PARAMETRIC MODELING AND PROJECT MANAGEMENT SYSTEMS

by

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ABSTRACT

A view missing from virtually all project management systems used in construction is the physical view of what is being built. This thesis describes several of the design features of a parametric modeling module capable of providing such a view. The use of this module for supporting a diverse range of project management functions is also described. A case study was conducted on an actual highrise project for the purpose of exploring the actual practices and demonstrate the benefits that may be gained from supporting a physical view of a project.

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CHAPTER 1 - INTRODUCTION

1.1 Objective

The objectives of this thesis are:

a) to explore the characteristics and usefulness of a physical view or parameter model of a project within a project management system; and,

b) to explore actual practice by way of a case study in order to demonstrate the benefits that could accrue from supporting a physical view in a project.

1.2 Background

The literature search performed resulted in very few findings relating to parametric estimating in the construction area and virtually no published research pertaining to the physical parameterization of construction projects. However, the literature found did help somewhat to structure the methodology for the parametric model.

Throughout the design and development process, actual project data and contexts have been used as the foundation for the design and investigation of requirements of a physical view or parametric modeling system and supporting templates. The design of the module is intended to facilitate a large variety of construction projects.

1.3 Thesis Layout

Chapter 2 defines the model which provides the physical description of the project and allows a project to be described in terms of its physical components and their associated parameters. Chapter 3 investigates the methods of estimating, planning, monitoring and overall review of an actual formwork company working on a highrise project currently under construction in Vancouver, British Columbia. It outlines the approach of the company during various aspects of a project and its views on what works well for it. Chapter 4 describes the benefits which may be realized by the implementation of a physical view or parametric modeling system as it relates to modeling, planning, monitoring and analyzing projects in "real world" situations". Chapter 5 presents a summary and conclusions arrived at and discusses possible future research relating to the topics discussed in this thesis.

1.4 The Physical Description Is Missing

What is missing from virtually all project management systems is the physical description of what is being built. Essentially all thought processes involved in constructing a project are centered around the physical components of a project and their attributes. Architects layout the physical components based on the required usage, consulting engineers do all their design work according to the layout of all the physical components, cost engineers and accountants base their estimates and cost tracking figures on the physical components of the structure being constructed, and finally the construction work is sequenced and implemented according to the physical elements being assembled. Nevertheless, most if not all project management systems approach a project from its activity and time based set of data rather than first and foremost focusing on the physical description and properties of the components and then designing the schedule around those components.

By describing the physical components associated with a construction schedule, activities, resources and pay items can be directly linked to the physical components of a project. This will give construction managers the ability to directly, and with more intuitiveness, associate all project management functions with each other. For example, by associating all aspects of a particular project element to a physical object such as slab (including activity data, duration, resource usage, material requirements, cost for associated materials and resources), a comprehensive overview and analysis may be produced. Furthermore, the workload required to fully develop a schedule will be greatly reduced. The redundancy of work is significantly lowered as common building components such as slabs, walls, columns, etc. need to have their parametric properties defined only once even though there may be many repetitive cycles of these same components (i.e. a high-rise may have many levels in which common attributes may be applied). Most current project management software does not support this type of functionality other than through editing, copying and pasting groups of activities and resources repeatedly, and then further redefining the properties of each.

1.5 The Current State of the Art

The current state of the art in scheduling uses activity based scheduling by assigning resources, predecessors, successors and resources to time based activities. Most currently available commercial software still is not specifically designed for the construction industry's unique requirements. Construction managers can create or purchase from various after-market software developers, standard templates for specific types of projects (such as roadwork, civil work, etc.). These templates essentially consist of a completed activity based schedule which is modifiable to suit the specific project. As well, these templates may contain macros to somewhat simplify data input and modification, however they cannot take into account the specific physical attributes which make each project unique. In terms of parametric modeling, it appears that a majority of the research and developments made into parametric modeling have been directed to the preliminary planning and estimating of construction projects, and not towards achieving an overall project management system which encompasses monitoring and post mortem functionality.

To date, no total project management software system has been found with the capability to perform parametric based functions. The only known software package which claims to utilize full parametric modeling capabilities is "SUCCESS" (http://www.uscost.com; download of sample program available). The main purpose of this package is to estimate and perform cost management requirements. It uses a tree structure to create a physical model of the project at hand and bases estimates and ongoing costs on this hierarchy. Other than the fact that both the research system used herein and SUCCESS implement a tree structure type of hierarchy to describe the physical characteristics of a project, SUCCESS uses its Work Breakdown Structure as an index with hyperlinks to the various estimating features intrinsic to estimating. Other than this feature, there is very little resemblance between the properties and functions of the two tree structures. The structure used by SUCCESS, although visually stimulating, appears to have the functionality similarly to that which can be achieved within the fields of a simple spreadsheet linked to a database. Further to the commercially available SUCCESS software package, some research papers discuss parametric modeling to some degree, however most are geared towards the abstract and support more academic objectives.

Shaked and Warszawski (1995) discussed construction planning through the implementation of a knowledge base expert system which integrated an object-oriented representation (physical view) of a building with algorithms to manipulate the various components (parameters). The system referred to as HISHED, is geared towards the development of schedules for highrise buildings by defining a building in terms of vertical and horizontal zones (i.e. vertical zones would refer to vertical components such as elevator shafts, and horizontal zones would refer to components constructed on common floors such as partitions, windows, floor finish, etc.) These zones are related to one another in terms of their proximity, for example, vertical zones are above or below one another and adjacent to specified horizontal zones. Furthermore, "functional systems" are used to define common components such as partitions which could include block walls, concrete walls, drywall systems, etc. The schedule would be generated by the assignment of work to the specific zones based on quantities and typical scheduling dependencies (i.e. SS, SF, FS, FF). Although the system may be useful in determining planning and scheduling information, it lacks the ability to monitor an ongoing project, perform a post mortem analysis, and therefore inherently learn from the as-built experience.

Furthermore, some fundamental developments into the methodology of modeling parameters, for example, volumetric calculations have been made by Brandon and Watson (1994). Their research elaborated on the use of "inference nets" which essentially describes a parameter in terms of its physical properties with the use of structured links between these properties. For example, considering a column, width and depth parameters are used to create an area parameter, which in turn is combined with a height to provide a volume parameter. These ideas were incorporated into an Expert System known as EDESIRL capable of providing mechanisms for strategic budget estimates and value engineering. Again, as noted above, little or no consideration appears to have been given to the inheritance of expertise and knowledge from past experiences and incorporating same into a knowledge base for future use.

Finally, Melin (1994) noted that contractors tend to be relying more and more on historical data to develop more competitive bids and focussed on a number of approaches into the development of parametric estimation methods related to software development to help achieve this. The ideologies presented the breakdown of past estimates into the parameters most commonly used to describe a project, for example, gross floor area, average ceiling height, number of stairwells, etc., into a format allowing for a standard item database which could be manipulated through area cost factors and wage rates. Furthermore, these general parameters should utilize the standard ways of describing major and minor tasks (i.e. floor area by square feet, heat by BTU, etc.). Also discussed was the importance of the hierarchy of the assemblies into logical building blocks which make up the project components. Further elaborated on was the requirements of a software package to be able to gather information from multiple projects (as few buildings are identical) and cross reference the appropriate assemblies (components) from different project models with the ability to add, delete, or override specific parameters in the model. For example, data compiled from the model of a warehouse structure may be used to estimate various components of a gymnasium.

1.6 Is There A Need For A New System

Throughout the industry there is little variation in the way construction projects are scheduled both for preliminary bids and actual project construction. A wide variety of tools are implemented whether it be "in-house" software designed specifically for a company's needs or readily available commercial packages such as Microsoft Project or Primavera P3 which are oriented to the spectrum of scheduling requirements found in many industries, not just the construction industry. Nearly all known packages function in relatively the same way and have adopted the industry standard activity based processes with very few venturing outside this realm.

The rate of advancements in current scheduling practices have essentially remained stagnant for the past several years. Although some minor innovations have been noted mostly as software enhancements, no real breakthroughs in the industry have been discovered through literature searches and the use of various commercially available software packages. As for many of the new innovations directed towards the construction industry, they may offer noteworthy results in terms of research goals but more often than not their complexity and staggering data requirements have made them ineffective tools to be used in real world situations.

The scheduling systems currently being implemented are adequate for use by the construction industry simply because these systems are the only ones readily available using the current technology. By improving the current state of the art and offering parametric modeling capabilities, a higher rate of efficiency, accuracy and understanding of construction management techniques is achievable. This will lead to more refined scheduling and therefore give the users of the new system a competitive advantage.

The benefits of parametric modeling can be realized at a number of different levels. By providing a physical description of the project, experts in other related disciplines such as consultants, subtrades, accountants, cost engineers, architects and owners may now have the capability to more fluently understand schedules and work at closer levels with construction managers to meet scheduling and resource demands. Techniques used to model and track construction activities will be clarified in a manner which is more intuitive to those not directly involved in the process and compel others to meet the scheduling constraints. Furthermore, the different players in the project will have their roles more clearly defined in their own eyes. Another benefit of parametric modeling may be realized as knowledge gained from past experiences can be used more efficiently by management if it is broken down into physical components or "building blocks" rather than strictly by activities.

CHAPTER 2 - THE PHYSICAL MODEL

2.1 Introduction

When developing any software platform, the objectives must be carefully thought out and established. In this case, the goal is to provide the ability to define a physical model of a construction project, and generate the type of useful information essential to the execution of various project management functions. This view should describe the physical characteristics of the overall configuration of the project (i.e. for a high-rise building, a description of the project in terms of a number of locations and their physical dimensions), as well as the attributes of physical systems and their elements to be built (i.e. superstructure - walls, columns, stairs, slabs). The physical view, or parametric model, described herein, is not intended to replicate the kind of detailed information contained in a CAD representation of a project, nor is it intended to replace the drawings and specifications essential to the day-to-day functioning of construction personnel. What it should embody is a flexible representation of the physical components that describe a project along with their description in terms of the quantitative and qualitative parameters that are used in the reasoning processes essential to the support of pre-construction, construction and post-construction project management functions. By incorporating a physical view of a project within a project management software system, significant benefits may be realized by the entire construction team.

For example, a time consuming task in the early stages of a project involves the generation of a baseline plan and schedule. For those cases where the project at hand exhibits similarities to past projects (e.g. high-rise residential construction, commercial office buildings, certain types of civil works), it is desirable to exploit past experience when generating a project schedule. Central to automation, at least in part of this task is access to the physical characteristics of a project. Then, previous schedules can be modified to reflect the scale of the project at hand.

Described in this chapter is the original conceptual design of a physical view of a project to which the author made substantive contributions. This design was later modified by the author's supervisor and implemented in order to demonstrate proof of concept (Russell and Chevallier 1988).

2.2 The Design Philosophy

Rather than try and fit all views of a project within the framework of a single structure, in particular the traditional work breakdown structure, we have opted for several hierarchical structures to represent the various views that describe a project, amongst and within which the user can make various associations. This provides more flexibility in describing a project, and more closely mirrors the way that practitioners build a project. A number of attributes are required of the design of the physical view module, if it is to be truly useful. They deal with flexibility, the transfer of experience, inheritance and different levels of detail.

2.2.1 Flexibility

Probably the most important attribute required by a parametric modeling system is the need for flexibility. To accommodate the vast scope of construction projects, great flexibility is demanded simply to address the many variations in management hierarchies, construction methods and activity schemes. Flexibility must also be inherent in the system so as to not suppress a contractor's own unique ideologies and methods involved in schedule and resource formulation. For example, if the user is a general contractor, the structure of the system must accommodate the desire by management personnel to describe work done by their own forces in more detail than subtrade work. Also, the system should offer assistance in how to describe the physical view, but allow this assistance to be overridden. The system must further be capable of handling a spectrum of projects, from small to large, with the former requiring very flat views (i.e. not a deep hierarchy), and the opposite being the case for complex projects comprised of many subprojects and multiple systems.

2.2.2 The Transfer of Experience and Knowledge

Another attribute desired deals with facilitating learning and the transfer of experience and knowledge. An ability to incorporate standards, at least in the context of the individual firm, should be included in the system design. These standards relate to the consistent use of terminology (e.g. names of building elements), standard units of measure, the ability to create templates of project components as well as complete project templates, and the ability to treat both quantitative and qualitative parameters to describe the features of a component.

Tied in with the foregoing is the design of a user-interface that assists in quickly sketching out the physical features of a project. The ability to import components from a standard library of elements as well as a library of physical view templates is required. Also required is access to an editable list of standard components and their associated parameters. A "language" which the system understands and hence which provides additional power to the user is essential. Included in this "language" is the pre-definition of different classes of components, the use of which is optional.

2.2.3 Inheritance

The notions of inheritance and aggregation must be included as they are key to the support of different project management functions. For example, one may plan at one level, and control at a higher level. Thus, to create an as-built view of progress to date, the requirement should exist to integrate over the components at one level to describe performance at the higher level (e.g. roll up performance at the element level to the system level). As part of this aggregation operation and others, the use of inheritance and the consistent use of language is required, so that the system can extract meaning from various user defined parameters.

2.2.4 Handling Varying Levels of Detail

A construction project can be broken down into an infinite number of details, from the excavation of the parkade to the number of screws needed to install each sheet of drywall. However, the resources required to develop the construction representation of a strategy and schedule, and to monitor the progress of such a detailed project would be overwhelming. The dilemma exists as to the level of detail required to encapsulate all the physical aspects of the project necessary to support project management functions. Not enough detail may render the parameter model incomplete and ineffective to perform the necessary scheduling requirements, whereas too much detail will burden the project management team with an overabundance of redundant and possibly useless information.

As the scope of work differs on all construction projects, varying level of details may be required by different construction experts. Some may act strictly as construction managers and subcontract all work to other trades therefore only requiring a very basic model with few components while some may perform all work with their own in-house crews therefore requiring a relatively detailed and robust parameter model. Regardless of the amount of detail required by the various construction firms it is always better to err on the side of simplicity as too much detail may become pointless and result in little benefit.

2.3 Developing The Conceptual Framework

In developing the conceptual framework for the parameter model, a number of different perspectives along with requirements for each need to be considered as these may vary depending on the composition of the construction team. First and foremost, the perspective of the project manager was considered. His main concerns are to complete the project in the most cost effective and timely manner possible with as few problems as possible. To help achieve this end result, the physical view of a project should have a hierarchical breakdown which would organize data in a way that minimizes the data input requirements, and at the same time provide a robust knowledge base capable of linking all data relating to the construction activities and pay items. It must also have the versatility to create, manage and manipulate the information in a flexible format or structure by the project manager. Further, information must be transferable bi-directionally between all the disciplines making up the project management team. When considering the information needs of the other players in the management team, weight must be placed not only on their requirements, but also on their potential expertise relating to construction. Those receiving information from the project manager, such as accountants, bookkeepers, etc., may not have the in-depth level of knowledge to filter through complex scheduling data. Therefore allowance must be made within the activity and pay item modules to accommodate the types of information specifically required by these other disciplines as well as in the presentation of the information to them.

The layout of the parametric modeling system shown in Figure 2.1 reflects the global link of the physical view to other aspects of the project management system (Note: Resource assignment is part of the process or activity view of a project). From the activity view, resource assignments can take place which will lead to planned productivity calculations and give the management team an overview of the project's scope, duration and material and equipment requirements allowing them to make the appropriate decisions as to the construction requirements and revisions to the schedule.

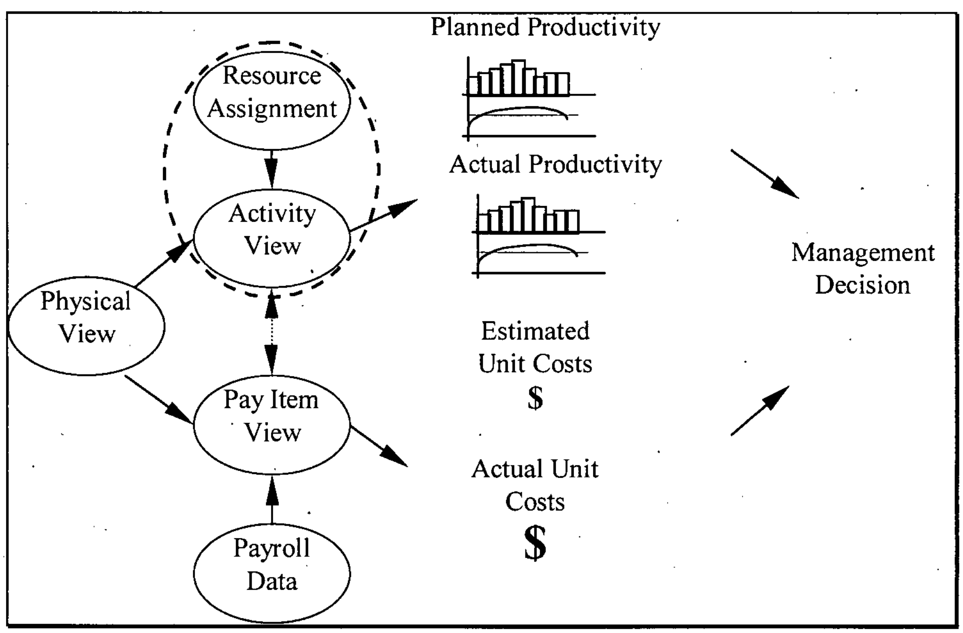

Figure 2.1 The Project Views

Our concept of a physical view essentially consists of a multi-leveled tree structured hierarchy that can be used to define a project in terms of its global project parameters such as location sets and physical systems and components which make up the physical building blocks of the project. It would include a toolkit of functions for formulating and manipulating the structure of the model as well as define the linkages with other project views. A physical description window would function as the main user interface to the parametric model with most of the functional features accessed from this window. This was decided upon to reduce much of the overhead and possibility of redundant data being created. In what follows, features of the physical view are described, along with designs of the interface. The emphasis is on design features, the reasons why, and how the systems would be used for various functions. Implementation is not part of the scope of the thesis.

2.3.1 The Parameter Model Defined

A hierarchical tree structure was chosen as the means to define the parameter model to allow for both maximum efficiency and intuitiveness when entering and editing data. The structure is essentially "open-ended" with few limitations on how the model should be defined. However, some organizational types of restrictions have been established to prevent the user from going astray and help to guide him/her through the model development process as well as meet the requirements of the software to properly administer the information.

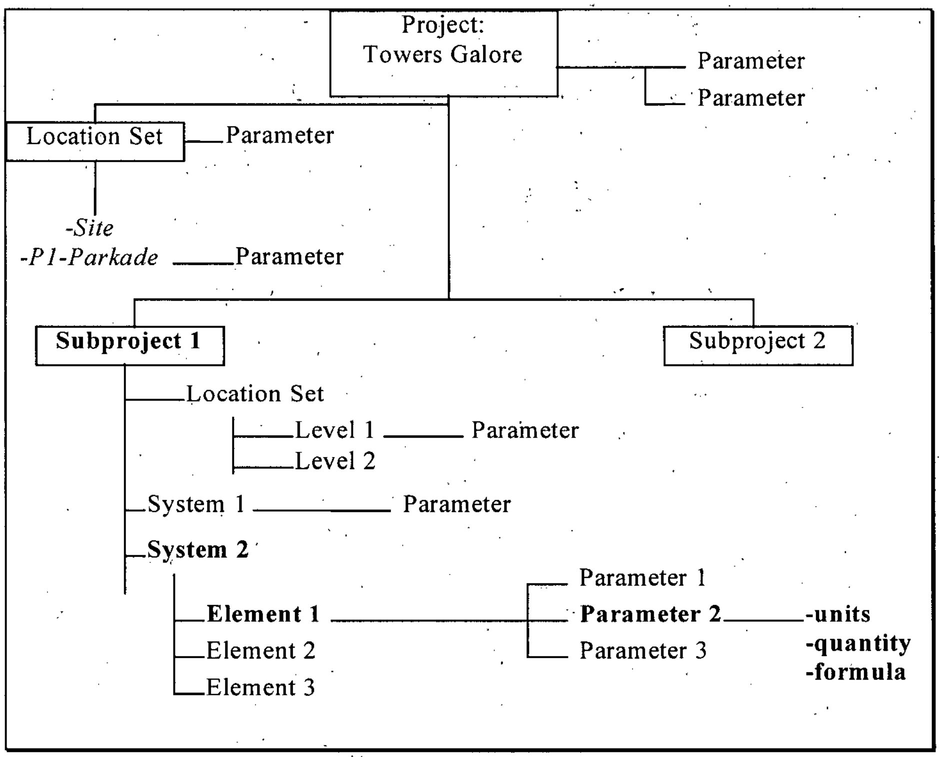

Figure 2.2 Hierarchical Layout For A Parametric Model

The parameter model will essentially define a project in terms of its physical components and form the basic building blocks as represented in Figure 2.2. All projects will be characterized by a number of specific fields to define the project's global parameters including the project's name, description and location sets as well as the same for any subprojects if they exist. Within each project and subproject, a location set will require input to define the breakdown of common grouping of systems or "work packages" such as superstructure, mechanical, electrical, etc. Within each system, a hierarchy of elements is used to define the next sublevel of components or building blocks of that system. An example of this is the "superstructure" system of the building which can consist of walls, columns and slabs (each being defined as an element within the superstructure). Each component in the hierarchy can be described in terms of user-defined parameters which specifically define the quantitative properties of each component. The parameter level properties can be described in terms of numerical values, indexed quantities and mathematical relationships which link the different parameters to each other.

2.3.2 Terminology Associated With The Model

The following vocabulary has been adopted in order to help describe the parametric model. Component refers to any physical object described. As mentioned previously, all components (element, system, subproject, project) can have their own parameter sets.

The typical layout of the physical view or parameter model of a project, assuming all levels of the hierarchy are used will consist of projects, subprojects, systems, subsystems, elements and subelements. The PROJECT level constitutes the global level which essentially contains all other sub-components, namely, a collection of all subprojects, systems and elements. It has a description assigned to it as well as user defined attributes. A SUBPROJECT will refer to a self contained entity within a PROJECT, such as a high-rise building within a group of buildings forming the global PROJECT. Each subproject will be comprised of a location set whose purpose is to categorize groups of locations which contain mutually similar parameters and properties such as common levels within a high-rise building or equivalent sections in a segmented bridge or highway project. SYSTEM or SUBSYSTEM refers to a collection of building components which constitute a physical system within a subproject or project such as a superstructure in the case of a high-rise building. An example of a SUBSYSTEM may be a building's HVAC units within a Mechanical SYSTEM. Each system or subsystem will contain ELEMENTS which are again a lower level breakdown of components within such as slabs, walls and columns, if the superstructure scenario is chosen. The SUBELEMENT level will be made up specific classifications of elements (e.g. round versus rectangular columns). Each of the foregoing components can be described in terms of quantitative and qualitative descriptors referred to as PARAMETERS, which form a group of attributes designed by the user to best define the physical properties describing the component being considered.

As noted, at the most fundamental level of the model exists PARAMETERS, which are used to specifically define the basic properties associated with the project. Ideally, the intention is to model a project using as few parameters as possible to define the complete scope of work, as well as maintain the capability to mathematically interrelate the different parameters, while allowing the model to refine many parameter values when the scope of work changes and one or several parameters are revised. For example, a slab in a building could be defined using the parameters, depth, width, length, reinforcement ratio, formwork surface area and formwork perimeter area (see Figure 2.3). As slab dimensions depth, width and length are revised, the system will modify the values of the final three parameters through the inherent knowledge given by assigning formulas to them. It is important that the level of information provided within the parameters reflect the appropriate property requirements to fully encompass the entity but not contain redundancies with each other.

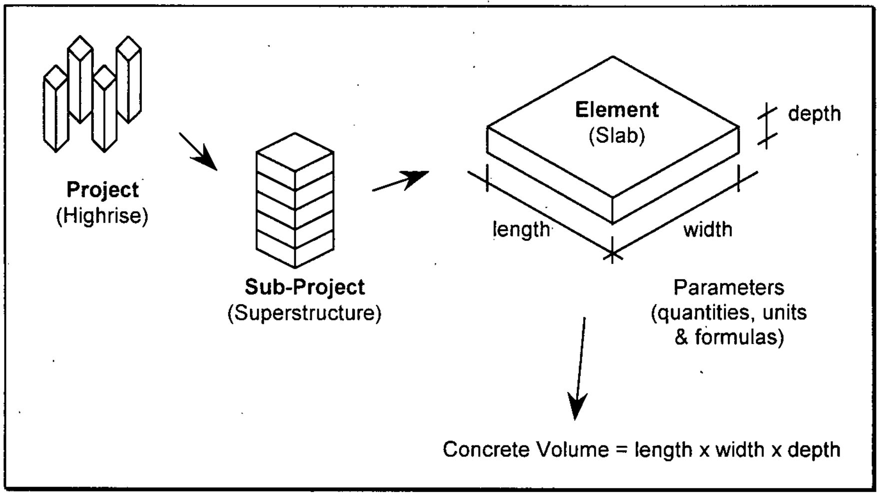

Figure 2.3 The Components of A Parameter Model

A STANDARD COMPONENT will represent an object as simple as a column containing parameters used to describe its geometric properties, to an entire building such as a high-rise which may actually be made up of a number of previously defined standard components, systems, subsystems and elements such as the column just mentioned. There are essentially no restrictions as to what defines a Standard Component other than it should represent the various common characteristics or "building blocks" which make up an overall project. However, the suggested guideline is that a standard component should represent characteristics of a project which contain related properties and mathematical representations common to many projects (i.e. a concrete slab in a high-rise building has the parameters slab depth, length, width, etc.).

The ability to apply a standard or previously defined component to a new project model will considerably decrease the overhead required to create and link all the various project parameters and hierarchical levels which define it. The use of Standard Components will be elaborated on later in this chapter.

2.4 Interactions Between Components

In a parameter model, relationships will exist at a number of intrinsic levels within an individual component, between different components, location ranges and between the different project views (acitivity view, resource view, pay item view, etc.). For a given component, relationships will exist between its individual parameters. For example, the geometric properties used to quantitatively describe a slab (e.g. length, width and depth) will be linked together via the concrete volume or formwork surface area parameter which are calculated based on the original descriptive parameters. At the next higher level, relationships will exist between components such as elements and subelements. This type of relationship can exist between all levels within the parameter model (see Figure 2.3). Consider a "typical floor" element within a highrise building which contains the subelements walls columns and slabs. The "floor to floor height" parameter which is attached to the element typical floor will have a direct multi-leveled relationship with the subelements walls and columns. This parameter will be used directly to establish their height and in turn calculate the original concrete volumes of each subelement. As well, between the various individual components and location sets exists a one to one type of relationship, for example between an element typical slab and a group of typical floors (i.e. levels 2 - 15). Finally at the highest level, associations between the different physical views will define the quantitative information used to link the physical attributes of the model with values associated with resource usage, pay items and productivity (see Figure 2.4).

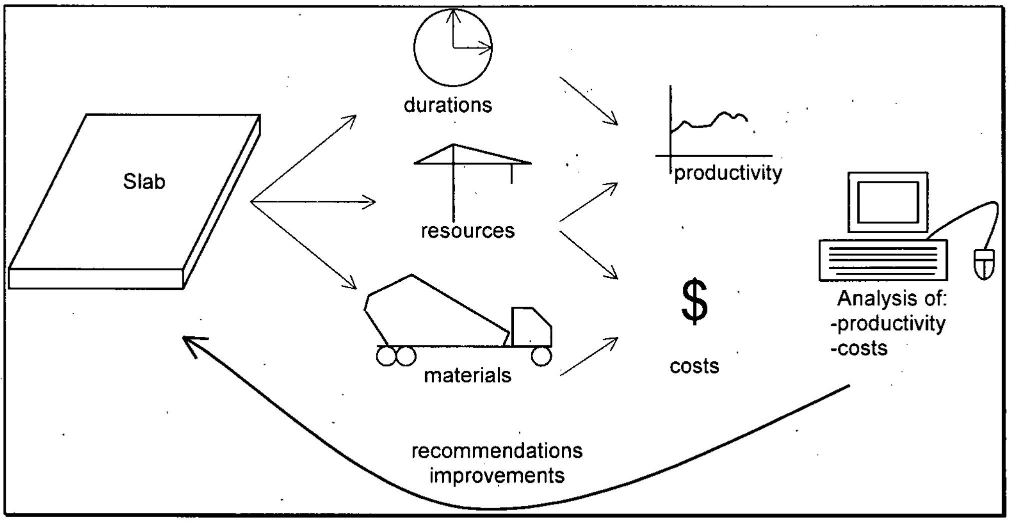

Figure 2.4 Interaction of The Model With Resources & Pay Items

2.5 Creating The User Interface

The following sections describe the various windows and user-interface designed which will be used to create a parameter model, link the model to other project management functions, and output the information assembled and calculated by the system. Each section will explain the different fields in each window and their related functions and interactions with other fields and windows in the module. The research system developed at UBC, called REPCON has been adopted as the eventual implementation environment for the physical view. The design of the physical view presented herein is reflective of many of the special modeling features found in REPCON plus aspects of its user interface.

2.5.1 The REPCON Main Menu

The REPCON Main Menu (see Figure 2.5) is divided up into five separate areas, grouped according to the different aspects required of construction management functions. The breakdown is as follows: System, Project, Planning & Scheduling, Cash Flow & Resources and Control & Project Admin. The first four are directly related to the Parametric Modeling Module which is formally called the Physical Component Breakdown Structure (PCSB). (see column 2 in Figure 2.5). The System subgroup contains submenus and commands which are used to administer the software setup requirements, file commands and global definitions which can be accessed and used by all projects within the system. It contains all functions globally related to all projects being modeled and contains "Project Files" which is used to create new projects and load current projects as well as the "Standards" sub-menu which is used to define all standards globally accessible by the project currently being worked on. The Standard PCBS is of interest to the parametric model as it contains templates of all the typical standard components which can be inserted into a model. The Project group is used to define the global aspects of each individual project from the project inception where the initial project properties such as location ranges and pay items, PCBS and pay item structures are setup. Under the "Project" heading is PCBS which is used to access the Physical Component Breakdown Structure window where the actual model components are added and defined. The Planning & Scheduling and Cash Flow & Resources groups are essentially self explanatory. All the dialog boxes described below will be reached from one of these aforementioned heading selections.

REPCON
Main Menu

SYSTEM	PROJECT	PLANNING & SCHEDULING	CASH FLOW & RESOURCES	CONTROL & PROJ. ADMIN
Program Files	Project Data	**Activities**	**Resources**	Daily Site
Standards	**PCBS**	Execute	Cash Flow	**Pay Item/Acct**
Configuration	Calendar	View	Sched of Values	Appl For
Stnd Projects	Pay Item/Acct	Batch Update		Payment
Utilities	Report Manager	Macros		Change Orders
Exit	Select/Sort	Reports		Records
	Reports	Summary Sched		

Figure 2.5 REPCON Main Menu

2.5.2 The Physical Component Breakdown Structure

We have adopted a physical component breakdown structure (PCBS) to describe the physical view of a project. As indicated through the definitions previously given, we suggest as a maximum a six level hierarchy as a standard approach. (We believe that for supporting project management functions, the user should err on the side of simplicity in describing the physical project within the system. Highly detailed descriptions imply a level of planning and control which is not reflective of day-to-day practice nor of the quality of data available.) The levels correspond to Project, Subproject, System, Subsystem, Element and Subelement. Depending on the complexity of the project at hand, the Subproject level is optional. It applies when a project is comprised of a number of distinct or self-contained physical components such as a parkade, tower A, tower B, etc. Alternatively, for small projects, or if attention is restricted to a specific project management function such as productivity measurement, a single level - e.g. Element, could be used. The System level corresponds to the description of a subproject in terms of the various physical systems that describe it, such as substructure, superstructure, enclosure, electrical, and so forth. The Element level deals with the decomposition of the System level into a number of components. For example, the Superstructure system may be viewed as being comprised of slabs, walls, and columns. What is important to note is that the physical view is restricted to physical components, and is basically silent on organizational issues (e.g. who is responsible for different components of the work) and on process issues (e.g. how a system or element will be constructed).

Shown in Figure 2.6 is an overview of the Physical Component Breakdown Structure (PCBS) screen. In terms of the bar menu of operations, the Setup and Window bar menu items are of interest here. The first, Setup, helps to define the basic structure of the physical view. The user specifies the global project name and description including the number of subprojects required. This allows the basic tree structure to be automatically defined. Then, using the Setup bar menu item, the user can import either standard Subproject (including lower level) templates, or import standard templates at the system level and lower. Setup helps to facilitate the efficient definition of the physical view. Alternatively, the user can establish the basic structure of the hierarchy as they see fit, using the various keys available to define, insert and delete levels.

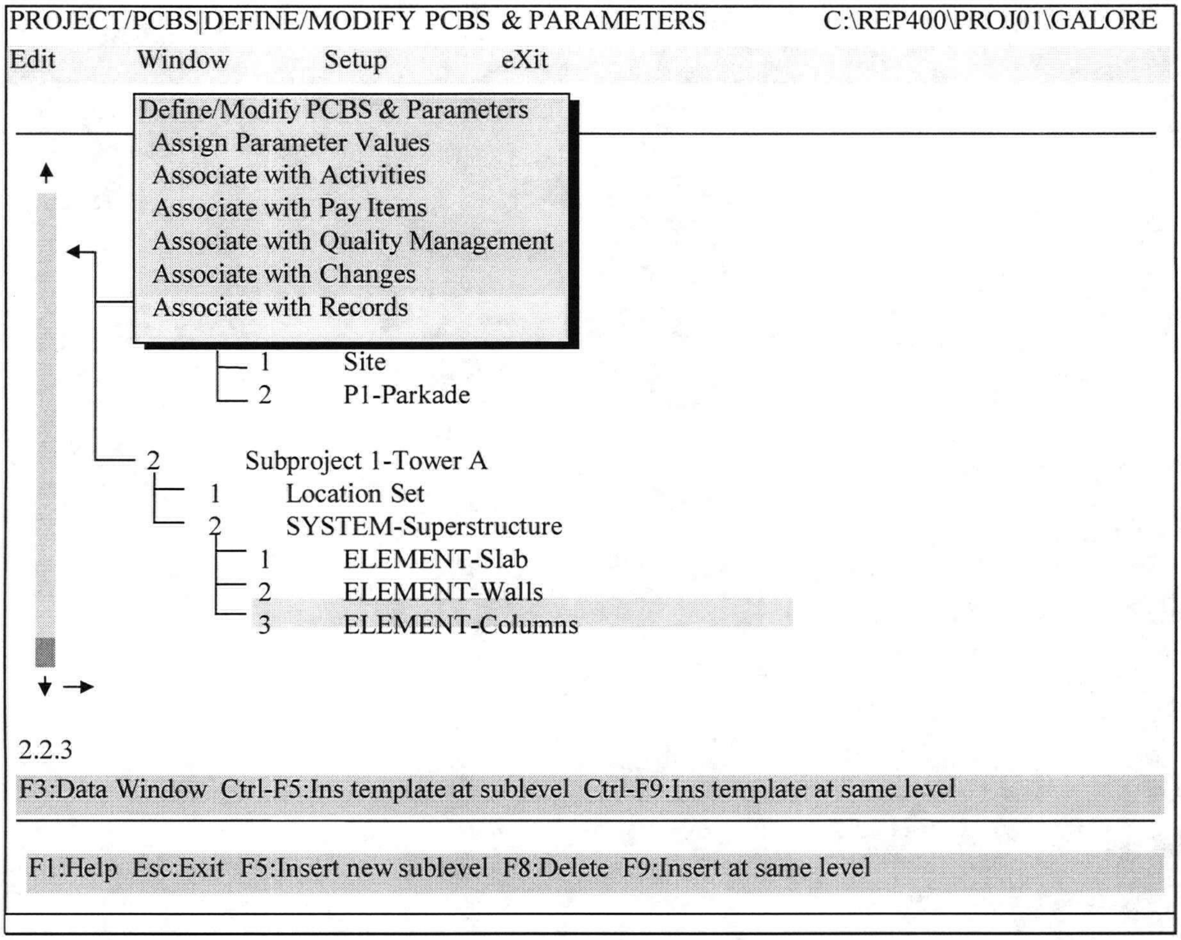

Figure 2.6 The Physical Component Breakdown Structure Window

As shown in the drop-down menu under the Window bar menu item in Figure 2.6, the user can define a number of parameters for each component in the PCBS, assign values to them, and make associations between components and activities (the process view), between components and pay items (the cost view), between components and quality management, between components and changes (change orders), and between components and project records, which are comprised of photos, videos, drawings, and correspondence. Thus, for example, to help in defining and assigning parameter values for a component, the user may view different records. Lastly, the user may wish to write a memo detailing special features or issues of concern with one or more components. All of the associations supported are of the many-to-many type, and are accessible through all of the views. For example, the user can associate components with activities through the PCBS, or conversely, make the association through the activity or process view.

2.5.3 The Setup Window

The "Setup" menu heading can be used to start building the parametric model. It will not be necessary to utilize the "Setup" option when creating a new parametric model as the user can create a model strictly from the PCBS window by inserting the appropriate levels and components. The setup window (see Figure 2.7) will however allow the user to specify the various global project components and descriptions such as the name and number of subprojects involved and the number of locations contained within each subproject and then suggest to the user the most efficient and effective hierarchical structure to describe the physical layout of the project. Once created, the hierarchy suggested by the module can be implemented and modified according to any specific needs or altogether discarded if it is deemed unsuitable.

When "Setup" is selected from the PCBS menu , the user will be prompted with the Setup window shown in Figure 2.7. A global project name and description will be entered, followed by the number of subprojects involved. The use of subprojects is optional, as a project may consist of only one entity (i.e. a high-rise tower), thus making the use of subprojects redundant. Alternatively, a number of subprojects may be defined to more accurately describe the physical aspects of the project. For example, if the user specifies that the new project is to be based on one high-rise building and one parkade structure (possibly selected from the Standard Component List of subprojects), the setup window will return two subprojects based on that data input. The first will be an high-rise tower and the second will be a parkade structure, each with unspecified names, descriptions and number of locations. These fields will be left up to the user to complete as he/she feels appropriate. Other subprojects can also be added, deleted and modified if necessary. When all the data requirements have been completed then the user will confirm the data entered which will build the basic parametric model and take the user to the PCBS window for further data input. This menu will only be accessible at the preliminary stage of creating a new parametric model.

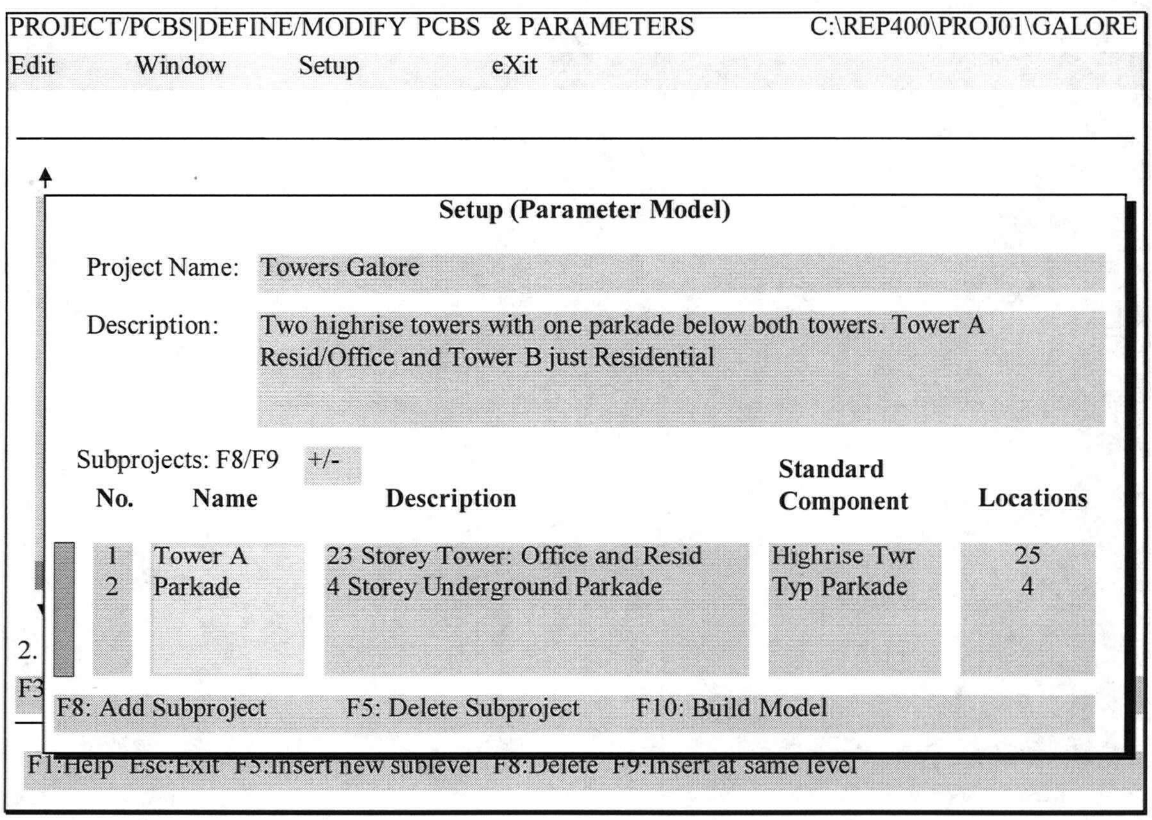

Figure 2.7 Setup New Project

2.5.4 Define/Modify PCBS and Parameters

Figure 2.8 Define/Modify PCBS and Parameters Window depicts the screen used for defining the parameters associated with the component type, Element, which belongs to the Superstructure System. If a standard system or element template had been imported, then, depending on how the standard had been defined, one or more of the parameters shown may have been predefined. Any number of parameters may be defined against a component, although it is expected that the number will generally be small.

The major objective of creating the parametric model is to essentially give the user a physical description of the project which can be manipulated to suit the users specific definitions of important aspects of the project. Once completed the physical component breakdown structure would be considered a representation of the qualitative properties of the project being described. However, this qualitative information has no value to the project manager unless it can be mathematically linked with the quantitative information. The Define/Modify PCBS and Parameters window is where the real capability of the module comes into being. Once the user has more or less completed generating the hierarchical layout of the project and has a reasonably robust physical description, he/she will need to define or describe quantitatively what each component in the model represents.

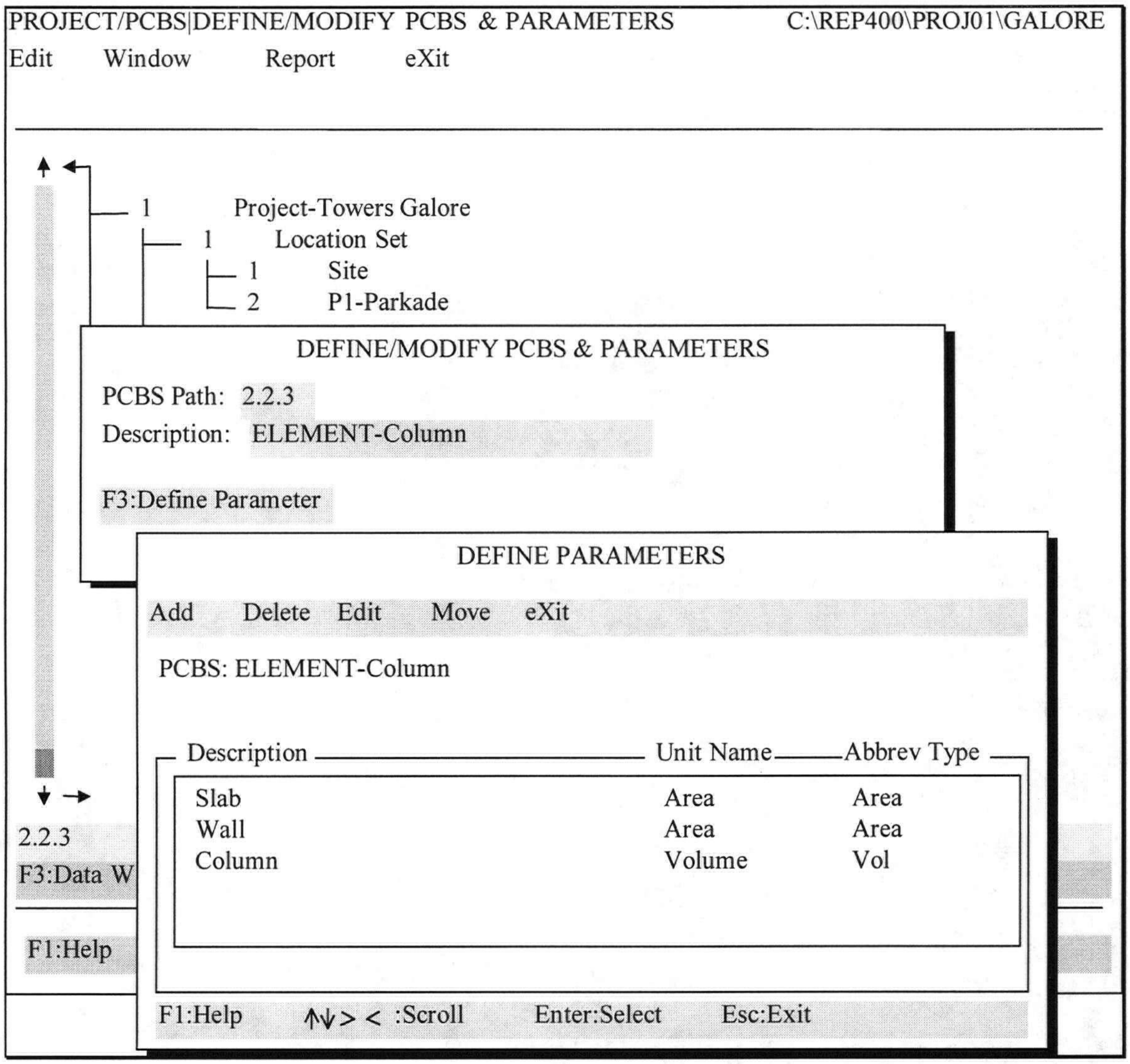

Figure 2.8 Define/Modify PCBS and Parameters Window

The PCBS window will specify which parameters will be associated with the current component selected. Parameters can be added to a component at any level in the PCBS and any number of parameters can be assigned. Each parameter will contain a number of specific fields used to define the various properties associated with it. The parameter's "Description" field will provide two functions, namely it will define the name of the parameter and also act as the description field to identify the function of the parameter to the user. Both the "Unit Name" and "Abbrev Type" fields will assign the quantitative measures to the selected parameter from the default lists, for example L, A, and V will represent length, area and volume measures respectively, and m, mm and m2 will represent metre, millimetre and square metre units respectively.

Going hand in hand with this is the need for inheritance - e.g. parameter definitions associated with the System level are automatically available at the Element level, and are flagged as being inherited. Both quantitative and qualitative parameter types need to be supported. Quantitative parameters are described by a measure symbol (e.g. L for length), and units of measure, with the conversion of units being automatically supported to permit operations to be conducted over a number of parameters or elements (a standard list of units of measure is supported to help avoid errors in defining units). For qualitative parameters an index is used to quantify a qualitative value, with its value expressed over the interval [0,1]. The goal is to take into account qualitative measures when estimating duration and productivity. Lastly, there is a need to be able to derive parameter values from other parameters. Hence, the facility should exist to enter functional relationships in the form of simplified formulas, as shown in Figure 2.10.

A "Formula" field will define the calculation that takes place on the values of other parameters to compute the value for the parameter at hand. The formula field is an optional field as a formula is not required for each parameter, however, each parameter which has no formula assigned to it will still have the ability to reference another parameter or parameter formula. By selecting "F2: Add/Edit/Delete Formula" the user will enter the edit mode in the formula field and be able to enter formulae and access the associated pop-up windows. Rather than allowing the user to enter a formula directly in from this window, more intuitiveness and flexibility could be built into the system by allowing a specific formula edit window with related options.

2.5.5 Location Ranges

Once the parameters for an element are defined, then values can be assigned to groups of locations as shown in Figure 2.9, with the locations in each group having identical parameter values.

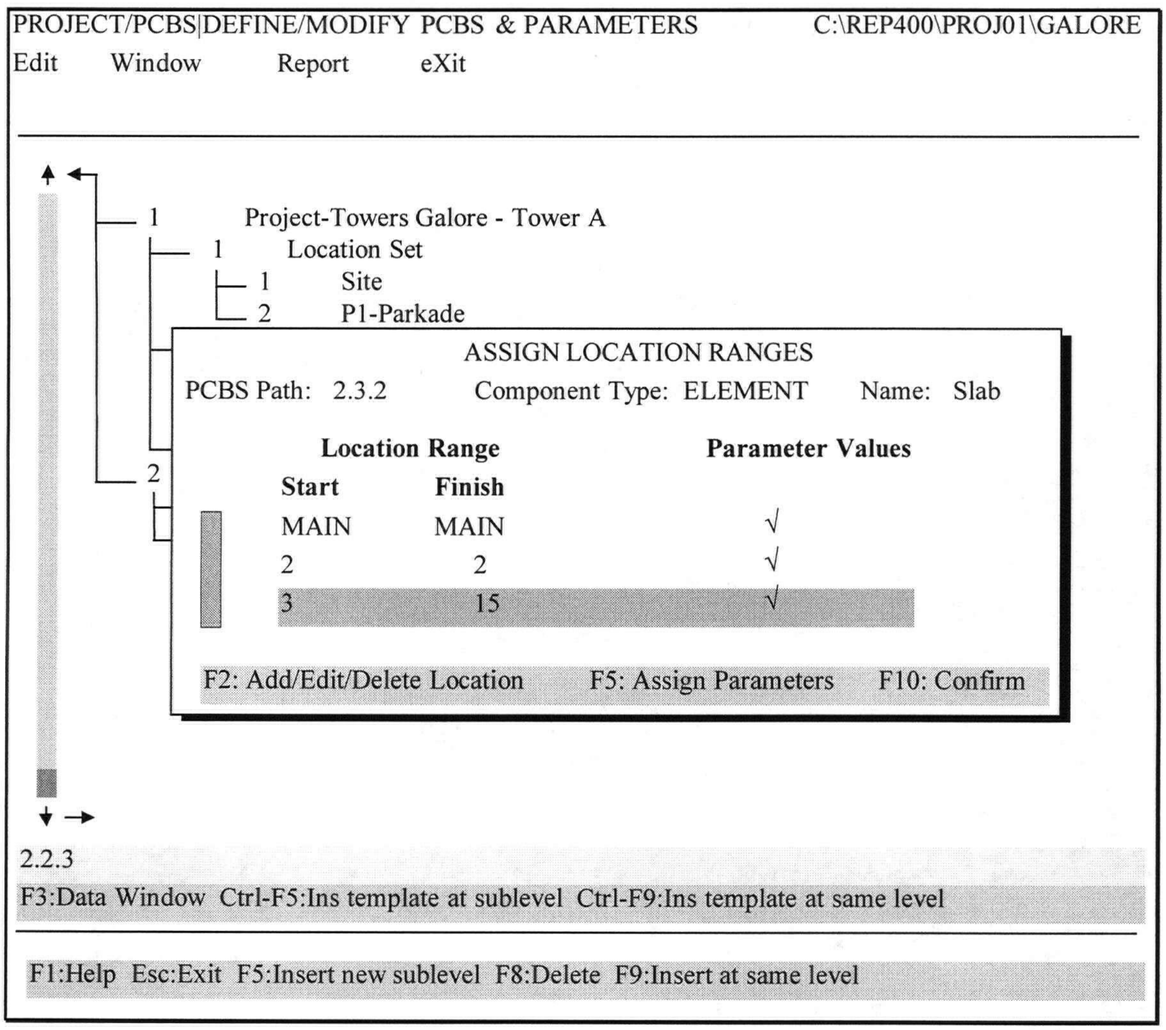

Figure 2.9 Assigning Location Ranges

This dialog box will function to modify the location ranges to represent the grouped segments of a project with common properties and assign parameters to the various location ranges specified in the "Location Set" component of the different subprojects (see Figure 2.9). For example, a high-rise building will be made up of a number of floors, some of which will be similar in nature. To optimize the users efficiency, the module will ask for floors which contain the same parameters and parameter values to be grouped as one item in this window. Referring to Figure 2.9, subproject Tower A consists of three location ranges which may use the same parameters but contain different parameter values, namely Main, Level 2 and Level 3 - 15. To add, edit or delete location ranges, the user will select the F2 key and enter the appropriate Location names in the start and finish fields. The check marks shown in the adjacent field will specify whether there are parameter values assigned to the location range (newly created ranges obviously will not have any values assigned to them).

2.5.6 Assigning Parameter Values To PCBS Components

All parameters must have numerical values, whether quantities or indexes, assigned to them in order for them to be useful in the calculation of the various scheduling information and resource quantities required by the project manager and others. If the example of a high-rise building is considered, the numerous levels of the building will all contain slabs, however there may be several variations in the slabs' dimensions. These groupings of common variable quantities will be broken down into location ranges for the purpose of minimizing the required data input by the user. Location ranges are defined as previously mentioned.

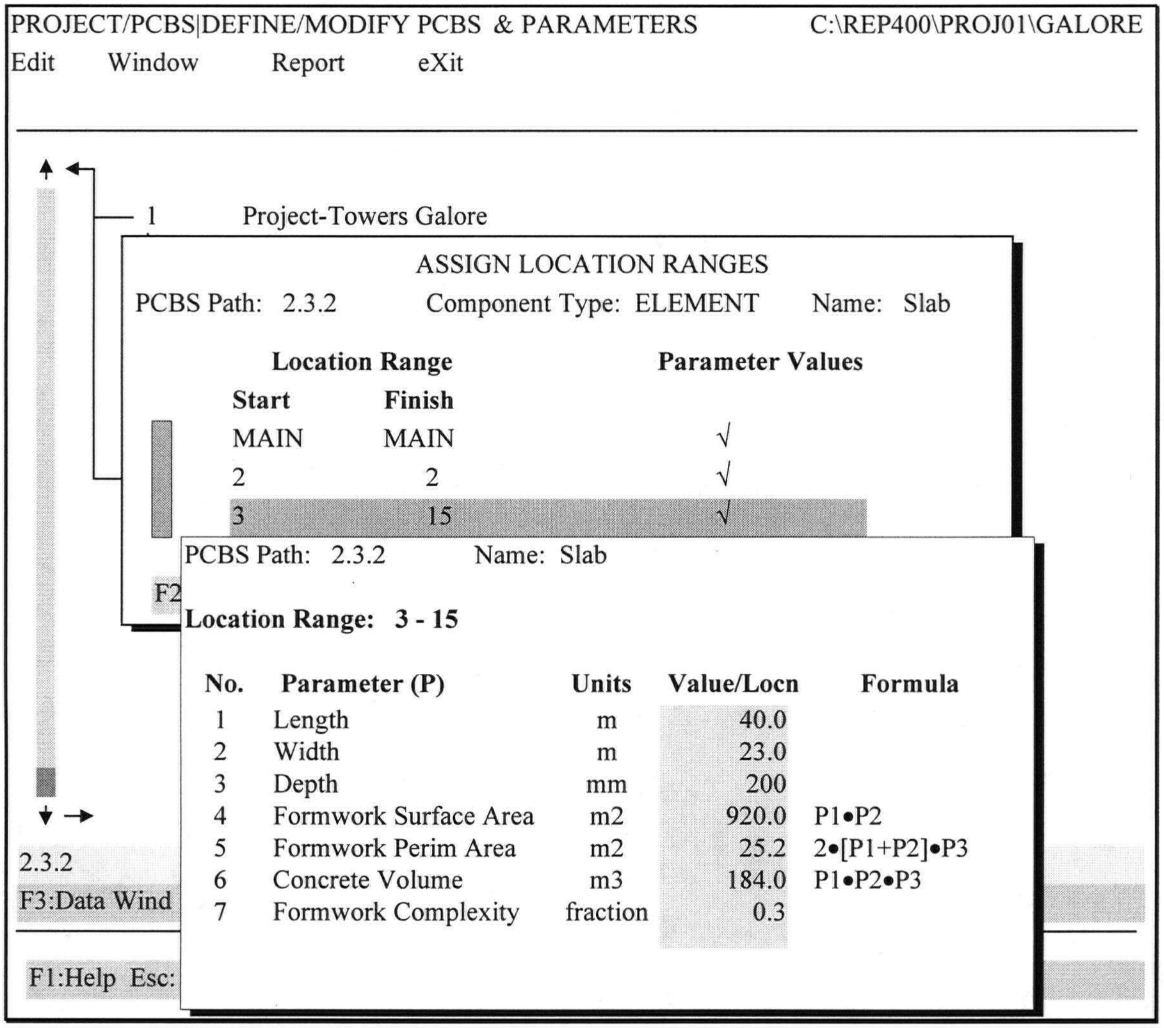

Figure 2.10 Assigning Parameter Values To The PCBS Components

To assign values to the appropriate parameters, the user will access the Assign Parameter Values window from the PCBS location range window (see Figure 2.10) by selecting the F3 key, "Assign Parameter Values". This window will have one modifiable field, namely the Value/Locn" field which will accept numerical values corresponding to the appropriate parameter. Once the fields have been filled the user will “F10: Confirm” the inputted values and be returned to the Location Ranges window. At this point either a new location range will be selected or the modifications made will be once again confirmed. Consideration was given to allow the user to have the option of assigning the previously entered parameter values to subsequent or multiple location ranges and have the user modify only those values which may have changed. For example, often concurrent slabs may have the same length and width but a different slab depth. However, it is believed that this would lead the user to rely heavily on this option and possibly make errors or unintentionally allow erroneous data to exist in the parameter model; therefore this feature is not included in the design.

Once the parameters for an element are defined, then values can be assigned to groups of locations as shown in Figure 2.10, with the locations in each group having identical parameter values. Later, when the cost and process views have been defined, associations can be made amongst them. For example, a single element may be associated with several activities, (e.g. slab may be associated with the form slab and place slab activities) but with different parameters of the element being relevant to different activities (e.g. formwork surface area and formwork perimeter area may be relevant to form slab, and concrete volume may be relevant to place slab). The assignment of parameters and their respective values to activities and cost items is central to productivity measurement and the derivation of comprehensive productivity estimation functions.

2.5.7 Associating Parameters With Activities

The window shown in Figure 2.11 allows the user to specify which activities are associated with the physical component of interest. Eventually, the goal is to allow the user to be able to express activity attributes (e.g. duration) in terms of physical component parameters as well as other variables. A many-to-many relationship will exist allowing multiple activities to be assigned to a component or conversely one activity assigned to many components.

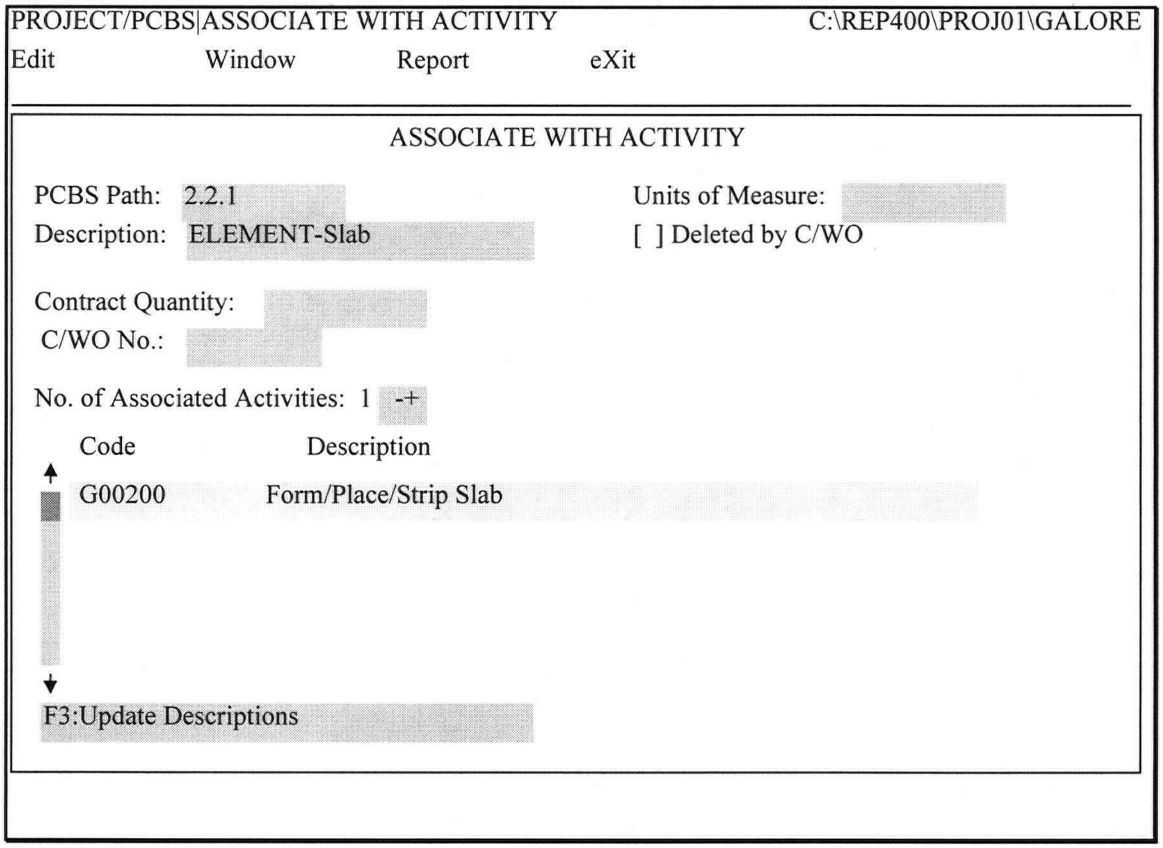

Figure 2.11 Associate Components With Activities Window

2.6 Standards

It is fundamental to the parametric modeling module to maintain an ongoing database of standards from which the user may select project, subproject, system, subsystem, element or subelement components along with units which have at one time or another been predefined. These database components will serve to allow the direct installment of the component into the current model being developed or any previous model being refined. By having this capability, previous knowledge and expertise which was used in the development of past projects can be inherited and used in current and future projects being modeled.

2.6.1 Standard Units

This dialog box will essentially contain a database of the units which may be assigned to particular parameter value measures (see Figure 2.12). The function of the standard units database is to give the user a list of specifically defined units from which units can be assigned to a physical component's parameter. Furthermore, relationships between units can be specified, allowing conversion of units to take place. For example, the standard units will define one metre as containing 1000 millimetres, and the equation will define the differences through arithmetic operators so other parts of the program will be able to convert the units and maintain proper unit consistency. Another example may be considered when looking at inverse productivity measures such as man-hours per cubic metre (mhr/m3). The user will enter a relationship equation which defines Productivity Type 1 as time in man-hours (mhr) divided by volume in cubic metres (m^3). It is essential that all units used by the parameter model be defined and entered into the "Standard Unit" database in order for the module to function correctly.

The Standard Units database will be accessed from the Main Menu by selecting Standards under the SYSTEM subheading and then selecting Standard Units. Once the user is viewing the window, a scrollable list of existing standard units will be seen giving the user the option to add or edit any of the units. The user will then be able to define the type of unit, its measure, the basic unit, and an equation field which will give the module the ability to automatically convert the units (see Figure 2.12). Entering new standard units is relatively straight forward. The "Type" field will serve as both the unit name and the descriptor field (although the program will internally use the index number to reference the unit as there may be similar unit names). The "Measure" field will serve as a variable label. The "Unit" field will display the quantitative value which the units are based on, for example mm represents millimetre, hr represents hours and mhr/m3 represents man-hours per cubic metre. If the last example given is considered, mhr/m3 representing productivity (see Figure 2.12), is actually a combination of two other existing units, namely manhours (mhr) divided by cubic metres (m3). In this way new units can be created from the existing standard units.

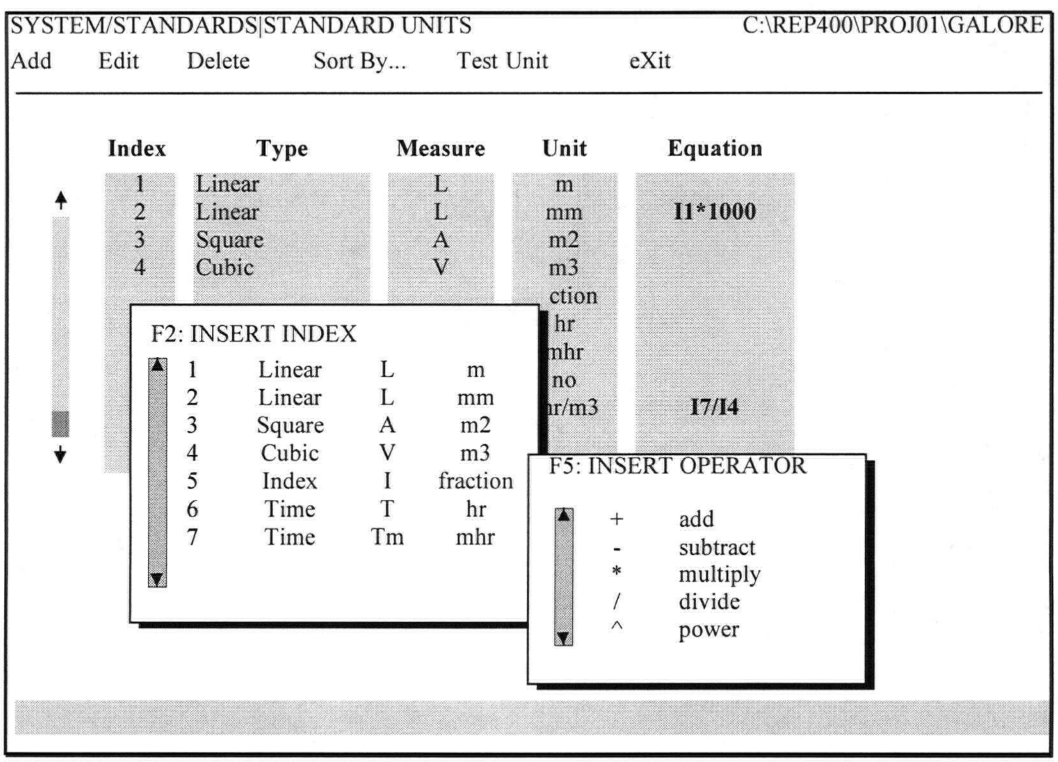

Figure 2.12 Standard Units Window

2.6.2 Standard Components

The Standard Components window (see Figure 2.13) can be accessed from the Standards option in the System sub-menu. The database of standard components is a container for components commonly found in various projects. When accessed during the creation of a new parameter model, the various components can be utilized and assigned to particular systems. When new components are created and saved in this database, they will maintain all the properties of linked lower level components which had been previously assigned to them (except for parameter values), including the parameter formulae, units, and internal links and associations made during their creation. The benefit of using these predefined components is considerable, and as the database of standard components expands, one of the significant powers of the parametric modeling module can be fully realized. Its at this time that the user begins to appreciate the benefits gained in time savings and overall accuracy and efficiency in the preliminary estimating and scheduling of projects.

As stated above the user can access this module from the standards option under System where a new component can be added or an existing component can be modified or deleted. No components should be removed from this list as this may invalidate the results of any previous parameter models in the system which use the component. Furthermore, if a component is to be modified, it should probably be copied and given a new name for the same reason. The typical way that this the Standard Component List would be used is by being accessed from the Physical Component Breakdown Structure (PCBS) window during the building of a new parameter model. As new levels and sublevels are added to the model, the user can at any time access the standard component list PCBS window by pressing the F2 key. Once in the window, an existing component can be added to the current PCBS path by selecting the "F2: Add To PCBS" function. Alternately a new component may be created or an existing component may be edited to suit the users needs by selecting the appropriate component and function from the menu bar. If a new component is created the name and description fields will be completed and then the component can be added to the PCBS.

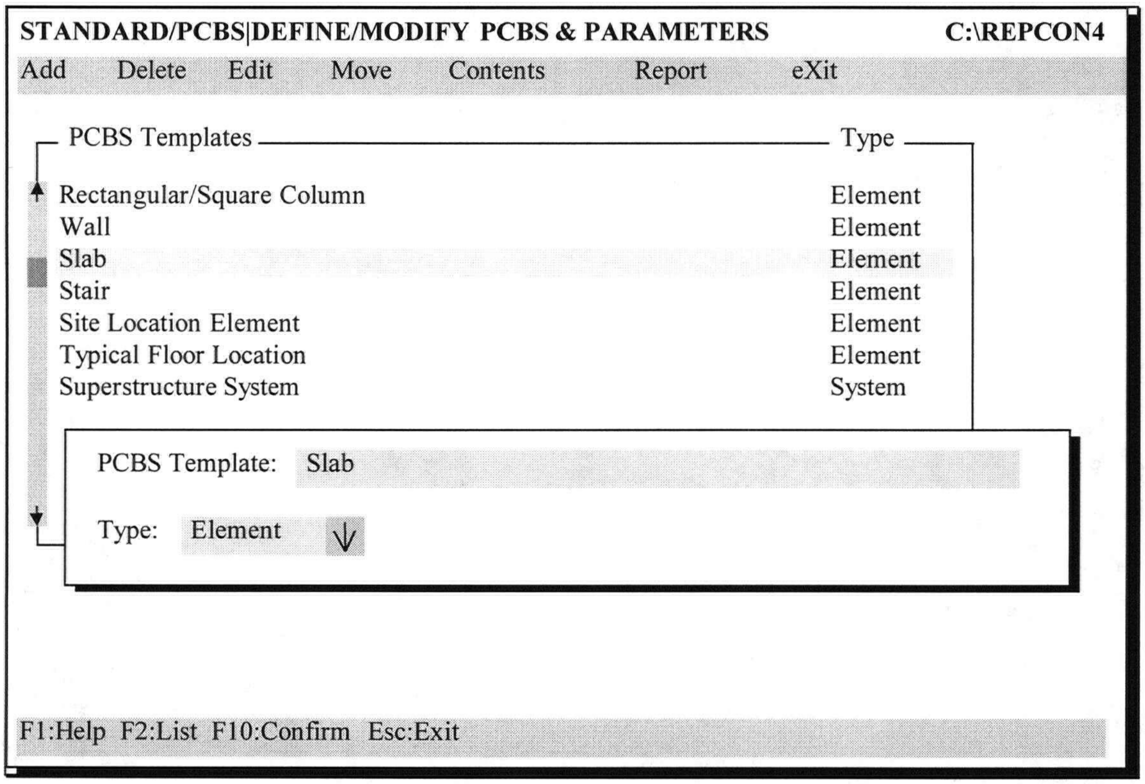

Figure 2.13 Standard Component List Window

2.7 Project Reports and Output

Project reports and output may be viewed or printed in a number of different ways in either tabular or graphical forms. These reports would be accessed directly from within the PCBS window under the Reports submenu (see Figure 2.14). The project manager would have the ability to define most reports and output in a limited number of user defined forms by specifying the profile content. Furthermore, customizable reports could be defined to provide the user with the flexibility of arranging the information in any format which would be most suitable for their specific requirements.

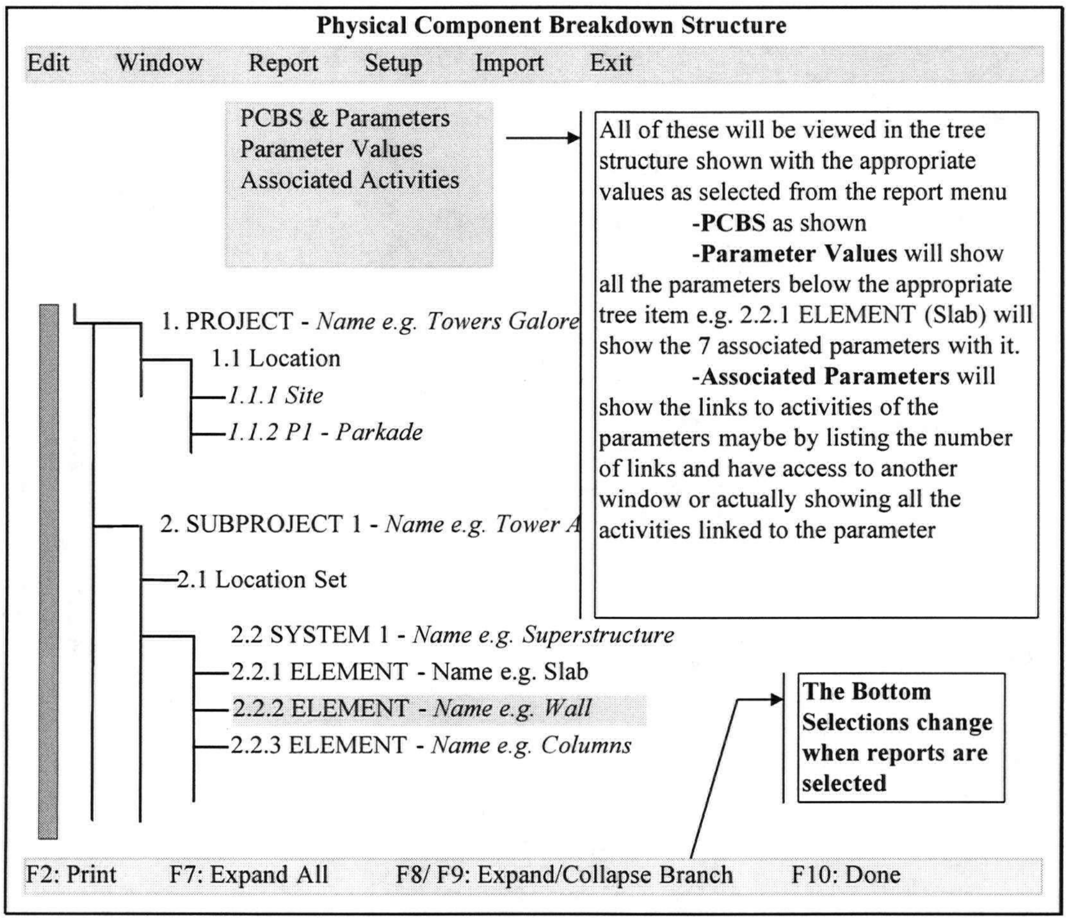

Figure 2.14 The Physical View Of The Project

2.7.1 Calculating Output Data

The Calculate Global Values window (Figure 2.15) will allow the user to define calculations for required output. These calculations will be different from the other calculation window used to calculate formulas for the parametric model. These calculations will be performed on the completed parametric model to give the user pertinent information that might be useful, such as the total volume of concrete for the entire structure or just for the slabs, walls and columns individually. Numerous tests will be performed when "F10: Confirm" is selected to ensure that valid results are calculated from the following dialog box such as:

- a test to ensure that all appropriate parameters are used
- a test to check all the units.
- a test to check all the formulas function properly
- a test to ensure that there are no overlapping or repeated values used

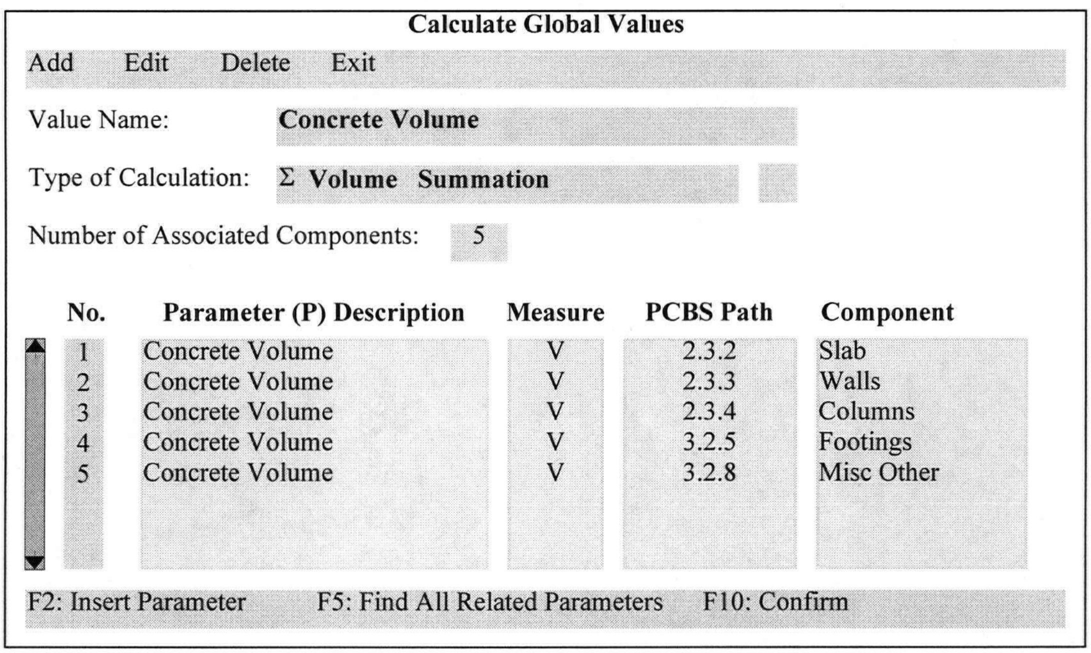

Figure 2.15 Calculation Window For Output

2.7.2 Assigning Resources

In combination with the physical view, the assignment of resources to the process view (i.e. assigning resources to activities), gives the capability of calculating resource productivity, cumulative productivity and average productivity relating to the specific components making up the parameter model. These productivity calculations can be performed once the associations between the defined activities and the physical components have been established. As shown in Figure 2.16, the planned productivity of the aforementioned activity or activities can be graphically represented over the location ranges of the parametric model. The graphs show both the ongoing productivity and the cumulative productivity respectively with both their associated averages. Once cost-coded payroll data is assembled and actual productivity is overlaid onto the planned productivity, the progress of the project as well as any potential problem areas with the resource allocations and productivity can easily be identified and corrected.

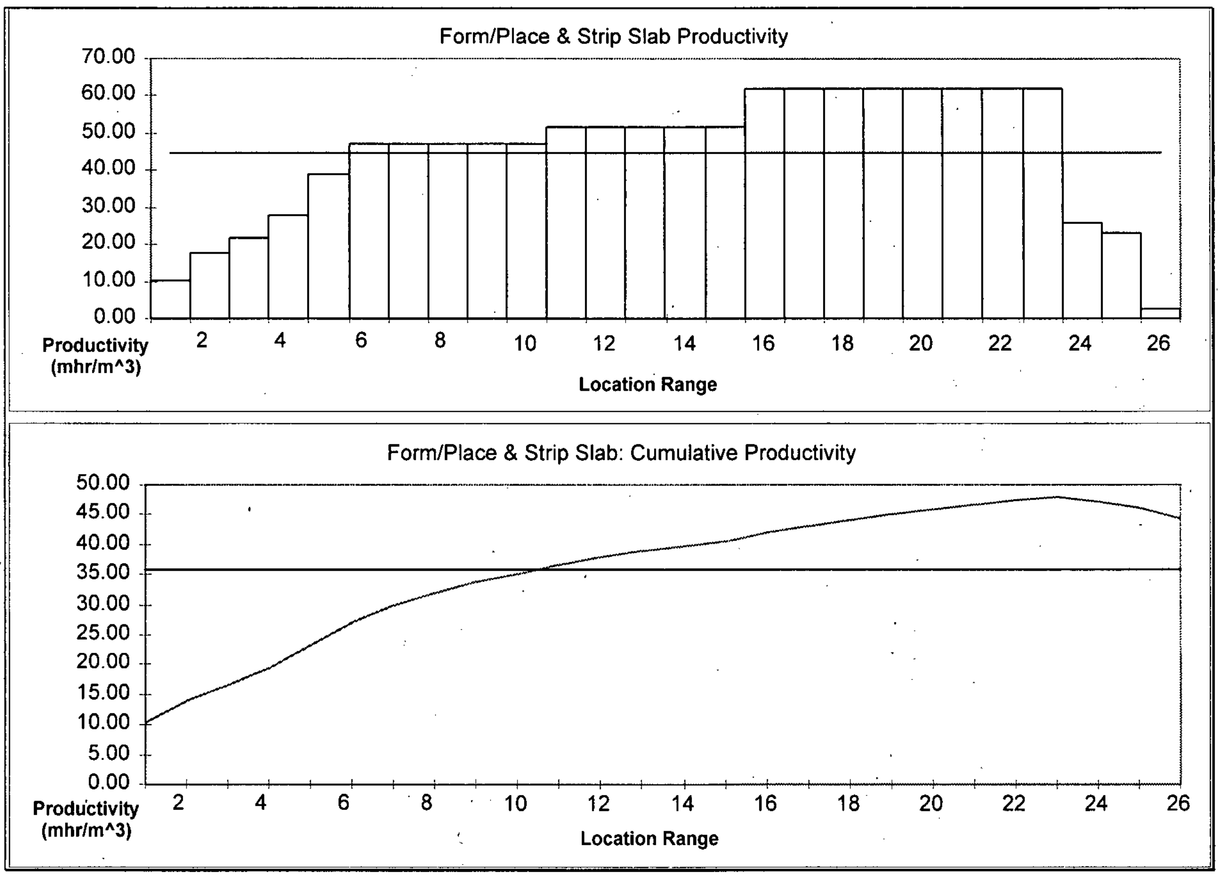

Figure 2.16 Planned Productivity Measure of Form/Place & Strip Slab

2.7.3 Pay Item Data

The Pay Item Breakdown Structure (PBS) has been modeled similarly to the PCBS and provides for a tree structure hierarchy to be assembled to represent all pay item requirements. Each pay item can be mapped onto the Physical Component Breakdown Structure by associating the appropriate pay items with the relevant physical components. Having the pay items linked with the physical description of the project will enable the system to perform some very powerful functions. Firstly, the system will be able to calculate both planned and actual unit costs for specific project components based on the materials used and resources allocated towards them. Secondly, comparisons can be made between the planned and actual productivity levels giving the opportunity to locate problem areas and strategically improve productivity where possible. Furthermore, these tools enable modifications to be made to the physical quantities of the parameters to represent any ongoing changes to the project and automatically have "up to the minute" actual costs and actual productivity levels without disrupting any linkages or making any changes to the system. Provided that some consistency exist between the pay items breakdown and the physical component breakdown, an exact one to one relationship need not exist between the two.

2.8 Conclusion

The parametric modeling system proposed herein is designed to provide a physical description of a project, and with associations to a defined list of activities, resource assignments and pay item data, offering the benefits of increased efficiency and the ability to more effectively plan, monitor and analyze a project from its conception through its completion. It should provide greater insight into a contractor's methods of planning and scheduling a project, tracking of unit cost and productivity rates and provide more effective means of value engineering and cost savings. The following chapters will consider actual practices as they relate to both the design concepts examined in this parametric modeling system with pre-construction, construction and post-construction project management functions.

CHAPTER 3 - CASE STUDY - WHAT IS ACTUALLY DONE

3.1 Introduction

A case study was done using an actual project and formwork contractor, both based in Vancouver, British Columbia. The focus of the study centered around the construction of the superstructure of a residential concrete high-rise building. This type of structure and scope of work provides an ideal scenario for the type of modeling described in this thesis. The objectives set for this case study were to examine the actual methods used by a construction company and establish the feasibility and requirements to adapt a parametric modeling system to suit the type of work they perform.

3.2 The Project

The project studied is a large, multi-use facility which consists of several towers. For the purpose of this study, one tower forming approximately 20 % of the overall project was focussed on, namely a 25 storey concrete residential structure (see Figure 3.1). As described later, the tower studied has a number of unique characteristics which provide challenges as well as demonstrate the capabilities needed of a software system.

The tower being studied consists of 170 strata titled residential units each of approximately 700 to 1000 square feet of living space. The construction is that of a standard concrete high-rise project in Vancouver with concrete flat plate slabs each approximately 7000 square feet, concrete columns and a central core area furnishing seismic provisions and containing two elevator shafts and scissor stairs (Figure 3.2).

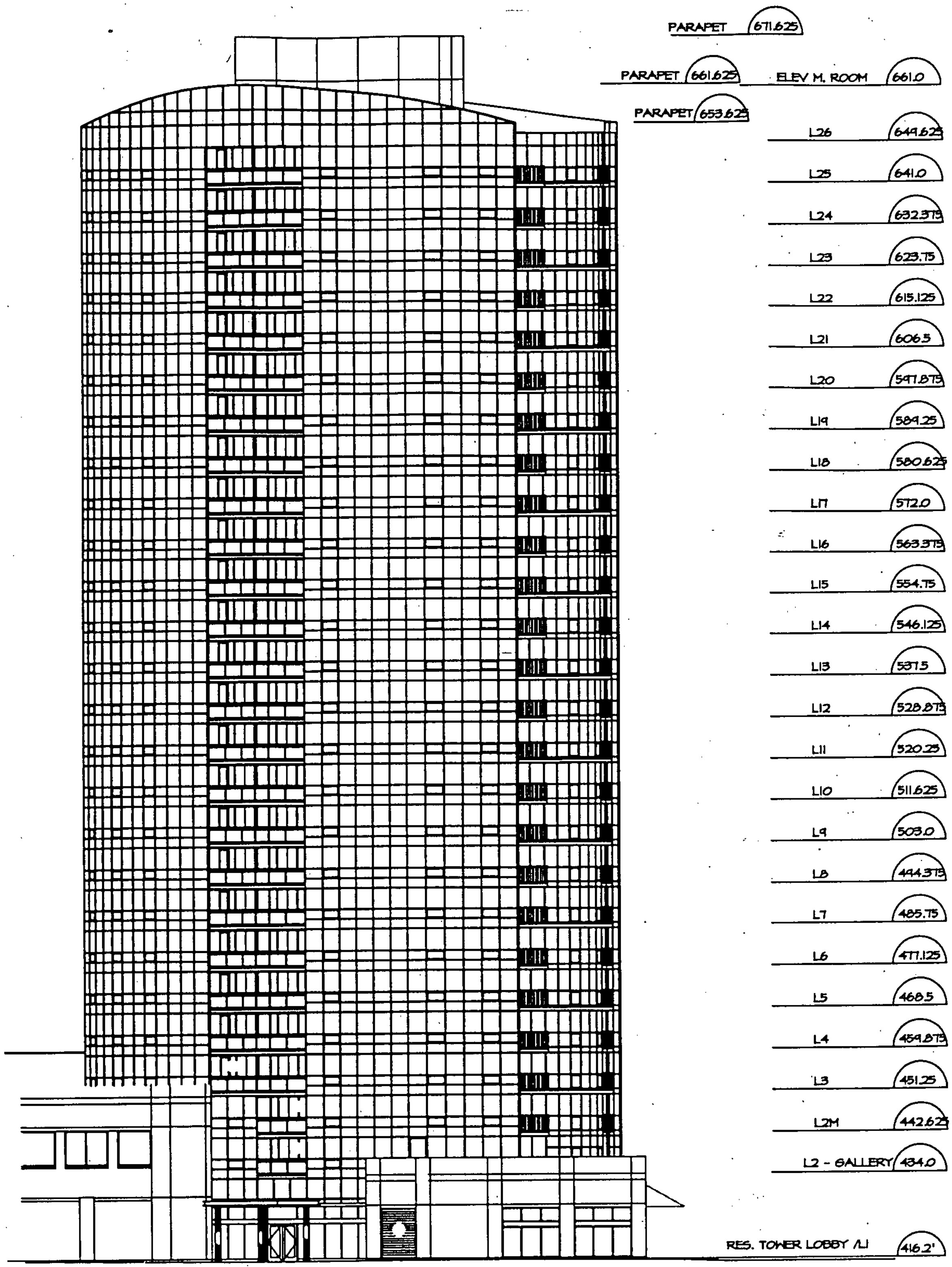

Figure 3.1 Elevation of Project Studied

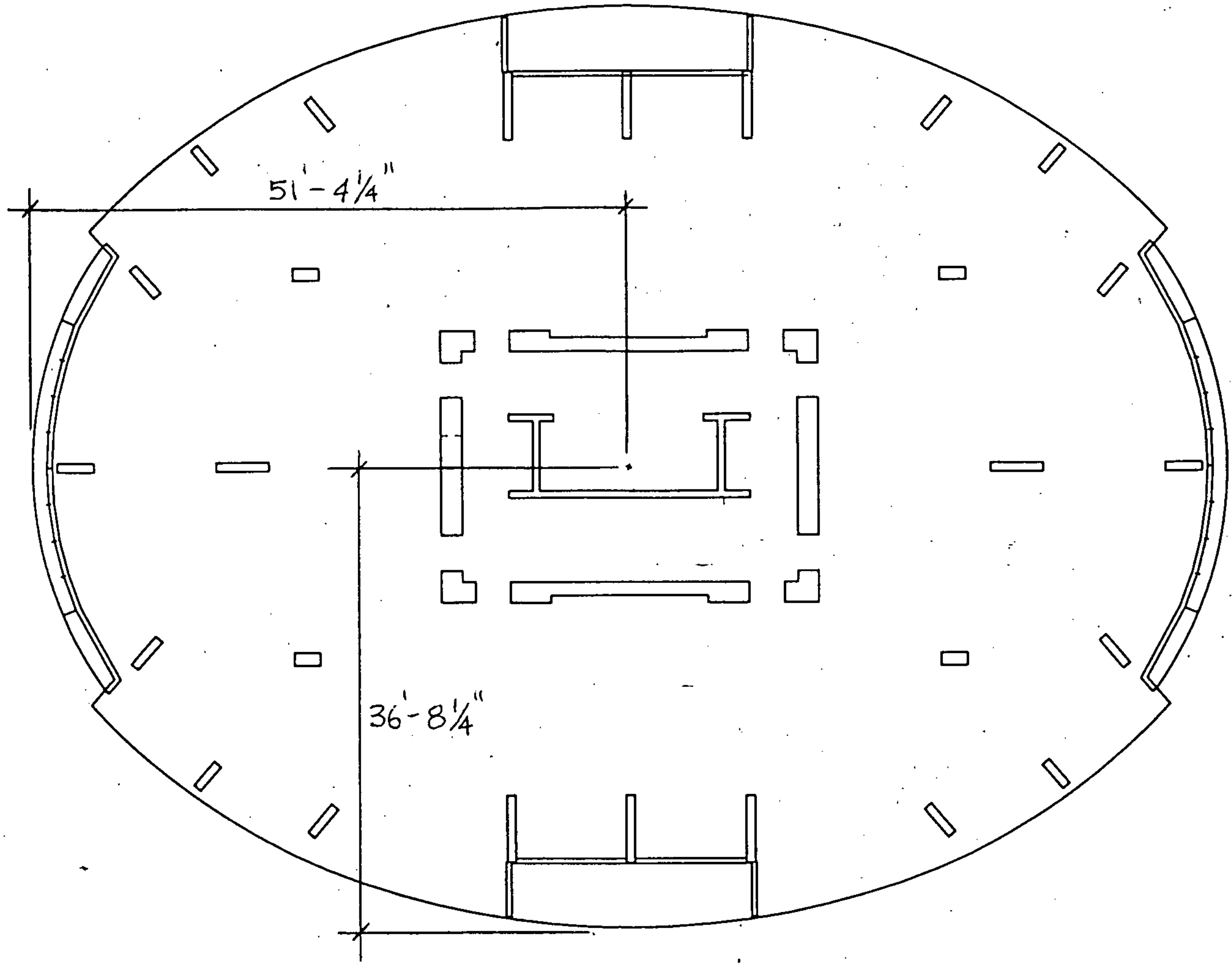

Figure 3.2 Layout of Typical Floor

The unique semi-elliptical shape of the building (see Figure 3.2) poses considerable constructability issues. The first issue which must be dealt with is the layout of the structural elements making up the building. As the slab is not a true elliptical shape (it is actually made up of 6 different radii each with its own unique center), the additional complexity of laying it out and determining the placement of formwork for walls, columns, and slab edge segments (88 segments in total), as well as for mechanical and electrical rough-in must be considered within the planning and scheduling of such a slab. To overcome part of this additional work, custom steel forms were fabricated to simplify the slab edge segment details. However, even the layout of these had to be individually surveyed for each floor.

Figure 3.3 Typical FlyForm Table

Another issue which had to be dealt with was the quality of work, because a portion of each floor slab and slab edge is exposed. The flat plate slabs were constructed using fly forms which are typically constructed of steel frames and form ply at the beginning of a project and used throughout the construction of the typical floor and then disassembled once complete (see Figure 3.3).

Figure 3.4 Rough Ceiling Finish

The form ply tends to delaminate and deteriorate after several uses resulting in rough concrete surfaces which must be ground and parged if the form ply is not replaced (Figure 3.4). The formwork contractor had to consider the effects of both cost and scheduling to decide on the appropriate direction to take (i.e. grinding the concrete surfaces after the forms are removed or replacing the form ply after every 10 - 12 uses).

3.3 The Company

The company studied is based in Vancouver, British Columbia and is well known as a leading formwork contractor in the area. The company has been in business for several years and was involved in the majority of the high-rise construction projects underway when this thesis was prepared. The company specializes in residential and commercial concrete construction projects. Although one of the larger formwork contractors in the lower mainland, the company is a family owned business which employs approximately 300 full-time, on-site staff including carpenters, labourers and foremen, and approximately 10 office personnel including management, secretaries and estimators. The firm runs a "very lean operation", unlike other firms which tend to be more top heavy in terms of management. The project studied employed approximately 150 of the company's staff on site at the peak period.

The company takes a simplistic approach to all aspects of its work, namely from the initial estimating and planning through tracking of its work and finally to analyzing their completed jobs. Rather than using sophisticated means and methods to plan and estimate work, they are more of a "shoot from the hip" type of company with most of the planning of jobs done in a group environment with the two partners and their supervisory staff which will be running the job after each has completed their own cursory evaluation. After being provided a schedule giving completion dates for various aspects of the job, the firm's owners will decide how long the job should take (or the timeframe in which they believe their men can complete the work), and for the most part, has been found to be relatively accurate. Furthermore, they tend to keep cost and profit information to themselves to prevent their "secrets from getting out", not wanting to share their experience or have others know how much is being made.

When considering new work, the company's estimates are based on its past historical information and experience with these rates and the insight of the owner's experience. They derive an approximate dollar figure of what the job should cost taking into consideration rough square footages and an approximate duration for the work and then work the data backwards based on their company's standard historical productivity rates.

3.4 The Level of Detail Used

As indicated earlier, the company studied takes a rather unsophisticated approach to the level of detail used in various aspects of its estimating, monitoring of work and post mortem review. An estimate is formulated relying on unit rates for the basic structural elements, namely, walls, columns and slabs. The cost and manpower requirements for these elements are typically calculated based on the quantity of that particular element (i.e. columns) or the square footage of formwork contact area (i.e. walls and slabs) with some variation (based somewhat on subjective judgement) given to unique or special circumstances. The typical unit rates the company uses are believed to have enough history behind them (including aspects of similar jobs in both size and complexity) that this simplistic approach is effective in their estimates.

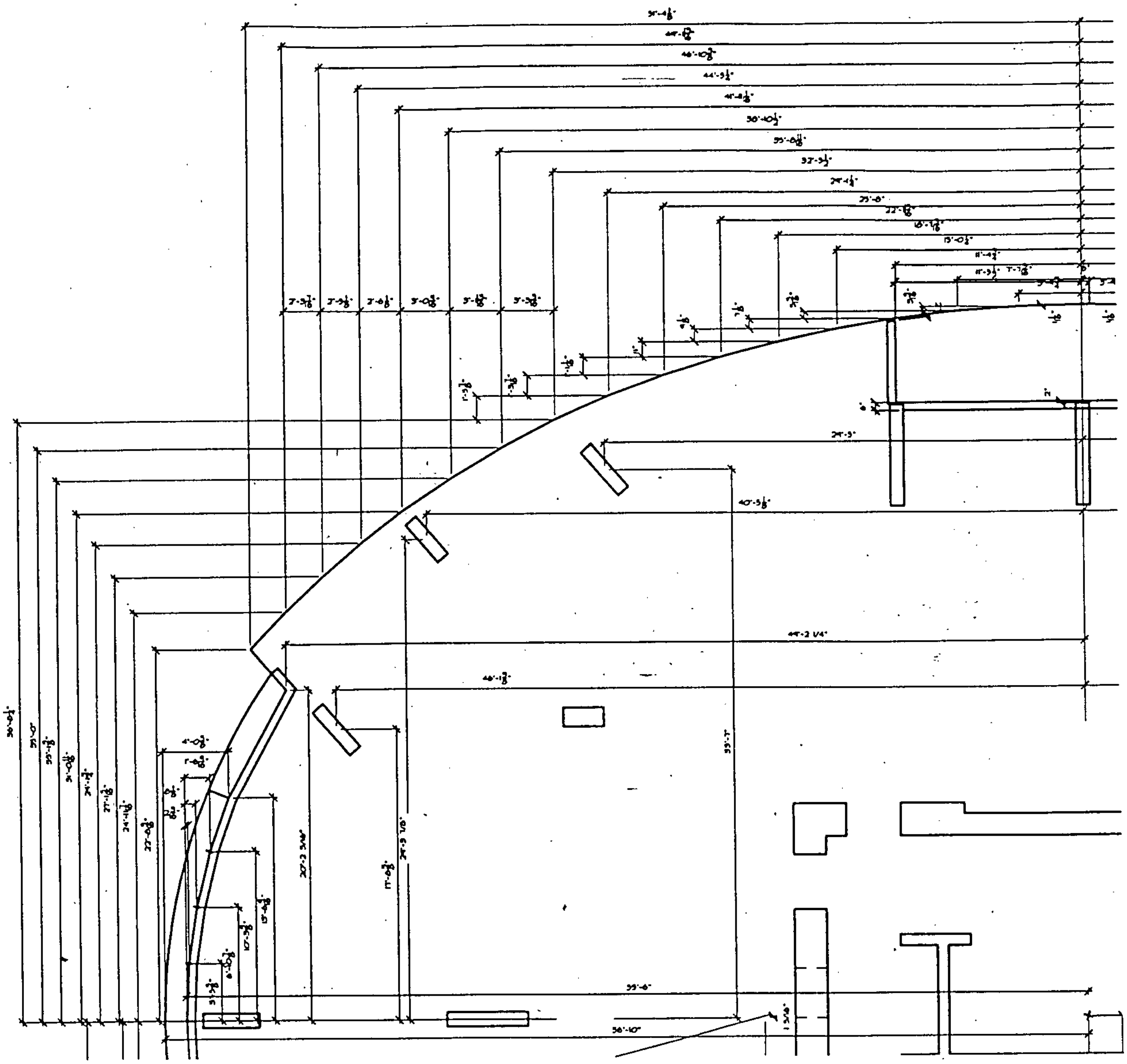

Figure 3.5 Slab Edge and Column Layout

A concrete column is considered the most basic element of the structure in terms of both estimating costs and scheduling the work. The company's philosophy essentially states that "a column is a column is a column". Thus, columns are counted and a cost, timeframe and labour resource usage is assigned for the total number of columns in a particular location. There is essentially no thought given to whether the column is round, square, rectangular, architecturally finished, etc., or whether it is being free-formed, gang-formed or constructed using some special forming material such as sonotube, unless there are extenuating circumstances (i.e. double lift column, a large number of special columns on a particular project, etc.). This is surprising, because, for example, the material and labour cost for using a sonotube to form a column would be considerably higher than that of a gang-form. Firstly, the sonotube may only be used once and has a higher labour unit rate than that of a gang-formed or prefabricated steel column which may also be reused a number of times. Furthermore, the labour involved in placing, leveling, pouring and stripping a sonotube column is also higher.

Figure 3.6 Project Overview Showing Radial Layout

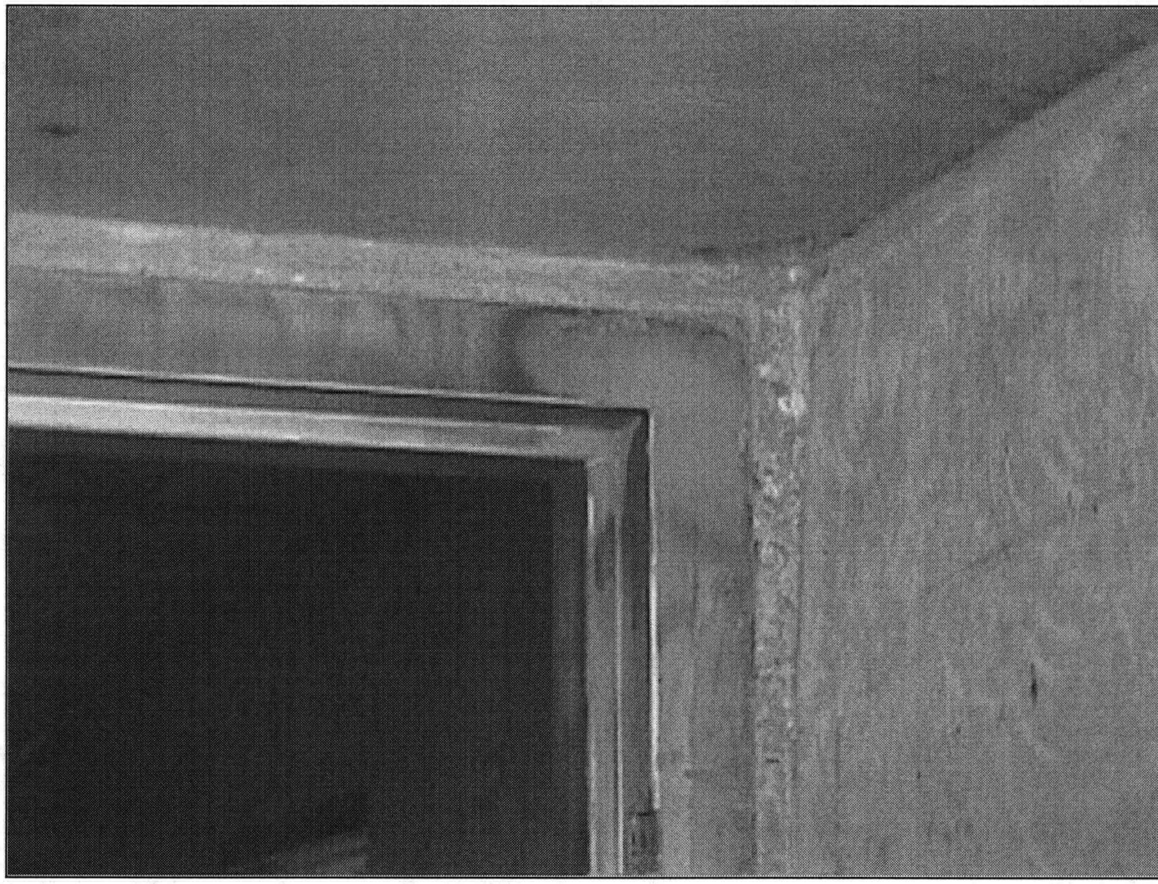

Figure 3.7 Misaligned Door Frame

When considering walls, a slightly more detailed approach is taken in the estimate by considering the various different dimensional parameters. To estimate walls, the typical measurements are used: length, height and thickness of wall will give the dimensional information required. However, as the values of these parameters increase, their relationship to cost is not linear. On a typical "Vancouver Special" high-rise, the parkade, typical floor and roof structure walls tend to have a basic configuration and are formed up with standard gang panels, etc. (i.e. easy to form and therefore estimate). For many of the newer projects in Vancouver, however, and particularly for the project studied, many of the structural elements, and particularly the walls are very "non-typical". Given the radial nature of the project (see Figure 3.5 and Figure 3.6) and layout most of the elements, particularly a majority of the walls were curved, adding considerable cost and time to the layout, material and labour costs. The company, in estimating these walls essentially added a factor to the wall material and labour quantities based on some past experience with the construction of curved walls. It was noted, however, that these adjustments were minimal and not to any degree o accuracy.

Greater consideration is given to the two other wall parameters, namely wall thickness and wall height. Wall thickness is considered in some situations. For example, situations arise where walls are too thick to allow door frames to be set straight and true so they must be installed afterwards. It was discussed that the benefit on the productivity end sometimes outweigh the higher cost to set frames afterwards. Even if the benefit didn't outweigh the costs, there may be cost and time savings gained afterwards of not having to repair door frames. This was discussed at the planning stage; however, it was not quantified or priced at the initial estimating stage.

In reference to the study project and Figure 3.7, a number of suite entry door frames in the building which had been cast into the core walls (2' - 0" thick) needed to be jack-hammered out and replaced (see Figure 3.8). This was because the core walls were leveled once the core wall forms were "buttoned up", which led to the frame being slightly out of skew. Additionally, a number of the frames bowed inward due to the hydrostatic pressure of the concrete, and had to be jack-hammered out and replaced at the formwork contractors cost.

The finished height of a concrete wall may have significant cost and schedule implications. Thus height dimensions are reviewed carefully. Typically as wall heights exceed the standard 8' - 0" floor to floor height, the cost and schedule implications to build them increases exponentially, for a number of reasons. First and foremost, labour costs increase significantly as wall heights increase, as workers must now erect and "tear down" scaffolding as well as operate in that same environment.

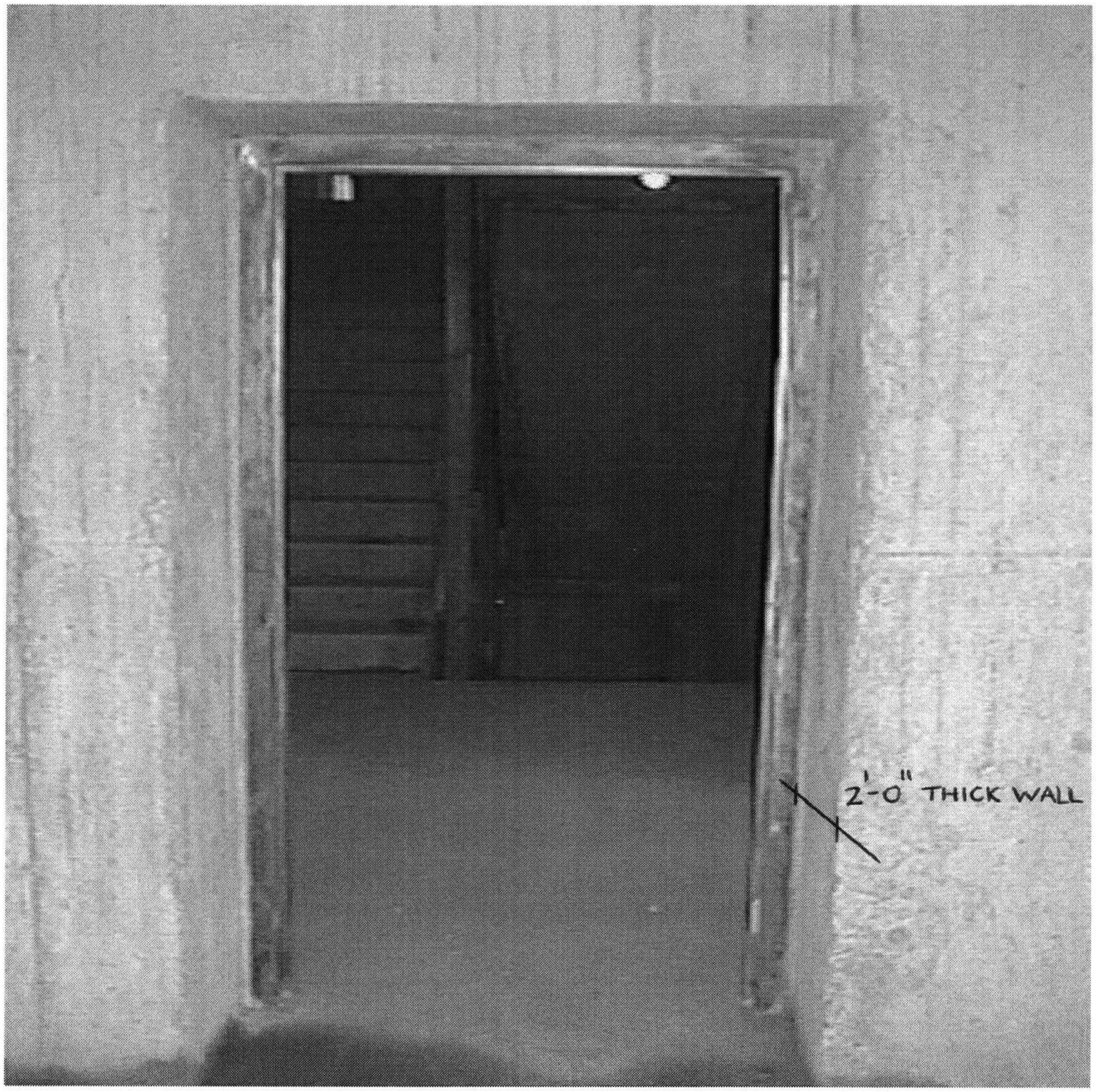

Figure 3.8 Door Frame Set in 2' - 0" Thick Concrete Wall

Working on scaffolding or areas higher than 10' - 0" above the ground provides workers with limited access to all areas and requires fall protection be worn (Figure 3.9), reducing productivity and increasing the timeframe to complete the same quantity of work.

Figure 3.9 Safety Requirements When Flying Tables

Slabs are probably the most carefully scrutinized structural elements considered when producing the estimate and planning the schedule. Slabs are typically divided into slab on grade, flat plate slabs, one way slabs and two way slabs and priced accordingly.

Figure 3.10 Typical Formwork

Still, the same properties of each are considered, namely square footage of the slab, square footage of the formwork contact area, the number of soffits, configuration of the slab and columns (complexity of layout), etc. Considering the study project, the suspended slabs up to level 3 are radial, therefore based on past experience, additional labour and material requirements had to be considered. Again, similar to walls, the height of the soffit of a slab plays a significant role in estimating and planning a job. The study project has standard height walls through the typical floors of the residential tower (see Figure 3.1); however, the first three above ground floors and one parkade level are double lifts (i.e. approximately 16 feet floor to floor height), adding significant costs and time. For high slab heights, the cost implications from a labour standpoint can be extraordinary, not to mention the additional material requirements such as for scaffold framing (3 frames high) which is usually rented, and crane time as most of the formwork can no longer be manhandled as for a typical 8 foot lift. The cost of scaffold frames for such a slab will further be increased as now these frames are required for reshoring which is typically done using more cost effective means such as with timbers or "jacks".

The required level of finish of a concrete surface plays a big factor to which serious consideration must be given. For example, the reveals and "ties holes" may have to be matched up vertically and/or horizontally. Sometimes the finished surface of the form is the finished surface of the concrete requiring the use of special material or particular type of form oil which may have to be rolled on versus sprayed therefore affecting productivity. Concrete finishing of slabs and pour joints need to be considered. The firm has found that it is more cost-effective to place sprayed foam in the plywood joints once they start to spread slightly and then grind the soffit of the slabs and walls, than it is to re-cut material for the forms. Some foremen would rather grind the slabs at a later date than remove the concrete slurry left under the slab soffit immediately after the forms have been stripped (see Figure 3.11). This may not directly affect the productivity aspect as much as the overall job cost. If productivity is gained in formwork, it is usually as a result of speed and efficiency and at the expense of quality. You lose the benefit of the high quality which has to be brought up to par, resulting in concrete finishing costs rising significantly.

Figure 3.11 Typical Ceiling Grinder

3.5 Estimating A Project

The company to some extent uses a traditional approach to estimating; work out quantities (i.e. square footage of contact soffits, volumes of concrete), then enter this information into a spreadsheet program to achieve totals. The actual quantity takeoff is done using a planimeter and scale. Based on these quantity values, unit rate adjustments or "extra value charges" are made (e.g. for different types of slabs such as flat plate slabs versus slab/slabband systems and/or for different thickness of concrete). Other items considered are soffit heights (which are a significant factor), and flat soffit versus one way beams versus two way beams. Both standard and adjusted unit rates are based on historical data which has been collected over the years.

Before a job is estimated, it will be assessed by doing a preliminary analysis on it to see if they want the job. At this point the status of their manpower as well as completions and start ups of other work already taken on will be considered, (i.e. find out when this job will come on line in relation to other jobs). Other factors considered are current company owned resource allocations. For example, they will see which cranes are available either as their own equipment or through rentals. Finally, the duration of the job being considered is reviewed. Once all these factors have been assessed and the job meets the company's criteria, the firm will quantify it, tender the job, and then they enter into negotiations to take on the work. Based on the company's track record and reputation to date, they have been relatively successful at "getting to the table", possibly more through negotiations rather than through the formal tendering process.

The final planning of the job (i.e. internal company negotiation between the firm's owners and it's foremen deciding how long they require to do the work; the foremen always want a longer duration than the owners) typically takes place the day before the job closes. At this time the detailed scheduling and resource assignment for the job takes place, with consideration being given to how many men they will have on the job, the number of man-hours expected per area or scope of work and the number of crews that will be assigned to the job. Further to this, the anticipated labour and material costs for the job as well as other secondary costs such as engineering, etc. will be calculated and verified to cross check against the estimate.

Labour budgets are set based on how long it takes to construct various elements. For example, if a typical high-rise flat plate slab can be poured every five days, 1.2 floors (i.e. 6 floors will be poured in 5 weeks) will be poured every week, based on a six a day work week with an average 10 hr workday and based on the expected number of workers. This average 10 hour workday (8 hours regular time + 2 hours overtime) is typical for the company and is actually part of the unit cost when projecting estimates and schedules. All the company's previous historical data is also based on this same 6 day, 10 hour per day work week and therefore the historical unit rate data already incorporates the overtime factor. Industry standard indices are not typically used. In terms of labour and productivity rates, these will essentially be based on unit rates which are arrived at through the company's own historical data.

At the end of each job, the data is looked at to see where shortfalls occurred, namely, where they made money versus where they should have paid a little more attention. This is done in a very broad sense by making comparisons to previous similar projects. Then the next estimate will incorporate some minor adjustments, based on previous job experience. Historical data is looked at in a broad sense, i.e. general areas are considered to see if they are "... selling themselves short".

3.6 Planning and Scheduling a Project

As previous noted, the firm's owners/estimators will come up with a draft schedule based on completion dates provided by the general contractor, of when they think the job will be done by, and then the field supervisory personnel are called in to see what they think of the draft, to critique it; and adjustments are made as required.

Activity ID	Activity Description	Orig Dur	Actual Start	Actual Finish
High Rise Level 15				
Structural Slabs				
R150-33101	FRP Struct Slab - L15 High Rise	3	14JUL98	17JUL98
Cure/Strip/Reshore/Strip Reshores				
R150-34102	Cure/Strip/Reshore Slab - L15 High Rise	4	18JUL98	21JUL98
R150-34103	Strip Reshores 50% Slab - L15 High Rise	2	04AUG98	05AUG98
R150-34104	Strip Reshores 100% Slab - L15 High Rise	2	11AUG98	12AUG98
Core Walls				
R150-31151	FRF Core Walls - L15 High Rise	1	18JUL98	20JUL98
R150-31152	Place Core Walls - L15 High Rise	1	20JUL98	20JUL98
R150-31153	Cure/Strip Core Walls - L15 High Rise	1	21JUL98	21JUL98
Columns (Area 1)				
R150-31401	FRP Columns - L15 High Rise	1	18JUL98	20JUL98
R150-31402	Cure/Strip Columns - L15 High Rise	1	21JUL98	21JUL98
High Rise Level 16				
Structural Slabs				
R160-33101	FRP Struct Slab - L16 High Rise	3	21JUL98	24JUL98
Cure/Strip/Reshore/Strip Reshores				
R160-34102	Cure/Strip/Reshore Slab - L16 High Rise	4	25JUL98	28JUL98
R160-34103	Strip Reshores 50% Slab - L16 High Rise	2	12AUG98	13AUG98
R160-34104	Strip Reshores 100% Slab - L16 High Rise	2	17AUG98	18AUG98
Core Walls				
R160-31151	FRF Core Walls - L16 High Rise	1	25JUL98	27JUL98
R160-31152	Place Core Walls - L16 High Rise	1	27JUL98	27JUL98
R160-31153	Cure/Strip Core Walls - L16 High Rise	1	28JUL98	28JUL98
Columns (Area 1)				
R160-31401	FRP Columns - L16 High Rise	1	25JUL98	27JUL98
R160-31402	Cure/Strip Columns - L16 High Rise	1	28JUL98	28JUL98
High Rise Level 17				
Structural Slabs				
R170-33101	FRP Struct Slab - L17 High Rise	3	28JUL98	31JUL98
Cure/Strip/Reshore/Strip Reshores				
R170-34102	Cure/Strip/Reshore Slab - L17 High Rise	4	01AUG98	04AUG98
R170-34103	Strip Reshores 50% Slab - L17 High Rise	2	18AUG98	19AUG98
R170-34104	Strip Reshores 100% Slab - L17 High Rise	2	24AUG98	25AUG98

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Critical Path

Figure 3.12 CPM Schedule Provided by the General Contractor

Consideration will be given to the available work area: they match their equipment to the size of the job, look at how material will get loaded, examine how they will move from one area to another, and then size the crews accordingly. Consider a large slab (e.g. 12,000 to 14,000 square feet), more effective resource utilization could be realized by breaking out the slab into two smaller areas of approximately equal size and staggered cycle times, without any significant effects to the schedule, rather than attempting to form and place the entire area at one time with a larger crew. For example, by staggering the work cycles between the two areas by a couple of days (i.e. walls and columns of the second area will follow two days behind the walls and columns of the first area), therefore taking 6 to 7 days to complete a floor as opposed to two completely separate pours taking 8 - 9 days, and furthermore, completing the work at a much higher productivity rate than either completing the floor in one or two individual cycles. As well, cost savings and productivity increases would be realized, firstly, as only half the material would be required to complete the work, and secondly, as material handling distances would be considerably reduced (only require to move men and material over to the next area). This decision is left to the determination of each individual foreman. They typically like to see slab sizes of between 7,000 SF to 10,000SF for a typical 4 to 5 day cycle, depending if the concrete is pumped or craned and whether the slab deck is formed or made up of tables. Free-forms (i.e. standard scaffolding, planks and form ply similar to those used to form a parkade) are about 80 to 85% as efficient as with fly tables, again dependant on the difficulty of the deck. Typical walls and columns (standard 8'-0" high sections) essentially don't change in complexity or difficulty.

When planning manpower allowances, significant consideration is given to cranage. A crane can typically service 20 -30 men. This also takes into account the type of work which is being done, for example, parkade structures which will maintain a typical crew size of approximately 30 men versus typical floors of a highrise which only supports 13 - 15 men, yet require a higher level of crane usage rate per unit area. Note that a crane is typically available for the duration of the project so the manpower allowance does not really fluctuate as the crew works up a building. For example, for the project studied, there were not 20 - 30 men working on the typical floors of the high-rise tower. However, there were two to three crews (including the crew on the typical floor, totaling approximately 20 -30 men at one time) working within the crane's radius and performing various tasks (such as pre-cast stairs, curbs and architectural features) on the lower levels surrounding the highrise tower, therefore the crane essentially serviced all these men with the number of men remaining approximately constant. As for the number of workers on a typical slab, it is essentially left up to the foreman to assemble the crew he wants to work with.

The company tries to maintain as large a ratio of field supervision to workers (i.e. maximize the number of workers per foreman) as possible. For example, at the study project there are two labour foremen for the whole job (for their own forces, not including their subcontractors such as the stripping crews, etc.). There is sometimes a diversified type of crew used on a project, say one carpenter foreman, a few carpenters and a couple of labourers, and at other times there is simply a foreman and carpenters on a crew, and when needed, the foreman calls the labour foremen and requests some labourers to perform certain work. It depends on how the crew is set up with each carpenter foreman being given the flexibility to set up his crew the way he feels most efficient. This may change based on the particular scope of the work. For all aspects of the study project (entire project), and due to its scale and complex scope, there were about 6 foremen (4 carpenter foremen and 2 labour foremen), outside of two general foremen (who oversaw the entire project). The typical ratio of foremen to workers essentially mirrors the crane ratio of 1: 25 to 30. Smaller jobs are not normally assigned a labour foreman.

Cycle time for a typical floor is set to a particular duration and then the plan to meet the cycle is set, for example, the study project was set to a 5 day cycle. Sometimes the firm will take a cross section of the job and determine a timeframe to complete that scope of work. Typically a crew will be sized to fit the typical cycle time or timeframe (see Figure 3.13). First a cycle time will be established and then a plan to meet the timeframe set.

1 Week Highrise Cycle (Formwork Labour Requirements)	Crane/ Rigger	Foremen	Carpenters	Labourers
Day 1: Strip Walls & Fly Tables	2	1	5	5
Day 2: Layout, Slab Edge, M & E Rough-in	2	1	5	5
Day 3: Layout, Slab Edge, M & E Rough-in	2	1	5	5
Day 4: Pour Concrete	2	2	2	9
Day 5: Vertical (Walls & Columns)	2	1	5	5

Figure 3.13 Typical Cycle From Formwork Contractor

Often, the timeframe for completion will be dictated by the general contractor. Concrete strengths, etc. may be revised from the original design strengths, for example, if a higher strength mix is required to meet the cycle time and drop/strip forms earlier, and is considered and negotiated with the general contractor (and the structural engineer involved). This is often done at tender time (i.e. by having a clause in the contract which states that they need "workable concrete" to suit cycle time, weather conditions etc.).

3.7 Construction Methods

There is a definite correlation between the construction methods and materials used and the construction schedule, with one often dictating another. Both during the estimating and scheduling phases is where most of the strategies for the project are established. For example, decisions as to whether walls and slabs are loose formed as opposed to flyformed or the use of gang panels are made. It is most often to their advantage if the formwork can be made modular.

The interdependence between method and material can clearly be demonstrated by considering the use of steel forms around the radial slab edge of the project studied. The company chose to use custom fabricated steel forms for the perimeter slab edge of all the typical forms and roof slab in lieu of the standard wood forms constructed on site. Although the cost of producing steel forms (which would only be appropriate for this particular project), was higher than that of using standard bulkheads it was decided that this method would be both more cost effective and benefit productivity over the duration. The decision to use these custom forms was made long after the job had started (i.e. it was not part of the original plan). It was made shortly before the start up of the typical floor forming with the final decision being left to both the tower foreman and site layout foreman. Firstly, the complexity of the slab edge was considered as the slab edge was pseudo-radial with most of the 90 odd segmented sections being different lengths. It was determined that the potential for error was very high if each segment had to be formed up on every floor. Secondly, the allowable tolerance was considered. The building envelope enclosure for the building consisted of a full height slab to slab window wall system which dictated the 3/8" (+/- 3/16" either way) allowable tolerance in the variation of the slab edge, which is very tight when working with concrete (see Figure 3.14). Using plywood, this level of tolerance would be very difficult to achieve. The hydrostatic pressure of the concrete on the bulkheads would cause them to expand slightly, particularly at the intersections of the segments. This would typically occur during the placement of the concrete as well as during the finishing which is typically done with a power trowel. With the use of steel forms, the tolerance of both the segment lengths and their locations as well as the verticality of the face of the slab edge could consistently be maintained. Furthermore, they could minimize the potential for significant productivity losses often encountered when remedial work is required. As well, this one set of forms could be used through the entire project for all the typical floors, increasing productivity though the benefits of the learning curve (i.e. the forms bolt together like a mechano set) as well as be able to follow the numbering of the formwork sections and therefore maintaining the correct slab segment configuration.

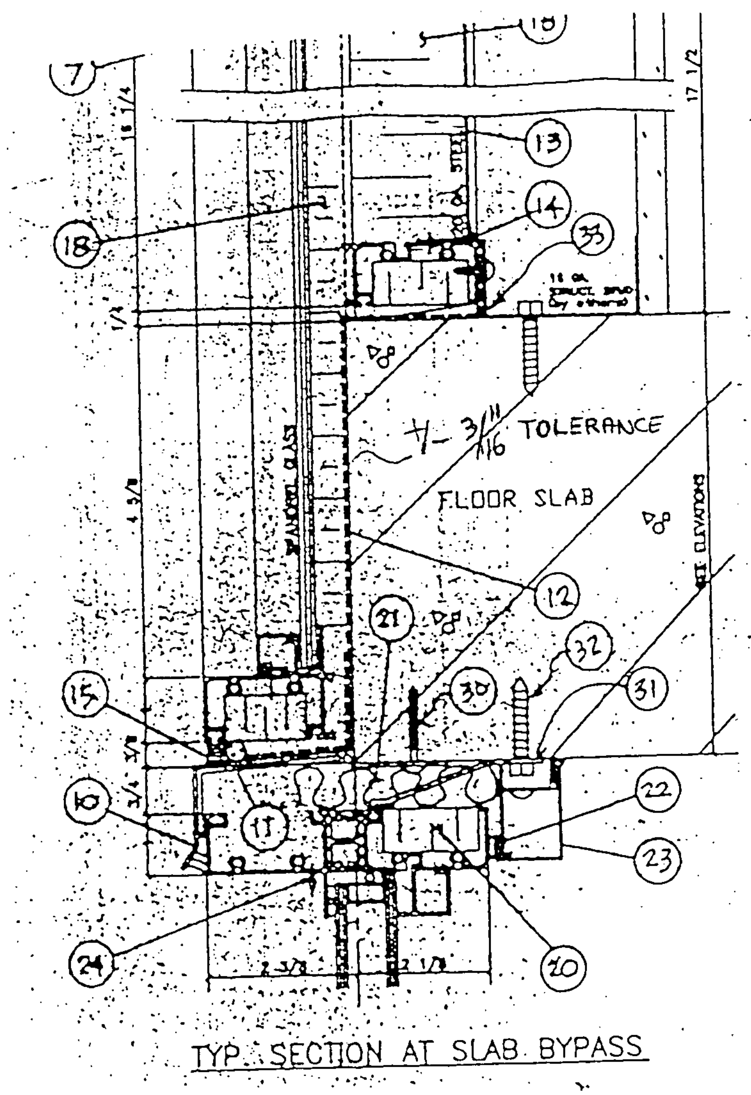


Figure 3.14 Cross- Sectional Detail of Window Wall System

Another example noted by the contractor of increased productivity through the use of different methodologies used on a different project is of interest here. For a project being constructed in the ski resort of Whistler, B.C., consideration was given to the use of a new type of flyform system. Instead of the typical truss system, they would use rollers which are mounted onto the vertical elements, (walls and columns) and have beams that run along these on rollers. The stringers actually travel out on these rollers which are bolted to the columns and walls, therefore removing the need for reshoring of the deck. This is more advantageous when you have a large flat deck to be formed because as there are no legs sticking down or reshore required other trades can immediately move into the area and continue the flow of work. The typical cycle time may not be reduced (due to the time span required for allowable concrete strengths to be reached). However, productivity is significantly increased as less manpower is required per unit area of formwork. This is a perfect example of cost saving through innovative methods. The company did not end up expending the capital to purchase the equipment as the equipment would see limited use. The typical project the company constructs does not justify using this system (typical slab size is to small to make it cost effective).

3.8 Factors Affecting Productivity and Resource Usage

When considering productivity and resource usage a number of factors, some obvious and others surprisingly inconspicuous, will need to be considered. Some of these are evaluated and accounted for during the estimating and planning phases, while others may not be considered for various reasons even though they may have some noticeable cost or time repercussions. Either they are too difficult to accurately quantify or are considered not worthwhile quantifying with the current systems used by them. The cause and effect of the following noted factors are based on seasoned knowledge gained over several years of experience in the formwork industry.

3.8.1 Time of Year

The time of year is taken into consideration but only to a limited extent. For example, placing footings in the winter versus summer, there are significant changes to the productivity rates which are noticed; however, very little consideration is given to this at the preplanning/tendering phase of the work. A certain timeframe is considered to do a portion of work regardless of what time of year it is. The company's view is that whether it is wet or extremely hot you will get a certain amount of production out of a worker and it will not vary significantly, therefore not affecting productivity to any considerable degree, unless extreme and/or long term weather patterns or conditions prevail such as might be expected in an area such as Whistler.

3.8.2 Location and Accessibility

Location and accessibility play a large role in the planning and scheduling of a project. Not so much the geographical location (as most work is done locally in town), but rather the immediate proximity of the project to the required amenities and or constraining factors. For example, if a project is being constructed in the central downtown core, a number of constraints impede the accessibility to the site. Firstly, on a major city artery or intersection there is very limited access and long delays for material and concrete deliveries due to constant traffic congestion. Overhead power and trolley lines limit the number of pick locations for the tower crane. Deliveries through the typical narrow lane ways cause both extensive delays for deliveries as well as provide accessibility problems for trucks which typically have a large turning radius. Furthermore, most new construction in a downtown core takes place between either large or very old buildings immediately adjacent to the project, further reducing accessibility and posing potential problems with damage to the existing structures. Accessibility problems as noted above give rise to additional delivery freight costs, increased labour costs (i.e. for overtime during lengthy concrete pours), reductions in productivity levels and delays to the construction schedule. For example, it may be necessary that materials be delivered to site in several smaller loads due to location constraints.

3.8.3 Scope of Project

In general, productivity rates and cost may fluctuate considerably as a function of the scope of work of the project. For a number of reasons the scope of work, and particularly the design of the project will dictate the efficiency of personnel, efficiency of material usage, purchasing power and the timeframe for various aspects of the project. A square building for example will allow for more economical and faster construction than a round building of the same square footage, and further, allow for a steeper learning curve. Furthermore, the amount of repetitiveness within the scope (i.e. repetitive cycles or similar layouts and configurations) to a large extent affects both productivity and cost..."repetitiveness is where we make our money". Considering economies of scale, suppliers will tend to provide better rates for material rentals and purchases if they are promised a certain volume of material within a specified timeframe.

With respect to the project studied, the scope of work had both positive and negative affects on productivity and economies of scale. Firstly, the intricacy/complexity of the project reduced the normal productivity rates, as the entire project is radial in design and included complicated detailing. As a result, every time the crew moved into a new area, this necessitated a re-thinking of the methods used and the strategies. In relation to material usage, this further increased costs and reduced productivity rates as there was a considerable increase in both material waste and labour to cut and place material (i.e. rectangular material is required to fit to a circular pattern). The complex curb and slab edge details further increased material waste. Furthermore, the ratio of vertical elements to horizontal elements was not as high as typically expected, therefore slightly decreasing the overall productivity rate for the job (note that the company did account for this in the estimate, and just noted this as an observation). However, the sheer size of the project (i.e. the large slab and slabband parkade providing approximately 1400 parking stalls) negated this reduction, and then some. The scale of the entire project contributed to significant productivity gains as a large worker base enabled the contractor to use specialized crews for performing specific tasks (i.e. columns, walls, shoring, decking, stripping, etc.). This allowed the average daily concrete volume placed to reach 300 to 500 cubic meters, with some days reaching well over 1000 meters. With a standard crew configuration, it may have only been possible to achieve an 80 % productivity rate of what was actually observed for this project. In terms of cost, the sheer scale of the project provided a substantial cost savings in material rental and purchases, which in turn was reflected in the estimate and bid.

Often, insufficient consideration is given in a complex design to important details, for example, slab edges or core layouts. As often is the case, the general contractor may request that some value engineering be performed. For example, a column shouldn't be placed 6 inches away from a wall, rather, the two elements should be connected or the wall redesigned to eliminate the column. While it sounds simplistic, even the most efficient and sophisticated designers have been known to provide such details.

3.8.4 Equipment Utilization and Material Handling

Material handling is a major factor in achieving high productivity rates. The crane is "key", and without efficient use of same it is virtually impossible to achieve any satisfactory level of productivity. The crane must be constantly operating. Some foremen are very effective at working a crane, "...if it sits for more than 2 -5 minutes in a day, the foreman is not doing his job". It was noted that at some of the company's competitors sites, the crane would sit idle for 15 - 20 minutes. If a foreman is an efficient organizer of the crane, the crane should always be doing something. Hand in hand with this, freeing up crane time must be done efficiently, by planning material laydown ahead of time, therefore minimizing the number of times material must be moved. On a project where the crane is always working, the contractor noted that they found the overall efficiency and productivity of a job is typically higher. Furthermore, there is a mentality associated with this, namely, if the crane is always working, momentum is created and carries on throughout the project, which in turn makes all the trades work more efficiently. By implementing an effective material handling process, the company has the ability to push all trades in the job through pushing their own work, thus setting the pace of the job.

When looking at both manpower and the efficiency of the crane, the amount of service which the crane is required to perform is critical, i.e. does the crane have too much work to do. Typically the area within the swing of a crane allows for approximately 30 workers to be supported efficiently; for example, 15 workers on a typical floor, with the balance doing pick up work around the tower. When manpower is increased beyond this, an area will tend to become over congested, especially when other trades are brought within the same vicinity, and the crane won't be able to efficiently service these workers. As higher floors of a high-rise tower are reached, productivity levels begin to decrease. This is a result of the increased time it takes to lift the same quantity of materials, therefore reducing the effectiveness of the workforce which loses their momentum and begin standing around more..."if you can't put material in front of the guys, they will not be able to perform".

When selecting a crane for a job, a number of factors must be examined, particularly the size and type of crane, which will affect hoisting and slewing speeds. Typically, a larger crane will lower the level of labour productivity achievable as it doesn't swing as fast and has an increased up and down travel time. Also, the height of a crane is very important, affecting hook time and travel time for tall buildings. Sometimes it may be more effective to use two smaller cranes instead of one large crane. Although, costs may increase by having to erect and tear down two cranes and pay for two operators and riggers, there could be a significant increase in productivity as more men can be serviced.

3.8.5 Availability and Skill Level of Workers

The availability and skill level of workers plays a big factor in the level of productivity which can be achieved by a particular crew and is somewhat a function of the prevailing market conditions (hot versus cold markets). During times of economic prosperity there is a considerable amount of construction activity, and therefore, a requirement for a large number of workers to work in the industry. It is important to have workers which are loyal and dedicated to the company. Firstly, without a dedicated workforce combined with a high demand for workers, it may be difficult to assemble or increase the size of a large skilled workforce. Secondly, the workers who are hired will tend to be less experienced (lower skill level), less motivated and more transient with the various companies in a region. This causes higher levels of turnover, affecting productivity, consistency of work and quality. "When it's a buyers market from a tradesperson point of view, and they're not loyal to you, and you haven't created something for them, they will go to the next subcontractor because they are paying additional money to them under the table or a higher wage. During economic recessions, the company went out of its way and took several jobs at cost or even slightly below cost to keep workers which were loyal to them and worked long hours during the construction boom, on the payroll".

There is a cost as well as a long term benefit in keeping a crew of workers employed. The benefits far outweigh the costs provided there is a reasonable amount of work available on a consistent basis. Once members of a "good crew" familiarize themselves with each other and can maintain a high level of productivity, it is advantageous that they be kept together. Furthermore, workers who are dedicated to the company will work harder and tend to have more pride in workmanship which seems to be harder.to find in the industry especially during times of economic growth.

The foreman running the crew plays a definite factor in improving productivity rates. Some foremen are exceptional at operating a crane and ensuring it stays busy (the foreman preplans and directs the crane). This is directly considered when assigning a project to a particular foreman and crew. Some foremen are exceptional at vertical construction, while others excel at constructing a large slab/slabband structure such as a parkade. Every different crew has both their strengths and weaknesses. To a point, crews are broken out by what there are better at, for example, one crew may be more efficient than another at constructing columns. For the project studied, there were essentially 4 different crews. Each crew worked as a unit, and some modifications were made to unit rates based on which crew was doing what kind of work.

3.8.6 Coordination of Other Trades On Site

The coordination of other trades plays a very crucial factor in productivity, yet is probably the one factor which is most overlooked. During the construction of the superstructure of a highrise building, the key trades must be in tune with the cycle time set by the formwork contractor. This applies in particular to the ready mix supplier, the reinforcing steel trade, and the electrical and mechanical contractors (which may include the sheet metal for duct work). Once the rhythm is set, each of the foregoing trades must work closely with one another to ensure the tightly choreographed cycle time is maintained. In order for the cycle time to work, it must be planned down to the hour, especially on an accelerated schedule which is becoming the norm (i.e. all jobs must be done at the absolute fastest pace possible).

The company involved in this case study had the ability to drive all the key trades through driving their own work at a high rate. They set the pace of the project and all other trades involved were "...along for the ride whether they liked it or not". Most trades benefit tremendously by keeping up this pace by increasing their own productivity and completing their work earlier than anticipated, enhancing profitability. However, this is not always the case. For example, for a previously completed project, the reinforcing subtrade was a union-based company and refused to keep up with the pace of the work, which eventually affected the overall pace of the whole project and the other subtrades' motivation levels. "The mentality of the workers plays a big factor in the pace of work" both quantitatively and qualitatively.

Most trades typically involved in high-rise construction tend to be relatively knowledgeable and aware of the importance of maintaining a flow. Even when considering past work experience working with a particular trade and/or even individual companies, it is still very difficult to estimate or plan for coordination issues which affect productivity. If other trades are lagging behind or are not sophisticated enough for the job (i.e. layout, etc.) then the productivity of all other trades will be affected. It is vital to keep the flow of work and productivity going and there must be a synchronicity between all the trades involved.

3.8.7 Overtime and Long Work Days

The typical work week for the company is made up of six, ten hour long days each with two 1/2 hour coffee breaks. On long weekends, they usually do not work in order to give the workers a three day break, provided the project schedule allows it. Surprisingly, they are amazed at seeing their workers go for 6 days a week and 10 hours a day year after year. Workers "burning out" has not really affected them significantly. Over a weekly time period there isn't an affect either. "Workers are hourly and want the hours to make the money,...they love driving their brand new trucks and Harley's". They have observed that 10 hour days do not affect the men's productivity to any noticeable degree. However, once they extend the work day and it approaches 12 to 14 hours, as sometimes happens, there is a significant drop in worker productivity. Hence, they try not to exceed a 10 hour day. Another surprising fact is that many of the workers work a number of years without a vacation time and then take a vacation which may last for 2 to 6 months. "This is their big vacation (more of a nationality type of thing)".

3.8.8 Changes, Errors and Deficiencies

Errors can often be quite costly and significantly impact a construction schedule. Most often these result from inconsistencies within the design or lack of coordination between the design drawings (i.e. architectural, structural, mechanical, electrical, etc.). With the increasing complexity of various building components (i.e. architectural details, electrical and mechanical systems, etc.), comes the greater potential for errors to occur. However, occasionally errors are made by the contractor resulting in significant loss of productivity and schedule. These errors are usually made when a drawing or detail is misinterpreted, or simply read incorrectly or missed entirely. The only way to really avoid or at least minimize the risk of this occurring is to stay on top of all the drawings, changes, etc.

Changes are usually motivated by either the owner or architect and if incorporated into the work early enough will generally not affect productivity to any degree. For the most part, and considering the status of the drawings on the project studied, most changes to the superstructure arose as a result of the incompleteness and inconsistencies in the drawings which were discovered during construction. Although not causing any significant delays or exorbitant costs, they did create a great deal of confusion and anxiety for the layout crew, resulting in the requirement that an architect be on site full time to clarify and make decisions relevant to the design of the superstructure (note that the architect was required on site full time for the entire job, not just the high-rise portion). It should be noted that the lack of timely responses to questions and the tendency for the architect to make decisions also increased the level of frustration for the general contractor and the subtrades. Some changes required that remedial work be done which affected productivity significantly because previous work has to be removed prior to being redone. This essentially cut the productivity by 2/3 in the immediate areas because the work had to be removed and replaced (this same work was essentially done 3 times; done once, removed, then done again; reducing the areas productivity to 1/3). Although, there were no significant impacts to the project schedule, there were issues relating to costs which had to be resolved. The workers who take pride in their efforts were irritated by this, therefore, unconsciously working slower resulting in further losses in productivity.

Deficiencies may also result in cost and schedule implications, although, not usually as significant as noted above. On the other hand, deficiencies may result from methods which increase productivity. For example, the quality of concrete surfaces may suffer as a result of increasing productivity levels. However, when balanced against the required remedial work to achieve the required quality, it is often confirmed that performing the remedial work is more advantageous in terms of time and cost. A good example of this can be seen when considering fly tables which typically are used on high-rise construction. After several uses, the plywood decks which make up these forms begin to delaminate and separate leaving a rough concrete surface which must be ground at a later time. It has been found that it is more cost and time efficient, and provides for better productivity rates to construct slabs in this fashion rather than to either re-deck the formwork surface or fix the surface at the locations where these deficiencies occur.

Typically, if speed is wanted then there will be deficiencies which will have to be remediated afterwards. This decision is usually made on site by the foremen running the particular job unless there is a stipulation of a certain quality which is to be achieved such as a level of surface finish, reveals in the surface, etc. The foreman is sometimes dictated a timeframe with which the superstructure must be completed and then he will make the decisions as to how to get there. Other times he is told that particular structural elements such as walls or columns require a certain level of finish. Consequently, appropriate time and care must be taken in order that this criteria is reached, with other areas not requiring the same level, leaving open the potential to "make up the time" (i.e. grind the slab after). As far as productivity, simply put, "you give up quality for speed".

3.8.9 Injury Rates and Site Safety

Injury rates and site safety play a much larger role in productivity rates that one may think. Considering an example from a previous job, a fatality had occurred as a result of one of the senior long term workers falling a number of floors onto a concrete slab. This incident had a profound long lasting effect on the workers morale and productivity levels. After the accident, the job slowed down significantly, with a reduction in worker productivity level to about 80% of the expected rates for approximately 3 months. The monetary effect to the company based only on loss of productivity was estimated to be approximately $ 350,000 (based on 100 workers being on the job at the time). A less serious accident such as a worker losing an eye, finger, etc. will still affect productivity, however for a shorter period of time.

Figure 3.15 Fall Protection Harness

Safety is the primary and foremost concern of the company However, its consideration has a direct affect on productivity by slowing down the pace of the job which cannot simply be increased by adding workers (in many cases it would lead to congestion further affecting productivity). This is considered an accepted cost of doing business-the company would have it no other way even if safety was not a mandatory requirement. However, the expectation of the marketplace is that the company maintain the same competitive unit rates which existed prior to the introduction of new safety regulation's, which reduce their productivity. Initially, when workers were required to wear full time fall arrest equipment there was a lot of complaining, but the workers were safer (see Figure 3.15 and Figure 2.1). The company was not paid any more by the general contractor despite losing productivity, but worker morale is now higher and the company is saving money on WCB rates which can be extraordinarily high for a company which promotes unsafe work practices.

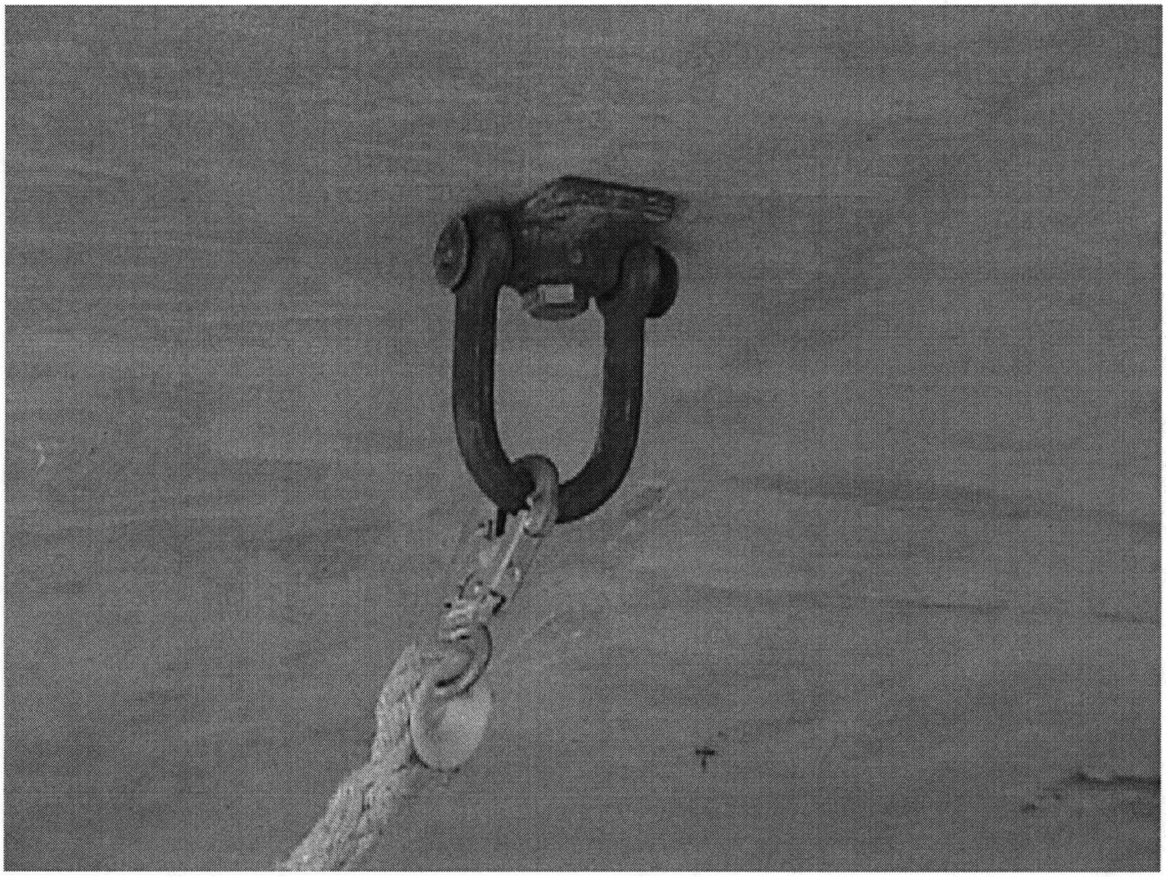


Figure 3.16 Tie-Off Anchor in Ceiling

3.9 Monitoring an Existing Project Through Data Collection

Successfully monitoring of a project requires that appropriate and properly coded data be collected on a regular basis. Various types of data are typically collected for both quantitative and qualitative analysis. These include timecards, manpower counts, weather conditions, daily material quantities (particularly concrete volumes), daily progress reports, as well as other site specific data.

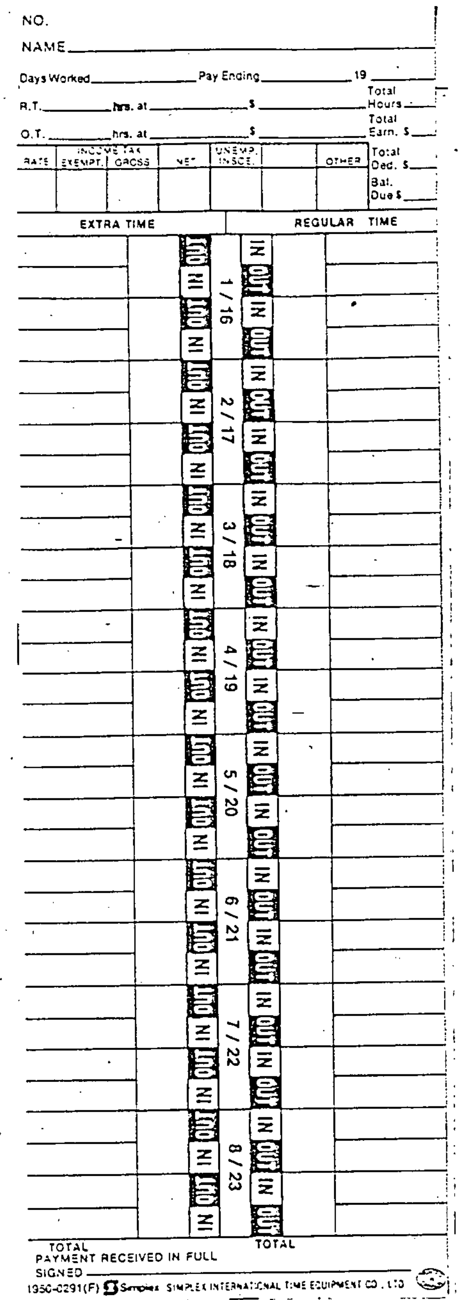
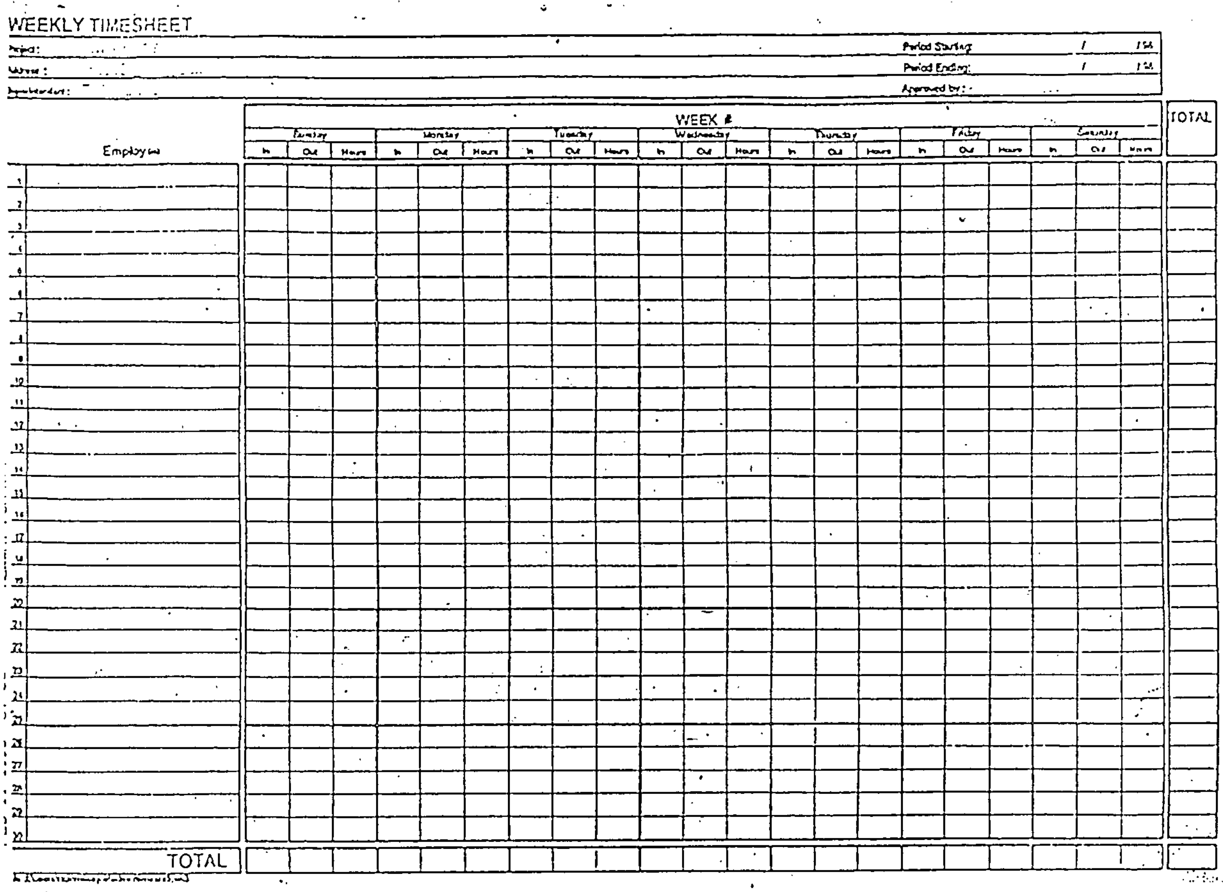


Figure 3.17 Daily Time Card

For the company being studied, some very basic information is used to monitor the progress of the job. The schedule (provided by the general contractor; see Figure 3.12) is used to ensure the physical progress of the project is maintained at the appropriate level, and to identify the company's manpower requirements needed. Other information which is used to monitor progress is compiled to form the company's cost reports. This information, which is essentially retrieved from timecard data (manhour counts, see Figure 3.17) and material invoicing (material cost), further indicates how successful the project is in terms of its forecasted cash flows (i.e. the firm wants to see if they are expending more labour than allocated for a specific scope of work). The only computer- based system in use by the company is the cost reporting system which is done using a commercial spreadsheet program set up to perform accounting tasks. Other data such as weather information (temperature, wind speed, precipitation) or daily progress reports (including site organization, problem areas, etc.) are typically not documented on a regular basis unless a potential problem could delay the schedule and/or create additional costs, for example a period of several days of high winds during which the tower crane cannot be used will be documented (see Figure 3.20).

By using a spreadsheet program, the company is able to process the limited site data and perform a rough analysis for determining the approximate productivity achieved. Because payroll data is not cost-coded, it is not detailed enough to provide an accurate reflection of specific types of work. When the time sheet is entered, the overall productivity rates within that cost period are calculated. This information then provides the company with an indication of where the job is heading in terms of cost and productivity.



WEEKLY TIMESHEET

Project: | Period Starting: / 19
Owner: | Period Ending: / 19
Superintendent: | Approved by:

	Employee	Sunday In	Sunday Out	Sunday Hours	Monday In	Monday Out	Monday Hours	Tuesday In	Tuesday Out	Tuesday Hours	Wednesday In	Wednesday Out	Wednesday Hours	Thursday In	Thursday Out	Thursday Hours	Friday In	Friday Out	Friday Hours	Saturday In	Saturday Out	Saturday Hours	TOTAL
1																							
2																							
3																							
4																							
5																							
6																							
7																							
8																							
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26																							
27																							
28																							
29																							
30																							
	TOTAL																						

Figure 3.18 Weekly Timesheet

They take what has been done to date on the job and extrapolate it to the end of the job in order to predict the likely outcome. It was noted by the individual interviewed that it would be very useful to have this information graphically represented (i.e. cash flow diagram) and would like to see such an approach incorporated into a piece of software.

EXTRA WORK TIMESHEET

Project # : 84 GOLD Subcontract with :

Project / Address :

Work Description :

Location : Building : Floor : Gridlines :

Referance Document:

		Trade Code	Carpenter		Carpenter				Labourer		Labourer				C'mnt Finshr				Supt		TOTAL		APPROVE BY:
	Day	Date	S/T	O/T	S/T	O/T	S/T	O/T	S/T	O/T	S/T	O/T	S/T	O/T	S/T	O/T			S/T	O/T	S/T	O/T	
W	Monday	/ /97																					
E	Tuesday	/ /97																					
E	Wednesday	/ /97																					
K	Thursday	/ /97																					
	Friday	/ /97																					
1	Saturday	/ /97																					
	Sunday	/ /97																					
W	Monday	/ /97																					
E	Tuesday	/ /97																					
E	Wednesday	/ /97																					
K	Thursday	/ /97																					
	Friday	/ /97																					
2	Saturday	/ /97																					
	Sunday	/ /97																					
		TOTAL																					

File : f:\users\rick\mastrjob\admin\timesht.wk3

Figure 3.19 Extra Work Timesheet

Ideally, the timesheets should be documented in a manner that would provide a detailed hourly, cost coded, per person breakdown of what type of element was worked on such as a column, straight wall, curved wall, etc. Currently, only the hours worked by each employee are documented (see Figure 3.18). Therefore, when planning a job, additional detail would provide for a more accurate reflection of the historical data such as unit labour costs for particular structural elements. The more information that could be gathered, the more comfortable they would be with the decisions made. If they had all the information, they would consider it worthwhile to devote the time to manipulate it and in the end see the payback.

DAILY CONSTRUCTION RECORD

Project : Project # 02 GO Date : / / 1997

Weather : Skies Rain ?

Temperature Wind Speed

Work Completed	Floor	Gridlines	Labourers	Lab. F'men	Carpenters	Carp. F'men	Cmnt. Finishers	Cmnt. Fin. F'men	Crane Operators	Riggers	Layoutmen	Superintendant	Manpower Total
												Total	

Problems / Delays :

Inspections :

Meetings :

Equipment Rented / Returned :

Information Requested / Received :

Notes :

Figure 3.20 Daily Construction Record

Other factors which must also be considered when attempting to collect and/or analyze data from an ongoing project include the confidence level in the information recorded and in the payback achieved. When considering the potential payback, issues such as the following have to be considered. If rainfall was monitored, it would be questionable as to how useful this would be in terms of monitoring the workers daily productivity levels. If an effect was noticed, the crew would simply have to work harder that day to keep up with the schedule demands. However, if weather patterns were followed a productivity rate might be established on a seasonal basis. For example, building footings in the winter may have a significantly lower productivity rate than in summer which may be incorporated into an estimate or plan based on the initial project schedule. The amount of time spent would be reflective of the type of information used, for example, considerably less time would be spent analyzing weather patterns than would be reviewing a wall that was curved and 12 feet high versus a wall which was straight and 12 feet high (looking at the material costs and labour costs, the nuts and bolts, but would also consider all the other factors). It must be established whether the amount of time devoted to monitoring certain information will justify the payback in terms of useful data. Once the data has been collected and analyzed, the confidence level must be considered. When questioning whether this entire process is worthwhile from an economic standpoint, note the following example. If a day is lost in the schedule, it would typically be made up by adding extra manpower or overtime. Consider a site with 100 workers and 3 tower cranes. If one day was lost, or on the other hand, one day could be saved, this would either decrease or increase the company's profit respectively by approximately $ 36,500 (based on 100 workers * $35/hour incl. burden * 10 hours + 3 * $500/day crane time = $ 36,500 per day), probably a lot less that it would cost to compile the data and analyze same for areas requiring improvement. Take into consideration losing a few weeks in the project schedule, not unrealistic for a project duration of 1 to 2 years.

3.10 The Post Mortem

Once a project has been completed, the owner and accounting staff perform and initial analysis of the "bottom line" to establish if the job was successful. Then there is a cursory review to try and establish the level of success of the job as well as the high and low points, namely, the areas in which the company excelled versus those where problems occurred and time and productivity were lost. If a project doesn't go as well as expected, they discuss the areas of difficulty with the supervisory staff working on the project, review the daily construction records and examine the timesheets to try and establish and isolate where and why the actual problem occurred in order to prevent it from reoccurring as well as to try and improve the productivity of the next job. Note that a majority of this is done based on discussions with the foremen, and from a qualitative perspective (i.e. as very little data is collected, this review is more subjective).

On a less successful project, overruns and underruns are looked at, again subjectively by using rough numbers based on timecard information and daily reports, with the intent of establishing how the construction methods used for each affected productivity. It would further be ascertained if they achieve the required productivity rate or not, and see what could have been done better. The individual methodologies would be analyzed and possibly perform an analysis of a "what if" scenario to see what expected productivity levels would have been realized had the work been done another way. By performing such an analysis, if the same situation is encountered again on a future job, the same mistakes or less efficient methods will not be repeated. If the productivity achieved was less than desired, then the source of the problem must be immediately detected and a plan to correct the problem established.

As previously mentioned, the rough analysis is based on information derived from the cost reports, but ideally the firm would like to have information based on a type of work package. For example, the construction of simple curbs tend to be a very expensive piece of formwork in relation to the scope of the project. Ideally, the company would like to have the ability to analyze the cost effectiveness and productivity variations for different methodologies of constructing these. Anything that can be panelized, modularized, or made into a system of some sort will increase productivity and therefore make money. These would be the first things that would be considered during the initial planning phase and during the job. The fewer steps that have to be taken (i.e. make the job as simple as possible) to complete a task, the less labour that is required, the more money that will be made and the lower the job could be bid for. A systematic analysis would tell you this information as well as the efficiency at doing a task.

3.11 The Company Wish List

Most of the items relating to the wish list centered around having the ability to manipulate data to achieve the desired goals, namely, accurately calculate unit rates and the results of the cause and effects of the data collected. If this is achievable without relying on a top heavy management staff, the company studied noted that they would expend the resources to collect the data.

Statistical data provided from one or more outside sources would be very useful. Currently, the firm does not use "Means" data but would like to use it as a guideline. Means does not describe what kind of personnel they develop their productivity statistics from (i.e. in terms of experience ratings, cross section of the workforce, etc.). Their company has been very fortunate at keeping long term staff, by take good care of their workers and provide a good working environment for them.

In terms of data collection, the lack of effort dedicated to this practice was due to the overhead of collecting this vast amount of information without having the ability to effectively use it. With this potential, the firm studied believes that, with more detail in their estimates, such as accurate historical data, they would gain a better perspective of exactly how much something would cost, how long it would take to complete the work, and therefore, be able to make money off it. It was noted that quantification of data is very time consuming and they would like to have the capacity to quantify "standard work packages" complete with unit rates for the various scopes of work which would automatically produce material and resource quantities. Tracking data, for example, worker hours and cost coding it by task is not done by the company studied; however, they would like to see it happen as it would provide the basis for generating productivity rates that could be used to estimate future projects. "It precipitates all the way down to if you are a little bit more accurate with your estimates based on historical data and productivity rates - you make more profit". Once a rough number is available, it can be refined. Then actual resource usage values and productivity rates could be provided for use with the next estimate and "... having all this automated would be ideal".

3.12 Conclusion

Although the firm studied may be very good at what they do, there appears to be a number of areas with room for improvement. Significant benefit could be realized by implementing a computer based system which models a project similarly to the way it is constructed. The physical model's capability described in Chapter 2 would address many of the issues noted as well as provide the firm studied and ones like it with many other benefits as will be demonstrated in the next chapter.

CHAPTER 4 - THE BENEFITS OF PARAMETRIC MODELING

4.1 Introduction

The level of architectural sophistication has increased significantly since the days of the "Vancouver Special" highrise building, as have the expectations of the owners and developers who are now typically more knowledgeable in construction. The marketplace dictates the pricing and bids of formwork contractors, and has little or no regard for a company's reputation. The "bottom line" is what decides which firm gets the job. Provided with more detail, the contractor could more accurately recognize actual cost and duration, and potentially gain an advantage over other contractors based on this knowledge. With the ability to model a project based on its physical characteristics, and through the use of a standardized information base, a contractor could estimate, plan, monitor, and finally analyze the completed work with greater efficiency and accuracy, and perhaps explore more methods of construction.

The previous chapter showed the rather minimal methods used by the company to monitor and improve on productivity. In this chapter, we discuss how the company would benefit through the implementation of the system described in Chapter 2. The current software which the company uses does not provide them with the level of detail required to model the intricate information as noted below. If the company management could overcome their resistance to accepting an integrated computer system, and could be convinced that it is economically viable to examine information at the level of detail described in Chapter 2, they could benefit from the additional knowledge made readily available to them.

4.2 The Physical View

The Physical Component Breakdown Structure (PCBS) proposed provides the information required to estimate cost and duration, plan crew size, allocate resources and sequence the work. It could provide the type of company studied in Chapter 3 with a computer model which is especially suited to the modeling of the type of work which the firm does, i.e. modular type of construction which involves a few key types of structural elements which are repeated many times.

The PCBS structure acts as a front end to a complete project management system, allowing for linkages to be formed between activity based information and estimating or quantitative information (quantitative and qualitative properties of the project). It provides the user with a means of firstly quantifying time, cost or other value type of data, then monitoring and tracking productivity rates and other as-built information at different levels of detail. For example, productivity could be tracked in a number of ways: by element type (walls, columns, slabs), by area (highrise typical floors, level 5, columns on level 5, etc.), or any combination of these, as deemed necessary. Upon completion of a project, the firm would be able to more efficiently analyze historical data and apply the findings from it.

4.3 The Standard Element Database

The standardization of data will provide the firm with a number of benefits. Firstly, the level of accuracy of the company's unit rate information will be higher and more easily maintainable. This will improve the level of productivity of the estimators and provide a higher level of comfort with the estimate. As each job is completed, as-built data is compiled and the estimates which follow become more accurate, therefore, a lower contingency rate can be built into the estimates, further increasing the company's competitive advantage.

The Standard Element database will provide the type of company studied with the ability to compile all pertinent information relating to their scope of work into logical structural components. These "standard components", each representing a standard building block of the structure, can exist at a number of different hierarchical levels. Note that certain parameters are specified at different levels of the hierarchical structure and their definition can be inherited downward. Considering the hierarchical levels of the project studied, a standard element could be identified as a "typical-floor", which is repeated 25 times, and forms the basis for the model of the highrise tower. Within each typical floor, are columns, walls and slabs each with their own intrinsic qualities. For example, at the "typical-floor" level, certain properties such as height (i.e. 8' - 7 1/2" floor to floor), will automatically be deduced and incorporated into the lower level components such as walls and columns.

4.4 The Benefits of Using the Knowledge Base

A number of benefits would be realized by the firm being studied and others like it with the implementation of a robust knowledge base. In addition to implementing the standard component database, the system would provide users with the ability to use data which identifies the characteristics unique to their company's way of accomplishing their work, including the specific traits of their workforce, and the methods that they use.

With the implementation of a knowledge base, the "global" variations (i.e. location, safety issues, etc.) which affect all jobs to a certain degree, would be monitored and further be incorporated into the firm's unit rate values. For example, if seen fit, the company could collect data pertaining to weather patterns, including seasonal changes in weather, or extreme weather areas in different locations, i.e. Whistler versus Vancouver, and have productivity rates automatically fine-tuned to accommodate their effects. Furthermore, as location plays a significant factor in construction, a "location factor" could be incorporated to adjust for relative proximity to services, suppliers or high traffic areas such as a downtown core where traffic congestion may be high (i.e. could base a weighted indices on the number of obstructions for simplicity, or on the amount of expected traffic delay, etc.). Company specific "global parameters" could be set which directly relate to the performance of manpower, equipment and various methodologies particular to the company.

A knowledge base could provide a means for the firm to identify project specific variables. The scope and scale of a project plays a significant role in determining productivity rates and effective resource usage. Considering the study project (all facets of it, not just the tower described in Chapter 3) which was essentially made up of 5 average sized projects, economies of scale played a significant factor which could not be neglected when pricing the job. Further to this, it is important that the physical characteristics of a project also be considered as part of the knowledge base. Some examples are the complexity of a project's components such as the walls and slabs, slab edges, layout configuration of columns and walls (i.e. are the structural components linear or radial, complexity of slab edge, etc.), which could be most easily quantified either by means of ratios (i.e. linear = 0 to fully radial = 1) or by means of a qualitative parameter (i.e. linear, part radial, very radial, fully radial). What must be understood is that all the above-noted parameter and index values would be approximations which would over time become more statistically accurate as the number of jobs entered into the knowledge base increases. Other areas which could be addressed as project parameters are: a ratio of vertical work to horizontal work (i.e. highrise versus parkade type structure), an indexed learning curve which may be project specific, the availability of site laydown/access, the quantification of quality such as level of finish (including remedial work required when accelerating a job) may be quantified at the planning stages, and possibly the "verticalness" of a project, i.e. as the building goes up vertically, the longer it takes to service the crew via the crane.

Specialized parameters may also be added to the various unique or standard components within a model. For example, walls which are higher than 8'-0" require additional resource and manpower, and costs and time associated with these will increase exponentially as the wall height increases, therefore, walls may be given an additional parameter which incorporate an index value or formulae in order that the effects are recognized and accounted for. It is also possible to set limiting relationships to adjust for these variations, (i.e. a conditional statement: if a wall > 8 feet then multiply by a formula or value). This would be particularly useful when costs and/or productivity values do not increase or decrease linearly. Referencing the previous example, various safety indices and costs may be accounted for directly within the wall height, and also allowance should be included for fall protection initiatives which must be implemented for any work platform over 10 feet high. As new regulations and/or technologies arise they may be easily incorporated into the system (safety related issues may be incorporated into unit rates, type of work, and be related directly to standard components) or simply modify values to predetermined indices.

Another area where potential advantages could be realized, and which warrants further exploration, is into the use of a parametric modeling system to perform value engineering services. This could provide significant benefits to the firm doing the work, as well as the general contractor and their client. The client would obviously appreciate this as he will save money and/or time, making everyone including the general contractor, the architect, the structural engineer as well as the firm itself look good. The would give the firm the capability to more accurately predict the effects of specifically value engineered items for cost, time and productivity before any work has been done, therefore allowing for a more educated analysis when comparing alternate methods. For example, considering the project studied, an analysis could have been made using the steel forms for the highrise typical floor slab edge prior to any work being done, rather than having the costly forms fabricated, and then reviewing the outcome with "as-built" information. This would have provided the firm with relatively accurate information and allowing for an educated management decision to be made in choosing an optimal work plan. This aspect of the software would make it easier to provide value engineering and cost savings with the detailed data the program provides. Furthermore, is could provide a more intuitive process of pricing and planning by effectively creating a "mock-up" computer simulated model of a project, thereby opening the door to uncover possible value engineering not previously considered or revealed.

The firm will be able to quantify productivity at any level of the model (as well as for costs, resource usage, etc.). This may be beneficial especially when in the negotiation stages with the general contractor by providing "quick and dirty", yet accurate estimates for specific job parameters, timeframes, crew sizes, duration, etc. This would also be advantageous to have more of a breakdown of productivity rates if a job which is out of balance (for the type of work) than what they are used to seeing, i.e. a project with a large underground parkade relative to the typical floors, or a large area of slabs and very few walls of a specific type such as straight versus curved. In this case, the unit rate used for "walls" will not accurately reflect the truth.

By using the sophisticated information provided by a robust knowledge base as described above, more educated managerial decisions could be made, which could increase a company's profitability and provide them with a competitive edge. It is recommended that a qualitative means of evaluation be used to quantify certain parameters, for example, if traffic congestion is considered, then the variables might be defined as low, medium, high, very high as opposed to a numeric value. The knowledge base and elements could also function based on a number of standard indices and relational limits which are set at the start of the planning stage. For example, manpower resource would be limited to the number of workers which could be serviced in an area (based on crane data and the size of the work area). A report could be printed which would itemize all index and/or similar information for purposes of review at the beginning of each project. At any stage of that same project the report could provide the current index values calculated based on the as-built information to check against the initial values used, and furthermore, at the end of a job to provide actual index values.

Over time, these index values will become more accurate for different types of projects, and could serve as a very valuable tool for estimating and planning future work.

4.5 The Benefits of Standardized Data

As the construction methods/materials used closely relate to each other, one often dictates the other based on schedule. The implementation of a physical view of a project and its integration with the process view will make it much easier to compare productivity rates for a large scope of work at the planning stages for comparisons and costs. Material takeoff will be a function of the model, therefore more closely reflect the actual values, as well as include for other contingent quantities such as guardrails or other items required for safety related issues. Furthermore, the firm will have the ability to quantify quality issues and identify strategies as to how best achieve quality standards while minimizing cost and time. In the past, these issues were treated as being peripheral to the work, for example, the firm studied how they had to be done, but they were never really quantified to any degree.

Another benefit of a physical view combined with a process view is that it can identify schedule implications at the time of planning the job, such as when productivity levels or resources are inconsistent or unrealistic based on past work. It may enable a company to better optimize their crew configuration for a specific type of work or project and make it easier to plan a crew size to meet the specified schedule. In terms of value engineering their own work, they will be given the ability to isolate areas where it may be advantageous to consider alternatives in methods and or materials, i.e. consider the steel slab edge forms which were only decided on once a level was formed with the standard materials (form ply and bracing). Some methods may not appear cost and time effective initially but when spanned over a long duration they are. The program will help identify these. A "what-if" type of scenario could be run on the program and the potential side effects could be seen without suffering the consequences of implementing an unproven method which may in the long term not be cost or time effective.

Although many of the items would appear to have an effect of increasing costs, resulting in the firm pricing itself, in fact, the opposite will occur. In reality, the actual construction costs may go up, however, they will be a more accurate reflection of reality, therefore requiring a significantly lower contingency (which is always used to make up for the unknown amounts now accounted for).

4.6 Monitoring The Progress

By using the parametric modeling system, monitoring the progress of a job may be more of an exercise in reviewing the data. As-built data will provide instantaneous information regarding any problem areas and/or allow for the fine tuning to optimize productivity. Based on the output reports, it would be possible to tell if the projected productivity rates were better or worse than anticipated, and identify exactly where problems are occurring. Furthermore, could identify why they are occurring, then more easily come up with a solution; by isolating the actual physical elements which caused the problems.

4.7 Conclusion

By implementing the kind of physical model described in Chapter 2, firm's of the type studied could significantly improve their practices, become more competitive and gain a stronger foothold in their marketplace position relative to the competition. As they will be working with more knowledge and more structured data, they will also have greater insights in their cost accounting, risk assessment, methodologies for planning and scheduling, and structure of their workforce, allowing them the opportunity to find more efficient work methods and cost saving measures.

CHAPTER 5 - SUMMARY AND CONCLUSIONS

5.1 Findings

This thesis has described several of the features required of a computer-based representation of the physical view of a project designed to support a range of project management functions and to assist in contributing to the goal of computer-integrated construction. This view is currently being implemented by others within a project management system along with support systems for the generation of preliminary plans and schedules, the tracking and reporting of productivity during construction and the post-project derivation of productivity estimating functions.

Chapter 2 describes the conceptual framework and interface of a parametric modeling system designed to describe the physical description of a project and generate the type of information essential to the execution of various project management functions. This physical description is established through the implementation of a physical component breakdown structure and provides for a hierarchy of levels used to parameterize the building components. This system has the ability to model a diverse range of construction projects and the ability to accommodate the varying levels of detail which may be required. Central to the system is the ability to inherit information from different levels within the project model. As well, this system offers the user a knowledge base to define and create standard components which facilitate the speedy definition of the physical view of new projects.

The case study presented in Chapter 3 revealed many of the actual practices implemented during the planning, construction and post mortem analysis of a project. A number of areas were identified which affected productivity and costs, however, the company participating in the case study took a rather unsophisticated approach towards utilizing the available information, because of limitations in the systems currently being used and lack of motivation to expend the resources to collect this data. In part, this lack of motivation is a result of the inability to efficiently transform the data into usable information. Therefore, areas with the potential for improvements in productivity, cost savings and/or value engineering were not investigated to the to their full potential.

Through the implementation of a parametric modeling system along the lines described in Chapter 2, better insights into a number of areas of concern could be achieved, as described in Chapter 4. A physical view facilitates the conversion of data collected into tangible and useful information for decision making (e.g. planned versus actual productivity). Thus, company's like the one studied could better monitor a project and identify areas where improvements to productivity and/or cost savings could be made.

5.2 Future Research

Throughout the design and case study processes, various ideas materialized which form a "wish list" for future work related to the scope of this thesis. Items included in this list relate to the user interface and the functionality of the module. For example, Standard components, including all lower level information and formulas should be automatically generated within a project and allow the user to have the option to breakout relevant portions to add to the Standard Component database. The ability to import components from a standard library of elements as well as a library of physical view templates is required, as is the ability to import breakdowns from software external to the project management system.

To further benefit the user, increasing the graphical capabilities of the module would be both more visually stimulating as well as provide the system with more intuitiveness when viewing information. Being able to see the model as either a two or three dimensional graphic and further being able to plot the information would give more assurance that the model has been developed correctly and possibly give insight into constructability concerns which may not otherwise be apparent. In addition, by working directly with the graphics shown on the screen, improvements to performance and efficiency would result. For example, it would be beneficial to be able to drag and drop the different parts of the Physical Component Breakdown Structure, allowing the user to regroup and reorganize data graphically. This would allow different views and scenarios to be analyzed very quickly. As well, research is warranted into developing the potential to create a physical description of the model by digitizing information directly from a set of drawings, as is the ability to import CAD files directly into the system and have the system directly develop a physical model based on the projects' physical characteristics.

By foregoing a tighter integration between the physical and process views of a project, eventually the system could automatically propose manpower, resource and productivity rates based on past projects. Caution would have to be used in the development of this aspect of the system and possibly have limits to restrict the user from relying to heavily on the data and not checking the calculated rates. Having the system suggest rates, calculations and other information would be ideal provided they are not directly incorporated into the system without authorization.

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