A VIRTUAL CONSTRUCTION ENVIRONMENT (VCE) FOR MACRO PLANNING

by

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ABSTRACT

Macro Planning of construction projects is among the most challenging tasks faced by the project team. Decisions made during this process have a tremendous impact on the successful execution of the project from its early conceptual phases, through the project construction and completion. For a large majority of construction projects, the current planning practices remain manually based. General and project specific data are communicated among project participants through design drawings in a 2D paper-based format. Due to the interdependence between the different elements and the large amount of information that needs to be manually processed, the current manual implementation approach is very difficult to undertake, and imposes a heavy burden on the project team to carry out the planning process.

Various research efforts have been undertaken in an attempt to capture current planning techniques and allow for the development of new innovative and automated ways in planning. The developed planning systems are characterized as responsive decision systems, relying mainly on programmed knowledge and heuristics for decision making, hence reducing or eliminating the role of the human planner.

This research presents the framework for a new interactive planning environment called the **V**irtual **C**onstruction **E**nvironment (**VCE**) that supports the thinking process of the project team during the macro planning phase of design-build projects. Unlike previous

responsive-type systems developed, the approach utilized in the VCE is supportive to the project team enabling them to be an active participant in the decision making process.

The main purpose of the VCE is to assist the project team during decision making, by providing pertinent information necessary for making appropriate decisions in a structured format. This information may be organized, stored, and retrieved by the project team whenever needed during the virtual sessions. The VCE also provides the project team with appropriate tools to test different work execution and site layout planning scenarios early during project development. During the virtual sessions, the project team reconstructs the facility by bringing graphical elements together. The project team's movements and interactions are recorded to capture their thinking process on how to construct the facility (i.e. sequence of major assemblies). Other project participants can retrieve recorded decisions for further review or modification. The project team is also able to specify construction methods, and allocate resources required for the implementation of major assemblies. The VCE guides the project team to perform these interdependent planning functions interactively and concurrently. Using system graphical libraries, major equipment and temporary facilities can be superimposed and displayed as graphical objects for site layout planning. This enables the project team to visually check for space and accessibility conflicts during different virtual construction time intervals.

In order to define required information in the VCE, the author has developed a **MA**cro **P**lanning **I**nformation **C**lassification (**MAPIC**) model under which information required for macro planning decision making could be classified and organized in a structured standardized format. The project team may then retrieve and utilize this information whenever needed during the virtual sessions.

A prototype computer tool is developed to illustrate the framework of the VCE. The computer prototype is implemented using available commercial software tools.

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1. INTRODUCTION

1.1 BACKGROUND

Planning construction projects is among the most challenging tasks faced by the project team (designers and/or constructors). Decisions made during this stage have a tremendous impact on the successful execution of the project from its early conceptual phases, through the project construction and completion. These decisions include processes that range from design reviews, selection of major construction strategies and work packages, to daily written detailed instructions for a small crew. Such planning processes may be divided into two distinctive and identifiable stages: pre-construction planning or *macro planning*, and during-construction planning or *micro planning*.

Macro Planning

Macro planning is mainly concerned with design review, site investigation, selection of the construction path sequence and major elements required for the execution of the work packages (i.e. primary means and methods and major resources). The project team reviews the design drawings and contract documents, and breaks down the facility into its major assemblies. This breakdown allows for a structured methodology to analyze the project assemblies and to make appropriate decisions on how these assemblies will be built and controlled on site when construction starts. The structured methodology involves the identification of major construction means and methods conceivable for the effective execution of each assembly. Due to the uniqueness of each project, the structured methodology depends primarily on the project team's knowledge and experience. The project team allocates different resources associated with major methods selected, and decides on the appropriate sequence of the assemblies. This macro plan helps in managing and executing major work packages and the overall workflow and direction.

The macro planning process also allows the project team to detect interferences, shortages, and other pitfalls before the execution of the work, hence, improve the project constructability. Project requirements and constraints (cost, duration, quality, and so on) are continuously monitored and/or modified. Design is subjected to constructability reviews. If problems are found, the project team reconsiders the design and planning decisions made, and attempts to satisfy the project requirements and constraints. This is achieved by an iterative process of revising the design drawings, re-examining the methods and resources selected, and rethinking the construction sequencing of assemblies. Once problems are resolved, planning at this level is finalized.

In a traditional project delivery system (Design-Bid-Build) the macro planning stage starts during the period prior to submission of the bid (usually several weeks to several months depending on the size of the contract) and continue after bid award through mobilization, to a certain point early in the construction (normally not more than several weeks beyond mobilization). In a Design-Build project delivery system, macro planning begins early during the project design phase, and extends through mobilization and may continue into the early weeks of construction.

Micro Planning

The micro planning process begins with the start of construction and involves decisions for providing all the detailed elements necessary to assist field crews in the management and execution of the day-to-day operations. Decisions on how to manage manpower, equipment, and material as well as scheduling of field tasks are performed on a daily, weekly, or monthly basis. Outcomes from the macro-planning phase are used as guidelines for implementing the details of the micro planning process (Waly et al., 1999). The project team breaks down major activities into more detailed executable and controllable tasks. Methods for the execution of the operations are identified, and required resources are allocated. Detailed information about resources, productivity, materials quantities, tools/equipment needed, and so on, is collected from databases and/or personal experience. For each major assembly extracted from the macro plan, the project team decides on the detailed sequence of operations and determines the duration for each operation. This detailed planning process is performed while satisfying the project requirements and constraints.

The micro planning process is more effective if developed during the construction phase of the project. Due to the dynamic nature and long time-periods needed for implementing construction projects, the project team can never predict future events with certainty and detail before the start of construction. A micro plan developed at the early phases would create the most unmanageable coordination problem. The quantity of information would be truly amazing and confusion profound (Neale and Neale, 1989).

1.2 PROBLEM STATEMENT

Planning the project, whether at the macro level or micro level, requires transformation of general and project-specific data, through manipulation and processing, into needed actions. With reference to Figure 1-1, acquired data (input) is usually transformed to the needed actions (output) through manipulation and processing that involves an iterative process, and utilizes knowledge and experience of the subject matter. Data, both general and project-specific, should be available for the project team in a suitable format. General project data may consist of alternative construction means and methods, resources, and general conditions. Project-specific data may include site information (e.g. location, weather, and adjacent sites), design intent (e.g. criteria and requirements), and project requirements and constraints (e.g. contract specifications and drawings, due date, budget, and work activities). During the project planning process, information required for the execution of the project needs to be extracted from the project data. The developed project information is then processed to formulate project knowledge necessary for the decision making process.

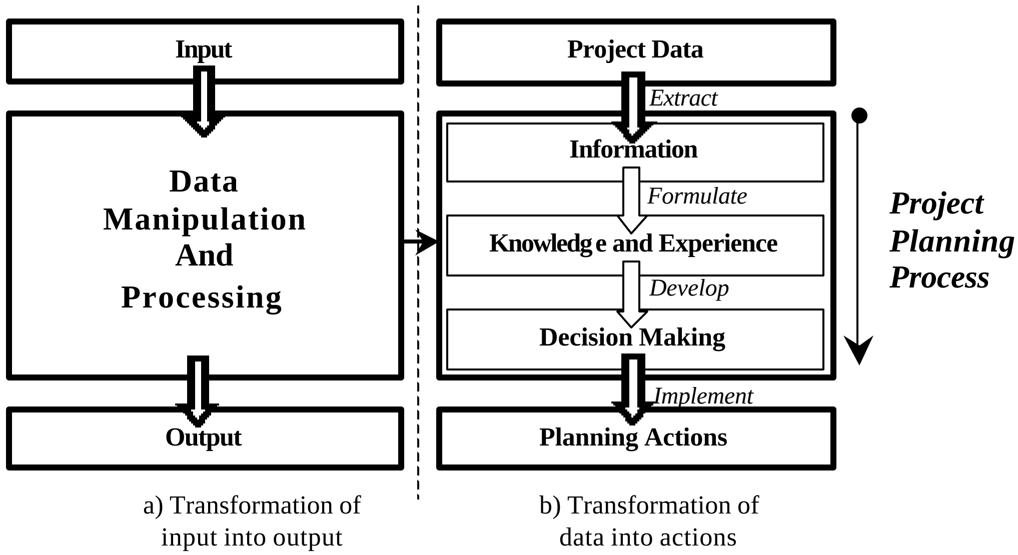


Figure 1-1: The project planning process: Transfer Data into Decisions/Actions

Current practices

For a large majority of construction projects, the current planning practices remain manually based (Figure 1-2). General and project specific data (product information) are communicated among project participants (owner/designer/constructor) through design drawings in a 2D paper-based format. This product information needs to be extracted from these drawings and processed to formulate project knowledge necessary for making decisions and taking actions (process information). The realization of the facility defined in these drawings becomes the responsibility of the user. Project participants involved in the project planning process are therefore expected to visualize in abstract terms the perceived characteristics and spatial relationships among various components of the project, including site-related activities. Introducing computers to the facility delivery process has changed the means of generating the paper-based drawings and reports, but it has not fundamentally changed the methods of sharing the data across organizational boundaries (Howard et. al., 1989). This paper-based exchange of large amount of information between participants usually leads to fragmentation and inefficiencies, and limits the ability of the project team to acquire and comprehend the information necessary for decision making.

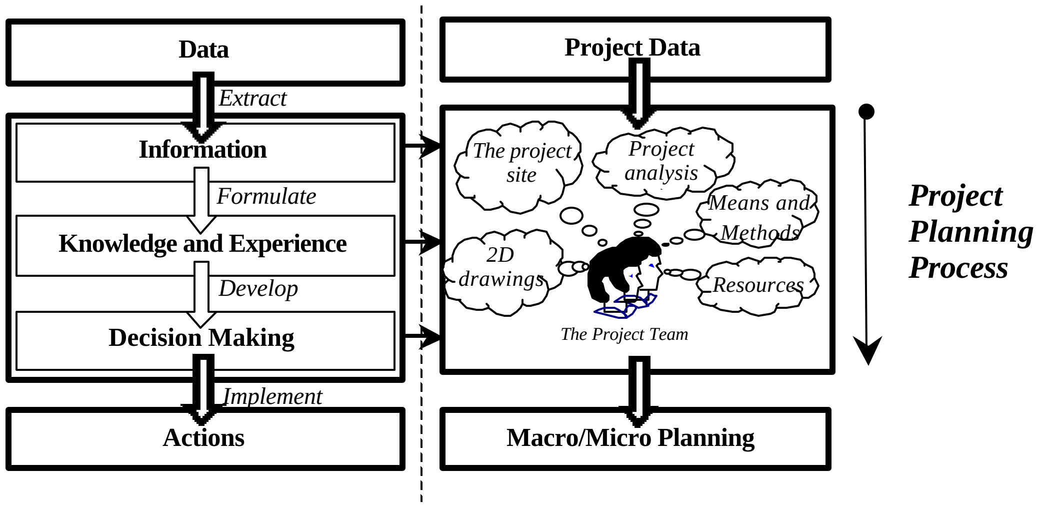


Figure 1-2: Current Implementation of the planning process: Manual Approach

Another drawback of the manual approach is that planning functions are performed separately in isolation of each other. Design and constructability reviews, decisions on how to physically erect the facility (i.e. plan), when to erect what (i.e. schedule), and the selection of major means and methods are all interdependent. These interdependent actions should be planned interactively. Coordinating these functions in isolation of each other, forces repeated recompilation of information throughout the facility delivery process. Any changes and revisions to the facility further complicate the planning effort.

Due to the interdependence between the different elements and the large amount of information that needs to be manually processed, the current manual implementation approach is very difficult to undertake, and imposes a heavy burden on the project team to carry out the planning process.

<u>Previous and current research attempts for improvement</u>

Various research efforts have been undertaken in an attempt to capture current planning techniques and allow for the development of new innovative and automated ways in planning. Embarking on advancements in 3D computer graphics and artificial intelligence, previous and current research efforts attempted to automate the planning process by developing tools to manipulate and process project information, carry out the decision-making, and generate the required actions. The following paragraphs present a summary of these researches and discuss the shortcomings of each. Further detailed discussion of this work is presented in chapter 2.

An early research direction focused on developing knowledge-based systems (KBS) for automated project planning. These methodologies/systems were developed mainly to facilitate automatic production of construction schedules. Heuristics and acquired construction knowledge rules and procedures were encapsulated in a prototype computer model to provide feedback and generate planning decisions. Few incorporated mechanisms to interpret 2D or 3D drawings, but most relied on some form of user input. Examples of knowledge-based systems developed in the late 80's and early 90's include: CONSTRUCTION PLANEX (Hendrickson et al., 1987), OARPLAN (Darwiche et al., 1988), GHOST (Navinchandra et al., 1988), KNOWPLAN (Morad and Beliveau, 1991), SCaRC (Thabet, 1992), COKE (Fisher, 1993), and HISCHED (Shaked and Warszawski, 1995). A major drawback to these systems is their reliance for making decisions on programmed knowledge. The user has the least control or responsibility during the planning session and is mainly involved during data input only.

A second research direction utilized advancements in computer graphics to develop 4D [3D + time] tools that enable graphic simulation and visualization of the construction process. These simulation tools combine 3D CAD model with the project schedule and represent the construction plan graphically. The CAD model is imported from the modeling environment (e.g. AutoCAD, MicroStation, 3DM) and the schedule is imported from the scheduling environment (e.g. Primavera, Microsoft Project). The CAD model and the schedule files are merged into a simulation file by individually relating each CAD component, or group of components, with one or more specific schedule activity to create the 4D simulation session. Examples of 4D research efforts include: The Visual Schedule Simulation (VSS) system (Skolnick et al., 1990), and 4D-Planner (4DP) (Williams, 1996). Improvements in 4D tools have also been the area of investigation in several recent research efforts such as 4D annotator (McKinney et al., 1998), 4D + x models (McKinney and Fischer, 1998). Other researches used 4D for space planning in order to solve time-space conflict (e.g.: (Riley, 1998) and 4D WorkPlanner (Akinci and Fischer, 1998)).

4D tools proved to be useful in assisting planners to visualize alternative construction sequences based on alternative decisions made. However, they should not be considered planning tools as they rely on available plan/schedule information to provide a graphical simulation of the project schedule. The planner uses these tools as means of visualizing and comparing, rather than developing and implementing different decision alternatives.

A third and recent research direction has been developed using object technologies and virtual reality (VR) interfaces to aid in the communication aspects of construction planning. Programmed knowledge, in the form of rules and methods, combined with 3D objects and advanced graphical simulation techniques, are used to develop different models to assist in the planning of construction projects. MDA-Planner (Jagbeck, 1994), uses construction information to produce schedules. Planning decisions are performed automatically through an algorithm that randomly selects and schedules activities. Another system, IV++ (Open den Bosch and Baker, 1995), solves the complex problem of modeling construction operations in real time virtual environments by providing the user with the choice of virtual construction equipment that can simulate the tasks needed to assemble building structural components. The assembly sequences are already contained in the building object definition file. The user's control is limited to creating and switching between different camera views, changing the construction site topography (terrain), and changing the illumination conditions (lights). Adjei-Kumi and Retik (1997) use virtual reality technology for the realistic visualization of simulation of construction projects at the activity and component levels. The strategy proposes the use of a pre-defined library of 3D graphical images of building components, facilities, etc., and their related activities. A knowledge-base module automatically sequences the activities needed for the erection of building components without the user control or interaction.

Systems developed under this third direction represent an advancement toward the use of 3D simulation and visualization techniques for better planning decisions. However, similar to the first research direction, these systems continue to rely more on programmed knowledge and heuristics to develop decisions and actions with minimal involvement from the human planner. Visualization of the simulation session is not interactive with users, and changes to the 3D views are made based on systems algorithms with no dynamic interaction with the graphical model. These shortcomings have resulted in lack of applicability of these systems to the majority of the construction industry.

Synopsis

The developed planning systems are characterized as responsive decision systems, relying mainly on programmed knowledge and heuristics for decision making, hence reducing or eliminating the role of the human planner. What is needed is a support tool to assist the planner in visualizing and analyzing construction processes, rather than a tool that replaces the planner and automates the planning process. This is necessary for several reasons:

- To benefit from the user creativity and ability in making knowledgeable decisions. This human knowledge and experience would, otherwise, require a large amount of time and skill to code into a computer domain (Houshyar and Bringelson, 1998). Construction strategies are also evolving, and unless the knowledge of the developed systems is continuously modified and updated, user's experience and direct involvement are required.

- The users have more ownership of the produced plan by being an active participant in its development, therefore, making the plan more acceptable to the project team.

- Due to the uniqueness of each project's criteria, requirements, and constraints, it would be tedious and time consuming to develop practical systems that would consider all execution strategies. The project team needs to be in charge of delivering the planning decisions to account for the specific conditions of each individual project.

1.3 RESEARCH OBJECTIVE AND SCOPE

The main objective of the research is to develop a framework for a new interactive planning environment to support the thinking process of the project team during the macro planning phase of design-build projects. Unlike previous responsive-type systems developed, the approach utilized in the new environment will be supportive to the project team enabling the users to be an active participant in the decision making process. A prototype computer tool is developed to illustrate the concept of the new environment. The research leverages emerging and existing modeling techniques to develop this interactive planning tool, which will enable the project team to undertake inexpensive rehearsals of major construction processes and test various execution strategies prior to the actual start of construction. The tool will provide all parties involved with the opportunity to think, make inputs, discuss, and modify the design and/or the proposed overall plan of execution.

The research focuses on the macro planning process during the pre-construction stage in a design-build format. Because macro planning begins at an early period in a project's life cycle, planning decisions made at this stage are crucial to the successful execution and completion of any project. The collaboration of the construction team and design team using this format enables communication of design, planning, and construction issues among the project team at this early stage, and thus provides for better opportunity for improving the project constructability. This is what makes the design-build format a better candidate for this research.

1.4 RESEARCH METHODOLOGY

In order to accomplish the research objective, several major steps had to be achieved:

1. ***Study the current macro planning practices, and identify the different decisions and actions made:***

   In order to formulate the different steps involved in the macro planning process, interviews were conducted with construction professionals from design, general contracting, and construction management companies involved in design-build projects. Information acquired from these interviews, along with the researcher's own knowledge, extensive literature review, and discussions with faculty, have enabled the researcher to identify the various elements and format of the macro planning process, as well as the different problems encountered.

2. ***Classify information necessary for macro planning decision making in a structured format.***

   In order to make appropriate decisions, the project team needs to extract various information from different data sources. The current macro planning practices leads to a tremendous amount of information that needs to be manually pieced together by the project team to develop a comprehensive plan.

Through extensive literature review and interviews with construction professionals, the author has developed a **MA**cro **P**lanning **I**nformation **C**lassification (**MAPIC**) framework under which information required for macro planning decision making can be classified and organized in a structured format.

3. ***Develop the framework for the Virtual Construction Environment.***

   The framework of an integrated virtual planning tool called the Virtual Construction Environment (**VCE**) is developed to support the project team in making appropriate planning decisions. The VCE enables the project to undertake inexpensive rehearsals of major construction and test various execution strategies in a near reality sense, prior to the actual start of construction.

4. ***Implement a prototype computer model to illustrate the concept of the Virtual Construction Environment.***

   A computer prototype model is implemented as a proof of the VCE concept. A hypothetical project is used for the implementation. The implementation efforts utilized a Silicon Graphics machine running Windows NT. The prototype's interactive 3D modeling environment is developed using AutoCAD Architectural Desktop 2.0. Databases are implemented using Microsoft Access 2000. Programming is performed for customizing the modeling environment, for developing User-Support Modules' procedures, and for linking the different software packages.

5. ***Gather the feedback of construction professionals on the Virtual Construction Environment.***

   Feedback of construction professionals on the VCE is gathered and their input is documented in the summary and conclusion chapter as recommendation for future research and computer implementation. Feedback was collected from construction professionals who were interviewed before for current macro planning practices formulation. Returning to the same construction professionals intended to assure that the VCE addresses the problems mentioned during the first interviews.

1.5 RESEARCH CONTRIBUTION

1. The development of a Macro planning Information Classification (MAPIC) model that allows for structured organization and retrieval of macro planning information.

2. The development of a framework for a new interactive planning environment that provides the project team with means/tools to:
   - Acquire various information necessary for decision-making in a structured easy to comprehend format.
   - Visualize the perceived characteristics and spatial relationships among various components of the project, including site-related activities.
   - Planning the project at the macro level, which includes design review for constructability improvement, major work execution decisions, and site layout planning.

- Document various decisions made throughout the macro planning process, as well as the rationale behind making these decisions, in an easy to acquire format.

3. The research builds on previous work in the area of automated project planning. The research makes a serious attempt to solve some of the major drawbacks associated with the previously developed tools. The major improvements suggested in this work are based on:
   - Developing of a virtual site to rehearse construction processes.
   - Planning decisions are formulated by the user during the construction sessions.
   - System architecture is designed to be supportive to user decisions, rather than responsive to user input.

1.6 RESEARCH LIMITATION

The interpretation of the current macro planning practices is based on the researcher's own knowledge and experience, discussion with faculty and interviews with construction professionals. The interviews were conducted to broaden the researcher knowledge about the subject matter and to provide for a practical comprehension of the current macro planning practices. It is essential to realize that these interviews were not intended to present a general survey for the prevailing macro planning practices in the construction industry. Therefore, the outcome of the interviews only reflects the practices and opinions of the interviewees.

The allocation of major resources is a main decision considered during macro planning. Major resources addressed in this research consist of the primary equipment (e.g. tower crane, concrete pump, …etc) that affects the selection of major means and methods, as well as the site layout. Other resources (e.g. crew) are not approached in this research. However, they may be easily incorporated in the environment through further research efforts.

The developed computer prototype intends to illustrate the framework of the VCE including the modeling environment and the User-Support Modules. Although the VCE may be utilized for variety of projects regardless of their volume or nature, the implemented computer prototype is limited to a number of work packages, and does not address an entire project. More programming and testing are required for the future implementation of a practical computer model, and more tests and validation will be needed.

In addition, the computer prototype implementation effort is limited to personal computer settings and no virtual environments (e.g. CAVE) were tested. Further development and programming will be also required to apply the VCE to such environments.

1.7 DISSERTATION ORGANIZATION

The dissertation consists of seven chapters. This chapter "**INTRODUCTION**" provides a background of the planning process at both the macro and micro levels. Problems encountered in the current practices for planning, as well as drawbacks of the previous attempts to improve the planning process are introduced. The research scope and methodology are discussed. Finally, the research contribution and limitation are presented.

The second chapter, **"CURRENT STATE OF KNOWLEDGE",** provides a literature and technology review of areas related to the research scope. This includes *Automated Planning tools*, *Methods Selection tools, Constructability concepts and tools*, and *the current macro planning practices*.

The third chapter, **"MACRO PLANNING PROCESS",** describes the current process of macro planning in a Design-Build delivery method. Components of the macro planning process (i.e. project data, decision-making process, and planning actions) are described in detail and illustrated with examples.

The reader may choose to skip the previous two chapters if he is familiar with the current state of knowledge related to the planning process, as well as the concepts of project planning at the macro level (i.e. pre-construction stage).

The fourth chapter, **"MAPIC – MACRO PLANNING INFORMATION CLASSIFICATION",** presents the MAPIC model. First, the development and structure of the model is discussed. Then, a detailed description of the various MAPIC categories, classes and attributes is presented. Finally, how MAPIC will be applied to improve the macro planning decision making process is described.

The fifth chapter, **"THE VIRTUAL CONSTRUCTION ENVIRONMENT (VCE)"**, presents the framework of the VCE. A general description of the VCE concept and the system architecture is presented. The chapter also includes description of how the project team's information retrieval, decision making, and collaboration is implemented in the environment. Finally, a detailed description of the User-Support Modules is included.

The sixth chapter, **"IMPLEMENTED PROTOTYPE",** includes computer implemented examples of how the project team may make decisions, retrieve various information, and take several actions for implementing the plan at the macro level through the VCE.

The final chapter, **"SUMMARY AND CONCLUSION"**, provides a closing chapter for the dissertation. A conclusion of the main points discussed in the document is outlined. The benefits and contribution of the research along with recommendations for future research and extensions are included.

2. CURRENT STATE OF KNOWLEDGE

2.1 INTRODUCTION

Construction planning has been the subject of research, development, and implementation for the last several decades. Due to the broad area of construction planning and the various subjects involved, the researcher categorized the subjects reviewed/covered into four distinct parts: *Automated Planning tools*, *Methods Selection tools, Constructability concepts and tools*, and *the current macro planning practices*. Each of these subjects is reviewed in this chapter.

The first part, automated planning tools, reviews the various research efforts undertaken in an attempt to capture current planning techniques and allow for the development of new innovative and automated tools for planning. Embarking on advancements in 3D computer graphics and artificial intelligence, previous and current research efforts have attempted to fully or partially automate the various planning tasks by developing tools to manipulate and process project information, carry out the decision-making, and generate the required actions. These efforts may be divided into three main directions: Knowledge-based Systems (KBS), 4D Models, and Virtual Environments. These three directions are discussed in detail in this chapter.

Construction planning involves various processes that impact its successful development. Selection of appropriate means and methods is a major process that should be carefully considered especially during macro planning. The second part of this chapter reviews the different method classification and selection systems.

Construction planning also involves improving the project constructability through design review and appropriate decision making. Poor constructability continues to be a leading factor to dominant problems of construction projects. Some examples of problems that may occur in a construction project due to poor constructability include low productivity and quality, higher costs and duration, out-of-sequence work, and inefficient use of resources (McCullouch and Patty, 1994; and Glavinich, 1995). The depiction of these problems during macro planning (i.e. before the beginning of the construction) would significantly reduce the cost and the duration of the project. The third part of this chapter discusses the causes and impacts of poor constructability. A classification of factors affecting the project constructability is presented, and constructability improvement strategies and models are reviewed.

After making this literature and technology review, the researcher felt the need to get a better understanding of the current macro planning practices including the problems encountered and the steps involved. Several interviews were conducted with industry professionals to help attain this objective. The outcome of these interviews, along with discussion with faculty and the researcher own knowledge and experience, were the basis for the development of chapter 3 - The Macro Planning Process - and chapter 4 - the Macro Planning Information Classification (MAPIC). The fourth part of this chapter briefly elaborates on the interviews conducted.

2.2 PART I - AUTOMATED PLANNING TOOLS REVIEW

Previous and current researches continue to develop automated approaches to assist industry professionals in planning construction projects. Implemented models may be categorized in three different stages according to the direction that the research follows. The first direction, expert systems, started at mid 80s and automated the planning process through the use of knowledge-based systems. The second direction, 4D models, started at the early 90s and combined 3D CAD models of the facility with an available project schedule to represent the plan graphically. The third research direction, virtual environments planning models, utilized programmed knowledge, in the form of rules and methods, combined with

3D objects and advanced graphical simulation techniques, to develop different models to assist in the planning of construction projects. Each of these research directions is presented in this section.

2.2.1 KNOWLEDGE-BASED SYSTEMS (KBS)

The first research direction focused on developing knowledge-based systems (KBS) for automated project planning. These methodologies/systems were developed mainly to facilitate automatic production of construction schedules. All of these systems use heuristics and acquired construction knowledge rules and procedures encapsulated in a prototype computer model to provide feedback and generate planning decisions. Few incorporate mechanisms to interpret 2D or 3D drawings, but most relied on some form of user input.

As shown in Figure 2-1, a typical knowledge-based system for planning consists of a context, a knowledge base, and an inference engine. The context contains information about the project on hand. The knowledge base consists of heuristics associated with the domain (planning) of the knowledge base. The inference engine works with the knowledge in the knowledge base, and the context to develop the plan.

Examples of knowledge-based systems include the following:

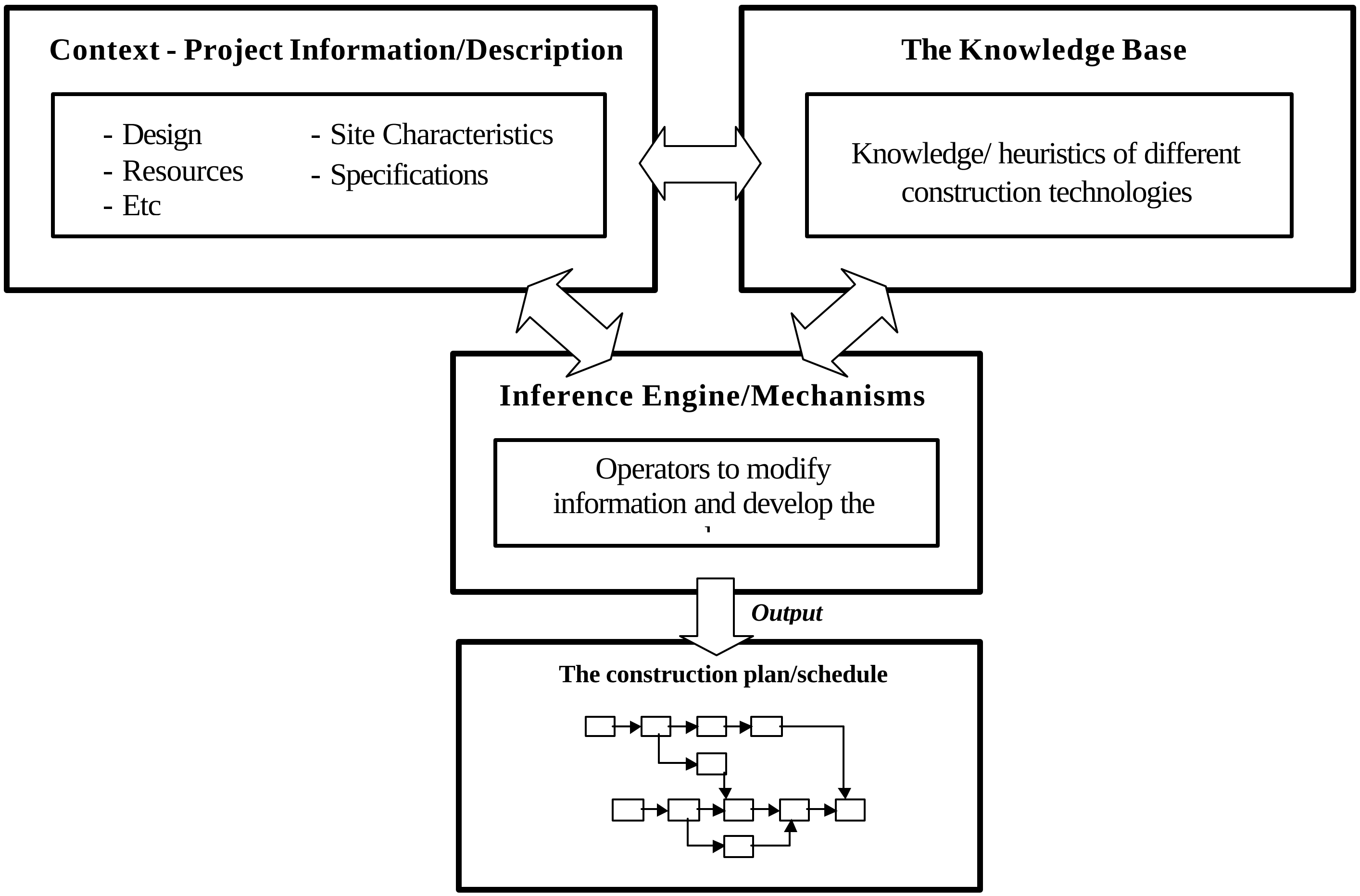


Figure 2-1: Knowledge-Based Systems

CONSTRUCTION PLANEX, developed at Carnegie Mellon University by Hendrickson, Zozaya, and others, is one of the first prototype systems that present a framework for the development of automated planning assistants based on knowledge-based expert system and artificial intelligent programming techniques (Hendrickson et al., 1987). This system was initially developed for excavation planning and the structural erection of concrete and steel-frame buildings. The input of the system consists of the specifications of the physical elements in the design, site information, and resource availability, and produces as output a complete plan, a provisional schedule and a cost estimate.

OARPLAN, the Object-Action-Resource Planning system, developed at Stanford University, is a an attempt to combine the generality and high performance of both the general purpose and domain-specific planning systems to generate project plans based on facility descriptions (Darwiche et al., 1989). OARPLAN takes as its input a description of the facility to be constructed and generates a hierarchical project plan for construction of the facility. The system derives most precedence relationships form topological, spatial and other relationships among the object associated with separate activities in the plan.

GHOST, developed by a group of researchers at Carnegie Mellon University and Massachusetts Institute of Technology, is another prototype knowledge-based system for construction networks generation (Navinchandra et al., 1988). This system takes another approach to construction planning than the previous systems. GHOST does not use its knowledge to build the network but only to criticize it. The system starts by the assumption that all activities can be executed in parallel, then uses several knowledge sources known as critics to modify the network. These critics know about physics and construction, perform refinement, and check for redundancy. The output is a temporally good network.

KNOWPLAN, is a knowledge-based planning system that integrates artificial intelligence technology with computer aided design (CAD) and 3D computer modeling technology to generate and visually simulate construction plans (Morad and Beliveau, 1991). The main objective of the system is to generate a dynamic sequence of the construction process by reasoning mainly about the geometric data of the different project components that is extracted from the CAD model of the facility. The final product is a visual simulation of the generated sequence of activities using simulation technique and animation techniques.

SCaRC (Space Constrained and Resource Constrained) scheduling system is developed by Thabet (1992) to generate construction schedules for the repetitive floors of multi-story buildings. The system utilizes a database system and a knowledge-based system for the overall schedule generation process. The database system acts as a user interface, provides for defining all necessary input data, and allows the user to view the output of the scheduling process. The knowledge-based system is responsible for the actual production of the schedule. It consists of three modules: an external data interface module, a controller module, and a sequence generation module. The output is a schedule with several output formats including a graphical format.

HISCHED, developed by Shaked and Warszawski (1995), is a knowledge-based expert system for the construction planning of buildings. The system is part of an automated building realization process. The targeted domain of the system is multistory buildings of any function, heights, and construction technology. HISCHED uses an object-oriented representation of the building and production rules, routines, and functions to manipulate objects and to generate the construction plan. The representation of the building includes three types of objects: Zones, which define the topology and nature of the building, functional systems, which define the components of the building and their construction technology, and works, which define the construction activity. The system receives the configuration of the building and the designation of its multimodules as input, and generates the tasks necessary for the completion of the building, the dependences between those tasks, the allocation of resources for their execution, and the construction schedule.

A major drawback to these knowledge-based systems is their limitation and their reliance for making decisions on programmed knowledge in the form of rules and methods, which leads to minimal user interaction, and responsibility during the planning process. The user has the least control during the planning session and is mainly involved during data input only. In addition, the fact that each construction project is unique and each construction team has its own capabilities leaves a set of defined rules inappropriate for decision making during the planning process. As a result, these systems have came short and did not make it to practice

2.2.2 4D MODELS

A second research direction utilized advancements in computer graphics to develop 4D [3D + time] tools that enable graphic simulation and visualization of the construction process. These simulation tools combine 3D CAD models of the facility with an available project schedule and represent the construction plan graphically.

As shown in Figure 2-2, the CAD model is imported from the modeling environment (e.g. AutoCAD, MicroStation, 3DM) and the schedule is imported from the scheduling environment (e.g. Primavera). The CAD model and the schedule files are merged into a simulation file by individually relating each CAD component, or group of components, with one or more specific schedule activity to create the 4D simulation session.

Examples of 4D research efforts include: The Visual Schedule Simulation (VSS) system (Skolnick et al., 1990), (Stumpf et al. 1994), and 4D-Planner (4DP) (Williams, 1996). Improvements in 4D tools have also been the area of investigation in several recent research efforts such as 4D annotator (McKinney et al., 1998), 4D + x models (McKinney and Fischer, 1998). Other researches used 4D for space planning in order to solve time-space conflict (e.g.: (Riley, 1998) and 4D WorkPlanner (Akinci and Fischer, 1998)).

Each of these systems is presented in detail in this section.

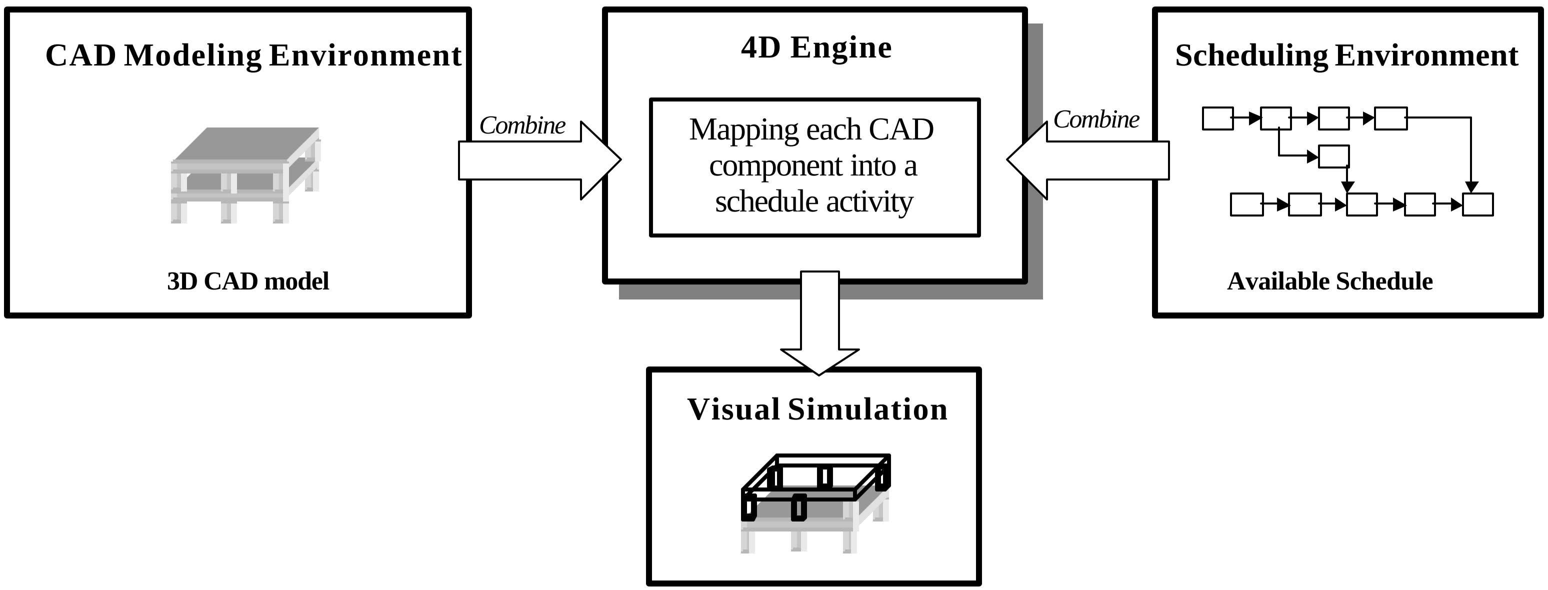


Figure 2-2: 4D models

1) The Visual Schedule Simulation

The Visual Schedule Simulation (**VSS**) system, developed by Skolnick et al. (1990), combines a CPM schedule and a 3D computer model of a construction project to produce a visual simulation of the construction sequence. The VSS allows the user to visually simulate the construction schedule for any time period during the construction sequence. The VSS system can also show both planned and actual progress at the same time using two identical 3D computer models of the construction project.

The system consists of three distinct phases, which can interact with each other via computer network: *the data preprocessor*, *the database manager*, and *the visual simulation*.

The Data Preprocessor

This is phase I of the VSS system. The data preprocessor involves the development of the construction network and a 3D computer model. The construction network is developed in a ".dbf" format using Primavera Project Planner and exported to the database manager. The VSS system uses WALKTHRU to interact with existing 3D computer models created on a 3D CAD system. The 3D computer model must be subdivided into individual objects to be able to reflect the CPM schedule related to the construction project.

The Database Manager

The database manager is phase II of the VSS system. The database manager links the construction schedule with the 3D computer model for the construction project, giving time values to each model object. This phase is a computer program developed using dBASE IV programming language. The database manager maps the schedule file with the model file.

The user must also input into the database manager the names of each object created in the 3D computer model. The final product of the database manager is an ASCII file defining the start and finish dates for each model object.

The Visual Simulator

Phase III of the VSS system consists of the Visual simulator. The visual simulator allows the user to produce a visual simulation of the construction process. The visual simulator uses the time values assigned to each 3D computer model object, during the previous phase, to define the parameters to visually simulate construction activities. The user has the flexibility to simulate early start and finish dates, late start and finish dates, or early starts and finish dates for planned construction. The user can also visually simulate actual construction progress. Both planned and actual construction progress can be viewed individually, or at the same time using two identical models of the construction project. The user can simulate the entire project or any segment desired.

2) ***Using CADD applications to support Construction Activities***

Stumpf et al. (1994) discussed how electronic CADD submittals from designers can be transformed into a format appropriate for construction planning and management. Three dimensional CADD (computer aided design and drafting) drawings with associated databases of components can be captured from design, added to during construction, associated with cost, schedule, and progress data in a multi-media format, and ultimately will represent the completed facility and its components. By using visualization and simulation tools with scheduling software, the facility can be `built' on the computer, and checked for interferences and schedule conflicts. Through the visual simulation of construction sequences, construction conflicts can be detected and prevented during construction planning. Visual simulation of a complicated construction operation can help improve productivity, safety and cost reduction of construction projects.

The 3D-object model is created in AutoCAD by inserting objects from a predefined object library database. The object library has attributes such as block file name, unit size, material property and primary key fields associated with the cost database, MCACES (a standard cost estimating software by the US Army Corps of Engineers). Schedule and subcontractor information for the newly developed objects is stored in a project-specific database table, which is associated with graphic objects in CADD systems. The CADD/Database linkage enables the user to check the cost for material, labor, equipment and duration for a specific component object as well as the project control information such as start/finish date, percent complete, subcontractor, etc. The simulation of alternative construction sequence is performed in WALKTHRU (a 3D graphic modeling software developed by Jacobus Technology Co.), using Construction Simulation Toolkit (CST). CST is a linker software that links activity in TIMELINE (a scheduling software) with objects in WALKTHRU in any relationship such as one-to-one, one-to-many or many-to-many, using activity-number. As a result, CST generates a scenario file for the visual simulation of construction sequence in WALKTHRU. As the last step, the simulation for construction sequence and scheduling is performed in WALKTHRU using the scenario and the object files.

The simulation of the construction facilities is useful for the following reasons:

- To visualize complex installation procedures as in the case of piping/plumbing for large facilities.
- To identify problems in the logical sequence of activities in the construction schedule, as when a component is scheduled to be installed before its supporting components are in place.
- To identify possible difficulties with construction such as movement of equipment through restricted spaces.
- To visualize the state of the site over the period of construction to identify the variation in site layout with the construction progress.

Deficiency and drawback

The system uses a visualization and simulation tools (WALKTHRU and CST) with scheduling software (TIMELINE) to build the facility on the computer with no user interaction or control on the planning process because the schedule was already developed prior to the use of this system.

3) 4D-Planner

4D-Planner, developed at Bechtel Corporation, is a tool that allows the user to combine the 3D CAD model with the project schedule and represent the construction plan graphically (Williams, 1996). This tool was developed in response to project visualization, simulation, and communication needs. 4D-Planner allows the project participants to review and understand the timing, sequencing, and status of the project.

The 4D-Planner User Interface

The user interface of the 4D-Planner is written in XWindows. XWindows provides intuitive and easy to use windows-like environment, which insulates the user from the need to enter Unix commands to interact with the system. Most actions in this user interface can be performed using a pointing device and various on screen menus. The user interface allows the user to open more than one window at the same time. One window may provide a view of the CAD model in any projection (e.g. plan, front, or isometric). This window also illustrates the result of a simulation when it is played back. Another window presents a view of the network schedule with the relationships between the different activities. This window allows the user to change the relationships between the activities by using the mouse. A third data entry window may contains activity information in a text format. This information includes the activity start date, duration, and milestone events.

4D-Planner Simulation file

The simulation file in the 4D-Planner imports the CAD model from the modeling environment where it was created. The modeling environment may be any system that can be converted to a Walkthru file format (e.g. MicroStation, PDS, 3DM, and AutoCAD). The simulation file also imports the schedule from Primavera. However, 4D-Planner enables the user to create the schedule through the data entry window. Each time this data is updated, a

CPM scheduling engine performs forward and backward passes on the schedule, computes common schedule information such as activity floats, early and late start and finish dates.

The CAD model and the schedule file are then merged into the simulation file by individually relating each CAD component, or group of components, with one or more specific schedule activity. When the simulation file is played back, the various components are displayed in the model at the end of the duration of the activity. This simulation enables the user to detect inappropriate schedule logic. In addition, there is an on-line interference detection that alerts the user if a clash occurs. This clash may be two components competing for the same space at the same time. The user may then change the information of the activities (e.g. duration or logical relationships) and runs the simulation again to illustrate the results of the schedule changes.

4) <u>4D Annotator</u>

McKinney et al. (1998) proposed plans to implement mechanisms for a 4D annotations environment generation in which planners can contextually visualize various types of planning information to better support decision making. The "4D annotations" visually explains to planners potential constructability problems or how a proposed construction sequence affects decision criteria such as cost, productivity, and safety. The scope of this work is not to develop an integrated and intelligent planning tool that can generate all kinds of planning information. Rather, the work focuses on understanding how best to structure and represent planning information to produce 4D annotations.

Today planners rely on a number of tools to support their decisions throughout the lifetime of a project. In most cases, though, these tools simply help planners to document the decisions made and then use that documentation as a reference to compare alternatives. Although 4D models are useful to communicate the overall sequence of construction, they are difficult to interpret and still do not provide enough feedback for planners. Current 4D systems lack the functionality to visually communicate non-descriptive information.

One of the challenging aspects of this work was the development of mechanisms to associate and relate various types of information to a 3D model. The use of features was selected for this job. Features may be defined as an entity used in reasoning of design, engineering, and manufacturing. Features have to be classified and represented in a building model library. During the 4D simulation a 4D analysis tool reasons about information to check that, for example, all of the support conditions for a roof are met. If a component does not have support at the time of installation, the tool uses the feature information to visually alert and inform the planner of a potential problem and where and when the problem occurs.

The Annotator System

The system is composed mainly of two components:

A. Feature Assigner:

There are four ways to define features:

- Automatic feature extraction.
- Manual assignment of features: this approach is the easiest to implement and to validate the feature concept. The planner first selects a building component in the model and then assigns a planning feature from a pre-defined set of planning features.
- Design with features.

- Embed feature knowledge in building component.

Ideally, a feature-based planning tool will need to provide functionality to support flexible generation and definition of features. Furthermore, if feature knowledge is embedded in the components, designers and engineers can design with features, capturing constraint knowledge. The output of the feature Assigner is a 4D model with planning features that can be used as input to planning systems that require knowledge of relationships between building components. Features, then, are the mechanism to generate constraints and establish functional relationship between components

B. Annotator Environment:

The 4D Annotator prototype tool is being developed in a VRML/Java environment. The Annotator graphic provides a series of options for the planner to view various types of planning information in the 4D context.

5) <u>4D + x models</u>

McKinney and Fischer (1998) explored how CAD information can be used to generate more realistic schedules and visualize planning information in what they refer to as 4D-CAD and the functionality of the next generation 3D and 4D tools needed to generate 4D + x models.

McKinney and Fischer noted that construction planners interpret design documentation (2D or 3D drawings and specifications) to produce a construction schedule of a set of activities and sequential relationships. While construction schedules communicate time and the sequence of construction activities, project participants must mentally associate this schedule information with the description of the physical building.

McKinney and Fischer indicated that, today, the purpose of building 4D models is primarily for visualization and communication. Current commercial 4D tools require planners to plan and schedule before they use a 4D tool since they have to generate and coordinate a priori a 3D-CAD model and construction schedule. This kind of 4D modeling is non-interactive and does not truly provide the opportunity for planners to use 4D tools for planning and to explore the relationships between the design and the construction schedule.

McKinney and Fischer presented current options and methods for the planners to interact with 4D content:

- Creating a series of image depicting the state of construction on a particular day. However, this can be a time consuming process and provides the planners with little opportunity to explore alternative construction sequences.
- The use of a 4D tool that enables a construction planner to associate 3D-CAD entities with construction activities where the 4D tool associates an important construction activity with an imported CAD layer or CAD entity. Such tools require the planner to organize the CAD model to match the construction schedule. This method requires the planners to carefully coordinate the layer names and construction activity names.

- The use of a 4D tool that enables a construction planner to link 3D-CAD entities with construction activities. However, these tools provide little opportunity for the planner to interact directly with the 4D content.

None of the previous tools allow the planner to interact with the CAD and schedule information within one environment. That's why, McKinney and Fischer proposed a prototype 4D tool where planners can 'interactively' generate CAD schedule and 4D content within one environment. The prototype is build on AutoCAD and linked to a knowledge-based engineering system, D++. The planner can open the 3D-CAD model of the roof-gutter assembly and edit that model, generate or edit the schedule information, and association CAD entities with construction activities within the CIFE 4D-CAD environment. The planner has access to all of the 4D content within one environment. With CIFE 4D-CAD, the planner can redesign, re-sequence, or re-associate CAD geometry with construction activities to quickly develop alternative construction sequences.

McKinney and Fischer also noted that various research and industry efforts are working towards standard data models of building and construction information. McKinney and Fischer' goal is to add to these efforts by generating 4D information modeling requirements based on case studies and examples of 4D analysis. Then the authors present different methods to assign component type:

- Assign component type during modeling by selecting a component from a component library.
- Assign component type after modeling by interpretation.

McKinney and Fischer also presented different methods to generate and acquire the relationships between the components:

- Capturing relationships as the 3D model is produced using available CAD tools. However, the inference engines of these tools require a lot of memory and, thus, reduce the speed of the modeling tool.
- Deriving relationships through geometric and knowledge-based reasoning. The problem with this method is the presence of a variety of support conditions that are difficult to infer using rules and require highly domain specific representations of building components within CAD models.
- Manually interpreting 3D-model components and assign relationships. This method provides the flexibility necessary to account for the unique nature of building construction but also requires construction planners to understand the purpose and process of assigning such relationships. In addition, this method can be feasible for a small detail, but adds an extraordinary amount of work to build a 4D model for an entire construction project.

McKinney and Fischer noted that to make full use of the information in the 4D + x models, the visualization of the construction component should alert planners to potential planning problems. Finally, McKinney and Fischer discussed two methods, 4D annotation and representation of temporary construction components, to visualize the 'x' aspects of the model.

6) 4D Space Planning Specification Development for Construction Work Spaces

Other researches used 4D for space planning in order to solve time-space conflict. Riley (1998) considered Space planning to be a technique to evaluate scheduling or sequencing alternatives to determine if spatial conflicts exist between different trades. He indicated that the construction industry needs a tool that aids construction planners in predicting and reducing workspace congestion and interference between crews and stored material. So Riley explored the inclusion of physical workspaces, storage areas, and material paths as 3D objects in a 4D analysis of a construction projects. Riley defined attributes and properties for the modeling of construction spaces, and discussed the primary inputs and outputs of the planning process to demonstrate the role of these properties in the 4D planning environment.

Four key spaces needed by crews were the focus of his work:

- Physical work space.
- Storage areas.
- Paths.
- Access points for unloading materials onto building floors.

Three categories of properties are needed to describe construction workspaces:

- Physical, which describes size, location, and density.
- Temporal, which associates the spaces to schedule data.
- Inherited, which associates spaces with product model objects and schedule activities.

Inputs and Outputs of the Space Planning Process

For space planning to be effective, it must be viewed as investment of planning resources.

Inputs to planning:

Different elements of 4D space planning may be automated.

- 3D model of each work area to be considered in the planning process.
- Property Database for work spaces and associated spaces.

Other elements require user input.

- A sequence in which model objects that are associated with unique construction activities become active.
- Assigned positions of material access points and storage areas.
- Lead times or fixed dates for material delivery to storage spaces.

Planning Outputs:

The ultimate product of 4D modeling and space planning should be a construction plan that is free from disruptive spatial conflicts. The automated detection of potential conflicts between work space, storage areas, and paths of different crews represents the primary goal of the 4D modeling process because it would permit complex and long duration work sequences to be evaluated, and reevaluated after adjustments are made.

Riley identified six types of spatial conflicts that would be beneficial to detect: $Work_a$-$Work_b$, $Storage_a$- $Work_b$, $Path_a$- $Work_b$, $Storage_a$ –$Storage_b$, $Path_a$- $Path_b$, and $Path_a$-$Storage_b$. It is assumed that conflicts between work, material, and paths for the same activities could be resolved by the crew performing the work and should therefore be ignored during planning.

Impact of Planning Environment on Modeling Detail

Most planning efforts require a judgment to be made on the level of detail that must be included in the development of a realistic plan. Four aspects of space planning provide opportunities to adjust the level of detail in the planning process were presented:

- *Planning Interval*: it is recommended that 4D modeling of workspaces be performed with one week planning intervals.
- *Space Usage*: Spaces that are occupied for only a day or less might be omitted.
- *Activity type*: it is recommended that 4D modeling of construction operations focus on the following types of crews and materials: HVAC, electrical, plumbing, fire protection, carpentry, and curtain wall.
- *Work Zone*: work zone may be defined by the geometry of a building floor.

7) 4D WorkPlanner

To solve the time-space conflict, Akinci and Fischer (1998) developed a 4D WorkPlanner that integrates location, space and time information by combining workspace requirements of activities within a 4D-production model. 4D WorkPlanner simulates the construction process, identifies time-space conflicts between activities, modifies productivity rates of interfering activities and provides an overall feedback about impacts of time-space conflicts in an existing schedule.

4D WorkPlanner Representation

4D WorkPlanner is built using a 4D production model which is an integrated model and process model with explicit representation of construction methods and geometric states of construction.

The interference detection and time-space conflict analysis of a given schedule is automated because Akinci and Fischer argued that there are several problems with visual time-space conflict analysis and can't be left to the user.

The micro-level space requirements of activities such as crews working around a component are modeled. Activity workspace requirements are represented as an envelope around a building component. Consequently, macro-level space requirements of activities (material storage) will also be represented.

Activity workspace requirements are added in a 4D-production model by representing them as resource requirements of activities in a construction method model. The work space requirements are stored generically within a construction method definition. This knowledge is passed on to activities, making the generic workspace representation project specific, when a 4D-production model is generated.

4D WorkPlanner Reasoning

4D WorkPlanner simulates the construction process, and within each simulation run, identifies time-space conflicts and modifies the productivity rates and duration of interfering activities. The output is a modified schedule incorporating the productivity impacts of time-space conflicts, a list of interfering activities and an explanation of how the initial schedule is changed to accommodate the productivity impacts of time-space conflicts. The user will then be aware of interference problems in a given 4D model and can choose to modify the schedule to minimize the time-space conflicts that have been identified.

4D WorkPlanner is composed of three modules:

- 4D simulator is the simulation engine of the 4D WorkPlanner. During each event, It identifies a list of concurrent activities and sends this information to Interference Detector.
- Interference Detector builds the space requirements of all concurrent activities and checks for spatial interference in all three dimensions. It provides a list of interfering activities to Productivity Modifier.
- Productivity Modifier reduces the productivity rates of interfering activities for the duration of an event by considering the level of interference for each interfering activity.

4D Models Conclusion

4D tools proved to be useful in assisting planners to visualize alternative construction sequences based on alternative decisions made. However, they should not be considered planning tools as they rely on available plan/schedule information to provide a graphical simulation of the project schedule. The planner uses these tools as means of visualizing and comparing, rather than developing and implementing different decision alternatives.

2.2.3 VIRTUAL ENVIRONMENTS PLANNING MODELS

A third and recent research direction has been developed using object technologies and virtual reality (VR) interfaces to aid in the communication aspects of construction planning. Programmed knowledge, in the form of rules and methods, combined with 3D objects and advanced graphical simulation techniques, are used to develop different models to assist in the planning of construction projects.

Examples of these systems include MDA-Planner (Jagbeck, 1994), IV++ (Op den Bosch and Baker, 1995), 3-D graphical simulation for temporary facility planning (Ito et al., 1996), Visualization of spatial and geometric databases for construction projects (Halfawy et al., 1996), and a Library-based 4D visualization construction processes (Adjei-Kumi and Retik, 1997). These examples are presented in this section.

1) MDA Planner

Jagbeck (1994) presented a system that is conceived as part of an integrated flow of information connecting the project model with construction knowledge using a mobile, computer-based diary for recording information on site in order to produce suitable and adjusted schedules. The system offers an environment within which the production process of a designed project can be calculated interactively as shown in Figure 2-3.

The construction knowledge is expressed as methods, facts about resources from internal and external sources, and progress data. All decisions about construction methods, the division and sequence of building parts, and the choice of resources are left with the user.

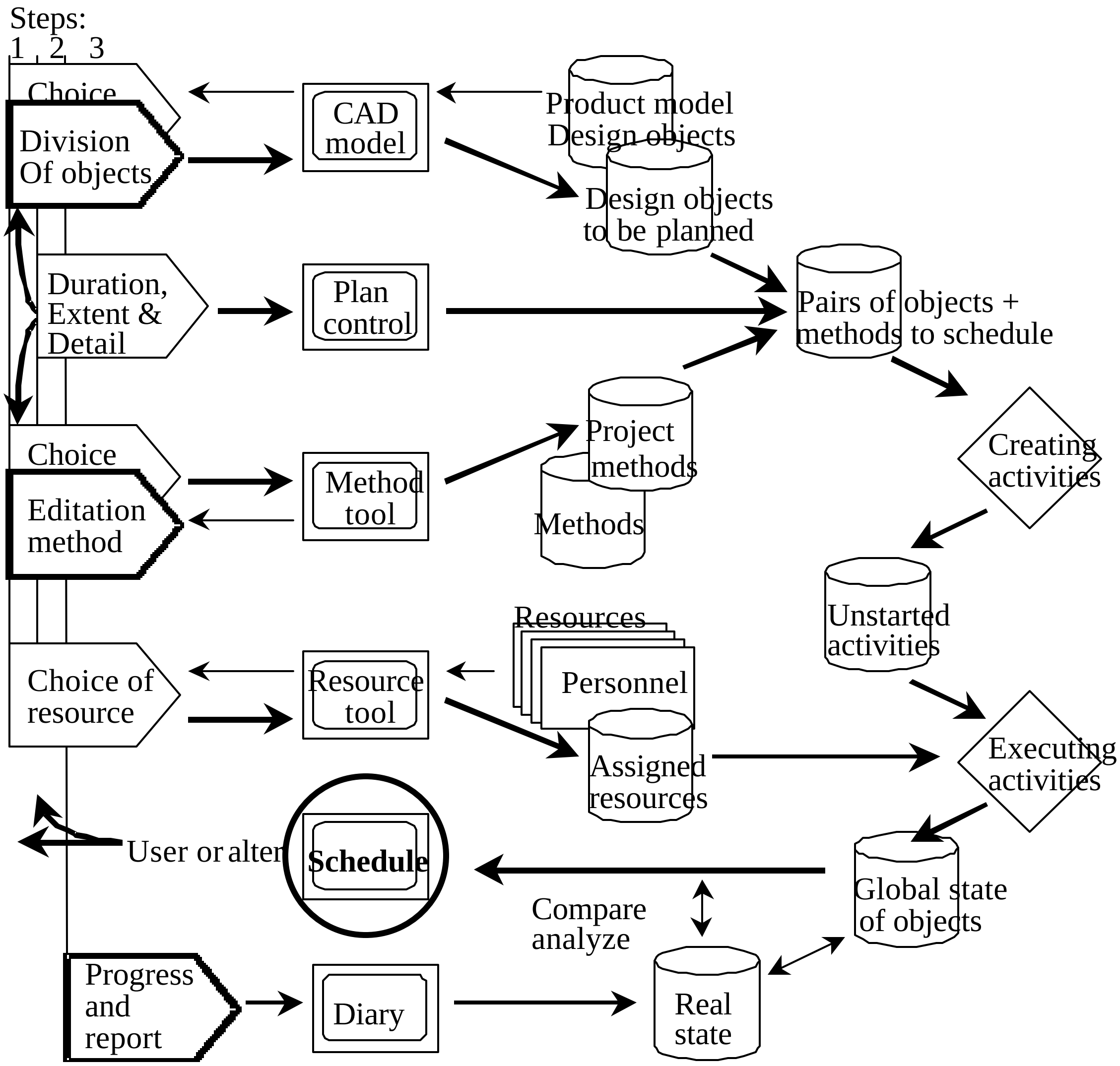


Figure 2-3: Operational procedural and Information Flow of MDA
(Regenerated from Jagbeck, 1994)

Choices are made by pointing at the items. Given the facts about building parts, methods, and resources, the system automatically generates activities and schedules them. Resulting plans or states are reflected both as bar schedule and in the model of the building. However, the planning program just handles personnel, and does not handle material, equipment, or subcontractors.

The core of the system is a model of the information needed and the algorithms used by the computer to produce a schedule. The main idea is that construction consists of a series of activities, gradually changing the initial status of the site to a complete building. To be able to compute such a process, two main bodies of information are used: information about the result (the building) and information about the process (construction methods). Thus combining a building with a suitable method results in a process in which an activity changes the status of the site to one containing the planned building.

Having determined the building parts to be planned and the suitable corresponding methods to be used, The system can generate the activities involved, including the resources needed. The activities are stored in an activity database together with their arguments. When planning is ordered, the scheduling algorithm starts to work in steps, scheduling one activity at a time. The algorithm takes one of the possible activities, calculates the amount of work to be done and the duration of the activity based on efficiency coefficients, and stores the stage change as the postconditions of the activity, in the global database. The process finishes when all activities are scheduled. The result is a database of performed activities.

The scheduling algorithm of the system can be regarded as the set of all activities forming an equation system. The goal of the scheduling phase is to solve that equation system, if that is possible. If not, there is no solution, meaning there is no logic plan, and the scheduling phase fails. The system notifies the user and backtracks into the method phase again. If there are several solutions, which is the typical case, the system chooses one.

Deficiency and drawback

Planning is performed automatically through an algorithm that selects randomly one of the possible activities, schedules the activities and stores it in a database. There is no user control on the sequence of the activities.

2) ***Interactive Visualizer Plus Plus (IV++)***

Op Den Bosch and Baker (1995) presented a computer environment called Interactive Visualizer Plus Plus (IV++) that is capable of simulating construction operations in real time with the user using virtual reality. The environment provides the user with the choice of virtual construction equipment that can simulate the tasks needed to assemble buildings and other structures. The new simulation technique accounts for the geometric characteristics of not only the building, but also the equipment and the construction site.

The basic function of the program is to interpret user defined construction goals (Building Objects) and complete the entire construction process by using the equipment selected by the user. The geometry of the construction equipment is defined with CAD and the behavior is programmed within IV++. The information about the construction goals is created using a new technique called Computer Aided Design and Assembly (CADA). There are three types of data associated with CADA: the geometric information associated with building primitives, the hierarchical information that establishes the relationship between building components, and the priority information that is used to ensure that the preconditions of a procedure are fulfilled. CADA is the technique used to define a Building Object. A building object is a list of primitive objects or components arranged in a hierarchical and sequential fashion. The sequences are determined by the order in which building components are scheduled to appear in the environment. The hierarchical is determined by the dependency that exists between components. The operations, associated with primitive objects that take place in the same hierarchical level will take place when the resources become available. The order in which these operations takes place is determined by the priority associated with the object in question. If no priorities are given to objects within a hierarchical level, the planner will assign them the same priority and process them in parallel. The Building Object is used in the interactive environment IV++ to represent the goal of the project.

Deficiency and drawback

- The user's control is limited to creating/switching to different points of view (cameras), changing the construction site topography (terrain), and changing the illumination conditions (lights).
- The assembly sequences is already contained in the building object definition file. The individual goals are extracted and transferred to the planner module that then distributes the tasks to the equipment according to their capability and availability.
- The planning is done automatically with no user control or interaction. The components' hierarchy is determined by the dependency that exists between them, and the order in which the operations, associated with primitive objects, take place is determined by the priority associated with the object.

3) 3-D Graphical Simulation for Temporary Facility Planning

Ito et al. (1996) proposed a 3-D graphical simulation system for temporary facility planning, with an object-oriented building product model that support simulation, visualization and documentation of temporary facility planning with user-friendly interfaces. During the crane simulation, the user will be able to compare different cranes. The user can print out the simulated results as 2-D drawings document, estimation sheet, or bar chart diagram in order to find the best plan from their simulation.

The system has the following main functions:

- Propose the list of appropriate cranes by evaluating the building element's locations, element weights, and element shapes and crane position.
- Propose the schedule and cost of the crane by evaluating the number of elements and the crane's loading ability.
- Simulate the steel construction work graphically by using the definition of construction zone and construction schedule.

The user interface of building element of the proposed system is comprised of:

- The detail section information of building element with material information as an object are defined in order to evaluate the loading ability of crane and positioning of crane.
- The relationship between elements as an attribute of object is defined to evaluate the sequence and interface between built elements and boom of the crane.

Deficiency and drawback

The system presents a visualization, simulation and documentation tool for temporary facilities by using a 3D CAD model and developed schedule, thus, does not enable the user to actually plan the project.

4) Visualization of spatial and geometric databases for construction projects

Research in Ohio State University attempted to develop a collaborative multi-agent environment for integrated product-process design of constructed facilities. A part of this research was the development and implementation a virtual environment to enable engineers to visualize, access, manipulate, and navigate through large spatial and geometric databases typically used in construction projects to support the decision making process during various phases of the project. The research employed ideas from other fields of research including data modeling and databases, computer graphics, virtual environments, and scientific visualization. The developed techniques enhance traditional computational tools by providing the users with better data visualization, exploration, and manipulation tools, eventually resulting in better understanding of the data and more optimal and efficient solutions (Halfawy et al., 1996).

Since perceptions are limited to three spatial dimensions and one time dimension, visualization models must also rely on interactive techniques to describe more variables. However, most visualization models that have been implemented in construction software are 2D- or 3D-based with limited capabilities of user interaction. Experience has shown that limited capabilities of information visualization and user interaction have always been a major impediment for effective application of software systems in the construction industry.

Halfawy et al. (1996) defined virtual environments as computer generated models of real environments in which users can visualize, navigate through, and interact with these models in an intuitive way.

Given the fact that most construction applications involve complex spatial and geometric data that need to be interpreted and manipulated by engineers, virtual environments have the potential to providing better visualization and user interaction tools that can potentially enhance existing systems and enable them to address more complicated problems. However, to develop a virtual environment with acceptable graphics performance and user interaction, the development of efficient spatial and geometric data models and graphics algorithms, that can support handling such data at an interactive rate, is needed.

Researchers at Ohio State University have developed a structural design virtual environment to support the generation, modeling, and analysis of structural designs, and to represent and incorporate all the information pertinent to the structure, function, and behavior of the designed facility into the design model. The primary scope of the environment is to support bridge design-construction projects.

With a 3D representation of the facility design that can be explored, interacted with, and examined interactively, designers can evaluate the design from multiple perspectives such as its structural integrity, constructability, or maintainability. The environment defines a set of objects with parameterized geometric representations, and provides the functions to position, orient, move, and delete objects. Designers will be able to:

- Navigate through and explore their designs to examine different aspects and spot problems.
- Evaluate and explore different alternatives, and access and modify the design database interactively.
- View all parts of the facility constructed together to verify the design and make any design changes well before the actual construction process begins.

Deficiency and drawback

The system presents a visualization tool for structural design but does not enable the user to interactively control the construction or the planning of the model.

5) *A Library-based 4D Visualization of Construction Processes*

Adjei-Kumi and Retik (1997) presented a strategic framework for the realistic visualization of simulations of construction projects at the activity and components levels. This strategy is based on the use of Virtual Reality (VR) technology to support practitioners to plan and visualize their plans in a near-reality sense. It proposes the use of a pre-prepared library of 3D graphical images of building components, facilities, etc. and their related activities, which constitutes the 'resource pool' on which this strategy thrives.

System Architecture and Operation

The system comprises three main modules, as shown in the following Figure 2-4:

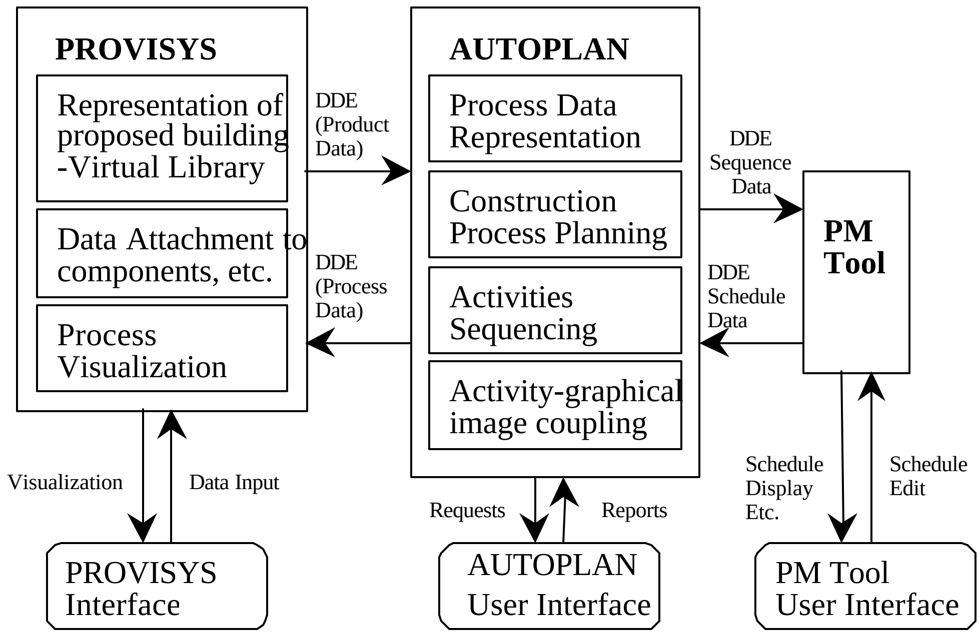


Figure 2-4 : The Model's Architecture (from Adjei-Kumi and Retik, 97)

PROVISYS Module

This module was developed using Superscape VRT, a non-immersive Desktop VR Toolkit that was used to develop the Virtual Library and the GUI. This module comprises:

- A Virtual Library of building components, equipment, plant, facilities and events. This library is utilized to represent the proposed building and to attach as many data as necessary for the construction management tasks of planning and scheduling, and to visualize these activities at a finer level. This library is divided into two main sections: (1) Product-based that includes items such as plant, equipment and facilities, which are represented mainly as 3D models. (2) Process-based that includes graphical representation of the various stages of construction of these components and these are the images employed to represent activities where necessary. These items are also represented graphically in the Virtual Library as 3D models, 2D surfaces, Lines, Icons, Pop-up messages, etc. depending on their real characteristics. These graphical objects have:

- A whole range of parametric attributes (geometry, position, location, orientation, dynamics, and color, …etc.) that define their behaviors under specific conditions.
- Variables that hold schedule and other visualization-based data that act as sensors of the virtual environment.
- Names and ID numbers that are unique in the library.

- A Graphical User Interface (GUI) which allows users to select items from this library and to customize to suit their requirements.

Building Design Representation

This module generates activities needed by each component, based on the construction method defined. During this process, activities are hooked onto their graphical images by functions in the KB application module. Activities generated are put in a sequence, which are also relayed automatically into a PM tool for scheduling and visualization.

From the Virtual Library, and according to the configuration of the building and as specified by the working drawings, the user starts modeling the proposed building graphically by selecting, duplicating, sizing and orienting and positioning the building components and facilities using the mouse pointer. PROVISYS attaches a unique name and object ID number for each component or facility selected and duplicated. The user is also prompted to input the floor level at which the object will be placed, the construction method or technology, the object number of the component below and WBS identifiers which seek to breakdown the building into working areas tracing the intended progress of work. All these data are attached to the graphical objects occupying the virtual construction site.

Process Schedule Visualization

The main purpose of the process data is to facilitate the visualization of the simulation of the generated construction schedule. This is done through two stages:

- The relevant process data (i.e. start times, finish times, duration, graphical images, etc.) generated and represented in the KB has to passed back into PROVISYS. Then, for each activity, activity name, activity image number, nature of activity, construction method, activity start week and activity finish week are all passed on into certain attribute holders in each component or facility. PROVISYS identifies the component or facility in question and then transfers the data into variables already established in these components.
- The simulation of the construction process. This is done through certain sensors attached to each object to reflect their behavior during the simulation process.

KB Application Module (AUTOPLAN)

This module is implemented using Kappa-PC, which is a frame-based expert system. The KB application module tends to structure the representation of data and information related to building elements and their components, site facilities, equipment and plant and all other resources necessary for the execution of a project. It also embodies the construction methods and knowledge about construction planning, scheduling, and the linkage of activities to their appropriate graphical representations.

A Project Management Module

This module consists of Primavera Project Planner for Windows adopted for scheduling purposes. This module is responsible for the display of schedules, resources, costs etc. ion the traditional way and gives the user the opportunity to undertake any changes.

Deficiency and drawback

The activities needed for the erection of building components are put automatically into a sequence by the knowledge base without the user control or interaction.

Virtual Environment Planning Models Conclusion

Systems developed under this third research direction represent advancement toward the use of 3D simulation and visualization techniques for better planning decisions. However, similar to the first research direction, these systems continue to rely more on programmed knowledge and heuristics to develop decisions and actions with minimal involvement from the human planner. Visualization of the simulation session is not interactive with users, and changes to the 3D views are made based on systems algorithms with no dynamic interaction with the graphical model. These shortcomings have resulted in lack of applicability of these systems to the majority of the construction industry.

2.3 PART II - METHODS CLASSIFICATION AND SELECTION REVIEW

Construction planning involves various processes that impact its successful development. Construction methods are means to transform work items into constructed product employing available resources. The construction method governs the development of the project activities, hence, directs the duration, cost estimation, and logical sequence of these activities. That's why the selection of appropriate means and methods is a major process that should be carefully considered especially during macro planning. This section reviews the different method classification and selection systems.

1) A Classification System for Construction Technology

Tatum (1988) described a classification system for construction technology, to suggest possible applications of this system in research and practice, and to develop conclusions concerning the nature of construction technology and the implications of its differences.

Hierarchy of the classification system

Tatum presented a hierarchy of four parts included in the classification system:

- The *components*: material and equipment resources, construction-applied resources, construction processes, and project requirements and constraints.
- The *elements*: these are parts of resources or parts of processes.
- The *attributes*: several attributes define each of the elements.
- The *values* for these attributes.

Description of the system components

Tatum then described each of the four components as follows:

A) *Materials and Permanent Equipment Resources*: The quantities of major construction materials and the permanent equipment define the scope of a project. Attributes of materials and permanent equipment have important implications for construction technology and provide restraints for planning and construction operations.

B) *Construction-Applied Resources*: This is what construction adds to increase the value of materials and permanent equipment in producing a constructed product. It consists of eight elements:

- *Information* provides the fundamental definition of design and construction requirements and therefore sets the choice for all other resources.
- *Skills* are often a key applied resource in efficiently performing a construction operation.
- *Equipment*: the type and extent of equipment use determine the degree of mechanization and automation used for an operation.
- *Tools*: large productivity changes can come from small but clever tools.
- *General conditions* are the facilities and services required supporting efficient construction operations.
- *Space*: the absence of adequate space can be a critical constraint on construction operations.
- *Energy*: the energy element of applied resources relates to the degree of mechanization of the construction operation.

- *Time*: alternate technologies differ in the time required to complete construction operations.

C) *Construction processes*: defines the way in which applied resources transform material and permanent equipment resources into constructed products. It includes 2 elements:

- *Construction Methods*: are the means used to transform resources into constructed products.
- *Construction Tasks*: focuses on field action and the work unit.

D) *Project requirements and constraints*: project objectives, regulatory requirements, contractor's capability, and area resource availability and practices form the constraints that create the project conditions.

Tatum then implemented a database structure. The database implementation of the classification provides a table of allowable values for the user as a part of the input forms. It also allows several uses that make the system a flexible tool for analysis of specific construction operations or comparison between various operations.

2) Construction Technology Information System (CTIS)

Ioannou and Leu (1991) described a Construction Technology Information System (CTIS), an object-oriented information representation model, based on the semantic data model (SDM), for the rapid identification and evaluation of potential technological solutions during the design and planning stages. The system consists of three hierarchies (construction products, materials, and equipment) which are integrated with construction methods to provide the required technology information for design and construction planning decisions in a manner that supports the changing needs during the various design and construction planning stages.

Ioannou and Leu defined construction technology to be a combination of resources (either materials and permanent equipment, or applied construction resources), methods (a means to build a constructed product), and environmental requirements and constraints (time and space) that produce a construction product.

The three-schema architecture

CITS is based on database design methodology called the three-schema architecture. This methodology defines three levels of abstraction:

A) *The external level* involves the collection and analysis of users' requirements (information on the functions of constructed products, the properties of applied materials, and the compatibility between adjacent materials). The required level of detail, however, changes depending on the project stage.

B) *The conceptual level* involves producing a conceptual data schema in a DBMS-independent high-level data model. The goal of the conceptual phase is to translate the requirements of the external level into a formal representation called a conceptual schema. This involves the design of the data structure, including meaning (semantics), interrelationships, and constraints.

The two principal Semantic Data Model (SDM) objects are classes (an abstract data type consisting of a data structure definition, and the properties and value sets describing the class) and instances (a specific instantiation of a class.) Six relationships, 4 from SDM (Generalization, Aggregation, Classification, and Association) and 2 new (Compatibility, and Application) are defined in CTIS:

- Generalization refers to an abstraction in which sets of similar classes are to form a higher level class. "is_a" or "can_be_a" represents this relationship.
- Aggregation is an abstraction for building composite objects from their component objects. It is identified by the "is_part_of", "composed_of" or "made_up_of" relationship.
- Classification is a form of abstraction in which a collection of instances is considered a class.
- Association is a form of abstraction in which a relationship between member objects is considered a higher level set object. It is represented by "is_member_ of".
- Compatibility is a relationship between materials used in neighboring products. It represents an "is_ compatible_with" relationship.
- Application is a form of relationship in which a specific method or material can be applied to a constructed product. It represents a "can_be_use_in" relationship.

Using SDM, the conceptual schemata of the CTIS can be established. Materials, constructed products, and equipment are broken down into their own abstraction hierarchies, depending on their function, component, etc. In each hierarchy, each individual chunk of information is treated as an object. Generalization, aggregation, and classification define the relationships between objects in each hierarchy. Association, application, and compatibility support non-hierarchical relationships.

C) *The internal level* involves mapping the conceptual schema to the data model of the chosen DBMS. On the internal level, a major task is to translate the conceptual schema to a logical schema.

A new mapping, the SDM to hypertext, is used to convert the CTIS conceptual schema to the logical schema. Hypertext is an information system that connects pieces of information by using associative links. In hypertext, data are stored in a network of nodes (containing numerical data, text, graphics, video, or other forms of data) connected by links. Users navigate from node to node to node via the hypertext links. CTIS uses two retrieval methods. (1) The on-line browsing is designed to help users navigate the system network structure through explicit hypertext links. (2) the keyword search which allows the user to jump directly to an unknown node of interest without browsing through unrelated nodes.

3) Advanced Construction Technology System (ACTS)

ACTS, presented by Ioannou and Liu (1993), is a computer-based database for classification, documentation, storage, and retrieval of information about emerging construction technologies. The primary objectives of ACTS are to allow the user to find all emerging technologies that relate to a specific domain or problem and to provide sufficient information to make the initial and crucial decision as to whether a certain technology is of interest and should be pursued further. Technologies in the ACTS have been documented using a standard format that prescribes the type of information that should be collected as well as its organization. The ACTS standard format is similar to a database record definition.

Critical Characteristics of Construction Technology Information Systems

Ioannou and Liu defined four critical characteristics that Construction technology information systems have:

A) Complexity which is the number of different items or elements that must be dealt with at the same time.

B) Uncertainty which is the variability of the items upon which elements are interrelated.

C) Interdependency which indicated the extent to which elements are interrelated.

D) Heterogeneity which is the contents of the construction technology information.

ACTS design objectives

1) ACTS should be very easy to use.
2) Administration and maintenance of the ACTS database should be equally user-friendly.
3) The user should never feel lost.
4) The system should never appear to be in control of the user's actions.
5) The ACTS software and its database should be independent of each other as much as possible.
6) The ACTS software should be developed concurrently with the technology identification and compilation activities while the documentation format is not completely finalized.

7) The ACTS data structure, as well as its user interface, should not limit its future growth.

8) The initial implementation of ACTS should be open system that does not constraint its future capabilities.

9) ACTS had to be hardware-independent.

10) ACTS should not require any software other than the operation system.

Information Storage Alternatives

The most interesting and challenging design objectives for ACTS relate to information storage and retrieval. Two information storage alternatives, separate text file or one large binary database file were studied. Each alternative has its advantages and disadvantages.

- Using *a single large binary database file* to store all technologies is more difficult to manage during the development of ACTS. Most of the fields in the standard ACTS technology documentation format contain variable-length text and thus have no field size or preset limits. Because of the variability of field sizes, it is obvious that fields could not have fixed storage requirements. Similarly, their content could not be viewed in a reporting form of predetermined size on a computer screen. Thus record retrieval based on field contents had very poor results.
- Using *individual text files* allowed the creation of documentation files prior to the completion of ACTS by using ordinary word processors. Storing the documentation of each technology as a separate text file enables the ease of reading both on-line and in printed form, and has none of the shortcomings of the storage in a single large binary

database file. However, it required a unique file-naming scheme, an intelligent mechanism for keeping track of unused or deleted file names, and more disk spaces.

Based on research and findings, the documentation of ACTS technologies had to be saved in individual text files. This decision necessitated that ACTS be able to manage a large collection of text documents, each describing one technology. The obvious problem was to how to structure ACTS so that it would be an easy-to-use, efficient, effective and yet flexible document storage and retrieval system. Ioannou and Liu presented a comparison between technology classification and indexing versus full-text search. The requirements of ACTS were met by using a hierarchical technology classification system and by indexing the technologies with keywords selected from a large predefined set.

ACTS Classification System

Ioannou and Liu also identified three suitable coding standards for classifying construction technologies in ACTS:

- *The Masterformat*: the 16-division Masterformat of the Construction Specifications Institute (CSI) is a hierarchical system of numbers and titles for organizing construction information. It provides a standard information filing-and-retrieval system that can be used for organizing information in project manuals and specifications, cost accounts, and cost data; and for filing product information and other technical data. In current design practice, information at the detail design and construction phases is typically organized according to the Masterformat.

- *The Uniformat*: the General Services Administration (GSA) issued the Uniformat, which uses a functional breakdown of building into subsystems. It includes 12 major divisions that are then broken down into two sublevels, and, unlike the Master format, it is not materials-oriented. In current design practice, the Uniformat is used primarily for functional breakdown at the early planning and design stages.
- The CI/SfB: the CI/SfB is based on the SfB system used in Sweden since 1950. After many modifications, the CI/SfB was introduced in 1969 and has since been adopted by many European countries. This coding system includes four main tables: building environment, elements, construction forma and materials, and activities and requirements. Each table can be used either independently or together with other tables, which makes this system more flexible than other coding systems, since it allows it to cover technology information from generic to specific forms.

The CSI Masterformat was selected as the technology classification system for ACTS because of its widespread use and recognition as a standard within the US construction industry. At the top of the Masterformat hierarchy are "general divisions". Each division is broken down into several "broad-scope sections", and each broad-scope section may be subdivided into several "medium-scope sections." Each technology in the ACTS database is classified so that it belongs to exactly one broad-scope or medium-scope section. The documentation of a technology is stored in a file in the ACTS subdirectory whose filename has the form ACT*ccccc.nnn*. The string "*ccccc*" represents the five-digit code of the corresponding broad-scope or medium-scope section. The extension "*nnn*" is an indexing number beginning with "001" for the first technology of the corresponding CSI number.

Storage and Retrieval Mechanism in ACTS

The entire Masterformat hierarchical structure has been coded and included in ACTS to provide a very effective storage and retrieval mechanism:

- Selecting a general division from a scrolling list immediately presents a list of the associated broad-scope sections.
- Selecting a broad-scope section brings up another list of associated medium-scope sections as well as a list of all technologies that belong to the selected broad-scope or any of its medium-scope sections. This list can be narrowed down by selecting one of the listed medium-scope sections.
- Selecting any of the retrieved technologies brings up its documentation in a separate window and allows the user to examine its content.

4) The Construction Method Selection (CMS) Model

Syal et al. (1993) presented the Construction Method Selection (CMS) model as an important step in the Construction Project Planning (CPP) stage. This selection process controls the formulation of project activities, which form the basis of the construction schedule of a project. The overall construction method selection process requires the following input for its successful execution:

1) The planner's judgement.
2) Knowledge about the decomposition of the work item into their respective subsection items and about the appropriate crew required for different subsection items.
3) Design information about the various design elements of the building.
4) Historical information about different resources.

Syal Defined the construction method associated with a work item as the combination of the construction option selected for the execution of the work item, and the associated resources required to perform the construction option (Syal, 1992).

The selection of the construction method consists of two major parts:

1) Construction Option: Associated with a given construction option for a work item, is the defined set of resources, which are required to perform that construction option.
2) Resources: involves the amount of resources, which are selected by the project planner, and is based upon a number of decision considerations.

A project is divided into work items prior to the construction method selection process. A work item is:

- Composed of one or more elements of the building design.
- Consists of a number of subsection items within a (or sometimes belonging to more than one) work division of a constructor classification system such as the Masterformat.

<u>Steps for Construction Method Selection</u>

There are three major steps, as depicted in figure 2-5, which take place during the selection of the construction method for a typical work item:

1) The construction option selected for the execution of the work item (*ex.: the type of formwork for a concrete wall.*)

2) The constituent subsection items of the work item along with the crew types (*ex.: place wall forms, place reinforcement, place structural concrete.*)

3) The associated resources required to perform the construction option (*ex.: material, labor, equipment, and space*).

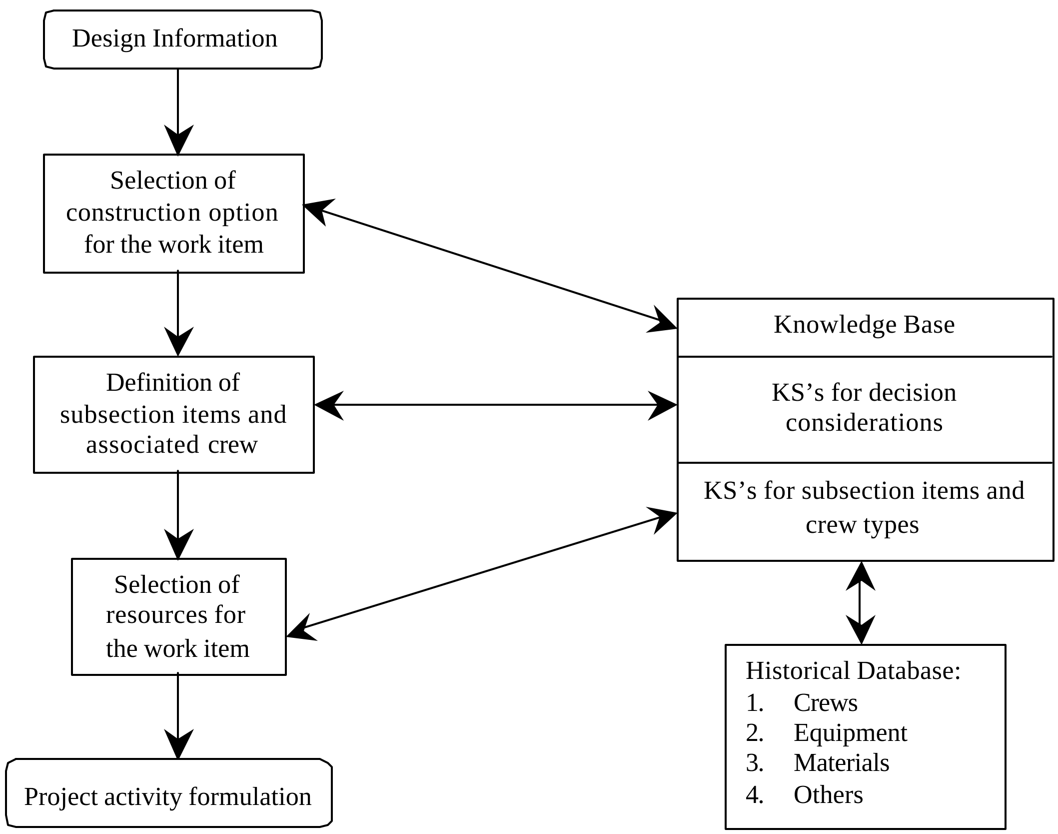


Figure 2-5: Major steps in Construction Method Selection Process (regenerated from Syal et al., 1993)

<u>Design Information Selection Hierarchy</u>

A vital part of the method selection model is the information gathered from the design. The design information selection hierarchy is laid out to follow the natural thought process, which the designer goes through in creating construction documents. As an architect transforms the design to construction documents, he will generally break the design down from the basic conceptual form of the building, to the definition of spaces within the building, to finally deciding the exact material makeup of those spaces.

1) Select building element.
2) Define its constituent parts.
3) Select option by which to further define that item.
4) Select the next constituent part, then the next building element and so on, until creating the entire design information database for the project.

<u>5) The Construction Methods Selection Assistant (CMSA)</u>

Russell and Al-Hammad (1993) presented an overview of a knowledge-based approach for the cataloguing and automated selection and analysis of construction methods. They defined Methods selection as basically a creative decision-making process that involves:

- An intimate knowledge of available technologies and their capabilities.
- An ability to visualize their application on site and thus their appropriateness for the project at hand.
- Knowledge of which ones can be best combined to address site and project specific conditions.

Construction method definition

Representation of a method in terms of a project plan usually involves a set of activities linked by precedence relationships. These activities and logic relationships may be intertwined with activities that describe methods related to other aspects of the work. It is this interdependency among methods that complicates considerably the methods selection problem. In other cases, the influence of a method is more localized, and it may be adequately described by a single activity.

In terms of general definition of a construction method, design deals with the conception, analysis, and detailing of temporary facilities (e.g. sheet piling). Construction strategy includes definition of the workday and workweek and specification of the activities and related operations and their sequencing necessary for execution of the method (e.g. Pile driving in singles or pairs). Resource requirements deal with the materials required and selecting and sizing the mix of manpower and equipment needed (e.g. selection of a pile hammer, the number of driving rigs, and supporting crews). Finally, process model deals with the suite of models used to predict the performance of the method and its components (e.g. the forecasting procedure for determination of the pile driving rate).

Methods decision-making paradigm

Once drawings and site conditions of the job have been reviewed, one or more brain storming sessions are held in which alternatives for the main methods selection problems are identified and quickly pruned. The principles guiding this process are usually framed as a series of questions for a particular alternative. The time devoted to evaluating alternatives is a function of job size and number and identity of competitors. Once an overall method has been selected, then sizing of components is governed by risk considerations in terms of ensuring reserve capacity in case difficulties are encountered.

The Knowledge based expert system framework for methods selection

Based on the previous definition of construction method and an understanding of the methods selection decision-making process, a two-phase system is conceived for ranking and synthesizing methods alternatives:

Phase 1: identification and elimination of preliminary feasible alternatives:

The objective of this phase is to identify and eliminate the number of preliminary feasible alternatives, thus, reducing them to a few candidates. This phase considers all alternatives options for methods under a scenario of project context (e.g. site layout and access, soil profile and conditions, and site location) and goals (e.g. duration, cost, safety). Preliminary screening follows after possible methods have been identifies. Some will be eliminated through considerations of one or more criteria (e.g. cost or time).

Phase 2: detailed specification for the feasible methods:

This phase carries out a feasibility analysis and methods specification at a detailed level. This phase consists of three main parts: low-level methods specification of the preliminary feasible candidates including specifying method attributes, process modeling, and method analysis. The description of the application of this phase may be illustrated in six steps:

- *Step 1*: The user inputs information to be used to help identify and screen possible methods.
- *Step 2*: A classification of the methods alternatives stored in the system's database, which provides a representation or categorization scheme for all methods such that other desired or new methods could be entered by the user.
- *Step 3*: The determination of feasibility of a construction strategy. The rule defines compatibility as the ability to combine a specific design alternative with a specific construction strategy. Construction strategy could be discussed at two levels: project level or activity level. If all strategies fail to be feasible, then the control system selects the next preferred design alternative.
- *Step 4*: Key resources are selected from a database of resource alternatives. The guiding principle in assigning resources is that the largest capacity equipment that satisfies space and/or availability constraints is selected, in order to maximize the production rate, and reduce production risks.
- *Step 5*: This step is directed at specifying the representation and analysis methods, given specification of the design alternative, construction strategy and resources assignment at the detailed level.
- *Step 6*: Control is then transferred to the process models, which are executed, and the results interpreted. If the predicted production rate and cost are below the required rates, possible changes to the process model or resource assignment may be suggested to the user so that model changes can be made.

2.4 PART III - PROJECT CONSTRUCTABILITY REVIEW

Macro planning involves major decisions that have a tremendous impact on the accomplishment of successful projects and the smoothness of the construction operations on site. Therefore, pertinent planning, especially during this early stage, improves the project constructability (O'Connor, 1985; O'Connor et al., 1987; Tatum, 1987; and Glavinich, 1995). Constructability is a major factor that determines to a far extent the success or failure of construction projects. Poor constructability continues to be a leading factor to dominant problems of construction projects. Some examples of problems that may occur in a construction project due to poor constructability include low productivity and quality, higher costs and duration, out-of-sequence work, and inefficient use of resources (McCullouch and Patty, 1994; and Glavinich, 1995). The depiction of these problems before the beginning of the construction would significantly reduce the cost and the duration of the project.

Many researchers have defined constructability in order to gain a better understanding of what should be done to improve it. The Constructability Task Force of the Construction Industry Institute (CII, 1986) has defined constructability as "the optimum integration of construction knowledge and experience in planning, engineering, procurement, and fields operations to achieve overall project objectives". The Construction Management Committee of the American Society of Civil Engineers (ASCE) Construction Division (1991) has defined constructability as "the capability of being constructed," and has defined a constructability program as "the application of a disciplined, systematic optimization of the construction-related aspects of a project during the planning, design, procurement, construction, test, and start-up phases by knowledge, experienced construction personnel who are part of a project team. Glavinich (1995) focused his research on constructability improvement during the design phase and defined constructability of a design as "the ease with which raw materials of the construction process can be brought together by a builder to complete the project in a timely and economic manner." Mendelsohn (1997) defined constructability as "the integration of construction expertise into the planning and design of a project so that the construction forces have the maximum opportunity to deliver the project in conformity with cost, quality, schedule and safety objectives of the project's stakeholders."

2.4.1 CAUSES AND IMPACTS OF POOR CONSTRUCTABILITY

Poor constructability can be greatly attributed to the limited understanding of the construction process by many of the project participants, and the lack of integration of the design/construction processes across all project phases.

During the design phase, professionals performing design may have little experience in construction practices, local considerations, the availability of different resources, and are not necessarily experts in construction means and methods. During the procurement phase, current available project documents, including construction drawings, and approaches that should assist the construction professional in studying the project to make appropriate decisions on project planning, are not fully contributive. During the construction stage, construction processes such as safety, storage access, security, quality, and schedule updating are major factors that influence the accomplishment of a successful project.

Many researchers have illustrated the impact of poor constructability. Tatum (1987) indicated that poor constructability during the conceptual planning phase results in many problems related to the overall project plan and the site layout. Problems that may result if the overall project plan is developed without construction experience include inappropriate sequence and schedule for design information and materials, unfeasibility of construction durations, and fail to recognize unusual local condition. Problems that may result from a poor layout include inadequate space for laydown and fabrication, limited access for materials and personnel, and incompatibility of the layout with a desirable division of the construction work. McCullouch and Patty (1994) stated that lack of coordination between design and construction typically creates problems during the construction phase. These problems are manifested in change orders, time extensions, increased costs and litigation. Glavinich (1995) confirmed that design-related constructability issues results in construction problems that can lead to delays, out-of-sequence work, and inefficient use of resources. Mendelsohn (1997) also noted the importance of constructability during the design phase by stating that 75% of the problem encountered in the field are generated in this phase.

2.4.2 CLASSIFICATION OF FACTORS AFFECTING CONSTRUCTABILITY

Different factors affect the constructability of construction projects. These factors should be considered during decision making in order to eliminate or, at least, minimize constructability problems. A classification of these factors in a categorized model helps decision makers to efficiently consider all the factors. Three researches have significantly contributed to classifying factors affecting constructability (Tatum, 1988; ASCE committee, 1991; and Hanlon and Sanvido, 1995).

Tatum (1988) developed a classification system for construction technology. The center of this classification consists of construction processes. Three other elements are associated with a construction process: material and permanent resources, construction-applied resources, and project requirements and constraints. These attributes were significantly in developing a comprehensive classification model.

The Construction Management Committee of the American Society in Civil Engineers (ASCE) Construction Division (1991) presented many constructability factors and their relationship with various phases of the project. The committee defined the different phases of a construction project to be Planning, Conceptual Design, Detail Design, Procurement, Construction, and Startup. Then, the committee presented different factors related to each of these phases, and explained the importance of considering each factor when integrating construction knowledge into each phase.

Hanlon and Sanvido (1995) developed a Constructability Information Model (CIM) that provides a classification framework that allows for identifying the possible areas of constructability improvement, and organizing the knowledge considered during constructability assessment. The model was tested for reinforced-concrete structural elements. However, the model's structure is generic and can be used by other construction project types with further testing and development. In order to define constructability information, Hanlon and Sanvido (1995) collected a comprehensive list of possible attributes from literature and interviews with industry experts. Then, by grouping similar attributes, information categories were formed.

The classification model presented, hereafter, utilizes the structure of the CIM developed by Hanlon and Sanvido (1995). Minor modifications were made according to the author's experience and understanding of the literature review. The model includes five major categories: Design Rules, Performance, Lessons Learned, Resources Constraints, and External Impacts (Figure 2-6). These categories should be considered when selecting a specific construction concept for the project on hand. A construction concept may be any abstract or generic idea that may be applied for achieving the job. The construction concept is usually applied to improve a construction process. A construction process consists of methods and tasks necessary for the execution of the work. If the selected concept does not interfere with any of these categories, then the concept may be approved and should be applied without producing constructability problems.

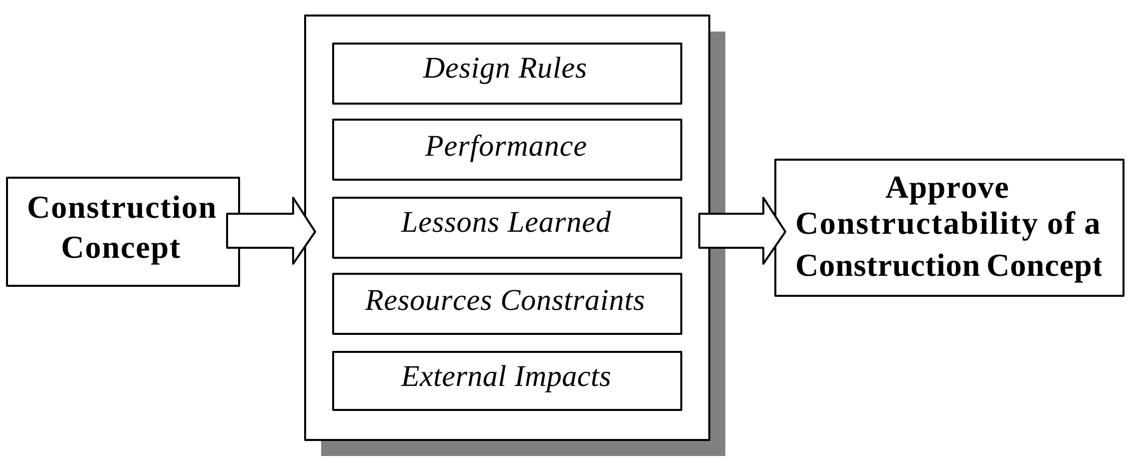


Figure 2-6: Factors affecting Constructability of a construction concept

A description of each of the five categories is presented as well as attributes associated with each category.

1) ***Design Rules***

The first factor that should be considered when applying a construction concept is "Design Rules". This category includes different attributes: Applicability, layout, dimensions, and details (Figure 2-7). The applicability indicates the economic and technical applicability of the process according to the project design. For example, using a flying form for slabs is known to be uneconomical for low-rise buildings. Design layout, dimensions, and details present attributes that describe constraints or suggestions for design if the concept is to be used. For example, a detail such as chamfering corners of concrete column form may improve the quality and durability. Also, a small dimension change may not affect the design concept, but may facilitate the installation, or reduce the cost, of an element.

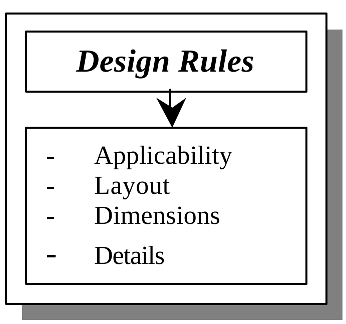


Figure 2-7: Design Rules Category and attributes

2) Performance

The performance is a major factor that should be considered when selecting a construction concept, and usually provides the major influence for choosing one concept over another. The performance of the construction concept will affect the cost, the productivity rate, the quality, and the safety of the project.

Different factors impact the performance of the construction concept (Figure 2-8). Direct factors include the concept's complexity, the method used, and activities' interdependency. Construction methods are the means used to transform resources into constructed products. They define how construction applies resources. The selection of the most desirable method requires several iterations between the design approach and the construction plan. The potential savings and constructability improvement make this iteration a worthwhile planning activity during earl project phases (Tatum, 1987). Also early input of construction knowledge/experience into planning the sequence of construction impacts activities interdependencies, thus, improves the construction concept performance.

Indirect factors that affect the performance include level of automation, primary construction location, and concept uncertainties.

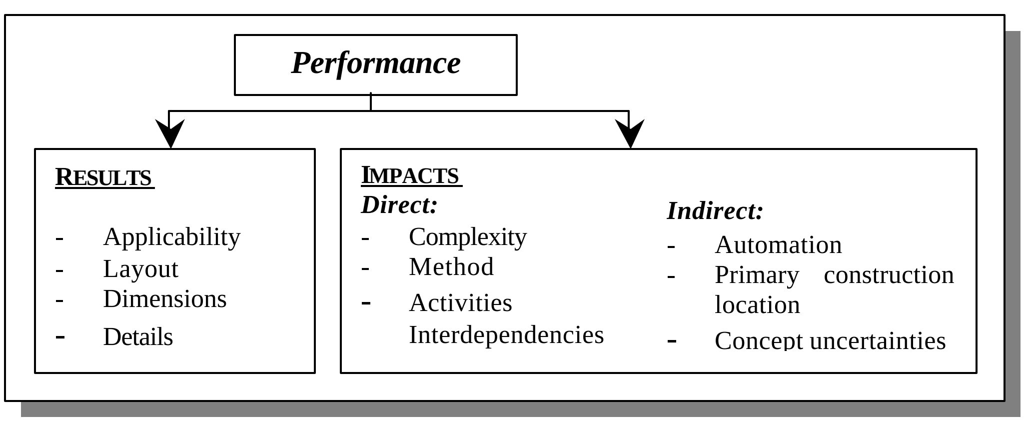


Figure 2-8: Performance Category and attributes

3) Lessons Learned

Experiences of past mistakes are crucial means for constructability improvement. A lesson may be defined as "an experience from which useful knowledge may be gained" (Kartam, 1997). The lessons learned category include general information about a project, a description of the attempted improvement, the corresponding result, and suggestions for future problem avoidance (Figure 2-9). Decision-makers should always consider checking lessons learned from previous experience before selecting a construction concept, and should also give their feedback after the utilization of a process to be documented for future reference.

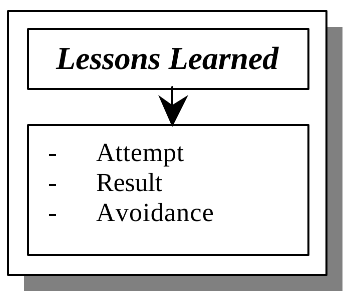


Figure 2-9: Lessons Learned Category and attributes

4) Resources Constraints

The resource constraints category describes the resource requirements for concept use. This category is divided into nine subcategories that can take many forms (Figure 2-10). Data or knowledge form includes the information subcategory. Physical form includes the equipment, crew, material, space, and accessibility subcategories. The last section includes physical form (facilities), services form (services and systems), energy input, and time allowed. Each subcatgory is described in detail in th next part.

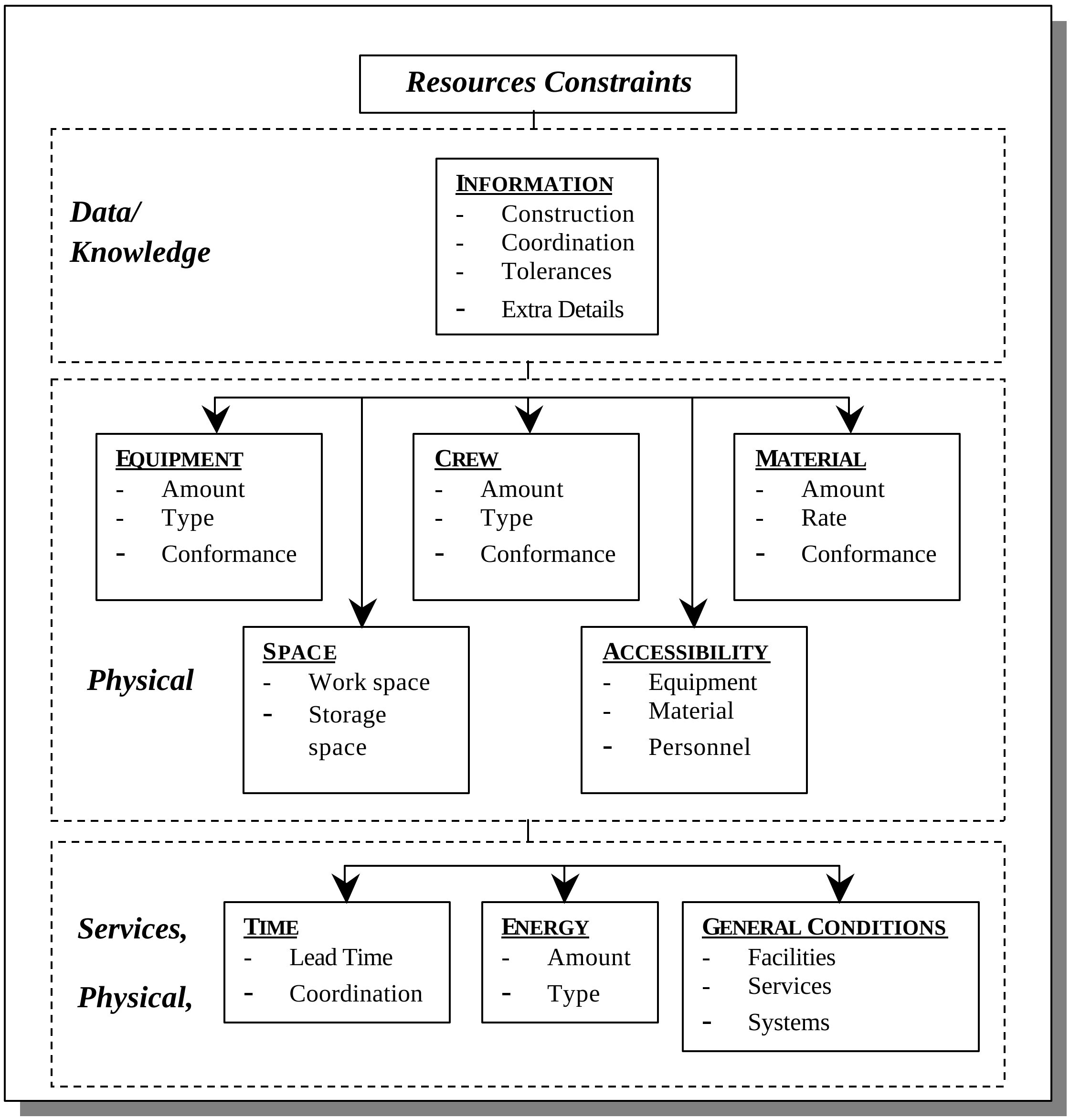


Figure 2-10: Resources Constraints Category and attributes

- *Information*

This subcategory describes the type of information required to achieve concept implementation. Information defines both the "what" and the "how" of a construction concept. In addition, this subcategory provides the fundamental definition of design and construction requirements and, therefore, sets the choice for all other resources. Information is needed to provide coordination and to define, plan, select methods for, and perform construction operations.

- *Equipment*

Construction equipment is the means to mechanize construction operations. This subcategory includes the amount, major type of construction equipment used, and degree of conformance to industry standards.

Several factors make construction equipment a key element of construction technology. The type of equipment and extent of equipment use determine the degree of automation used for an operation. In addition, equipment introduces new limitations, such as access requirements or maximum allowable loading on a foundation, that tremendously impact a concept use. If the concept selected requires a piece of equipment that, for any reason (cost, accessibility, space, availability), is hard to get, then the concept should be substituted in order to improve the project constructability.

- *Crew*

This is a fundamental resource in performing a construction concept. A construction crew consists of labor and tools. Tools are hand instruments that assist in performing construction tasks. Tools are generally less expensive than equipment and require greater human effort to use. The attributes describe the amount and type of crew required to applying a specific concept, as well as the degree of conformance to industry standards.

- *Material*

The material category describes the amount, types, and delivery rates and flow required for the major construction materials.

- *Space*

The absence of adequate space can be a critical constraint on construction operations. Space availability determines the use of other applied resources, such as large equipment, and heavily influences the efficiency of construction operations. This subcategory includes workspace needed for the execution of different activities. This workspace may be occupied by equipment or personnel. Storage space required to store materials is also included.

- *Accessibility*

Accessibility is a major area that should be considered for constructability improvement. This subcategory describes the path needed for equipment, material, and personnel accessibility to and from the site, as well as between different work and storage spaces.

- *Time*

The time is one of the major resources that should be considered in constructability improvement. Construction processes differ in the time required to complete construction operations. In addition, lead or preparation time for the execution of a construction operation, as well as activities coordination time should be considered when selecting a construction concept. Time is usually considered through the construction schedule.

- *Energy*

Energy is consumed in producing the constructed product. It relates to the degree of mechanization of the construction operation. This subcategory describes the amount and type of energy required for the execution of the construction concept.

- *General Conditions*

General conditions consist of the special facilities, services, and systems required to supporting efficient construction operations. When, these conditions (e.g. necessary utilities) are not available, construction operations are severely affected.

5) External Impacts

External impacts to and from external sources should be considered when selecting a construction concept. Attributes for this category include impacts to and from the environment, the adjacent sites, and the infrastructure (Figure 2-11). For example, the use of a specific pile driving method may impact the safety of an adjacent historic building.

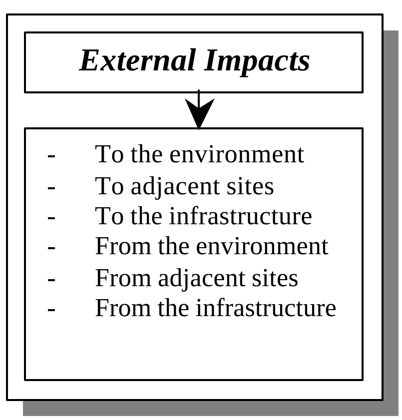


Figure 2-11: External Impacts Category and attributes

2.4.3 <u>CONSTRUCTABILITY IMPROVEMENT STRATEGIES</u>

Constructability improvement strategies are concepts and approaches that should be applied in order to rectify the project constructability throughout the life of the project. These strategies are identified after thoroughly studying and analyzing (O'Connor, 1985; Tatum, 1987; O'Connor et al., 1987; ASCE committee, 1991; Cross, 1991; Glavinich, 1995; Mendelsohn, 1997). The strategies are divided into Design-related and Planning-related strategies.

1) Design-related Strategies

Design-related strategies consist of constructability improvement concepts and approaches that should be considered during the design of the project. These strategies include:

- *Design Simplification*

Design should be simplified and configured to facilitate and enable efficient construction. The use of minimum number of components, readily available materials in common sizes and configurations, and simple easy to execute connections are some examples of simplified design without sacrificing other project objectives such as safety, operability, maintainability, and aesthetics. Design simplification will increase the design effort, but, on the other hand, the required construction manpower is likely to decrease.

- *Standardization*

Standardization implies the use of uniform design elements. Standardization of building systems, material types, construction details, dimensions, and elevation increases field efficiency.

- *Prefabrication and Preassembly*

Prefabrication is the manufacturing process of joining various materials to form a component part of a final installation. Preassembly is the process of joining various materials at a remote location for subsequent installation as a subunit. Prefabrication and preassembly designs should be prepared in order to facilitate fabrication, and transport, and installation, thus, reducing the cost and duration of the project.

- *In-house Design-Phase Constructability Review*

In-house design-phase constructability review involves the continuous inspection and analysis of the basic philosophy in relation to design criteria, as well as technical issues of the design (e.g., connections, insulation and isolation details). This process is better than the detailed independent check of drawings and specifications because the checking process usually takes place very late in the design process, making it difficult to make fundamental changes in the design.

2) ***Planning-related Strategies***

Planning-related strategies consist of constructability improvement concepts and approaches that should be considered when planning the project during the design and/or procurement phases. These strategies include:

- *Design-phase construction scheduling*

This strategy involves the development and subsequent revision of construction schedule throughout the design process. This scheduling effort should include looking at the construction activities, their projected duration, the sequence of their execution, methods and resources required, as well as procurement of necessary materials and equipment. The purpose of preparing and updating a design-phase schedule is to detect and correct potential problems that may occur during the execution of the project, during the design process. This is the time when these problems can be corrected easily and economically with minimum impact on the overall project schedule.

- *A Construction-Driven Schedule*

The overall project schedule should be driven by the needs of the construction. The construction schedule must, then, be developed before the design and procurement schedules are initiated. The process of overall scheduling should start from the project due date and work backward (backward pass) to establish the duration of the various tasks (design and procurement) since, in general, it is cheaper to speed up the design process than it is to speed up construction. The construction-driven schedule have a significant impact on the project duration, the delays in the field, prioritization of procurement activities, work packaging, and the awareness of the schedule goals to project personnel.

- *Overlaying for Accessibility Review*

The design should promote accessibility of equipment as well as of manpower and materials. The access to the site greatly affects the selection of equipment that can be used in the project. Accessibility problems often cause delays in progress, slowed productivity, and increased damage to completed work. Timely review of project plans by construction personnel is the most effective mechanism for assuring accessibility. Manual or CAD overlay techniques have proven to be useful for visually studying accessibility problems.

2.4.4 CONSTRUCTABILITY IMPROVEMENTS MODELS

Different solution models for constructability improvement were also implemented to assist the project team in integrating construction knowledge/experience during the pre-construction stage (Fisher, 1993; Patty et al., 1995; Moore and Tunnicliffe, 1995; and Kupernas et al., 1995; Kartam and Flood, 1997). The models were focused on implementation during design development. The objective of these models is mainly to provide the designers with tools to guide them in designing more constructable designs.

1) COnstruction Knowledge Expert (COKE)

Fischer (1993) presented a software tool that provides designers with construction input during the design process. COKE is a construction knowledge base that guides engineers towards designing more constructable structures. The tool cuts across the traditional boundaries of design and construction and provides designers with direct and specific construction input to the structure they are currently designing.

- *System Architecture*

COKE is comprised of a CAD package and an expert system. The expert system contains the constructability knowledge base and reasoning functions that compare the constructability knowledge to the project data and give a designer feedback about the constructability of a proposed design.

The knowledge base contains 250 items of constructability knowledge grouped into five categories:

- Application heuristics are knowledge items that relate overall project parameters to the applicability of a given construction method.
- Layout Knowledge is constructability knowledge that constraints the vertical and horizontal layout of structural elements.
- Dimensioning knowledge constraints about the dimensions of structural elements.
- Detailing knowledge relates the requirements of a given construction method to structural details.
- Exogenous knowledge describes the requirements of construction methods with respect to factors that are not under the control of the designer.

- *Reasoning in COKE*

In COKE, functions perform the constructability reasoning. For each knowledge item, a function tests whether the structure fulfills the necessary requirements. These functions are grouped by construction methods to check all the requirements for one method with one function call.

Three types of reasoning are performed:

- Reasoning about attributes of objects.
- Reasoning about relationships between attributes of objects.
- Spatial reasoning.

At the beginning of constructability reasoning, designers can specify the construction methods for which they would like to receive feedback. COKE then compares the data in the symbolic model with the constructability knowledge for the applicable construction methods and gives the designer feedback about the constructability requirements and the structure at hand. Designers can then disregard the constructability advice if other constraints make the consideration of the advice impossible, or they can incorporate the suggested changes in the CAD model.

2) A Computerized Constructability Support Multimedia System

Patty et al. (1995) presented a computer tool that captures, records, and stores constructability concepts and lesson learned, while providing design professionals with easy access and graphical retrieval of concepts and lessons to deepen their understanding of constructability issues. This tool gives the designer the capability of accessing constructability information at the point of design. The tool stores construction "lesson learned" and provides a user-friendly mechanism for locating and retrieving into the design environment. The tool utilizes multimedia because of its ability to represent a broad field of knowledge, which is a major characteristic of constructability knowledge.

The screen of this tool is comprised of the following four windows. Double clicking on an icon in the first window opens the second window and so on.

- The main level display contains four main construction categories: Bridges, Roads, Environmental, and Contracts.
- The organizational level contains design category icons (ex.: Foundations, concrete bridges girders)
- The detail level contains actual constructability "lessons learned".
- Graphic representing the lesson learned. This fourth window is connected to a search process for the lesson learned. Hyperlinks are established in the lesson learned to other appropriate and supporting media forms.

The benefits of using this computer tool is:

- Lowers Project Cost.
- Enables Locating and Educating.
- Eliminates Construction Related Design Errors Before They Occur.
- Enabling Technology for Artificial Intelligence Modules.
- Fills the Ergonomic Interface Void.

3) An Automated Design Aid (ADA):

Moore and Tunnicliffe (1995) presented an Automated Design Aid (ADA) which is intended as an 'adviser' on the constructability of creative designs produced using CAD software. The tool should provide the designer with useful decision support regarding design corrections and adaptations.

The proposed ADA is not intended to rely on case based reasoning for its operation. This is due to the belief that traditional expert system approaches may not be suitable when dealing with new constructability knowledge. Moore and Tunnicliffe proposed the use of Skill Modeling as a suitable approach for conveying construction process knowledge to the design process worker. Skill Modeling does not seek to impose construction methods or technologies on the designer. It seeks to accept the designer's implicit selection of general methods and technologies that occurs when he assigns to the artifacts within the design solution.

4) Three-dimensional model

Kupernas et al. (1995) introduced a methodology to use a computer aided drafting (CAD) three-dimensional model of a project to review design layouts and to identify design conflicts as part of a preconstruction constructability review.

The proposed model combines the benefits of constructability reviews (Shortened construction durations, fewer schedule delays, and reduced risk premiums that the contractors include in their bid) and three dimensional CAD modeling (Benefits planning and estimates, improves productivity, assists in construction scheduling, and can be used in claim analysis). Within this methodology, the inference check and planning strengths of the three dimensional CAD modeling are used to identify potential construction conflicts as part of the optimization of construction included in a constructability review. Within this methodology also, two reviews are performed:

- A *composite review* shows interferences between major subsystems.
- A *subsystem review* tests each element of a subsystem against other elements within the same subsystem.

Each three-dimensional constructability composite or subsystems review report includes both a graphic and printout. The graphic includes an isometric image of the area of subsystem or subsystems tested. The printout describes the test setup, summarizes the test results, and supplies detailed information regarding each conflict discovered by the interference check software.

This three dimensional constructability review would ideally be conducted at the fifty to ninety percent construction document level of the project prior to the job bidding so there will still be time to review results of the review and make corrections prior to the job bidding.

*5) **The Constructability Lessons Learned Database (CLLD)***

Kartam and Flood (1997) presented the Constructability Lessons Learned Database (CLLD) prototype that provides an interactive computerized method of collecting, storing, and making constructability knowledge available. The CLLD concept was created to provide contractors with a comprehensive tool to augment their daily decision making with the most efficient work practices on construction sites. The result is a resource comprising proven solutions to problems encountered during construction and an efficient tool for capturing construction knowledge.

There are three main uses of a construction lesson learned system:

- Decision Support Tool.
- Training Tool.
- Tapping Intellectual Knowledge.

- *System Design and Implementation*

The lessons learned database operates on a personal computer through the use of Microsoft Lotus Notes software. Lotus Notes was used because of its ability to provide two key features necessary for effective use of constructability information:

- Electronic mail and conferencing capabilities.
- Document storage and information retrieval abilities.

The information contained within the CLLD system is classified through the CSI Masterformat consisting of 16 subdivisions relating to every aspect of the construction industry. The CLLD allows access to the database through a myriad of routes including category, lesson date, lesson title, ACI, keyword, OSHA subpart, ANSI, lesson contributor, and project name.

2.5 PART IV - CURRENT PLANNING PRACTICES REVIEW

After making the literature and technology review presented in the previous three parts, the researcher felt the need to get a better understanding of the current macro planning industry practices. Several interviews were conducted with industry professionals to help attain this objective. The outcome of these interviews, along with discussion with faculty and the researcher own knowledge and experience, were the basis for the development of the next two chapters (The Macro Planning Process and the Macro Planning Information Classification model – MAPIC). This part discusses the interviews procedure and feedback.

Companies selected for interviews were all involved in Design-Build projects. Interviews were conducted with professionals from one design firm, three general contracting companies, and two construction management companies. Professionals interviewed were all involved in the pre-construction stage of the project life cycle. A record of each interviewee's position and companies' information is provided in Appendix A.

2.5.1 INTERVIEWS PROCEDURE

A questionnaire was first sent to two of these companies, followed by personal interviews. However, questionnaire responds were not helpful. So for the following two companies, the researcher was using the questionnaire as an agenda for the personal interviews. Finally for the remaining two companies, only personal interviews were conducted.

The interviews were mainly focusing on:

1) The format of the Design-Build projects, in which the company was involved.
2) The company role and duties in the preconstruction stage of the projects.
3) Formal steps that the company takes for planning the project at the macro level.
4) The communication and collaboration process and format among the project participants.
5) The constructability review process (what does it consist of and how often does it occur).
6) Problems encountered during the preconstruction stage and that has an influence on the macro planning process.

2.5.2 INTERVIEWS FEEDBACK

The feedback that the researcher obtained from the interviews was extremely helpful in acquiring a better and practical understanding of the current macro planning industry practices. In fact, two points were crucial for this research:

1) For a large majority of construction projects, the current planning practices remain manually based:

Construction professionals use a manual approach to develop planning decisions. General and project specific data (product information) are communicated among project participants (owner/designer/constructor) through design drawings in a 2D paper-based format. This product information needs to be extracted from these drawings and processed to formulate project knowledge necessary for making decisions and taking actions (process information). The realization of the facility defined in these drawings becomes the responsibility of the user. Project participants involved in the project planning process are therefore expected to visualize in abstract terms the perceived characteristics and spatial relationships among various components of the project, including site-related activities.

In all the companies interviewed, no automated systems are being utilized for the development of macro planning decisions. Although the manual approach imposes a heavy burden on the project team to carry out the planning process, the project team prefers to be in charge for the decision making to be fully responsible for the produced plan.

2) There are no formal steps for planning the project at the macro level – Each project is different:

Although the steps may be the same, each company carries out the macro planning process in a different way based on various factors. There is no one right way to do it and there are no formal steps that the companies follow to plan the project at the macro level. The duration and the time of occurrence for each step depends on several factors such as the project complexity, the owner's requirements, the project team preference and style, …etc. For example, for some projects, the owner requires a formal constructability review every fours weeks and at the end of specified project milestones, while on the contrary, for other projects, this requirement does not exist. Also, some sites require several visits to extract the required information, whereas other sites need to be investigated only once or twice.

2.6 CONCLUSION

This chapter presents the current state of knowledge related to the research scope. First, a review of various research efforts to develop new innovative ways of planning is presented. These research efforts have attempted to fully or partially automate the different planning tasks by developing systems to manipulate and process project information and generate planning decisions. The developed systems are characterized as responsive decision systems, relying mainly on programmed knowledge and heuristics for decision-making; reducing or eliminating the role of the human planner. The user has minimal interaction and control during the planning sessions, and is mainly involved during data input. The indirect involvement of users in the plan generation is a major drawback of these systems and has limited, if not eliminated, their wide spread adoption by the construction industry.

Then, different means and methods classification and selection systems are presented as an example of a major process performed during macro planning. The classification models present a categorization of the means and methods conceivable for construction projects. The selection systems are tools that fully automate the methods selection process. Therefore, the user involvement is limited to data input.

The chapter also discusses the causes of poor constructability and its impact on the development of successful projects. A classification of factors affecting the project constructability is presented, and constructability improvement strategies and models that may be applied during macro planning are reviewed.

The last part of the chapter covers briefly interviews made by the researcher to acquire a better and practical understanding of the current macro planning industry practices. This part presents the interviews procedure and feedback.

3. THE MACRO PLANNING PROCESS

3.1 INTRODUCTION

During the pre-construction stage, planning decisions are made at a macro level. This allows for review/modification of the design for better constructability, identification major means and methods for work packages, allocation of major resources, proper sequencing of major assemblies, and selection the location of temporary facilities and major equipment, and the preparation of an overall execution strategy (Figure 3-1). Information required for macro planning needs to be extracted from available data, then processed to formulate the project knowledge necessary for the decision making process. The pertinence of the information gathered, along with the project team's knowledge and experience, are what lead to the development of appropriate decisions.

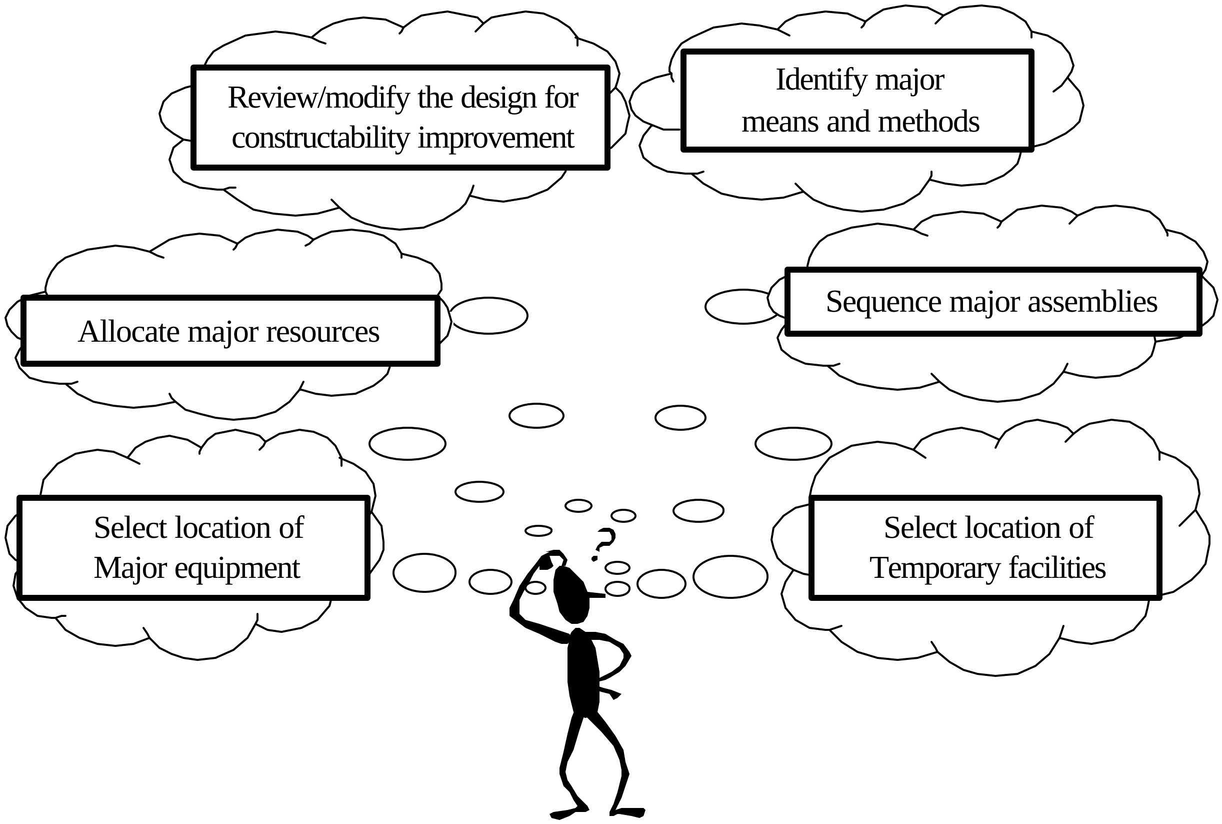


Figure 3-1: Various macro planning decisions/actions

In a traditional project delivery system (Design-Bid-Build) the macro planning stage starts during the period prior to submission of the bid (usually several weeks to several months depending on the size of the contract) and continue after bid award through mobilization, to a certain point early in the construction (normally not more than several weeks beyond mobilization). In a Design-Build project delivery system, which is the scope of this research, macro planning begins early during the project design phase (usually after the development of the schematic drawings), and extends through mobilization and may continue into the early weeks of construction.

Because macro planning begins at an early period in a project's life cycle, planning decisions made at the pre-construction stage are crucial to the successful execution and completion of any project. Such decisions allow all parties involved the opportunity to think, make inputs, discuss, and modify the design and/or the proposed overall plan of execution. This also allows the project team to detect interferences, shortages, and other pitfalls before the execution of the work, hence, improve the project constructability.

In order to formulate the different steps involved in the macro planning process, the researcher has conducted several interviews with construction professionals from design, general contractor, and construction management companies involved in design-build projects. Information acquired from these interviews, along with the researcher's own knowledge, extensive literature review, and discussions with faculty, have enabled the researcher to formulate the macro planning process in a design-build delivery method.

This chapter describes the process of macro planning in a Design-Build delivery method. Components of the macro planning process (i.e. project data, decision-making process, and planning actions) are described in detail and illustrated with examples.

3.2 THE CURRENT MACRO PLANNING INDUSTRY PRACTICES

The current macro planning industry practices involves an iterative process throughout the pre-construction stage. This process starts when the schematic drawings are developed and continues through mobilization. With reference to Figure 3-2, the project team starts by gathering and analyzing information necessary for decision-making. This involves reviewing project data including the schematic design drawings and contract documents, and breaking down the facility into its major assemblies. This breakdown allows for a structured methodology to analyze the project assemblies, to extract information, and to make appropriate decisions on how these assemblies will be built and controlled on site when construction starts.

After that, the project team makes major work execution and site layout planning decisions. This process involves the identification of major construction means and methods conceivable for the effective execution of each assembly, the allocation of different resources associated with major methods, and the determination of the appropriate sequence of the assemblies. This process also involves the selection of adequate locations for temporary site facilities and major equipment. Due to the uniqueness of each project, this process depends primarily on the pertinence of information gathered and on the project team's knowledge and experience.

Design is continuously subjected to constructability reviews. Project's requirements and constraints (cost, duration, quality, and so on) are regularly monitored and/or modified. If problems are found, the project team reconsiders the design and planning decisions made, and attempts to satisfy the project requirements and constraints. This is achieved by revising the design drawings, re-examining the methods selected and the associated resources, and by rethinking the assemblies' sequencing and relationships. If, after a reasonable number of iterations and trials to adjust the plan and to review constructability, project requirements and constraints are not met, further design modifications can help minimize construction problems that would be encountered in the field. Once problems are resolved, planning at this level is finalized.

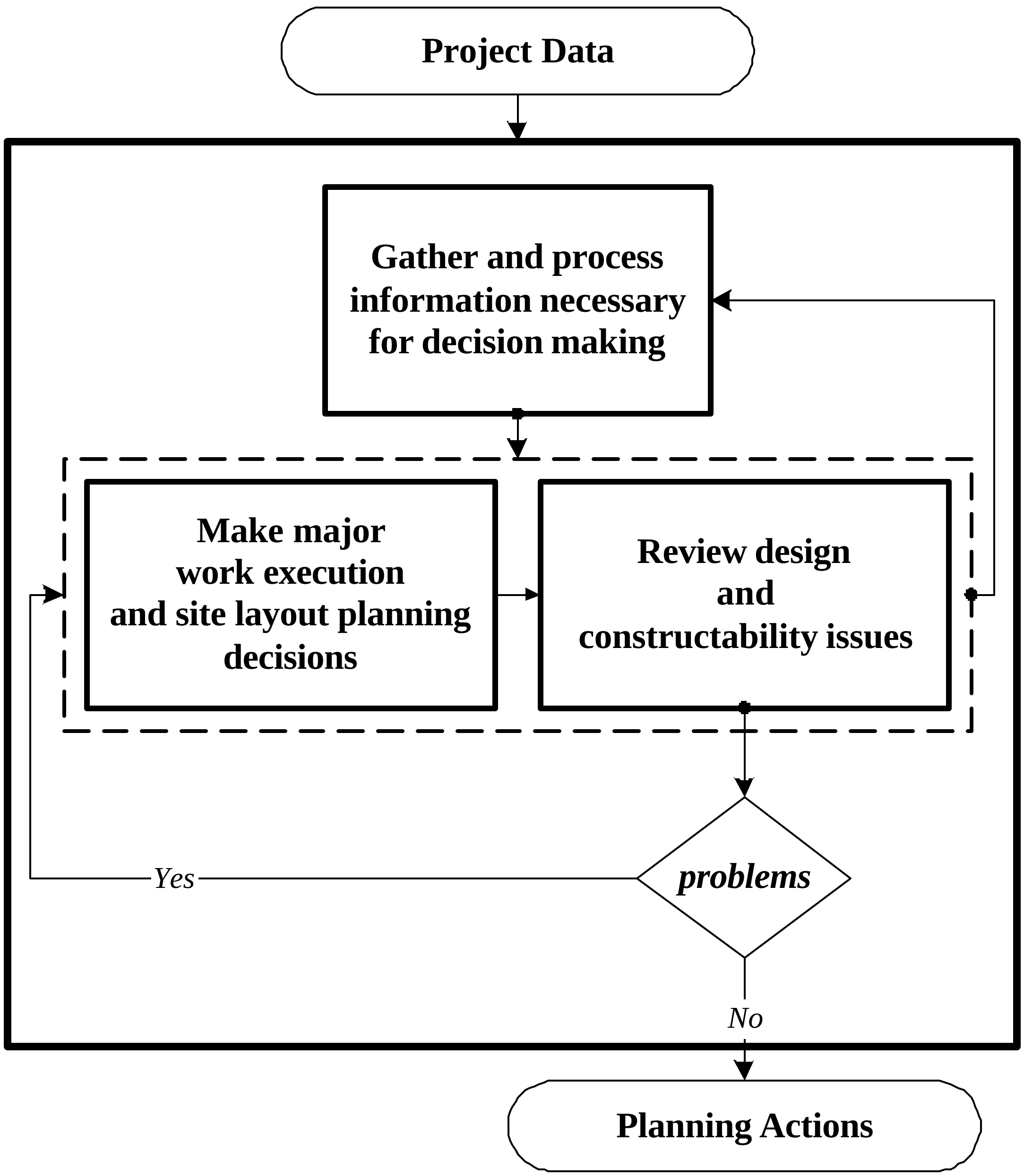


Figure 3-2: The current macro planning industry practices

In the next subsections, the various components of the current macro planning practices are discussed. These components consist of ***the project data (input)***, ***the decision making process***, and ***the planning actions (output)***.

3.2.1 PROJECT DATA (INPUT)

The project data presents the input to the decision making process. As illustrated in Figure 3-3, project data may be categorized in three distinct groups: generic construction data, company-specific data, and project-specific data.

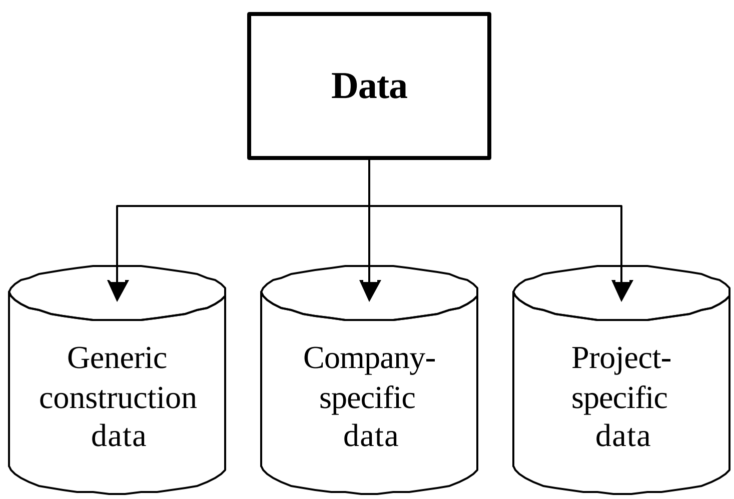


Figure 3-3: Various types of data

- ***Generic Construction Data:***

This group comprises of construction data that is not related to a specific company or project. Examples of this data include productivity and cost of construction resources and standard means and methods for various operations. Although this data is considered to be general, it could differ from one area to another. Therefore, generic data can be further

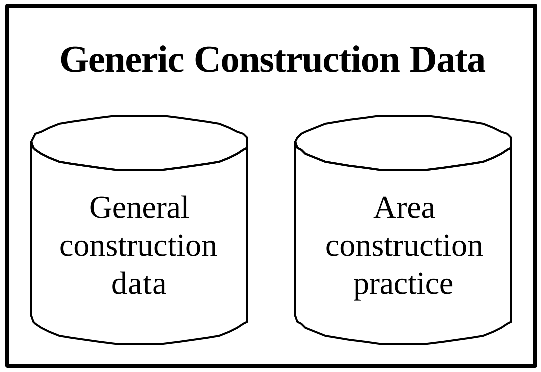


Figure 3-4: Generic Construction Data

divided into general construction data and area construction practice (Figure 3-4).

The general construction data is usually available in general databases such as RS Means and Richardson Engineering Services. These databases present general data about the cost and productivity of construction resources. These databases also include conversion indexes for each local area/state. General construction data about equipment cost and productivity is also available in manufacturers' manuals (e.g. Caterpillar manual), as well as in manufacturers' web site (e.g.: www.Liebherr.com).

The area construction practice presents a significant source of data for the project team. This data allows the project team to understand the dominant method of doing business in the project geographical area (Barrie and Paulson, 1992). The project team has to collect data about the prevailing practices in the area in which the project is being constructed. The project team will be able to know for example if sheet-metal flashing is to be furnished and installed by the roofing contractor or by a separate sheet-metal contractor. The project team can also collect data about specific local resource costs, productivity, and availability. This may be achieved through discussions with local contractors and suppliers, labor union personnel, and key business agents of each trade, as well as through inspecting several projects in the area. For example, in some areas, extensive coffee breaks, long lunch hours, and early quitting times affect the cost and productivity of labors. Data collected on available crafts has also a great impact on the design during macro planning. Key design decisions can sometimes be influenced to change specifications from those requiring chronically scarce craftsmen to alternate methods for which sufficient manpower is available. Data on locally favored methods and materials, and their subsequent utilization where possible in the specifications, has to be gathered. The project team should become familiar with this data as it may significantly reduce project costs. Other data that should be collected for the area construction practice includes key local prices for standard items such as sand, gravel, lumber, ready-mix concrete, precast concrete, …etc. This data is critical in comparing alternative methods as well as in developing the preliminary estimate.

- ***Company-Specific Data:***

This group consists of data that are company-specific (Figure 3-5). Examples of this data include the company's policies on safety, and the company's own resource productivity data, which may be different than the average productivity given by general databases. This data is usually available through the company's strategy documents and databases.

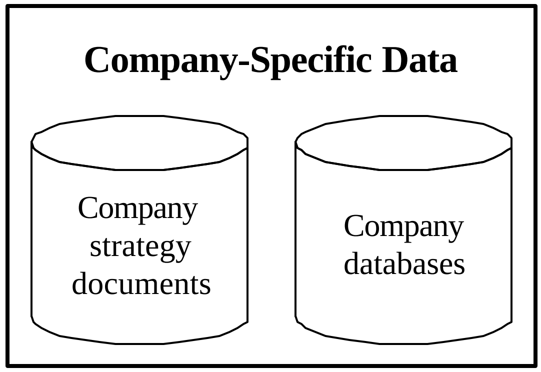


Figure 3-5: Company-Specific Data

The company's strategy documents include guidelines and programs that explain the main standards and principles of the company. Programs such as risk analysis, safety, total quality management, value engineering, and constructability are always significant during macro planning as they may encourage or prevent the use of a specific system or method. Adhering to this data enables the project team to execute the project while satisfying the company objectives and requirements.

The company's databases are one of the most important sources of data during macro planning. These databases present historical data about the company's means and methods, and resources productivity rates, crew sizes, and so on, which were utilized in previous projects. Each company is different and each company applies its own methods and resources in a different manner. That's why this data is usually the best practical indication of the company's resources real performance.

- ***Project-Specific Data:***

This group contains data exclusive to a particular project. Examples of this data include the facility's spatial dimensions and site soil characteristics. This data is acquired from the contract documents (design drawings and project specifications) and through site visits (Figure 3-6).

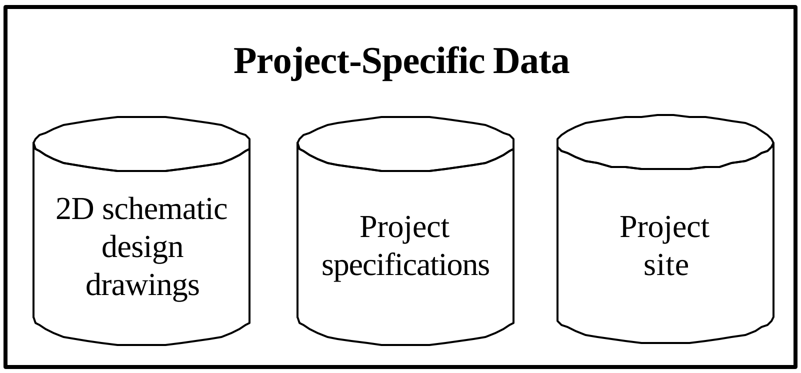


Figure 3-6: Project-Specific Data

In a Design-Build delivery method, design drawings used for macro planning are usually at schematic stage and are developed by the design team or by the owner's consultant. The schematic design consists commonly of sketches and/or "one-line" drawings that represent the designer's idea and conception. 2D schematic drawings are used mainly to visualize the project and to extract information on the facility physical properties. These drawings portray the physical aspects of the structure, showing the arrangement, dimensions, materials, and other data necessary for planning the construction of the project. The data in the drawings is mainly numerical, along with some textual description for some components.

Project specifications are written instructions concerning project requirements. The project specifications describe what results are to be achieved. The term "specifications" include the bidding and contract documents together with the technical specifications (Clough and Sears, 1996). The project team utilizes this data to identify the project and owner constraints and requirements.

3.2.2 DECISION-MAKING PROCESS

The second component of macro planning is the decision making process. This process involves the selection of major elements required for planning the execution of the project. These elements include major means and methods, major resources, proper sequence of major assemblies, the location of temporary facilities and major equipment, and an overall execution strategy for better constructability. Although, these interdependent actions should be planned interactively, these decisions are performed separately in isolation of each other. Coordinating these functions in isolation of each other, forces repeated recompilation of information throughout the facility delivery process.

In the current macro planning industry practices, in order to reach optimum decisions for planning the project, the project team employs an iterative process of selecting, reviewing, checking, and modifying the design and the major decisions made. Although the process is iterative, it can be defined in three major steps (Figure 3-7):

- ***Gathering and processing information***: this step involves reviewing the design and other project data, breaking down the facility into its major assemblies, and extracting the pertinent information necessary for decision making.

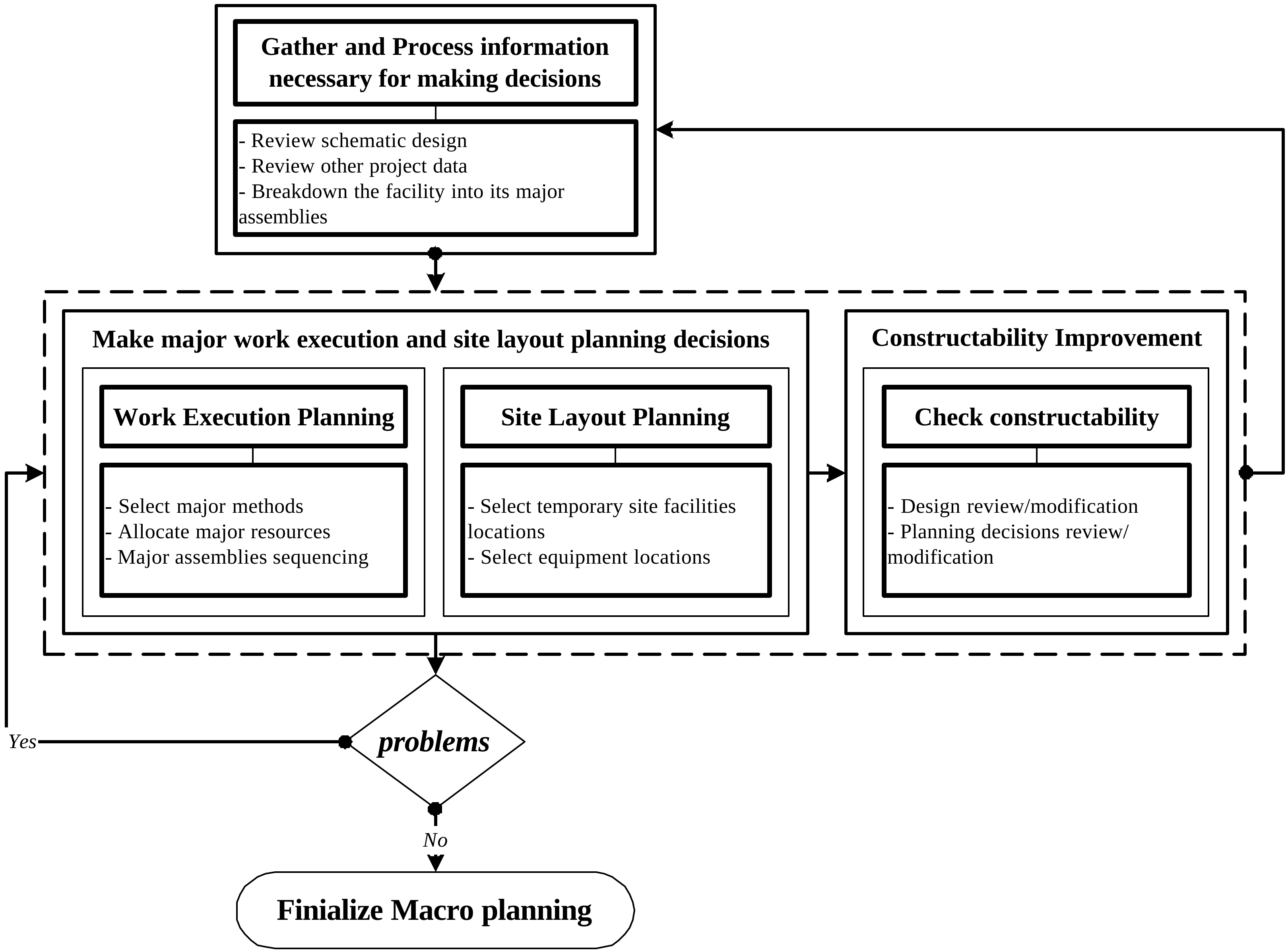


Figure 3-7: The decision-making process

- ***Making major decisions***: this step comprises making major decisions for work execution planning and site layout planning. Work execution planning involves selecting major means and methods, allocating major resources, and deciding on major assemblies sequencing. Site layout planning involves selecting appropriate locations for temporary site facilities and major equipment.

- ***Reviewing and checking for constructability conflicts:*** this step involves reviewing/modifying the design and planning decisions in order to improve the project constructability.

Each of these decision making steps is described in this subsection.

I. Gathering and Processing Information

Information necessary for decision making is extracted form available data presented in the previous subsection 3.2.1 (Figure 3-8). This includes information on the project site, the facility to be built, prevailing construction practices (e.g. means and methods and resources) in the project area, and the company's rules and policies.

Information on the project site is extremely significant during early project phases. Site investigations usually occur before the start of the design and happen again on a regular interval (e.g. when the design is 15% complete, then 30% complete, and so on). Project site information that is necessary for decision making includes information on the soil characteristics, existing of underground utilities and aboveground structures and utilities, weather, and so on. Information on soil characteristics may impact the method selected for implementing the foundations. For example, information on the soil condition in Georgia (red clay hard cohesive soil) enabled the contractor to pour concrete foundations against the earth to save formwork cost (ASCE, 1991). The presence of underground utilities (e.g. electricity and phone lines) may obstruct the excavation operations and, hence, may require special attention during planning. Weather condition may have an impact on the sequence of

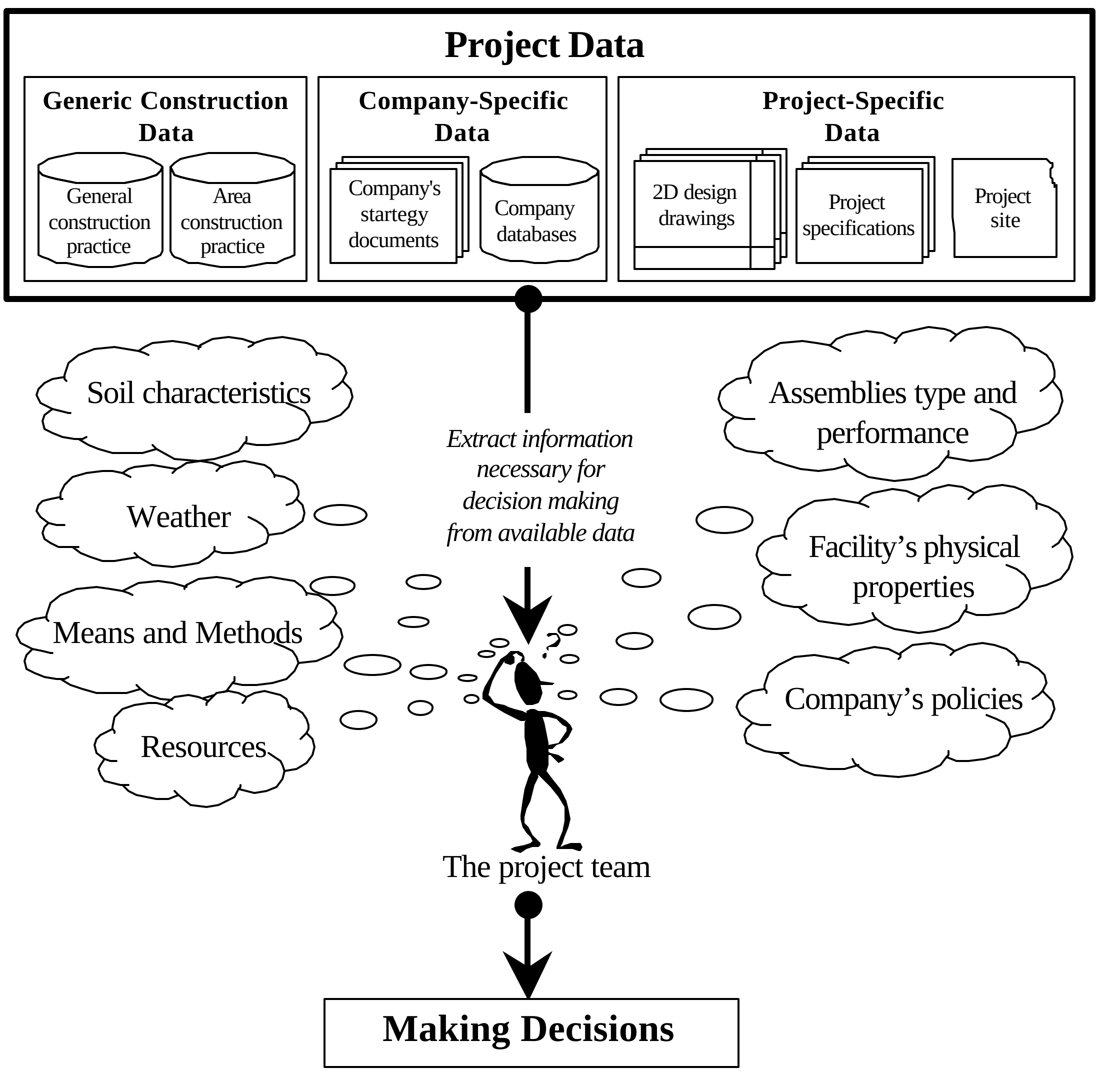


Figure 3-8: Current information extraction process

major assemblies. For example, in raining seasons, the project team may execute the exterior closure as early as possible to protect the interior of the facility.

Once the schematic design drawings are developed, the project team starts to gather information on the facility to be implemented. Using available 2D paper-based drawings, the project team breaks down the facility into its major assemblies (usually according to the CSI divisions) (Interview 6). This breakdown allows for a structured methodology to analyze the project assemblies, and to extract required information on each assembly. This breakdown also simplifies the job of the project team when making decisions on how these assemblies will be built and controlled on site. The breakdown level of detail is based on the complexity of the project. As a rule of thumb, the project team attempts to reach a level of detail where each assembly requires one method, with the associated resources, to be executed without going into too much detail (Interview 3). This enables the project team to produce a plan that is practical to use and maintain. Information on each assembly, which will enable the project team to make required decisions, includes physical properties, type, performance, materials, and arrangement of spaces.

Information on the prevailing construction practices in the area in which the project is to be constructed needs to be gathered. If the project is to be implemented overseas for example, the project team has to gather thorough information on the area construction practices. Means and methods employed as well as information on resources availability, performance, and cost is this area have a tremendous impact on the project team's decisions.

Information on the company's rules and policies needs also to be reviewed. This information may affect the project team's decisions. For example, for safety purpose, the company may prevent the utilization of specific equipment (e.g. equipment that affects the indoor air quality during construction).

II. <u>Making Major Decisions</u>

After gathering the required information for decision making, the project team starts to make the major decisions necessary for the execution of the work packages and for site layout planning (Figure 3-9). Major decisions for the work execution planning involves selecting major methods, allocating major resources associated with each method, and deciding on the major assemblies sequencing. Site layout planning involves selecting appropriate locations for the temporary site facilities, and the major equipment.

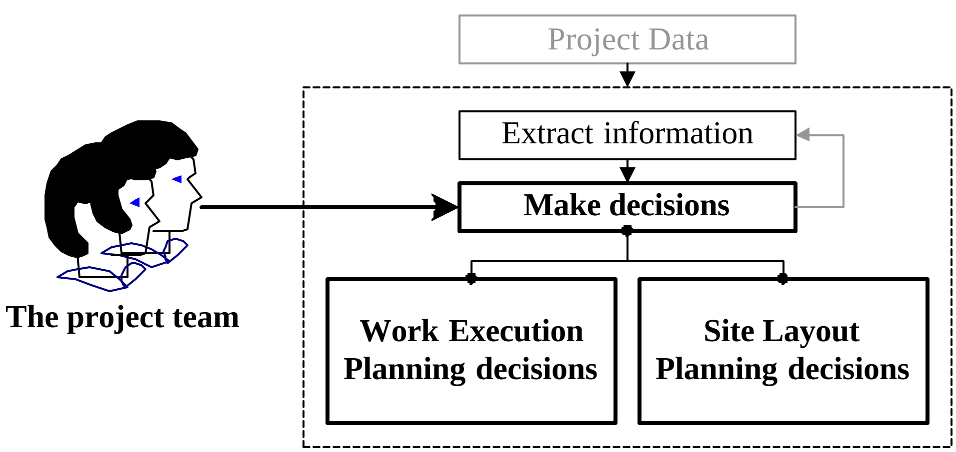


Figure 3-9: Major decisions for macro planning

A) **Work Execution Planning**

Work Execution Planning involves major decisions concerning the implementation of the facility/structure. In the current macro planning industry practices, the project team utilizes the information gathered, along with their own knowledge and experience, to make appropriate decisions. The project team selects the appropriate method for executing the assemblies, allocates the major resources associated with each method, and decides on the major assemblies' sequences (Figure 3-10).

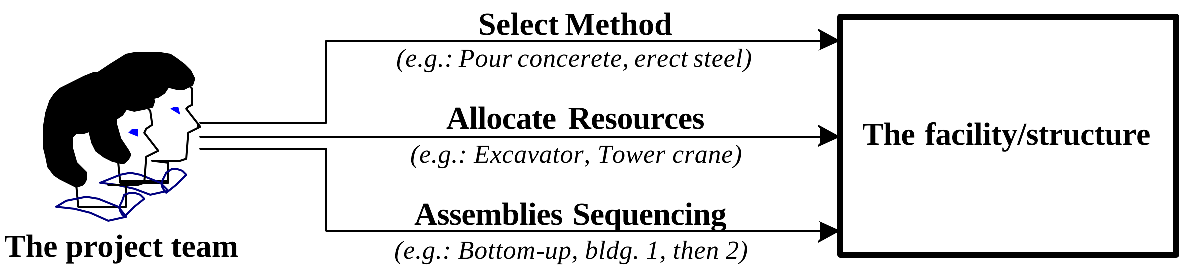


Figure 3-10: Major work execution planning decisions

Major decisions for work execution planning are presented hereafter:

1) Select Methods

This step involves the selection of appropriate methods required for the execution of major assemblies. These decisions are particularly significant due to its direct impact on the resources allocation, and thus, the cost and duration of the project. An example of a method selection decision is the use of flying form for slabs of a high-rise building, which makes this method economical (ASCE, 1991).Various factors govern the selection of methods (Syal, 1993). The project team has to gather all the information related to these factors to be able to make adequate decisions. As shown in Figure 3-11, these factors include:

- Company-related factors:

Each company has a different strategic plan and different policies that affect the selection of methods for construction projects. Examples of the company-related factors that should be considered during methods selection are *safety, quality, rent vs. own, subcontracting, and new technology.*

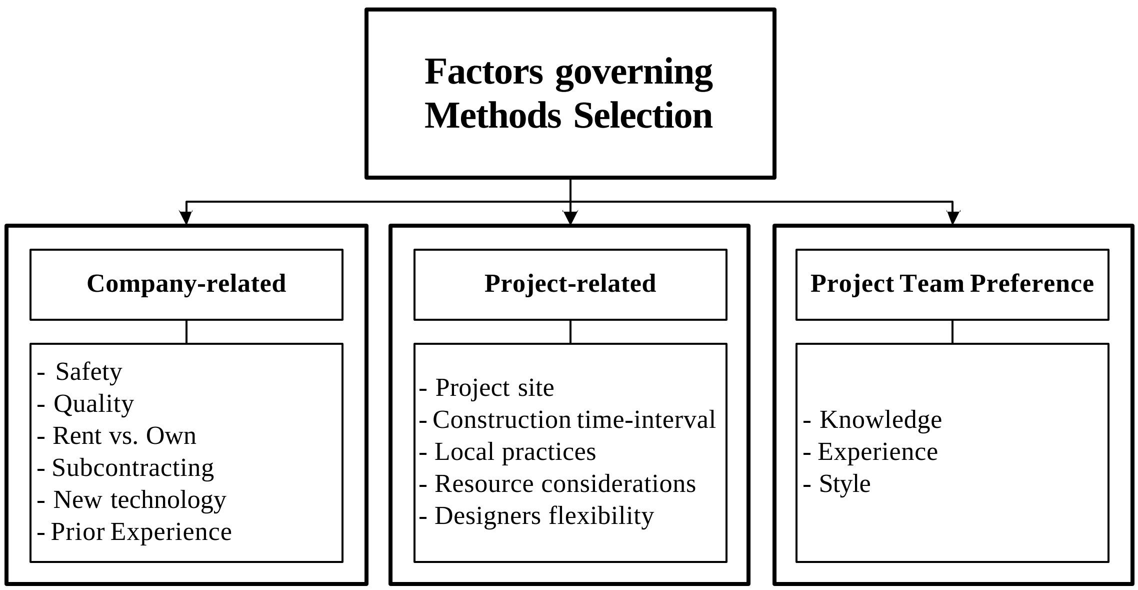


Figure 3-11: Factors governing methods

- Project-related factors:

Each project is unique. Various project-related factors influence the selection of methods for construction projects such as *project site, time-interval of construction, local practices, resource considerations, and designer flexibility.*

- Project team preference:

If there exist various methods for executing the assembly and they all satisfy the above considerations and constraints, then the project team will select the method that they prefer according to their own knowledge, experience and style.

2) Allocate Resources

After selecting methods for the execution of major assemblies, the project team allocates the resources associated with each method. Equipment is the major resource considered during macro planning. The equipment required for the execution of a specific operation is directly associated with the method selected. For example, if during method selection, the project team has selected "concrete pumping" as the method for pouring concrete. This method implies the use of specific equipment (in this case, a concrete pump and a ready-mix truck) to perform the concrete placement. During resources allocation, the project team selects the type (e.g. piston vs. pneumatic pumps), the amount (one or more pumps), and the required performance (e.g. a 100-ft. vertical reach pump) of the equipment.

Different factors govern the resources allocation process. Due to the direct relation between the method selected and the associated resources required, almost all the factors are similar to those governing methods selection, such as: safety, quality, rent vs. own, and the site location and condition. However, three main factors control resources allocations (Figure 3-12). These factors are resources availability, performance, and cost.

- Resources availability:

The project team should, preferably, allocate a piece of equipment that is available in the company's backyard or in the local market. Other than that, it will be difficult and probably expensive to get the required equipment.

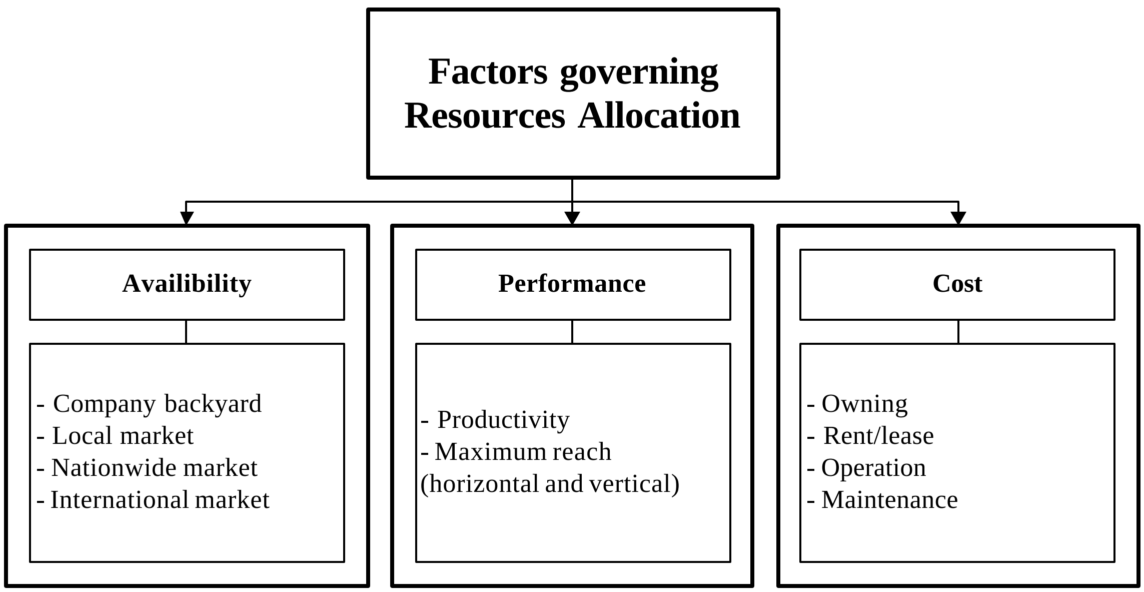


Figure 3-12: Major factors governing resources allocation

- Resources performance:

The project team should allocate a piece of equipment that has the capability of performing the required operation. For example, the project team must consider the maximum reach of a concrete pump (e.g. a 100-ft vertical reach and a 500-ft horizontal reach) as well as its productivity (e.g. 100 cu-yd/hr) before allocating this pump to place the concrete.

- Resources cost:

The equipment owning, rent/lease, operation, and maintenance cost is very significant as it may lead to an over budget project. Therefore, this factor should be considered carefully during early phases.

3) Decide on assemblies sequencing

This step involves the development of an adequate sequence for the major assemblies. An example of the assemblies sequencing decision made during macro planning is the project team's decision to work from grade down in a multilevel underground facility adjacent to Boston harbor. This decision helped the project team in avoiding problems of dewatering a structure that was below sea level and within 50ft to 100ft of the harbor. Slurry walls were installed and later replaced with concrete. Afterward, the interior of the structure was excavated, and floor slabs were installed to act as diaphragms to hold the concrete walls (ASCE, 1991).

In order to make sequencing decision, the project team must have good knowledge of the different factors that govern the assemblies sequencing logic. Factors identified by Echeverry et al. (1991) include physical relationships among building components, trade interaction, path interference, and code and safety regulations. However, the author believes that one of the most significant factors, which was not included in Echeverry's work, and which distinguishes assemblies sequencing from one planner to another, is the planner's own style and preference. Following is a brief description of these factors (Figure 3-13).

- Physical relationships among building components:

The way building components are physically related to each other impacts the assemblies sequencing logic. The different types of physical relationships among building component that affect the sequencing of their corresponding assemblies mostly deal with the support of gravity loads, spatial relationships among components and weather protection. These physical relationships are s*upported by, covered by, embedded in, relative distance to support, relative distance to access, weather protected by.*

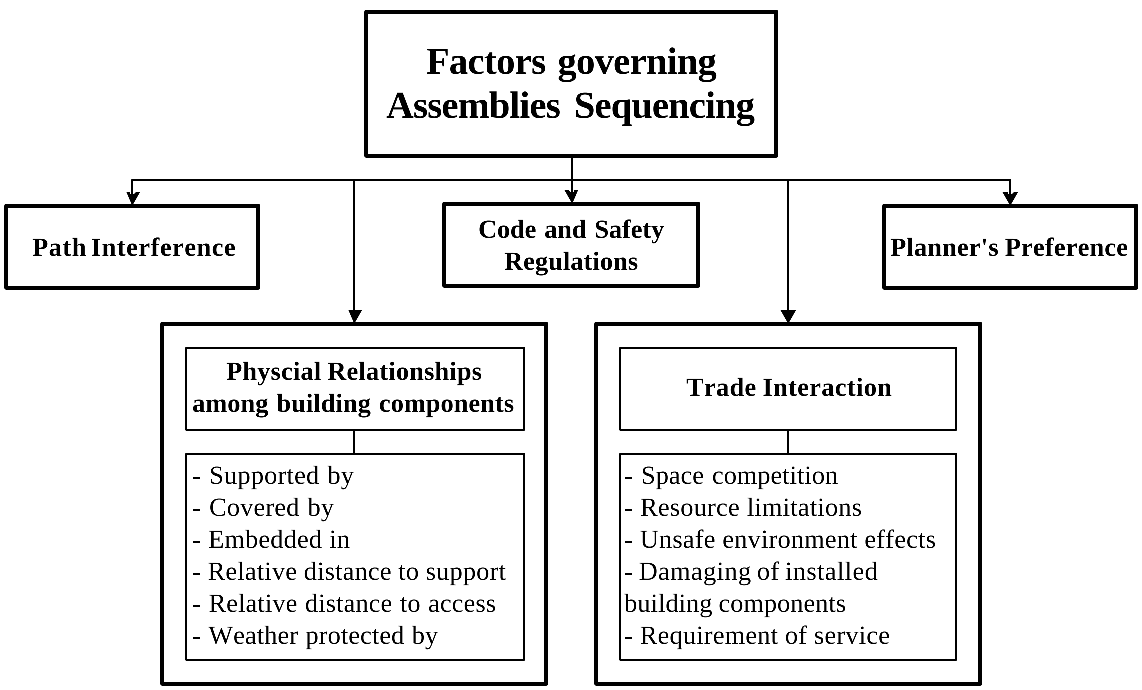


Figure 3-13: Factors governing assemblies sequencing

- Trade interaction:

Interaction among trades (i.e. subcontractors, crew, equipment, and material) is one of the main factors governing the assemblies sequencing. Examples of trade interaction sequencing constraints include *space competition, resource limitations, unsafe environment effects, damaging of installed building components, requirement of service*.

- Path interference

An interference free path is required to bring a component from its temporary site storage location to the place where it has to be installed. Also the path for equipment and crew should be free.

- Code and safety regulations

Code and safety regulations govern the assemblies sequencing in order to protect workers and the general public during construction, and to enable the inspection of the quality on work in place. This is the case when erecting a steel frame. The Occupational Safety and Health Administration (OSHA) requires the installation of a temporary or permanent floor not more than two stories or 30-ft. (9,14 m) below the actual frame erection operation.

The different factors described above have varied degrees of flexibility. Some of these factors are unavoidable and considered inflexible (hard logic). This includes supported by, covered by, embedded in (contributing to structural function), requirement of service, and code regulations. Other factors are flexible (soft logic) and may be bypassed with the expectation of cost, time, and risk increase.

- Planner's preference

This is a major factor that differentiates assemblies sequencing from one planner to another. Each planner has his own style. It is this style that distinguishes one planner over another. For flexible constraints, the planner may select the sequence that he or she believes is the optimum for the specific situation based on his own knowledge and experience.

B) <u>Site Layout Planning</u>

Site Layout Planning involves major decisions concerning the organization of the project site facilities and major operations (Figure 3-14). The project team selects the locations for the temporary site facilities (e.g. office trailers, storage, temporary parking, batch plants, … etc), and major equipment (e.g. Tower cranes). These decisions are

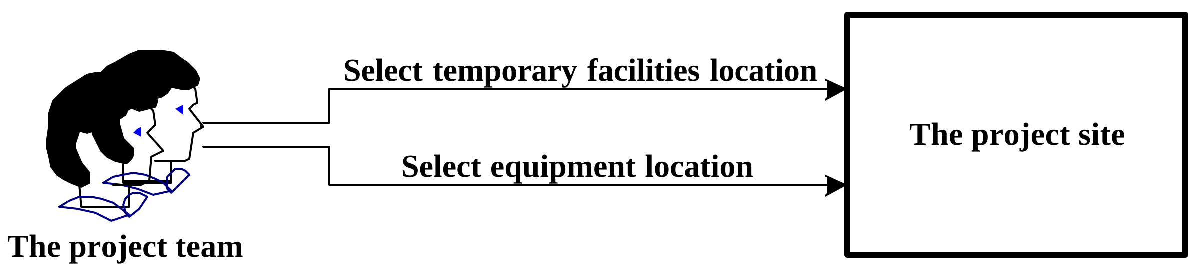


Figure 3-14: Major site layout planning decisions

particularly significant during macro planning in order to ensure a productive and safe site. For example, the selection of an appropriate batch plant location that ensures easy access of material and equipment will assist the project team in increasing the productivity of concrete operations.

In the current macro planning industry practices, the project team utilizes the 2D schematic drawings to locate the temporary site facilities and the major equipment.

Locations for temporary site facilities and equipment, as well as the maximum reach of the equipment, are sketched on the site layout plan (Interview 6).

Major decisions for site layout planning are presented hereafter:

1) Select temporary site facilities location

Temporary facilities include temporary offices, temporary storage, parking for construction workers, fabrications yards, …etc. The prime concern in siting temporary facilities is to best accommodate its function and purpose. Locations must be selected so they don't interfere with other facilities or accessibility. Underground utilities must also be considered when locating these temporary facilities.

The selection of temporary facilities locations depends mainly on the characteristics of the job itself. Each project's characteristics will pinpoint the locations for temporary facilities. For example, in a concrete batch plant, with provision for waste and wash-water disposal, is central to the operation, its location and space requirement will be given high priority (Oglesby et al., 1989). In other situations, primary attention will be given to space for storing materials for example. In large sites, the first consideration is to find the logical center of activity while minimizing the total job travel. This requires comprehensive studies of the costs and operating constraints associated with the movement of personnel and materials during the life of the project.

While selecting temporary site facilities locations, considerations must also be given to prevailing winds and drainage pattern. Noisy and dusty operations should be downwind from the temporary offices, repair shops, and warehouses. Also wet operations such as a concrete batch and aggregate plants should be located where their drainage will have little or no adverse effect on other activities or on adjacent properties.

2) Select equipment location

Major equipment include cranes, concrete pumps, excavators, … etc. Appropriate selection of major equipment locations requires gathering various information about the equipment (e.g. maximum reach), the operation for which the equipment is required, space availability, accessibility issues, and soil condition. The locations for equipment are chosen according to several criteria. Some criteria are general for all equipment. The equipment should be able to reach all required places from the selected location. Each equipment has a maximum reach capability that can not be exceeded. For example, concrete pumps have booms capable of placing concrete up to 180ft (55m) vertically and 167ft (50m) horizontally (Putzmeister manuals). Cranes are capable of reaching a working area with a 330ft (100m) radius (Liebherr web site). The project team reviews the properties of the allocated equipment and places it in a location where all the intended operations are within its reachable capability.

Some criteria for selecting equipment locations are exclusive for specific types of equipment. When locating a tower crane, for example, the project team has to locate it where there is adequate place for the crane footing. In addition, an erection area for the exclusive use of the crew must be provided. This area should be large enough to permit the components to be stacked and the crane to be erected without interfering with or impacting the safety of other site personnel. Also, the crane location should be based on its proximity to other cranes, particularly when their working areas might overlap. The project team places the equipment in a location that satisfies all these requirements.

III. Constructability Review

The macro planning decision making process involves also reviewing project constructability in order to depict conflicts that may arise during the construction of the project. This constructability review is crucial during macro planning since depicting these problems at the early phases will have a great impact on the project duration and cost.

Using 2D schematic drawings, and based on the different planning decisions taken, the project team reviews the applicability of these decisions with the project design, requirements, and constraints. If problems are depicted, the project team takes corrective actions to solve these problems during this early stage. Depending on the problem encountered, major/minor modifications can be made to adjust the design and/or the planning decisions.

During macro planning, constructability review is usually performed on a regular basis (every 2 to 4 weeks based on the project complexity) as the design is developed. Although this iterative constructability review process helps the project team in depicting some constructability problems, other conflicts, which could easily be eliminated during macro planning, still arise during construction. The use of the dominant 2D format of design drawings limits the project team capability of visualizing possible conflicts. In addition, the interdependence between the various information required to check for constructability and the planning decisions made, limits the project team in depicting many constructability problems.

<u>1) Design Review/Modification</u>

The project team reviews the schematic drawings to ensure that the design won't lead to constructability problems during construction and that it complies with the decisions taken. Design review includes examining the location of the facility/structure on site, and reconsidering the different types of systems and materials as well as their physical properties. This review allows the project team to depict several constructability problems early during design development. The project team may then modify the design in order to solve these constructability problems (Figure 3-15). Examples of design modifications and their impact on the project constructability include:

- Moving a building 5ft from the originally planned location to avoid shoring of adjacent buildings (Tatum, 1987).
- Aligning structural columns at an apartment building to allow the use of flying forms. This modification reduced the cost of concrete formwork and the duration of the project (CII, 86).
- Reselecting a cheaper material for exterior wall covering. The initially selected material was unnecessarily expensive, since the wall will be destructed after six months for building expansion. This modification eliminated unnecessary expenditure (interview 6).

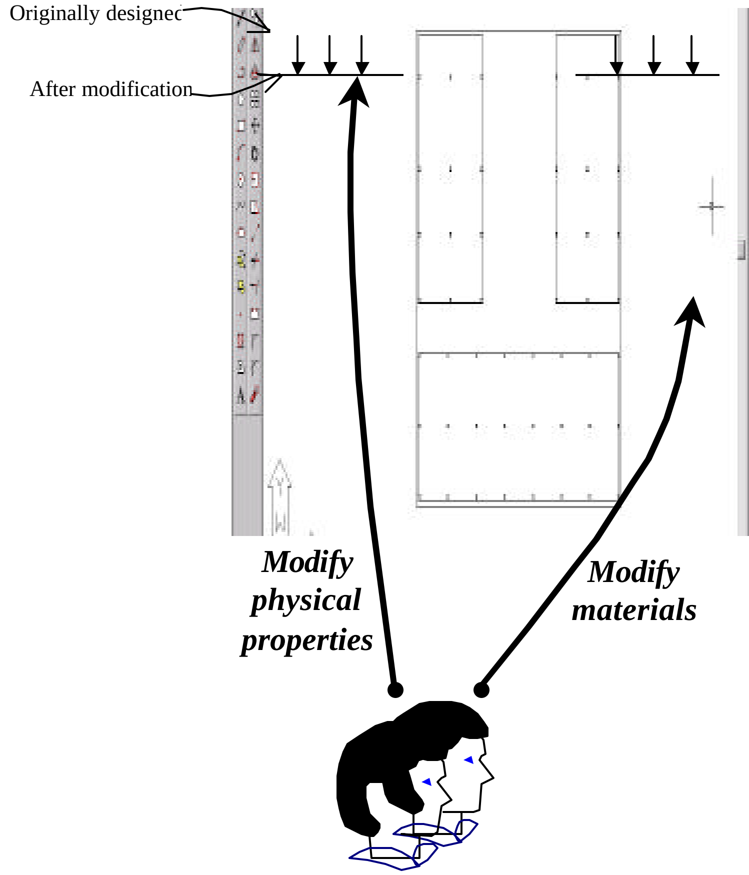


Figure 3-15: Design Review/Modification

Design changes may sometimes require further modification of planning decisions to fix the problem encountered. For example, the project team may decide to change the type of the superstructure system from concrete post-tensioned into a steel structure (major change). This design change leads to the modification of methods selected, resources allocated, and assemblies sequence. On the other hand, some design changes may directly solve the problem encountered without requiring further modification of planning decisions. For example, the project team may change the distance between two buildings, bay sizes, or column heights to satisfy an equipment accessibility conflict (minor changes). The equipment accessibility problem is then solved without changing any of the decisions taken (e.g. allocating another equipment).

2) Planning Decisions Review/Modification

Along with the design review, the project team reviews the work execution and site layout planning decisions made during the decisions making process to ensure the appropriateness of these decisions and their impact on the project constructability. If constructability problems are depicted, the project team rethinks all the decisions made and attempts to find the best way to solve the problem encountered.

1) Review/Modify methods selected

The project team reviews the methods selected to ensure that these methods are appropriate for the project in term of quality, cost, and time. Methods may be modified during the decisions making process to solve constructability problems. Changing the method usually required allocating new resources. A review is then needed to check if the new resources do not lead to other constructability conflicts, hence the iteration of the decision making process steps. For example, the project team may change/reselect the method of concrete placement from "concrete pumping" to "crane and bucket" because the performance of the concrete pump is not adequate, for any reason (e.g. maximum reach), to perform the required operation.

2) Review/Modify resources allocated

Resources allocated for the execution of selected methods are also considered. The project team ensures that the allocated resources will be available during the specified time interval to perform the job. If the company does not own the required resource, then the project team checks if it can be rented/leased when needed.

Performance of each piece of equipment is also reviewed. If the equipment productivity, for example, is less than the requirement, which will affect the project duration, the project team may then select another pump with better performance. The project team may also increase the amount of pumps for the operation (i.e. allocate more than one concrete pump for the operation).

The project team also ensures that the resources allocated are suitable for the project. For example, if a tower crane is allocated, soil stability and bearing capacity must be taken into account. The ground foundation or structure, which is to support the crane, must be sufficiently strong and stable to take the loading without any sinkage or deflection.

As mentioned earlier, allocating a new resource is usually mandatory if the project team selects to change the selected method. However, the project team may select not to change the method, but only to change the resources associated with this method to solve the constructability conflict. For example, the project team may select to change the concrete pump selected for concrete placement into another pump with a different boom reach or productivity rate. After changing the resource, the project team rechecks the availability, performance, space, and accessibility conflicts for the new resource.

3) Rethink the major assemblies sequence

Reviewing the planning decisions also include rethinking the major assemblies sequence. Changing the assemblies sequence may have a great affect on the duration of the project and may solve many constructability problems especially those related to resources allocation, and space and accessibility. This is true in two cases.

Case 1: two parallel operations require the resources that are available only for one of them. This is the case if using one crane for concrete placement and brick handling for example.

Case 2: two parallel operations require two different resources and there are space and/or accessibility conflicts to perform these operations. This is the case if using a concrete pump for concrete placement, a crane for brick handling, and there is no space available for both the pump and the crane.

In both cases, the two operations may not be performed in parallel. Modifying the logic of the two parallel operations into sequential relationship will solve these problems. However, the project team has to review the effect of these changes on the project duration.

4) Review/Modify the site layout plan

The project team reviews the locations of temporary site facilities and major equipment and attempts to solve any constructability conflict (Figure 3-16). The locations of temporary site facilities are usually flexible and may easily be modified to fix the encountered problem. Modifying the locations of major equipment may solve space and accessibility conflicts, as well as problems related to the equipment reachable capability.

Space availability for major equipment is reviewed. The project team uses the equipment manufacturer manual to acquire the required space for the equipment and ensures that enough space is available in the planned locations. Accessibility of major equipment through the site and to the selected locations to perform the required operations is examined. For example, the distance between two buildings or the bay sizes may prevent equipment to reach its location. Major equipment access to the site is also reviewed. The project team ensures that there are no accessibility problems from the surrounding streets. This is especially significant in urban areas.

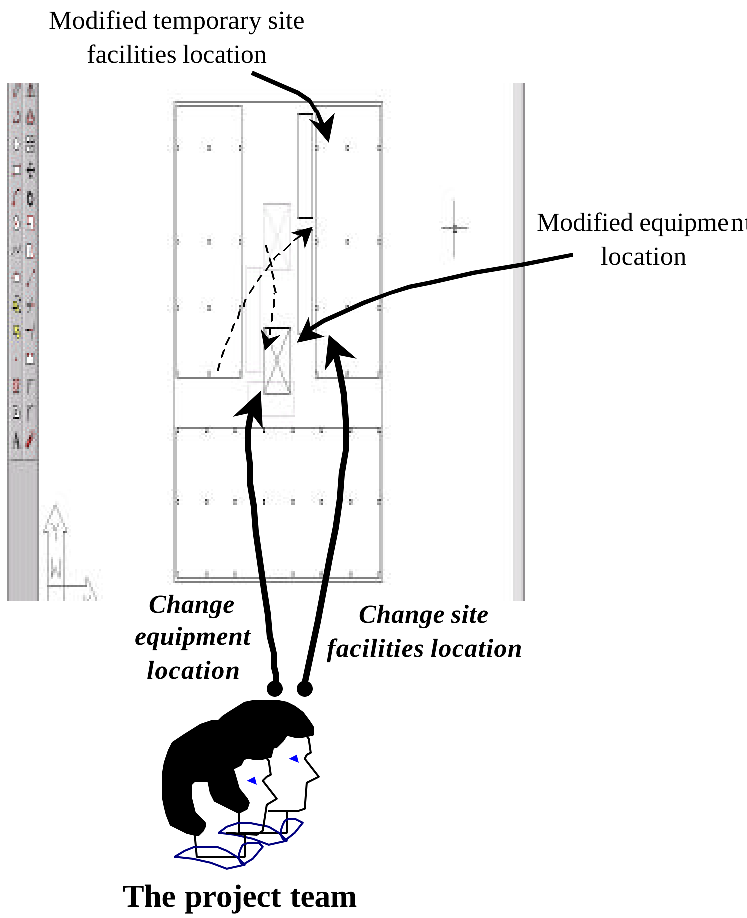


Figure 3-16: Modifying site layout planning decisions

If the project team depicts that the allocated equipment will not be able to reach all required operations from the selected location, then changing the equipment location to another place may be the solution.

Changing the equipment location is usually a major concern that requires thorough planning during the early phases especially in the case of immobile equipment such as tower cranes. In this case, changing the location of the tower crane at this phase solves the problem encountered and saves a lot of time and money that would have been spent if this action is not taken until encountered on site during the construction.

3.2.3 PLANNING ACTIONS

The output of the current macro planning industry practices consists of a document that contains abstract information about the major elements required for the execution of the project. This includes the primary systems and major assemblies definitions, the methods selected for the execution of these assemblies, the major resources associated with the methods, the major assemblies sequence, and a site layout with the temporary site facilities and major equipment locations. This information is presented abstractly at the macro level due to the dynamic nature and long time periods needed for implementing construction projects. These issues prevent the project team from predicting future events with certainty and in detail at early phases (i.e. design/procurement) before the start of construction. A detailed plan developed at the early phases would create the most unmanageable coordination problem. The quantity of information would be truly amazing and confusion profound

(Neale and Neale, 1989). In addition, with a large number of activities and subactivities implemented in the macro plan, it becomes tedious and time consuming to update the plan whenever changes occur. Therefore, the project team limits the detail of the macro plan in order to keep it practical to use and maintain. This macro plan presents the basis for conceptual estimate and preliminary schedule.

The format of the prevailing macro planning output includes textual information explaining the definitions, methods, and resources required. 2D site layout drawings are used to illustrate the locations of temporary site facilities and the major equipment. Free-line sketches and annotations are used to show the equipment reachable area. It is then the responsibility of the project team to use the 2D drawings, along with the textual information, to figure out how the project should be implemented.

3.3 EXAMPLES OF THE CURRENT MANUAL APPROACH

In order to illustrate the current manual approach for macro planning, the author developed three examples. The scenario in these examples is mainly based on information from the interviews conducted and presented in the previous chapter, as well as the author's own knowledge and experience.

The first example illustrates the major decisions described in this chapter (i.e. assemblies sequencing, methods selection, and resources allocation). The following two examples present specific problems and illustrate the approach used by the project team to overcome these problems. A flow chart of each example is also presented to show the major steps involved and to illustrate the documents and data sources utilized to extract necessary information.

In order to illustrate the benefits of using the VCE for macro planning, these three examples will be presented again in chapter 6. This time, the examples will illustrate the approach that may be used by the VCE users to acquire the necessary information, make appropriate decisions, and overcome the encountered problems.

Example 1 – MAKING INTERDEPENDENT PLANNING DECISIONS:

This example illustrates the manual approach for:

- Extracting information.	- Selecting Methods.
- Sequencing Assemblies.	- Allocating resources.

Background

During planning a construction project at the macro level, the project team makes various interdependent work execution decisions. This example describes the approach the project team is using to extract necessary information and to make these decisions for a couple of work packages.

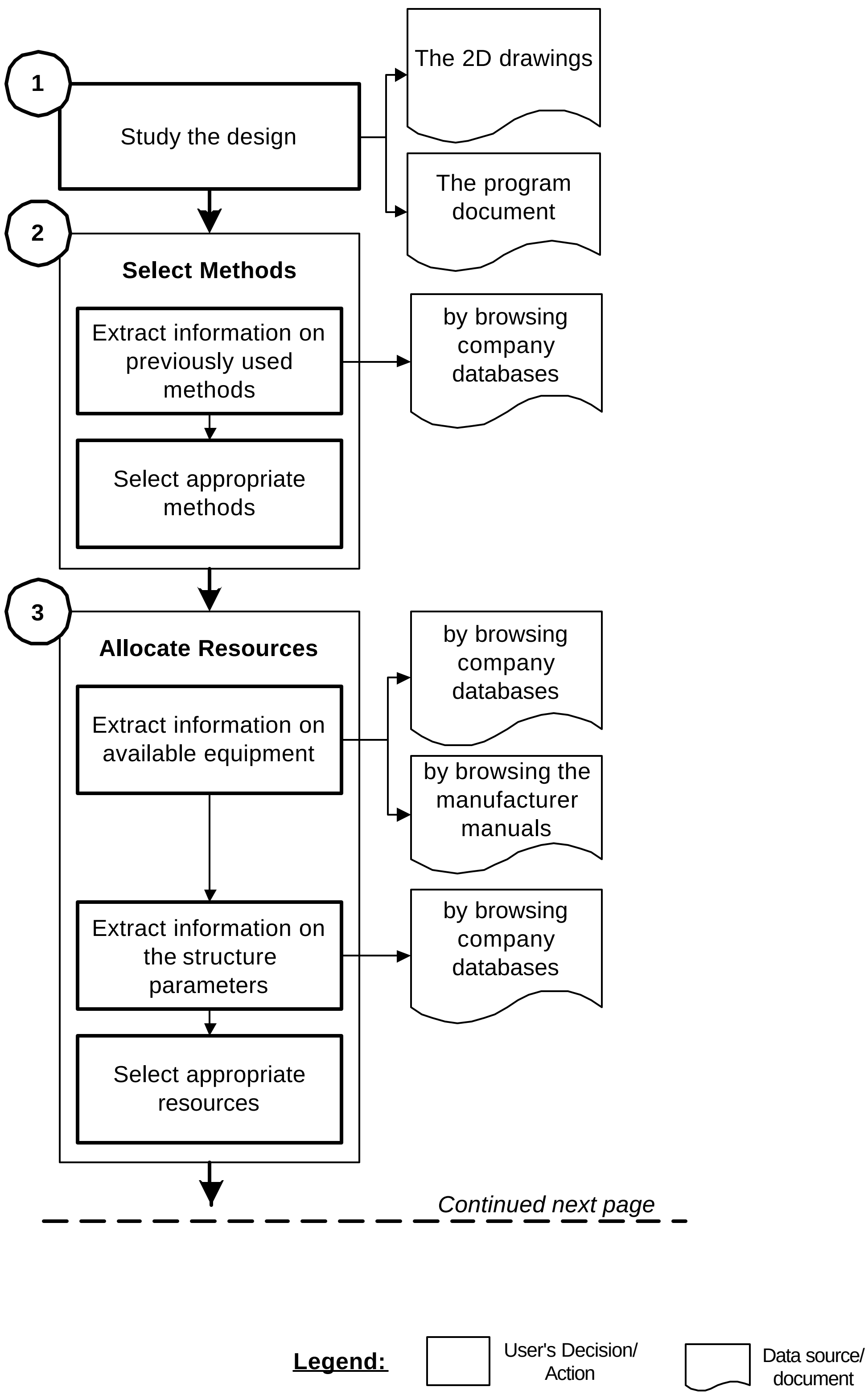
Decision Making Process

1) **Study the schematic design**. This is performed by reviewing the *2D design drawings, along with the program document*, and extracting various information on the product model.

2) **Select methods for concrete placement and brick handling.** This requires extracting information *from the company historical databases* about the methods used for such operations. The project team, then, decides to use pumping for concrete placement and a crane for brick handling (Figure 3-18).

3) **Allocate appropriate resources**. After selecting the methods for all work packages, the project team starts to allocate resources associated with these methods. This requires, first, reviewing the types of pumps and cranes available in the company and extracting information (e.g. maximum reach and maximum lifting capacity) on these pieces of equipment (*from the company database and the manufacturer manuals*) as well as on the structure parameters (*from the 2D design drawings*).
Based on this information, along with the project team's knowledge and experience, a specific pump and crane are allocated.

4) **Decide on appropriate sequence for these two work packages**. According to their knowledge and experience, the project team starts to visualize how the building will be constructed on site, and decides on the appropriate sequence of the major assemblies (Figure 3-19). This is usually performed in the form of a logical network diagram that illustrates the sequence of major operations.


1
Study the design
The 2D drawings
The program document
2
Select Methods
Extract information on previously used methods
by browsing company databases
Select appropriate methods
3
Allocate Resources
Extract information on available equipment
by browsing company databases
by browsing the manufacturer manuals
Extract information on the structure parameters
by browsing company databases
Select appropriate resources
Continued next page
Legend:
User's Decision/ Action
Data source/ document

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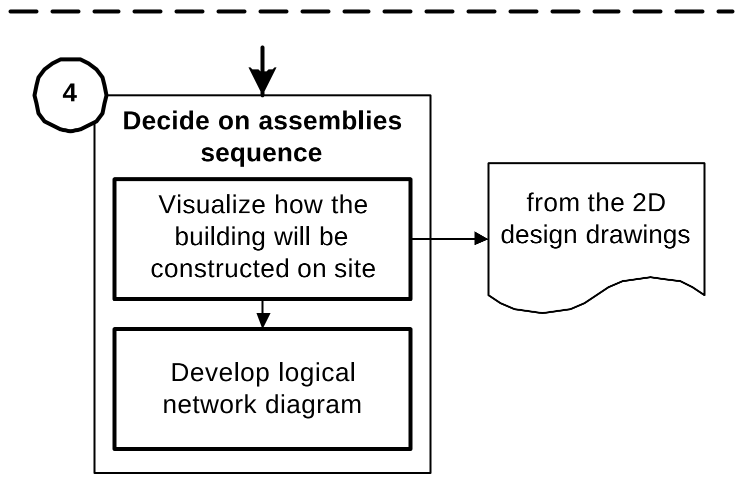


Figure 3-17: Flow chart of example 1 – Making interdependent planning decisions

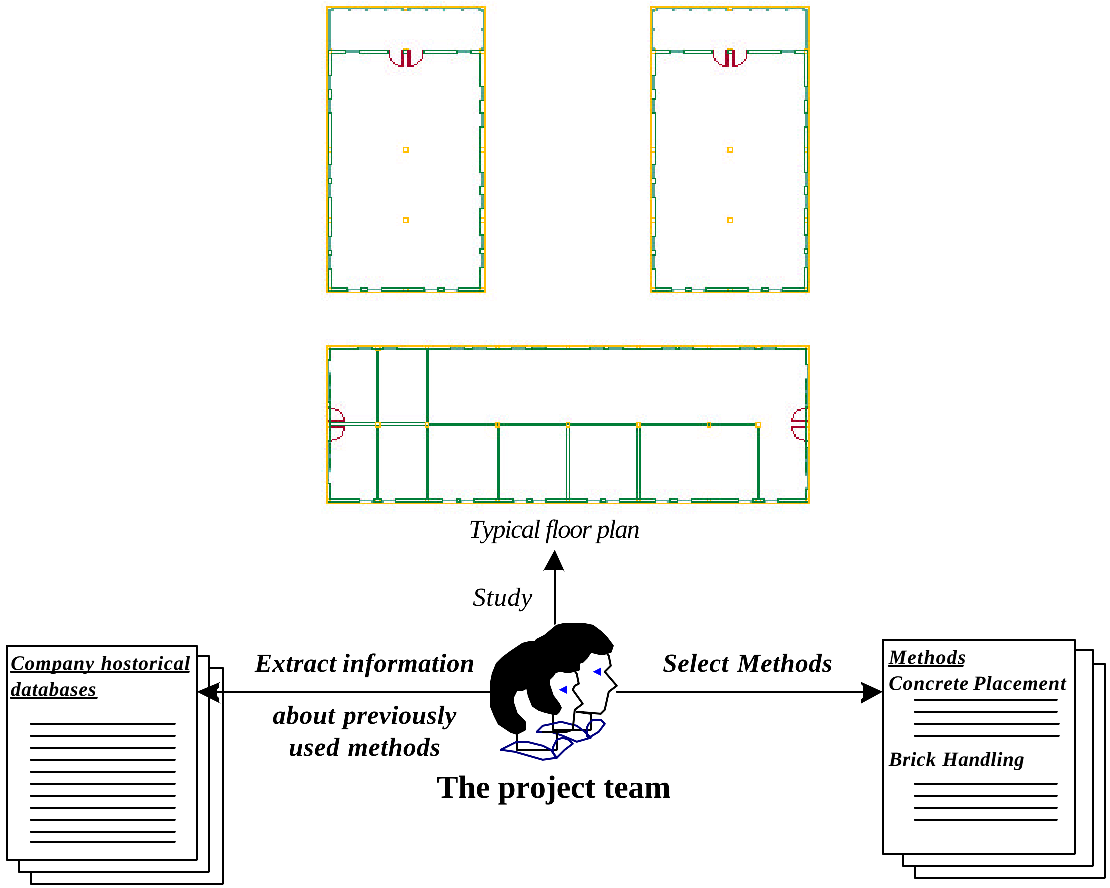


Figure 3-18: Review the design, acquire necessary information, and select appropriate methods

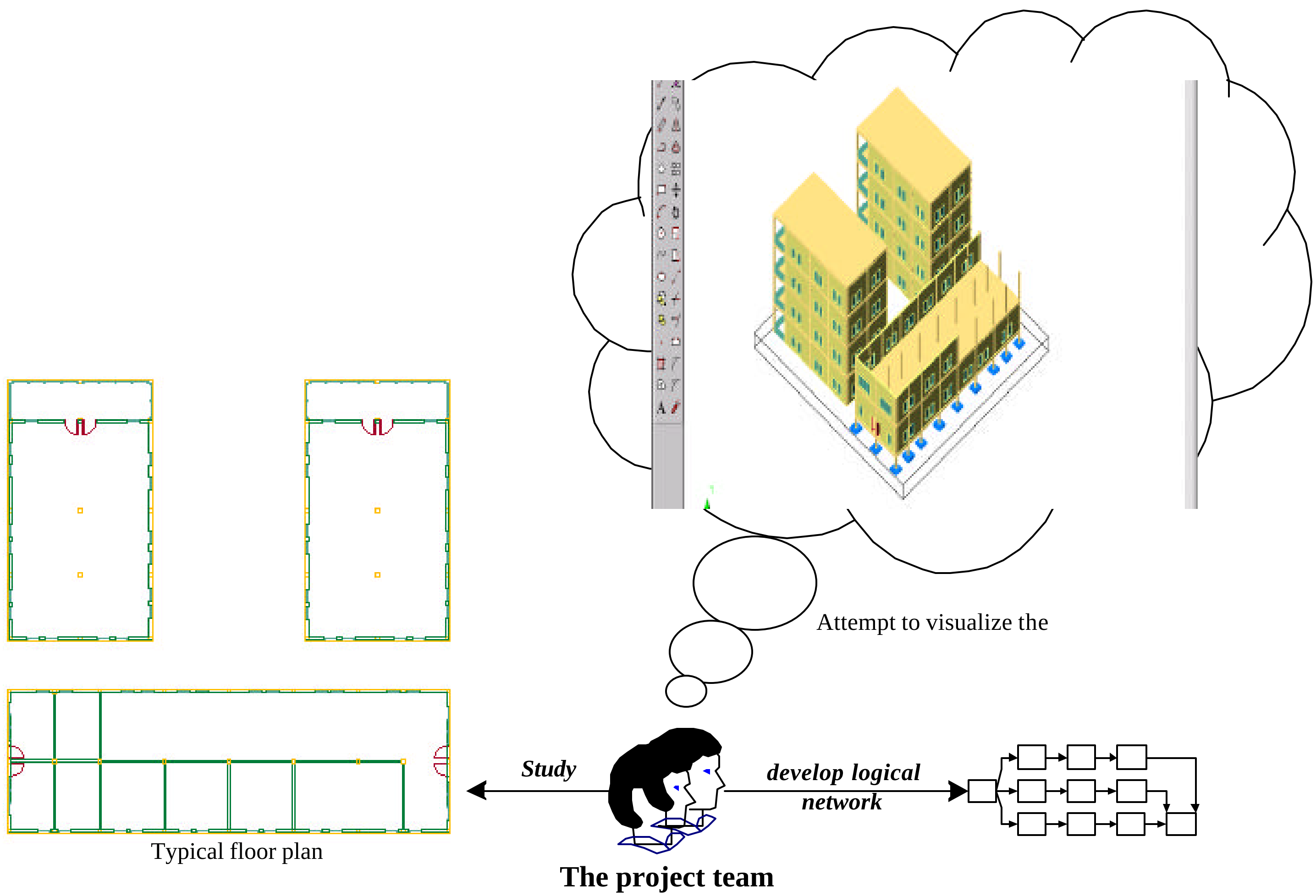


Figure 3-19: Develop logical network for major assemblies

Example 2 – SELECTING LOCATION FOR MAJOR EQUIPMENT:

This example illustrates the manual approach for:
- Extracting information.
- Allocating resources.
- Selecting major equipment location.
- Checking crane's maximum reach.

Background

During planning the execution of a building in a metropolitan area, the construction team decides to utilize a tower crane to perform major operations for this project. This decision is based mainly on the project criteria, as well as the construction team's knowledge and experience.

Decision Making Process

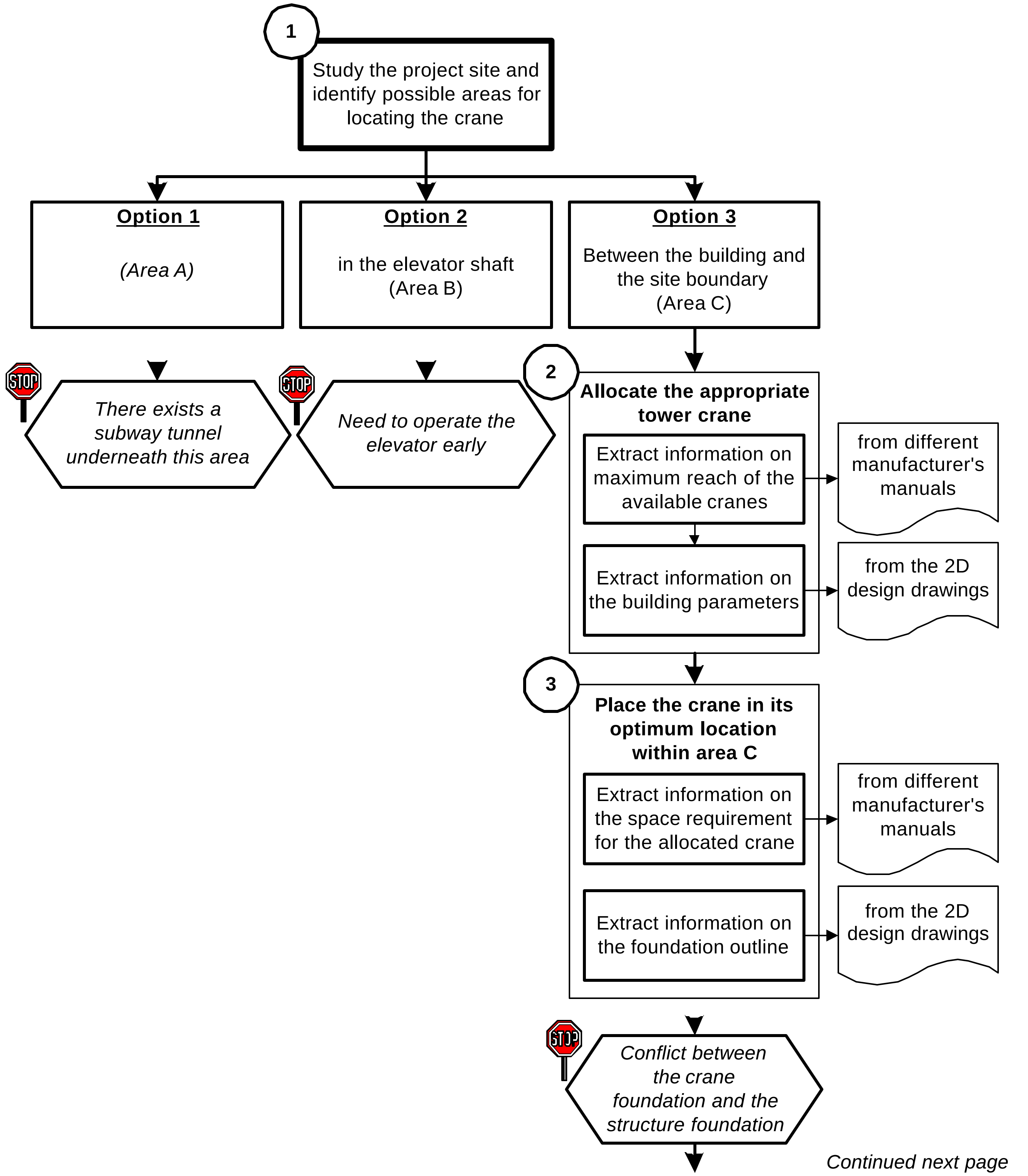
1) **Study the project site and identify possible areas for the crane locations**: This is performed by reviewing the 2D design drawings. This enables the construction team to identify three potential options for the location of the crane (Figure 3-21).
   - Option 1: in **area A**
     Conflict*: there exists a subway tunnel underneath this area. This information was collected during site investigation. No tower crane may then be placed in this area.*
   - Option 2: in the elevator shaft (**area B**).
     Conflict*: the project team needs to operate the elevator early. So this option is excluded.*
   - Option 3: Between the building and the site boundary (**area C**). This seems the only feasible location.

2) **Allocate the appropriate crane.** The project team, then, has to allocate a tower crane that can reach all the required locations from this location (i.e. area C).
   This requires extracting information on the maximum reach of the available cranes *(from the different manufacturer's manuals*), as well as information on the structure parameters *(from the 2D design drawings).*
   Based on this information, along with the construction team's knowledge and experience, a specific tower crane is allocated.

3) **Place the crane in its optimum location within area C**. This requires from the construction team, first, to extract information on the space requirement for this crane *(extracted from the different manufacturer's manuals*).
   Conflict*: Due to the limited space available between the structure and the site boundary, there is a conflict between the crane foundation and the structure foundation.*
   In order to depict this problem, the construction team has to extract information on the foundation outline (*from the foundation drawings*) (Figure 3-22). If this conflict is not depicted before pouring the concrete foundations, it would cost a lot to fix it.

4) **Shift the crane location**. To solve this conflict, the project team tries to shift the crane location around the structure (*by specifying points on the 2D drawing, which represent the suggested locations for the crane*). For each new location, the construction team reviews the space availability for the crane (*using the 2D drawings*), and reviews the maximum reach (*by drawing an arc with the radius equal to the crane maximum reach*) to ensure that the crane will still be able to reach all required places from this location.
   Conflict*: The foundation conflict remains unsolved.*
   So the project team decides to place the crane outside the site boundary.
   Conflict*: This is not possible being in a downtown area.*

5) Finally, the construction team informs the design team that they require a modification to one of the footing design (*by making a mark on the specified footing and stating it in text*) so it can pick up the load of the column plus the load of the tower crane. The structural engineer reviews the design and the identified footing was modified.



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Legend: User's Decision/ Action; Conflict; Data source

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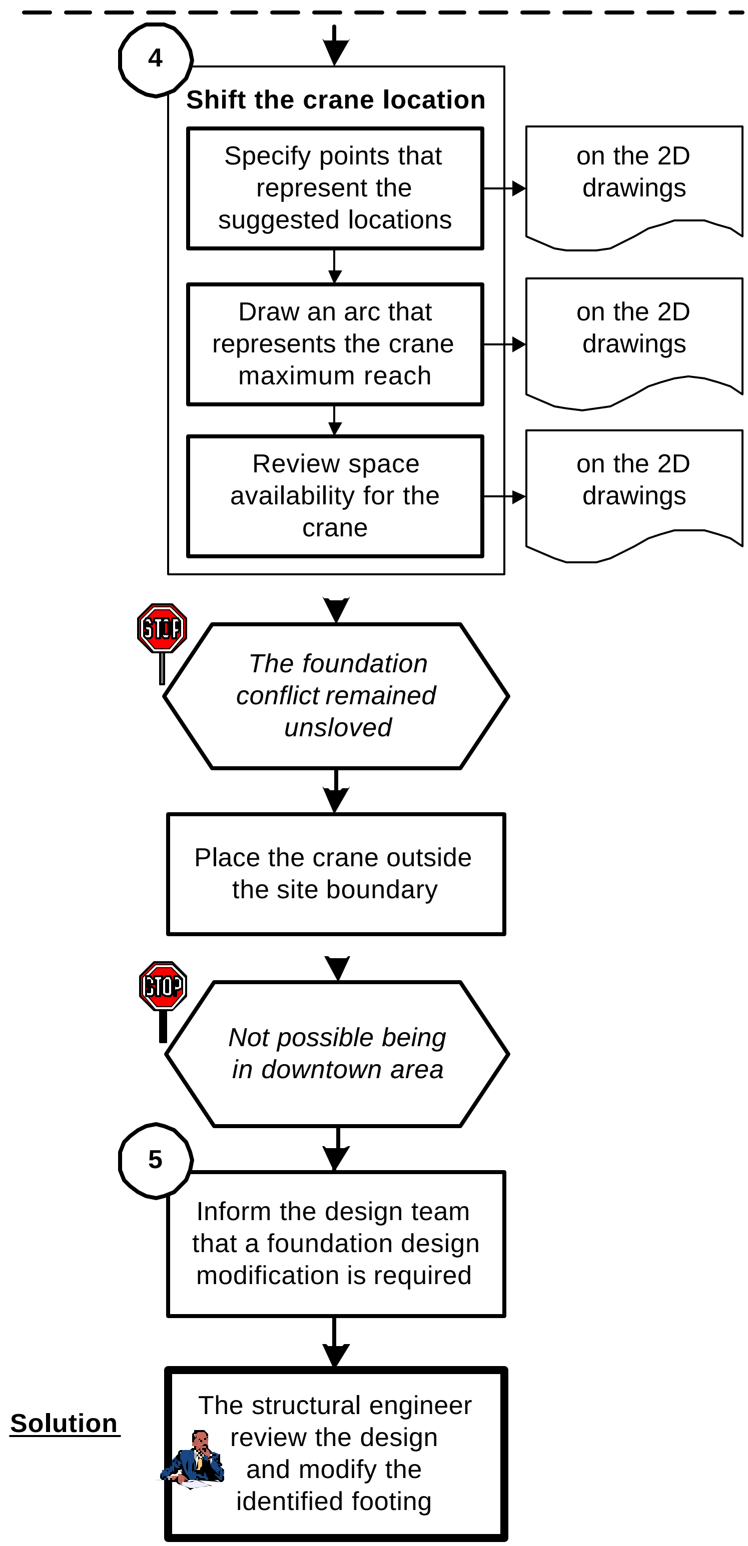


Figure 3-20: Flow chart of example 2 – Selecting Location for Major Equipment

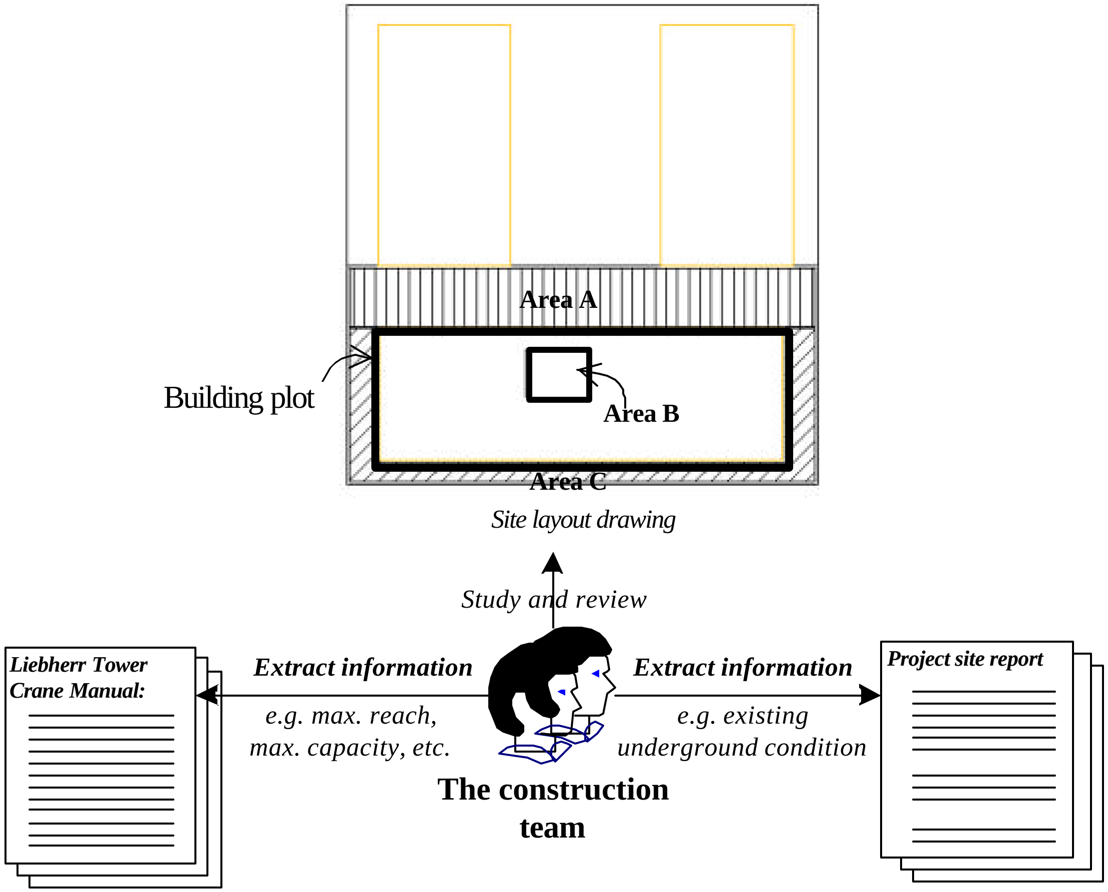


Figure 3-21: ***Manual Approach*** **-** Identify possible areas for the crane location

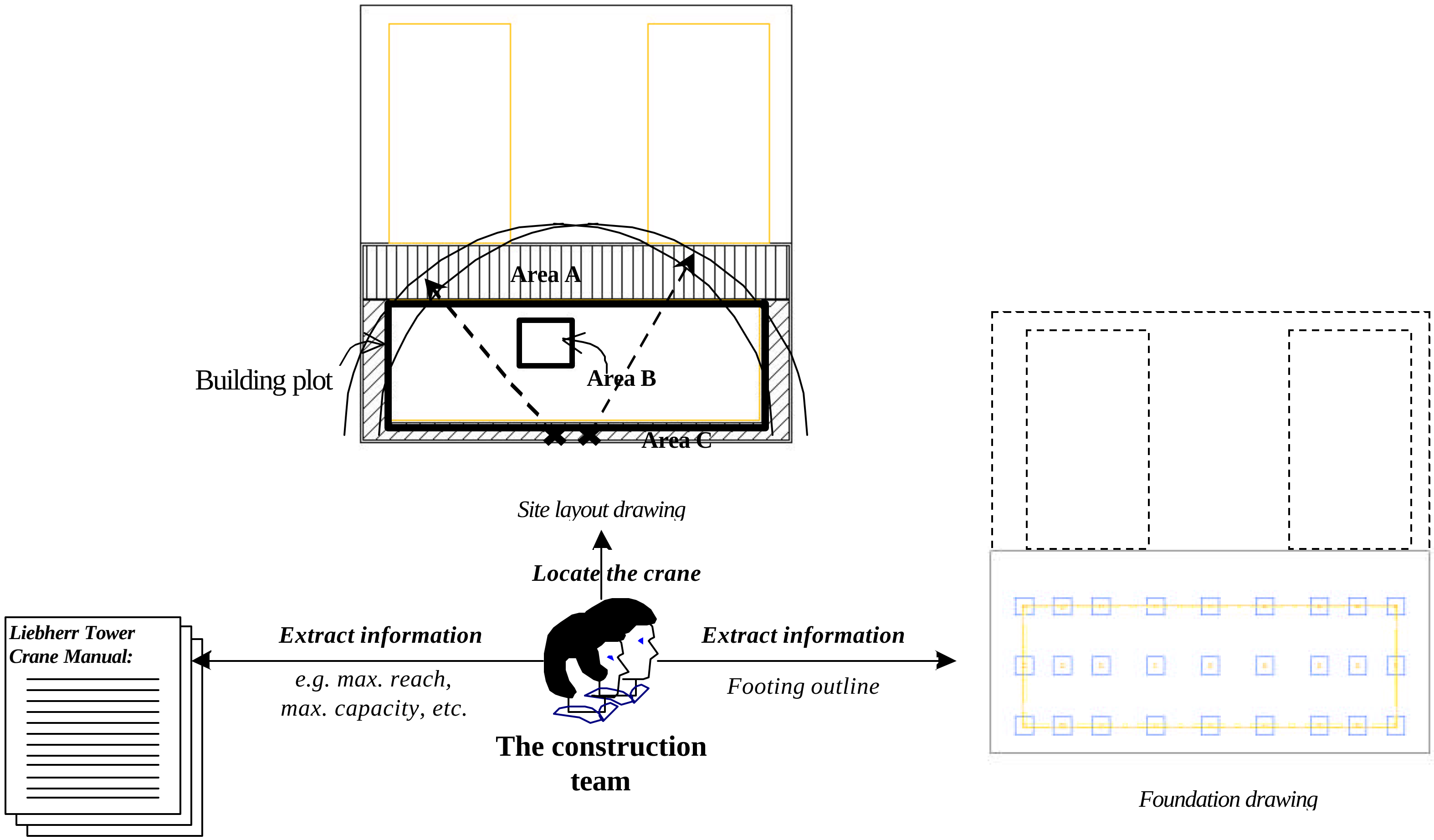


Figure 3-22: ***Manual Approach*** - Place the carne in its optimum location and check for conflicts

Manual Approach

Example 3 – MODIFYING DESIGN DECISIONS:

This example illustrates the manual approach for:

- Extracting information.
- Reviewing the design.
- Modifying the design.
- Collaboration between the design and construction team.

Background

While reviewing the schematic design drawings, the construction team found that the cost for implementing the design is greater than the initial maximum price guaranteed (IGMP) to the owner. The construction team then attempts to identify systems that may be modified to reduce the project total cost.

Decision Making Process

5) **Review the design.** This is performed *by reviewing the 2D design drawings along with the program document* to extract information about the different systems (e.g. system type, description and cost) (Figure 3-24). This enables the construction team to identify several systems that may be modified to reduce the project total cost.

6) **Suggest alternatives**: After reviewing different alternatives for each of the identified systems as well as the cost of each alternative (*by browsing the manufacturer catalogs*), the construction team suggests an alternative for each system.

   Send the drawings with the suggested modifications to the design team along with the manufacturer catalogs. The drawings mainly include marks on the selected systems as well as the suggested alternatives.

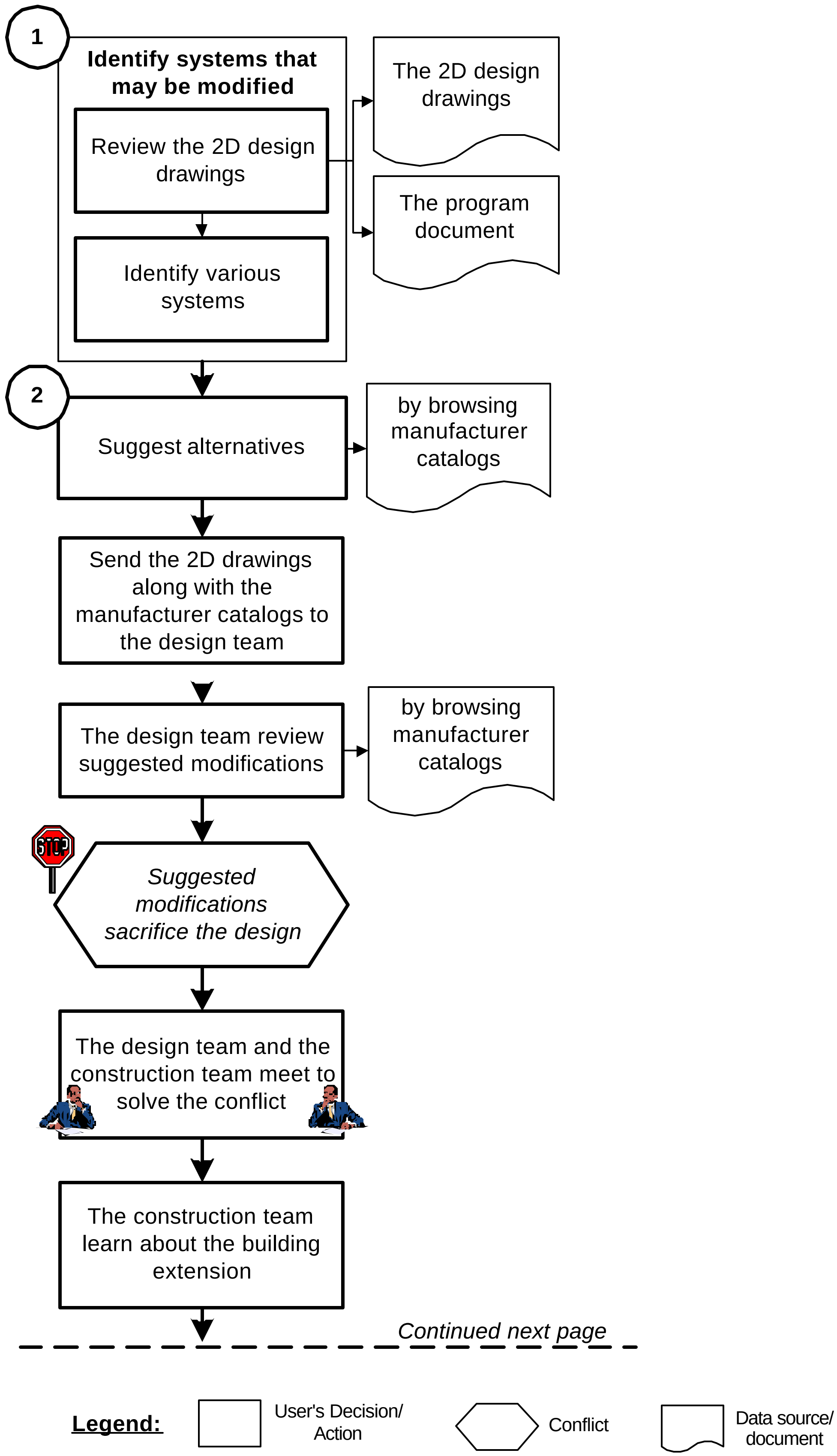
7) **The design team reviews the suggested modifications** *by browsing the manufacturer catalogs*. However, the design team doesn't approve any modification since modifying any of these systems meant sacrificing the design.

The design team and construction team finally meat to discuss this subject. During the meeting the construction team learned that there will be an extension to the building that will begin in 6 months. This extension will lead to the destruction of one of the exterior walls (East Side). This information, although is available in the contract documents, is not presented in the drawings. Therefore, the team reviewing the drawings has no idea about this extension.

8) **Suggest modifying the system of the east wall from Brick to Stucco.** The construction team suggests modifying the east wall system from brick to stucco since it will be demolished anyway in 6 months (Figure 3-25).

The design team approves the changes and the project cost had been reduced down to the initial guaranteed maximum price.

If this information is presented in the drawings and in an easy to visualize format, the construction team reviewing the drawings would have solved the problem initially without having to spend extra unnecessary effort and time.


1
Identify systems that may be modified
Review the 2D design drawings
Identify various systems
The 2D design drawings
The program document
2
Suggest alternatives
by browsing manufacturer catalogs
Send the 2D drawings along with the manufacturer catalogs to the design team
The design team review suggested modifications
by browsing manufacturer catalogs
STOP
Suggested modifications sacrifice the design
The design team and the construction team meet to solve the conflict
The construction team learn about the building extension
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Legend:
User's Decision/ Action
Conflict
Data source/ document

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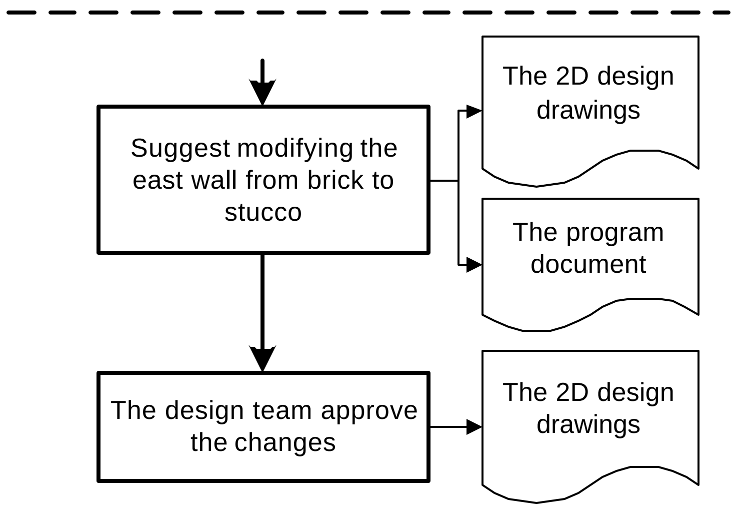


Figure 3-23: Flow chart of example 3 – Modifying Design Decisions

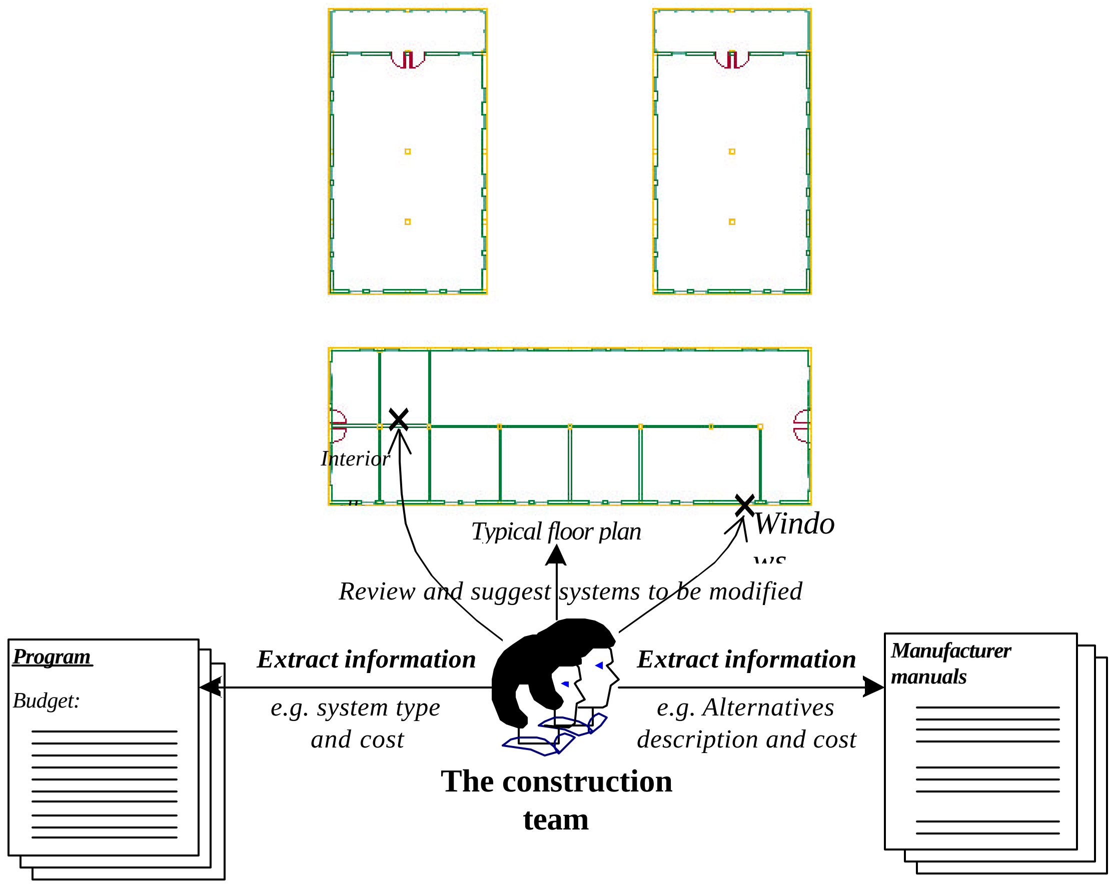


Figure 3-24: Review the design and identify systems that may be modified

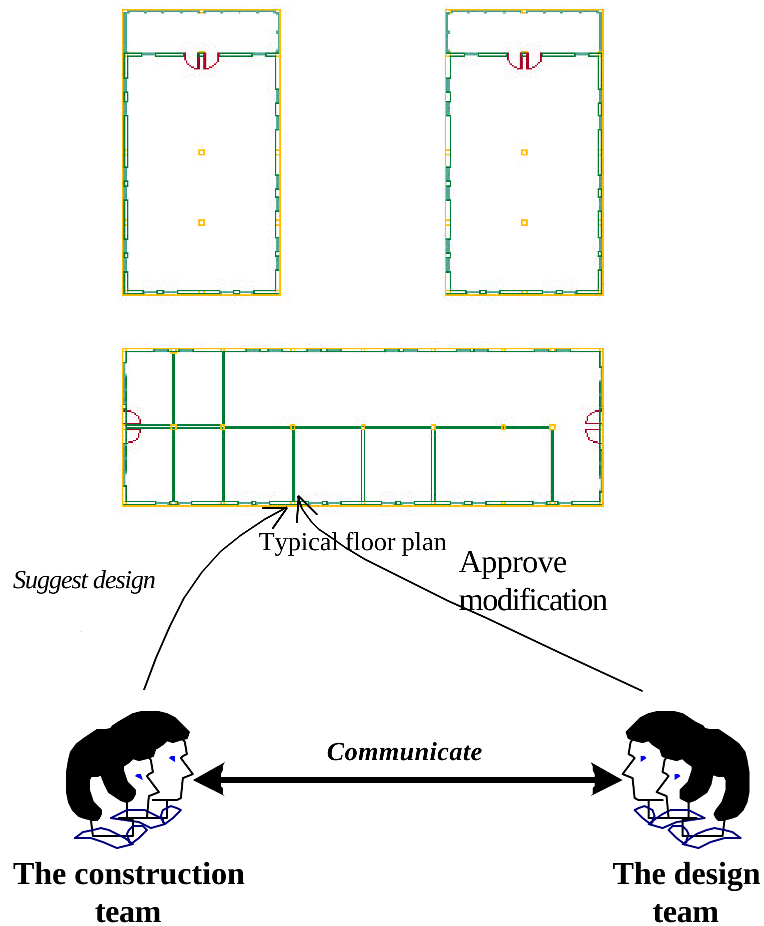


Figure 3-25: The design team and construction team meeting

3.4 CONCLUSION

This chapter presented a detailed description of the macro planning process in the Design-Build delivery method. Elements involved in the macro planning process were described in details and illustrated with examples. These elements include the project data, the decision making process, and the planning actions. The project data consist of generic construction data, company-specific data, and project-specific data. The decision making process includes an iterative process of gathering and processing information, making major work execution and site layout planning decisions, reviewing and checking for constructability, and taking corrective actions by modifying the design and/or the planning decisions. The output of the macro planning process consists of a document containing abstract information on the major elements required for the execution of the project, as well as the site layout showing locations of major equipment and temporary site facilities.

The macro planning process has assisted the project team in making appropriate planning decisions and improving the constructability of construction projects. However, the diversity and large amount of information required for decision making, as well as the format of presenting this information (e.g. 2D drawings, various textual databases, …etc) limits the ability of the project team in considering all the information and in depicting some constructability conflicts that may arise during the construction of the project. in addition, in the current practices for decision making, planning functions are performed separately in isolation of each other. Design and constructability reviews, decisions on how to physically erect the facility (i.e. plan), when to erect what (i.e. schedule), and the selection of major means and methods are all interdependent. These interdependent actions should be planned interactively. Coordinating these functions in isolation of each other, forces repeated recompilation of information throughout the facility delivery process. Any changes and revisions to the facility further complicate the planning effort.

4. MAPIC - MACRO PLANNING INFORMATION CLASSIFICATION

4.1 INTRODUCTION

Decisions made during macro planning are critical and affect, to a great extent, the successful development of construction projects. In order to make appropriate decisions, the project team needs to extract various information from different data sources. The information required varies and include general construction, company-specific, and project-specific information.

As discussed in the previous chapter, planning functions (i.e. making major work execution decisions, site layout planning decisions, and reviewing for constructability improvement) are generally planned independently of one another through an iterative process. These independent functions unnecessarily require the extraction of the same information several times throughout the decision making process. This extraction process is tedious and time consuming. In addition, this redundant processing leads to a tremendous amount of information that needs to be manually pieced together by the project team to develop a comprehensive plan. This process limits the ability of the project team to adequately consider each and every piece of required information, and thus, impose a heavy burden on the team to carry out the planning process.

The construction industry needs a structured model that allows the project team to review and categorize all the information required for macro planning decisions. The model should allow the project team to store information extracted from various sources of data. The model should also allow for easy retrieval and utilization of this information whenever needed during the decision making process.

Through extensive literature review and interviews with construction professionals, the author has developed a **MA**cro **P**lanning **I**nformation **C**lassification (**MAPIC**) model under which information required for macro planning decision making can be classified and organized in a structured format. The MAPIC model arranges macro planning information into various categories. Information required for decision making may be gathered and stored under its relative category in the MAPIC model. The structured classification will assist the project team to retrieve and utilize this information whenever needed without having to unnecessarily extract it several times from the various data sources.

This chapter presents the MAPIC model. First, the development and structure of the model is discussed. Then, a detailed description of the various MAPIC categories, classes and attributes is presented. Finally, how MAPIC will be applied to improve the macro planning decision making process is described.

4.2 MAPIC DEVELOPMENT AND STRUCTURE

The goal of MAPIC is to classify information required for making appropriate macro planning decisions in a structured format. The first step in developing this model was to obtain a comprehensive list of required information from the literature and interviews with industry experts. Then, the researcher defined the attributes that best store this information. Examples of these attributes include systems geometry, and resources output. Then, the second step was to arrange the various attributes to form possible classes. Each class presents a group that shares common attributes. For example, resources availability, resources output, and resources space requirement information are all characteristics for the same class called "Resources". Each class may be divided into subclasses. For example, the "Means and methods" class is divided into several subclasses such as "Earth moving", "Concrete placement", and "Pile driving". The subclasses inherent the same attributes from their parent class. Finally, related classes were grouped under their relevant category. For example, the "Means and methods" and "Resources" classes are grouped under the

"Construction technology" category. After several refinements and modifications, the MAPIC model was developed. The structure of the MAPIC model is presented in Figure 4-1.

The major categories of MAPIC are "**MANAGERIAL**", "**FACILITY/STRUCTURE**", "**CONSTRUCTION TECHNOLOGY**", and "**PROJECT SITE**". The "**MANAGERIAL**" category is divided into "STRATEGY" and "CONTRACTUAL" classes; the "**FACILITY/STRUCTURE**" category into "PARAMETERS" and "SYSTEMS" classes; the "**CONSTRUCTION TECHNOLOGY**" category into "MEANS AND METHODS" and "RESOURCES" classes; and the "**PROJECT SITE**" category into "ACCESSIBILITY", "SPACE", and "CONDITION" information classes. Each of these classes is further divided into subclasses, and contains attributes that define the characteristic of the information required. A detailed description of the MAPIC categories, classes, and attributes is presented in the next section.

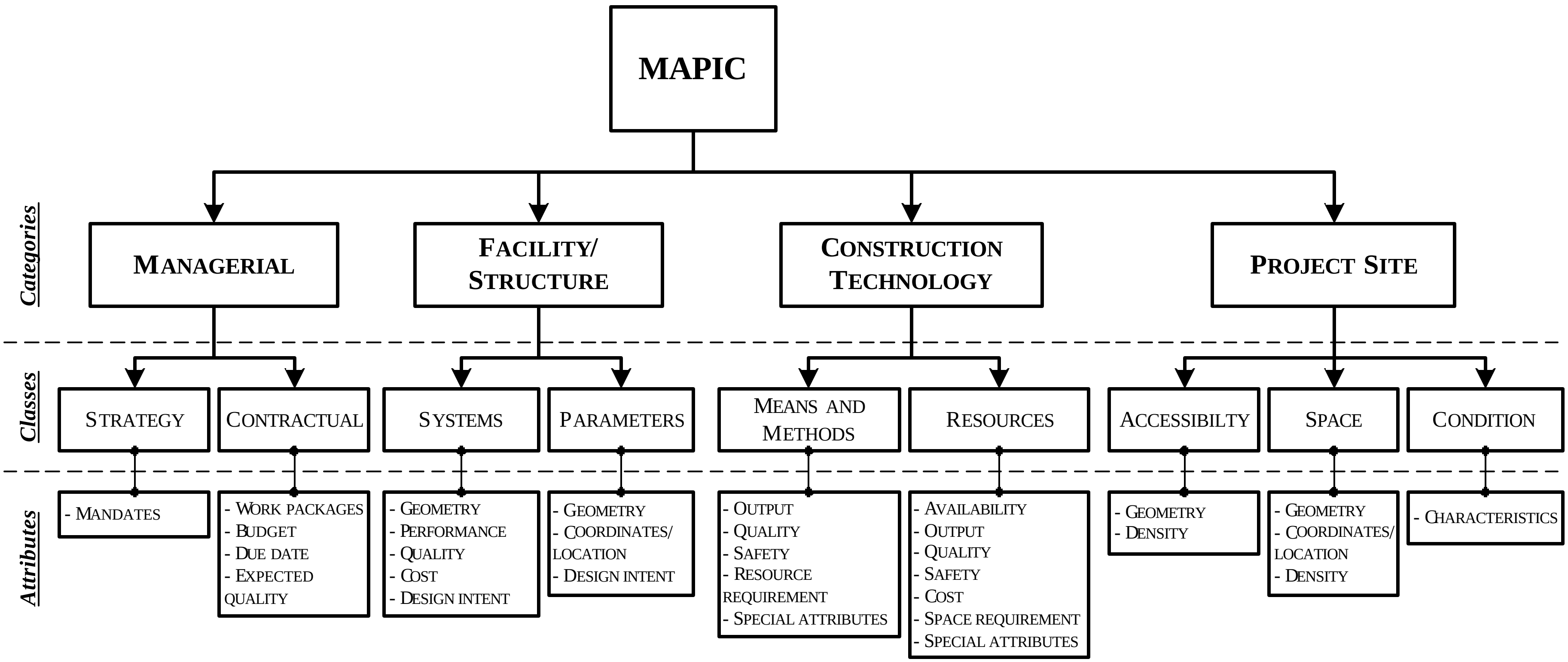


Figure 4-1: The Macro Planning Information Classification (MAPIC) model

4.3 MAPIC DESCRIPTION

This section presents a detailed description of the MAPIC model. Each category is presented along with its classes, subclasses, and attributes.

4.3.1 "MANAGERIAL" CATEGORY

This category includes information on managerial issues related to the execution of the project. This information is divided into two major classes (Figure 4-2): a "STRATEGY" class and a "CONTRACT" class.

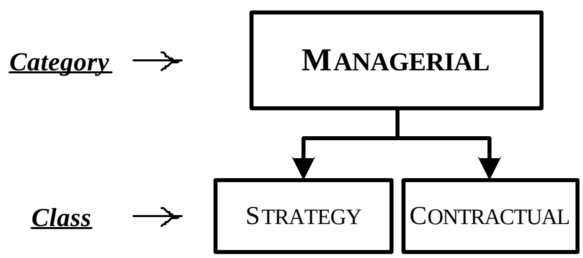


Figure 4-2: The "MANAGERIAL" Category

4.3.1.1 Class "STRATEGY"

This class carries information on the company strategies and programs that must be considered during macro planning. As shown in Figure 4-3, this class is further divided into various subclasses: "*Risk Analysis program*", "*Safety program*", "*Quality Control system*", "*Cost Control system*", "*Value Engineering program*", and "*Constructability program*". Each subclass includes one of the company's programs/strategies. There is one attribute for this class: "*MANDATES*". This attribute presents the requirements of each subclass. This information assists the project team in adequately making major decisions for project implementation while satisfying the company's strategies. The project team usually acquires this information through training sessions as well as the company's program brochures.

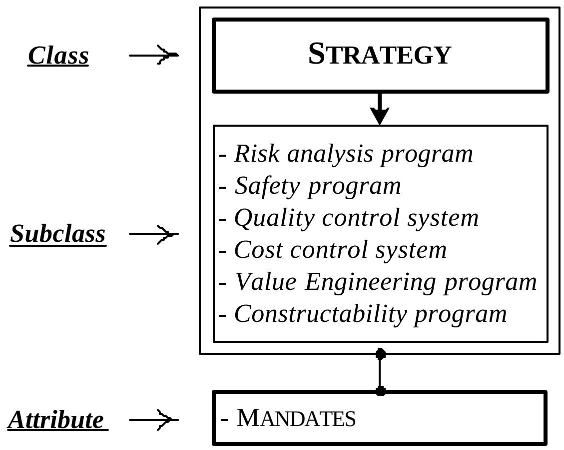


Figure 4-3: Subclasses and attributes of the "STRATEGY" Class

The subclasses and the attribute of the "STRATEGY" class are described in this section.

1. Risk Analysis Program

Risk analysis is a comprehensive approach to handling exposure to risk. The project team should be aware of the risk analysis strategy that the company is applying. This information enables the project team to recognize and identify the various risks that apply to the construction process. These risks may include external unpredictable (e.g. natural hazards), external predictable uncertain (e.g. social and environmental impact), internal non-technical (e.g. schedule delays and cost overruns), technical (e.g. changes in technology), and legal (e.g. licenses and lawsuits). During macro planning, the project team has to consider the logic flowchart for risk decisions developed by the executive management to make a "go/no-go" decision on risk assumption (Clough and Sears, 1996).

2. Safety Program

Construction work, by nature, is hazardous and accidents are frequent and often severe. The fatality rate of construction workers is among the highest of all American industries (Clough and Sears, 1996). Therefore, during macro planning, in addition to the safety and health standards developed by the Occupational Safety and Health Act (OSHA), the project team should review and apply the company's safety program, which may include additional regulations, in order to help minimize these accidents. The contract should also contain provisions that require the constructor to conform to all applicable law, ordinances, rules, and regulations that pertain to project safety. A comprehensive safety program is an important attribute of a risk management program.

3. Quality control system

The project team should consider the company's quality control system that ensures the accomplishment of the construction work in accordance with the requirements specified in the contract. During macro planning, the project team should consider the company's standards and criteria for construction performance, usually specified through the plans and specifications. The standards help the project team in developing a macro plan that meets the company's expected performance. The criteria will help the inspector (Architect/Engineer, owner's consultant, or construction manager) responsible for the quality control of materials, workmanship, and methods to ensure that the work conforms to the company's standards.

4. Cost control system

Project cost control is a company information system designed to assist the project team in controlling construction costs. This monitoring process provides feedback to the management concerning project expenses and how they compare to the project budget. Knowing in advance the criteria for evaluating the actual cost of construction, this information will assist the project team in developing a feasible project budget.

5. Value Engineering Program

The company's value engineering program contains incentive information that helps the project team in reducing the required construction time and life-cycle cost of a project without sacrificing its value. This information assists the project team in considering maximum economy and value in the selection and use of construction materials and methods within the limits dictated by the design. These decisions will lead to the accomplishment of the project at less cost with the same or even better quality.

6. Constructability Program

A constructability program aims to assist the project team in applying systematic optimization of the construction-related aspects of a project throughout its life. During macro planning, the project team should have thorough understanding of the company's constructability program. This may affect major decisions such as the selection of systems and methods.

- ***Attribute "MANDATES"***

The "STRATEGY" class includes one attribute – "*MANDATES*". This attribute presents the requirements of the different company strategies. Each strategy/program requires, prevents, or recommends the use of specific materials, methods, resources, … etc. For example, the Risk Analysis program may require the project team to perform an adequate subsurface exploration and interpretation of the data before committing to a contract. The Safety program may prevent the project team from using specific materials (e.g. asbestos) due to their hazardous effect on the workers. The Value Engineering program may require the project team the use of alternate materials to decrease the project cost. The constructability program may recommend the use of flying forms for all buildings more than six stories high.

4.3.1.2 Class "CONTRACTUAL"

This class accommodates contractual information required during macro planning. This information mainly describes the company's commitment to the owner. This information is essential as it enables the project team to make the appropriate decisions to meet or exceed the owner expectations. It also allows the project team to avoid potential legal problems and disputes.

As shown in Figure 4-4, this class is further divided into different subclasses according to the contract type. Information on the contract type is critical for its ability to address project risk. These subclasses are "*Lump Sum*", "*Unit Price*", and "*Cost-plus-fee*".

This class includes four attributes: "*WORK PACKAGES*", "*BUDGET*", "*DUE DATE*", and "*EXPECTED QUALITY*".

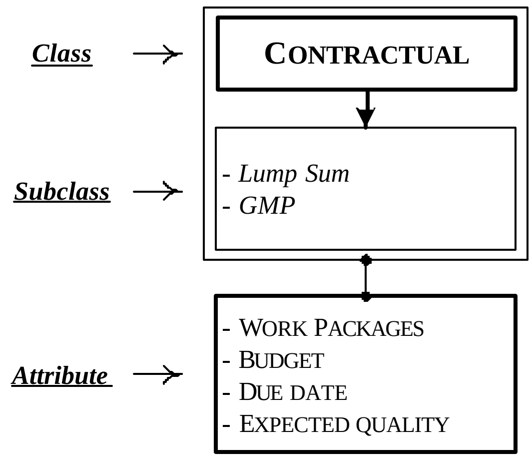


Figure 4-4: Subclasses and attributes of the "CONTRACTUAL" Class

The subclasses and attributes of the "CONTRACTUAL" class are described in this section.

1. Lump Sum

In lump Sum (also called; single fixed price) contracts, the contractor provides a specified amount of work for a specific sum. This type is not usually used in design-build projects since the project scope must be clearly defined and a complete set of contract documents has to be prepared before the contractor can bid the project.

2. Guaranteed Maximum Price (GMP)

In Guaranteed Maximum Price (GMP) contracts the contractor is reimbursed at cost with an agreed-upon fee up to the GMP. Beyond this point the contractor is responsible for covering any additional costs within the original project scope.

- ***Attribute "WORK PACKAGES"***

A work package (also called bid package) is the organizational tool used to breakdown the construction project (Gould, 1997). The work package contains all the information necessary to describe the work that needs to be performed. Work packages should be established so that they can be easily priced and scheduled according to the way the trade contractors in the local region are organized. The scope of an appropriate work package breakdown allows the project team to coordinate and budget complicated construction projects. This information enables the project team to know exactly the scope of the work required.

- ***Attribute "BUDGET"***

The project team should have pertinent information on the budget allocated for the job. This information enables the project team to make appropriate decisions during macro planning for accomplishing the project within budget. The project team must especially consider the equipment budget. The budget is usually prepared in terms of the total estimated work quantity, unit cost of labor and/or equipment, and total labor and/or equipment cost for each work cost code involved in the job.

- ***Attribute "DUE DATE"***

Information on the contract due date enables the project team to make appropriate decisions during macro planning for accomplishing the project on time. The project due date indicates the day when the project (or work package) must be submitted to the owner. This information affects the project team's selection of methods and resources. The project team should ensure that the methods selected and resources allocated will be able to accomplish the job by the due date.

- ***Attribute "EXPECTED QUALITY"***

The project team has to know the expected quality of the work. This information is usually acquired through the drawings and specifications requirements. This information describes the product (and not the process) that the company has committed to deliver to the owner. During macro planning, the project team has to make appropriate decisions that lead to the implementation of the work according to the expected quality stated in the contract.

4.3.2 "FACILITY/STRUCTURE" CATEGORY

This category accommodates information on the facility to be built. Major decisions made for work execution planning depends directly on this category's information. The project team has to study this information thoroughly to be able to select appropriate methods, allocates primary resources, and decides on the adequate sequence of major assemblies.

This category includes two classes (Figure 4-5): the "SYSTEMS" class and the "PARAMETERS" class. Each class is presented in this section.

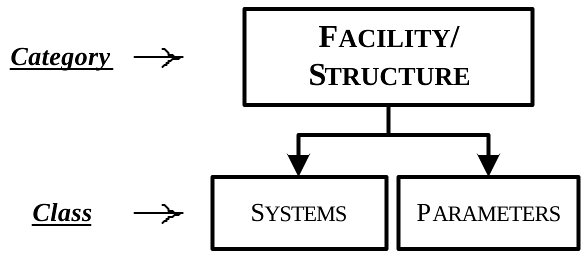


Figure 4-5: The "FACILITY/STRUCTURE" Category

4.3.2.1 Class "SYSTEMS"

This class carries information on major systems that may be utilized in the facility/structure. The project team should have pertinent understanding of the different systems to be able to make the appropriate decisions and plan for the execution of these systems. Systems that should be considered during macro planning include "*Substructure/Foundations*", "*Superstructure*", "*Exterior Closure*", "*Interior Closure*", "*Mechanical*", and "*Electrical*". As shown in Figure 4-6, these systems presents the subclasses of this class. For each of these subclasses, information on "*GEOMETRY*", "*PERFORMANCE*", "*QUALITY*", "*COST*" and "*DESIGN INTENT*" is required during macro planning.

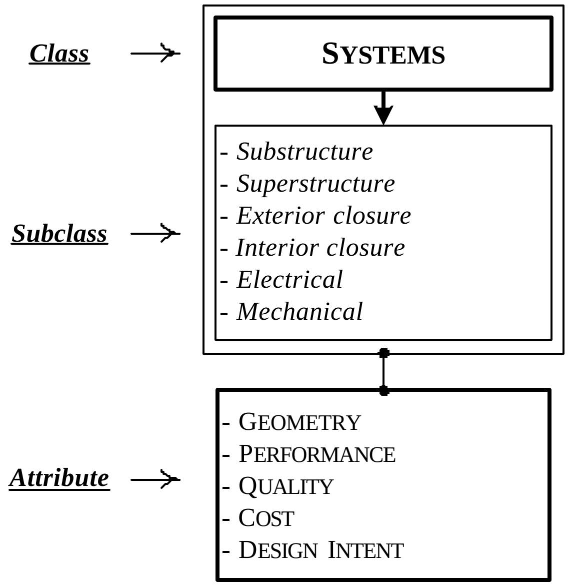


Figure 4-6: Subclasses and attributes of the "SYSTEMS" Class

Each of these subclasses may be further divided into more detailed systems. For example the "*Superstructure*" system may be divided into frame systems, floor systems, roof systems (Figure 4-7). Furthermore, each of these systems has different types. For example, the floor system may be a one-way solid floor system, a two-way flat plate floor system, a two-way solid flat floor system, a one-way joist floor system, a two-way joist (waffle) floor system. Information on the type of each system is crucial for decision making. This information is usually available in the design drawings and the project specifications. The type of the system directly impacts major decisions such as means and methods selection, resources allocation, and assemblies sequencing.

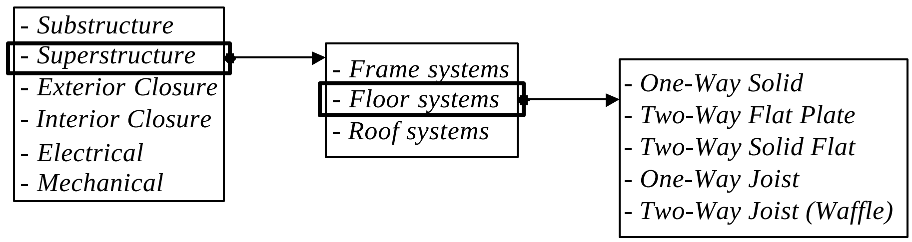


Figure 4-7: Possible hierarchy of the "*Superstructure*" subclass

The subclasses and attributes of the "SYSTEMS" class are described in this section.

1. Substructures/Foundations

The substructure is that part of the building that is below the natural or artificial ground level, and that supports the superstructure. The foundation is that part of the building that transmits the superimposed load of the building to the supporting soils (Andres and Smith, 1998). There exist four major types of foundations: Isolated, Strip, Raft, and Pile.

2. Superstructure

The superstructure of the facility is that part of the building that is above the natural or artificial ground level. As stated earlier, the superstructure consists of frame systems, floor systems, and roof systems. Each of these systems may be further divided based on the material used for its execution. Materials used for the implementation of superstructure systems are timber, concrete, steel, or composite. Thorough and pertinent information of the superstructure system enable the project team to select the appropriate method for the execution of this system.

3. Exterior Closure

Information on exterior closure has to be considered during macro planning. The project team has to review the system selected and check that it is resistant to the effects of various elements. For example, colors must be resistant to fading, materials must be resistant to air pollution and rain penetration, as well as the effects of extreme temperature changes. Different materials and systems are used for exterior closure such as polished stones, clay brick, wood, cast in place concrete, precast concrete panels, and others.

4. Electrical Systems

Information on electrical systems is essential especially in some types of facilities such as industrial plants, which are machine and production oriented. A complete listing of the utilization equipment that is to be supplied by the system must be readily available. This enable the project team to review the adequacy of the system to deliver sufficient electrical energy of the correct frequency, phase relationships, and voltages to each piece of utilization equipment under normal continuous load conditions. This information also enable the project team the protection of the system to minimize power outages and damage in the event of prolonged overloading or insulation breakdowns.

5. Mechanical Systems

Information on mechanical systems should be collected as early as possible during macro planning due to their impact on some major design and construction decisions such as floor systems, floor heights, and others. Examples of mechanical systems include water systems, sewage disposable systems, storm drainage systems, plumbing systems, heating, cooling, and ventilation systems.

- ***Attribute "GEOMETRY"***

This attribute includes information on the geometrical properties for each system. Geometrical properties include dimensions (length, width, and height/thickness), elevation/position, …etc. This information is extracted from the design drawings. This information is required for various decisions such as estimating quantities of major materials required for the execution of the system.

- ***Attribute "PERFORMANCE"***

The performance of each system is a valuable information that affects different decisions during macro planning. The information content in this attribute varies based on the system (e.g. mechanical vs. superstructure). For example, for a mechanical system, the performance of a machine is presented by its output in horsepower. On the other hand, for a superstructure system (e.g. floor system), the performance is presented by the maximum allowable superimposed load or the maximum allowable span. This information is extracted from the project specifications as well as the general construction knowledge. This information enables the project team to implement the system (e.g. floor system) that conforms to this criterion (i.e. performance)

- ***Attribute "QUALITY"***

The quality of systems has a great effect on the decisions made during macro planning. The implementation of a high quality system requires special methods and/or resources that should be thoroughly considered. During constructability review, the project team has to know the quality of the system so that any modification done to the system does not affect its quality. The quality of each system should meet or exceed the expected quality agreed upon in the contract. Otherwise, purpose should be clearly stated.

- ***Attribute "COST"***

Although this information won't affect work execution and/or site layout planning decisions, it is crucial for constructability review. The project team has to review the cost of the systems to assure that they adhere with the budget.

- ***Attribute "DESIGN INTENT"***

The description of systems' type, geometry, quality, and performance is usually provided by the design team through the drawings and specifications. The "DESIGN INTENT" attribute presents the reasons in favor of a given design description as well as the rationale against other plausible design possibilities.

The project team has to understand the design intent of the system in order to be able to make appropriate decisions for its execution. This is particularly true if the project team would like to make any modifications to the system (e.g. change the floor system type from a two-way joist floor system to a two-way solid flat floor system). The understanding of the design intent allows the project team to make appropriate modifications that, for example, improve the project constructability while satisfying the project constraints, requirements, as well as the designer preferences.

4.3.2.2 Class "PARAMETERS"

This class carries information on the physical properties whose values determine the characteristics or behavior of the facility. This information is typically extracted from the design drawings. This class is divided into two subclasses: "*Exterior*", and "*Interior*". Attributes of this class include "*GEOMETRY*", "*COORDINATES/LOCATION*", "*SPATIAL*", and "*DESIGN INTENT*" (Figure 4-8).

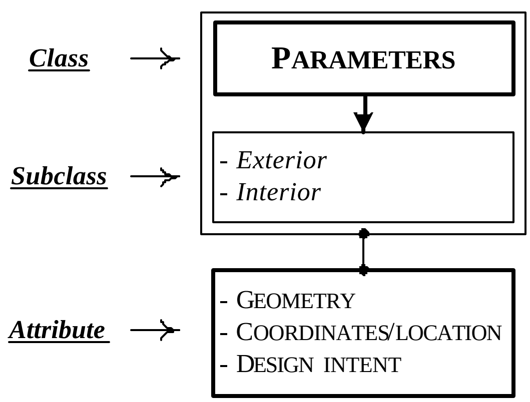


Figure 4-8: Subclasses and attributes of the "PARAMETERS" Class

The subclasses and attributes of the "PARAMETERS" class are described in this section.

1. Exterior

Information on design parameters of the facility exterior includes the physical properties (e.g. shape and form) of the facility as a whole. Information in this subclass may include information from various systems. For example, the shape of the facility depends on the shape/geometry of the superstructure and the exterior closure systems. An exterior perspective of the facility would best assist in visualizing this information.

2. Interior

This subclass carries information on the interior arrangement of the facility spaces. This includes spaces surrounded by the interior closure systems. Information in this subclass assists the project team in understanding the interior pattern of the facility.

- ***Attribute "GEOMETRY"***

Information on the geometrical properties of the facility includes various characteristics such as height, width, and length of the entire structure (in the case of exterior parameters) or of the interior space (in the case of interior parameters). This information is required for several purposes. For example, the total height of the structure implies the use of specific equipment that will be able to perform the job. When placing concrete for multi-story buildings, the use of pump may, then, be impractical for the top floors. Also the geometry of the interior spaces of the facility enables the project team to acquire the available spaces for resources that need to operate from inside the facility.

- ***Attribute "COORDINATES/LOCATION"***

This attribute carries information on the exact location of the facility as a whole, as well as the facility's interior spaces. Information on the x, y, z coordinates of the facility enables the project team to determine the position of the facility on site. Also coordinates of interior spaces enables the project team to acquire its location relative to the facility.

- ***Attribute "DESIGN INTENT"***

The "DESIGN INTENT" attribute presents the reasons in favor of a given exterior and/or interior parameter. For example, the intent of choosing a specific clearance for the typical floor should be well understood by the project team. This information enables the project team to make appropriate decisions during macro planning. In this situation, knowing why the design team has selected the floor clearance specified in the drawings will allow the project team to select, for example, the appropriate HVAC system that satisfies this design intent. Also this information is crucial if the project team has to make any design modification.

4.3.3 "CONSTRUCTION TECHNOLOGY" CATEGORY

Advanced construction technologies have emerged over the past few decades and have led to the evolution of innovative construction methods and their associated resources. Having a thorough knowledge about the construction technologies available for the execution of different operations allows the project team to select the most appropriate methods and allocate the adequate resources for the accomplishment of the project.

This category will accommodate information on the various construction technologies for the execution of construction operations. The category consists of two classes (Figure 4-9): "MEANS AND METHODS" and "RESOURCES".

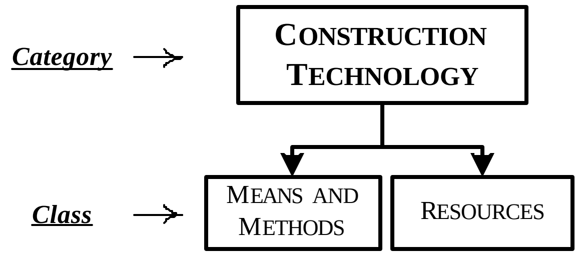


Figure 4-9: The "CONSTRUCTION TECHNOLOGY" class

4.3.3.1 Class "MEANS AND METHODS"

This class consists of information on major means and methods required for the execution of different systems and assemblies. Thorough information on various means and methods should be readily available. The project team extracts the required information from the general construction databases (e.g. RS Means), the company databases, as well as his own knowledge and experience.

There exist different methods for the implementation of various systems. These methods depend directly on the system to be executed (e.g. mechanical, electrical, superstructure). For example, for mechanical systems, the method that is considered during macro planning is the means for system installation. For superstructures, the potential methods for the execution of each system type mainly depends on the characteristics of the system as well as the material used for its execution (e.g. steel superstructure vs. cast-in-place concrete superstructure). For steel superstructures, the project team considers methods of erection that may be utilized. For cast-in-place concrete superstructures, methods to be considered are those for concrete placement.

This class may be divided into several subclasses presenting major methods utilized in the construction industry. Subclasses discussed here are "*Earth Moving*", "*Concrete Placement*", "*Material Handling*", "*Pile driving*", and "*Rock drilling*". Attributes of this class include "*OUTPUT*", "*QUALITY*", "*SAFETY*", "*RESOURCE REQUIREMENT*", and "*SPECIAL ATTRIBUTES*" (Figure 4-10).

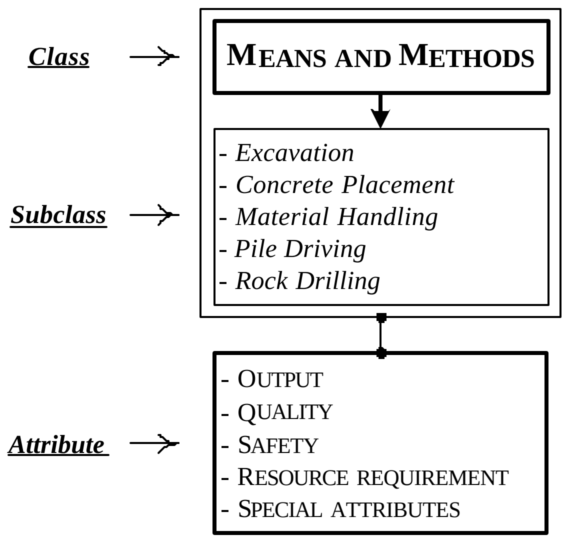


Figure 4-10: Subclasses and attributes of the "MEANS AND METHODS" Class

Each of these subclasses may be further divided into more detailed methods. For example the "*Concrete Placement*" subclass may be divided into Belt Conveying, Pumping, Buggies, Buckets, Droppies (Figure 4-11).

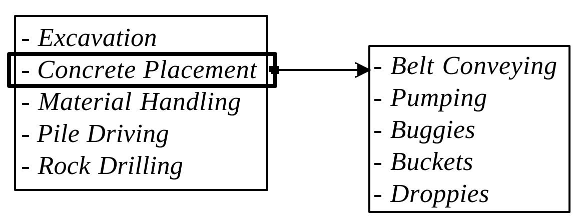


Figure 4-11 Possible hierarchy of the "MEANS AND METHODS" Class

The subclasses and attributes of the "MEANS AND METHODS" class are described in this section.

1. Excavation

This subclass accommodates information on the methods used for excavation. Excavation methods vary widely according to the equipment utilized. Equipment utilized for excavation includes bulldozers and graders, loaders, scrapers, hydraulic excavators, backhoes, as well as cranes with dragline or clamshells attached to its boom. A number of factors must be considered when selecting the appropriate method for excavation. These factors include the type of soil to be excavated, the volume of material to be removed, the depth of excavation, the disposal of the excavated material, and the distance from excavation and spoil bank.

2. Concrete Placement

Concrete placement is one of the major operations in the execution of cast-in-place concrete structures. Concrete must be placed as nearly as possible in its final position. It should not be placed in large quantities in one position and allowed to flow or be worked over a long distance in the form (Andres and Smith, 1998). That's why it is crucial to select the appropriate method for concrete placement.

3. Material Handling

Material handling methods are almost always used in the construction site (e.g. handling steel members, bricks, reinforced steel, …etc). The appropriate method to handle materials depends mainly on two material considerations: the total quantity of material and the size of the individual pieces. The quantity of material and the time constraints influence the selection of equipment as to the type, size, and number of machines. Larger units generally have lower unit-production cost, but there is a trade-off higher mobilization and fixed costs.

4. Pile Driving

Piles are driven into the ground by means of a pile driver striking the pile head. Pile drivers may consist of a drop, mechanical, or vibratory hammer. A drop hammer is the simplest type of machine, consisting of a heavy weight, lifted by a cable and guided by leads, which is allowed to drop freely on the pile head. The hammer of a mechanical driver operates like a piston actuated by steam, compressed air, or the internal combustion of diesel fuel. A vibratory hammer is secured to the head of a pile and operates by delivering vibrations to the pile head in up-and-down cycles.

5. Rock Drilling

This subclass will carry information on the methods used to drill holes in rock. Because the purposes for which drilling is performed vary a great deal from general to highly specialized applications, it is desirable to select the method that is best suited to the specific service. Factors affecting the method selection include the nature of the terrain, the required depth of holes, the hardness of rock, the extent to which the formation is broken or fractured, the size of the project, the availability of water for drilling purposes, and the size of cores required for exploration.

- ***Attribute "OUTPUT"***

This attribute accommodates information on the maximum output (also called productivity) that can be achieved through the utilization of this method. Regardless of the resource utilized, each method has its own capabilities and capacities based on its type. The maximum output denotes the maximum amount of work (e.g. cu. yd.) that may be accomplished in a specific time frame (e.g. hr.). For example, the maximum output of the "*concrete pumping*" method is 260 cu-yd/hr (200 cu-m/hr). This value represents the maximum productivity that a concrete pump can achieve.

- ***Attribute "QUALITY"***

This attribute will carry the degree of excellence that a method can achieve. For example, for a specific project, the owner's requirement may be a specific degree of quality for the concrete. This quality can be only achieved through some of the concrete placement methods. Information in this attribute may be presented through a specific weight (e.g. 9, or good, …etc) for each method.

- ***Attribute "SAFETY"***

The "*SAFETY*" attribute presents the likelihood of being injured if utilizing this method. In addition, this attribute will accommodate information on the safety codes related to methods utilization. Some methods may be safer to use than others. The information in this attribute should be carefully considered during the selection of the methods.

- ***Attribute "RESOURCES REQUIREMENT"***

Each method requires the use of specific types of resources. During macro planning, major equipment is the primary resource that is considered when selecting a method for work execution. Information on the equipment required for each method allows the project team to consider this equipment while selecting the method. For example, the "*concrete pumping*" method requires not only a pump as equipment, but also a ready-mix truck to deliver pumpable concrete.

- ***"SPECIAL ATTRIBUTES"***

Beside the attributes presented above, each method may have exclusive characteristic that needs to be considered during method selection. As shown in Figure 4-12, special attributes for the "*Concrete Pumping*" method, for example, are "*Boom sections*", "*Vertical reach*", "*Horizontal reach*", and "*Reach depth*". The concrete pumping methods has pumps with maximum boom sections of 5, a maximum vertical reach of 180-ft (55m), a maximum horizontal reach of 167-ft (50m), and a maximum reach depth of 135-ft (41m) (Putzmeister manuals). Due to the diversity of methods available for different construction operations, attributes that are exclusive for each method are presented in MAPIC as "SPECIAL ATTRIBUTES".

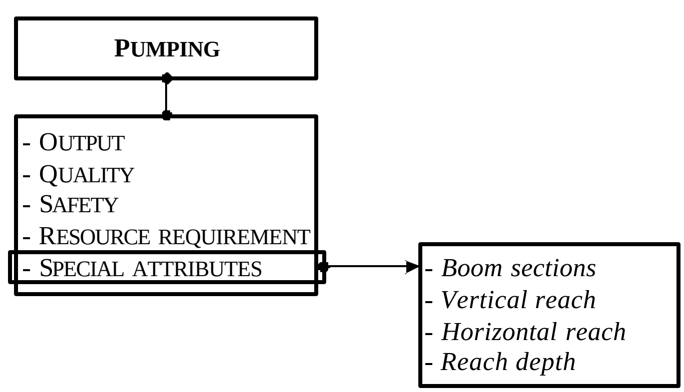


Figure 4-12: Special attributes of the "*Concrete Pumping*" method

4.3.3.2 Class "RESOURCES"

This class accommodates information on major resources required for the execution of the project. Pertinent information on the resources allocated is extremely significant due to the direct relation between the resource utilized and the project cost, duration, and quality. Information on major resources may be extracted from the company databases and/or the general construction databases (e.g. RS Means).

Different categories of resources exist including labor, equipment, material, and others. However, the main resource that is usually considered during macro planning is the equipment. The "Resources" Class may then be divided into several subclasses that present various sets of equipment. Subclasses discussed here are "*Excavator*", "*Crane*", "*Scraper*", "*Tractor*", and "*Concrete Pump*". Attributes of this class include "*AVAILABILITY*", "*OUTPUT*", "*QUALITY*", "*SAFETY*", "*COST*", "*SPACE REQUIREMENT*", and "*SPECIAL ATTRIBUTES*" (Figure 4-13)

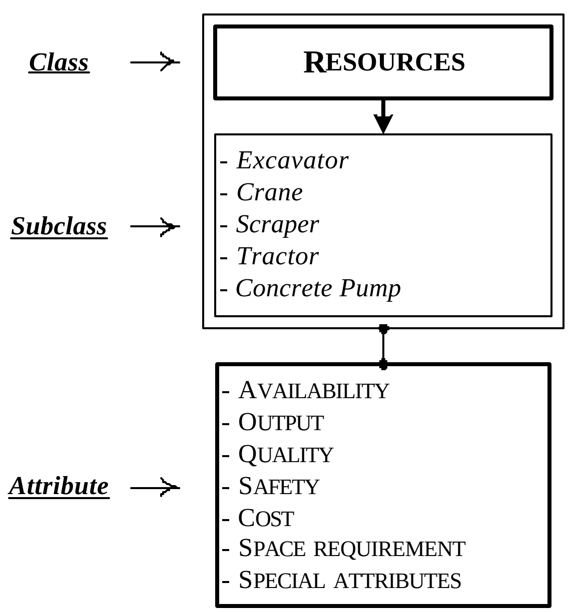


Figure 4-13: Subclasses and attributes of the "RESOURCES" Class

Each subclass (i.e. set of equipment) contains various equipment types. Each subclass may then be divided into more detailed subclasses according to the equipment types it accommodates. For example, the "*Crane*" subclass includes various types of cranes that share the same attributes with the "RESOURCES" class. This subclass may then be divided into as *tower crane*, *crawler crane*, *hydraulic truck*, *lattice-boom truck*, *rough-terrain*, and *all-terrain crane* subclasses (Figure 4-14).

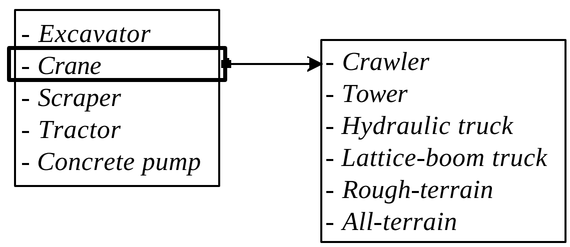


Figure 4-14: Possible hierarchy of the "RESOURCES" Class

The subclasses and attributes of the "RESOURCES" class are described in this section.

1. Excavator

This subclass will accommodate information on equipment utilized to excavate earth and rock in construction operations. It maybe then divided into more detailed subclasses according to the equipment set. This includes draglines, clamshells, hydraulic excavators, loaders, and trenching machines. Each of these subclasses includes various types. For example, draglines may be categorized as crawler-mounted, wheel-mounted self-propelled, and truck mounted. In addition, some of these machines may be further divided into more detailed subclasses. For example, hydraulic excavators may be divided into shovels and hoes, and loaders may be divided into wheel and track.

2. Crane

This subclass will carry information on cranes, which are a broad collection of construction equipment used to hoist and place loads. Cranes are almost always required on a construction site. As mentioned earlier, this subclass is divided into more detailed subclasses that present the various types of cranes available. Tower cranes, for example, are mandatory to perform various operations especially when site conditions are restrictive, lift height and reach are extreme, and there is no need for mobility. This type of cranes provides a high-lifting height with good working radius, and takes up limited place. The utilization of tower cranes requires considerable planning because the crane is fixed for the duration of the operations. Therefore, the project team must ensure that the tower crane will be able to reach all points from which loads are to be lifted and the locations where the loads must be placed. Also the project team must ensure that the weight of the loads can be handled at their corresponding required radius. This information is usually available in the manufacturer brochures.

3. Scraper

This subclass carries information on tractor-pulled scrapers. This equipment is designed to load, haul, and dump loose material. Scrapers are primarily classified according to the number of powered axles or by the method of loading. Therefore, this subclass may be further divided into more detailed subclasses according to the machines currently available. This includes push-loaded (single-powered axle and tandem-powered axle), push-pull, tandem-powered axles, and elevating.

4. Tractor

This subclass may include information on tractors, which are self-contained units that are designed to provide tractive power for drawbar work. Tractors are classified on the basis of running gear. They may be then divided into crawler type and wheel (single-axle, two-axle) type.

Bulldozers are considered tractor units that have a blade attached to their front.

5. Concrete Pump

This subclass will accommodate information on concrete pumps utilized for concrete placement. One fourth of all concrete in the United States is placed through pumping due to its high productivity. This subclass may be further divided into more detailed subclasses based on the type of the pump. This includes piston pumps, pneumatic pumps, and squeeze pressure pumps.

- ***Attribute "AVAILABILITY"***

This attribute presents information on the availability of resources. Different levels of availability may be considered. This is illustrated in the following cases.

Case 1: The resource is available in the company's backyard during the required time frame.

Case 2: The resource is available in the company backyard but not in the required time frame.

Case 3: The resource is not available in the company backyard but is available in the local area and may be hired/rented.

Case 4: The resource is neither available in the company backyard nor in the local area.

Information on the availability of resources is crucial during macro planning, as it is a major determinant in the potentiality of allocating this resource for the project.

- ***Attribute "OUTPUT"***

This attribute will include the output that the equipment may achieve in a specific time frame under normal conditions. Information on resources productivity may be extracted from general construction knowledge (e.g. RS Means and Richardson). However, these databases present an average productivity rate. Each company should customize its database to reflect the practical productivity of its own resources. The productivity may be different due to several reasons such as weather.

- ***Attribute "QUALITY"***

This attribute will carry the degree of excellence that equipment can achieve. For example, concrete pumps may place concrete that has better quality than chutes. Information in this attribute may be presented through a specific weight (e.g. 9, or good, …etc) for each piece of equipment.

- ***Attribute "SAFETY"***

Some equipment (e.g. electric saw) may require particular precautions during its utilization. The "*SAFETY*" attribute presents the likelihood of being injured if utilizing this equipment. In addition, this attribute will accommodate information on the safety codes related to the equipment utilization.

- ***Attribute "COST"***

The cost of equipment has a major influence on the total cost of the project. Therefore the equipment cost, among others, is a determinant factor during resources allocation process. The cost of the equipment may include the cost of purchasing or hiring/renting, operation, maintenance, insurance, depreciation, … etc. This information depends also to a great extent on the geographic location of the project.

- ***Attribute "SPACE REQUIREMENT"***

This attribute accommodates information on the space required for each piece of equipment. This information is essential during site layout planning. Knowing the space required for the allocated equipment allows the project team to check for space availability for this piece of equipment.

- ***"SPECIAL ATTRIBUTES"***

Beside the attributes presented above, each piece of equipment may have exclusive characteristic that needs to be considered during resources allocation. As shown in Figure 4-15, special attributes for the "*Crane*" subclass, for example, are "*maximum hook height*", "*maximum lifting capacity*", and "*maximum working radius*". On the other hand, special attributes for draglines are "*swing angles*", "*size and type of bucket*", and "*length of boom*". Due to the diversity of equipment utilized for different construction operations, attributes that are exclusive for each equipment are presented in MAPIC as "SPECIAL ATTRIBUTES".

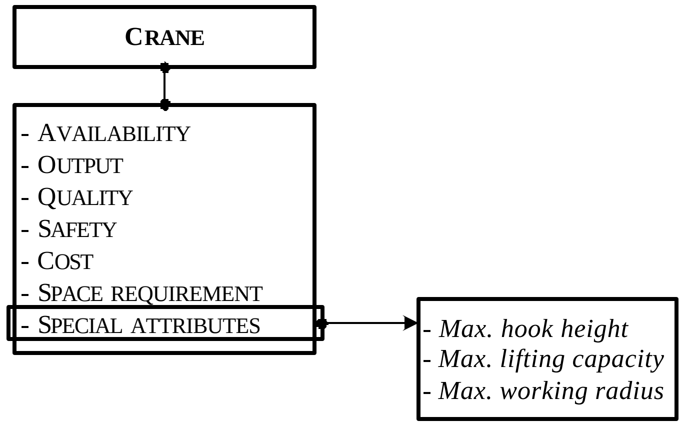


Figure 4-15: Special attributes of the "*Crane*" subclass

4.3.4 "PROJECT SITE" CATEGORY

This category accommodates information on the construction site where the facility/structure is to be implemented. Each site has its own characteristics. Gathering thorough information about the site, as early as possible, is essential. This information affects major decisions regarding the execution of the project.

This category is divided into three classes (Figure 4-16): "ACCESSIBILITY", "SPACE", and "CONDITION".

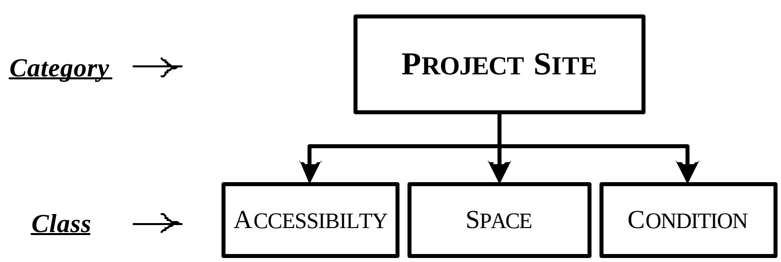


Figure 4-16: The "PROJECT SITE" Category

4.3.4.1 Class "ACCESSIBILITY"

Site accessibility is a major factor that influences different decisions during macro planning. Accessibility conflicts may lead to several problems such as delays and damage to completed work. This class consists of information required to assist the project team in preventing accessibility problems that may occur during construction. This information may be extracted from local work jurisdiction, the drawings, and the project site.

As shown in Figure 4-17, this class is further divided into various subclasses: "*Work Paths*", "*Access roads to site*", and "*Right-of-way*". For each of these subclasses, information on "*GEOMETRY*", "*COORDINATES/LOCATION*", and "*DENSITY*" is required during macro planning.

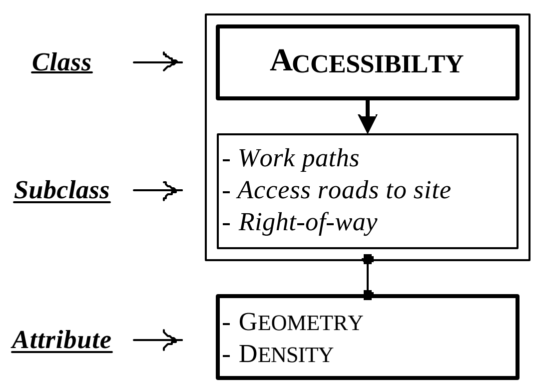


Figure 4-17: Subclasses and attributes of the "ACCESSIBILITY" Class

The subclasses and attributes of the "ACCESSIBILITY" class are described in this section.

1. Work Paths

This subclass will carry information on the work paths available in the project site. During macro planning, the project team has to ensure that there are pertinent paths between the different work areas, materials delivery spaces, and equipment entrance to the site. Materials and equipment have to be able to reach the desired location when needed. Trucks transporting the materials should have easy access to the designated work area. The project team should ensure that workers will have the material where needed on time. Equipment should be located in places where it can easily perform the required operations without interference (i.e. clear path between equipment and work area). This information is essential especially for equipment such as cranes, concrete pumps, etc.

2. Access roads to site

Projects on tight urban areas and where road capacity is limited are likely to confront problems due to the surrounding access roads to the site. Information on the surrounding access roads (maximum width, maximum height, regulations, etc.) to the site should be collected as they may fix the size of equipment that can be brought to the site. In addition, information on the condition of the surrounding access roads (e.g. type of soil) to the site should be gathered as they may limit the type of equipment that can be brought to the site. This is typically the case when constructing projects in the desert of Egypt where the sand is really dense, which prevents some semi trucks, carrying other equipment, to reach the site.

3. Right-of-way

Information on right-of-way is required early during project development. Limited right-of-way may limit the operability/maneuverability of some equipment. This information is essential specifically for roadway rehabilitation projects (Russell, 1991).

- ***Attribute "GEOMETRY"***

The size of paths required for accessibility is clearly a critical attribute during site planning. This attribute will accommodate information on the geometrical properties (height, width, and length) of the required and available space for each path (e.g. work paths and surrounding roads). The size of work paths required and available for accessibility present a constraint during site planning that may affect the sequence of major operations, as well as the methods and resources utilized. Also, the size of space available for accessibility from the surrounding roads present a constraint that directly affect the methods and resources selection process.

- ***Attribute "DENSITY"***

This attribute includes information about the density of the required space for the different paths. This information describes the ability of a path to share a portion or all of its physical space with other path or space concurrently. For example, the work path between a concrete pump and the location where the concrete is being placed may be described as dense because this path can not be interfered throughout the length of the operation. On the other hand, the path between the storage and work areas may have less density as it may be partially interfered.

4.3.4.2 Class "SPACE"

This class presents information on space available for major operations and equipment. This information enables the project team to appropriately perform site planning while preventing space conflicts that may occur during construction. Information on space availability is acquired from the drawings and the project site.

There exist different description for space based on the activity/item that requires this space. This class may then be divided into subclasses according to this description. This includes "*laydown and fabrication*", "*storage*", "*material delivery*", "*temporary facilities*", and "*temporary structures*" (Figure 4-18). Attributes of this class are "*GEOMETRY*", "*COORDINATES/LOCATION*", and "*DENSITY*".

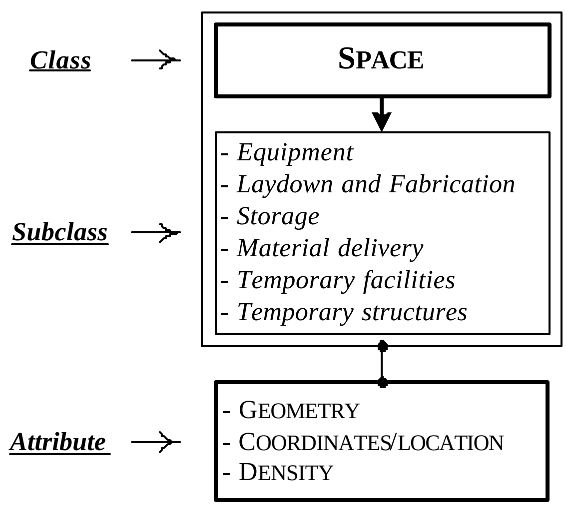


Figure 4-18: Subclasses and attributes of the "SPACE" Class

The subclasses and attributes of the "SPACE" class are described in this section.

1. Equipment

Locating major equipment is a major decision during site layout planning. This subclass will carry information on the available space on site that may accommodate major equipment. This space should not interfere with other spaces presented hereafter (e.g. laydown and fabrication). This space should also not interfere with the work paths identified for various operations.

2. Laydown and fabrication

Adequate space for laydown and fabrication should be considered during macro planning. This information may have an influence on the major systems, and means and methods selected. If space for laydown and fabrication is limited the project team may, for example, select to utilize precast concrete vs. cast-in-place concrete.

3. Storage

Space is required to store different materials and elements required for the execution of the project. The project team should plan for storage space adequately. Easy access and security for these spaces must be considered. The type of material to be stored affects the storage requirement. For example, in case of storing cement, the project team should plan for indoor/covered storage to protect the cement from severe weather conditions. On the other hand, the storage of precast concrete members won't demand such a requirement.

4. Material Delivery

Trucks transporting material to the site should find sufficient space for material delivery. Whether this material will be stored or consumed immediately, the project team should plan the appropriate location for material delivery and ensures that the space is enough for truck maneuverability.

5. Temporary facilities

Temporary facilities include trailers for temporary offices, parking, …etc. This information enables the project team to perform adequate site planning. Information on required temporary facilities has to be considered especially during the selection of major equipment and during locating this equipment on site.

6. Temporary structures

This attribute includes information of space required and space available for temporary structures. Example of a temporary structure that is usually considered during macro planning, and that requires space is scaffolding. This information may affect the selection of major means and methods. For example, the project team may select the use of pre-cast concrete, if the space required for formwork support for cast-in-place concrete exceeds the space available.

- ***Attribute "GEOMETRY"***

As stated for the accessibility class, the size of the space available for major operations and equipment is a crucial attribute during site layout planning. This attribute denotes information on the geometrical properties (height, width, and length) of the available space on site. Knowing the available space size allows the project team to place the allocated equipment in an appropriate location with enough space.

- ***Attribute "COORDINATES/LOCATION"***

The position of the space varies depending on the type of operation/equipment that requires this space. This attribute will carry information on the coordinates/location of this space. Example of position types are unit, linear, linear overhead, and vertical (Riley, 1998). For example, the position of the space required for wall work may be considered as linear space, and the position required for column work may be considered as a vertical space.

- ***Attribute "DENSITY"***

This attribute will accommodate information on the density of the required space. This information describes the ability of a space to share a portion or all of its physical space with other space concurrently. For example, the workspace occupied by an equipment (e.g. crane) may be described as dense because this path can not be interfered throughout the length of the operation. On the other hand, the space required for crew (laborer and tools) placing concrete may have less density as it may be partially interfered.

4.3.4.3 Class "CONDITION"

The condition of the site is a determinant factor in the project planning process. This condition may limit the selection of systems and/or means and methods alternatives.

Therefore, pertinent information on the site condition is required as early as possible during design development.

The condition of the site may be expressed in different ways. This includes the site "*soil*, "*existent*", and "*weather*" (Figure 4-19). The attribute of these subclasses is the "*CHARACTERISTICS*".

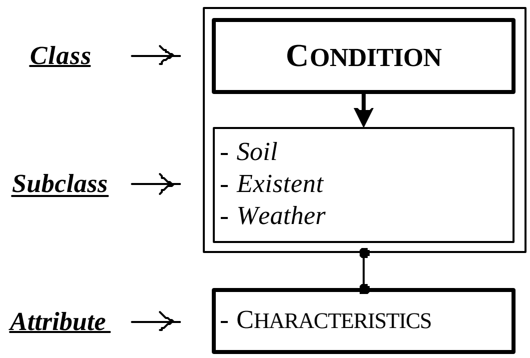


Figure 4-19: Subclasses and attributes of the "CONDITION" Class

1. Soil

The soil condition is a critical issue for construction projects. The project team will seldom start planning the project without performing various site studies and tests to gather information on the soil of the site. Site topography (e.g. slopes) may completely affect the design of the project. Also the geology and the soil properties (e.g. strength) affects the major means and methods selection process.

2. Existing Utilities

Electricity, Telephone, sanitary sewer, gas lines and others should be taken into account before laying out the site. Contacting responsible authorities is required to acquire information on, or to know the possibility of relocating these lines.

3. Weather

The weather has a great impact on major macro planning decisions. Pertinent information on weather condition should be available for the project team as early as possible. Severe weather condition may require the use of some materials (e.g. cement additives) and may affect the selection of some methods (e.g. concrete placement). Some major operations (e.g. concrete placement) are more comfortable to perform during good weather conditions. Therefore, the project team has to consider the weather condition during making decisions especially for the preparation of the preliminary schedule.

- ***Attribute "CHARACTERISTICS"***

The attribute of the condition class consists of the characteristics of each site condition. The content of this attribute will greatly differ from one condition nature to another. For example, the characteristic of the soil condition may be expressed in terms of bearing capacity. On the other hand, the precipitation, humidity, and temperature may express the characteristics of the weather condition. The characteristics the site condition enables the project team to make appropriate work execution and site layout planning decisions. For example, knowing the characteristics of the soil and existing underground utilities allows the project team to select an adequate location for major equipment.

4.4 THE APPLICATION OF MAPIC IN MACRO PLANNING DECISION MAKING

The utilization of the MAPIC model for assisting the project team in making macro planning decisions requires, first, that the company provides necessary information. This information is then stored in its relative locations classified by the MAPIC categories and classes. This should be performed by the project participants assisted by experts, if required, to ensure the pertinence and thoroughness of the stored information.

Storing information required for macro planning should be done as early as relevant data sources are available, so that all information is stored before the project team starts making decisions. For the "CONSTRUCTION TECHNOLOGY" category, as well as the "STRATEGY" class of the "MANAGERIAL" category, information is project-independent and thus may be provided before the start of projects. This information may then be updated regularly. For example, if the company purchases a new mobile crane, this information may be added to the "AVAILABILITY" attribute, of the "*Crane*" subclass, of the "RESOURCES" class, of the "CONSTRUCTION TECHNOLOGY" category (or, for simplicity: "CONSTRUCTION TECHNOLOGY" > "RESOURCES" > "*Crane*" > "AVAILABILITY" attribute). For the "FACILITY/STRUCTURE" and "PROJECT SITE" categories, as well as the "CONTRACTUAL" class of the "MANAGERIAL" category, information required is project-specific and thus has to be provided for each project separately. This information should also be reviewed regularly to ensure it is up-to-date. For example, if a design modification has been made to the dimensions of a waffle slab, the project team has to ensure that this modification is reflected in the "FACILITY/STRUCTURE" > "SYSTEMS" > "*Superstructure*" > "*floor systems*" > "*two-way joist (waffle)*" > "GEOMETRY" attribute (Figure 4-20). By storing and updating all required information in its relative locations through the

MAPIC model, the project team will be able to locate the place where the information is stored, and to easily retrieve each and every piece of information required for making macro planning decisions whenever needed.

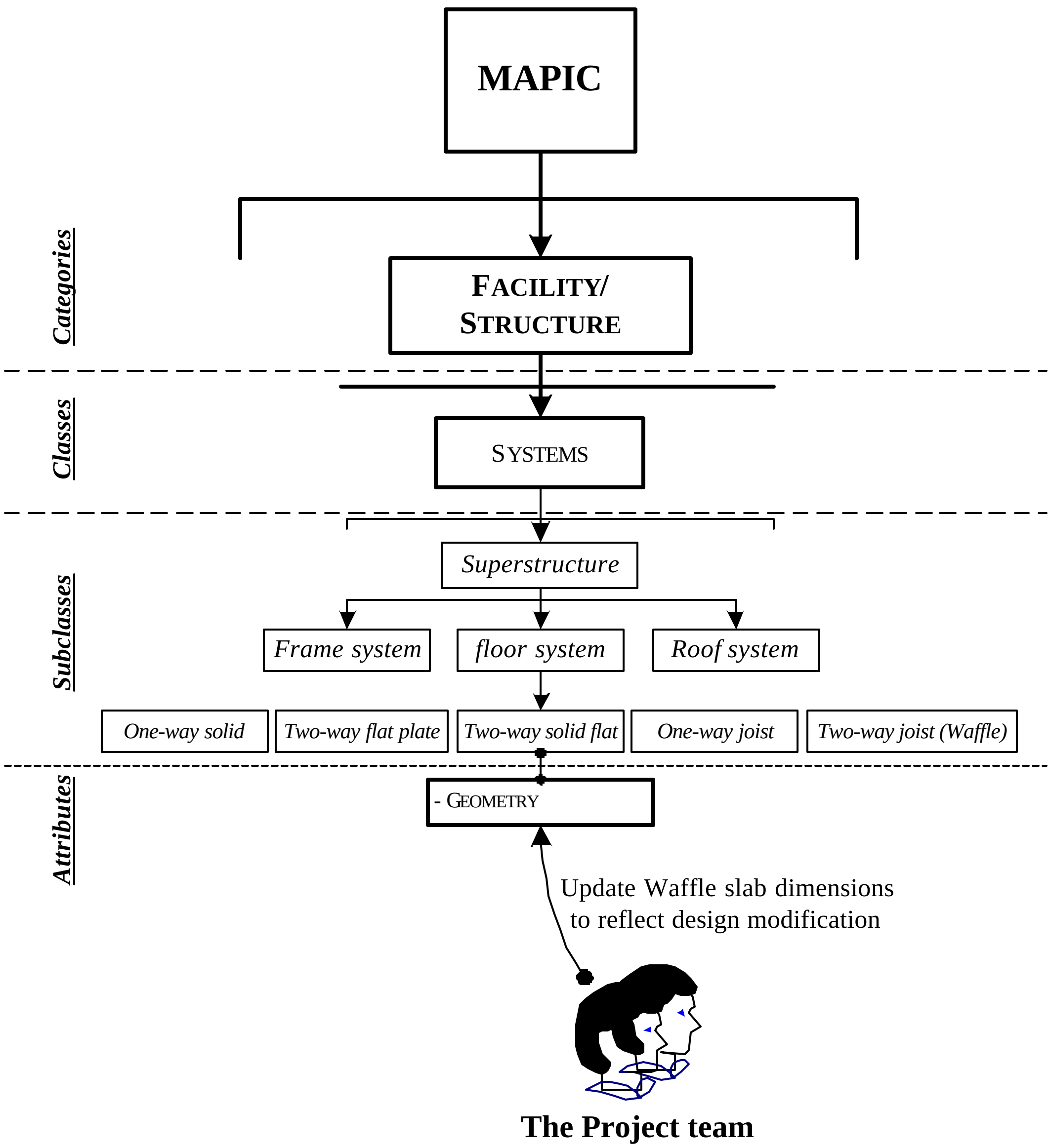


Figure 4-20: Updating information

To illustrate how the project team may apply the MAPIC model in the macro planning decision making process, the following example is developed. The example shows how the project team utilizes the MAPIC model when selecting a location for a tower crane during macro planning. The tower crane is required for several operations around the site. The crane should be located in a place where it can cover all points from which loads are to be lifted and to reach the locations where the loads must be placed.

In order to select an appropriate location for the tower crane, the project team will need to gather various types of information (Figure 4-21). First, information on the allocated tower crane is required. This includes information on the crane's space requirement, and the crane maximum hook height, maximum working radius, and maximum lifting capacity. The project team gathers this information from the "CONSTRUCTION TECHNOLOGY" > "RESOURCES" > "*Cranes*" > "*tower crane*" > "SPACE REQUIREMENT" and "SPECIAL ATTRIBUTES" (Figure 4-21a). Information on the facility size and location is also required. This information, along with the crane maximum work radius, hook height, and lifting capacity information, is needed to determine the potential location of the crane relative to the facility. The project team collects this information from the "FACILITY/STRUCTURE" > "PARAMETERS" > "*Exterior*" > "GEOMETRY" and "COORDINATES/LOCATIONS" attributes (Figure 4-21b). Once this information is collected, the project team will be able to determine the possible locations from which the carne will be able to perform required operations.

After determining the potential locations, the project team has to check that enough space is available to accommodate the tower crane. The project team may gather this information form the "PROJECT SITE" > "SPACE" > "*Equipment*" > "GEOMETRY", "COORDINATES/LOCATIONS", and "DENSITY" attributes (Figure 4-21c). For potential spaces, the project team may also need to check for soil and existing underground conditions. This information may be gathered from the "PROJECT SITE" > "CONDITION" > "*Soil*" and "*Existent*" > "CHARACTERISTICS" attribute (Figure 4-21d). This information is significant as it affects the foundation design of the tower crane. Also information on accessibility should be reviewed to ensure that the selected location does not interfere with work paths. This information is collected from the "PROJECT SITE" > "ACCESSIBILITY" > "*work paths*" > "GEOMETRY", and "DENSITY" attributes (Figure 4-21e).

This example shows how the utilization of MAPIC model to classify and store macro planning information assists the project team in easily retrieving necessary information while making macro planning decisions. Without utilizing the MAPIC model, the project team would have to search for the various information in the different data sources. This process is time consuming and does not grant the consideration of all the information that impact the decision making process.

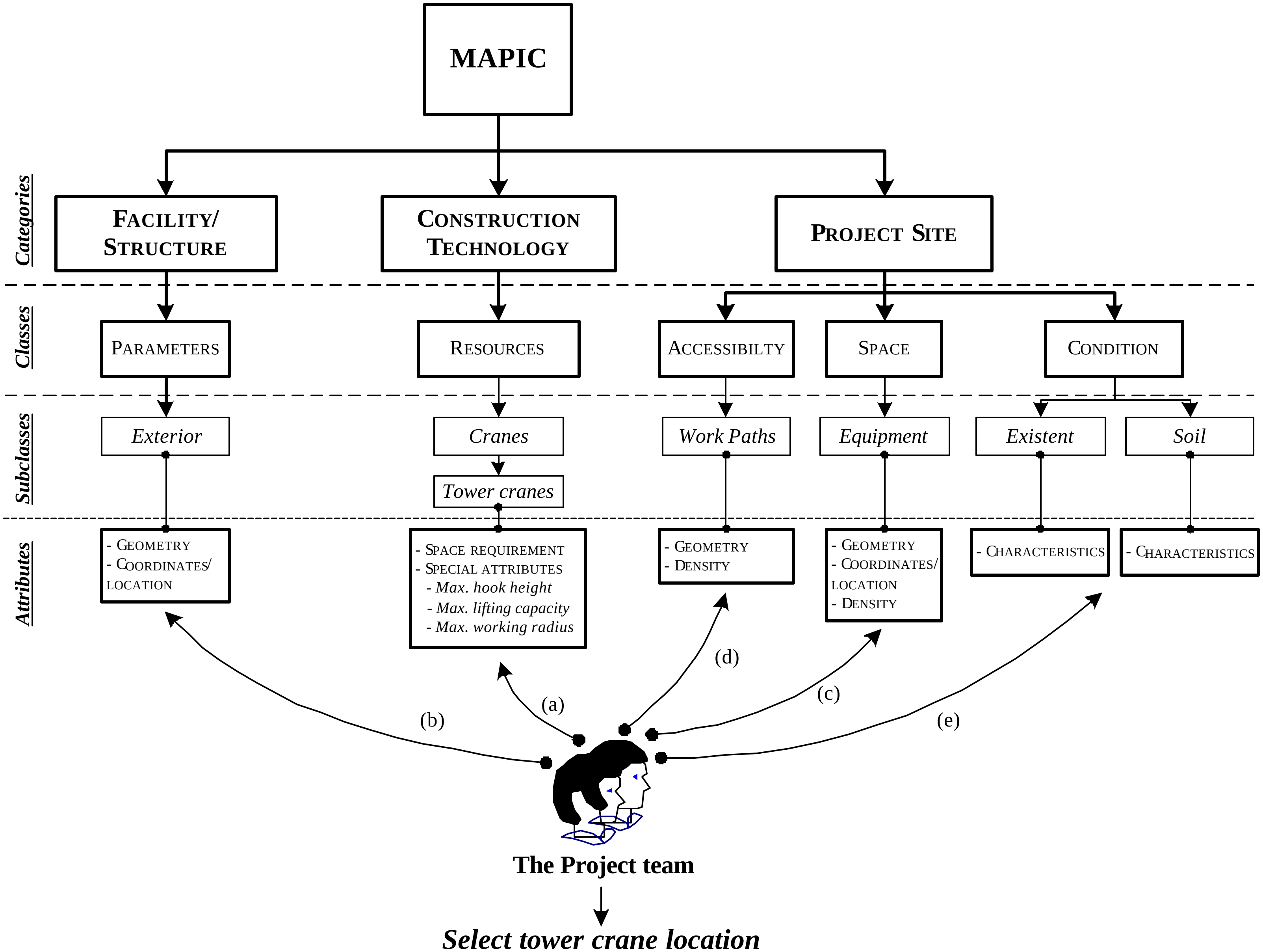


Figure 4-21:Utilizing the MAPIC model to extract information

4.5 CONCLUSION

This chapter has introduced the MAPIC model. The goal of MAPIC is to classify information required for macro planning decision making in a structured format. This classification assists the project team in storing and easily retrieving macro planning information.

First, the chapter discussed the development and structure of the MAPIC model. The model consists of a hierarchical breakdown of macro planning information attributes grouped in subclasses, classes, and categories. The major categories accommodate Managerial, Facility/Structure, Construction Technology, and Project Site information. Each category is further divided into classes. The "MANAGERIAL" category is divided into "STRATEGY" and "CONTRACTUAL" information classes; the "FACILITY/STRUCTURE" category into "SYSTEMS", and "PARAMETERS" information classes; THE "CONSTRUCTION TECHNOLOGY" category into "MEANS AND METHODS" and "RESOURCES" information classes; and the "SITE" category into "ACCESSIBILITY", "SPACE", and "CONDITION" information classes. Each of these classes may is further divided into subclasses. Each of the classes contains attributes that define the characteristic of the information required. The categories, classes, subclasses, and attributes of the MAPIC model were described in detail. Finally, how the project team can apply the MAPIC model in macro planning decision making was presented along with an example to illustrate this process.

5. THE VIRTUAL CONSTRUCTION ENVIRONMENT (VCE)

5.1 INTRODUCTION

The **Virtual Construction Environment** (**VCE**) is an interactive environment developed to support the thinking process of the project team during macro planning of design-build projects. The main concept of the VCE is to assist in relieving the heavy burden imposed on the project team during decision making, by providing pertinent information necessary for making appropriate decisions in a structured understandable format. This information may be organized, stored, and retrieved by users whenever needed during the virtual sessions. In addition, the VCE attempts to guide the project team to perform the interdependent planning functions (e.g. methods selection, resources allocation, and site layout planning, …etc) interactively and concurrently. During the virtual sessions, the users will be directed toward making decisions for planning these interrelated planning functions simultaneously.

The Virtual Construction Environment also provides the project team with appropriate tools to test different work execution and site layout planning scenarios early during project development. During the virtual sessions, the project team re-constructs the facility by bringing graphical elements together. Users' movements and interactions are recorded to capture their thinking process on how to construct the facility (i.e. sequence of major assemblies). Other planners can retrieve recorded decisions for further review or modification. The users are also able to specify construction methods, and allocate resources required for the implementation of major assemblies. Using system graphical libraries, major equipment and temporary facilities can be superimposed and displayed as graphical objects for site layout planning. This enables the users to visually check for space and accessibility conflicts during different virtual construction time intervals.

The concept of VCE is built on the hypothesis that the product model of the facility is developed in a 3D object-oriented format. The researcher envisions that in the near future, most designs will be developed using object-oriented technology in a 3D format. Computer companies already started to develop CAD packages, such as AutoCAD Architectural Desktop 2.0 (Autodesk, 2001), that are object-oriented and that enables easy implementation of 3D product models. The 3D format allows for better visualization and interpretation of the product model. The object-oriented technology enables the designer to attach relevant information/properties during and/or after design development. This information becomes essential during macro planning, and allows the project team to acquire information on the different systems (e.g. type, performance, …etc) portrayed in the 3D model.

This Chapter presents a general description of the VCE concept and its system architecture. The chapter will also include a description of how the project team's information retrieval, decision making, and collaboration is implemented in the VCE. Finally, a detailed description of the user-support modules will be discussed.

5.2 THE VCE SYSTEM ARCHITECTURE

The VCE consists of two components: an Interactive Virtual Interface (IVI), and a set of User Support Modules (USM). The IVI is a dynamic virtual setting that allows the project team to rehearse constructing the facility in a near reality sense. The User-Support Modules are developed to provide the project team with support information necessary for decision-making. Planning decisions developed by the users are based on a dynamic interaction between the user and these two components during the interactive virtual sessions (Figure 5-1).

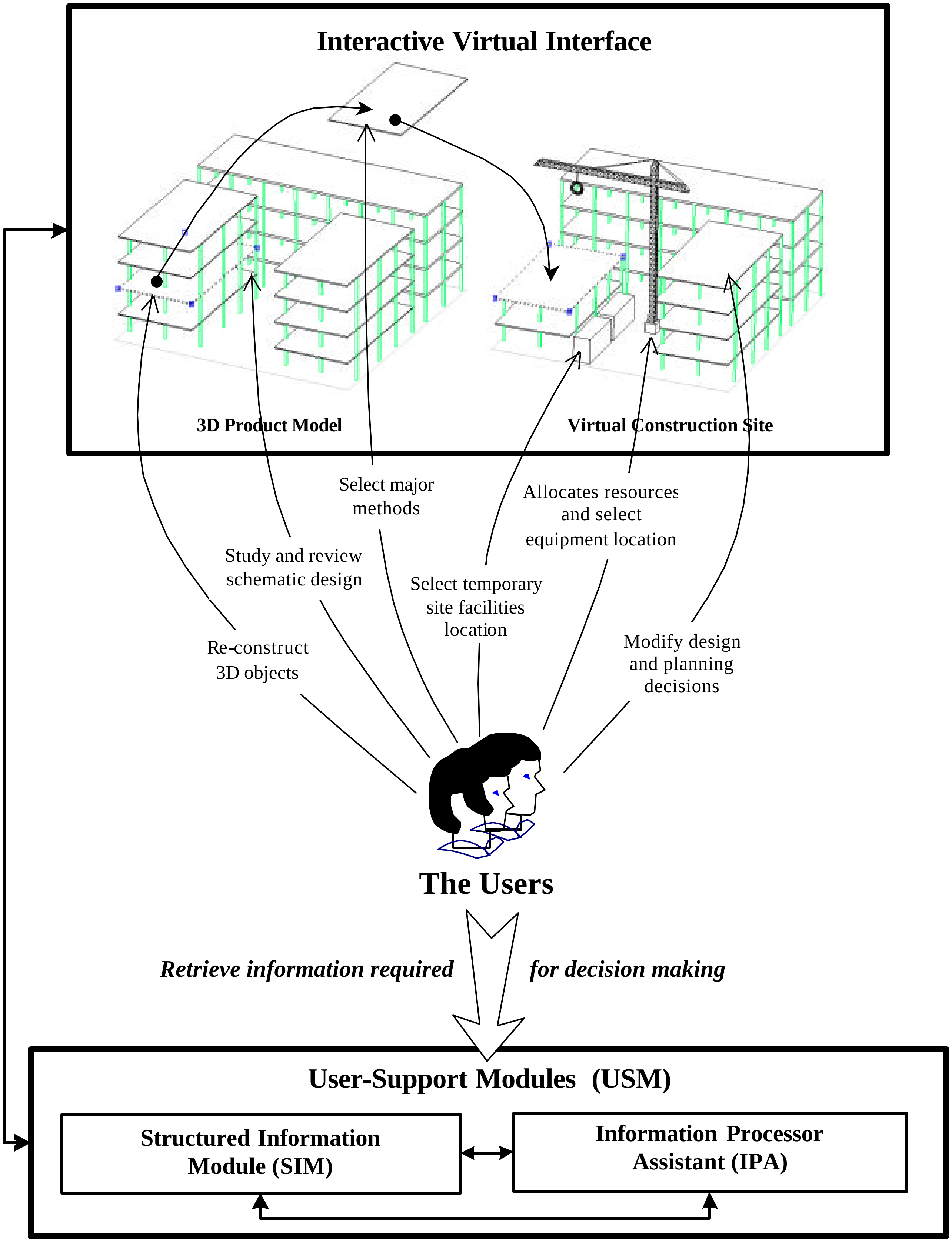


Figure 5-1: The VCE system architecture

5.2.1 INTERACTIVE VIRTUAL INTERFACE (IVI)

The IVI is a dynamic virtual setting that allows the project team to rehearse constructing the facility in a near reality sense. The virtual rehearsals are based on manipulating and modifying a pre-defined 3D product model of the facility. While navigating and interacting with the 3D product model, the project team is able to analyze project constraints and test alternative execution sequences and methods.

With reference to figure 5-2, the IVI consists of two windows: the 3D product model window (left) and the virtual construction site window (right). The 3D product model window is where the object-oriented 3D CAD model generated during design development and comprising entities of the project facility will be imported to the IVI. Design developed using object-oriented CAD systems allows for associating other properties/information about

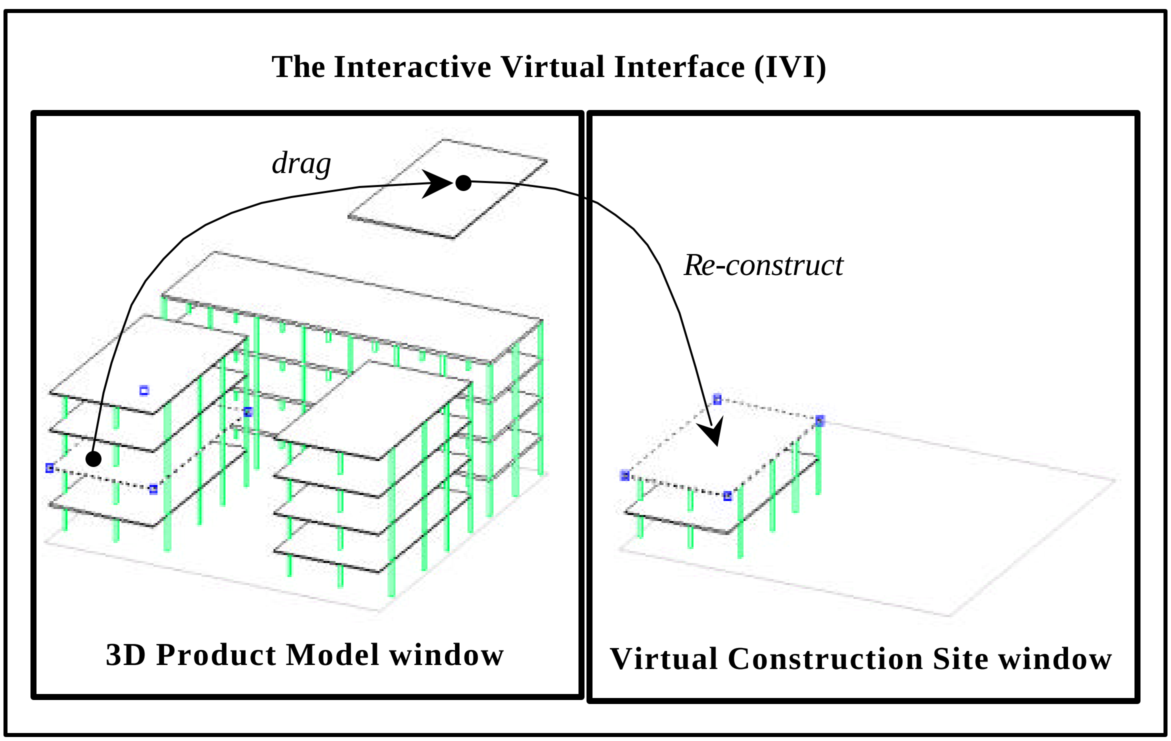


Figure 5-2: The Interactive Virtual Interface (IVI)

these objects in addition to geometrical information (i.e. size, shape, and position). Information is efficiently represented in an object-oriented modeling environment due to its prominent characteristics in data representation (Best and De Valence, 1999). Properties attached to each assembly include information such as component type, physical and material characteristics, possible construction means and methods, design intent, and so on. This information allows the project team to understand the design rationale and make appropriate planning decisions during the virtual rehearsal sessions.

The core of the IVI module is a virtual construction site window. At the beginning of the virtual sessions, this window is empty. During the virtual sessions, users are able to drag graphical assemblies from the 3D model window and re-construct the facility in the virtual construction site window by bringing components together in the perceived order of execution. During each interactive step, decisions on the construction of the assembly can be made. Major construction methods and resources can be selected and attached to each assembly/system. Initial design intent can be reviewed, and questions can be posed to the designer on potential changes. As the user constructs the facility, user decisions are recorded to capture their thinking process on what methods will be used and the order in which the assemblies will be constructed. User decisions recorded during the virtual sessions can be retrieved for further modifications/review by other planners, either independently or collaboratively.

The IVI also allows users to perform space and accessibility conflict checks for major operations. This will be achieved using a set of graphical objects. Based on the equipment allocated, a 3D object representing this piece of equipment can be displayed (i.e. superimposed) on the assembled product model at any stage of the virtual construction.

The IVI also enables the project team to model objects that represent additional required site information and activities, such as temporary facilities, temporary structures, storage areas, site access points, and so on. These objects are also superimposed on the assembled product model in their appropriate locations to support the decision process during the planning sessions.

5.2.2 USER-SUPPORT MODULES (USM)

The User-Support Modules (USM) provide the project team with support information necessary for decision-making. This enables the project team to review and extract relevant information based on the specifics of each individual situation. The modules also enable the project team to store and query decisions made, which allows for collaboration among the project team members.

With reference to Figure 5-3, The USM consists of two main parts: Structured Information Module (SIM), and Information Processor Assistant (IPA). Each of these parts is briefly described in this section.

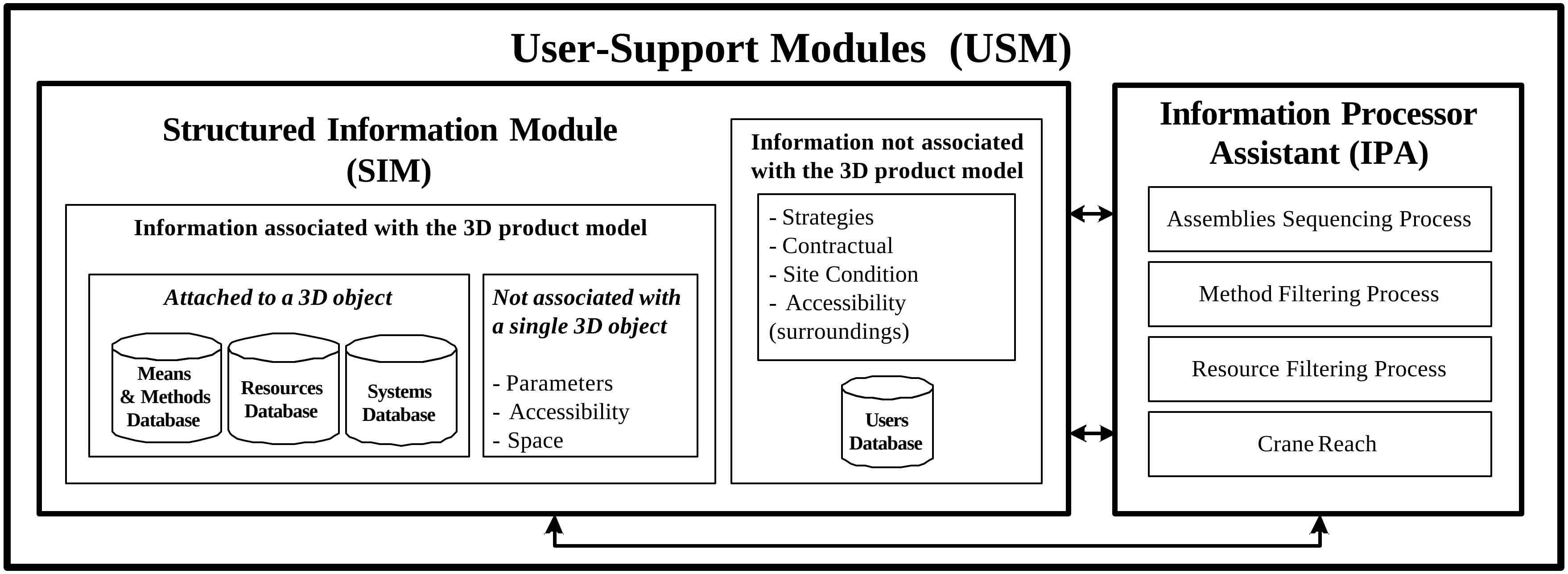


Figure 5-3: The User-Support Modules (USM)

- The Structured Information Module (SIM) provides the project team with relevant data and information required during the macro planning sessions. The SIM includes two main categories of information representation: *Information associated with the 3D product model,* and *Information not associated with the 3D product model.* The first category involves information related to 3D objects in the CAD environment. Visualization of this information is performed through the manipulation of 3D objects in the IVI. Various databases are developed to enable storing and retrieving this information. A *Means and Methods database* includes various methods conceivable for the execution of different operations. A *Resources database* contains information on the major equipment available in the company. The resources database also includes a graphical database/library of 3D objects. This library contains object-oriented 3D objects that represent major equipment. Information on each piece of equipment is directly attached to the 3D object. A *systems/assemblies database* contains various assemblies' information (e.g. slabs' description, performance, and design intent). Information is this database is stored during design development and queried during the virtual sessions to acquire information on the different systems of the 3D product model. Decisions made during the virtual sessions (e.g. methods selection and resources allocation) are also stored in this database. During design and planning decisions review, the project team may modify information in this database to improve the project constructability.

  The second category in the SIM involves information unrelated to 3D objects in the CAD environment. This information is presented to the VCE users through electronic document format (e.g. PDF) that may be browsed whenever needed from within the IVI. Also this category includes a *Users database* that contains information on the VCE users. The purpose of this database is to assist in controlling user's login to the VCE, which allow for recognize the user who made a decision/modification.

- The second part of the USM is the Information Processor Assistant (IPA). The IPA allows for capturing user input, processing user request for information, and filtering and extracting project data. The IPA includes different procedures intended for supporting the users in decision-making. An *Assemblies Sequencing Process* captures and records the users movement and manipulation of the 3D objects to create the logical relationships of the assemblies, and to establish activities that represent the manipulated assemblies. A *Method Filtering Process* extracts information for the user-selected graphical component, queries the means and methods database, and provides the users with the conceivable methods for executing the selected assembly. Users are then able to select the appropriate method from a list of alternative selections according to their knowledge and experience, and the specifics of the situation in the virtual session. A *Resources Filtering process* acquires the selected method, determines the resources required, filters the resources database, and provides the users with the available resources associated with the selected method. A *Constructability Check Process* is also available to assist the users in checking constructability conflicts. A maximum reach process is an example of the constructability check processes. This process acquires information on the equipment selected by the users (e.g. crane), and utilizes the maximum work radius attribute of that equipment to visually provide the users with its reachable area.

5.3 Implementation of the Project Team Decisions/Actions in the VCE

The VCE enables the project team to perform several decisions/actions for macro planning. Examples of these decisions/actions are shown in Figure 5-4:

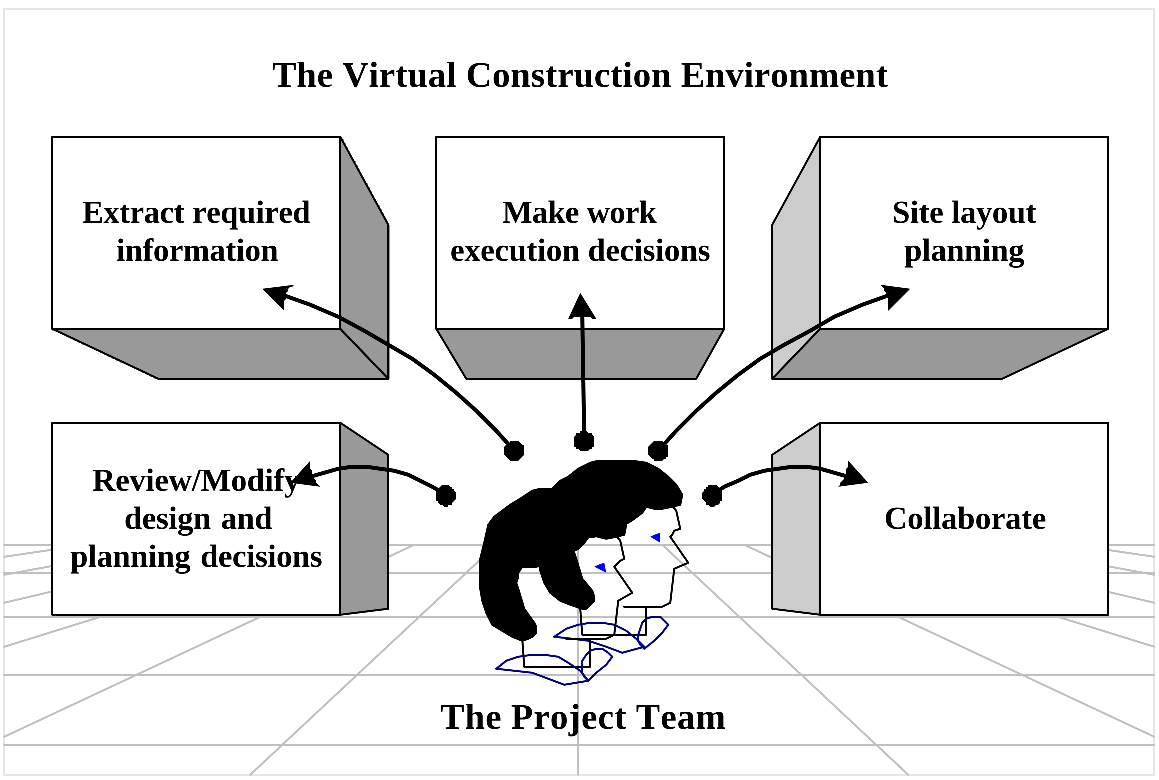


Figure 5-4: The project team decisions/actions in the VCE

- ***Extracting information***: Acquire and visualize all the information relevant to the macro planning decision making process.

- ***Making major macro planning decisions***: Make major work execution and site layout planning decisions in a suitable interactive setting.

- ***Reviewing design and planning decisions for constructability improvement***: Review the design along with the planning decisions made during the decision making process in order to depict any constructability conflict.

- ***Collaborating and communicating***: Captured users' decisions are documented to enable other users to retrieve these decisions with all specific information including who made them, as well as when and why the decisions were made.

The following section discusses how the Virtual Construction Environment assists the project team in performing these decisions/actions during the virtual sessions:

5.3.1 EXTRACTING INFORMATION

The VCE provides the users with means to acquire various information classified under the MAPIC model in an easy to comprehend format. Each class of information is stored in a separate place in the VCE as will be discussed later in this chapter. Before starting the macro planning process, the users have to ensure that various information is available in their correspondent places. This information may then be retrieved easily whenever needed during the virtual sessions. Each attribute of the MAPIC model is presented in the most understandable format (i.e. visually and/or textually).

Information classified under the MAPIC model may be acquired in the VCE as follows:

- ***Managerial information:***

  Information on company strategies and project contract should be prepared in an electronic format (e.g. PDF) and saved in their correspondent places in the VCE. The VCE provides for a direct link to this information within the IVI (Figure 5-5). The users may review this information by browsing these electronic documents.

  In a design-build delivery method, the project is usually broken down into work packages. By specifying a particular work package (e.g. concrete work), the VCE presents to the users exclusively the information relevant to this work package (i.e. the budget, due date, and expected quality).

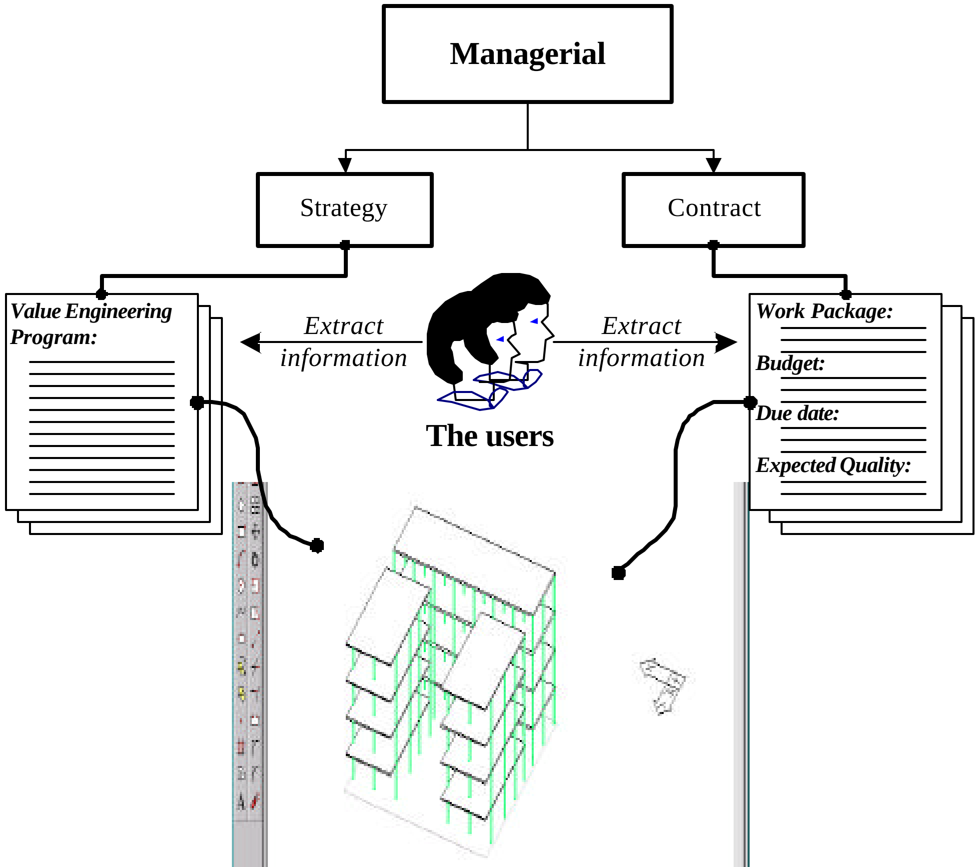


Figure 5-5: Extraction of Managerial information in the VCE

- ***Facility/Structure information:***

3D CAD models provide excellent capabilities for the visualization and acquisition of the facility physical properties. The users may review the geometry of the facility as well as spatial relationships by directly interacting with the 3D CAD model of the facility (Figure 5-6). Decisions made during design development may also be reviewed. This includes the system description, performance, and design intent. The VCE also provides the users with information on who made/modified these decisions and when.

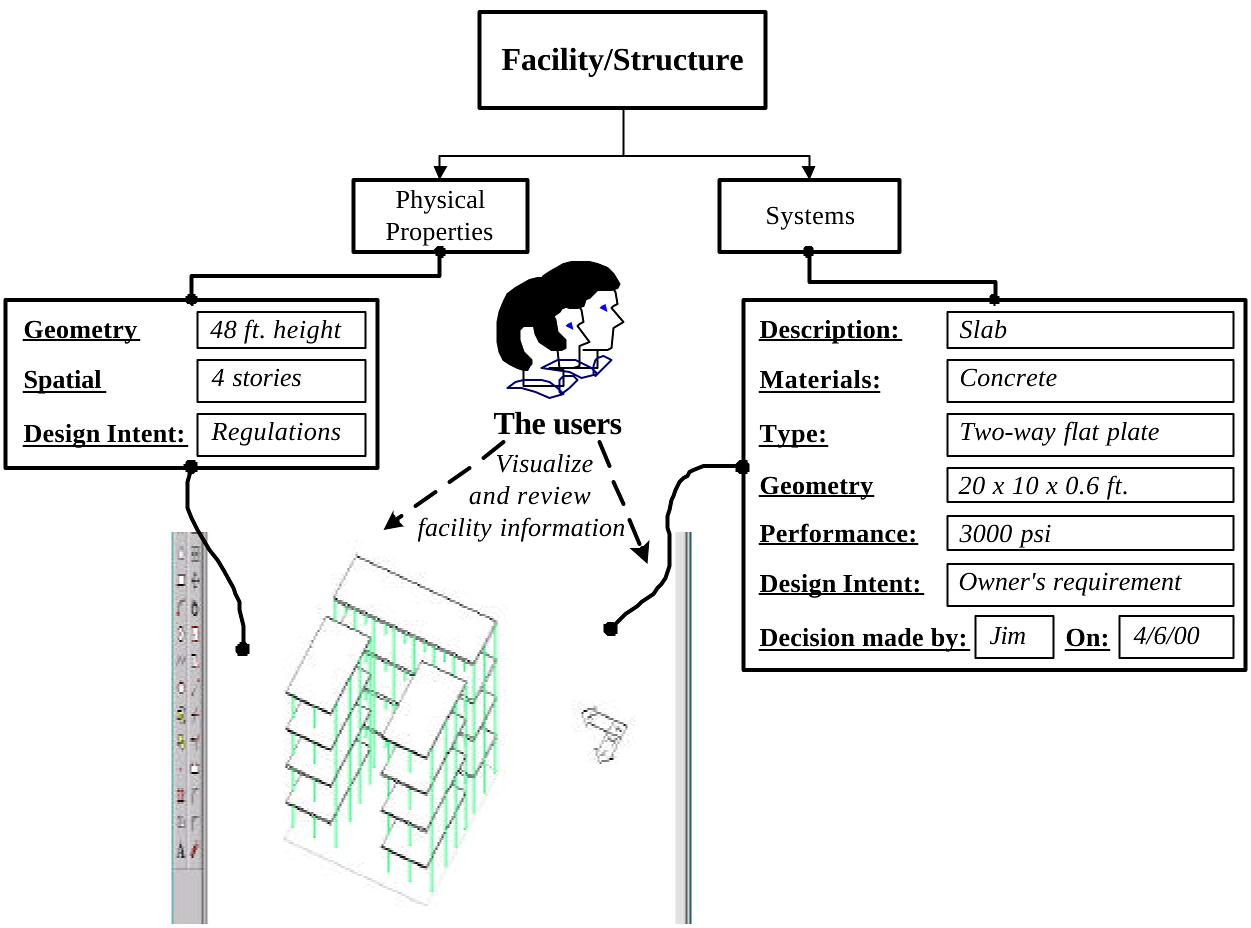
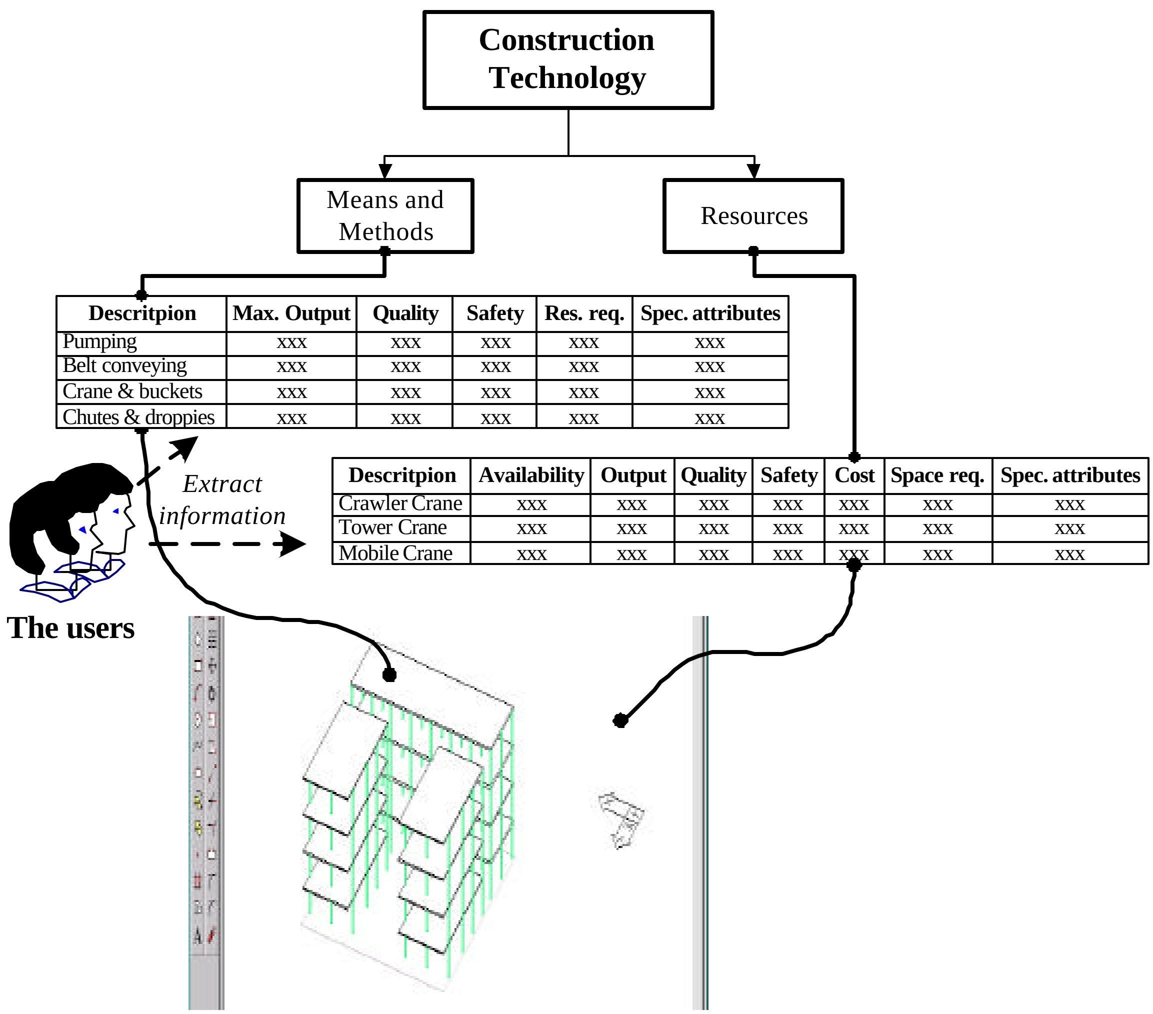


Figure 5-6: Extraction of facility/structure information in the VCE

- ***Construction Knowledge information:***

The VCE enables users to retrieve construction technology information during the virtual sessions (Figure 5-7). Based on the definition of the system, the VCE provides the users with corresponding means and methods conceivable for the execution of this system. For example, for a cast-in-place concrete slab, the VCE filters the various means and methods and presents solely the concrete placement methods. This includes each methods maximum output, quality, safety, and resources requirement. The users may then review information of these methods.



Descritpion	Max. Output	Quality	Safety	Res. req.	Spec. attributes
Pumping	xxx	xxx	xxx	xxx	xxx
Belt conveying	xxx	xxx	xxx	xxx	xxx
Crane & buckets	xxx	xxx	xxx	xxx	xxx
Chutes & droppies	xxx	xxx	xxx	xxx	xxx

Descritpion	Availability	Output	Quality	Safety	Cost	Space req.	Spec. attributes
Crawler Crane	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Tower Crane	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Mobile Crane	xxx	xxx	xxx	xxx	xxx	xxx	xxx

Figure 5-7: Extraction of Construction Technology information in the VCE

Resources information is also provided to the users in an easy to acquire format. Based on the method selected, the VCE extracts the resources requirement for this method and presents this information to the users. So for example, if the method selected for concrete placement is "Crane and bucket", then the VCE filters the various resources, and provides the users exclusively with information on the different cranes. Users are then able to review the availability, output, quality, safety, cost, space requirement, as well as the special attributes (e.g. maximum hook height, lifting capacity, and working radius) for these cranes.

- ***Project site information:***

  Virtual environments provide excellent capabilities for the visualization of space, accessibility, and existent site condition (e.g. existing structures) information. By navigating/walking through the project site and specifying required spaces, the VCE users acquire information on the geometry of these spaces. For example, if the users specify a space between two buildings (Figure 5-8), the VCE automatically extracts the length, width, height, and volume of this space from the 3D CAD model and presents this information to the project team. This allows for checking space information for various operations, resources, and accessibility.

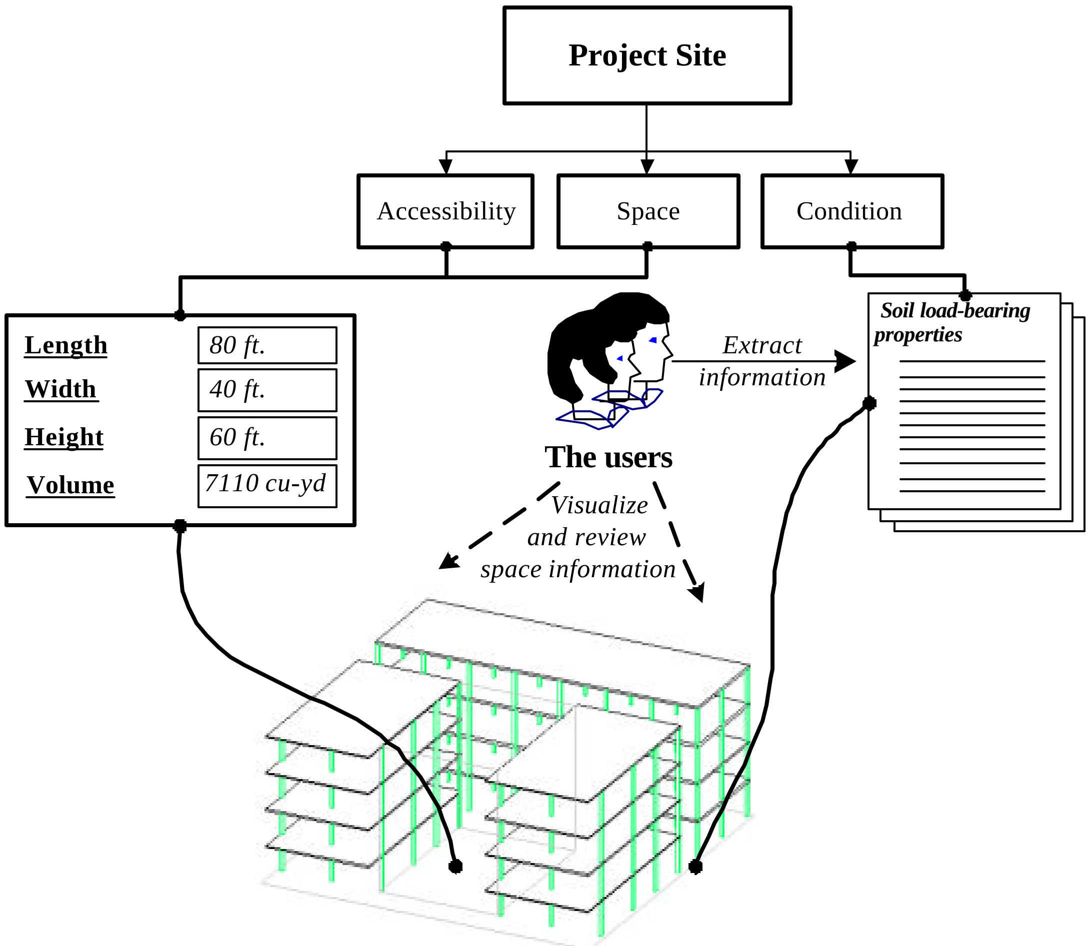


Figure 5-8: Extraction of project site information in the VCE

Site condition information (e.g. weather, and soil bearing capacities) and some accessibility information that may not be illustrated graphically (e.g. maximum clearance of surrounding bridges) should be prepared in an electronic format and saved in their correspondent places in the VCE. The VCE provides for a direct link to this information within the virtual environment. The users may review this information by browsing these electronic documents.

5.3.2 MAKING MACRO PLANNING DECISIONS

During the virtual sessions, the VCE enables the project team to make various work execution and site layout planning decisions. Users are able to select methods, allocate major resources, and decide on the path of construction and major assemblies sequencing. Users are also able to select appropriate locations for the temporary site facilities and for the major equipment. These interdependent planning decisions may be performed interactively and simultaneously during the virtual sessions. This is illustrated in the following parts.

- ***Decide on assemblies sequencing:***

  The VCE provides the users with tools to enable developing an adequate sequence for the major assemblies. During virtual sessions, users select one or more assemblies from the 3D product model window, move them to the virtual construction site window, and place them in their relative location (Figure 5-9). These movements are captured and utilized in the implementation of the assemblies sequencing. Assemblies manipulated by the users within each movement are presented by one activity in the developed sequence. The number of assemblies included in each movement and reconstructed by the users depends on the level of detail required. Users may develop a sequence that represents the relationship between each assembly (e.g. 1st floor slab, then 2nd floor wall-a, …etc), or between group of assemblies (e.g. 1st floor, 2nd floor, …etc). When locating the assemblies in the virtual construction site window, users are prompt to name the activity representing these assemblies (e.g. "Construct 1st floor"). Default relationships captured by the users movement is Finish-to-Start. However, while naming the activities, users are able to modify the relationships and may apply any required lead or lag.

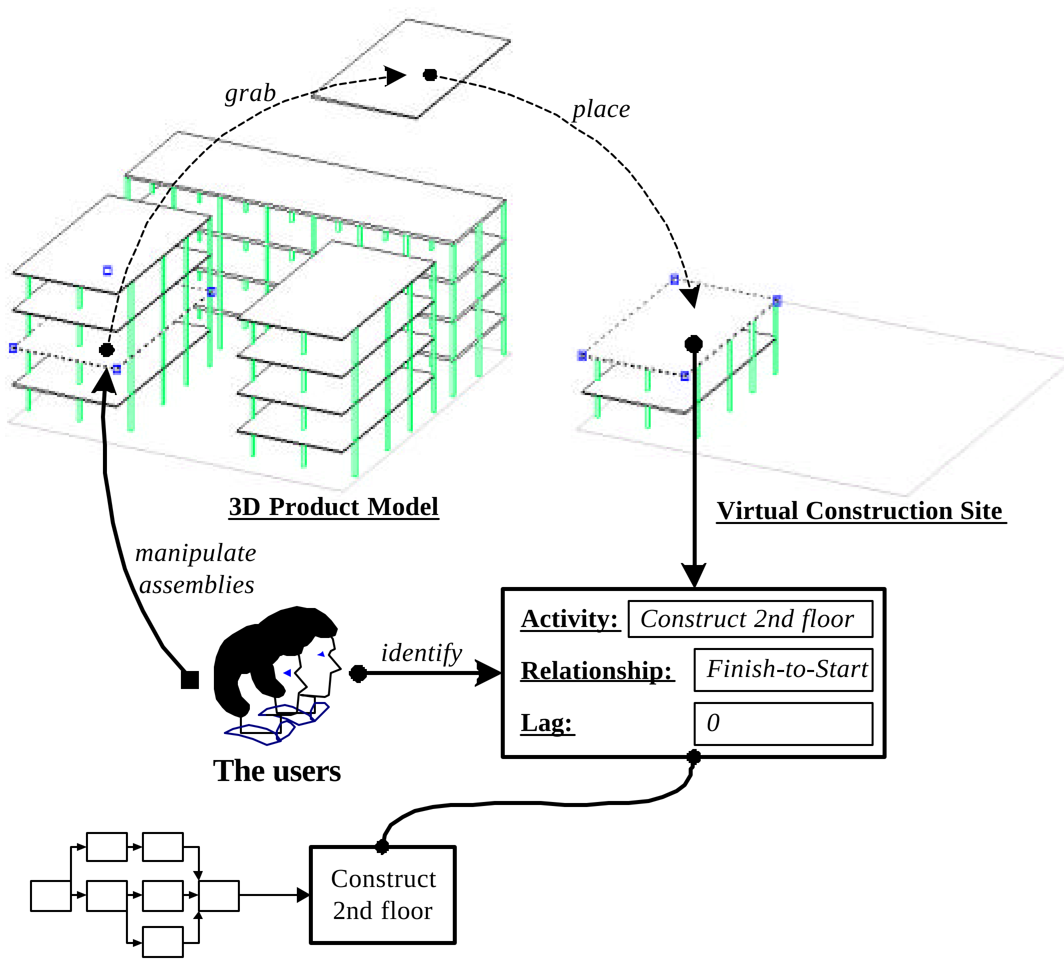


Figure 5-9: deciding on major assemblies sequencing

- ***Select Methods:***

The VCE provides the users with tools to enable selecting the appropriate method for the execution of each system (Figure 5-10). Various factors governing methods selection may be reviewed as needed. During the virtual sessions, once the users re-construct an assembly in the virtual construction window, the VCE filters various methods, based on the system definition, and presents to the users exclusively the methods conceivable for executing this assembly/system. If the system specified is not defined, the VCE prompts the users to first define the system. After reviewing the information presented for each method (i.e. maximum output, quality, safety, and resources requirement), as well as any other information required, users select the appropriate method according to their knowledge and experience.

- ***Allocate resources:***

Users are able to allocate major resources (i.e. equipment) associated with the methods selected (Figure 5-10). This process is similar to the method selection process described in the previous part. Once the users select a method, this process is executed automatically to let the users allocate the resources associated with the selected method. However, users may decide to allocate resources in a different planning session. Users, then, have to specify the system for which resources need to be allocated. If no method was selected for the specified system, the VCE prompts the users to first select a method for the system. Based on the method selected for this system, the VCE extracts the resources required for the execution of this method, and presents this information to the users. The users review the information available for each resource (i.e. availability, output, quality, safety, cost, space requirement, and special attributes) and select the appropriate equipment for this operation according to their knowledge and experience.

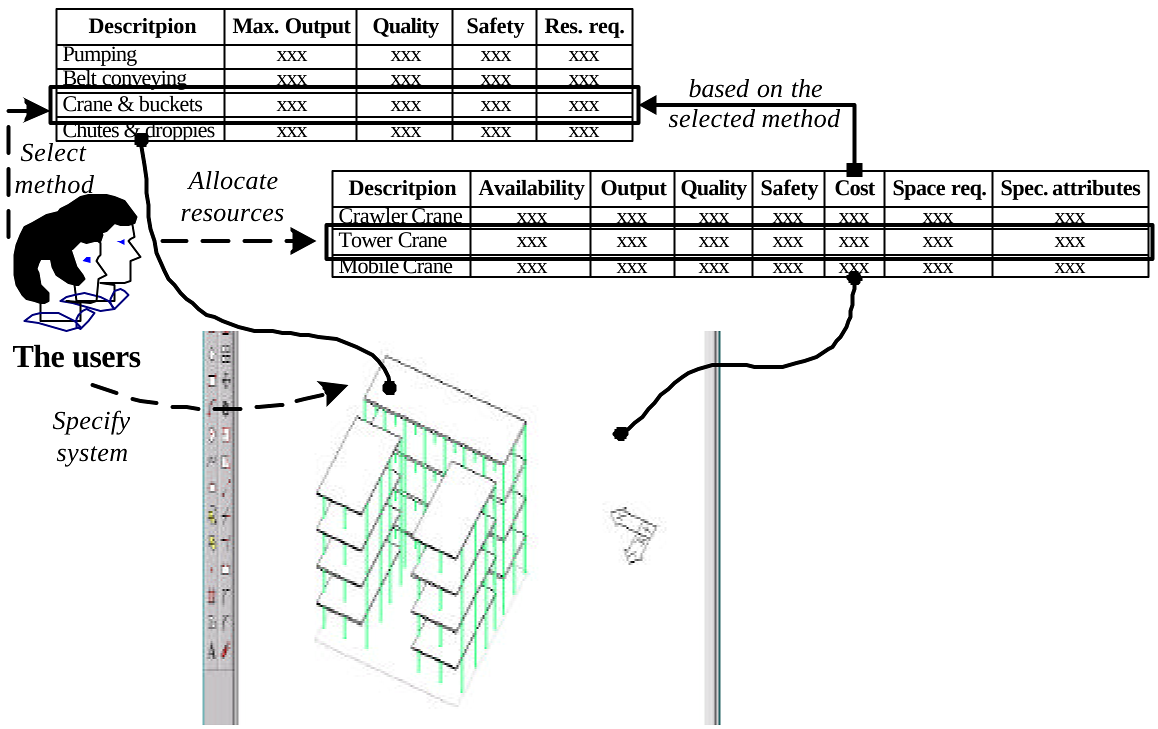


Figure 5-10: Select methods and allocates resources in the VCE

- ***Select temporary facilities location:***

  The VCE provides the project team with capabilities for selecting appropriate temporary site facilities location. Users are able to adequately visualize and navigate through the project site and to draw 3D objects that represent some temporary facilities (e.g. trailers for temporary offices, temporary storage, and fabrication yards). Then, according to their knowledge, experience and understanding of the job characteristics, users may select the appropriate location for temporary site facilities. During virtual sessions, users superimpose the 3D objects representing the temporary facilities on the virtual construction site (Figure 5-11). By enabling users to visualize and navigate through the project site,

- ***Select major equipment locations:***

  Appropriate selection of major equipment locations requires gathering various information about the equipment (e.g. maximum reach), the operation for which the equipment is required, space availability, accessibility issues, and soil condition. This information may be reviewed as discussed in earlier.

  The VCE provides the users with the capability of selecting appropriate locations for major equipment. During virtual sessions, once the users allocate a piece of equipment, the VCE provides the users with a 3D object that represents the equipment selected (Figure 5-11). Users can superimpose the equipment on the selected location in the virtual construction site. By allowing navigation through the project site, the VCE enables users to visualize, study, and try different locations for the equipment

Descritpion	Availability	Output	Quality	Safety	Cost	Space req.	Spec. attributes
Crawler Crane	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Tower Crane	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Mobile Crane	xxx	xxx	xxx	xxx	xxx	xxx	xxx

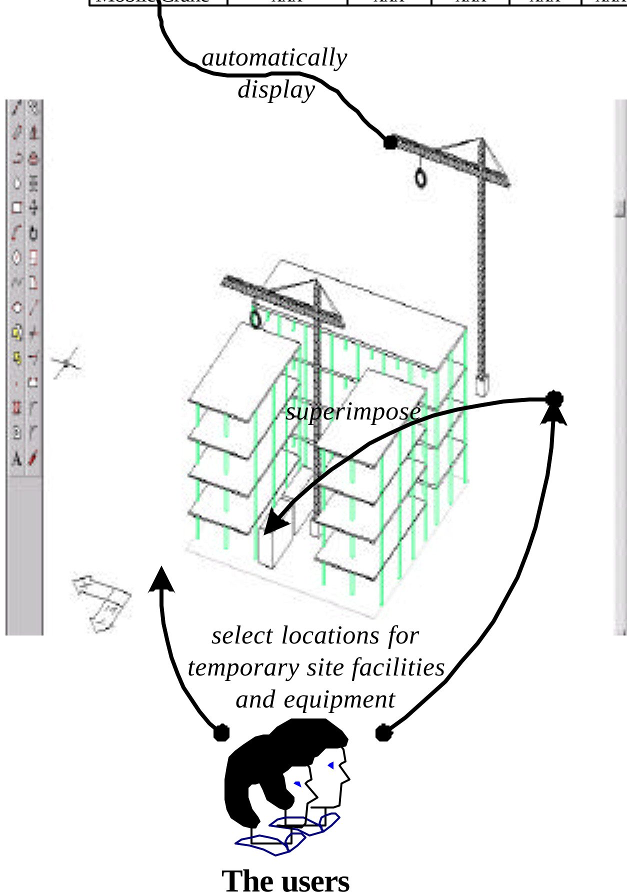


Figure 5-11: selecting locations for temporary site facilities and major equipment

5.3.3 CONSTRUCTABILITY REVIEW:

By enabling users to undertake rehearsals of major construction strategies in a near reality sense while supported by Users-Support Modules (USM), the VCE assists the project team in depicting constructability conflicts that may arise during the construction of the project. Users are able to review the design and site layout, to visually check for space and accessibility conflicts, to verify the selection of various methods and the allocation of major resources, and to rethink the major assemblies sequence. This is done in the VCE through the design and planning decisions review.

- ***Review design:***

  In general, the use of 3D CAD models and walkthrough technology assists the project team in better visualizing and understanding the design. In addition to this capability, the VCE allows the users to analyze, interact with, and manipulate 3D product model objects (i.e. assemblies). This enables users to better realize and review the design. The VCE also allows re-constructing the facility by bringing graphical elements together. This re-construction process allows the project team to review the design in, virtually, different phases of the construction process. Users are able to review the design when only the structural system in erected, then with the addition of the exterior closure, and so on. This enables the project team to depict various constructability problems such as those related to design rules (e.g. interference of systems).

If problems are depicted, the project team may modify the design decisions to improve project constructability. As depicted in Figure 5-12, the VCE enables the users to modify each system interactively. The users first specify the system that needs modification. Information on the 3D object class (e.g. columns, slabs, … etc) is directly extracted from 3D object-oriented CAD models and presented to the users. According to the description of the system specified during design development, the VCE provides to the project team a list that includes the pertinent alternatives of the types associated with the system. For example, for concrete slabs, various alternatives presented include one-way solid floor system, two way flat plate floor system …etc. Users may then pick the system type from the list of alternatives. In addition, users may modify the performance expected from the system (e.g. 3000 psi), and may document the rationale behind making these decisions (e.g. owner requirements, designers preference, …etc). The users may also provide any remarks they believe might affect the macro planning decisions.

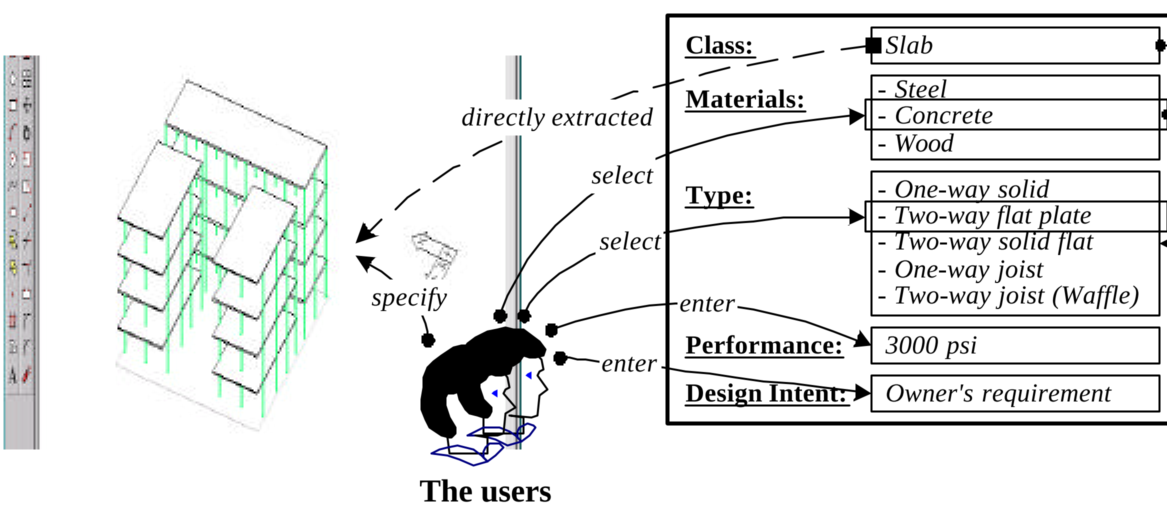


Figure 5-12: Systems definition in the VCE

- ***Review planning decisions:***

  Along with the design review, the VCE enables the project team to review major work execution and site layout planning decisions to ensure the appropriateness of these decisions and their impact on the project constructability. Users are able to review the method selected and the resources allocated for each assembly. This task is hectic and time consuming if performed manually. The project team would have to search in the document where different methods and resources for the assemblies are identified. Then, the project team would have to find the assembly for which methods and resources information is required. After finding the assembly and identifying the method selected and the resources allocated, the project team has to search for information on these resources. This information may be acquired from manufacturer manuals. In the VCE, users acquire this information by directly interacting with the 3D model of the assembly (Figure 5-13). This allows the project team to easily investigate these methods and resources for constructability improvement.

  Users are also able to review the sequence/relationship between various assemblies. Again this task is complex when performed manually. The project team would have to search for the activity representing the required assembly in the project network and recognize its relationship with its predecessor and/or successor. In the VCE, users acquire this information by directly interacting with the assembly (Figure 5-13). By specifying a certain assembly, the VCE provides the users with information on the activity presenting this assembly's, as well as information on its relationship with its predecessor and/or successor.

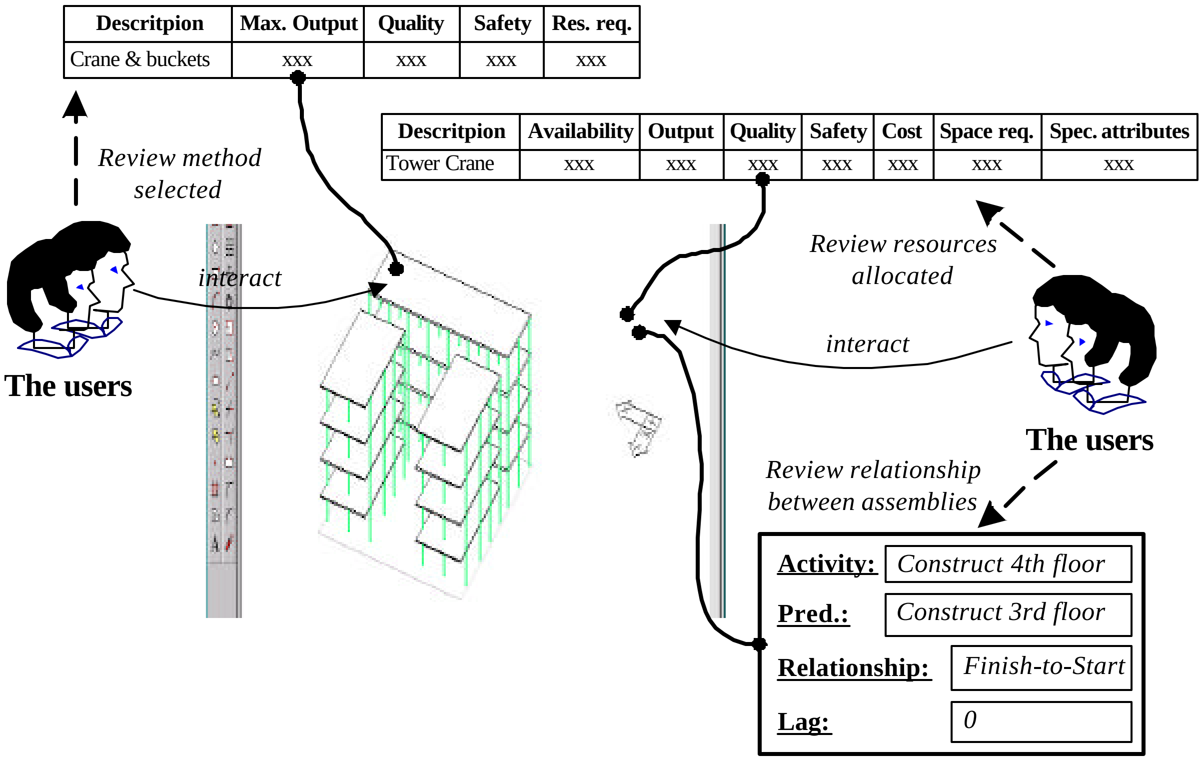


Figure 5-13: Reviewing methods, resources and sequence

The ability to walkthrough the project site allows users to better inspect the site layout. Spaces required for various operations and major equipment, as well as accessibility points to the sites and paths may be reviewed. Users are also able to review the temporary site facilities locations and whether these facilities interfere with any operation or path.

The VCE also provides the users with means to inspect the locations of major equipment. The appropriateness of the equipment location depends mainly on its ability to perform the job from this location (i.e. maximum reach). In order to assist the users in checking for equipment maximum reach, the VCE portray a cylinder that represents the reachable area of the equipment (Figure 5-14). This allows the users to visually check that all the operations, for which this crane is allocated, are within this cylinder (i.e. its reachable area).

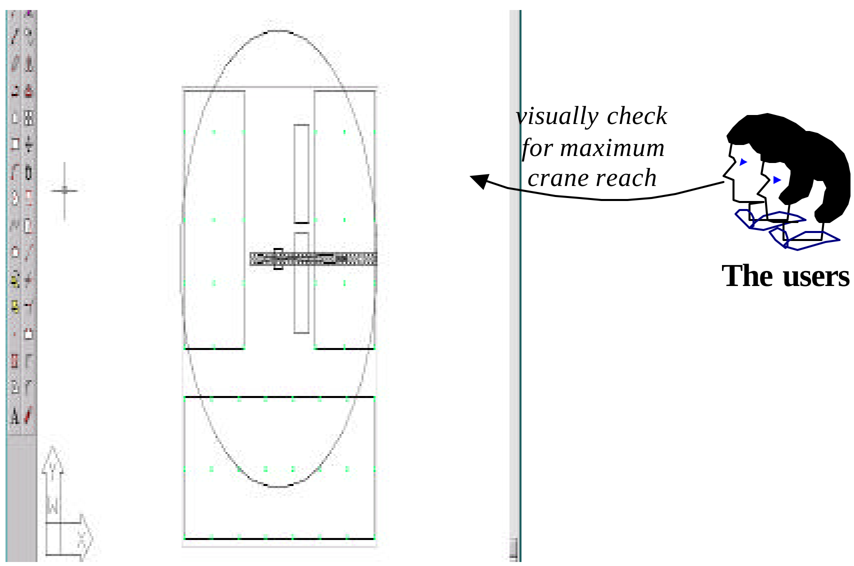


Figure 5-14: users visually check for maximum crane reach

5.3.4 COLLABORATING AND COMMUNICATING:

In a design-build delivery method, the design team and the construction team has to communicate and collaborate continuously throughout the different project phases. This continuous communication allows for making appropriate macro planning decisions and facilitates the interpretation of constructability issues which result in a more cost effective design, minimization of overall project duration and more effective transformation of design into construction reality (Rizzo, 1997).

There is an ultimate scenario for collaboration among project participants in a design-build delivery method. Before making design decisions, the design team and the construction team communicates, discusses the various options available, and agrees on the decision (Figure 5-15a). However, in practical, this scenario is not always the case. In some design-build projects, the design team individually makes the decision without even

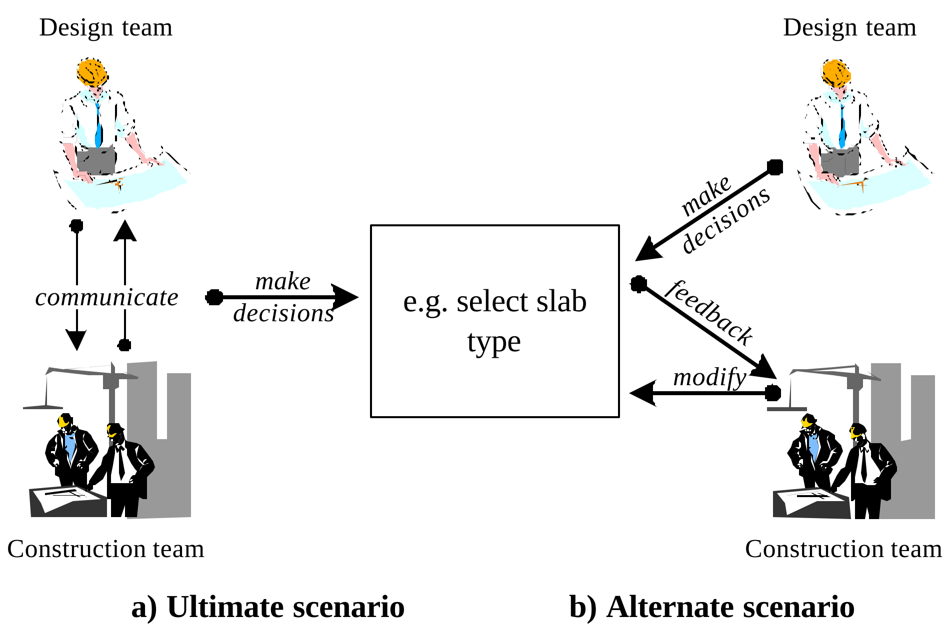
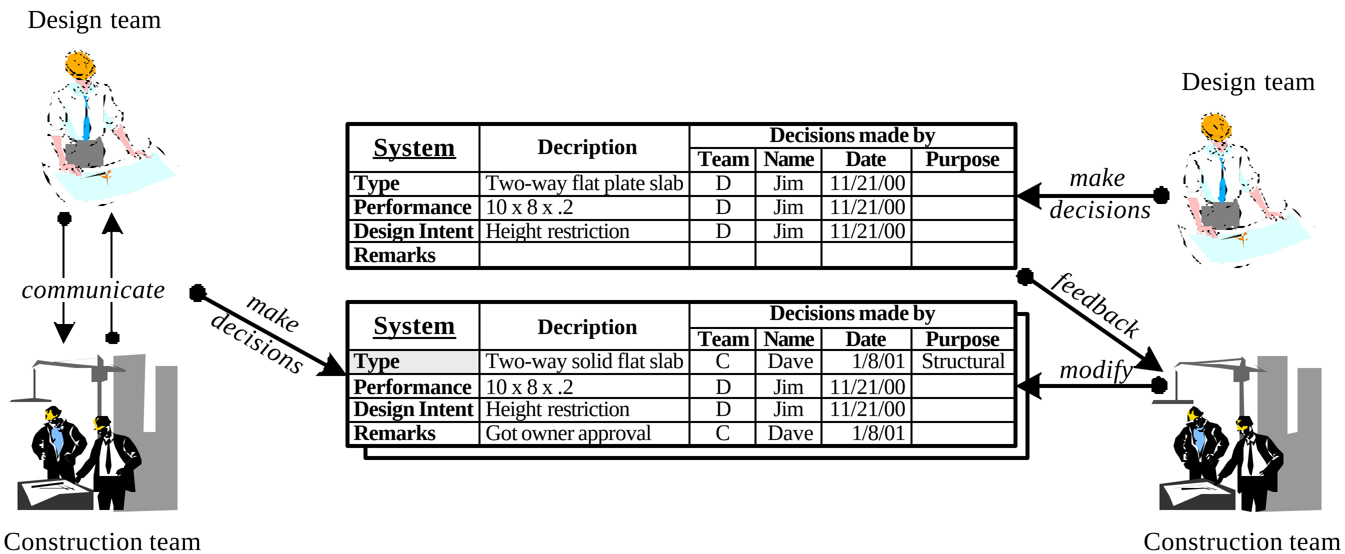


Figure 5-15: collaboration scenarios in a design-build delivery method

consulting the construction team. Then, during design review for constructability improvement, the construction team modifies these decisions and informs the design team of changes made (Figure 5-15b).

For any of these two scenarios, the VCE presents the means for the project team to communicate and collaborate in a structured environment (Figure 5-16). For the ultimate scenario, the design team and the construction team may communicate and makes agreed upon decision in the VCE as one design-build team. For the other scenario, the design team may individually make a decision. The VCE stores this decision in a particular place. The construction team is then able to review, and if needed, modify this decision. Purpose of modification and any remarks required may also be included. The VCE enables modification of decisions made while preserving previous decisions. This enables project participants to review previous decisions and modifications before making any changes. The construction team may easily retrieve decisions and modifications made by the design team and vice versa. The date of decisions and modifications, as well as the name of the team member who made them, is automatically added to document all changes made to the project. At the end of the project, the result is a thorough interpretation of the project team decisions during the macro planning process. This information is extremely significant as it may be reviewed and used during macro planning future projects as lessons learned examples. The project team may acquire the different decisions and modifications made in similar situation and may use this knowledge to make better decisions for the project in hand.



System	Decription	Decisions made by			
		Team	Name	Date	Purpose
Type	Two-way flat plate slab	D	Jim	11/21/00	
Performance	10 x 8 x .2	D	Jim	11/21/00	
Design Intent	Height restriction	D	Jim	11/21/00	
Remarks					

System	Decription	Decisions made by			
		Team	Name	Date	Purpose
Type	Two-way solid flat slab	C	Dave	1/8/01	Structural
Performance	10 x 8 x .2	D	Jim	11/21/00	
Design Intent	Height restriction	D	Jim	11/21/00	
Remarks	Got owner approval	C	Dave	1/8/01	

a) Ultimate scenario **b) Alternate scenario**

Figure 5-16: collaboration scenarios through VCE

5.4 USER-SUPPORT MODULES (USM)

The User-Support Modules (USM) provides for support information and procedures necessary to assist the VCE users in making macro planning decisions. The USM consists of two main parts: *Structured Information Module (SIM)*, and *Information Processor Assistant (IPA)*. Each of these parts is described in detail in this section.

5.4.1 THE STRUCTURED INFORMATION MODULE (SIM)

The structured Information Module (SIM) provides the project team with relevant data and information required during the macro planning sessions. for an appropriate format that enables the project team to retrieve relevant information required for making macro planning decisions. The MAPIC model is used to define the information structure in the SIM environment.

Information in the SIM is divided into two main categories: Information associated with the 3D product model and Information not associated with the 3D product model. Information in each class of the MAPIC model may be presented through one of these two categories. These two categories are presented in detail in this section.

- ***Information associated with the 3D product model***

This category involves information related to 3D objects in the CAD environment. Visualization of this information in the VCE is performed through the manipulation of 3D objects in the IVI. This category includes information attached to a 3D object, as well as information not associated with a single 3D object.

1) Information attached to a single 3D object

This type of information representation benefits from the use of the object-oriented computer-aided design (OOCAD) environment, which enables information organization into objects that directly symbolize the entities in the real-world domain (Fischer and Froese, 1996). So for example, information about a specific system (e.g. a wall) is stored through the "walls" class in the OOCAD environment. The use of OOCAD has then allowed for the direct extraction of some information (e.g. geometrical properties) from the 3D CAD object specified.

MAPIC classes that are represented through this category are "SYSTEMS", "MEANS AND METHODS", and "RESOURCES". The SIM includes databases to enable storing and retrieving this information. Records in the databases are connected to objects in the IVI. The users envision this information by directly manipulating the intended 3D object in the IVI. By interacting with the 3D object, information in the database record representing this object is presented to the users. For example, by selecting a slab, the users are able to acquire all information, such as type, geometry, method selected for its execution, resources allocated, and so on, about that assembly/system.

The Methods, Resources, and Systems databases are developed to present information on their relative class in the MAPIC model. So the Methods database accommodates information classified under the "MEANS AND METHODS" class in the MAPIC model; the

Resources database accommodates information classified under the "RESOURCES" class; and the Systems database accommodates information classified under the "SYSTEMS" class.

A Database Management System (DBMS) is used to create and manipulate these databases. A relational data structure is selected for the implementation of all databases in the SIM. In relational databases, data resides in relations/tables. Each table contains data for one MAPIC subclass. For example, in the resources database, each subclass (i.e. crane, excavators, …etc) forms a table. Each table contains several rows (usually called records) and columns (usually called attributes). Data stored in the databases are called entities. This structure is selected because it eliminates redundancy and thus makes it easier to maintain database consistency during operation. In addition, relational database supports a controlled method for introducing the sometimes required redundancy (e.g. duplicate records in different databases) to improve performance.

- ***Methods Database***

This database contains information on the methods conceivable for the execution of different assemblies/systems. As mentioned earlier, the structure of the database is developed based on the classification of the "MEANS AND METHODS" class in MAPIC. As depicted in Figure 5-17, each table in the database represents a subclass (e.g. concrete placement) of the "MEANS AND METHODS" class. Records in each table represent various methods of the subclass. So for concrete placement, for example, records are pumping, conveying, and so on. Attributes of the "MEANS AND METHODS" class comprise the tables' columns. Special attributes of each subclass (e.g. maximum vertical reach for concrete placement methods) are included in their relative tables.

Methods Database

Concrete Placement

Descritpion	Max. Output *(yd³/hr)*	Quality	Safety	Resources requirement	Max. Vert. reach	Max. Horiz. Reach	Reach depth
Pumping	260	excellent	5-20%	pump and ready-mix truck	180'0"	167'0"	135'0"
Belt conveying	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Crane & buckets	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Chutes & droppies	xxx	xxx	xxx	xxx	xxx	xxx	xxx

Figure 5-17: The Methods database

- ***Resources database***

This database contains information on the major equipment available in the company. The structure of this database reflects the classification of the "RESOURCES" class in MAPIC. Each table in this database represents an equipment subclass (e.g. excavator, crane). Records in each table represent types of the equipment subclass. So for example, for the "*Crane*" subclass, records may be crawler crane, tower crane 1, tower crane 2, and so on. Attributes of the "RESOURCES" class comprise the table's column. Special attributes of each subclass (e.g. maximum hook height, and maximum lifting capacity for cranes) are included in their relative tables.

As discussed in previous sections, major pieces of equipment are displayed as 3D objects in the virtual construction site to be superimposed by the users in appropriate locations. A 3D visual library is implemented for that purpose. Each piece of equipment in the resources database is modeled as a 3D object and saved in this visual library. Each record in the database is connected to its correspondent 3D object (Figure 5-18). As new records are added to the database, the new pieces of equipment may then be modeled, saved in the 3D visual library, then connected to their relative record in the database. The VCE provides an easy method for this connection. The name of the 3D object in the Visual Library should exactly match the description of the piece of equipment in the database.

Although they may be easily modeled, the graphical 3D models are available for purchase from some CAD companies (e.g. www.3dcafé.com). In addition, we anticipate that, eventually, the equipment manufacturers will provide these models at no cost.

Resources Database

Cranes

Descritpion	**Availability**	**Output** *(yd³/hr)*	**Quality**	**Safety**	**Cost**	**Space requirement**	**Max. hook height (ft.)**	**Max. Lifting Capacity (kg)**	**Working radius (ft)**
Tower 1	2	10	very good	15-25%	$550	100 sf	200	6000	200
Tower 2	1	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Mobile	2	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Crawler	2	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

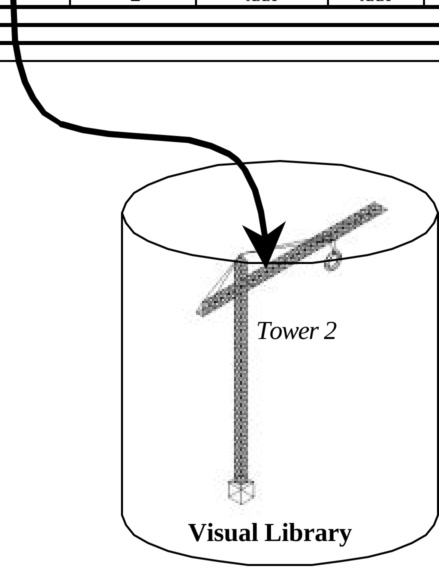


Figure 5-18: The Resources database and the Visual Library

The methods database and the resources database are project independent and thus their entities may be added before the start of the project. The Methods database should contain information on the methods that the company may use in the execution of various systems. The Resources database should contain all the equipment available (or may be rented) in the company. This information should be updated regularly, especially before the start of the virtual sessions, to ensure comprehensiveness of the databases. Innovative methods that may be utilized by the project team, and new equipment should be added once available.

In order to add this information, new records need to be created in the methods and resources databases. This requires the users to deal directly with the DBMS. Because they are project independent there is no need to perform this function through the VCE. On the other hand, Information extraction and acquisition should be performed easily during the virtual sessions, thus, is achieved directly through the IVI. By directly manipulating a 3D assembly and inquiring for methods and/or resources information, the project team is able to browse/visualize the database's record that represent this method/resource. In addition, users are able to know who selected this method or allocated this resource, as well as the date and purpose of the decision.

- ***<u>Systems database</u>***

This database contains information on the systems/assemblies portrayed in the 3D product model. The structure of this database reflects the classification of the "SYSTEMS" class in MAPIC. So for the superstructure for example, each subclass (e.g. slabs, walls, …etc) is presented by a table in this database. Each object/assembly in the 3D model is presented by a record in its relative table. Attributes of the "SYSTEMS" class comprise the table's column. This includes geometry, performance, cost, and design intent.

In addition to the attributes of the "systems" class, tables in this database includes other attributes used by the Information Processor Assistant (IPA) to save necessary information. As shown in Figure 5-19, these attributes are ID, method selected, resource allocated, activity, preceding activity, relationship, lag, user name, user team, and date. The purpose of the ID attribute is to differentiate between various systems in the product model. The ID is unique to each system/assembly and may be automatically extracted from the 3D model. The purpose of the remaining attributes is to store entities required by the different processes of the IPA as will be discussed later in this chapter.

The use of OOCAD for the development of the 3D product model allows for structured implementation of this database's record. This structure enables differentiating between the various systems portrayed (e.g. walls vs. columns). So for example, once the users specify a slab in the 3D product model, the description of this assembly/slab is automatically recognized, and hence a record is created in the "slabs" table. The ID of the slab specified, as well as its geometrical properties, is then automatically extracted from the OOCAD environment and added to this record. The designers may then input the entities for the description (e.g. waffle slab), performance (e.g. 3000psi), cost, and design intent. Entities for remaining attributes are added automatically when the users make decisions during the virtual sessions.

Systems Database

Slabs

ID	Description	Geometry	Performance	Cost *(per sqft)*	Design Intent	Method selected	Resources allocated	Activity	Preceding activity	Rel.	Lag	User name	User team	Date
018234	Waffle	15 x 20 x 0.6	3000psi	200	Structural req.	Crane & Bucket	Tower 2	Construct 1st fl. slab	Construct 1st fl. col	FS	7	Jim	Design	2/15
123494	Flat plate	15 x 20 x 0.4	2000psi	300	Owner requirement	Crane & Bucket	Tower 2	Construct 2nd fl. slab	Construct 2nd fl. col	FS	7	Bill	Design	2/22
693845	Waffle	15 x 20 x 0.6	3000psi	200	Structural req.	Crane & Bucket	Tower 2	Construct 3rd fl. slab	Construct 3rd fl. col	FS	7	Jim	Design	2/15
198765	Waffle	15 x 20 x 0.6	3000psi	200	Structural req.	Crane & Bucket	Tower 2	Construct 4th fl. slab	Construct 4th fl. col	FS	7	Jim	Design	2/15

Figure 5-19: The Systems database

During design review, the project team may need to make some modifications to the system definitions to improve the project constructability. The VCE provides for an easy method to modify this database's entities directly through the IVI without having to deal with the DBMS. Once the users specify a system to define, the record associated with this system is accessed and displayed to the users. The users may then select another entity for required fields from a list of available alternatives. For example, in the "slabs" table, alternative description may be "waffle" and "flat plate". This eliminates redundant data entry and facilitates the job of the project team during systems modification.

2) Information not associated with a single 3D object

Some graphical information is related to the CAD environment but not necessarily associated with a single 3D object. This type of information presentation benefits from the utilization of the CAD technology, which allows the users to visualize and gather spatial information in a 3D environment. Using the CAD Technology, the users are able to acquire the total height of the facility, the distance between two buildings, the volume of available space for a specific operation, and so on.

MAPIC classes that falls under this category are "PARAMETERS", "ACCESSIBILITY", and "SPACE". The users envision this information by specifying several points/objects in the IVI and inquiring for the information. So for example, for acquiring information on the total height of the facility, the users can specify a point at grade (ground level) and another point that represents the highest (or the target) point on the facility in the IVI. Then, by inquiring for the distance, this information will be displayed for the users. The same procedure is performed to acquire a volume of a specific space. The users may specify any three points in the IVI, inquire for the volume, and the information will be instantly displayed.

- ***Information not associated with the 3D product model***

This category includes information unrelated to 3D objects in the CAD environment. This information is presented to the VCE users mainly through electronic document format (e.g. PDF) that may be browsed whenever needed using the IVI. A structured format for these documents is developed and each company should use this format to store the required information. So for example, the company should save the electronic document including the contractual information in its designated location so the users may acquire this information during the virtual sessions.

Information in the "STRATEGIES", "CONTRACTUAL", and "SITE CONDITION" classes of the MAPIC model is presented through this category. Also information on the surroundings in the "ACCESSIBILITY" class (e.g. maximum clearance under surrounding bridges) is presented through this category, as it can not included in the 3D CAD model. The users envision this information by directly inquiring about the class under which the information lays. So for example, during the virtual sessions, if the users want to acquire the mandates of the safety program that their company implies, the users may directly inquire for this information through the IVI (e.g. by selecting an item from a drop-down menu). This will automatically display the electronic document that carries this information.

This category also includes a *Users database* that carries information about the VCE users. The purpose of this database is to assist in controlling user's login to the VCE. It, then, becomes easy to track who made any decision/modification during a particular session.

The database consists of various tables. Each table presents a particular team (e.g. design, and construction) and includes records containing team member's name and password (Figure 5-20). The users do not need to deal with the DBMS in order to manipulate this database's records. Users' records addition and password modification is performed through the VCE during login.

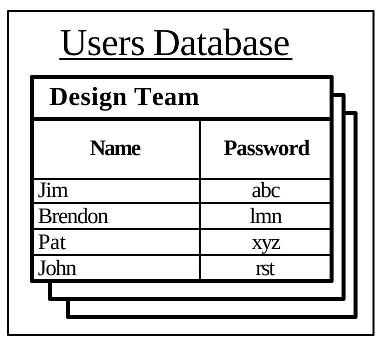


Figure 5-20: The Users database

To start a virtual session, the user has to login with the name and password specified in this database. If a new user is logging in, a new record is automatically created in the correspondent table. During the virtual session, each time the user makes a decision or a modification, his name and team information is extracted from this database and added to the relative record in the system, methods and resources databases. The date of making the decision/modification is also automatically added to these records. During decision review, the project team may then identify who made the decision/modification, as well as the date when the decision was made.

5.4.2 THE INFORMATION PROCESSOR ASSISTANT (IPA)

The Information Processor Assistant (IPA) allows for capturing user input, processing users request for information, and filtering and extracting project data. The IPA includes four main processes for supporting the users in decision making: An *Assemblies Sequencing Process*, a *Methods Filtering Process*, a *Resources Filtering Process*, and a *Constructability Check Process*. These processes are presented in detail in this section.

In order to perform the interdependent planning functions in coherence, these processes are executed automatically once the users make specific decisions. For example, once the users re-construct an assembly in the virtual construction site, the Assemblies Sequencing Process is executed automatically to capture and record the users movement, and to establish an activity to represent the assembly. Also once the users select a method for the execution of the assembly, the Resources Filtering Process is executed automatically so the users may acquire information on, and allocate the equipment associated with the selected method. Furthermore, once the users select a location for the equipment on site (i.e. superimpose the 3D object representing the equipment on the virtual construction site), the Constructability Check Process is executed automatically to allow the users to check for the maximum reach of the equipment, thus the appropriateness of the location selected.

In some instances, the users may require to execute exclusively a specific process. This is the case during a site layout review session when the users may want to only check for the constructability of the pieces of equipment in the virtual construction site. This issue is considered during the development of the VCE. The IPA is flexible and allows for the manual execution of any single process.

- ***Assemblies Sequencing Process***

The function of the Assemblies Sequencing Process is to capture and record users movement during the virtual re-construction session, and to establish an activity that represents the manipulated assembly. As shown in Figure 5-21, this is performed through the following steps:

Step (1): Through the IVI, the users select an object from the 3D product model (at left), drag it, and place the assembly in its relative location in the virtual construction site (at right).

Step (2): Once the assembly is placed, the IPA extracts the system ID for the object from the IVI.

Step (3): Then, the IPA browses the systems database and, by using the object ID, the system record is identified.

Step (4): The IPA extracts information on the preceding activity, the relationship, and the lag, displays this information, and prompts the user to label the activity representing the assembly. The preceding activity, by default, is the activity associated with the last assembly moved by the user. The default relationship is Finish-to-Start and the default lag is zero.

Step (5): The users review the information recorded on the preceding activity, the relationship, and the lag and modify the default values if necessary. Then, the users input a label for the activity representing the assembly (e.g. construct 1st floor slab).

Step (6): The IPA acquires the user input, and saves it in the assembly's record in the systems database.

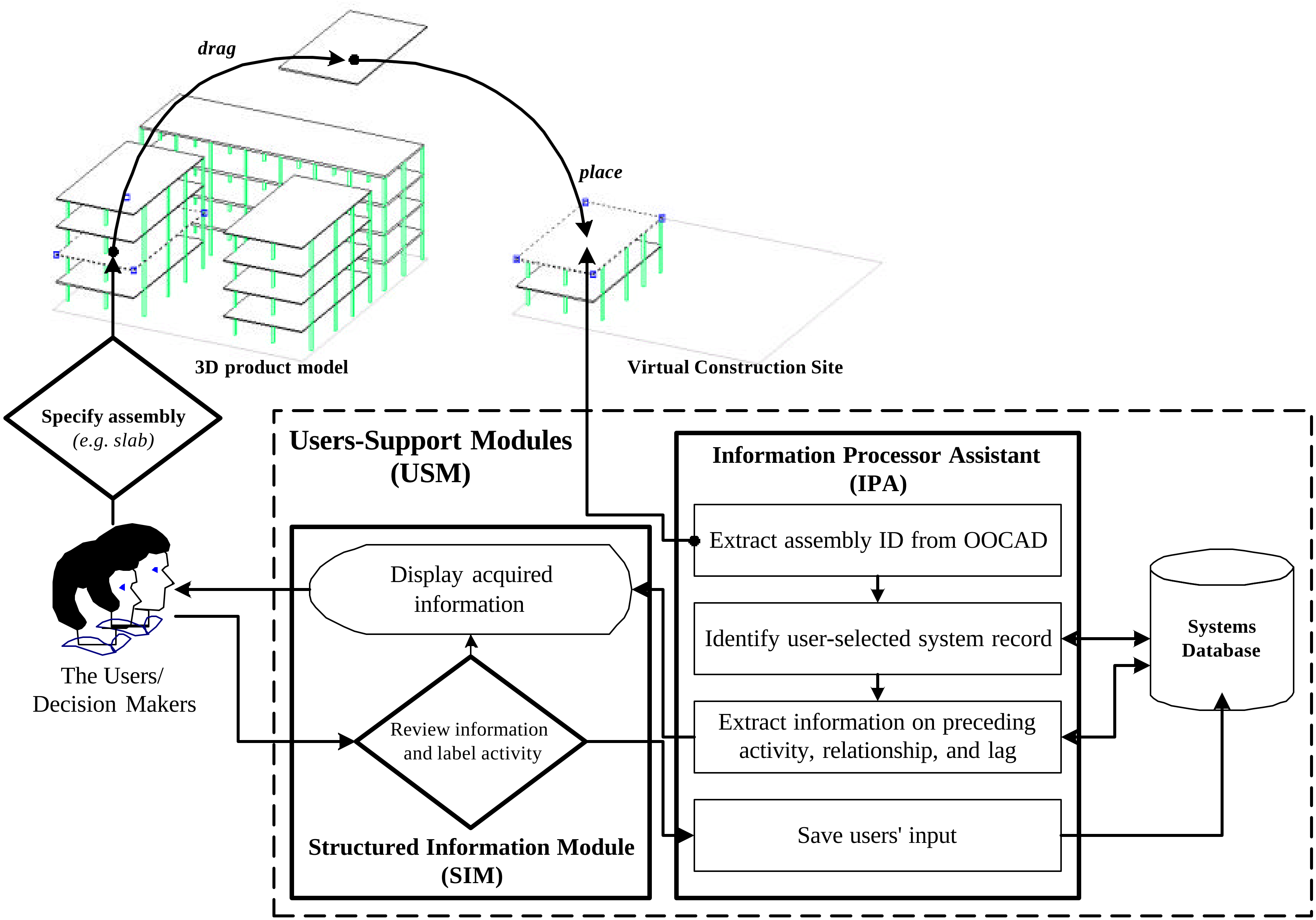


Figure 5-21: Assemblies Sequencing Process

- ***<u>Methods Filtering Process</u>***

The function of the Methods Filtering Process is to extract information for the user-selected graphical component from the systems database, queries the methods database, and provides the users with the conceivable methods for executing the selected assembly. As depicted in Figure 5-22, this is performed through the following steps:

Step (1): Through the IVI, the users specify a graphical object that represents the assembly for which information needs to be collected.

Step (2): Then, the IPA extracts the slab ID of the user-selected graphical component from the IVI. As mentioned earlier, the use of OOCAD in design development allows the determination of unique ID to each assembly/system during systems definition.

Step (3): Once acquiring the assembly ID, the IPA browses the systems database and identifies the system record.

Step (4): Information required (i.e. system materials and type) is then extracted from the system record.

Step (5): The IPA utilizes this information to search in the methods database for the methods conceivable for the execution of such an assembly. So for a cast-in-place concrete slab for example, the IPA filters all the tables in the methods database and search for the concrete placement methods.

Step (6): The IPA presents to the users the table representing the methods conceivable for the execution of the user-selected assembly.

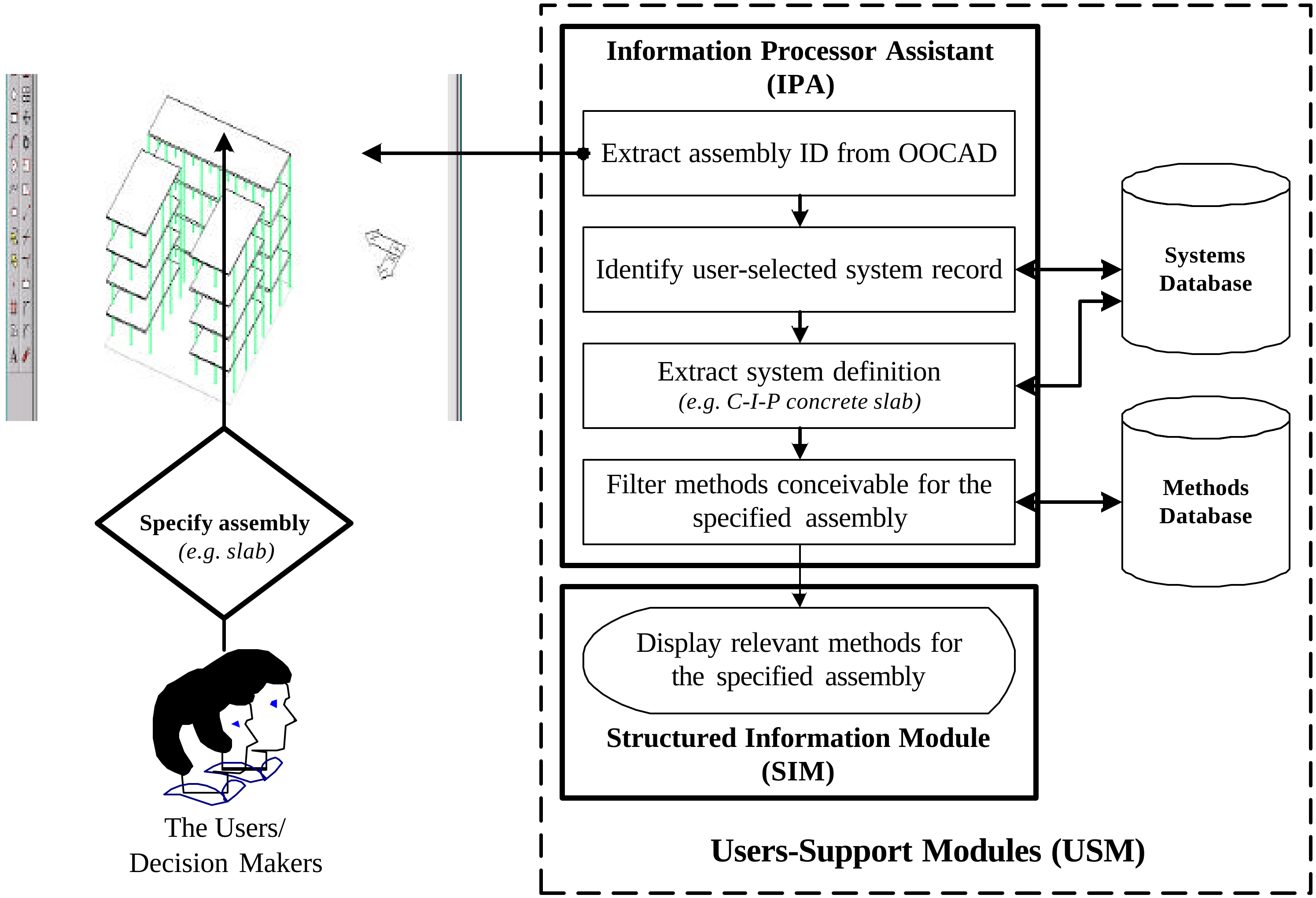


Figure 5-22: Methods Filtering Process

- ***<u>Resources Filtering Process</u>***

The function of the Resources Filtering Process is to determine the resources required based on the method selected, filters the resources database, and provides the users with the resources associated with the selected method. As depicted in Figure 5-23, the Resources Filtering Process is performed through the following steps:

Step (1): Through the IVI, the users specify a graphical object that represents the assembly for which information needs to be collected.

Step (2): Then, the IPA extracts the slab ID of the user-selected graphical component from the IVI.

Step (3): Once acquiring the assembly ID, the IPA browses the systems database and identifies the system record.

Step (4): Information on the methods selected for the execution of this system is then extracted from the system's record.

When the Resources Filtering Process is executed automatically after method selection, the IPA skips steps (1) to (4) and starts this process by executing the next step.

Step (5): Once the method is acquired, the IPA browses the methods database, searches for the record representing the selected method, and acquires information on the resources requirement for that method.

Step (6): The IPA then utilizes this information to search in the resources database for the list of resources associated with the selected method acquired through step (6). So for

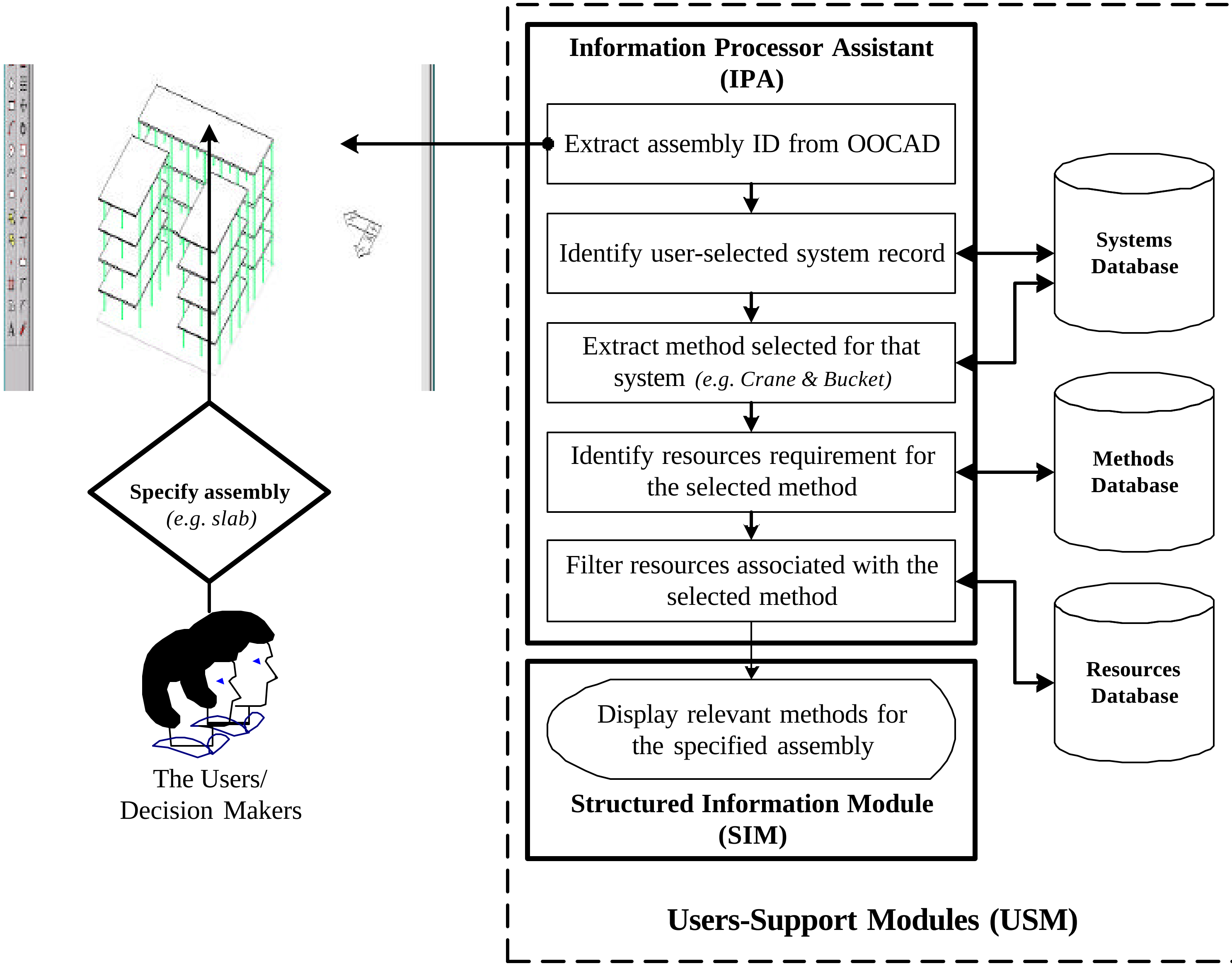


Figure 5-23: Resources Filtering Process

example, if the method selected for concrete placement is "crane and bucket", the IPA filters all the tables in the resources database and searches for the cranes table.

Step (8): Finally, the IPA presents to the users the table representing the resources conceivable for the execution of the user-selected assembly.

- ***Constructability Check Process***

The function of the Constructability Check Process is to graphically illustrate the maximum reach for major equipment. This enables the users to visualize and check for all the points the equipment can reach. As shown in Figure 5-24, this is performed through the following steps:

Step (1): The users specify a graphical object that represents the equipment for which maximum reach needs to be checked.

Step (2): The IPA extracts the equipment ID of the user-selected graphical component from the IVI.

Step (3): Once acquiring the equipment ID, the IPA browses the resources database and identifies the equipment record.

Step (4): Information on the maximum horizontal reach and the maximum vertical reach is then extracted from the equipment record. For example, for a tower crane, this presents the maximum work radius and the maximum hook height.

Step (5): Using this information, the IPA draws a form (e.g. cylinder) that represents the equipment maximum reach. The form will have, as a radius, the maximum horizontal reach of the equipment, and as a height, the maximum vertical reach of the equipment.

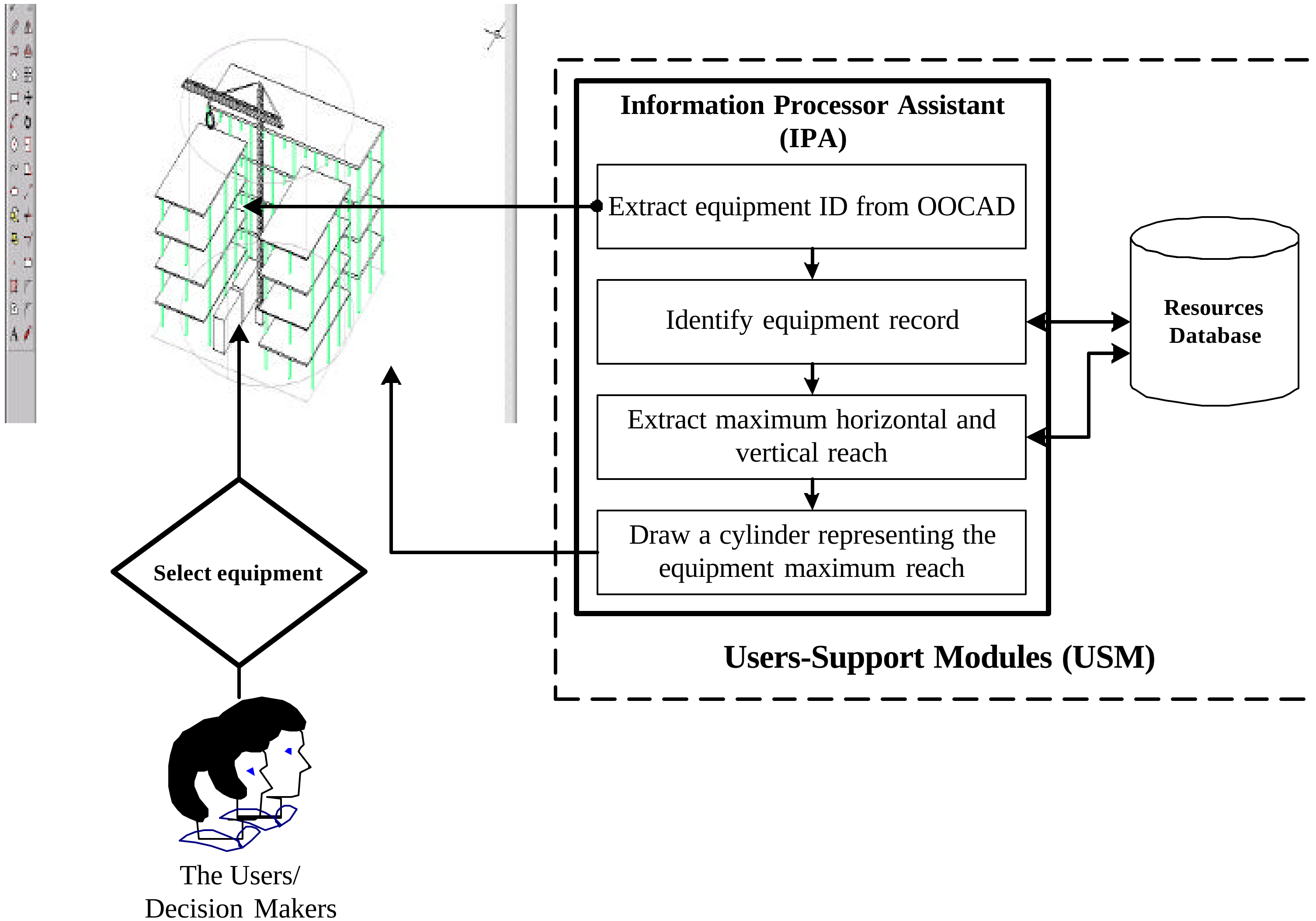


Fig. 5-24: Constructability Check Process

5.5 CONCLUSION

This chapter presented a new interactive environment developed to support the thinking process of project team during macro planning. The Virtual Construction Environment (VCE) intends to relieve the heavy burden imposed on the project team while making macro planning decisions due to the large amount of information that needs to be manually processed by providing the pertinent information in a structured understandable format. The environment will also allows for making the interdependent planning decisions interactively/simultaneously in order to eliminate, or at least reduce, the recompilation of information throughout the facility delivery process. Furthermore, the VCE enables collaboration among project participants, which provides for a better decision-making process.

The chapter has first presented the framework of the VCE. A general description of the VCE concept and the system architecture was presented. The implementation of the project team decisions/actions was discussed. Finally, a detailed description of the User-Support Modules (USM) including the databases, the Structured Information Modules (SIM), and the Information Processor Assistant (IPA) was presented.

6. COMPUTER PROTOTYPE

6.1 INTRODUCTION

This chapter presents the computer prototype implemented to illustrate the framework of the VCE. The computer prototype is implemented on available commercial software packages. An Object-oriented Computer Aided Design (OOCAD) package – AutoCAD Architectural desktop 2.0 – is utilized for the development of the Interactive Virtual Interface (IVI). A Database Management System (DBMS) – Microsoft Access 2000 – is used for the development of the Users-Support Modules' databases. Programming is performed mainly to customize the AutoCAD interface to reflect the functions required (Figure 6-1), to connect the CAD package with the DBMS, and to implement the procedures of the Information

Processor Assistant (IPA). The required code is written using Visual Basic for Applications. For a complete list of the programming code, please refer to Appendix C.

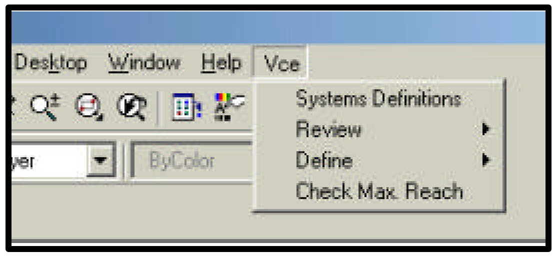


Figure 6-1: The VCE drop-down menu to AutoCAD

Various interviews were conducted with construction professionals to show them the computer prototype and to gather their feedback for future enhancements and extensions. Interviews were conducted with professionals from two General Contracting companies and two Construction Management companies. For a list of professionals interviewed, please refer to Appendix A.

Various examples are used in this chapter to apply the major functions of the VCE, as well as to illustrate how the users interact with the environment. This includes how project data is utilized to acquire information necessary for macro planning, how the major decisions are made, how some constructability issues are reviewed, and how corrective actions are taken.

6.2 THE 3D PRODUCT MODEL

A hypothetical project is utilized throughout this chapter to illustrate the computer prototype. The hypothetical project consists of three 4-story buildings. The 3D product model is developed using AutoCAD Architectural Desktop 2.0 (Figure 6-2). This software provides for an excellent capability for the visualization and acquisition of design parameters (e.g. shapes, spatial relationships, …etc). In addition to that, OOCAD packages, such as AutoCAD Architectural Desktop 2.0, started to provide for the capability of attaching information to the CAD objects.

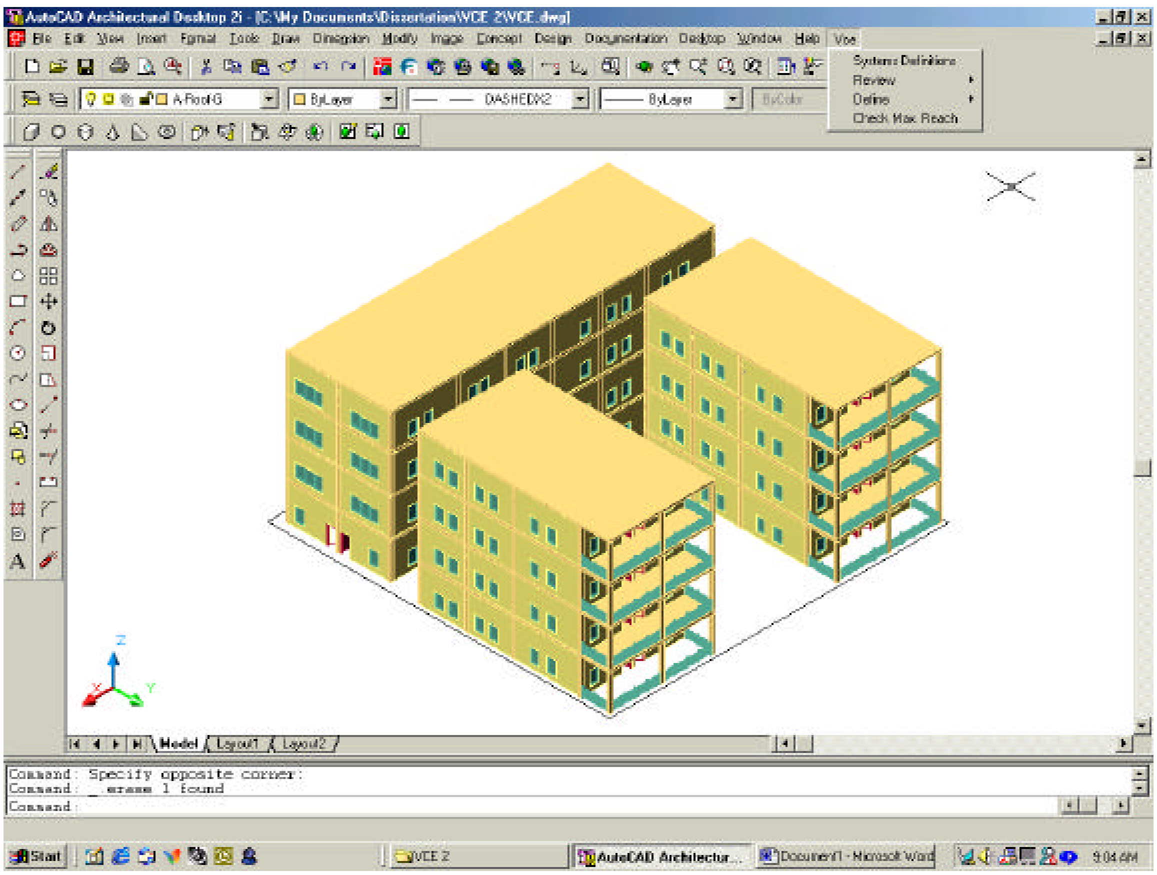


Figure 6-2: The 3D product model

For the purpose of this prototype implementation, programming is used to enable easy attachment of macro planning information to the 3D product model. During design development, information on portrayed systems (e.g. type, description, performance, and design intent) was entered and attached to the correspondent systems. However, this step should not be required in the near future as we envision that 3D product models will be developed with all information required attached to the 3D objects.

6.3 THE VIRTUAL SESSIONS

The virtual sessions start when the 3D product model, including defined systems, is imported/inserted into the assigned window (at left) in the IVI. The virtual construction site window (at right) remains empty until the users start to make the decisions for macro planning (Figure 6-3).

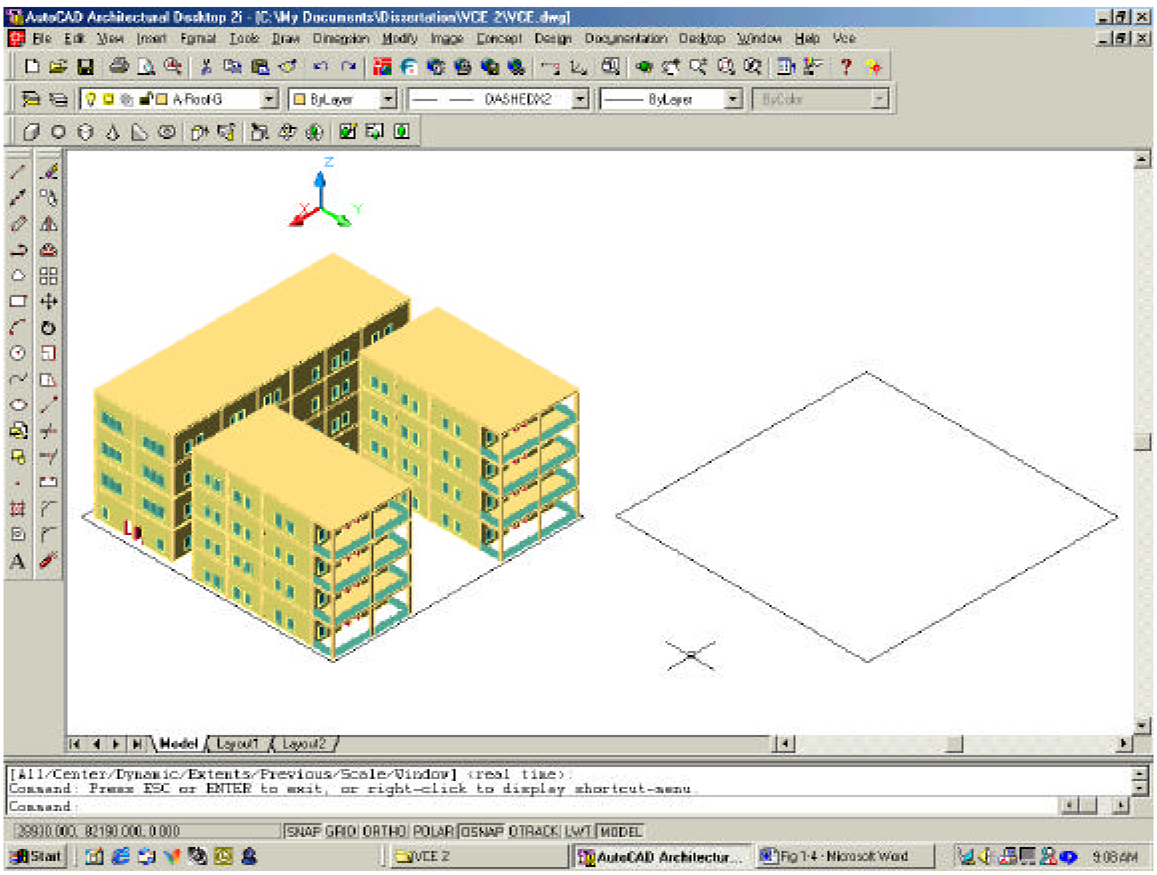
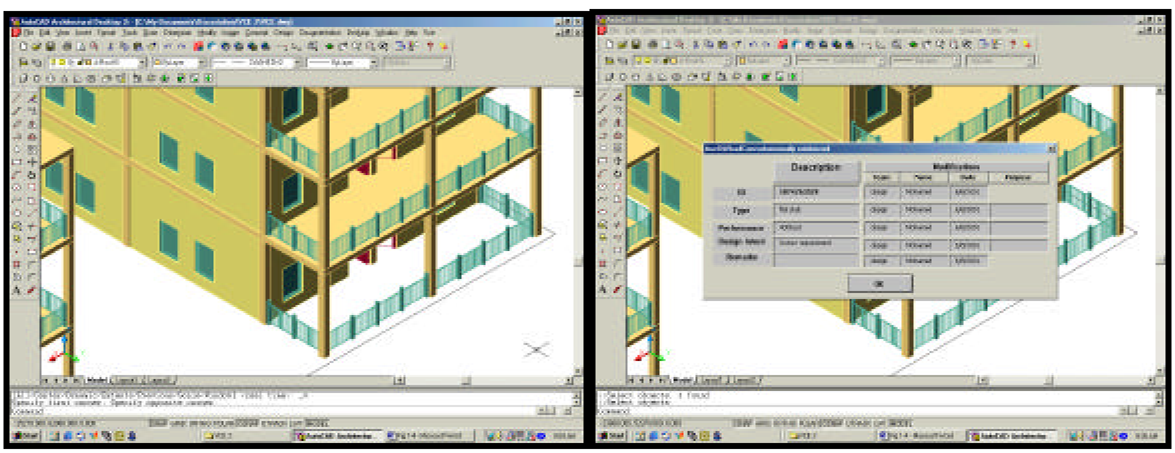


Figure 6-3: The Interactive Virtual Interface (IVI)

This section illustrates the major decisions/actions that the project team may perform during the virtual sessions. First, how the users study the 3D product model and acquire design information is presented. Then, how the project team makes major work execution and site layout planning, checks for equipment maximum reach, as well as reviews/modifies design and planning decisions is described.

6.3.1 STUDY THE 3D MODEL AND ACQUIRE INFORMATION

The project team may choose to start the virtual sessions by studying the 3D product model and by acquiring information on the various systems. To study the 3D product model, the user utilizes navigation tools (e.g. zoom, pan, view) to get closer look and to have different views of the schematic design (Figure 6-4a). To inquire for systems information, the user selects the "*Review*" option from the VCE drop-down menu. Then the user selects "*System Information*" from the sub-menu. A window will pop-up asking the user to select a system. The user selects the system for which information need to be acquired. All information on the system (e.g. type, description, performance, and design intent), as well as information on who made these design decisions, and when and why these decisions were made, are acquired and displayed to the user (Figure 6-4b). The user may review this information but is not yet allowed to make any modification at this stage.



a) Navigate and zoom to get a closer look b) Acquire system information

Figure 6-4: Study the 3D model

Once acquiring all the required information, the project team may start to make major decisions for macro planning. The implemented prototype is flexible and allows the user to select the decision they would like to start with (e.g. decide on assemblies' sequences or select methods). However, some decisions have prerequisites in order to be executed. For example, if the user chooses to allocate resources for the execution of a specific system and no method is yet selected for this system, the user will be alerted that no method is selected for this system. This is due to the fact that the USM will not be able to determine the equipment alternatives (i.e. execute the resources filtering process) that may be used for the execution of the system if no method is identified. In addition, the computer prototype enables the user to make all the interdependent decisions for a specific system simultaneously. By selecting the *"Define"* option from the VCE menu, then *"All"* from the associated sub-menu, the user is able to consecutively decide on the sequence, select a method, allocate an equipment, and place the equipment in its appropriate place.

6.3.2 Decide on Assemblies' Sequences

In order to decide on the major assemblies' sequences, the project team needs to reassemble the 3D objects of the product model, through the perceived order of construction, in the virtual construction site window. The user needs first to select the *"Define"* option from the VCE drop-down menu. Then, the user selects *"Assemblies Sequence"* from the sub-menu. A window pops-up asking the user to specify a base point. This enables the user to reassemble the objects in their exact locations portrayed in the 3D product model. After specifying the base point, the user is prompted to select the object he/she would like to reassemble, and to place it, using the base point, in the virtual construction site window (Figure 6-5). Once this action is accomplished, a window pops-up with information on the predecessor activity, the relationship, and the lag. The predecessor activity is, by default, the last activity that the user had placed in the virtual construction site window. However, the user is able to change the predecessor by selecting another object from the virtual construction site window. The default relationship is Finish-to-Start, but the user is also able to select another relationship from a list of alternatives (i.e. Start-to-Start, Star-to-Finish, and Finish-to-Finish). The default lag is "0", but may be modified to a positive or negative (i.e. lead) number. The user also has to input in this window the name of the activity representing the reassembled object (e.g. construct 1st floor col-a).

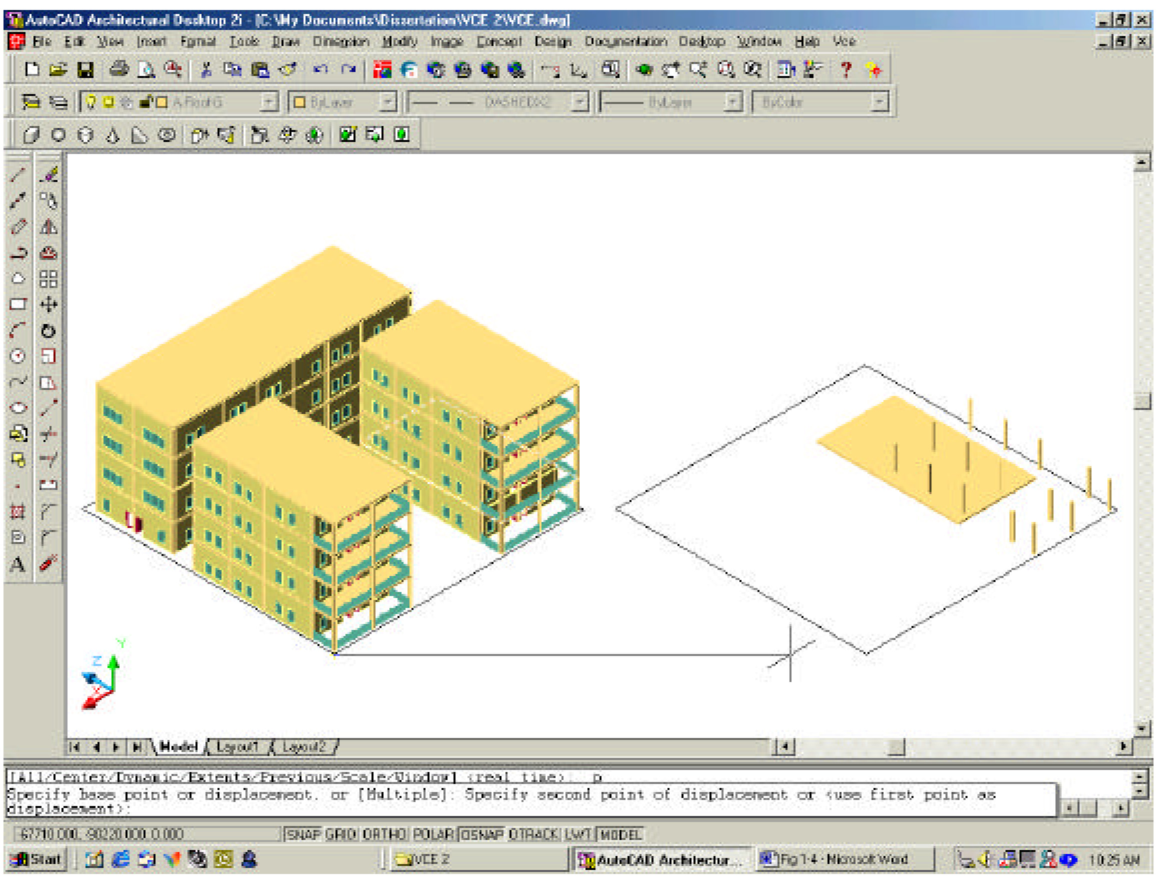


Figure 6-5: Decide on assemblies' sequence

6.3.3 SELECT METHODS

The selection of methods conceivable for the execution of major assemblies/systems is an interactive, easy to perform, step through the VCE. Once the user reassembles an object in the virtual construction site window, he/she will be automatically prompted to select a method for this assembly. This assists in the adequate consideration of the interdependent planning. However, the prototype is flexible and allows the project team to select methods whenever needed during the virtual sessions. The user may select *"Define"* from the VCE menu, then "*Select Methods*" from the sub-menu. A window pops-up asking the user to select the system, for which the method is to be applied. The user selects then a system (e.g. 2nd floor slab) from the virtual construction site window. The IPA extracts required information about this slab from the systems database, filters the conceivable methods, and displays them in a list to the user to select from. For example, if the 1st floor slab is a cast-in-place concrete slab, then alternatives presented to the users will consist of concrete placement methods (Figure 6-6). This is due to the fact that this major operation requires the utilization of major equipment and, hence, is considered during macro planning.

The displayed list of concrete placement alternatives includes information on each method (e.g. maximum output, maximum horizontal and vertical reach, …etc). The user reviews this information, and according to the various constraints and specifics of the situation, along with his/her own knowledge and experience, selects the optimum method (e.g. crane and bucket) for this operation.

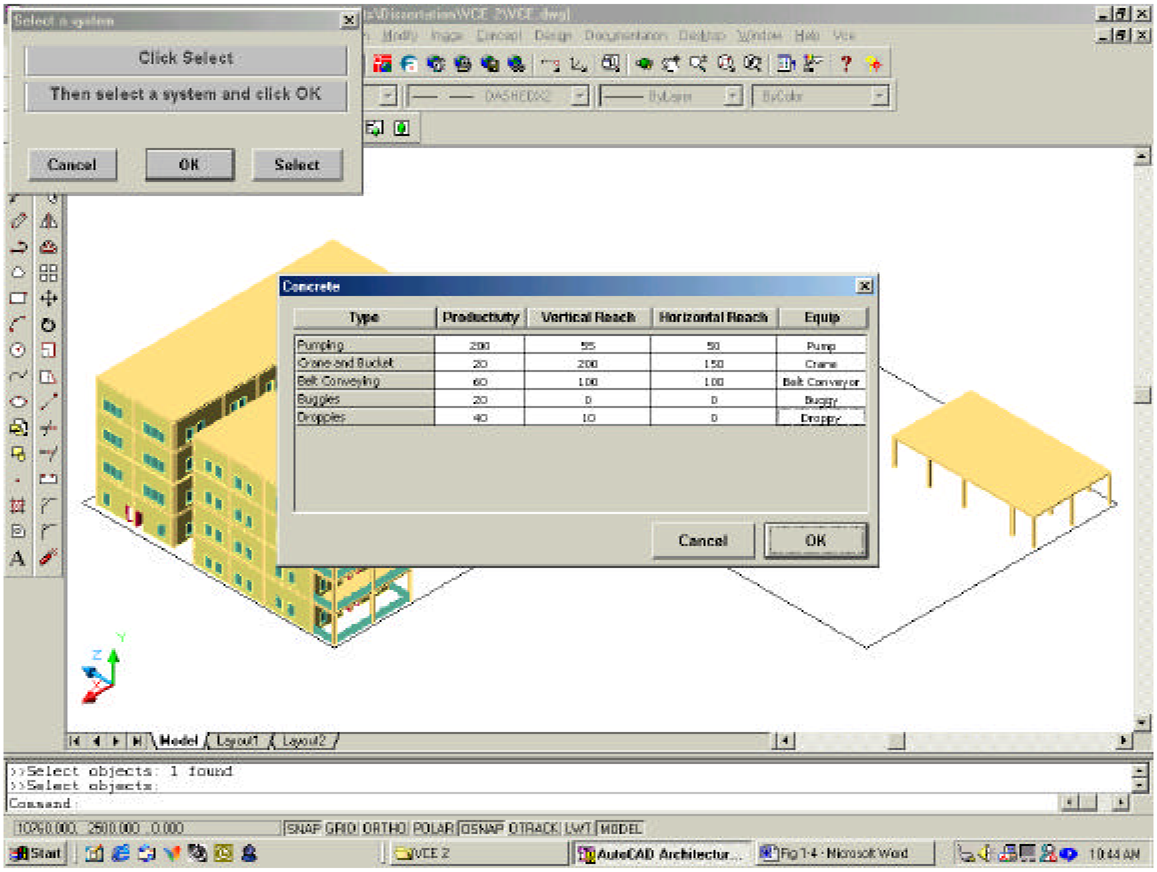


Figure 6-6: List of conceivable methods

6.3.4 ALLOCATE RESOURCES

During the virtual sessions, once the user selects a method, he will be automatically prompted to allocate a resource from a list of available equipment. This enables the project team to consider the equipment that will be utilized while selecting a specific method for the execution of an assembly. If the project team would like to allocate a resource in any other time during the virtual session, the user may selects *"Define"* from the VCE menu, then *"Allocate Resources"* from the sub-menu. A window pops-up asking the user to select the system, for which the resource is required. After selecting a system (e.g. 2^{nd} floor slab) from the virtual construction site window, the IPA extracts required information (i.e. method selected) on this slab from the systems database, filters the available equipment associated with this method, and displays them as a list to the user to select from. For example, f the method selected for the 2nd floor is crane and bucket, then alternatives presented to the users will consist of different available cranes (Figure 6-7).

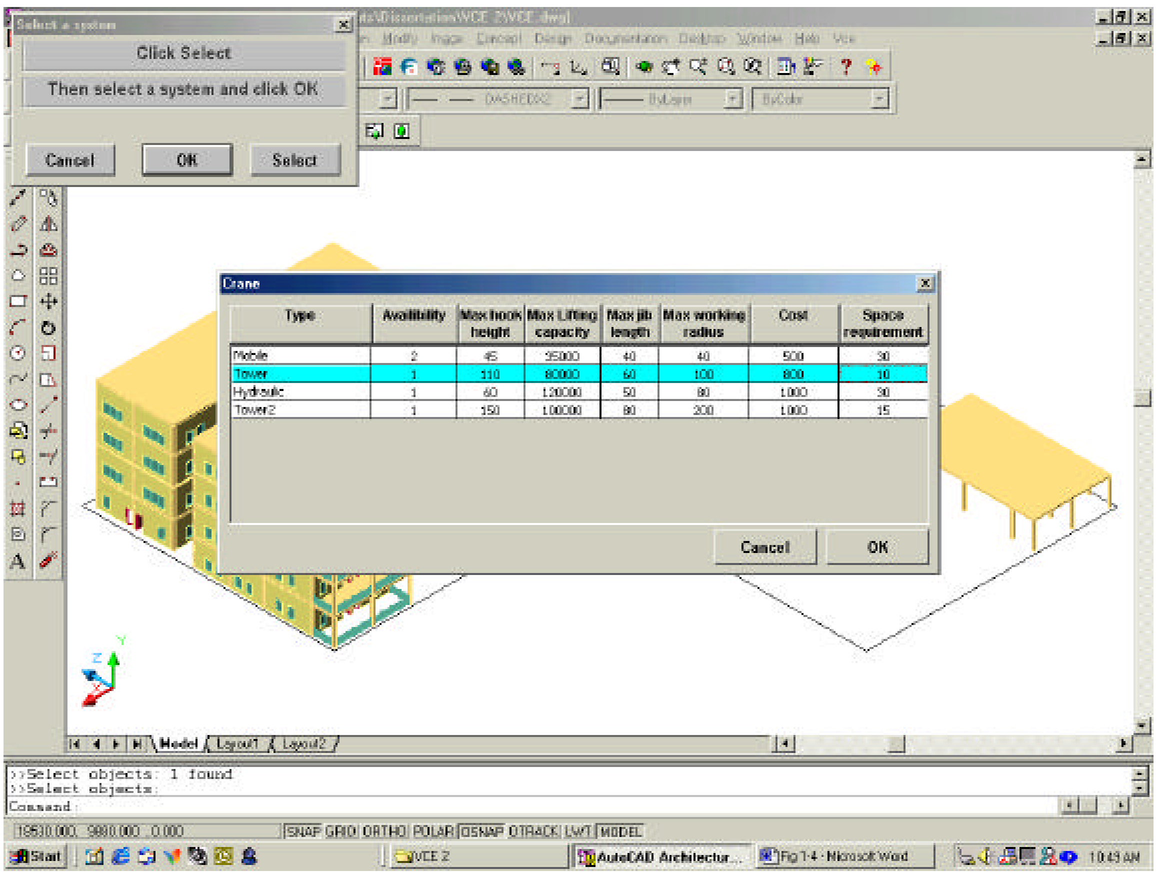


Figure 6-7: Allocate a resource in the VCE

6.3.5 SELECT LOCATION FOR MAJOR EQUIPMENT

This process is executed automatically when the user allocates a resource, and may not be manually executed. Once the user selects a resource from the list of alternatives, a 3D objects representing the piece of equipment is displayed and a window pops-up and prompts the user to select a location for the equipment. The user then places the equipment in its appropriate location (Figure 6-8).

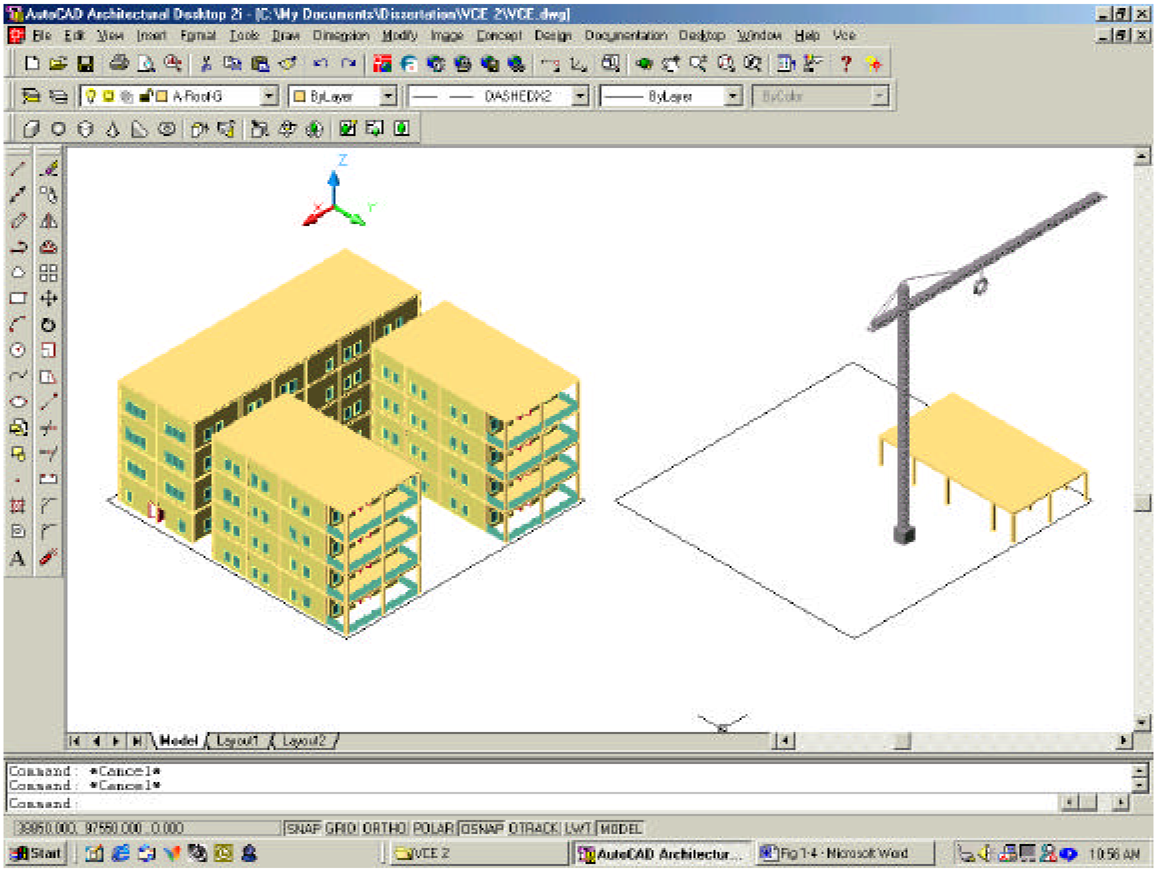


Figure 6-8: Place the crane in its optimum location

6.3.6 CHECK FOR MAXIMUM REACH

This process is implemented as an example of the constructability checks that the VCE can perform. To check for the maximum reach of specific equipment, the user selects *"Check Max. Reach"* from the VCE menu. The user is then prompted to select the equipment for which maximum reach need to be checked. After selecting the equipment, the view changes automatically to a top plan view in order to enable the user to better inspect the equipment maximum reach. Then a circle that represents the crane maximum reach is drawn.

The user is also able to rotate the crane to visually check for all the places that this crane may reach (Figure 6-9).

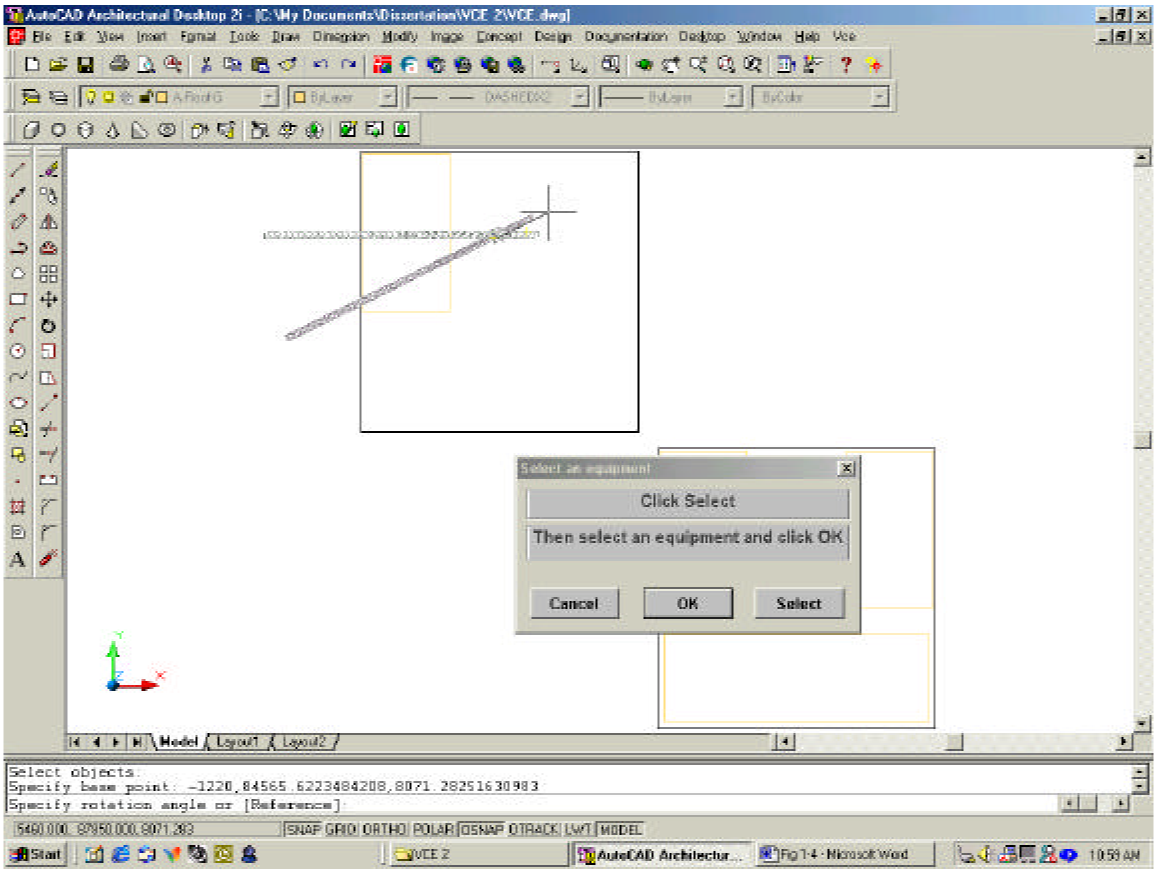
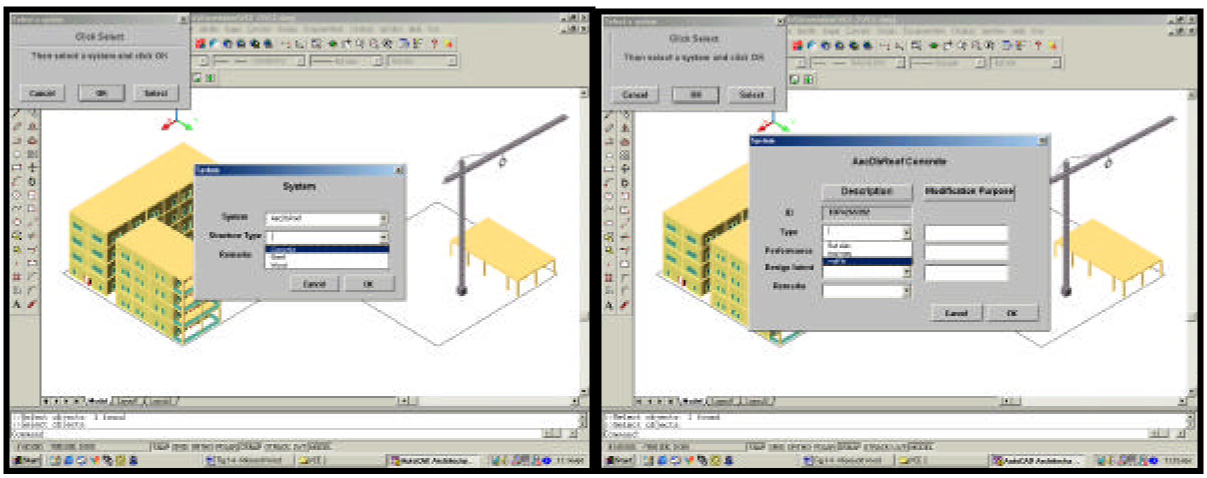


Figure 6-9: Check crane's maximum reach

6.3.7 MODIFY DESIGN DECISIONS

During the virtual sessions, the project team may encounter problems that require a design change. The implemented computer prototype enables the user to easily make these changes. Two pop-up menus are utilized to modify the type, performance, design intent, …etc of the systems. According to the system specified (e.g. slab, wall, …etc), the drop-down list of the first window includes alternatives conceivable for this system. For example, if the system specified is a slab, then alternatives for the structure type/description includes concrete, steel, and wood (Figure 6-10a). Also, according to the user selection in the first menu, the drop-down list of the second window includes alternatives applicable to that selection. For example, f the user selects “concrete” as the slab type, then alternatives will include “waffle”, “One-way”, “two-way”, … etc for the slab type (Figure 6-10b). The changes are then saved. The design team may come back later, review these changes, and approves them or not.



a) Alternatives for the structure type b) Alternatives for the system type

Figure 6-10: Modify design decisions

6.4 EXAMPLES OF THE VCE APPROACH FOR MACRO PLANNING

In order to illustrate the difference between using the current manual approach and the VCE approach for macro planning, this section presents the three examples discussed in chapter 3. Though, this time, we describe how the project team may use the VCE for planning these projects. By comparing the two approaches, it becomes obvious how the VCE facilitates the job of the project team, and enable them to easily acquire various information, make major decisions, and depict some problems that may arise during construction.

Example 1 – MAKING INTERDEPENDENT PLANNING DECISIONS:

This example illustrates the manual approach for:

- Extracting information.
- Sequencing Assemblies.
- Selecting Methods.
- Allocating resources.

Background

During planning a construction project at the macro level, the project team makes various interdependent work execution decisions. This example describes how the VCE users may extract necessary information and make these decisions for a couple of work packages.

Decision Making Process

1) **Study the schematic design**: This is performed *by navigating through the 3D product model, and by directly interacting with the 3D objects* to acquire required information on the product model.

2) **Decide on appropriate sequence**. According to their knowledge and experience, the project team starts to re-assemble the 3D objects of the product model in the perceived order of construction. Being able to drag and drop the objects in the virtual construction site window allows the project team to visualize the construction process more efficiently. While the project team is reassembling the 3D objects, the VCE is developing the logical sequence for these assemblies (Figure 6-12).

3) **Select methods for concrete placement and brick handling.** While reassembling the 3D objects, the project team is able to interactively make various interdependent planning decisions. To select appropriate methods, the project team needs to acquire information on the methods previously used for such operations. This is performed *by directly interacting with the 3D objects* (Figure 6-13). The project team, then, decides to use pumping for concrete placement and a crane for brick handling.

4) **Allocate appropriate resources**. While selecting the method for a work package, the project may also allocate the equipment associated with this method. This requires reviewing the types of pumps and cranes available in the company and acquiring information (e.g. maximum reach and maximum lifting capacity) on these pieces of equipment (*by directly interacting with the 3D objects*) as well as on the structure parameters (*by directly interacting with the 3D product model*).
   Based on this information, along with the project team's knowledge and experience, a specific pump and crane are allocated.

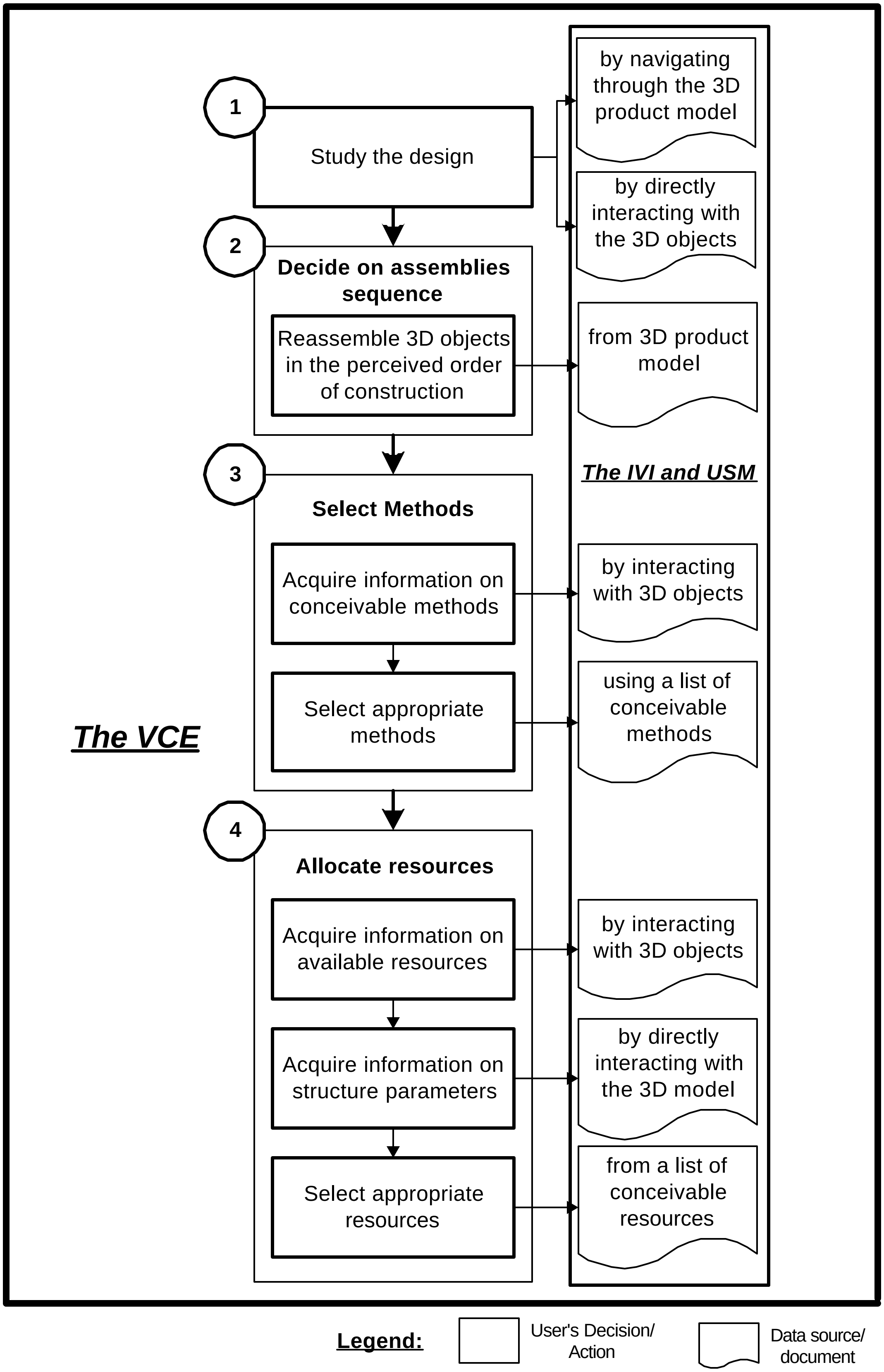


Figure 6-11: Flow chart of example 1: Making interdependent planning decisions

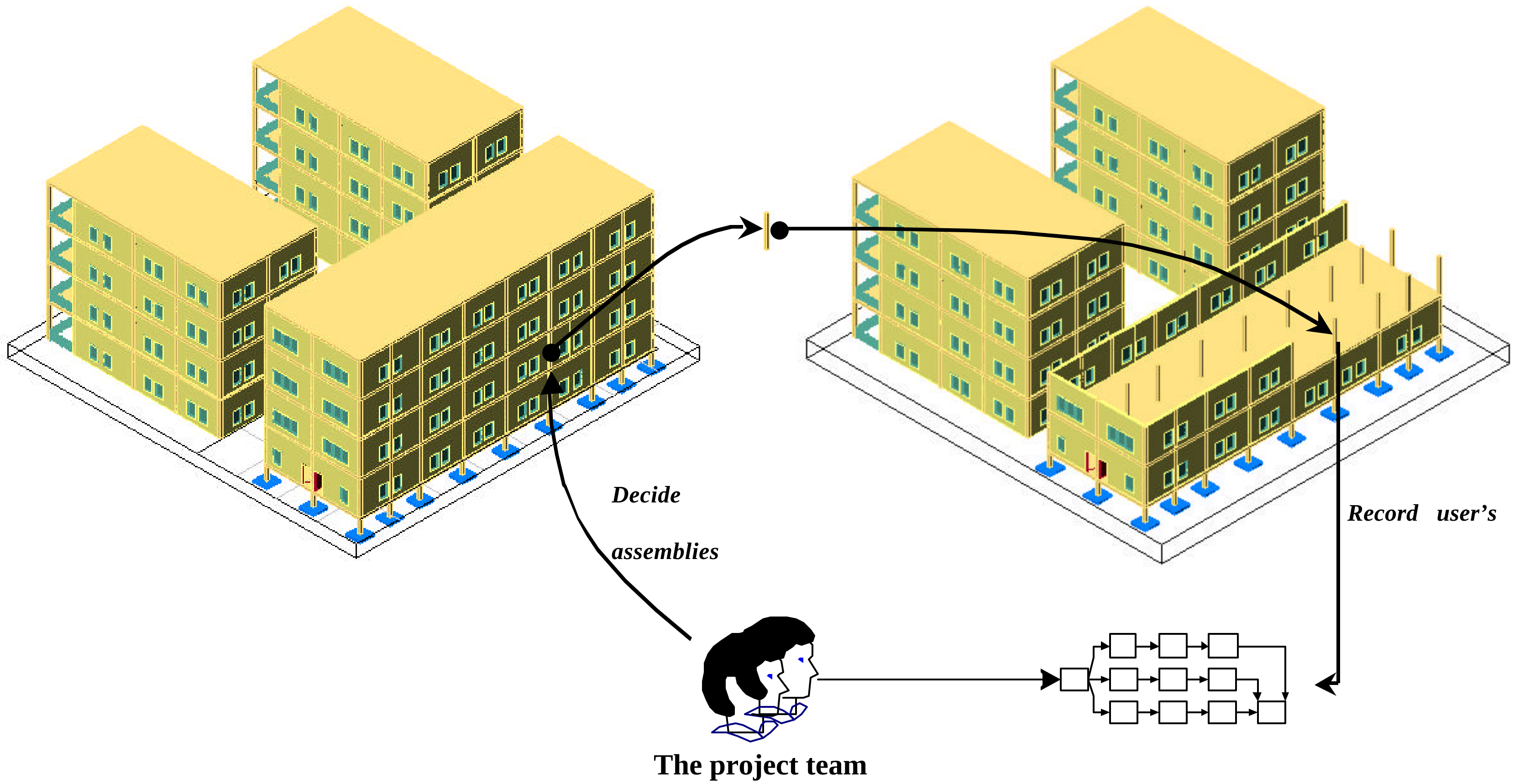
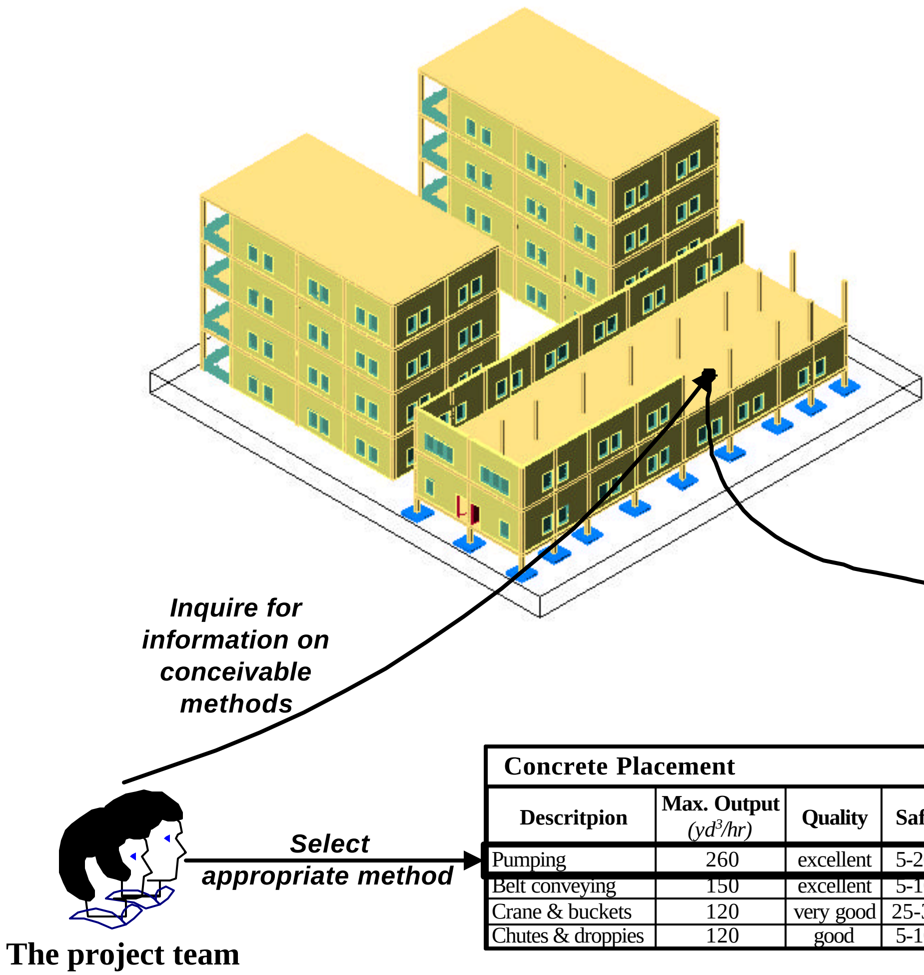


Figure 6-12: Develop logical network



Concrete Placement

Descritpion	Max. Output (yd^3/hr)	Quality	Safety	Resources requirement	Max. Vert. reach	Max. Horiz. Reach	Reach depth
Pumping	260	excellent	5-20%	pump and ready-mix truck	180'0"	167'0"	135'0"
Belt conveying	150	excellent	5-10%	Belt conveyor	100'0"	200'0"	NA
Crane & buckets	120	very good	25-30%	Crane	200'0"	300'0"	NA
Chutes & droppies	120	good	5-10%	Chutes	80"o"	10'0"	10'0"

Figure 6-13: Select appropriate method

Advantages of using the VCE in this example:

1) The ability to reassemble the 3D objects to develop an appropriate sequence of major assemblies allows the project team to visualize how the design will be implemented on site. This feature is extremely helpful and solves the problem of inaccurate visualization of the construction process when using 2D drawings.

2) The project team is able to make all interdependent planning decisions interactively and simultaneously.

Example 2 – SELECTING LOCATION FOR MAJOR EQUIPMENT:

This example illustrates the VCE approach for:

- Acquiring information.
- Allocating resources.
- Selecting major equipment location.
- Checking crane's maximum reach.

Background

During planning the execution of a building in a metropolitan area, the construction team decides to utilize a tower crane to perform major operations for this project. This decision is based mainly on the project criteria, as well as the construction team's knowledge and experience.

Decision Making Process

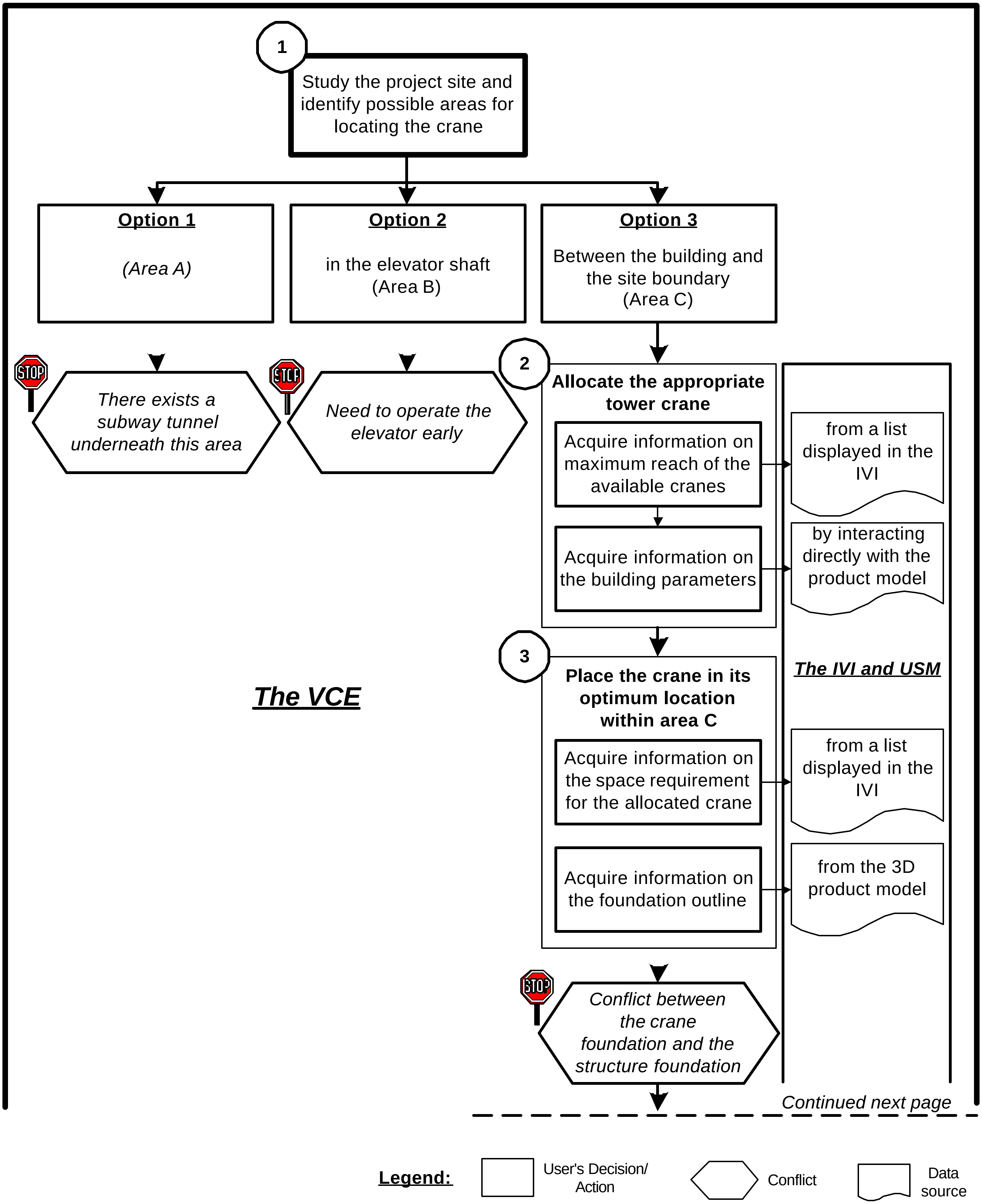
5) **Study the project site and identify possible areas for the crane locations**: This is performed by navigating into the project site and manipulating the 3D objects of the product model. This enables the users to identify three potential options for the location of the crane (Figure 6-15).
   - Option 1: in **area A**
     Conflict*: there exists a subway tunnel underneath this area. This information is collected during site investigation and is presented through the 3D product model. No tower crane may then be placed in this area.*
   - Option 2: in the elevator shaft (**area B**).
     Conflict*: the project team needs to operate the elevator early. So this option is excluded.*
   - Option 3: Between the building and the site boundary (**area C**) - the only feasible location.

6) **Allocate the appropriate crane.** The project team, then, has to allocate a tower crane that can reach all the required locations from this location (i.e. area C).
   This required acquiring information on the maximum reach of the available cranes *(from a list displayed in the IVI*), as well as information on the structure parameters *(by interacting directly with the 3D product model).*
   Based on this information, along with the construction team's knowledge and experience, a specific tower crane is allocated.

7) **Place the crane in its optimum location with in area C**. This requires from the construction team, first, to gather information on the space requirement for this crane *(from a list displayed in the IVI*).
   Conflict*: Due to the limited space available between the structure and the site boundary, there existed a conflict between the crane foundation and the structure foundation.*
   This conflict is easily depicted when the users are trying to place/superimpose the 3D object representing the carne in its optimum location (Figure 6-16). If this conflict is not depicted early, it would cost a lot to fix it.

8) **Shift the crane location**. To solve this conflict, the project team tries to shift the crane location around the structure *(by moving the 3D object representing the crane to different possible locations in the virtual construction site window)*. For each new location, the construction team reviews the space availability for the crane, and the maximum reach *(by clicking on a button, which draws a circle that represents the crane's reachable area, and by enabling the users to rotate the crane and visually check for maximum reach)* to ensure that the crane will still be able to reach all required places from this location.
   Conflict*: The foundation conflict remains unsolved.*
   So the project team decides to place the crane outside the site boundary.
   Conflict*: This is not possible being in a downtown area.*

9) Finally, the construction team informs the design team that they require a modification to one of the footing design *(by making a mark on the specified footing and stating it in text)* so it can pick up the load of the column plus the load of the tower crane. The structural engineer reviews the design and the identified footing was modified.


1
Study the project site and identify possible areas for locating the crane
Option 1
(Area A)
Option 2
in the elevator shaft (Area B)
Option 3
Between the building and the site boundary (Area C)
STOP
There exists a subway tunnel underneath this area
Need to operate the elevator early
2
Allocate the appropriate tower crane
Acquire information on maximum reach of the available cranes
from a list displayed in the IVI
Acquire information on the building parameters
by interacting directly with the product model
The IVI and USM
The VCE
3
Place the crane in its optimum location within area C
Acquire information on the space requirement for the allocated crane
from a list displayed in the IVI
Acquire information on the foundation outline
from the 3D product model
Conflict between the crane foundation and the structure foundation
Continued next page
Legend:
User's Decision/ Action
Conflict
Data source

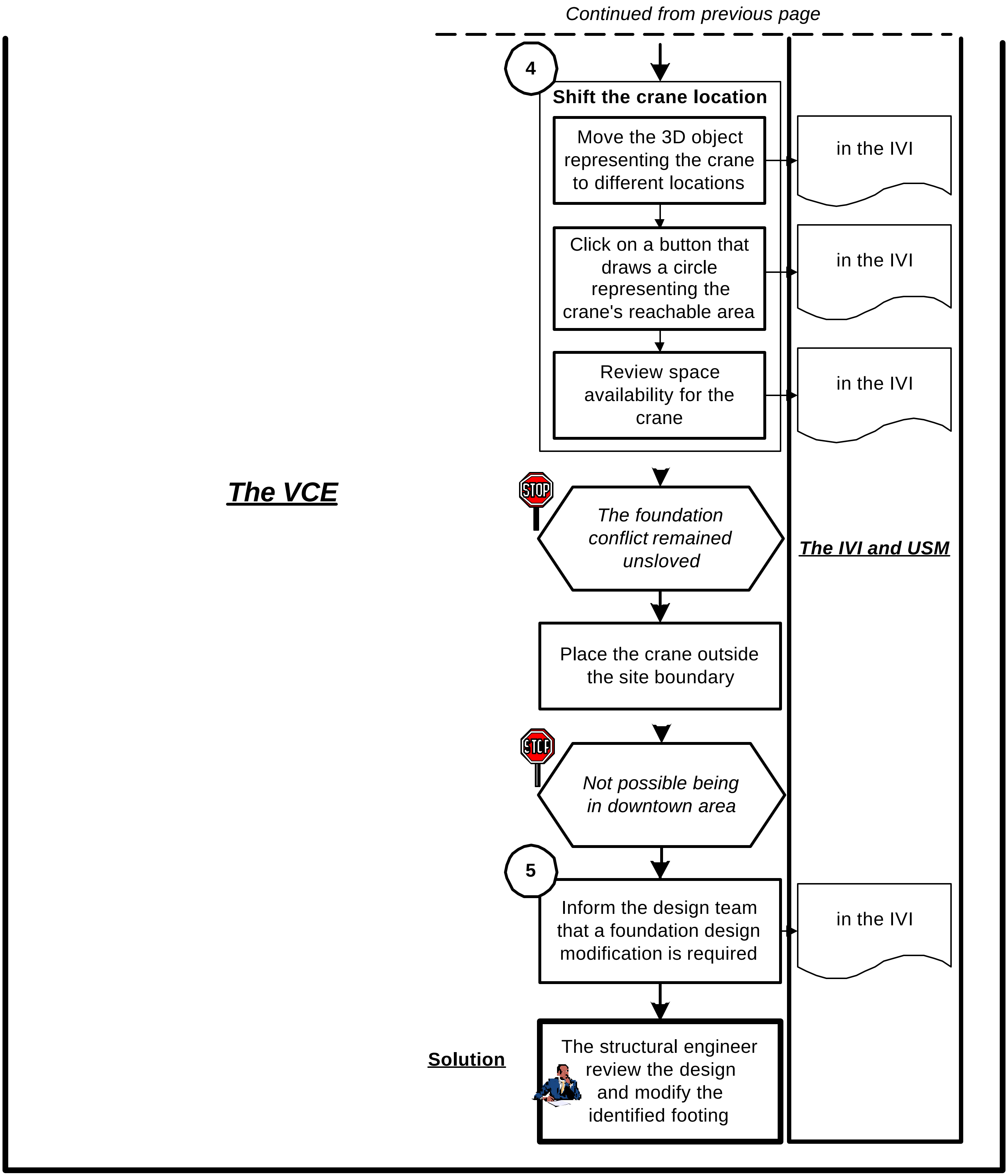
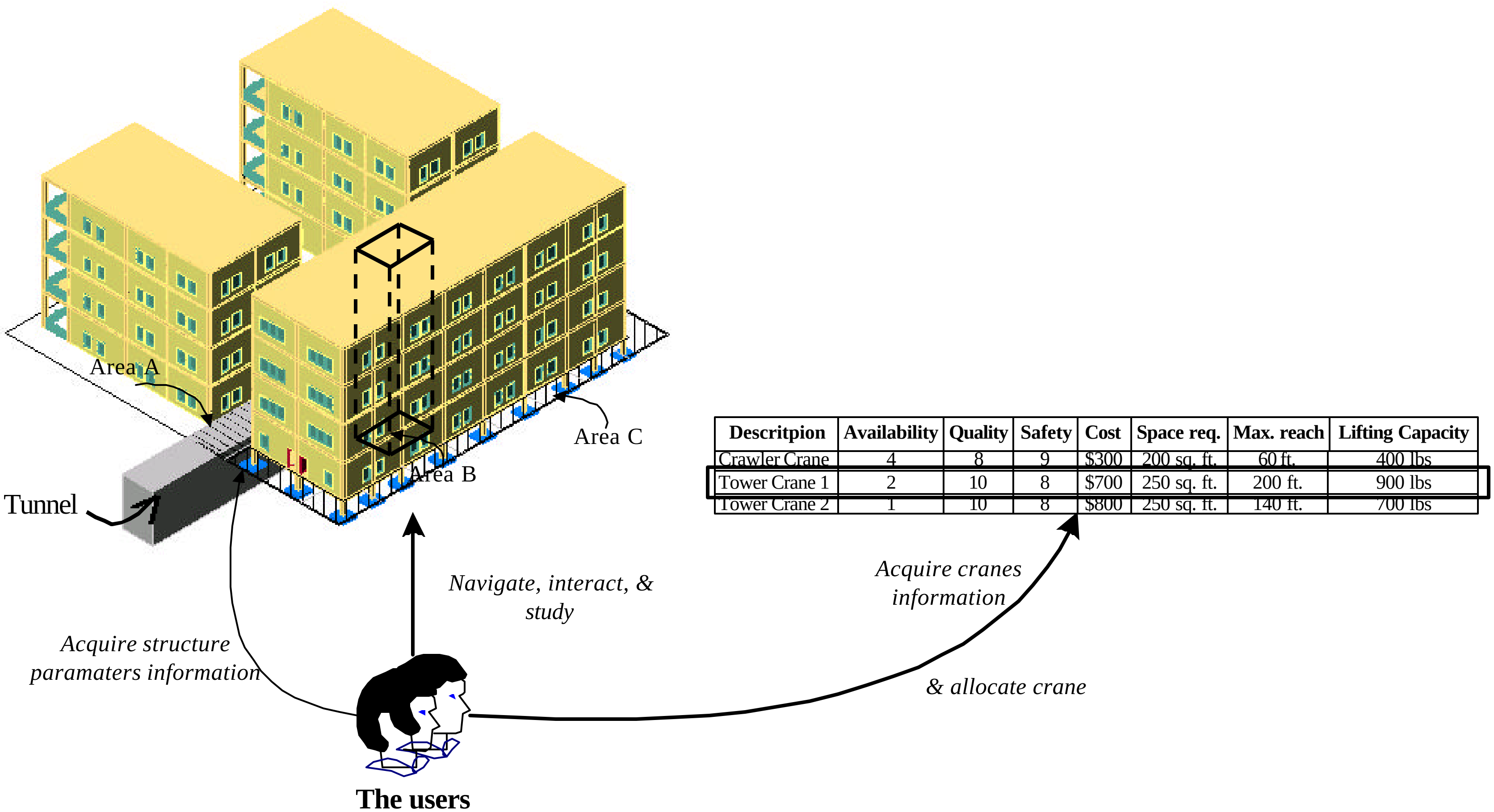


Figure 6-14: Flow chart of example 2 – Selecting Location for Major Equipment



Descritpion	Availability	Quality	Safety	Cost	Space req.	Max. reach	Lifting Capacity
Crawler Crane	4	8	9	$300	200 sq. ft.	60 ft.	400 lbs
Tower Crane 1	2	10	8	$700	250 sq. ft.	200 ft.	900 lbs
Tower Crane 2	1	10	8	$800	250 sq. ft.	140 ft.	700 lbs

Figure 6-15: Identify possible areas for the crane location

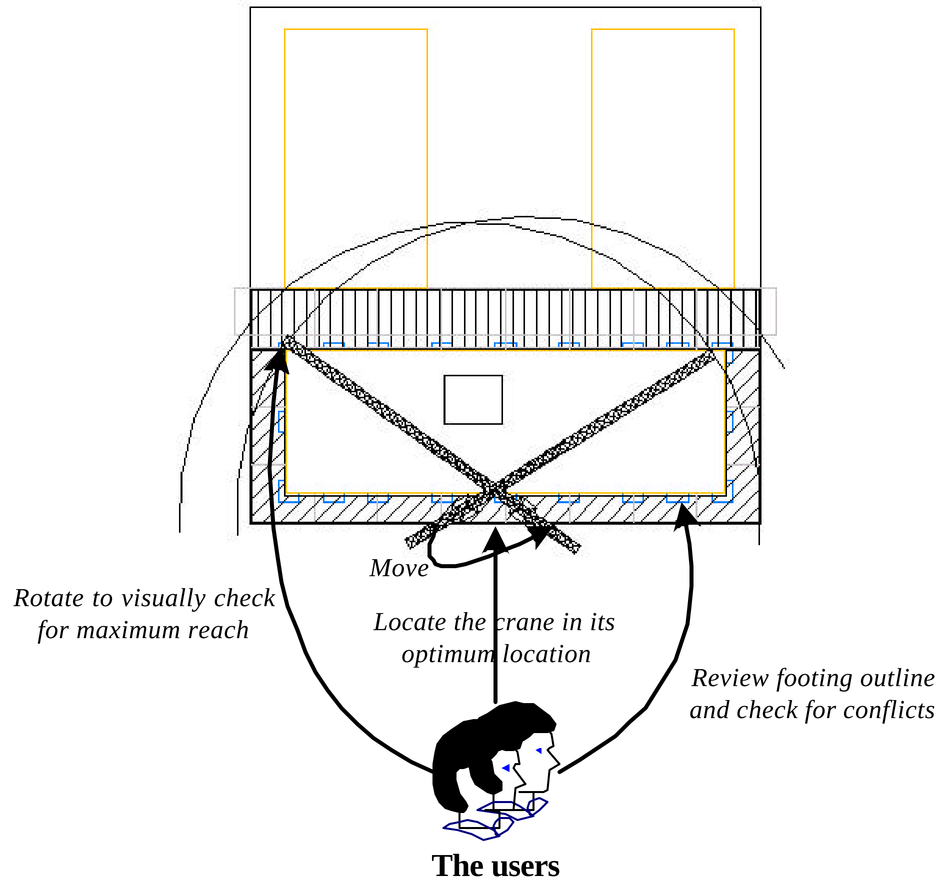


Figure 6-16: Place the carne in its optimum location and check for conflicts

Advantages of using the VCE in this example:

3) All required information attached to the 3D product model and can be easily retrieved. On the other hand, using the current manual approach, the construction team had to extract this information from:
   - Various data sources including the site layout and foundation plan drawings, different equipment manuals, and the site report.
   - Other individuals who may be difficult, or time consuming, to reach or to get their input.

   This may be confusing and time consuming.

4) Superimposing the crane on its optimum location enabled the users to depict the footing conflict, which may have been undetected if using the manual approach. This is due to the fact that the construction team usually utilizes the site layout plan for locating major equipment. This drawing lacks many other important information such as existing underground objects, footing foundation.

5) By rotating the tower crane in the VCE, the users can check for maximum reach and can easily move the crane to various locations until deciding on the optimum one. This eliminates manual drawing and erasing.

Example 2 – MODIFYING DESIGN DECISIONS:

This example illustrates the manual approach for:
- Acquiring information.
- Reviewing the design.
- Modifying the design.
- Collaboration between the design and construction team.

Background

While reviewing the schematic design drawings, the construction team found that the cost for implementing the design is greater than the initial maximum price guaranteed (IGMP) to the owner. The construction team then attempted to identify systems that may be modified to reduce the project total cost.

Decision Making Process

In order to identify systems that may be modified to reduce the project total cost, the construction team has to:

10) **Review the design.** This is performed by navigating through the 3D product model and directly interacting with the 3D objects to acquire required information (e.g. system type and description) (Figure 6-18).

    While reviewing the 3D product model, the construction team depicted an extension to the building that will begin in 6 months, which will lead to the destruction of one of the exterior walls (East Side).

11) **The construction team then suggests modifying the system of the east wall from Brick to Stucco.** This is performed by marking the 3D object representing the East wall, and by selecting "Stucco" from the list of alternatives displayed to the users (Figure 6-19).

12) **The design team reviews the suggested modification** *(by directly interacting with the 3D object representing the east wall)* **and approves the changes**. The project has then been reduced down to the initial guaranteed maximum price.

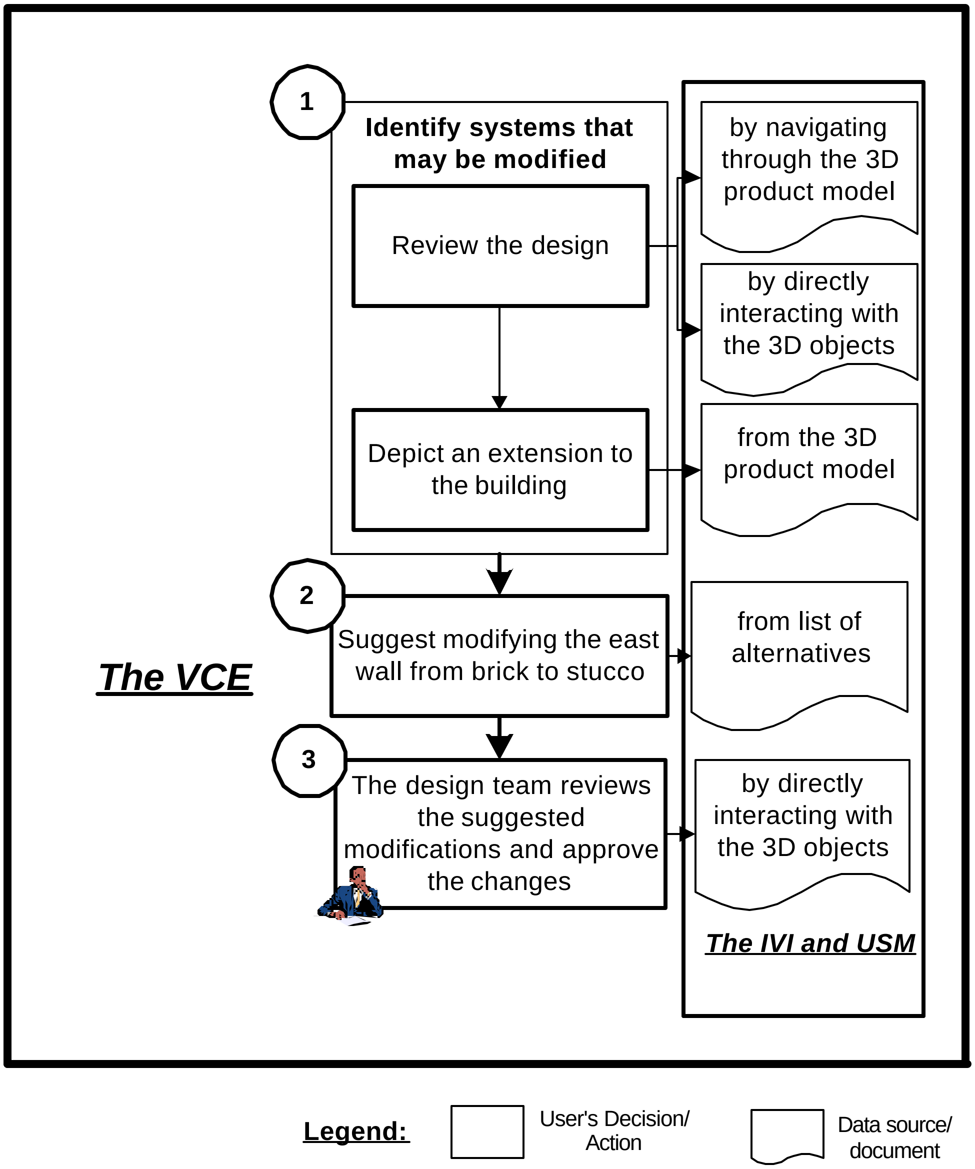


Figure 6-17: Flow chart of example 3 – Modifying Design Decisions

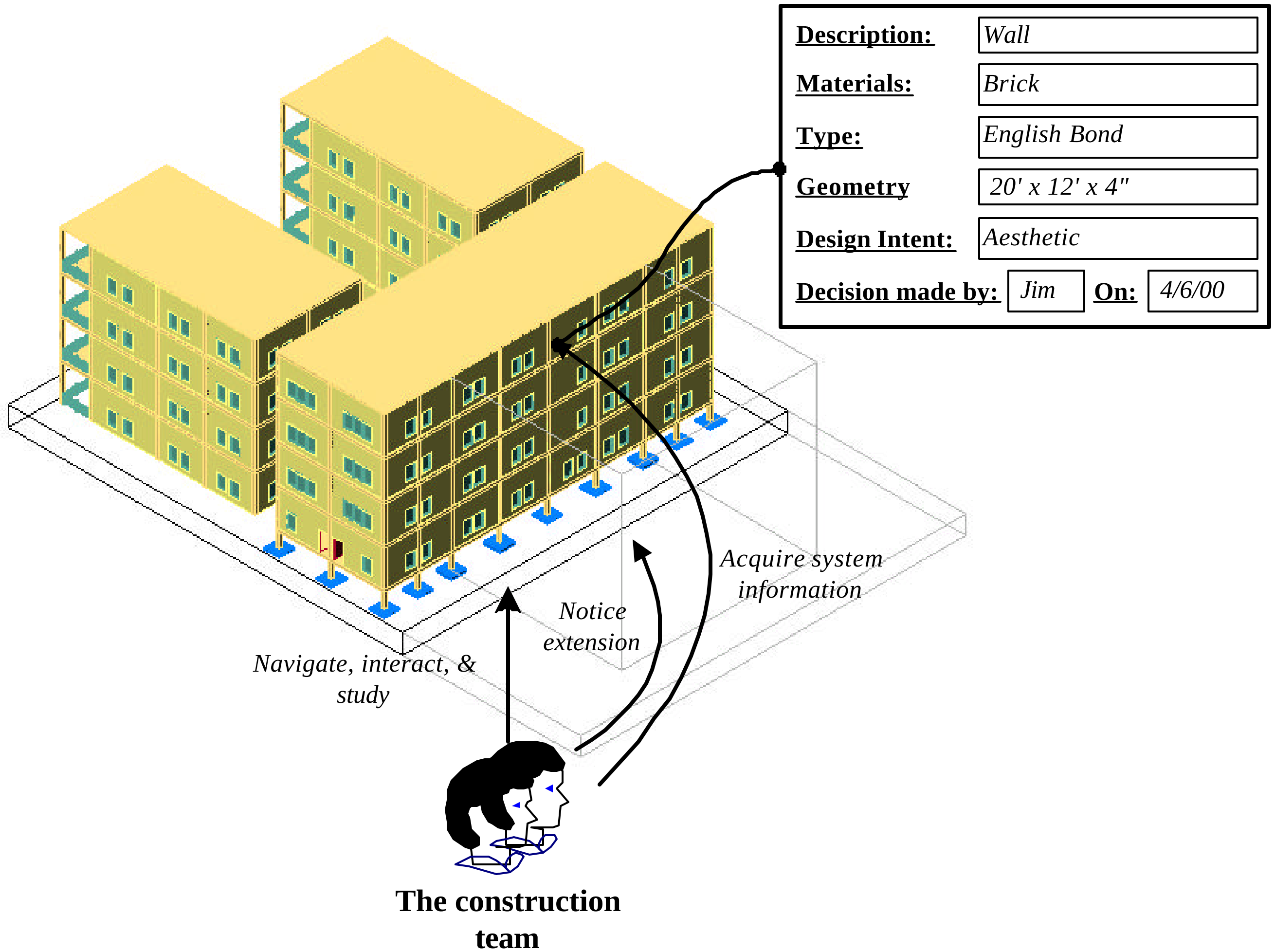


Figure 6-18: Review design and acquire necessary information

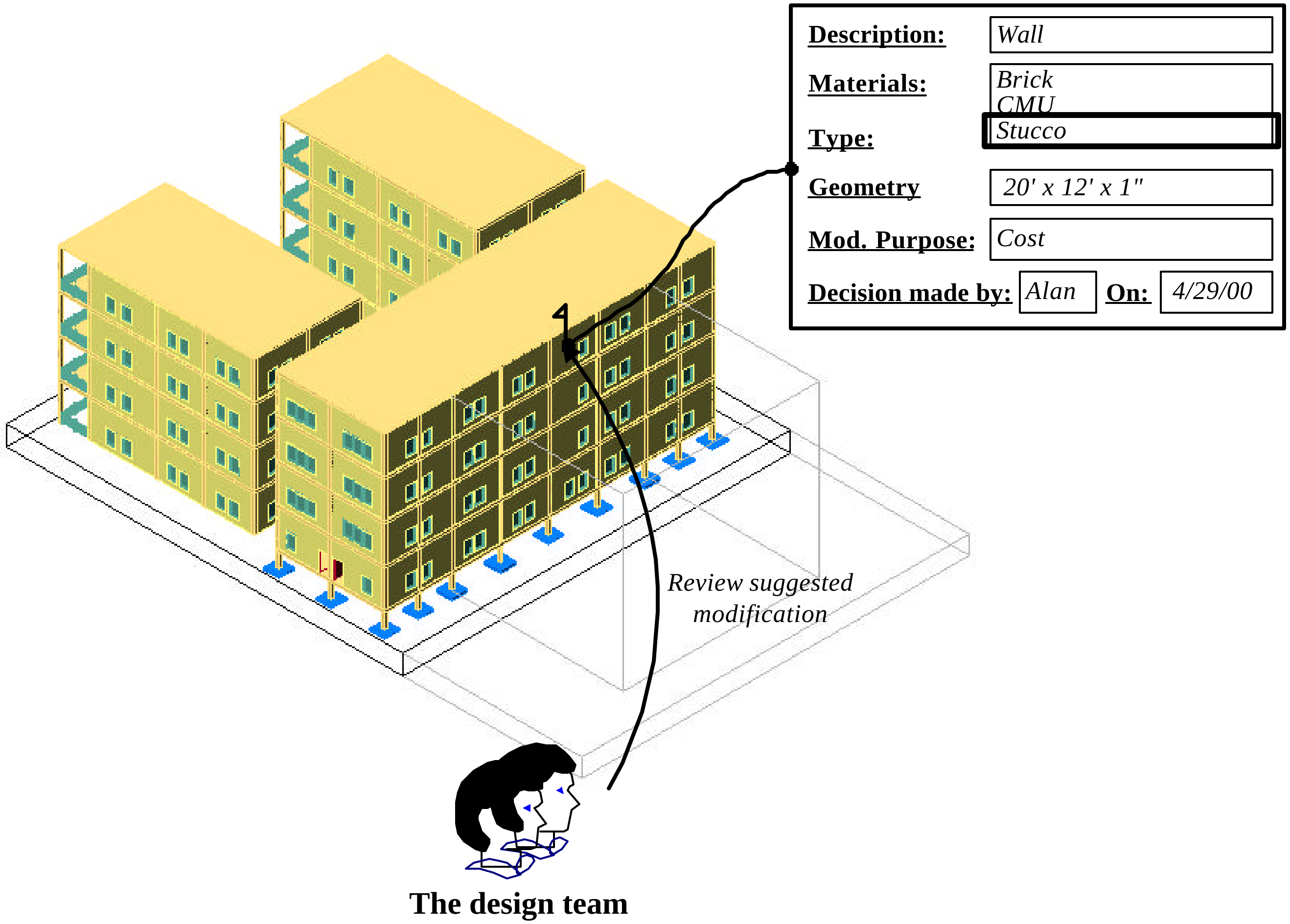


Figure 6-19: The design team reviews the suggested modification

Advantages of using the VCE in this example:

1) The use of a 3D product model and the ability to navigate through this model, along with necessary information presented in an easy to visualize and understand format enabled the construction team to detect the extension of the building. This information was not discovered using the manual approach.

2) The ability to suggest changes in the VCE provides for easy collaboration among project participants. The construction team marked the system that needs to be modified, identified the purpose of modification, and suggested alternatives. This information was then easily acquired by the design team.

6.5 CONCLUSION

This chapter presented the computer prototype implemented to illustrate the framework of the VCE. Various examples were used in this chapter to apply the major functions of the VCE, as well as to illustrate how the users interact with the environment. The chapter also presented the use of the VCE for the three examples discussed in chapter 3. This illustrated the benefits that the VCE approach has over the current manual approach.

7. SUMMARY AND CONCLUSION

7.1 INTRODUCTION

This research presents the framework for a new interactive planning environment called the **V**irtual **C**onstruction **E**nvironment (**VCE**) that supports the thinking process of the project team during the macro planning phase of design-build projects. Unlike previous responsive-type systems developed, the approach utilized in the VCE is supportive to the project team enabling the users to be an active participant in the decision making process.

The main purpose of the VCE is to assist the project team during decision making, by providing pertinent information necessary for making appropriate decisions in a structured format. This information may be organized, stored, and retrieved by users whenever needed during the virtual sessions. The VCE also provides the project team with appropriate tools to test different work execution and site layout planning scenarios early during project development. During the virtual sessions, the project team re-constructs the facility by bringing graphical elements together. Users' movements and interactions are recorded to capture their thinking process on how to construct the facility (i.e. sequence of major assemblies). Other planners can retrieve recorded decisions for further review or modification. The users are also able to specify construction methods, and allocate resources required for the implementation of major assemblies. The VCE guides the project team to perform these interdependent planning functions interactively and concurrently. Using system graphical libraries, major equipment and temporary facilities can be superimposed and displayed as graphical objects for site layout planning. This enables the users to visually check for space and accessibility conflicts during different virtual construction time intervals.

In order to provide the VCE users with information necessary for decision making in an easy to acquire format, the author has developed a **MA**cro **P**lanning **I**nformation **C**lassification (**MAPIC**) model under which information required for macro planning decision making can be classified and organized in a structured format. The project team may then retrieve and utilize this information whenever needed during the virtual sessions.

A prototype computer tool is developed to illustrate the framework of the VCE. The computer prototype is implemented on available commercial software packages. An Object-oriented Computer Aided Design (OOCAD) package – AutoCAD Architectural desktop 2.0

– and a Database Management System (DBMS) – Microsoft Access 2000 – are utilized to implement the different components of the VCE. Programming is performed mainly to customize the AutoCAD interface to reflect the functions required, to connect the CAD package with the DBMS, and to implement the procedures of the VCE. The required code is written using Visual Basic for Applications.

7.2 SUMMARY OF THE MAPIC MODEL

The author has developed a **MA**cro **P**lanning **I**nformation **C**lassification (**MAPIC**) model under which information required for macro planning decision making can be classified and organized in a structured format. The MAPIC model arranges macro planning information into various categories: "**MANAGERIAL**", "**FACILITY/STRUCTURE**", "**CONSTRUCTION TECHNOLOGY**", and "**PROJECT SITE**". The "**MANAGERIAL**" category is divided into "STRATEGY" and "CONTRACTUAL" classes; the "**FACILITY/STRUCTURE**" category into "PARAMETERS" and "SYSTEMS" classes; the "**CONSTRUCTION TECHNOLOGY**" category into "MEANS AND METHODS" and "RESOURCES" classes; and the "**PROJECT SITE**" category into "ACCESSIBILITY", "SPACE", and "CONDITION" information classes. Each of these classes is further divided into subclasses, and contains attributes that define the characteristic of the information required. Information required for decision making may be gathered and stored under its relative category in the MAPIC model. The structured classification assists the project team to retrieve and utilize this information whenever needed without having to unnecessarily extract it several times from the various data sources.

7.3 SUMMARY OF THE VCE FRAMEWORK

The VCE consists of two components: an Interactive Virtual Interface (IVI), and a set of User Support Modules (USM). Planning decisions developed by the users are based on a dynamic interaction between the user and these two components during the interactive virtual sessions.

The IVI is a dynamic virtual setting that allows the project team to rehearse constructing the facility in a near reality sense. The virtual rehearsals are based on manipulating and modifying a pre-defined 3D product model of the facility. While navigating and interacting with the 3D product model, the project team is able to analyze project constraints and test alternative execution sequences and methods.

The IVI consists of two windows: the 3D product model window (left) and the virtual construction site window (right) (Figure 7-1). The 3D product model window is where the object-oriented 3D CAD model generated during design development and comprising entities of the project facility will be imported to the IVI. The core of the IVI module is a virtual construction site window. At the beginning of the virtual sessions, this window is empty. During the virtual sessions, users are able to drag graphical assemblies from the 3D model window and re-construct the facility in the virtual construction site window by bringing components together in the perceived order of execution. During each interactive step, decisions on the construction of the assembly can be made. Major construction methods and resources can be selected and attached to each assembly/system. Initial design intent can be reviewed, and questions can be posed to the designer on potential changes. As the user constructs the facility, user decisions are recorded to capture their thinking process on what methods will be used and the order in which the assemblies will be constructed. User

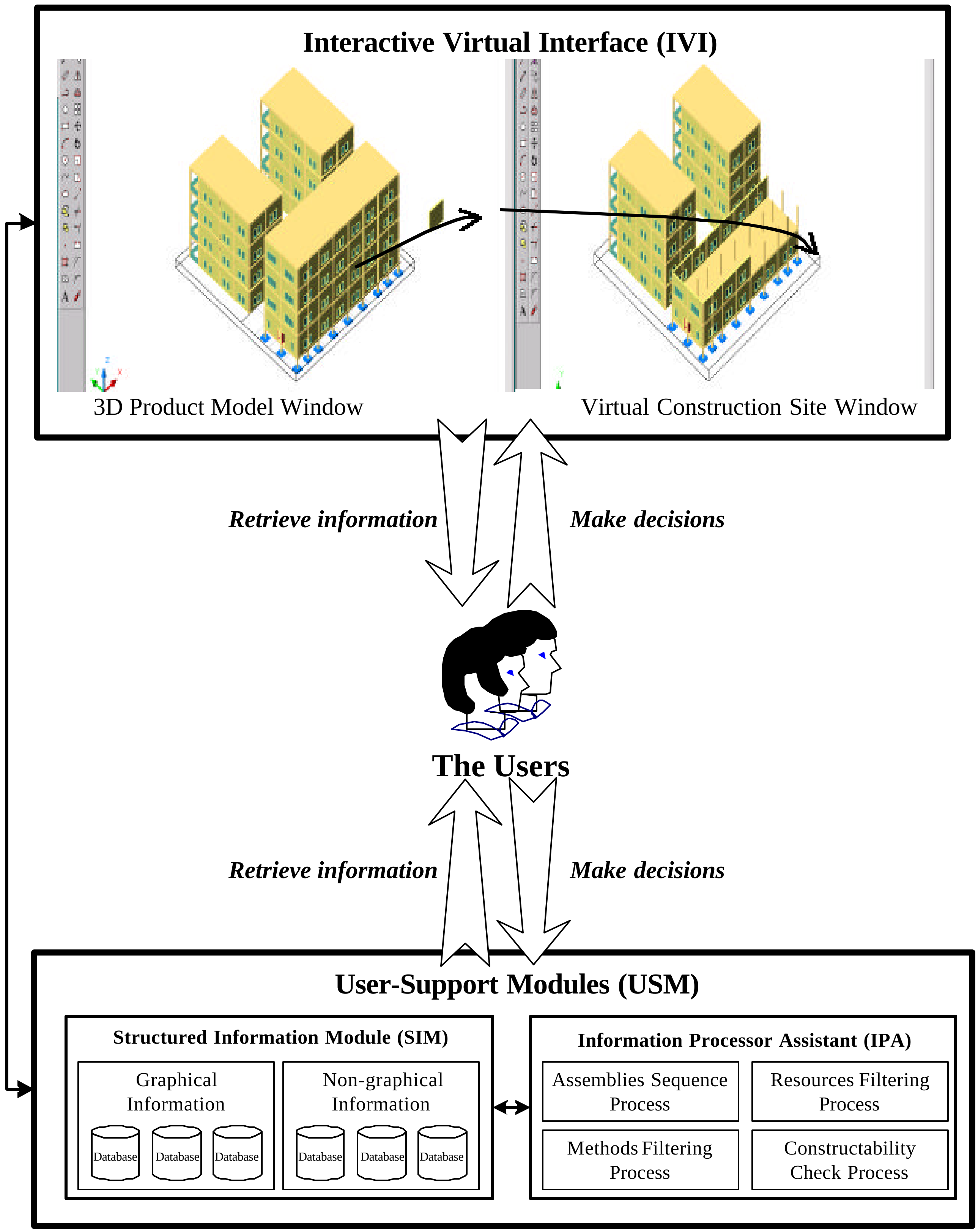


Figure 7-1: The VCE framework

decisions recorded during the virtual sessions can be retrieved for further modifications/review by other planners, either independently or collaboratively.

The User-Support Modules (USM) provide the project team with support information necessary for decision-making. This enables the project team to review and extract relevant information based on the specifics of each individual situation. The modules also enable the project team to store and query decisions made, which allows for collaboration among the project team members.

With reference to Figure 7-1, the USM consists of two main parts: the Structured Information Module (SIM) and the Information Processor Assistant (IPA). The SIM formulates the way the project team retrieves information in the VCE. The SIM includes two main categories of information representation: *Graphical information*, and *Non-graphical information*. Graphical information is information associated with 3D objects in the CAD environment. Visualization of this information is performed through the manipulation of 3D objects in the IVI. Non-graphical information is mainly textual information unrelated to 3D objects in the CAD environment. This information is presented to the VCE users through electronic document format (e.g. PDF) that may be browsed whenever needed from within the IVI. Different databases – Means and Methods, Resources, Systems, …etc – are developed to enable storing and retrieving required information in the SIM. These databases represent information on their relative class in the MAPIC model.

The IPA allows for capturing user input, processing user request for information, and filtering and extracting project data. The IPA includes different procedures intended for supporting the users in decision-making. An *Assemblies Sequencing Process* captures and records the users movement and manipulation of the 3D objects to create the logical relationships of the assemblies, and to establish activities that represent the manipulated assemblies. A *Method Filtering Process* extracts information for the user-selected graphical component, queries the means and methods database, and provides the users with the conceivable methods for executing the selected assembly. Users are then able to select the appropriate method from a list of alternative selections according to their knowledge and experience, and the specifics of the situation in the virtual session. A *Resources Filtering process* acquires the selected method, determines the resources required, filters the resources database, and provides the users with the available resources associated with the selected method. A *Constructability Check Process* is also available to assist the users in checking constructability conflicts. A maximum reach process is an example of the constructability check processes. This process acquires information on the equipment selected by the users (e.g. crane), and utilizes the maximum work radius attribute of that equipment to visually provide the users with its reachable area.

7.4 CONTRIBUTION OF THE RESEARCH

Current and previous planning systems are characterized as responsive decision systems, relying mainly on programmed knowledge and heuristics for decision making, hence reducing or eliminating the role of the human planner. This research contributes a framework for a new planning approach to support the thinking process of the project team during the macro planning phase of design-build projects. Unlike previous responsive-type systems developed, the new approach will be supportive to the project team enabling the users to be an active participant in the decision making process. This approach benefits from the user creativity and ability in making knowledgeable decisions. This human knowledge and experience would, otherwise, require a large amount of time and skill to code into a computer domain. The user will also have more ownership of the produced plan by being an active participant in its development, therefore, making the plan more acceptable to the project team. In addition, the user will be in charge of delivering the planning decisions to account for the specific conditions of each individual project. This is necessary due to the uniqueness of each project's criteria, requirements, and constraints. In summary, the VCE is:

- *Supportive:*

  Enable the user to acquire various information necessary for decision-making in a structured easy to comprehend format.

- *Virtually interactive:*

  Enable the user to plan the project virtually at the macro level.

- *Collaborative:*

  Document various decisions made throughout the macro planning process, as well as the rationale behind making these decisions.

In order to provide the VCE users with information necessary for decision making in an easy to acquire format, this research contributes a **MA**cro **P**lanning **I**nformation **C**lassification (**MAPIC**) model under which information required for macro planning decision making can be classified and organized in a structured format. The project team may then retrieve and utilize this information whenever needed during the virtual sessions. In summary, MAPIC allows for:

- *Standardization of data access/storage:*

  Allow for structured organization and retrieval of macro planning information.

- *Collaboration:*

  Enable easy storage and retrieval of macro planning information.

The research makes a serious attempt to solve some of the major drawbacks associated with the previously developed tools by:

- Developing a virtual site to rehearse major construction processes.
- The user formulates planning decisions during the construction sessions.
- System architecture is designed to be supportive to user decisions, rather than responsive to user input.

7.5 RECOMMENDATIONS AND FUTURE RESEARCH

During the development of the VCE framework and prototype, several issues became obvious that need further investigation and enhancement. In addition, the author gathered the feedback of construction professionals as well as issues that need further research. Implementation of all these issues in the current state of the VCE will make it a more comprehensive project planning environment.

This section describes various issues that can enhance the capabilities of the VCE. These issues are grouped under two categories:

1. Issues requiring additional enhancements.
2. Issues for future extensions.

7.5.1 ISSUES REQUIRING ADDITIONAL ENHANCEMENTS

This part discusses issues that need more research and development to enhance the capability of the VCE. This includes:

1. Redesign and ensure user-friendly interface

The interface of the VCE needs more development and enhancement. In order to attain this goal, research need to be conducted to better understand how human beings interact with information, how do we perceive it visually and non-visually, how the mind works when searching for both known and unknown information, and how the mind solves problems. Good Human-Computer Interaction (HCI) is a must, but it is not enough. In designing visualization systems, we also need to better implement what we know about humans understanding and interact with information and the perceptual system. A related challenge involves learning how to create flexible user interfaces, navigation tools, and search about methods appropriate for each of the existing types of users, applications, and tasks (Gershon and Eick, 1997).

In addition, the Users Support Modules developed in the VCE require more development to ensure their comprehensiveness. Databases included only present a prototype/sample. Also, more processes need to be added to perform the various functions required.

2. VCE Validation

The VCE framework is a virtual environment to support the project team in making appropriate planning decisions. The environment needs to be validated by testing it to real case scenarios in order to verify the developed processes, as well as the comprehensiveness of information classification provided.

3. Study the application of the VCE on various projects

The VCE may be utilized for any project regardless of its type or size. However, no research has been made to study the range of projects' types and sizes for which using the VCE is most advantageous. For example, it may be more beneficial to utilize the VCE for repetitive projects, or it may be time consuming. Also it may not be worth using it for small simple projects. Research is required to test the use of the VCE on various projects with different types and sizes, and to identify the advantages of using the VCE for these projects as well as the ultimate project type and size.

4. Enable easy input of design information.

The concept of the VCE is built on the hypothesis that the 3D product model is developed with information on various systems included and attached to the 3D objects. Although current object oriented CAD packages have started to allow for such process, more research is required to enable easy input of systems information during design development. Example of issues that should be considered includes how the design team may smoothly input the same piece of information for a group of objects, and what is the optimum method to input the required information (e.g. from a list of alternatives, from a visual library, … etc).

5. Enable interaction with the interior objects hidden by the exterior shell

Current implementation of the VCE does not allow for easy interaction with interior objects of the 3D product model, since these objects are hidden by the exterior shell. The users may only display some of the objects by turning on and off the layer on which the object exists. So objects on the same layer are either all displayed or not. More research is required to enable easy visualization and manipulation of these objects. One solution may be to enable the users to define the objects that need to be displayed regardless of their layer. Code may be written to filter the systems in the systems database and display only systems with a specific criterion (e.g. according to floor level). This will allow the users to visualize and interact with all the interior objects of this floor.

6. Allow for making decisions on more than one object at a time

Current prototype implementation allows for making decisions on one object at a time. This is hectic and time consuming. Enhancement is needed to enable the users to make decisions for multiple objects at the same time.

7. Enable more than one predecessor for each activity during assemblies sequencing

Improvement is required to allow the users to have more than one predecessor for each activity. This should be performed by enabling reassembling more than one object at the same time so these objects will all be predecessors of the next reassembled object. Also the window that pops up during the assemblies sequencing process should contain options to allow for selecting more than one predecessor.

7.5.2 ISSUES FOR FUTURE EXTENSIONS

This part presents some ideas for future research related to the subject of this dissertation. This includes:

1. Appropriately breakdown the 3D product model

The 3D product model used in the VCE is broken down into various assemblies/systems. Each system (e.g. walls, columns, … etc) is currently represented on a different layer. This reflects the thinking process of the design team. On the other hand, the construction industry is set up according to the 16 divisions of the CSI format. The construction team utilizes this format to breakdown the schematic drawings to make various decisions. Research is then needed to develop an improved method for breaking down the 3D product model. The method should consider different breakdown criteria to allow for multi-breakdown, hence, accommodating thinking processes of different users.

2. Develop modules to check for different constructability conflicts

Current implementation of the VCE includes a "Crane maximum reach" process as an example of constructability checks that may be implemented in the VCE. Future extension of this research should include efforts for developing modules that check for different constructability conflicts. Some software packages, such as Pro/ENGINEER 2001 (URL 1) that perform these kinds of checks already exist. The challenge is how to apply these theories in the VCE.

3. Apply the relation between distance and productivity in the VCE

Current information available in the VCE databases on equipment productivity is customized by each company and should represent average productivity of the equipment. More research is required to study how to apply the relation between equipment productivity and distance in the VCE. For example, the productivity of pumping concrete for the 1st floor slab should be different than for the 5th floor slab. Also, the research may take into account the learning curve factor.

4. Study the use of the VCE to assist in conceptual estimating

The output of the macro planning process presents the basis for the baseline scheduling and conceptual estimating processes. The current output of the VCE may be directly used as input for the development of the outline schedule. However, more research is required to study the use of the VCE to assist in developing appropriate conceptual estimate. The research should mainly focus on functions that allow for material take-off during the virtual sessions. It will be advantageous to implement processes that calculate the cost of each system once re-assembled in the virtual construction site window.

5. Apply the VCE for Micro Planning

The VCE is currently developed to assist the project team in making appropriate macro planning decisions. Research needs to be conducted to identify what should be added to allow for making micro planning decisions in the VCE. The research should mainly focus on information required, processes, and modules that have to be developed for micro planning decision making.

6. Develop a module for Path Planning

The use of the VCE allows for rehearsing major construction processes and for testing various execution strategies in a near reality sense. Developing a module that enables detailed path planning will definitely assist the project team in making better work execution and site layout planning decisions.

7. *Directly transfer the output of the assemblies sequencing process into a scheduling software*

The output of the assemblies sequencing process for the implemented prototype mainly consists of a table that includes the activity name, predecessor, relationship, and lag. Future extension of this work should include processes that calculate, by using the quantities and productivity, the duration of each activity and directly transfer the output to a scheduling software package (e.g. Primavera).

8. *Replay the sequencing process*

One of the features that may be added to the VCE implementation is a process that enables replaying the assemblies sequence. This feature will be advantageous especially if the project team would like to review their assemblies sequencing decisions or would like to show this sequence to other project participants (e.g. the owner).

9. *Implement the VCE in an immersive Virtual Environment (e.g. CAVE)*

To enhance the virtual setting, and allow for a better collaboration among project members, further development of the VCE using an immersive environment is required. A major distinction of virtual environment systems is the mode with which they interface to the user. The mode used for the implementation of the VCE prototype is classified as a *Window on World System (WoW).* This basically involves the use of conventional computer monitor to display the visual world. Other common modes used in virtual environments systems are:

- *Video Mapping*: This is a variation of the WoW approach that merges a video input of the user's silhouette with a 2D computer graphic. The user watches a monitor that shows his body's interaction with the world.
- *Telepresence*: Telepresence is a variation on visualizing complete computer generated worlds. This technology links remote sensor in the real world with the senses of a human operator.
- *Mixed Reality*: This technology merges the computer-generated inputs with telepresence inputs and/or the user view of the real world.
- *Fish Tank Virtual Reality*: This combines a stereoscopic monitor display using LCD shutter glasses with a mechanical head tracker. The resulting system is superior to simple stereo-WoW systems due to the motion parallax effects introduced by the head tracker.
- Immersive Systems: These systems ultimately immerse the user's personal viewpoint inside the virtual world. These systems are often equipped with a Head Mounted Display (HMD) that is a helmet or a face mask. This helmet holds the visual and auditory displays and may be free ranging, tethered, or it might be attached to some sort of a boom armature. An example of these systems is the Cave Automatic Virtual Environment (CAVE^{TM}). The CAVE is a multi-person, room-sized, high-resolution, 3D video and audio environment. The CAVE is recommended for further implementation of the VCE for several reasons:

- It has a high capability to process real-time graphics. This allows the user to interact with a virtual environment, and increase the sense of realism. The four-sided displays increase the subjective feelings of the user (Barfiled and Furness, 1995).
- It is a collaborative environment, and therefore, is suitable for the implementation of the VCE, where more than one user may be immersed in an inclusive environment at the same time.
- It is located on Virginia Tech's main campus and is easily accessible for research implementation.

A more detailed description of the CAVE, as well as current programming capabilities and enhancements required to allow for implementing the VCE in the CAVE, is presented in Appendix II.

10. Conducting remote collaborative virtual sessions

The CAVE™ will provide a better setting for the project team to interact and collaborate. However, collaboration will be confined to a single location. Further research should also investigate new web-based VR tools that could allow for conducting remote collaborative virtual rehearsal sessions.

7.6 CONCLUSION

Planning construction projects is among the most challenging tasks faced by the project team. Decisions made during this stage have a tremendous impact on the successful execution of the project from its early conceptual phases, through the project construction and completion. During the project planning process, information required for the execution of the project needs to be extracted from the project data. The developed project information is then processed to formulate project knowledge necessary for the decision making process. For a large majority of construction projects, the current planning practices remain manually based. General and project specific data are communicated among project participants through design drawings in a 2D paper-based format. This paper-based exchange of large amount of information between participants usually leads to fragmentation and inefficiencies, and limits the ability of the project team to acquire and comprehend the information necessary for decision making. Another drawback of the manual approach is that planning functions are performed separately in isolation of each other. Due to the interdependence between the different elements and the large amount of information that needs to be manually processed, the current manual implementation approach is very difficult to undertake, and imposes a heavy burden on the project team to carry out the planning process.

Various research efforts have been undertaken in an attempt to capture current planning techniques and allow for the development of new innovative and automated ways in planning. Embarking on advancements in 3D computer graphics and artificial intelligence, previous and current research efforts attempted to automate the planning process by developing tools to manipulate and process project information, carry out the decision-making, and generate the required actions. The developed planning systems are characterized as responsive decision systems, relying mainly on programmed knowledge and heuristics for decision making, hence reducing or eliminating the role of the human planner.

The research presented in this research provides a significant step in developing more effective planning environments. By enabling the user to be an active participant in the decision making process, the VCE benefits from the user creativity and ability in making knowledgeable decisions. The VCE also allows the project team to have more ownership of the produced plan by being an active participant in its development, therefore, making the plan more acceptable to other project participants.

BIBLIOGRAPHY

(Adjei-Kumi and Retik, 1997) Adjei-Kumi, T., and Retik, A. (1997), "A Library-Based Visualization of Construction Processes." *Proceedings of the 1997 International Conference on Information Visualization, IV*, London, England, pp. 531-538.

(Adrian, 1987) Adrian, J. J. (1987) "Short-Interval Scheduling: A technique for increasing productivity", Construction and Real Estate Newsletter, Vol. 10, No. 2

(Andres and Smith, 1998) Andres, C. K., and Smith, R. C. (1998)"Principles and Practices of Heavy Construction", 6^{th} ed., Prentice-Hall, N. J.

(Akinci and Fischer, 1998) Akinci, B., and Fischer, M. (1998), "Time-space conflict analysis based on 4D production models." *Proceedings of the 1998 International Computing Congress on Computing in Civil Engineering,,* Boston, MA, USA, pp. 342-353.

(ASCE Committee, 1991) The Construction Management Committee of the ASCE Construction Division (1991), "Constructability and Constructability Programs: White Paper." *Journal of Construction Engineering and Management*, Vol. 117, No. 1, pp. 67-89.

(Ballard and Howell, 1997) Ballard, G. and Howell, G. (1997), "Shielding Production: An Essential Step in Production Control", Technical Report No. 97-1, Construction Engineering and Management Program, Department of Civil and Environmental Engineering, University of California.

(Barfield and Furness, 1995) Barfield, W., and Furness, T. (1995) "Virtual Environments and Advanced Interface Design, Oxford University Press, ISBN 0-19-507555-2.

(Barrie and Paulson, 1992) Barrie D. S., and Paulson, B. C., (1992) "Professional Construction Management: including C.M., Design-

Construct, and General Contracting", 3rd ed., McGraw-Hill, N. Y.

(Bosch and Baker, 1995) Bosch, A. O. d., and Baker, N. (1995), "Simulation of Construction Operations in Virtual Interactive Environments." *Proceedings of the 2nd Congress on Computing in Civil Engineering*, Atlanta, GA, USA, pp. 1435-1442.

(CII, 1986) Construction Industry Institute (CII) (1986), "Constructability: a primer" Publication 3-1, University of Texas at Austin, Texas.

(Clough and Sears, 1994) Clough, R. H., and Sears, G., (1994), "Construction Contracting" 6th ed., Wiley, New York.

(Cross, 1991) Cross, D. M. (1991), "Project Constructability - A Contractor's View." *Proceedings of the Construction Congress*.

(Darwiche et al., 1988) Darwiche, A., Levitt, R. E., and Hayes-Roth, B. (1988), "OARPLAN: Generating Project Plans by reasoning about Objects, Actions, and Resources" *AI EDAM* Vol. 2, No. 3, pp. 169-181.

(Echeverry et al., 1991) Echeverry, D., Ibbs, W., and Kim, S. (1991), "Sequencing Knowledge for Construction Scheduling" *Journal of Construction Engineering and Management*, Vol. 117, No. 1, pp. 118-130.

(Faniran et al., 1998) Faniran, O. O., Love, P. E. D., and Li, H. (1998), "Optimal Allocation of Construction Planning Resources" *Journal of Construction Engineering and Management*, Vol. 125, No. 5, pp. 311-319.

(Fischer, 1993) Fischer, M. (1993), "Linking CAD and Expert Systems for Constructability Reasoning." *Proceedings of the 5th Conference on Computing in Civil and Building Engineering, ICCCBE*, Anaheim, CA, USA.

(Gershon and Eick, 1997) Gershon, Nahum and, Eick, Stephen G. (1997) "Information Visualization", *IEEE Graphics and Applications*, Vol. 17, No. 4. Jul-Aug 1997, p. 29-31.

(Gupta et al., 1998) Gupta, S. K., Paredis, C. J. J., and Brown P. F. (1998), "Micro Planning for Mechanical Assembly Operations" Proceedings of the 1998 IEEE International Conference on Robotics & Automation, Leuven, Belgium, May 1998.

(Glavinich, 1995) Glavinich, T. E. (1995), "Improving Constructability during Design Phase." *Journal of Architectural Engineering*, Vol. 1, No. 2, pp. 73-76.

(Gould, 1997) Gould, F. E. (1997), "Managing the Construction Process" Prentice Hall, ISBN 0-13-352337-3.

(Hadavi and Krizek, 1993) Hadavi, A. and Krizek, R. J., (1993) "Short-term Setting for Construction", *Journal of Construction Engineering and Management*, Vol. 119, No. 3, pp. 662-630.

(Halfawy et al., 1996) Halfawy, M. R., Hadipriono, F. C., Duane, J. W., and Larew, R. E. (1996), "Visualization of Spatial and Geometric Databases for Construction Projects." *Proceedings of the conference on Computing in Civil Engineering*, pp. 920-926.

(Hanlon and Sanvido, 1995) Hanlon, E. J., and Sanvido, V. E. (1995), "Constructability Information Classification Scheme." *Journal of Construction Engineering and Management*, Vol. 121, No. 4, pp. 337-345.

(Hendrickson et al., 1987) Hendrickson, C., Zozoya-Gorostiza, C. Rehak, D., Baracco-Miller, E. and Lim, P., (1987) "Expert System for Construction Planning" *Journal of Computing in Civil Engineering*, Vol. 1, No. 4, pp. 253-269.

(Houshyar and Bringelson, 1998) Houshyar A. and Bringelson L. (1998), "A Review of Facilities Planning and Human/Computer Interaction" International Journal of Modeling and Simulation, Vol. 18, No. 2.

(Ioannou and Leu, 1991) Ioannou, P. G., and Leu, S. S. (1991), "Construction Technology/Method Identification and Selection System." *Proceedings of the Preparing for Construction in the 21st Century Construction Congress*, pp. 638-643.

(Ioannou and Liu, 1993) Ioannou, P. G., and Liu, L. Y. (1993), “Advanced Construction Technology System - ACTS.” *Journal of Construction Engineering and Management*, Vol. 119, No. 2, pp. 288-306.

(Ito et al., 1996) Ito, K., Kano, Y., Ueda, J., and Setoguchi, S. (1996), “3-D Graphical Simulation for Temporary Facility Planning using Object-Oriented Building Product Model.” *Proceedings of the third ASCE Congress on Computing in Civil Engineering*, Anaheim, CA, USA, pp. 49-55.

(Jagbeck, 1994) Jagbeck, A. (1994), “MDA Planner: Interactive Planning Tool Using Product Models and Construction Methods.” *Journal of Computing in Civil Engineering*, Vol. 8, No. 4, pp. 536-554.

(Kartam and Flood, 1997) Kartam, N., and Flood, I. (1997), “Constructability Feedback Systems: Issues and Illustrative Prototype.” *Journal of Performance of Constructed Facilities.*, Vol. 11, No. 4.

(Kerzner, 1989) Kerzner, H. (1989) “Project Management: A system approach to planning, scheduling and controlling”, 3rd ed., ISBN 0-442-20751-4.

(Kirby et al., 1988) Kirby, J. G., Furry, D. A., and Hicks, D. K. (1988), “Improvements in Design Review Management.” *Journal of Construction Engineering and Management*, Vol. 114, No. 1, pp. 69-82.

(Kupernas et al., 1995) Kupernas, J. A., Um, J. T., and Booth, C. E. (1995), “Use of CAD Three Dimensional Modeling as a Constructability Review Tool.” *Proceedings of the 2nd Conference on Computing in Civil and Building Engineering*, Atlanta, GA, USA.

(Laufer and Tucker, 1997) Laufer, A., and Tucker, R. L. (1997), “ Is construction project planning really doing its job? A critical examination of focus, role and process” *Journal of Construction Management and Economics, Vol. 5, Number 3, winter 1987, ISSN 0144-6193.*

(McCullouch and Patty, 1994) McCullouch, B., and Patty, B. (1994), “A Hypermedia Constructability System.” *Proceedings of the 1st*

Congress on Computing in Civil Engineering, pp. 1397-1404.

(McKinney et al., 1998) McKinney, K., Fischer, M., and Kunz, J. (1998), "4D Annotator: A Visual Decision Support tool for Construction Planners." *Proceedings of the 1998 International Computing Congress on Computing in Civil Engineering*, Boston, MA, USA, pp. 331-341.

(McKinney and Fischer, 1998) McKinney, K., and Fischer, M. (1998), "Generating, Evaluation, and Visualizing Construction Schedules with CAD tools." *Journal of Automation in Construction*, Vol. 7, pp. 433-447.

(Mendelsohn, 1997) Mendelsohn, R. (1997), "The Constructability Review Process: A Constructor's Perspective." *Journal of Management in Engineering* (May/June).

(Moore and Tunnicliffe, 1995) Moore, D., and Tunnicliffe, A. (1995), "An Automated Design Aid (ADA) for Constructability." *Proceedings of the 2nd Congress on Computing in Civil Engineering*, New York NY, USA.

(Morad and Beliveau, 1991) Morad, A. A. and Beliveau, Y. J., (1991), "Knowledge-Based Planning System" *Journal of Construction Engineering and Management*, Vol. 117, No. 1, pp. 1-12.

(Navinchandra et al., 1988) Navinchandra, D., Sriram, D., and Logcher, R. D. (1988) GHOST: Project Network Generator, Journal of Computing in Civil Engineering, Vol. 3, No. 2, July, 1988, 239-254

(Neale and Neale, 1989) Neale, R., and Neale, D. (1989) "Construction Planning", Thomas Telford, London, ISBN 0-7277-1322-1

(O'Connor, 1985) O'Connor, J. T., (1985), "Impacts of Constructability Improvement" *Journal of Construction Engineering and Management*, Vol. 111, No. 4, pp. 404-410.

(O'Connor et al., 1987) O'Connor, J. T., Rush, S. E., and Schulz, M. J. (1987), "Constructability Concepts for Engineering and Procurement." *Journal of Construction Engineering and Management*, Vol. 113, No. 2, pp. 235-248.

(Oglesby et al., 1989) Oglesby, C. H., Parker, H. W., and Howell, G. A. (1989), "Productivity Improvement in Construction" McGraw-Hill, ISBN 0-07-047802-3.

(Patty et al., 1995) Patty, B., McCullouch, B., and Vanegas, J. (1995), "Automating Constructability during Design." *Proceedings of the 1995 Congress on Computing in Civil Engineering*, San Diego, CA, USA.

(Riley, 1998) Riley, D. (1998), "4D Space Planning Specification Development for Construction Work Spaces." *Proceedings of the 1998 International Computing Congress on Computing in Civil Engineering*, Boston, MA, USA, pp. 354-363.

(Rizzo, 1998) Rizzo, J. (1998), "Design-Build Alternative: A Contracting Method" *Construction Congress V: Managing Engineering Construction in Expanding Global Markets*, Minneapolis, Minnesota, USA, pp. 613-618.

(Russell and Al-Hammad, 1993) Russell, A., and Al-Hammad, I. (1993), "A Knowledge-Based Framework for Construction Methods Selection." *Canadian Journal of Civil Engineering*, Vol. 20, No. 2, pp. 236-246.

(Russell, 1991) Russell K. L. (1991) "Designing plans for constructability". *Preparing **for** Construction in the 21st Century Constr Congr. Publ by ASCE, New York, NY, USA. 91. p 744-749*.

(Shaked and Warszawski, 1995) Shaked, O. and Warszawski, A. (1995), "Knowledge-Based System for Construction Planning of high-rise Buildings" *Journal of Construction Engineering and Management*, Vol. 121, No. 2, pp. 172-182.

(Skolnick et al., 1990) Skolnick, J., Morad, A, and Beliveau, Y., (1990) "Development of a CAD-Based Construction Visual Schedule Simulation System," *Proceedings of the Project management Institute*, Oct. 1990, pp. 334-340.

(Smith, 1968) Smith, M. R., (1968) "Short-Interval Scheduling: A systematic approach to cost reduction"

(Stumpf et al., 1994) Stumpf, A. L., Liu, L. Y., Chin, S., and Ahn, K. (1994), "Using CADD Applications to Support Construction Activities." *Proceedings of the 1st Congress on Computing in Civil Engineering*, pp. 531-538.

(Syal, 1992) Syal, M. G. (1992), "Construction Process Knowledge Model to Assistant Method Selection in Project Planning" Ph.D. Dissertation, Pennsylvania State University, University Park, PA.

(Syal et al., 1993) Syal, M. G., Parfitt, M. K., Willenbrock, J. H., and Duff, W. S. J. (1993), "Design Information Hierarchy for Construction Method Selection Process." *Proceedings of the Fifth International Conference on Computing in Civil and Building Engineering*, Anaheim, CA, USA, pp. 742-749.

(Tatum, 1987) Tatum, C. B. (1987), "Improving Constructability during Conceptual Planning." *Journal of Construction Engineering and Management*, Vol. 113, No. 2, pp. 191-207.

(Tatum, 1988) Tatum, C. B. (1988), "Classification System for Construction Technology." *Journal of Construction Engineering and Management*, Vol. 114, No. 3, pp. 344-363.

(Thabet, 1992) Thabet, W. Y. (1992), "A Space-Constrained Resource-Constrained Scheduling System for Multi-story Buildings" Ph.D. Dissertation, Virginia Tech, Blacksburg, VA.

URL 1 http://www.ptc.com/products/proe/2001/index.htm (accessed on 5/25/01

URL 2 http://www.sv.vt.edu/future/vt-cave/whatis/ (accessed on 7/29/00)

(Waly et al., 1999(a)) Waly, A. F., Thabet, W. Y., and Wakefield, R. (1999) "An Automated Model for Generating a Short-Interval Schedule", *proceedings of 8DBMC conference and CIB W78 Workshop*, May 30- June 3, 1999, Vancouver, Canada, pp. 2386-2392.

(Waly et al., 1999(b)) Waly, A. F., Thabet, W. Y., and Beliveau Y. (1999) "Virtual Construction for Constructability Improvement", *the Fifth International Conference on the Application of Artificial Intelligence*, Civil Comp., September 13-15, 1999, Oxford, England, pp. 71-76.

(Waly and Thabet, 2000) Waly, A. F., and Thabet, W. Y., (2000) "A Virtual Construction Environment for Project Planning", *Proceedings of the Conference on Construction Applications of Virtual Reality: Current Initiatives and Future Challenges, September 4-5, 2000, University of Teesside UK, pp. 43-53.*

(Waly and Thabet, 2001) Waly, A. F., and Thabet, W. Y., (2001) "A Virtual Construction Environment (VCE) for Pre-construction Planning", *accepted for publication, Journal of Automation in Construction*.

(Williams, 1996) Williams, M. (1996) "Graphical Simulation for project planning: 4D-Planner" Proceedings of Computing in Civil Engineering, pp. 404-409.

APPENDIX A

INTERVIEWS:

Interviews were conducted with construction professionals twice during the research. The first times interviews were conducted to identify the current macro planning practices for design-build projects. The second set of interviews intended to present the computer prototype and to gather the feedback of the construction professionals on the VCE. A brief description of the interviews and a list of the construction professionals interviewed are provided in this appendix.

I. FIRST SET OF INTERVIEWS

Interviews were conducted with professionals from one design firm, three general contracting companies, and two construction management companies. Companies selected for interviews were all involved in Design-Build projects. Professionals interviewed were all involved in the pre-construction stage of the project life cycle. A record of each interviewee's position is provided below:

- **Design Firm:**

  - ***Interview 1:*** *Smith Group Incorporated, Washington DC*: Interview with Gilbert, architect, November 2000.

- **Construction Management Companies:**

  - ***Interview 2:*** *McDonough Bolyard Peck (MBP), Roanoke Virginia*: Jordan Peck, and John Mackay, Associate, March 2000.
  - ***Interview 3:*** *Belstar, Inc., Fairfax, Virginia*: Ozzie Belchter, President and Principal, May 2000.

- **General Contracting Companies:**

  - ***Interview 4:*** *Branch and Associates, Inc, Roanoke, VA*: Interview with Heather Brown, Project Manager, February 2000.
  - ***Interview 5:*** *Hubert Construction, LLC, Fredrick, MD*: Interview with J.J. McCarthy, Vice President of pre-construction services, May 2000.
  - ***Interview 6:*** *Centex Construction Group, Washington DC*: Interview with Paul Nassetta, Vice President for operations, November 2000.

II. SECOND SET OF INTERVIEWS

Interviews were conducted with construction professionals to gather their feedback on the VCE. Interviews were conducted with professionals from two General Contracting companies and two Construction Management companies. The researcher selected to go back to companies interviewed before to assure that the VCE addresses the problems mentioned during the first interviews. During the interviews, the researcher discussed the concept and contribution of the VCE, and presented the implementation computer prototype. The feedback of the construction professionals is used to implement the recommendations for future research and computer implementation. A record of each interviewee's position is provided below:

- **<u>Construction Management Companies:</u>**
  - ***Interview 7:*** *McDonough Bolyard Peck (MBP), Roanoke, Virginia*: John Mackay, Associate, May 2001.
  - ***Interview 8:*** *Belstar, Inc, Fairfax, Virginia*: Rod Beltcher, Director of Construction Management & Scheduling, William Young, Director of Cost Estimating and Cost Control, and Ted Clark, Senior Project Manager, May 2001.

- **<u>General Contracting Companies:</u>**
  - ***Interview 9:*** *Branch and Associates, Inc, Roanoke, Virginia*: Interview with Heather Brown, Project Manager, and Mike Cagle, Estimator, May 2001.
  - ***Interview 10:*** *Centex Construction Group, Washington DC*: Interview with Rebecca Nordby, Assistant Superintendent, May 2001.

APPENDIX B

THE CAVE AUTOMATIC VIRTUAL ENVIRONMENT (CAVE):

The CAVE™ is a multi-person, room-sized, high-resolution, 3D video and audio environment that was developed at the Electronic Visualization lab of the University of Illinois, Chicago in early 90s. It consists of a theater 10x10x9 feet, made up of three rear-projection screens for the front, right and left walls and a down-projection screen for the floor. In the current configuration, graphics are rear projected in stereo onto three walls and the floor, and viewed with stereo glasses. As a viewer wearing a position sensor moves within its display boundaries, the correct perspective and stereo projections of the environment are updated by a supercomputer, and the images move with and surround the viewer. Hence stereo projections create 3D images that appear to have a presence both inside and outside the projection-room continuously. To the viewer with stereo glasses the projection screens become transparent and the 3D-image space appears to extend to infinity (URL 2). This setting provides excellent capabilities for visualizing and easily understanding 3D models. Information may be presented through 3D holograms (visual information) and through images projected on the walls (visual and textual information).

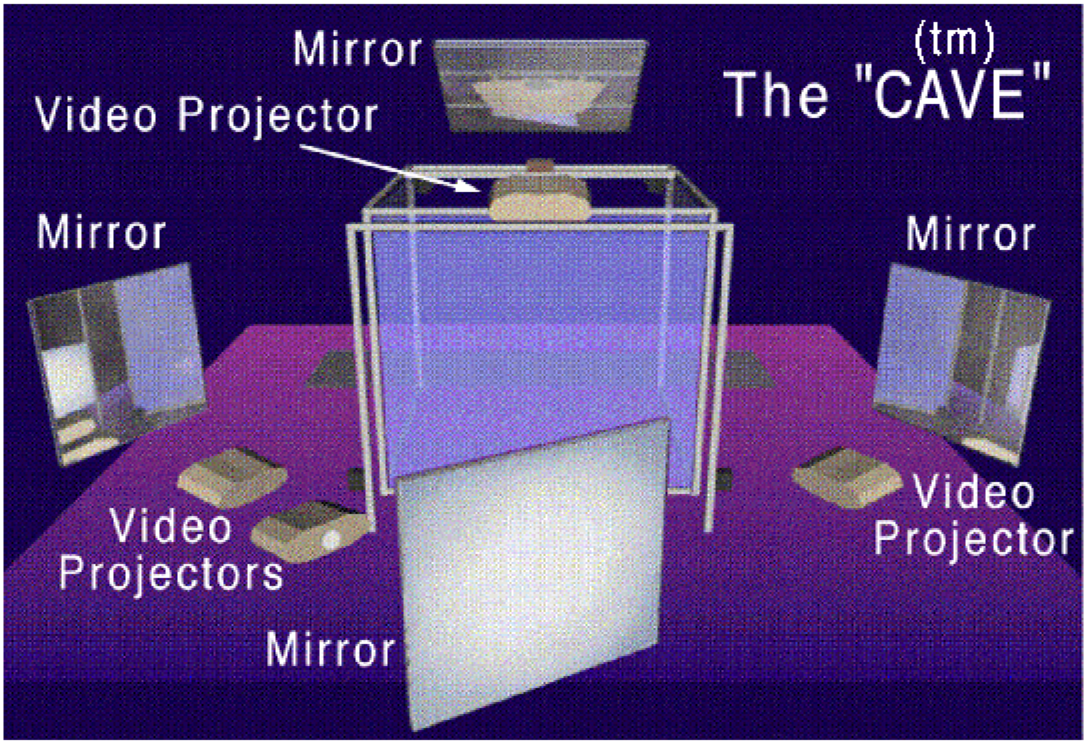


Figure B-1: The CAVE (from URL 2)

Current programming capabilities enable the users to view the models in the CAVE™, navigate around them, and create animated paths to walk or fly through the environment. The 3D model will be created in a 3D modeling software such as AutoCAD and converted into the CAVE. To accomplish this, several steps should be achieved. First, the model developed in AutoCAD ".dxf" file format needs to be converted to the open inventor ".iv" file format. Two options are presented for that conversion (Figure B-2):

(1) the use of "dxftoiv" converter, or (2) exporting the AutoCAD file to 3Dstudio and saved it as a VRML1.0 ".wrl" file format, then rename the file to be ".iv". Once the AutoCAD file is in the ".iv" format, "pfnav" software may be utilized to open the file and view the model in the CAVE™ or in the CAVE™ simulator.

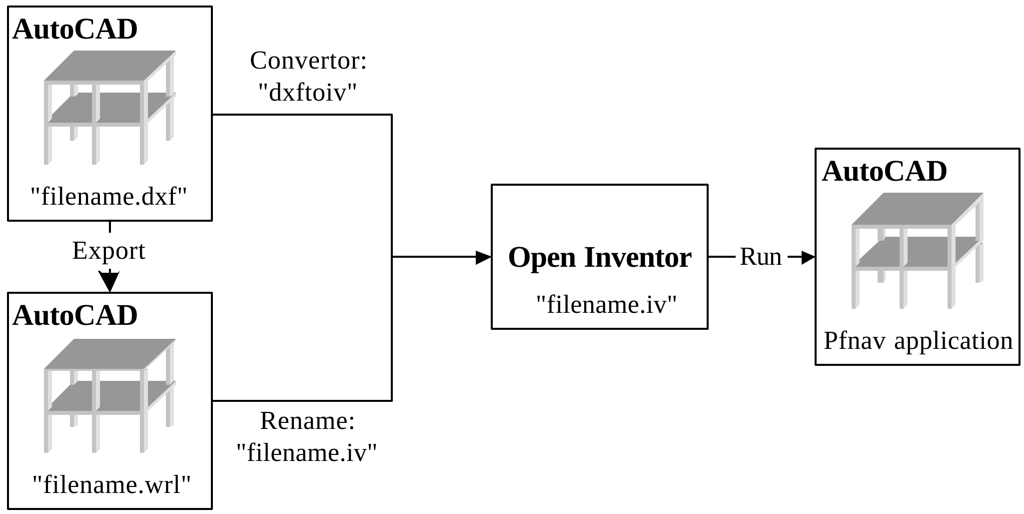


Figure B-2: Current conversion of AutoCAD models into the CAVE

The process of converting an AutoCAD file into the CAVE™ has been developed and utilized for several researches and projects. However, this process does not enable the user to interact with the 3D model in a manner that allows the application of the proposed Virtual Construction Environment. In order to allow the user to interact and manipulate 3D models generated by AutoCAD in the CAVE™ environment, programming in VRML2.0 is needed. VRML2.0 enables the user to interact with the 3D model. However, the software “pfnav” currently utilized by the CAVE™ only support VRML1.0. This software will require to be modified to support VRML2.0 (Figure B-3).

There exist a number of other programming options that may be considered to interact with the 3D model in the CAVE™. One of these options is the use of the CAVE™ Collaborative Console (CCC) performer files. CCC is a Performer-based user interface written in C/C++ developed at Virginia Tech. The idea of the Console began from a need to

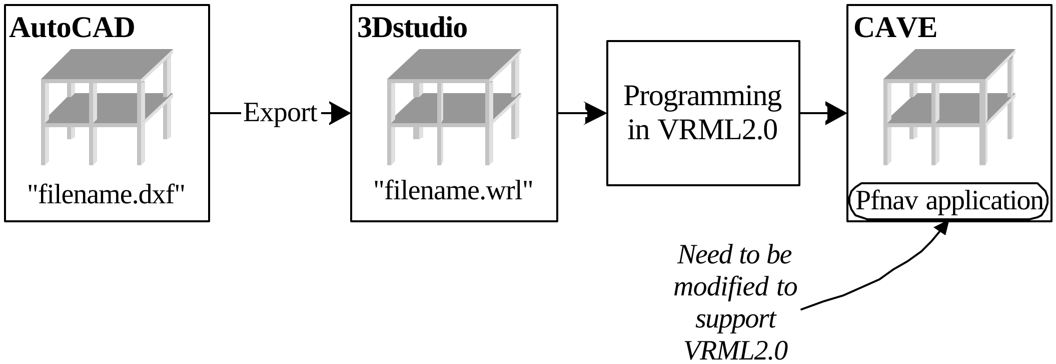


Figure B-3: Future conversion of AutoCAD models into the CAVE

not only address issues of awareness, but to somehow provide an interface that gave the user control over his/her tools. The CAVE™ Collaborative Console extends CAVERNsoft and LIMBO by providing users with a suite interface devices and functions that are needed for an efficient and effective collaborative session. The application is intended to be somewhat generic and flexible and yet is implemented with many utilities that support awareness, presence, and collaborative manipulation. Performer files of the CCC may have the ability to enable multi-users to interact with 3D models in the CAVE. Also, if the 3D model is developed using OpenGL, the user may interact with the model in the CAVE. However, developing the 3D model in OpenGL is not practical, especially in the construction industry and the complexity of today's buildings.

APPENDIX C

THE VISUAL BASIC CODE:

This appendix provides the programming code written to customize the AutoCAD interface to reflect the functions required, to connect the CAD package with the DBMS, and to implement the procedures of the information Processor Assistant (IPA).

In order to upload this code, the user needs to use the AutoCAD menu as follows:

Tools> Macro> Load Project> select "Project", and open.

Tools> Macro> Macros> select "createvce" and run.

Tools> Macro> Macros> select "initializeevents" and run.

The VCE menu is now uploaded and the program is ready.

The Code is written in Visual Basic for Applications/AutoCAD architectural desktop 2.0. It consists of 2 main parts: Modules, and forms. The code for each of these parts is provided in this appendix:

1. MODULES

Codes

This part presents the codes written to create and manipulate the “VCE” menu and submenus

```
Global loginflag As Boolean
Global x As New EventClassModule
Global objss As AcadSelectionSet
Global selobj_name As String
Global selobj_id As String
Global entity_ref As AcadEntity
Global user_team As String
Global user_name As String
Global user_date As Date
Global work_sel_method_flag As Boolean
Global work_sel_resource_flag As Boolean
Global sys_def_flag  As Boolean
Global base_point_flag As Boolean
Global base_point
Global assembly_bookmark
Global sys_point
Global place_system_flag As Boolean
Global syscopy_id As String
Global define_all_flag As Boolean
Global define_all_base_point
Global define_all_selobj_name As String
Global define_all_selobj_id As String

'Global base_point_picked  As Boolean
Sub initializeevents()
Set x.app = ThisDrawing.Application
Set x.doc = ThisDrawing
End Sub
Public Sub createvce()

Dim objmenus As AcadPopupMenus
Dim objvcemenu As AcadPopupMenu
Dim newmenuname As String

Dim objvcemenuitemsys As AcadPopupMenu

Dim objvcemenuitemreview As AcadPopupMenu
Dim objvcemenuitemreview_systems As AcadPopupMenuItem
Dim objvcemenuitemreview_methods As AcadPopupMenuItem
Dim objvcemenuitemreview_resources As AcadPopupMenuItem
Dim objvcemenuitemreview_sequence As AcadPopupMenuItem
Dim objvcemenuitemreview_physical As AcadPopupMenuItem
Dim objvcemenuitemreview_space As AcadPopupMenuItem
Dim objvcemenuitemreview_accessibility As AcadPopupMenuItem
Dim objvcemenuitemreview_strategies As AcadPopupMenuItem
Dim objvcemenuitemreview_contract As AcadPopupMenuItem
Dim objvcemenuitemreview_site As AcadPopupMenuItem
Dim objvcemenuitemreview_access As AcadPopupMenuItem
```

```
Dim objvcemenuitemreview_separator1 As AcadPopupMenu
Dim objvcemenuitemreview_separator2 As AcadPopupMenu

Dim objvcemenuitemwork As AcadPopupMenu
Dim objvcemenuitemwork_methods As AcadPopupMenuItem
Dim objvcemenuitemwork_allocate_resources As AcadPopupMenuItem
Dim objvcemenuitemwork_select_materials As AcadPopupMenuItem
Dim objvcemenuitemwork_assemblies_seq As AcadPopupMenuItem
Dim objvcemenuitemwork_define_all As AcadPopupMenuItem

Dim objvcemenuitemConstructability As AcadPopupMenu
'Dim objvcemenuitemConstructability_check_max_reach As AcadPopupMenuItem

'adding the vce menu to the menu bar
Set objmenus = ThisDrawing.Application.MenuGroups.Item(0).Menus
On Error Resume Next
Set objvcemenu = objmenus("Vce")
If Not objvcemenu Is Nothing Then
   MsgBox ("Menu already exists")
   'Exit Sub
End If
Set objvcemenu = objmenus.Add("Vce")
objvcemenu.InsertInMenuBar ThisDrawing.Application.MenuBar.Count

'adding the menu items under the VCE
Set objvcemenuitemsys = objvcemenu.AddMenuItem(objvcemenu.Count, "Systems Definitions", "-
vbarun sysdef  ")
Set objvcemenuitemreview = objvcemenu.AddSubMenu(objvcemenu.Count, "Review") ', "-vbarun
revinf  "
Set objvcemenuitemwork = objvcemenu.AddSubMenu(objvcemenu.Count, "Define") ', "-vbarun
workplan  "
Set objvcemenuitemConstructability = objvcemenu.AddMenuItem(objvcemenu.Count, "Check Max.
Reach", "-vbarun check_max_reach  ")

Set objvcemenuitemreview_systems =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Systems", "-vbarun rev_sys  ")
Set objvcemenuitemreview_methods =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Methods", "-vbarun
rev_method ")
Set objvcemenuitemreview_resources =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Resources", "-vbarun
rev_resource  ")
Set objvcemenuitemreview_sequence =
objvcemenuitemreview.AddMenuItem(objvc emenuitemreview.Count, "Sequence", "-vbarun
rev_sequence  ")
Set objvcemenuitemreview_physical =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Physical Prop", "-vbarun
rev_phisycals  ")
Set objvcemenuitemreview_space =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Space", "-vbarun rev_space  ")
Set objvcemenuitemreview_accessibility =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Accessibility", "-vbarun
rev_accessibility  ")
```

```
Set objvcemenuitemreview_strategies =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Managerial Strategies", "-
vbarun rev_manag  ")
Set objvcemenuitemreview_contract =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Contact", "-vbarun rev_contact
")
Set objvcemenuitemreview_site =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Site", "-vbarun rev_site  ")
Set objvcemenuitemreview_access =
objvcemenuitemreview.AddMenuItem(objvcemenuitemreview.Count, "Access", "-vbarun rev_access
")

Set objvcemenuitemwork_methods =
objvcemenuitemwork.AddMenuItem(objvcemenuitemwork.Count, "Select Method", "-vbarun
workmethod  ")
Set objvcemenuitemwork_allocate_resources =
objvcemenuitemwork.AddMenuItem(objvcemenuitemwork.Count, "Allocate Resource", "-vbarun
work_resource  ")
'Set objvcemenuitemwork_select_materials =
objvcemenuitemwork.AddMenuItem(objvcemenuitemwork.Count, "Select Materials", "-vbarun
work_matrials  ")
Set objvcemenuitemwork_assemblies_seq =
objvcemenuitemwork.AddMenuItem(objvcemenuitemwork.Count, "Assemblies Seq.", "-vbarun
work_assemblies  ")
Set objvcemenuitemwork_define_all =
objvcemenuitemwork.AddMenuItem(objvcemenuitemwork.Count, "Define All", "-vbarun
work_define_all  ")

Set objvcemenuitemreview_separator1 = objvcemenuitemreview.AddSeparator("Physical Prop")
Set objvcemenuitemreview_separator2 = objvcemenuitemreview.AddSeparator("Managerial
Strategies")

'Set objvcemenuitemConstructability_check_max_reach =
objvcemenuitemConstructability.AddMenuItem(objvcemenuitemConstructability.Count, "Check Max.
Reach", "-vbarun check_max_reach  ")

End Sub
Public Sub sysdef()
If loginflag = False Then
sys_def_flag = True
uselogin.Show
Else: syschosen.Show
End If
End Sub
Sub revinf()

End Sub
Sub workplan()

End Sub
Sub rev_sys()
get_rev_sys.Show
End Sub
Sub rev_method()
```

```
get_rev_method.Show
End Sub
Sub rev_resource()
get_rev_resource.Show
End Sub
Sub rev_sequence()
    get_sys_sequence.Show
End Sub
Sub rev_phisycals()

End Sub
Sub rev_space()

End Sub
Sub rev_accessibility()

End Sub
Sub rev_manag()
    ThisDrawing.SendCommand ("start" & vbCr)
    ThisDrawing.SendCommand (ThisDrawing.Path & "\Managerial.pdf" & vbCr)
End Sub
Sub rev_contact()

End Sub
Sub rev_site()

End Sub
Sub rev_access()

End Sub
Public Sub workmethod()
If loginflag = False Then
work_sel_method_flag = True
uselogin.Show
Else: method_choose.Show
End If
End Sub
Sub work_resource()
If loginflag = False Then
work_sel_resource_flag = True
uselogin.Show
Else: resource_choose.Show
End If
End Sub
'Sub work_matrials()
'
'End Sub
Sub work_assemblies()
    get_point_frm.Show
End Sub
Sub work_define_all()
    define_all_frm.Show
End Sub
Sub check_max_reach()
```

```
equip_choose.Show
End Sub
Function warn_msg(msg As String, cap As String) As Integer
message_frm.Caption = cap
message_frm.p.Caption = msg
message_frm.Show vbModal
msg_frm = 1
End Function
Function note_msg(msg As String, cap As String) As Integer
Note_frm.Caption = cap
Note_frm.p.Caption = msg
Note_frm.Show vbModal
note_msg = 1
End Function
Sub emp_objss()
ThisDrawing.SelectionSets.Item("selobj").Delete
Set objss = ThisDrawing.SelectionSets.Add("selobj")
End Sub
Sub false_flags()
   sys_def_flag = False
   work_sel_method_flag = False
   work_sel_resource_flag = False
End Sub
Sub load_frm()
   If sys_def_flag = True Then syschosen.Show
   If work_sel_method_flag = True Then method_choose.Show
   If work_sel_resource_flag = True Then resource_choose.Show
End Sub
Function open_db_method(dbname As String) As String
   dbstr = ThisDrawing.Application.ActiveDocument.Path
   Set methoddb = OpenDatabase(dbstr & "\" & dbname & ".mdb")
   Set methodtab = methoddb.OpenRecordset(dbname)
   open_db_method = dbname
End Function
Function open_db_resource(dbname As String) As String
   dbstr = ThisDrawing.Application.ActiveDocument.Path
   Set resourcedb = OpenDatabase(dbstr & "\" & dbname & ".mdb")
   Set resourcetab = resourcedb.OpenRecordset(dbname)
   open_db_resource = dbname
End Function
Function check_syscopy_id(sys As String) As String
   With map_sys_id
      .Index = "copy_id"
      .Seek "=", Val(sys)
      If Not .NoMatch Then check_syscopy_id = .Fields("sys_id") _
      Else check_syscopy_id = ""
   End With
End Function
Function check_sys_id(sys As String) As String
   With map_sys_id
      .Index = "sys_id"
      .Seek "=", Val(sys)
      If Not .NoMatch Then check_sys_id = .Fields("copy_id") _
      Else check_sys_id = ""
```

```
    End With
End Function
```

dbs

This part presents the code written to manipulate the databases

```
Global logindb As Database
Global systemdb As Database
Global methoddb As Database
Global logintab As Recordset
Global resourcedb As Database
Global systemtab As Recordset
Global assembly_seq As Recordset
Global methodtab As Recordset
Global resourcetab As Recordset
Global map_sys_id As Recordset
Global dbstr As String
```

2. FORMS

Assembly_choose

This form allows the user to select a system to define

```
Private Sub CommandButton1_Click()
    Dim r As Integer
    'check if there is a selected object in the drawing
    'if not message choose an object
    If objss.Item(0) Is Nothing Then
        MsgBox ("pls choose a system first")
    Else
        'if an object is selected
        'load System_frm and proceed with it
        Set entity_ref = objss.Item(0)
        selobj_name = entity_ref.ObjectName
        selobj_id = entity_ref.ObjectID
        'empty the selection set object here
        'backup these values for the define all
        define_all_selobj_name = entity_ref.ObjectName
        define_all_selobj_id = entity_ref.ObjectID
        'backup these values for the define all
        If Not objss Is Nothing Then objss.Delete
        Dim h As Integer
        h = note_msg("Place The System", "Place")
        ThisDrawing.SendCommand ("_copybase" & vbCr & base_point(0) & _
        "," & base_point(1) & "," & base_point(2) & vbCr)
        ThisDrawing.SendCommand (Format(sys_point(0), "0.000") & "," & Format(sys_point(1),
"0.000") & "," & Format(sys_point(2), "0.000") & vbCr)
        ThisDrawing.SendCommand (vbCr)
        ThisDrawing.SendCommand ("_pasteclip" & vbCr)
        Unload Me
        sys_relation_frm.Show
    End If
End Sub
```

```
Private Sub CommandButton2_Click()
   Unload Me
End Sub
Private Sub CommandButton3_Click()
   make_your_selection
End Sub
Sub make_your_selection()
   'On Error Resume Next
   If ThisDrawing.SelectionSets.Count = 0 Then
   Set objss = ThisDrawing.SelectionSets.Add("selobj")
   Else
   ThisDrawing.SelectionSets.Item("selobj").Delete
   Set objss = ThisDrawing.SelectionSets.Add("selobj")
   End If
   If Not (objss Is Nothing) Then
        sys_point = ThisDrawing.Utility.GetPoint
        objss.SelectAtPoint sys_point
'         objss.SelectOnScreen
        objss.Highlight True
   End If
End Sub

Private Sub Label1_Click()

End Sub

Private Sub Label2_Click()

End Sub

Private Sub UserForm_Click()

End Sub
```

Define_all_frm

This form allows the user to perform “assemblies sequence”, “methods selection”, and “resources allocation” in sequence.

```
Private Sub Command_allocate_resources_Click()
'    If loginflag = False Then
'          work_sel_resource_flag = True
'          uselogin.Show
'    Else
         ' resource_choose.Show
         With systemtab
             .Index = "sys_id"
             .Seek "=", define_all_selobj_id
             If Not .NoMatch Then
                 If .Fields("method_flag") = True Then
                     'open the specified resources database
                     rstr = open_db_resource(.Fields("resource_db"))
                     'open the specified resources database
```

```
                    resources_frm.Show
                Else
                    r = note_msg("No method is identified for this system", "Warning")
                End If
            Else
                r = note_msg("No system definitions for this object", "Warning")
            End If
        End With

'    End If
End Sub

Private Sub Command_assembly_Click()
    define_all_flag = True
    work_assemblies
End Sub

Private Sub Command_ok_Click()
    Unload Me

End Sub

Private Sub Command_select_method_Click()
'    If loginflag = False Then
'            work_sel_method_flag = True
'            uselogin.Show
'    Else
        'method_choose.Show
        With systemtab
            .Index = "sys_id"
            .Seek "=", define_all_selobj_id
            If Not .NoMatch Then
                rstr = open_db_method(.Fields("struct_type"))
                Methods_frm2.Show
            Else
                r = note_msg("No system definitions for this object", "Warning")
            End If
        End With
'    End If
End Sub

Private Sub UserForm_Terminate()
    define_all_flag = False

    define_all_selobj_id = ""
    define_all_selobj_name = ""
End Sub
```

Equip_choose

This form allows the user to select a piece of equipment, and check for maximum reach.

```
Dim r As Integer
Dim c '(0 To 2) As Double
```

```
Dim circle_obj As AcadCircle
Dim tmpstr As String
Dim blk_ref As AcadBlockReference
Dim blk_name As String
Private Sub CommandButton1_Click()
'check if there is a selected object in the drawing
'if not message choose an object
If objss.Item(0) Is Nothing Then
MsgBox ("pls choose a system first")
Else
'if an object is selected
'load System_frm and proceed with it
Set blk_ref = objss.Item(0)
blk_name = blk_ref.Name
'empty the selection set object here
If Not objss Is Nothing Then objss.Delete
'search for the database and open it if the object type exist
With systemtab
    .Index = "sys_resource"
    .Seek "=", blk_name
    If Not .NoMatch Then
        If .Fields("resource_db") <> "" Then tmpstr = open_db_resource(.Fields("resource_db"))
        'adjust the record of the equipment
        adjust_record
        'adjust the record of the equipment
        'change the view to top
        ThisDrawing.SendCommand ("-view" & vbCr & "_top" & vbCr)
        'change the view to top
        Dim h As Integer
        h = note_msg("Please specify the base point.", "Base Point For Rotation")
        base_point_flag = True
            prompt1 = "Click the drawing to specify the base point"
            base_point = ThisDrawing.Utility.GetPoint(, prompt1)
        base_point_flag = False
        'process drawing the circle
        Dim w As Boolean
        w = adjust_record
        If w = True Then Set circle_obj = ThisDrawing.ModelSpace.AddCircle(base_point,
resourcetab.Fields("Maximum working radius"))
        circle_obj.Highlight True
        'process drawing the circle
'       blk_ref.Rotate base_point, rot_angle
        ThisDrawing.SendCommand ("rotate" & vbCr & base_point(0) & _
        "," & base_point(1) & "," & base_point(2) & "  " _
        & base_point(0) & "," & base_point(1) & "," & base_point(2) & vbCr)
    Else
        r = note_msg("No Max Reach to review for this equipment", "Warning")
    End If
End With
'search for the database and open it if the object type exist
End If
End Sub
Function adjust_record() As Boolean
With resourcetab
```

```
If Not .BOF Then .MoveFirst
Do While Not .EOF
If .Fields("Type") = blk_name Then
adjust_record = True
Exit Do
End If
If Not .EOF Then .MoveNext Else Exit Do
If .EOF Then Exit Do
Loop
End With
End Function
Private Sub CommandButton2_Click()
Unload Me
End Sub
Private Sub CommandButton3_Click()
make_your_selection
End Sub
Sub make_your_selection()
On Error Resume Next
If ThisDrawing.SelectionSets.Item("selobj") Is Nothing Then
Set objss = ThisDrawing.SelectionSets.Add("selobj")
Else
ThisDrawing.SelectionSets.Item("selobj").Delete
Set objss = ThisDrawing.SelectionSets.Add("selobj")
End If
If Not (objss Is Nothing) Then
  objss.SelectOnScreen
'objss.Highlight True
End If
End Sub

Private Sub Label1_Click()

End Sub

Private Sub Label2_Click()

End Sub

Private Sub UserForm_Initialize()
dbstr = ThisDrawing.Application.ActiveDocument.Path
Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
Set logintab = logindb.OpenRecordset("logintab")

Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
Set systemtab = systemdb.OpenRecordset("systemtab")
Set assembly_seq = systemdb.OpenRecordset("assembly_seq")
Set map_sys_id = systemdb.OpenRecordset("map_sys_id")
End Sub
```

get_point_frm

This form allows the user to select a base point of the equipment for the purpose of rotation to check for maximum reach

```
Dim pressed_flag As Boolean
Private Sub CommandButton2_Click()
   Unload Me
End Sub
Private Sub CommandButton3_Click()
'    Dim h As Integer
'    h = note_msg("Please specify the base point.", "Base Point")
   base_point = ThisDrawing.Utility.GetPoint(, "Click to specify the base point")
   'save this point in case of the define all
   If define_all_flag = True Then define_all_base_point = base_point
   'save this point in case of the define all
   pressed_flag = True
End Sub
Private Sub CommandButton4_Click()
   Dim h As Integer
   If pressed_flag = True Then
      Unload Me
      assembly_choose.Show
   Else
      h = note_msg("Please specify the base point.", "Base Point")
   End If
End Sub

Private Sub Label1_Click()

End Sub

Private Sub Label2_Click()

End Sub
```

get_rev_method

This form allows the user to review information about the method selected for a system

```
Dim nr As String

Private Sub CommandButton1_Click()
Dim r As Integer
If objss Is Nothing Then r = warn_msg("Pls select an object first and press enter", "warning")
'first check the existance of the selected object
If objss.Count <= 0 Then
r = warn_msg("Pls select an object first and press enter", "warning")
Exit Sub
End If
'first check the existance of the selected object
With systemtab
    Dim m As Integer
    m = 0
   .Index = "sys_id"
   Do While m < objss.Count
   .Seek "=", objss.Item(m).ObjectID
   If Not .NoMatch Then Exit Do
```

```
    m = m + 1
    Loop
    '.Seek "=", objss.Item(0).ObjectID
    If Not .NoMatch Then
        'fill the form texts and load it
        method_review.Caption = .Fields("method_db")
        'fill the form texts
        fill_form_texts
        method_review.Show
    Else
        nr = check_syscopy_id(objss.Item(0).ObjectID)
        If nr <> "" Then
            prcess_sys_id
            Unload Me
            Exit Sub
        End If
        'empty the objss
        emp_objss
         r = warn_msg("No Method is identified for this system" & vbCr & " Please select a method then retry", "Note")
        Exit Sub
    End If
End With
Unload Me
End Sub
Sub prcess_sys_id()
    With systemtab
          .Index = "sys_id"
          .Seek "=", nr
          If Not .NoMatch Then
               'fill the form texts and load it
               method_review.Caption = .Fields("method_db")
               'fill the form texts
               fill_form_texts
               method_review.Show
          End If
    End With
End Sub
Sub fill_form_texts()
Dim r As String
With method_review
If systemtab.Fields("method_userteam") <> "" Then .team_combo.Text = systemtab.Fields("method_userteam")
If systemtab.Fields("method_username") <> "" Then .name_combo.Text = systemtab.Fields("method_username")
If systemtab.Fields("method_userteam") <> "" Then .date_combo.Text = systemtab.Fields("method_userdate")
'load the grid
With systemtab
    .Index = "sys_id"
    If nr <> "" Then
        .Seek "=", nr
    Else
        .Seek "=", objss.Item(m).ObjectID
```

```
    End If
    If Not .NoMatch Then
        r = open_db_method(.Fields("method_db"))
        adjust_method_record
        fill_m_grid
    End If
End With
'load the grid
End With
End Sub
Sub adjust_method_record()
With methodtab
If Not .BOF Then .MoveFirst
Do While Not .EOF
If .Fields("description") = systemtab.Fields("sys_method") Then Exit Do
If Not .EOF Then .MoveNext Else Exit Do
If .EOF Then Exit Do
Loop
End With
End Sub
Sub fill_m_grid()
With method_review.m_grid
.Col = 0
If methodtab.Fields("description") <> "" Then .Text = methodtab.Fields("description")
.Col = 1
If methodtab.Fields("Productivity") <> "" Then .Text = methodtab.Fields("Productivity")
.Col = 2
If methodtab.Fields("Vertical Reach") <> "" Then .Text = methodtab.Fields("Vertical Reach")
.Col = 3
If methodtab.Fields("Horizontal Reach") <> "" Then .Text = methodtab.Fields("Horizontal Reach")
.Col = 4
If methodtab.Fields("Resource Requirement") <> "" Then .Text = methodtab.Fields("Resource Requirement")
End With
End Sub
Private Sub CommandButton2_Click()
Unload Me
End Sub
Private Sub CommandButton3_Click()
make_your_selection
End Sub

Private Sub Label2_Click()

End Sub

Private Sub UserForm_Click()

End Sub
Private Sub UserForm_Initialize()
dbstr = ThisDrawing.Application.ActiveDocument.Path
Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
Set logintab = logindb.OpenRecordset("logintab")
Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
```

```
Set systemtab = systemdb.OpenRecordset("systemtab")
Set assembly_seq = systemdb.OpenRecordset("assembly_seq")
Set map_sys_id = systemdb.OpenRecordset("map_sys_id")
End Sub
Sub make_your_selection()
On Error Resume Next
If ThisDrawing.SelectionSets.Item("selobj") Is Nothing Then
Set objss = ThisDrawing.SelectionSets.Add("selobj")
Else
ThisDrawing.SelectionSets.Item("selobj").Delete
Set objss = ThisDrawing.SelectionSets.Add("selobj")
End If
If Not (objss Is Nothing) Then
  objss.SelectOnScreen
End If   'If objss Is Not Nothing Then
End Sub
```

get_rev_resource

This form allows the user to review information about resources allocated for a system

```
Dim nr As String

Private Sub CommandButton1_Click()
Dim r As Integer
If objss Is Nothing Then r = warn_msg("Pls select an object first and press enter", "warning")
'first check the existance of the selected object
If objss.Count <= 0 Then
r = warn_msg("Pls select an object first and press enter", "warning")
Exit Sub
End If
'first check the existance of the selected object
With systemtab
    Dim m As Integer
    m = 0
   .Index = "sys_id"
   Do While m < objss.Count
   .Seek "=", objss.Item(m).ObjectID
   If Not .NoMatch Then Exit Do
   m = m + 1
   Loop
   '.Seek "=", objss.Item(0).ObjectID
   If Not .NoMatch Then
      'fill the form texts and load it
      resource_review.Caption = .Fields("sys_resource")
      'fill the form texts
      fill_form_texts
      resource_review.Show
   Else
      nr = check_syscopy_id(objss.Item(0).ObjectID)
      If nr <> "" Then
         prcess_sys_id
         Unload Me
         Exit Sub
```

```
        End If
        'empty the objss
        emp_objss
          r = warn_msg("No Resource is identified for this system" & vbCr & " Please select a resource
then retry", "Note")
        Exit Sub
    End If
End With
Unload Me
End Sub
Sub prcess_sys_id()
    With systemtab
           .Index = "sys_id"
           .Seek "=", nr
           If Not .NoMatch Then
                'fill the form texts and load it
                resource_review.Caption = .Fields("sys_resource")
                'fill the form texts
                fill_form_texts
                resource_review.Show
           End If
    End With
End Sub
Private Sub CommandButton2_Click()
Unload Me
End Sub
Private Sub CommandButton3_Click()
make_your_selection
End Sub

Private Sub Label2_Click()

End Sub

Private Sub UserForm_Click()

End Sub
Sub make_your_selection()
On Error Resume Next
If ThisDrawing.SelectionSets.Item("selobj") Is Nothing Then
Set objss = ThisDrawing.SelectionSets.Add("selobj")
Else
ThisDrawing.SelectionSets.Item("selobj").Delete
Set objss = ThisDrawing.SelectionSets.Add("selobj")
End If
If Not (objss Is Nothing) Then
   objss.SelectOnScreen
End If   'If objss Is Not Nothing Then
End Sub
Private Sub UserForm_Initialize()
dbstr = ThisDrawing.Application.ActiveDocument.Path
Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
Set logintab = logindb.OpenRecordset("logintab")
Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
```

```
Set systemtab = systemdb.OpenRecordset("systemtab")
Set assembly_seq = systemdb.OpenRecordset("assembly_seq")
Set map_sys_id = systemdb.OpenRecordset("map_sys_id")
End Sub
Sub fill_form_texts()
Dim r As String
With resource_review
If systemtab.Fields("resource_userteam") <> "" Then .team_combo.Text = systemtab.Fields("resource_userteam")
If systemtab.Fields("resource_username") <> "" Then .name_combo.Text = systemtab.Fields("resource_username")
If systemtab.Fields("resource_userteam") <> "" Then .date_combo.Text = systemtab.Fields("resource_userteam")
'load the grid
With systemtab
    .Index = "sys_id"
    If nr <> "" Then
        .Seek "=", nr
    Else
        .Seek "=", objss.Item(m).ObjectID
    End If
    If Not .NoMatch Then
        r = open_db_resource(.Fields("resource_db"))
        adjust_resource_record
        fill_m_grid
    End If
End With
'load the grid
End With
End Sub
Sub adjust_resource_record()
With resourcetab
If Not .BOF Then .MoveFirst
Do While Not .EOF
If .Fields("type") = systemtab.Fields("sys_resource") Then Exit Do
If Not .EOF Then .MoveNext Else Exit Do
If .EOF Then Exit Do
Loop
End With
End Sub
Sub fill_m_grid()
With resource_review.m_grid
.Col = 0
If resourcetab.Fields("type") <> "" Then .Text = resourcetab.Fields("type")
.Col = 1
If resourcetab.Fields("Availibility") <> "" Then .Text = resourcetab.Fields("Availibility")
.Col = 2
If resourcetab.Fields("Max hook height") <> "" Then .Text = resourcetab.Fields("Max hook height")
.Col = 3
If resourcetab.Fields("Max Lifting capacity") <> "" Then .Text = resourcetab.Fields("Max Lifting capacity")
.Col = 4
If resourcetab.Fields("Max jib length") <> "" Then .Text = resourcetab.Fields("Max jib length")
.Col = 5
```

```
If resourcetab.Fields("Maximum working radius") <> "" Then .Text = resourcetab.Fields("Maximum working radius")
.Col = 6
If resourcetab.Fields("Cost") <> "" Then .Text = resourcetab.Fields("Cost")
.Col = 7
If resourcetab.Fields("Space requirement") <> "" Then .Text = resourcetab.Fields("Space requirement")
End With
End Sub
```

get_rev_system

This form allows the user to review information on the system definition

```
Dim nr As String

Private Sub CommandButton1_Click()
Dim r As Integer
If objss Is Nothing Then r = warn_msg("Pls select an object first and press enter", "warning")
'first check the existance of the selected object
If objss.Count <= 0 Then
r = warn_msg("Pls select an object first and press enter", "warning")
Exit Sub
End If
'first check the existance of the selected object
With systemtab
     Dim m As Integer
     m = 0
    .Index = "sys_id"
    Do While m < objss.Count
    .Seek "=", objss.Item(m).ObjectID
    If Not .NoMatch Then Exit Do
    m = m + 1
    Loop
    '.Seek "=", objss.Item(0).ObjectID
    If Not .NoMatch Then
        'fill the form texts and load it
        system_reveiw.Caption = .Fields("sys") & .Fields("struct_type") & .Fields("remarks")
        'fill the form texts
        fill_form_texts
        system_reveiw.Show
    Else
        nr = check_syscopy_id(objss.Item(0).ObjectID)
        If nr <> "" Then
            prcess_sys_id
            Unload Me
            Exit Sub
        End If
        'empty the objss
        emp_objss
        r = warn_msg("No definitions specified for this object", "Note")
        Exit Sub
    End If
End With
Unload Me
```

```
End Sub
Sub prcess_sys_id()
    With systemtab
        .Index = "sys_id"
        .Seek "=", nr
        If Not .NoMatch Then
            'fill the form texts and load it
            system_reveiw.Caption = .Fields("sys") & .Fields("struct_type") & .Fields("remarks")
            'fill the form texts
            fill_form_texts
            system_reveiw.Show
        End If
    End With
End Sub

Sub fill_form_texts()
With system_reveiw
.t_id = systemtab.Fields("userteam")
.t_type = systemtab.Fields("userteam")
.t_perform = systemtab.Fields("userteam")
.t_design = systemtab.Fields("userteam")
.t_remarks = systemtab.Fields("userteam")

.n_id = systemtab.Fields("username")
.n_type = systemtab.Fields("username")
.n_perform = systemtab.Fields("username")
.n_design = systemtab.Fields("username")
.n_remarks = systemtab.Fields("username")

.d_id = systemtab.Fields("userdate")
.d_type = systemtab.Fields("userdate")
.d_perform = systemtab.Fields("userdate")
.d_design = systemtab.Fields("userdate")
.d_remarks = systemtab.Fields("userdate")

If systemtab.Fields("sys_mod") <> "" Then .p_type = systemtab.Fields("sys_mod")
If systemtab.Fields("perform_mod") <> "" Then .p_perform = systemtab.Fields("perform_mod")
If systemtab.Fields("design_mod") <> "" Then .p_design = systemtab.Fields("design_mod")

If systemtab.Fields("sys_id") <> "" Then .sys_id = systemtab.Fields("sys_id")
If systemtab.Fields("sys_type") <> "" Then .sys_type = systemtab.Fields("sys_type")
If systemtab.Fields("perfom_des") <> "" Then .perfom_des = systemtab.Fields("perfom_des")
If systemtab.Fields("design_des") <> "" Then .design_des = systemtab.Fields("design_des")
If systemtab.Fields("remarks2") <> "" Then .Remarks = systemtab.Fields("remarks2")
End With
End Sub
Private Sub CommandButton2_Click()
Unload Me
End Sub
Private Sub CommandButton3_Click()
make_your_selection
End Sub

Private Sub Label2_Click()
```

```
End Sub

Private Sub UserForm_Click()

End Sub
Private Sub UserForm_Initialize()
dbstr = ThisDrawing.Application.ActiveDocument.Path
Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
Set logintab = logindb.OpenRecordset("logintab")
Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
Set systemtab = systemdb.OpenRecordset("systemtab")
Set assembly_seq = systemdb.OpenRecordset("assembly_seq")
Set map_sys_id = systemdb.OpenRecordset("map_sys_id")
End Sub
Sub make_your_selection()
On Error Resume Next
If ThisDrawing.SelectionSets.Item("selobj") Is Nothing Then
Set objss = ThisDrawing.SelectionSets.Add("selobj")
Else
ThisDrawing.SelectionSets.Item("selobj").Delete
Set objss = ThisDrawing.SelectionSets.Add("selobj")
End If
If Not (objss Is Nothing) Then
  objss.SelectOnScreen
End If   'If objss Is Not Nothing Then
End Sub
```

get_sys_sequence

This form allows the user to review information on the sequence of a system

```
Private Sub CommandButton1_Click()
   Dim r As Integer
   If objss Is Nothing Then r = warn_msg("Pls select an object first and press enter", "warning")
   'first check the existance of the selected object
   If objss.Count <= 0 Then
   r = warn_msg("Pls select an object first and press enter", "warning")
   Exit Sub
   End If
   'first check the existance of the selected object
   With assembly_seq
      .Index = "sys_id"
      .Seek "=", objss.Item(0).ObjectID
      If Not .NoMatch Then
         'fill the form texts and load it
         sequence_review.Caption = .Fields("sys_name")
         'fill the form texts
         fill_form_texts
         sequence_review.Show
      Else
         Dim nr As String
         nr = check_syscopy_id(objss.Item(0).ObjectID)
         If nr <> "" Then
```

```
            prcess_sys_id
            Unload Me
            Exit Sub
        End If
        'empty the objss
        emp_objss
            r = warn_msg("No Sequence is identified for this system" & vbCr & " Please Specify a
sequence then retry", "Note")
        Exit Sub
      End If
    End With
    Unload Me
End Sub
Sub prcess_sys_id()
    With systemtab
        .Index = "sys_id"
        .Seek "=", nr
        If Not .NoMatch Then
            'fill the form texts and load it
            sequence_review.Caption = .Fields("sys_name")
            'fill the form texts
            fill_form_texts
            sequence_review.Show
        End If
    End With
End Sub
Private Sub CommandButton2_Click()
    Unload Me
End Sub
Private Sub CommandButton3_Click()
    make_your_selection
End Sub
Sub make_your_selection()
    'On Error Resume Next
    If ThisDrawing.SelectionSets.Count = 0 Then
    Set objss = ThisDrawing.SelectionSets.Add("selobj")
    Else
    ThisDrawing.SelectionSets.Item("selobj").Delete
    Set objss = ThisDrawing.SelectionSets.Add("selobj")
    End If
    If Not (objss Is Nothing) Then
      objss.SelectOnScreen
    End If   'If objss Is Not Nothing Then
End Sub
Sub fill_form_texts()
    With sequence_review
    If assembly_seq.Fields("activity") <> "" Then .activity_txt.Text = assembly_seq.Fields("activity")
    If assembly_seq.Fields("predecessor") <> "" Then .prdecessor_txt.Text =
assembly_seq.Fields("predecessor")
    If assembly_seq.Fields("relationship") <> "" Then .Relationship_txt.Text =
assembly_seq.Fields("relationship")
    If assembly_seq.Fields("lag") <> "" Then .lag_txt.Text = assembly_seq.Fields("lag")
    End With
End Sub
```

```
Private Sub Label2_Click()

End Sub

Private Sub UserForm_Initialize()
    dbstr = ThisDrawing.Application.ActiveDocument.Path
    Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
    Set logintab = logindb.OpenRecordset("logintab")
    Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
    Set systemtab = systemdb.OpenRecordset("systemtab")
    Set assembly_seq = systemdb.OpenRecordset("assembly_seq")
    Set map_sys_id = systemdb.OpenRecordset("map_sys_id")
End Sub
```

method_choose

This form allows the user to select a method for an assembly

```
Private Sub CommandButton1_Click()
Dim r As Integer
'check if there is a selected object in the drawing
'if not message choose an object
If objss.Item(0) Is Nothing Then
MsgBox ("pls choose a system first")
Else
'if an object is selected
'load System_frm and proceed with it
Set entity_ref = objss.Item(0)
selobj_name = entity_ref.ObjectName
selobj_id = entity_ref.ObjectID
'empty the selection set object here
If Not objss Is Nothing Then objss.Delete
'search for the database and open it if the object type exist
With systemtab
    .Index = "sys_id"
    .Seek "=", selobj_id
    If Not .NoMatch Then
        rstr = open_db_method(.Fields("struct_type"))
        Methods_frm2.Show
        Unload Me
    Else
        r = note_msg("No system definitions for this object", "Warning")
    End If
End With
'search for the database and open it if the object type exist

End If
End Sub
Private Sub CommandButton2_Click()
Unload Me
End Sub
Private Sub CommandButton3_Click()
make_your_selection
End Sub
```

```
Sub make_your_selection()
On Error Resume Next
If ThisDrawing.SelectionSets.Item("selobj") Is Nothing Then
Set objss = ThisDrawing.SelectionSets.Add("selobj")
Else
ThisDrawing.SelectionSets.Item("selobj").Delete
Set objss = ThisDrawing.SelectionSets.Add("selobj")
End If
If Not (objss Is Nothing) Then
   objss.SelectOnScreen
'objss.Highlight True
End If
End Sub

Private Sub Label2_Click()

End Sub

Private Sub UserForm_Click()
'dbstr = ThisDrawing.Application.ActiveDocument.Path
'Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
'Set logintab = logindb.OpenRecordset("logintab")
'
'Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
'Set systemtab = systemdb.OpenRecordset("systemtab")
End Sub
```

method_review

This form allows the user to review information on the method selected

```
Private Sub Command_ok_Click()
Unload Me
End Sub

Private Sub Label10_Click()

End Sub

Private Sub Label8_Click()

End Sub

Private Sub m_Equip_Click()

End Sub

Private Sub m_Productivity_Click()

End Sub

Private Sub m_Type_Click()

End Sub
```

```
Private Sub name_combo_Change()

End Sub

Private Sub team_combo_Change()

End Sub

Private Sub UserForm_Initialize()
adjust_grid
End Sub
Sub adjust_grid()
Dim i As Integer
With m_grid
    .ColWidth(0) = m_Type.Width * 19.5
    .ColWidth(1) = m_Productivity.Width * 20
    .ColWidth(2) = m_Vertical_Reach.Width * 20
    .ColWidth(3) = m_Horizontal_Reach.Width * 20
    .ColWidth(4) = m_Equip.Width * 20
For i = 0 To 4
.ColAlignment(i) = 5
Next i
End With
End Sub
```

resource_choose

This form allows the user to allocate a resource for an assembly

```
Private Sub CommandButton1_Click()
Dim r As Integer
'check if there is a selected object in the drawing
'if not message choose an object
If objss.Item(0) Is Nothing Then
MsgBox ("pls choose a system first")
Else
'if an object is selected
'load System_frm and proceed with it
Set entity_ref = objss.Item(0)
selobj_name = entity_ref.ObjectName
selobj_id = entity_ref.ObjectID
'empty the selection set object here
If Not objss Is Nothing Then objss.Delete
'search for the database and open it if the object type exist
With systemtab
    .Index = "sys_id"
    .Seek "=", selobj_id
    If Not .NoMatch Then
        If .Fields("method_flag") = True Then
            'open the specified resources database
            rstr = open_db_resource(.Fields("resource_db"))
            'open the specified resources database
            resources_frm.Show
            Unload Me
        Else
```

```
            r = note_msg("No method is identified for this system", "Warning")
        End If
    Else
        r = note_msg("No system definitions for this object", "Warning")
    End If
End With
'search for the database and open it if the object type exist
End If
End Sub
Private Sub CommandButton2_Click()
Unload Me
End Sub
Private Sub CommandButton3_Click()
make_your_selection
End Sub

Private Sub Label2_Click()

End Sub

Private Sub UserForm_Click()

End Sub
Sub make_your_selection()
On Error Resume Next
If ThisDrawing.SelectionSets.Item("selobj") Is Nothing Then
Set objss = ThisDrawing.SelectionSets.Add("selobj")
Else
ThisDrawing.SelectionSets.Item("selobj").Delete
Set objss = ThisDrawing.SelectionSets.Add("selobj")
End If
If Not (objss Is Nothing) Then
   objss.SelectOnScreen
'objss.Highlight True
End If
End Sub
```

resource_review

This form allows the user to review information on the resource allocated

```
Private Sub Command_ok_Click()
Unload Me
End Sub

Private Sub m_grid_Click()

End Sub

Private Sub name_combo_Change()

End Sub

Private Sub r_Availibility_Click()
```

```
End Sub

Private Sub r_cost_Click()

End Sub

Private Sub r_max_hook_height_Click()

End Sub

Private Sub r_Max_jib_length_Click()

End Sub

Private Sub r_Max_Lifting_capacity_Click()

End Sub

Private Sub r_max_work_radius_Click()

End Sub

Private Sub r_Space_requirement_Click()

End Sub

Private Sub r_Type_Click()

End Sub

Private Sub team_combo_Change()

End Sub

Private Sub UserForm_Click()

End Sub
Private Sub UserForm_Initialize()
adjust_grid
End Sub
Sub adjust_grid()
Dim i As Integer
With m_grid
    .ColWidth(0) = Me.r_Type.Width * 19.5
    .ColWidth(1) = Me.r_Availibility.Width * 20
    .ColWidth(2) = Me.r_max_hook_height.Width * 20
    .ColWidth(3) = Me.r_Max_Lifting_capacity.Width * 20
    .ColWidth(4) = Me.r_Max_jib_length.Width * 20
    .ColWidth(5) = Me.r_max_work_radius.Width * 20
    .ColWidth(6) = Me.r_cost.Width * 20
    .ColWidth(7) = Me.r_Space_requirement.Width * 20
For i = 0 To 7
.ColAlignment(i) = 5
Next i
```

```
End With
End Sub
```

sys_relation_frm

This method allows the user to, while deciding the assemblies' sequence, name the activity and to review/modify the predecessor, the relationship, and the predecessor.

```
Private Sub activity_txt_Change()

End Sub

Private Sub Command_change_Click()
    Dim ss As AcadSelectionSet
    Dim r As Integer
    'add temporary selectionset
    Set ss = ThisDrawing.SelectionSets.Add("ss")
    If Not (ss Is Nothing) Then
        ss.SelectOnScreen
    End If
    'add temporary selectionset
    With assembly_seq
        .Index = "sys_id"
        .Seek "=", ss.Item(0).ObjectID
        If Not .NoMatch Then
            If .Fields("activity") <> "" Then prdecessor_txt.Text = .Fields("activity")
        Else
            r = note_msg("No activity is related to this system", "Warning")
        End If
    End With
    ThisDrawing.SelectionSets.Item("ss").Delete
End Sub
Private Sub CommandButton1_Click()
    'save the record to the assembly_seq table
    With assembly_seq
        .AddNew
        If selobj_id <> "" Then .Fields("sys_id") = selobj_id
        If selobj_name <> "" Then .Fields("sys_name") = selobj_name
        If activity_txt.Text <> "" Then .Fields("activity") = activity_txt.Text
        If prdecessor_txt.Text <> "" Then .Fields("predecessor") = prdecessor_txt.Text
        If rel_combo.Text <> "" Then .Fields("relationship") = rel_combo.Text
        If lag_txt.Text <> "" Then .Fields("lag") = lag_txt.Text
        .Update
    End With
    'save the record to the assembly_seq table

    'save this record to the map_sys_id table
    With map_sys_id
        .AddNew
        .Fields("sys_id") = selobj_id
        .Fields("copy_id") = syscopy_id
        .Update
    End With
    'save this record to the map_sys_id table
```

```
    Unload Me
End Sub
Private Sub CommandButton2_Click()
    Unload Me
End Sub

Private Sub Label1_Click()

End Sub

Private Sub Label2_Click()

End Sub

Private Sub Label3_Click()

End Sub

Private Sub Label4_Click()

End Sub

Private Sub lag_txt_Change()

End Sub

Private Sub prdecessor_txt_Change()

End Sub

Private Sub rel_combo_Change()

End Sub

Private Sub UserForm_Initialize()
    dbstr = ThisDrawing.Application.ActiveDocument.Path
    Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
    Set logintab = logindb.OpenRecordset("logintab")

    Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
    Set systemtab = systemdb.OpenRecordset("systemtab")
    Set assembly_seq = systemdb.OpenRecordset("assembly_seq")
    Set map_sys_id = systemdb.OpenRecordset("map_sys_id")

    With rel_combo
        .AddItem "Start-to-Start"
        .AddItem "Start-to_Finish"
        .AddItem "Finish-to-Start"
        .AddItem "Finish-to-Finish"
    End With
    'load the predecessor
    With assembly_seq
        If Not .EOF Then
            .MoveLast
```

```
            If .Fields("activity") <> "" Then prdecessor_txt.Text = .Fields("activity")
        End If
    End With
    'load the predecessor
End Sub
```

System_frm

This form allows the user to define an assembly

```
Dim sys_tab As Recordset
Dim struct_tab As Recordset
Dim remarks_tab As Recordset
Private Sub CommandButton1_Click()
'save the current choices before exit this screen
With systemtab
.AddNew
If sys_combo.Text <> "" Then .Fields("sys") = sys_combo.Text
If struct_combo.Text <> "" Then .Fields("struct_type") = struct_combo.Text
If remarks_combo.Text <> "" Then .Fields("remarks") = remarks_combo.Text
If selobj_id <> "" Then .Fields("sys_id") = selobj_id
'save the log in -user details
.Fields("username") = user_name
.Fields("userteam") = user_team
.Fields("userdate") = user_date
.Update
End With
System_frm2.cap_label.Caption = sys_combo.Text & " " & struct_combo.Text & " " &
remarks_combo.Text
System_frm2.Show
false_flags
Unload Me
End Sub
Private Sub CommandButton2_Click()
false_flags
Unload Me
End Sub

Private Sub sys_combo_Change()

End Sub

Private Sub UserForm_Initialize()

Set sys_tab = systemdb.OpenRecordset("select distinct sys from systemtab ;")
Set struct_tab = systemdb.OpenRecordset("select distinct struct_type from systemtab ;")
Set remarks_tab = systemdb.OpenRecordset("select distinct remarks from systemtab ;")

fill_all_combos

sys_combo.Text = selobj_name

End Sub
Sub fill_all_combos()
'fill sys_combo  struct_combo and remarks_combo
```

```
With sys_tab
    'fill the sys_combo
    '.Index = "sys"
    If Not .BOF Then .MoveFirst
     Do While Not .EOF
        If .Fields("sys") <> "" Then sys_combo.AddItem .Fields("sys")
        If Not .EOF Then .MoveNext Else Exit Do
     Loop
End With
With struct_tab
    'fill the struct_combo
     '.Index = "struct_type"
     If Not .BOF Then .MoveFirst
     Do While Not .EOF
        If .Fields("struct_type") <> "" Then struct_combo.AddItem .Fields("struct_type")
        If Not .EOF Then .MoveNext Else Exit Do
     Loop
End With
With remarks_tab
    'fill the remarks_combo
     '.Index = "remarks"
     If Not .BOF Then .MoveFirst
     Do While Not .EOF
        If .Fields("remarks") <> "" Then remarks_combo.AddItem .Fields("remarks")
        If Not .EOF Then .MoveNext Else Exit Do
     Loop
End With
End Sub
```

System_frm2

This form allows the user to continue defining the assembly

```
Private Sub sys_type_combo_Change()

End Sub

Private Sub UserForm_Click()

End Sub
Private Sub UserForm_Initialize()
Dim tmptab1 As Recordset
Dim tmptab2 As Recordset
Dim tmptab3 As Recordset
Dim tmptab4 As Recordset

dbstr = ThisDrawing.Application.ActiveDocument.Path
Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
Set logintab = logindb.OpenRecordset("logintab")

Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
Set systemtab = systemdb.OpenRecordset("systemtab")
Set map_sys_id = systemdb.OpenRecordset("map_sys_id")
```

```
sys_id.Text = selobj_id
'load combos
Set tmptab1 = systemdb.OpenRecordset("select distinct sys_type from systemtab where sys ='" & selobj_name & "';")
With tmptab1
If Not .BOF Then .MoveFirst
Do While Not .EOF
If .Fields("sys_type") <> "" Then sys_type_combo.AddItem .Fields("sys_type")
If Not .EOF Then .MoveNext Else Exit Do
Loop
End With

Set tmptab2 = systemdb.OpenRecordset("select distinct perfom_des from systemtab where sys ='" & selobj_name & "';")
With tmptab2
If Not .BOF Then .MoveFirst
Do While Not .EOF
If .Fields("perfom_des") <> "" Then perfom_des_combo.AddItem .Fields("perfom_des")
If Not .EOF Then .MoveNext Else Exit Do
Loop
End With

Set tmptab3 = systemdb.OpenRecordset("select distinct design_des from systemtab where sys ='" & selobj_name & "';")
With tmptab3
If Not .BOF Then .MoveFirst
Do While Not .EOF
If .Fields("design_des") <> "" Then design_des_comb.AddItem .Fields("design_des")
If Not .EOF Then .MoveNext Else Exit Do
Loop
End With

Set tmptab4 = systemdb.OpenRecordset("select distinct remarks2 from systemtab where sys ='" & selobj_name & "';")
With tmptab4
If Not .BOF Then .MoveFirst
Do While Not .EOF
If .Fields("remarks2") <> "" Then Remarks_comb.AddItem .Fields("remarks2")
If Not .EOF Then .MoveNext Else Exit Do
Loop
End With

'load combos
End Sub
```

uselogin

This form allows the user to log in to start making the decisions

```
Dim dbstr As String
Dim teamtab As Recordset
Dim nametab As Recordset
Private Sub Commandok_Click()

If team_combo.Text = "" Then
```

```
a = warn_msg("Please enter the user team", "Warning")
team_combo.SetFocus
Exit Sub
End If
If name_combo.Text = "" Then
a = warn_msg("Please enter the user name", "Warning")
name_combo.SetFocus
Exit Sub
End If
If Password.Text = "" Then
a = warn_msg("Please enter the your password", "Warning")
Password.SetFocus
Exit Sub
End If
If Date_txt.Text = "" Then
a = warn_msg("Please enter the date", "Warning")
Date_txt.SetFocus
Exit Sub
End If
'this flag indicates that you have thus login for later use

With logintab
.Index = "t_n_p"
.Seek "=", team_combo.Text, name_combo.Text, Password.Text
If Not .NoMatch Then
loginflag = True
'fill the current details to variables as follows
user_team = Trim(team_combo.Text)
user_name = Trim(name_combo.Text)
user_date = Date_txt.Text
Unload Me
load_frm
'syschosen.Show
Exit Sub
End If
.Index = "t_n"
.Seek "=", team_combo.Text, name_combo.Text
If .NoMatch Then
   'if any new field then enter the new record in db as follows
   .AddNew
   .Fields("userteam") = team_combo.Text
   .Fields("username") = name_combo.Text
   .Fields("userpassword") = Password.Text
   .Fields("userdate") = Date_txt.Text
   .Update
   MsgBox ("The new user is successfully added")
Else
    .Index = "userPassword"
    .Seek "=", Password.Text
    If .NoMatch Then
      r = MsgBox("Add this as a new user ?!", vbYesNo, "Is this a new user")
      If r = vbNo Then
         MsgBox ("Thus Please check your password")
         Password.SetFocus
```

```
            Password.SelLength = Len(Password.Text)
            Exit Sub
        Else  'r = vbyes
            .AddNew
            .Fields("userteam") = team_combo.Text
            .Fields("username") = name_combo.Text
            .Fields("userpassword") = Password.Text
            .Fields("userdate") = Date_txt.Text
            .Update
            message_frm.p.Caption = ("The new user is successfully added")
            message_frm.Show vbModal
            'MsgBox ("The new user is successfully added")
        End If 'If r = vbNo Then

    End If  'If .NoMatch Then
End If
End With
loginflag = True
'fill the current details to variables as follows
user_team = team_combo.Text
user_name = name_combo.Text
user_date = Date_txt.Text
'syschosen.Show
'false_flags
Unload Me
load_frm
End Sub
Private Sub Commandcancel_Click()
End
End Sub
Private Sub name_add_Click()
name_combo.Text = ""
End Sub
Private Sub team_add_Click()
team_combo.Text = ""
End Sub

Private Sub Team_Combo_Click()
'fill the name combobox
empty_name_combo
name_combo.Text = ""
With logintab
    .Index = "userteam"
    .Seek "=", team_combo.Text
    If Not .NoMatch Then
        Do While UCase(.Fields("userteam")) = UCase(team_combo.Text)
            If Not .EOF Then name_combo.AddItem .Fields("username")
            If Not .EOF Then .MoveNext Else Exit Do
            If .EOF Then Exit Do
        Loop
        If name_combo.ListCount > 0 Then
        name_combo.Text = name_combo.List(0)
        name_combo.SelLength = Len(name_combo.List(0))
        End If
```

```
    Else
    'this team is not entered thus
    name_combo.SetFocus
    name_combo.Text = ""
    End If
End With
End Sub

Private Sub Team_Combo_KeyDown(ByVal KeyCode As MSForms.ReturnInteger, ByVal Shift As
Integer)
If KeyCode = 13 And team_combo.Text <> "" Then
name_combo.SetFocus
name_combo.SelLength = Len(name_combo.Text)
End If
End Sub

Private Sub UserForm_Initialize()

Call initializeevents

dbstr = ThisDrawing.Application.ActiveDocument.Path
Set logindb = OpenDatabase(dbstr & "\logindb.mdb")
Set logintab = logindb.OpenRecordset("logintab")

Set systemdb = OpenDatabase(dbstr & "\systemdb.mdb")
Set systemtab = systemdb.OpenRecordset("systemtab")
Set assembly_seq = systemdb.OpenRecordset("assembly_seq")
Set map_sys_id = systemdb.OpenRecordset("map_sys_id")

Set teamtab = systemdb.OpenRecordset("select distinct userteam from systemtab")
Set nametab = systemdb.OpenRecordset("select distinct username from systemtab")

Date_txt.Text = Format$(Now, "mm/dd/yyyy")
'fill the team combobox
fill_team_combo
fill_name_combo
End Sub
Sub fill_team_combo()
With teamtab  'logintab
'.index = "userteam"
If Not .BOF Then .MoveFirst
Do While Not .EOF
If Not .EOF Then team_combo.AddItem .Fields("userteam")
If Not .EOF Then .MoveNext Else Exit Do
Loop
End With
End Sub
Sub fill_name_combo()
With nametab   'logintab
'.Index = "username"
If Not .BOF Then .MoveFirst
Do While Not .EOF
If Not .EOF Then name_combo.AddItem .Fields("username")
If Not .EOF Then .MoveNext Else Exit Do
```

```
Loop
End With
End Sub
Sub clr_all()
team_combo.Text = ""
name_combo.Text = ""
Password.Text = ""
Date_txt.Text = ""
End Sub
Sub empty_name_combo()
Dim i As Integer
With name_combo
i = .ListCount - 1
Do While i >= 0
.RemoveItem i
i = i - 1
Loop
End With
End Sub
```

VITA

The author was born on December 21, 1971 in Cairo, Egypt. He received his Bachelor of Science degree in Architectural Engineering from Cairo University in July 1994. Between August 1994 and July 1996, he joined Dr. Tarek Abdel Latif's Architecture and Planning firm as a Junior Architect and Project Manager. Meanwhile, he was pursuing a professional program in Project Management at the American University in Cairo (AUC) and received a professional certificate in May 1996. In August 1996 he started graduate studies in the Civil, Environmental, and Ocean Engineering Department at Stevens Institute of Technology, New Jersey, USA where he was awarded a Master of Science degree in Construction Management in December 1997. In January 1998, he joined the department of Building Construction at Virginia Tech, Blacksburg, Virginia where he was awarded a Doctor of Philosophy degree in Environmental Design and Planning (EDP) in June 2001.