foreman (Out)
16 Carpenter.
4 Rodmen (reinf.)
2 Laborers
1 Cement Finisher
1 Equipment Operator
1 Gas engine vibrator
1 concrete pump (small)

111110	Foundation Footing F2

Crew ID
C14C

Resources
1 Carpenter Foreman (Out)
6 Carpenter.
2 Rodmen (reinf.)
4 Laborers
1 Cement Finisher
1 Gas engine vibrator

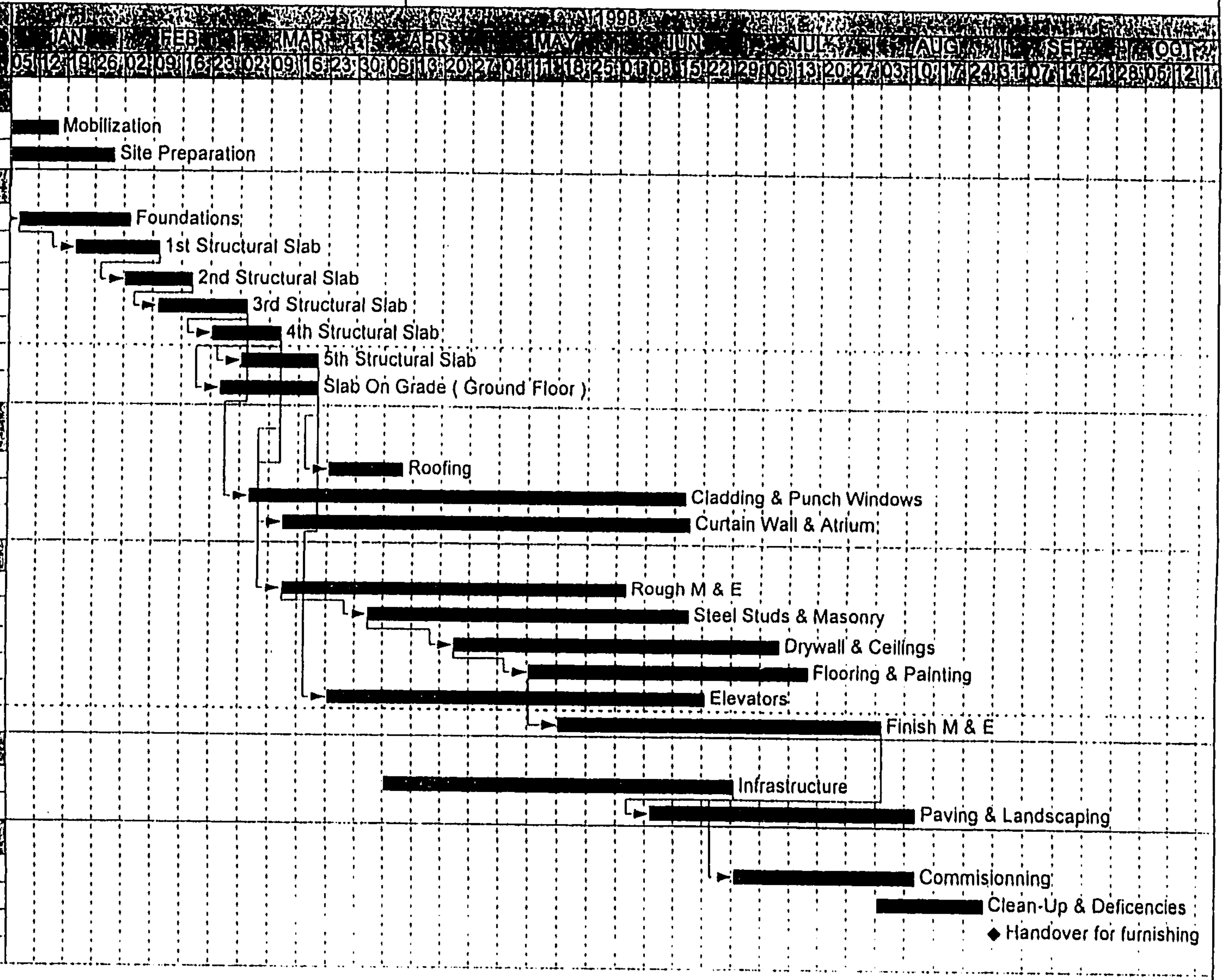
Resources

APPENDIX C

NORTEL PROJECT SAMPLE DOCUMENTATION

- Project Schedule (for Tender, 1997).
- Basement Floor Plan.

Act ID	Description	Start	Finish
Mobilization			
900	Mobilization	05JAN98 *	16JAN98
1000	Site Preparation	05JAN98 *	30JAN98
Structure			
1010	Foundations	07JAN98	03FEB98
1020	1st Structural Slab	21JAN98	10FEB98
1030	2nd Structural Slab	02FEB98	18FEB98
1040	3rd Structural Slab	10FEB98	03MAR98
1050	4th Structural Slab	23FEB98	11MAR98
1060	5th Structural Slab	02MAR98	20MAR98
1065	Slab On Grade (Ground Floor)	25FEB98	20MAR98
Enveloppe			
1070	Roofing	23MAR98	10APR98
1080	Cladding & Punch Windows	04MAR98	17JUN98
1090	Curtain Wall & Atrium	12MAR98	18JUN98
Interior Work			
1100	Rough M & E	12MAR98	03JUN98
1120	Steel Studs & Masonry	02APR98	18JUN98
1130	Drywall & Ceilings	23APR98	10JUL98
1140	Flooring & Painting	11MAY98	17JUL98
1150	Elevators	23MAR98	22JUN98
1160	Finish M & E	18MAY98	04AUG98
Site Services			
1170	Infrastructure	06APR98 *	29JUN98
1180	Paving & Landscaping	09JUN98	12AUG98
Close Out			
1190	Commisionning	29JUN98	12AUG98
1210	Clean-Up & Deficencies	03AUG98	28AUG98 *
1225	Handover for furnishing	31AUG98 A	
1235		01OCT97	01OCT97



MAGIL VANBOTS CONSTRUCTION

Date	Revision	Checked	Approved
15DEC97	For Tender	AG	JM

NOTES GENERALES

FONDATIONS, EXCAVATION ET REMBLAYAGE

ACIER D'ARMATURE

BETON

ACIER DE CHARPENTE

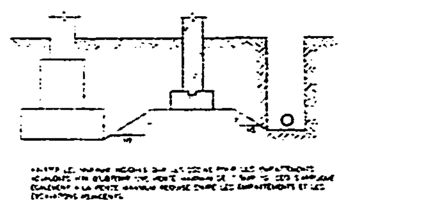
PONTAGE METALLIQUE

DALLES SUR SOL

MACONNERIE

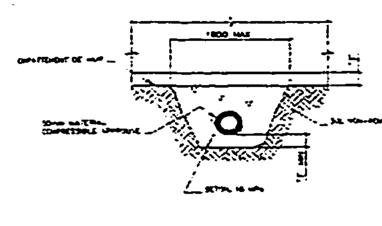
CRITERES DE CONCEPTION

NIVEAUX DES EXCAVATIONS ET EMPATTEMENTS ADJACENTS

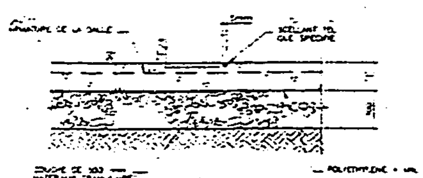


101M

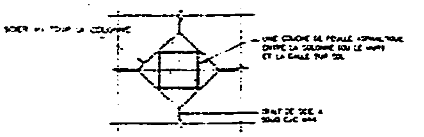
TUYAU EN DESSOUS D'EMPATTEMENT



TRAITS DE SCIE, DALLES SUR TERRE

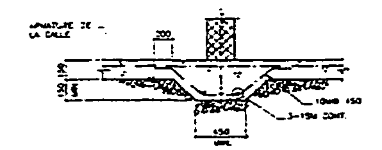


COUPE



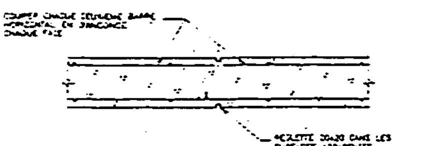
PLAN A LA COLONNE

108M

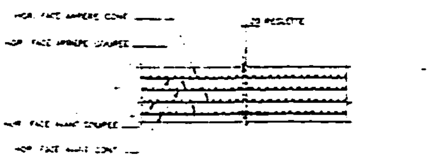


DETAIL DE LA DALLE SUR SOL EN DESSOUS DE CLOISON EN BLOC

JOINTS DE CONTROLE DANS LES MURS



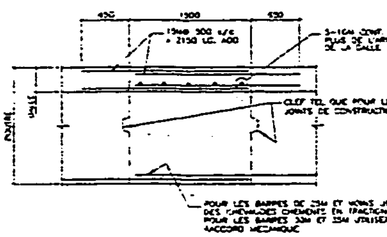
PLAN



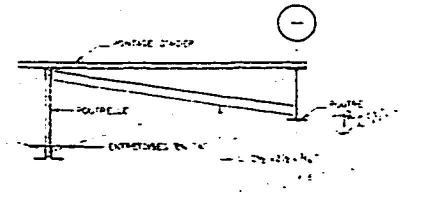
ELEVATION

252M

DETAIL DE BANDE DE RETRAIT



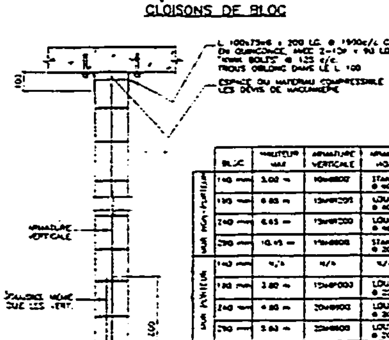
DALLES ET POUTRES



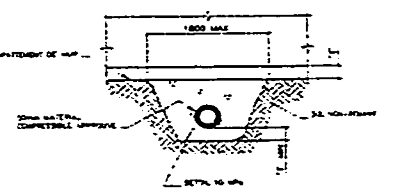
DETAIL TYPIQUE DES ENTRETOISES AUX POUTRES PERIPHERIQUES

509M

CLOISONS DE BLOC

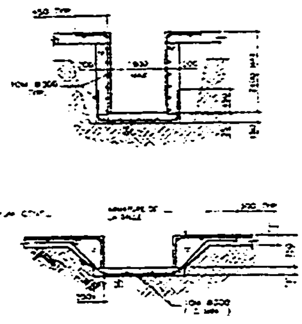


TUYAU EN DESSOUS D'EMPATTEMENT

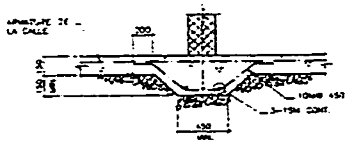


106M

DETAIL DE PUISARD



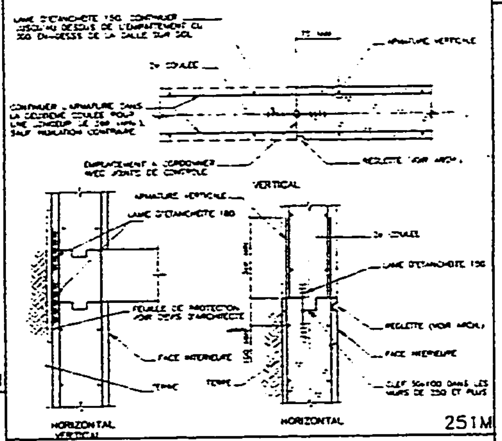
107M



DETAIL DE LA DALLE SUR SOL EN DESSOUS DE CLOISON EN BLOC

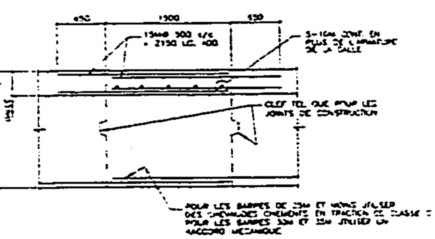
109M

JOINT DE CONSTRUCTION DE MUR EXPOSE A LA TERRE OU AUX INTEMPERIES



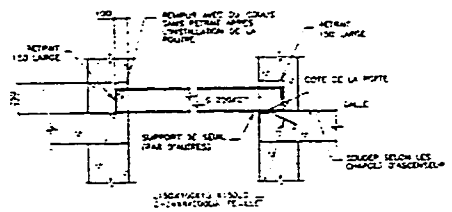
251M

DETAIL DE BANDE DE RETRAIT

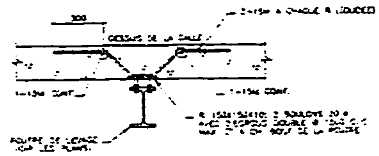


DALLES ET POUTRES

254M



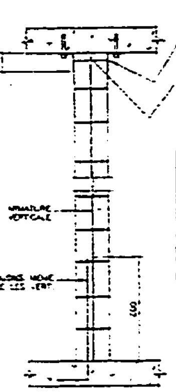
DETAILS D'INSTALLATION DES POUTRES D'ASCENSEUR



ANCRAGE POUR POUTRE DE LEVAGE

402M

CLOISONS DE BLOC

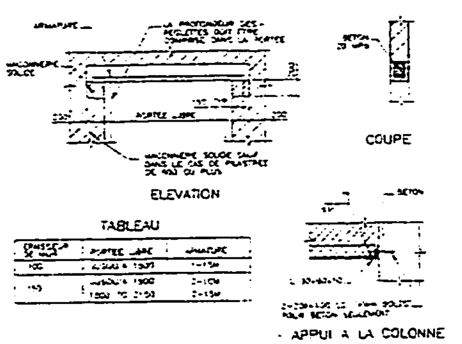


	BLOC	HAUTEUR MAX	ARMATURE VERTICALE	ARMATURE HORIZ.
MUR NON-PORTEUR	140 mm	3.00 m	10M@800	STANDARD @ 400
	190 mm	6.65 m	15M@1200	LOURDE @ 400
	240 mm	6.65 m	15M@1200	LOURDE @ 400
	290 mm	10.45 m	15M@800	STANDARD @ 200
MUR PORTEUR	140 mm	N/A	N/A	N/A
	190 mm	3.80 m	15M@1200	LOURDE @ 200
	240 mm	4.80 m	20M@1200	LOURDE @ 200
	290 mm	3.65 m	20M@1200	LOURDE @ 200

ARMATURE HORIZONTALE
CONFORME A ASTM A82 ET ACNOR G30.3

601M

LINTEAUX MUR DES BLOCS



ELEVATION

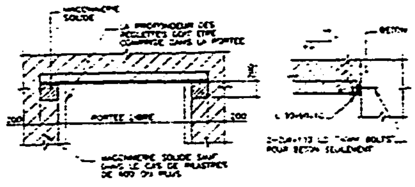
COUPE

APPUI A LA COLONNE

TABLEAU

602M

LINTEAUX MUR DES BLOCS



ELEVATION

APPUI A LA COLONNE

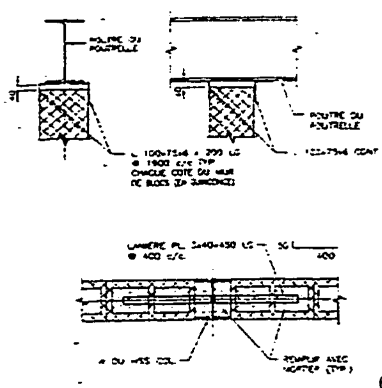
TABLEAU

PORTEE LIBRE	MUR DE 200 TYPE	MUR DE 200 CORNIERE	MUR DE 250 TYPE	MUR DE 250 CORNIERE	MUR DE 300 TYPE	MUR DE 300 CORNIERE
JUSQU'A 1200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1200 A 1800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1800 A 2100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTES:
1. SOUDER LES CORNIERES DOS-A-DOS PAR DES SOUDURES ... @ 400 c/c HAUT ET BAS.
2. AU CAS OU LES SURFACES D'APPUI DES CORNIERES SONT AUX DIFFERENTS NIVEAUX, UTILISER DES CALES POUR METTRE LES SURFACES AU MEME NIVEAU.
3. LA HAUTEUR MAXIMUM DU MUR AU DESSUS DE LINTEAU = 4.5 M

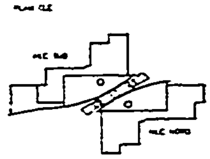
603M

DETAIL TYP. POUR MURS DE BLOCS



605M

NORTEL
NORTHERN TELECOM
NORTEL MONTREAL EXPANSION



No	DATE	REVISION
0	96-11-21	POUR CONSTRUCTION

QUINN DRESSEL et ASSOCIES

Bouthillette Parizeau & associés inc.

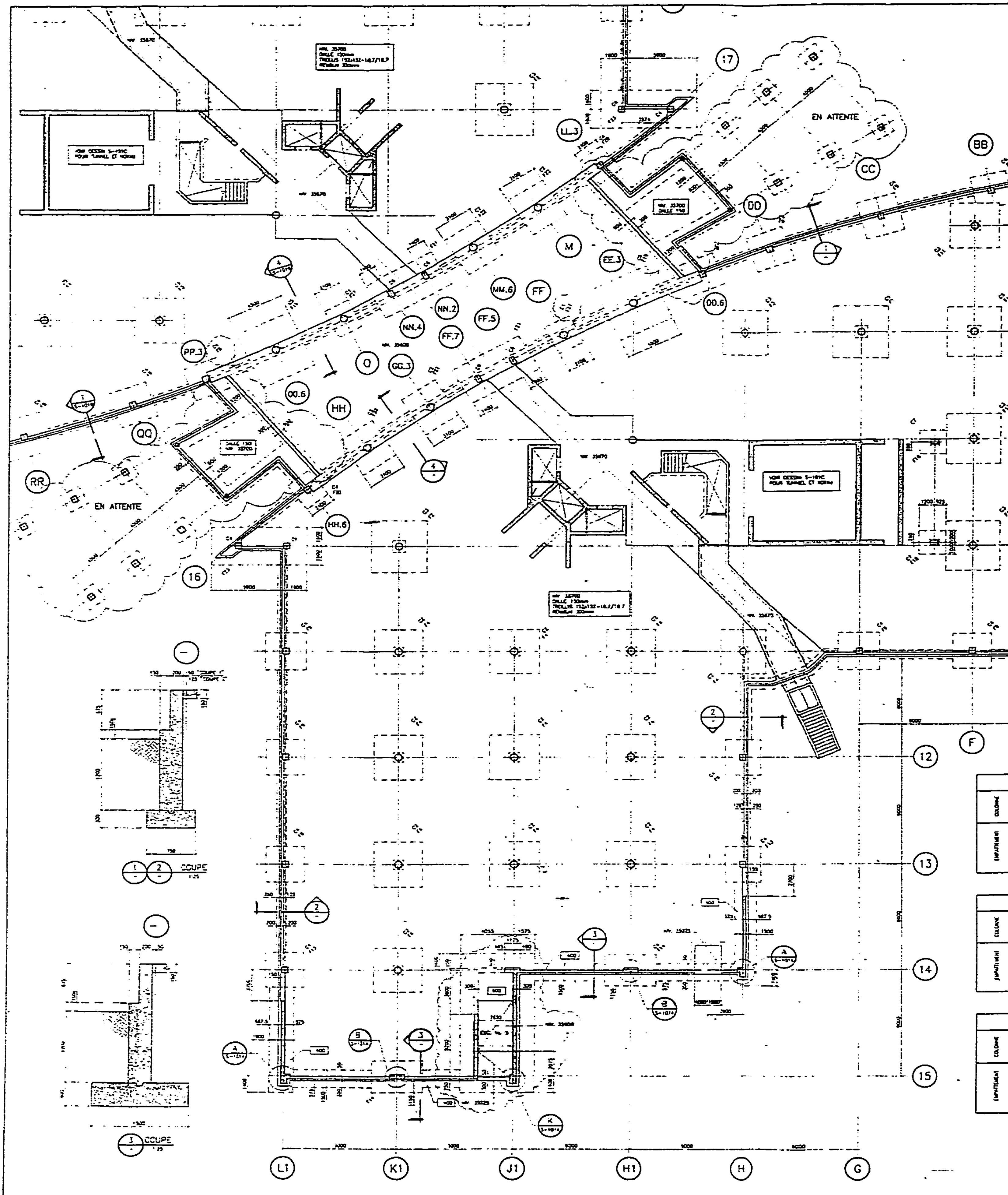
MCW CONSULTANTS LTD.

CIMA

Nortel

NOTES GENERALE ET DETAILS TYPE

S-100



EN ATTENTE
EN ATTENTE
(17)
(LL.3)
(BB)
(CC)
(DD)
(M)
(EE.3)
(MM.6)
(FF)
(00.6)
(NN.2)
(FF.5)
(NN.4)
(FF.7)
(PP.3)
(O)
(GG.3)
(00.6)
(HH)
(QQ)
(RR)
(HH.6)
(16)
(F)
(12)
(13)
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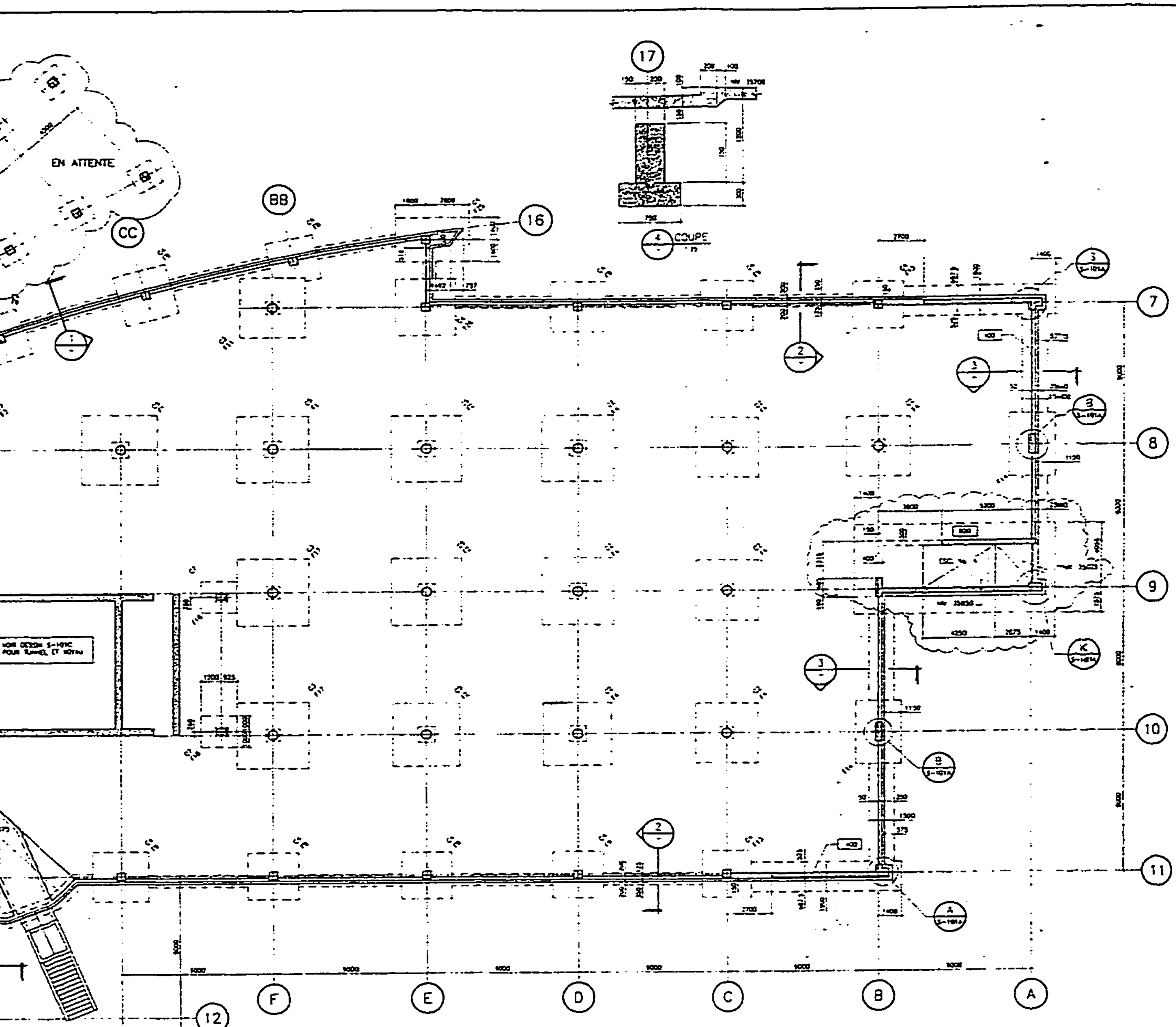
(15)
COUPE
COUPE
(L1)
(K1)
(J1)
(H1)
(H)
(G)



TYPE		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
COLONNE	COLLONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	DIMENSION	900ø	800ø	600ø	600ø	300x300	300x300	600ø	300x600	300x600	600ø	600ø	[illegible]
EMPATTEMENT	DIMENSION	5000	4800	4400	4200	1800	2000	2200	2800	3400	3200	3800	[illegible]
	PROFONDEUR	950	900	900	800	350	400	450	900	600	600	730	[illegible]
	ARMATURE BAS CH. CH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TYPE		F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24
COLONNE	COLLONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	DIMENSION	300x300	400x1175	600ø	400x1175	600ø	400x400	600ø	300x300	400x750	600ø	300x300	[illegible]
EMPATTEMENT	DIMENSION	3000	4000x2700	2850	4400x3700	4200	2300x2175	4300x4800	2100x2500	5800x3200	[illegible]	[illegible]	[illegible]
	PROFONDEUR	600	[illegible]	700	735	750	475	475	425	325	600	450	[illegible]
	ARMATURE BAS CH. CH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TYPE		F25	F26	F27	F28								
COLONNE	COLLONS	[illegible]	[illegible]	[illegible]	[illegible]								
	DIMENSION	300x300	300x300	600ø	600ø								
EMPATTEMENT	DIMENSION	4400x2800	2800	2100x2500	3400								
	PROFONDEUR	500	425	425	550								
	ARMATURE BAS CH. CH	[illegible]	[illegible]	[illegible]	[illegible]								

NORTEL
NORTHERN TELECOM
NORTEL MONTREAL EXPANSION

No.	DATE	RÉVISION
4	98-01-28	TEL QU'INDIQUÉ
3	98-01-26	TEL QU'INDIQUÉ
2	98-01-21	TEL QU'INDIQUÉ
1	98-01-20	POUR CONSTRUCTION
0	98-01-06	POUR SOUMISSION
A	97-12-19	ÉMIS POUR PERMIS

INGÉNIEUR Joseph Galloccio 38842 QUÉBEC

QUINN DRESSEL et ASSOCIÉS

BPA Bouthillette Parizeau & associés inc.

MCW CONSULTANTS LTD.

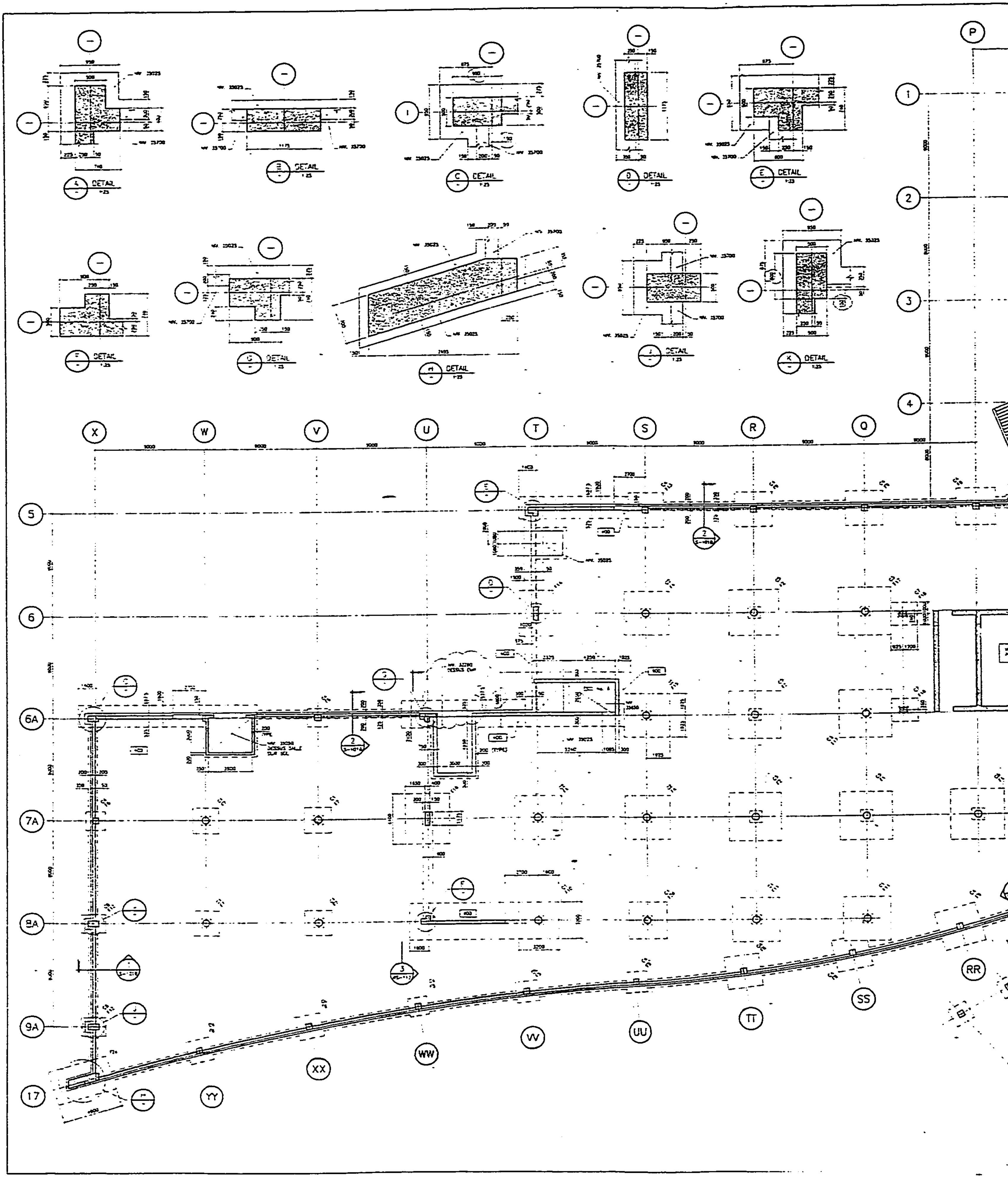
CIMA

Nortel

ÉCHELLE 1:125
DATE 97-12-18

PLAN R. DE C.
AILE NORD

S-101B



A DETAIL 1:25
B DETAIL 1:25
C DETAIL 1:25
D DETAIL 1:25
E DETAIL 1:25
F DETAIL 1:25
G DETAIL 1:25
H DETAIL 1:25
J DETAIL 1:25
K DETAIL 1:25
P
1
2
3
4
X
W
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U
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Q
5
6
6A
7A
8A
9A
17
RR
SS
TT
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VV
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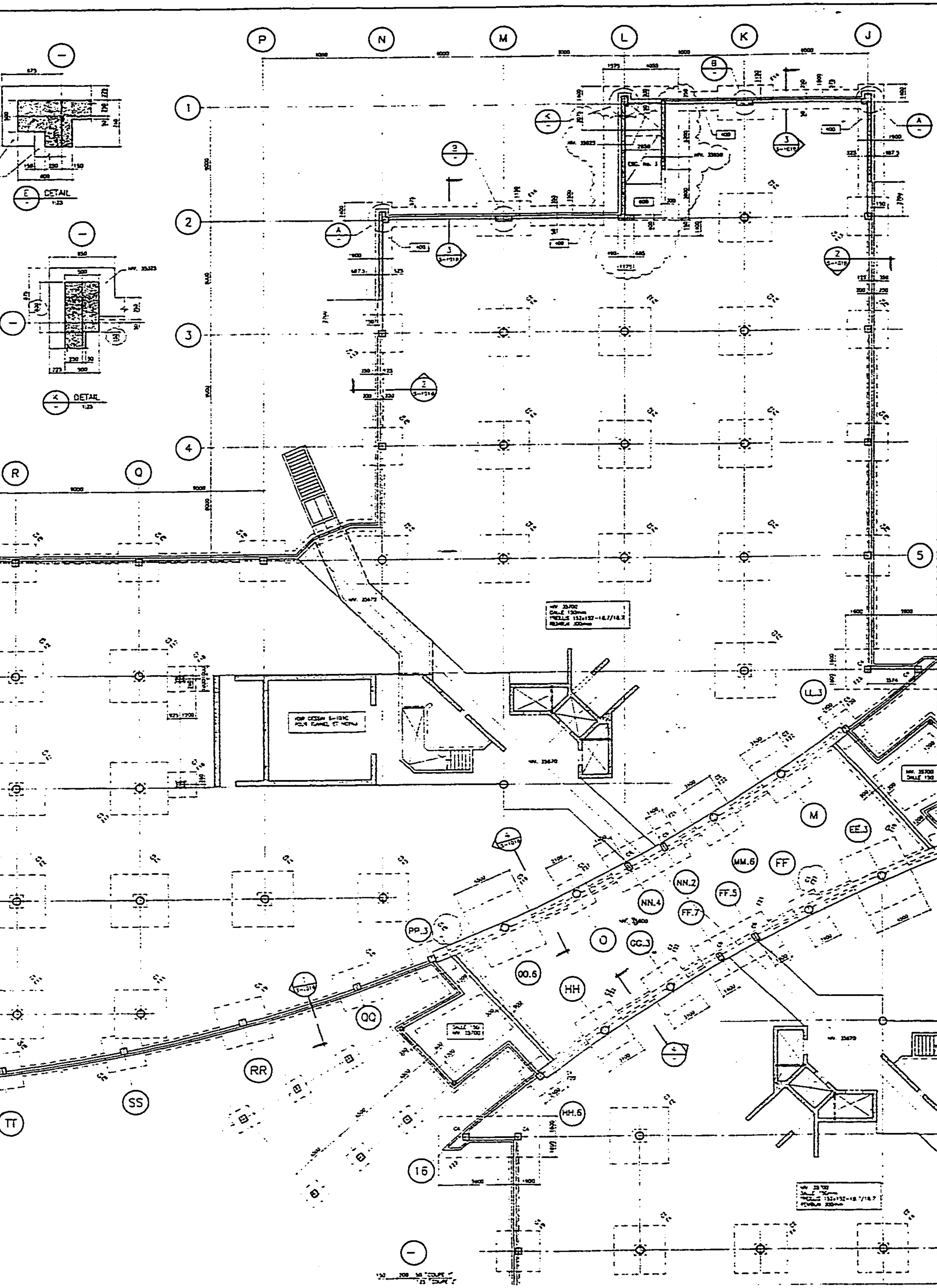
YY



NORTEL
NORTHERN TELECOM
NORTEL MONTREAL EXPANSION

No.	DATE	REVISION
4	98-01-25	TEL QU'INDIQUE
3	98-01-26	TEL QU'INDIQUE
2	98-01-21	TEL QU'INDIQUE
1	98-01-20	POUR CONSTRUCTION
0	98-01-06	POUR SOUMISSION
A	97-12-16	EMIS POUR PERMIS

INGENIEUR
Joseph Callaccio
35842
QUEBEC

QUINN DRESSEL
et ASSOCIES

Bouthillette Parizeau
& associés inc.

MCW CONSULTANTS LTD.

CIMA
SOCIETE D'INGENIERIE

Nortel

DESSINÉ PAR S. DEVOW	ÉCHELLE 1:125
VÉRIFIÉ PAR J. CALLACCIO	DATE 97-12-16

PLAN R. DE C.
AILE SUD

PROJET No. [illegible]737	DESSIN No. S-101A
RÉVISION No. 4	