An Interactive Visual Approach to Construction Project Scheduling

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AN INTERACTIVE VISUAL APPROACH TO CONSTRUCTION PROJECT SCHEDULING

by

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A Thesis submitted to the faculty of Graduate school,
Marquette University,
In Partial Fulfillment of the Requirements for
the Degree of Masters in Science

Milwaukee, Wisconsin

December 2009

Abstract

Sound project management is an important pillar of success for a construction company. Project schedules are the primary tools for communicating the thinking and planning by the management team to all the stakeholders in a construction project. Traditional project scheduling software have become an indispensable tool for managers in various project-oriented industries for tracking the schedule, the budget and resource requirements of a project as well as for preparing reports, providing on-line access to project information and communication with the members of the project team. However, these benefits are realized only after the project information is entered into the computer and updated periodically. Setting up a computer schedule for a construction project requires entering into the computer not only all project activities and their durations and resource requirements but also organizing and sequencing of project activities. This requires considerable time and effort and consequently a full-scale time study is not usually performed for all projects.

New parametric CAD software is revolutionizing the way architects, engineers and contractors work and can significantly increase construction management productivity by substantially reducing the manual work necessary for computerized construction scheduling. The data model of new parametric CAD software allows easy exchange of building design information among various software systems during design, construction and service life of projects. Research is underway at Marquette University to investigate how new parametric CAD software such as Autodesk Revit can improve construction scheduling and project control functions. The main objective of the research is to find a

simple and intuitive way for transferring the necessary project information from an architectural CAD model to scheduling software and streamlining sequencing and organizing project activities. Achieving this objective will eliminate one of the most tedious and time consuming steps in creating a construction project schedule.

The study proposes a visual approach to extracting project information and transferring them to scheduling software. In this approach, first a 3D model of the project is created using project's digital Revit CAD files. Extraction, organizing, sequencing and transferring of project elements to scheduling software is performed during a walkthrough of the 3D model. During a walkthrough, the user can select a building element by pointing to the element. This capability allows the user to select both an element and its predecessors before executing a command that sends the information to the scheduling program. This approach reduces the tedious task of listing, organizing, sequencing, and transferring construction project information to scheduling software to a simple expedition inside the building.

Acknowledgement

I would like to thank all those who helped and inspired me during my master's study and research work.

I would like to express my deep felt gratitude to my advisor Dr. Saeed Karshenas for his guidance during my research and study at Marquette University. His great insight, perspective and enthusiasm about the research have always inspired me. I am grateful to him for his encouragement, support, patience and suggestions which provided strong motivation for all the time put into completing the research and writing work.

Sincere thanks to Dr. David Haber for giving his best suggestions for the development this application and for improving it.

I am thankful to Dr. Christopher M. Foley and Dr. Sriramulu Vinnakota , Department of Civil Engineering for their constructive comments on this thesis. I am thankful that in the midst of all their activities they accepted to be members of reading committee.

I convey special acknowledgement to Dr. Stanley Jaskolski, OPUS Dean and Dr. Michael S. Switzenbaum, Executive Associate Dean, College of Engineering, Marquette University for taking special interest in this research and for their encouragement.
I am grateful to Department of Civil and Environmental Engineering, Marquette University for the encouragement and support to conduct the research. Special thanks to

Dr. Thomas Wenzel, Chairperson, Department of Civil Engineering for taking interest in this research.

I would like to thank my family and all my friends for their love, generosity, forgiveness and support. I am most grateful to my parents for their unconditional love and support in pursuing my interests. I am thankful to my father Dr. R.K. Sharma, who showed me the joy of intellectual pursuit ever since I was a child and, my mother Mrs. Santosh Sharma for inspiring me in every walk of life and raising me with utmost love. I would also like to thank my sisters Shikha Sharma and Ritu Sharma for their love, support and encouragement. Finally, I would like to thank everybody who was important to the successful realization of thesis.

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CHAPTER 1

Introduction

With the growing complexity of construction projects and shortage of resources there is a need for better, more sophisticated tools for construction planning and management. There is a need for systems which run more efficiently (save time and money, requires less resources and without compromising the quality), that facilitate better coordination and communication among project team members, and also communicate the same idea of the project to all stakeholders involved in the life cycle of the project. This research proposes a visual method of scheduling which provides visualization of the project at the initial stage and an intuitive way of transferring most of the information from a 3D CAD model to a scheduling software to minimize tedious manual time consuming steps for creating a project schedule allowing schedulers to spend more time on the design instead of data entry.

Building information modeling (BIM) is revolutionizing the way construction is done. It is increasing the speed of delivery. There is better coordination and fewer errors, which decreases the costs and provides better productivity with higher quality of work. Contractors and architects are realizing its importance. BIM is also helping in visualizing the schedule of the construction projects prior to the start of actual construction. 4D modeling and schedule visualization is a process in which a 3D model is linked with a schedule and visualization of the construction schedule can be done to identify any problem that may arise during the construction process. Time is the fourth dimension in

4D. Considerable research has been going on to improve visualization of construction project schedules

4D modeling allows project team to visualize construction plans; identify construction consequences and space conflicts; identify safety issues and improve communication of the project team members (Koo and Fisher 2000). 4D visualization helps the project team in visualizing the spatial attributes of the project and in identifying problems which are not understandable by looking at the Gantt charts or CPM networks such as space conflicts. It helps in optimizing labor, material, equipment and space for the whole construction phase. Everyone participating in the project can see the 4D visualization as intended and have a better understanding of the project. It facilitates collaboration of ideas and better communication of the project schedule to all the stake holders of the project.

However, the benefits of 4D Visualization are realized only after project information is entered into the computer and updated periodically. Setting up a computerized schedule for a construction project requires entering into the computer not only all project activities and their durations and resource requirements, but also organizing and sequencing project activities. This requires considerable time and effort and consequently a full-scale time study is not usually performed for all projects. This research focuses on reducing the tedious manual scheduling work by visually extracting and transferring information from 3D CAD models to the scheduling software.

This research has the primary objective to make the process of sequencing project activities more intuitive and less manual labor intensive. The hypothesis of this research is that this approach is more intuitive, more user friendly, less manual work intensive and more efficient because it digitally transfers most of the information from a CAD model to the scheduling software and therefore reducing the manual work of entering any data. This was tested using a small group of students and the feedback has been very positive.

The following assumptions were taken into consideration to come up with the visual scheduling technique as an alternative way of scheduling construction projects:

1. 4D simulation programs require a schedule to link with the program for visualization of construction process, which implies that unless a schedule is prepared, 4D simulation and visualization cannot be done.
2. Current 4D scheduling software requires a considerable amount of manual work. How can the manual work be reduced by directly transferring the information from the CAD model to scheduling software?
3. It was observed that there is a need for a program that makes scheduling simpler just as CAD made it simpler to create drawings for projects as compared to traditional hand drawing. This can be done by developing user interface which is more intuitive and user friendly.

These discussions led to developing a program which facilitates visually scheduling a construction project by walking inside the 3D model, selecting tasks and sequencing them visually.

This chapter provides a brief description of current 4D modeling and simulation techniques and software applications available for 4D scheduling. It also discusses the limitations of current 4D scheduling techniques. It provides a description of the research problem and discusses the research goal, objectives, scope, research approach adopted, research steps undertaken and contributions of the research. Finally, it describes the organization of the thesis.

1.1 Review of Scheduling techniques and technology used in construction scheduling

Bar charts are one of the most familiar and accepted traditional methods of scheduling projects. It is still popular due to its simplicity and ease of understanding as no special skills are required to create and read bar charts. But, it is one of the most error prone methods of scheduling. It fails to identify critical activities which directly affect the progress of the project. It does not show any effect due to changes made in the schedule nor does it show any interdependencies between the activities. All these shortcomings in the process of scheduling lead to many change orders, project delays and monetary losses.

Critical Path Method (CPM) scheduling changed the way projects were traditionally planned. This method is now one of the most widely accepted scheduling methods. This method helps in identifying which activities are critical and need to be done in time according to the schedule. Otherwise it can result in delay of the completion of the project. CPM scheduling has its own disadvantages, too. It can become complex and one requires training to be an effective user. CPM charts are large and require special sized sheets to print.

With the advent of personal computers in mid 1980s many software companies developed computerized scheduling programs. By 1990s many construction companies started using these program applications. They were based on CPM scheduling. The most popular scheduling programs are Microsoft Project, Primavera Project Planner and SureTrak Project Manager.

The schedules using above mentioned techniques are created from 2D drawings by mentally visualizing the sequence of the activities. “It requires special skills and experience to read 2D drawings and relate it to the schedule. Such schedules force planners to visualize and interpret the activity sequence in their minds. Also, some planners will have different interpretations of the same schedule, which makes it difficult to communicate and discuss whether a certain problem actually existed or not” (L. Wang 2007). With growing complexity of projects, it is not easy to accurately schedule a project by visualizing it mentally.

Four dimensional computer-aided drawings (4D-CAD) are breakthrough advancements in the way scheduling is now done. 4D-CAD models are 3D Models of a project linked with a schedule. To create 4D-CAD models a 3D model is created first. Many software applications are available to create 3D model of a project such as AutoCAD, Autodesk Revit, Google SktechUp. The model and the schedule are then linked using a third party application which provides a visual simulation of the building construction process. Some of the software applications available for 4D Simulation are Autodesk Navisworks, Synchro 4D. But these software applications require a schedule for visualization of the project and do not reduce the tedious time consuming manual work of entering data.

1.2. Description of Research Problem

This section provides an overview of this research which includes research goals, objectives, approach, contribution and scope.

1.2.1. Research Goal

The goal of this research is to make sequencing of project activities simpler and more intuitive, and to provide visualization of the construction process at an early planning stage. The program developed transfers most of the information from a 3D model to scheduling software and reduces manual time consuming data entry.

To obtain 4D visualization of a construction project a schedule is required by the 4D simulation software to link with the 3D model. It is very difficult and time consuming to schedule a project looking at a list of project activities and elements. This study provides a visual approach for sequencing activities by walking inside the virtual 3D model and selecting elements during the walkthrough.

1.2.2. Objective

1. Simplify process of sequencing of construction activities and make it more intuitive by understanding the modern theories of cognitive science and interactive visualization.
2. Develop a program which facilitates interactive visualization and visual scheduling for construction projects.

1.2.3. Research Approach

1. **Literature Review:** A literature review was conducted in the field of automated scheduling, intelligent scheduling using computers, building information modeling, visualization, 4D scheduling, virtual reality in construction, and current scheduling techniques. A literature review in the field of cognitive theories and human computer interaction was also done to understand the functioning of the human brain and memory models to create a more intuitive and user friendly user interface.
2. **Building Information Modeling:** The Associated General Contractors (AGC) of America defines building information modeling (BIM) as "the development and use of computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility."

   The software applications available to create a BIM are Benteley Architecture, Tekla, Graphisoft AchiCAD, Vector Works ARCHITECT, Autodesk Revit and Architectural Desktop. For the purpose of this research Autodesk Revit Architecture was used to create a building information model of the project.

3. **Visual Scheduling Application Development:** A graphics application was then developed using Microsoft DirectX library to assist the visual scheduling process. Both geometry and material information extracted from Autodesk Revit program is used to create the virtual environment and generate a 3D model of project. Both first and third person cameras are available for navigation and interaction with the 3D model. Users can walk around and inside the virtual building for visualization of the project and visually sequence the activities by selecting tasks and predecessors while walking in the building. This approach is based on the findings of modern cognitive theories which emphasize visualization in the form of images or walkthroughs helpful for reducing the load on user's memory. Less recollection is necessary when sequencing activities visually as compared to sequencing them using a long list of tasks.
4. **Assessment and Validation of the Software:** A commercial medium-sized project was visually scheduled to assess the application program. Chapter 7 provides case study which shows step by step procedure to visually schedule building. This Visual scheduling approach was then demonstrated to contractors and industry professionals for their feedback about the methodology. According to the contractor, this methodology simplifies the process and it saves time. Some of the suggestions were implemented in the revisions. Those suggestions which required more time and resources were documented and should be done in future improvements.
5. **Documentation and Future Work Remarks:** All the steps discussed above were documented and suggestions, feedback and observations by the reviewers which

were not implemented due to time and resource constraints were recorded for future modification of the application.

1.2.5. Research Scope

This research focuses on a visual scheduling approach for construction projects. Scheduling of construction projects involves defining construction methods and tasks, sequencing of tasks, resource allocation, resource leveling, activity duration estimating, cash flow analysis, and calendar and staff allocations. This study is limited only to activity sequencing because of time and resource constraints.

1.3. Thesis Organization

The thesis is divided into three sections. First section is Introduction which consists of chapters 1 and it provides an introduction to research problem, approach, scope and contributions of the research.

Section two is Literature Review and it consists of chapters 2 through 4. Chapter 2 provides an overview of current scheduling practices and literature review of sequencing approaches and scheduling techniques. Chapter 3 discusses the impact of building information modeling on construction industry and how BIM is poised to fundamentally change the way construction is done. Chapter 4 discusses virtual reality and its uses in construction, interactive visualization and cognitive approach to visualize construction projects

Third section is called Research Methodology and Conclusion. It consists of chapter 5 through chapter 7. Chapter 5 discusses scheduling application architecture. It explains how data is stored by the program developed and its interaction with Revit and MS Project. Chapter 6 provides a case study of commercial project scheduled using application developed. It also explains the basic components of the interface of the program and step by step description of visual scheduling approach. Chapter 7 is Conclusion which provides research summary, contribution of the research and its limitation and an outline of recommendations for future research.

CHAPTER 2

Construction Project Scheduling

This chapter provides an overview of construction project scheduling. It presents a brief overview of successful scheduling and provides literature review in sequencing approaches and current scheduling techniques.

2.1. Scheduling for Construction projects

A good plan for a construction project is not a plan which can complete the project in the shortest time but it is the plan which can safely execute the project in a given time and budget without compromising the quality and without any litigation. It assists in development of a realistic schedule and budget for the project. Scheduling is one of the most important steps in the process of planning a construction project and determines the success of the project. Following are the steps for creating a schedule:

1- **Define Construction Methods:** The choice of construction methods to be used should be preplanned and decided beforehand. It affects the cost estimate as well as the schedule of the project. For example method of pouring concrete can be either by a pump or it can be transported in buckets. This decision directly affects the budget and the time duration for the completion of the activity.

2- **Define schedule tasks:** This involves decomposing the project into activities and sub-activities. This is the most cumbersome job to do as there can be thousands of activities for a construction project but this is one of the important steps assisting in the development of a formal schedule of the project. Schedule tasks are usually organized in a project schedule using Work breakdown structure (WBS). It is a decomposition of complex projects into tasks, subtasks and work packages. It is a planning tool for effective project management but it is not a scheduling method. As shown in Fig. 3.1, WBS consist of product breakdown structure (PBS), activity breakdown structure (ABS) and organizational breakdown structure (OBS).It divides the project into various levels in which upper levels represent the major deliverables. The intermediate levels are sub tasks and the lowest levels are work packages. Once created, it can be reused for future projects also.

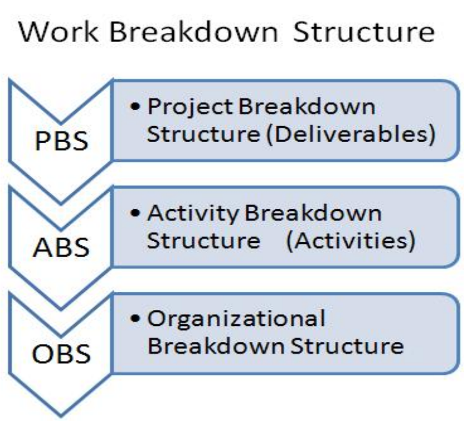

Figure 2.1 Work Breakdown Structure

The focus of project breakdown structure is to identify what the product shall produce and not the activities performed. Project breakdown structure does not map any activities and no particular sequence of events. It is a tree structure reflecting the work products on all levels produced by a project. The work breakdown structure defines activities which are required to produce the work product to the required quality. Work breakdown structure organizes the sub-activities or packages into levels that can be developed into a summary. It is defined by using nouns and adjectives – not verbs. Following is an example of work breakdown structure for site work and concrete work for a commercial construction project:

- 1.0. Commercial Project
  - 1.1. Site Work
    - 1.1.1. Clear and grub
    - 1.1.2. Excavation
    - 1.1.3. Backfill
    - 1.1.4. Hand grade finish
  - 1.2. Concrete
    - 1.2.1. Form footing
    - 1.2.2. Reinforcing
    - 1.2.3. Concrete placement
    - 1.2.4. Bulkheads forms
    - 1.2.5. WWF
    - 1.2.6. Concrete slab
    - 1.2.7. Steel trowel finish

3- **Sequence schedule tasks:** Proper sequencing of the activities plays a very important role in the success or failure of the schedule. Activity sequencing is the order in which each activity should be arranged and then performed on the site. There are a number of factors which govern the activity sequencing which maintain structural integrity, trade interaction, path interference and safety regulations.

4- **Estimate resource requirement of each task:** This step identifies the resources required to complete the project. By estimating the resources required for each activity which comprises the project, the resource requirements of the project are identified. This is done before calculating the duration of the activities. By identifying the resources required for the completion of the project potential bottlenecks related to resource allocation and activity sequencing can be avoided. Estimating activity resources involves identifying the number and type of workers, material and equipment required.

5- **Estimate duration of each task:** Activity duration is the time required to complete the activity satisfying the conditions of quality, safety, and budget satisfaction. Duration can be calculated if the quantity of work and the productivity of the crew are known by simply dividing quantity by productivity. It can also be calculate by referring to historical records of past projects. The practical way is to get the durations from experienced people who are out in the field doing the work. No one knows durations better than an experienced project manager or superintendent.

6- **Schedule development/ schedule generation:** Once the project has been divided into activities and sub-activities, a logical order in which they should be sequenced is identified, resources and the duration required determined, a schedule is developed such that the project can be executed and completed safely without compromising quality, within budget and in the shortest possible time. This is done by using methods such as critical path, network logic diagram, schedule compression, resource leveling. With advances in technology, now there are software packages available which reduce the manual work and provide better, faster and more accurate schedules.

7- **Project Control:** This is the last step which involves monitoring the project execution during construction and making sure that activities are taking place at their scheduled time and in case there are deviations from the schedule taking necessary action to keep the project on schedule.

The planning described above has to be done by a scheduler. He/she has to breakdown the project into tasks, subtasks and work packages by mentally visualizing the project. The breakdown of project into activities and sub-activities is done by considering a number of factors such as trade interaction, path interference, safety regulations etc. This division of project is done differently by different participants involved in construction of a project. For example a designer would divide the project differently from a contractor. CAD software applications divide the project the way designers see it (i.e. in uniformat). The Visual Scheduling Application developed in the research extracts information from the CAD application in this format. Since the main concentration of the research is to provide visual sequencing for scheduling construction projects the following sections provides literature review for sequencing approaches and various techniques used for scheduling.

2.2. Literature review of Sequencing Approaches:

The planning task involves choosing a set of actions, arranged chronologically, that will achieve some given goals. (Navinchandra, Sriram , Logcher, 1988). "Traditional network based tools employing critical path methods (CPM) and project evaluation and review techniques (PERT) algorithms can help in analyzing a plan, not in generating it. The definition of activities and their predecessors must be provided to such systems by a human planner." (Kartam, Levitt 1990). "One of the crucial problems faced when generating a construction schedule is to produce an adequate sequencing of activities involved (Echeverry, Ibbs, Kim 1991)" There is difficulty in sharing schedule at different levels. It is common knowledge that no two schedulers develop the same schedule for the same project since each of them makes different assumptions select different construction methods and represents the schedule at different levels of details. (Fisher, Aalami 1996)

On industrial projects, planning steps need to generate and sequence over 5,000 activities for contact level and over 15,000 activities for tactical plans. Today's project planning tools requires the manual generation and sequencing of each activity. Hence, it is often not economically feasible to generate and evaluate appropriate and accurate alternative plans. (Aalami, Kunz, Fisher, 1998)

During the past two decades a considerable amount of research has been done to automate sequencing of construction activities. Various systems have been developed by researchers to computerize the process of sequencing. These systems have migrated from the early general – artificial intelligence planning systems to knowledge based planning systems and ultimately to model based planning systems (Alami, Kunz, Fisher, 1998). A brief summary of these systems is given in the following section. Some of the previous works in sequencing the activities are as follows:

CONSTRUCTION PLANEX was developed by Hendrickson, Gorostiza, Rehak, Miller and Lim (1987) which is a frame based hierarchical system for scheduling construction projects. It has table for different functions like construction technology selection, form project activities, duration estimation, cost, predecessor selection, etc.

Navinchandra, Sriram and Logcher developed program for Generation of Hierarchical networks for construction (GHOST, 1988). This methodology generates or modifies the topology of construction activity networks. Knowledge is not used to build the network but to criticize it. It starts by assuming all the activities will be executed simultaneously but it then modifies the network by examining what cannot be done in parallel. It starts with a general network and subdivides it into sub activities. It takes a list of object and preparers a schedule. The final step is to generate a list of activities in report form and to plot a project network. This planning technique takes a list of activities as input and produces a schedule as output by setting up the predecessors among the activities.

Kartam and Levitt (1990) studied intelligent planning of construction projects (SIPE) and proposed sequencing to be done based on common principles or constraints such as “supported by”, “enclosed in” etc. Their approach relies on structural support and generates a network. Echeverry, Ibbs and Kim (1991) proposed formalization of sequencing knowledge for construction scheduling by developing knowledge based prototype system which incorporates the principles. Bjork (1994) provided research details of RATAS project which was about developing an infrastructure for computer integrated construction and digital transfer of information between applications.

Cherneff, Logcher Sriram (1990) developed BUILDER which integrates CAD with construction schedule generation. It is based on object oriented programming. It consist of two main knowledge modules (KMs) first “Draw” for creating and interpreting architectural floor plans and “Planner” for producing construction schedule.

Researchers at the Center of Integrated Facility at Stanford University have carried out a considerable amount of research for automating sequencing of construction activities and developing knowledge based environments for scheduling. Fischer and Aalami (1995) demonstrated scheduling with computer interpretable construction method models. The feasibility study of 4D in commercial construction by Koo and Fisher in 1999 showed that 4D modeling helps in analyses concerning cost, productivity, safety and resource allocation. It is also helpful in the integration and collaboration between members of teams. It also supports early detection of problems. 4D visualization systems require a project schedule before they can produce a graphical simulation of the project’s construction process. It is a tool which facilitates effective visualization but it does not make scheduling easier nor reduces the work involved when manually entering project tasks. Planners mostly use 4D visualization tools as a means of visualizing and comparing, rather than implementing different decision alternative (Waly, et.al, 2002).

It can be seen that these past research efforts are based on principles or constraints such as “supported by” or “connected to” or “enclosed in”. These constraints decide how the project should be schedule. As it is well known that no two projects planners or schedulers have same style of scheduling a project this rule driven approach may not be flexible enough to accommodate every scheduler's style.

To the author's knowledge it is the first attempt to improve the process of sequencing activities adopting the modern cognitive theories which govern human brain processing and building information modeling.

2.3. Literature review of Scheduling Techniques:

The following section provides a brief summary of some of the methods which are used for scheduling construction projects.

2.3.1. Bar Charts:

Bar charts are one of the traditional scheduling methods. It was the most popular method of scheduling because of its simplicity. These schedules are easily read and understood therefore they have been the primary source to communicate the project plan to the stake holders. It is a familiar and accepted schedule for most field personnel. Figure 1.1 shows a bar chart schedule for construction of mall home. It can be seen that bar charts gives a graphic representation of the process which helps in understanding the schedule and when which activity should take place. This process is no more considered an apt option for scheduling because it has many disadvantages. Bar charts do no t show all the interdependencies between activities and do not allow for variable float control at those activities events. There are also limits to the number of activities, usually around50 that can be tracked on a bar chart before the chart becomes overloaded and the milestones within the bar chart schedule miss the marks. (Hutchings, 2004). “It is very difficult, if not impossible, with a bar chart to see the effects of a change and whether or not a potential change will affect the project completion date. This becomes appoint of contention between the owner and the contractor when changes are proposed.” (Newitt, 2009)

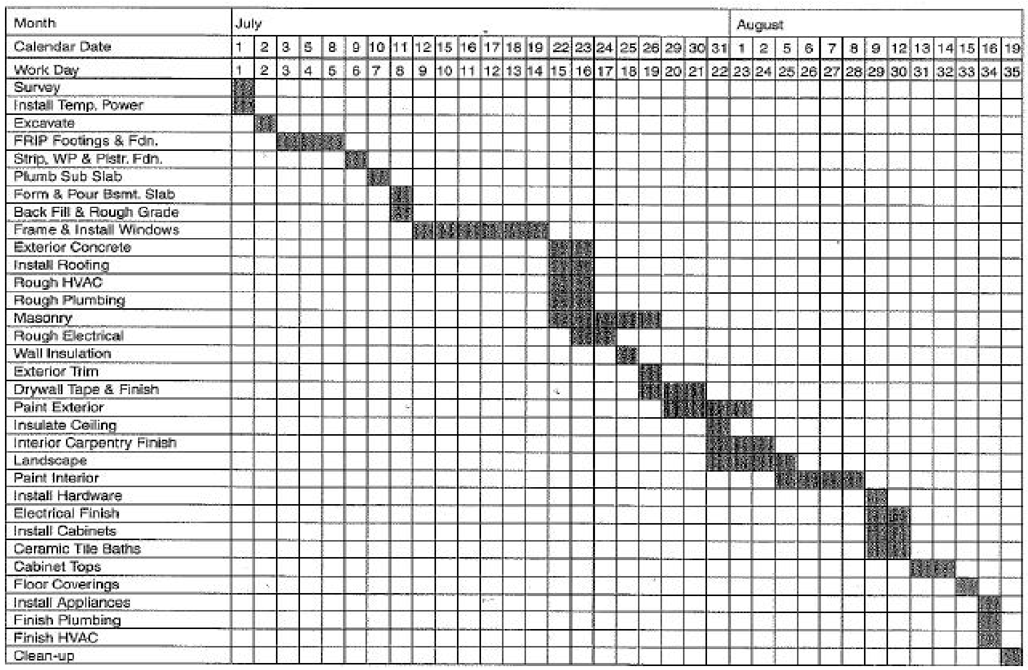

Figure 2.2 Bar Chart Schedule for the construction of small home from Newitt, 2009

2.3.2. Critical Path Method:

Critical path method or critical path scheduling is most widely used scheduling techniques. This method calculates the minimum completion time for a project along with the possible start and finish times for the project activities. This method helps in identifying which activities are critical and need to be done in time as per the schedule otherwise can result in delay of the complete project. If the information about costs, crash cost and time is available, CPM also helps in determining how long the project will take to complete and which activities should be crashed or speed up. Figure 1.2 shows an example of CPM network for a hotel project.

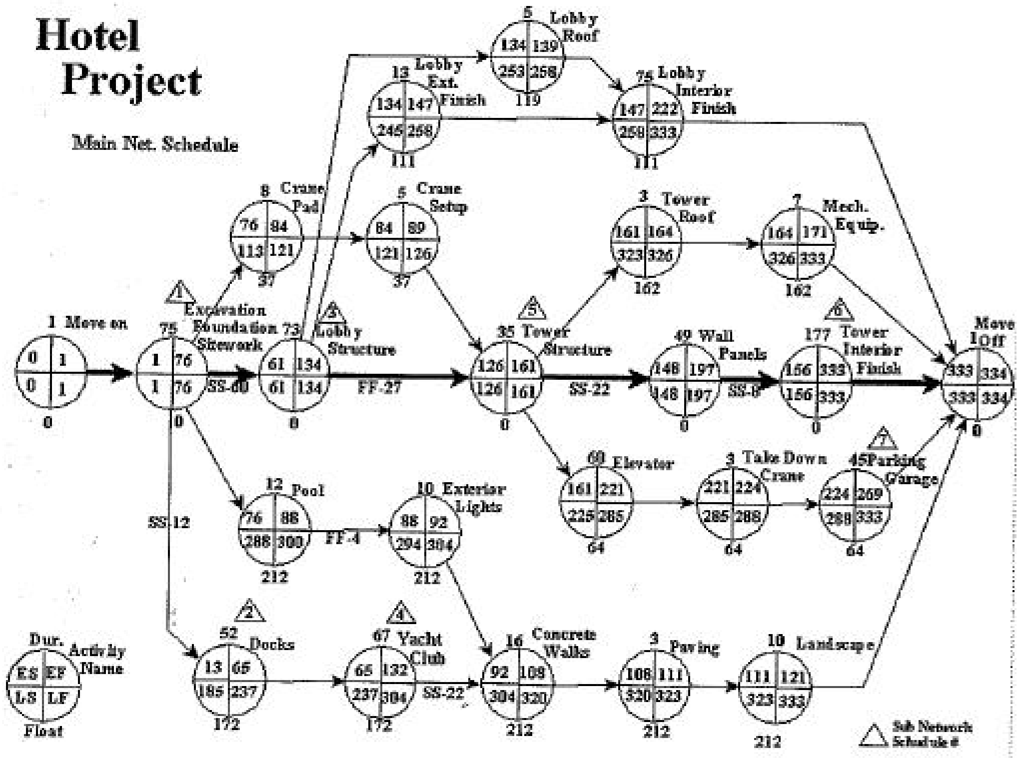

Figure 2.3 Hotel Project example for CPM Method from Hutchings 2004

Following is the outline summary of CPM Method:

- Determine the individual activities
- Sequence those activities
- Draw network diagram
- Estimate duration of each activity
- Determine the longest path of the network(critical path)
- Update the CPM diagram as the project proceeds.

CPM explicitly defines precedence relationship between the activities. It also helps in identifying the early start, late start, and slack for each activity. But CPM has its disadvantages too. There can be thousands of activities and individual dependencies relationship. It can become complex and one requires training to be an effective user. It will increase the total contract price as such schedules are expensive to create and maintain. These charts are large and require a number of special size pages to print.

2.3.3. Linear or Line-of-Balance Schedule:

Line of balance schedule or linear scheduling method shows the project schedule in a unique format that would be very helpful for certain construction projects. It is well suited for project where the activities are of a repetitive nature. The construction projects which usually use this method of scheduling are horizontal in nature instead of vertical e.g. highways, pipelines and railroads. It can also be used for projects where there are numbers of common activities or one activity with a long duration. A line of balance shows the rate at which the work that makes up all the activities should be undertaken to stay on the schedule. It shows relationship between groups of activities to the preceding group and if a group runs behind the schedule it will impact the following group. This type of scheduling helps project managers visualize time and space conflict between activities.

Following is the summary of steps to develop linear schedule:

- Identify the activities.

- Estimate activity production rates.
- Develop activity sequence
- Create a velocity diagram for the first activity
- Add the velocity diagram for each additional activity.
- Look for conflicts and buffer.

2.4. 4D Simulation:

4D modeling and scheduling is a method of linking elements of 3d model with activities of the construction schedule for visualization. Time is the fourth dimension in 4D models. It has many advantages over traditional methods of scheduling
The traditional methods like Gantt charts and CPM networks cannot show the spatial attributes of the project. Each team member has different way of perceiving the design and the drawings when shown in two dimensions. Not everyone perceives the idea in same manner and which causes difference in understanding the bigger picture of the project.

4D modeling of the projects helps in improving the quality of the project. It helps the project team in visualizing the spatial attributes of the project and in identifying problems which are not understandable by looking at the Gantt charts or CPM networks such as space conflicts. It helps in optimizing the labor, material, equipment and space for the whole project construction phase. It improved communication and collaboration. Everyone participating in the project can see the 4D visualization as intended and have better understanding of the project. It facilitates collaboration of ideas and better communication of project schedule to all the stake holders of the project. It also saves time and reduces cost by identifying potential problems even before the construction starts 4d modeling reduces the cost of the project and time for the completion. A problem that may arise due to conflicts in space usage or resource conflicts is identified using a 4D model and schedule simulation and allows the project team to take necessary steps to address such problems before construction starts.

4D scheduling has its own disadvantages too. “4D CAD models rely heavily on the availability of full plan or schedule information to provide graphical simulations of the project schedule. (Baldwin, Kong, Huang, Guo, Wong and Li 2008)”.therefore, visualization can be done only when a schedule is created. It is a tool which facilitates effective visualization but it does not make scheduling easier or lessen the manual entering of tasks. The planner mostly uses these tools as a means of visualizing and comparing, rather than for implementing different decision alternative (Waly and Thabet, 2002). There is no dynamic interaction with the 3D model, it only relates the schedule and the 3D model but a user cannot make changes while visualizing the project. In addition, 4D CAD systems cannot effectively simulate construction processes in which various resources are used to transform construction from one stage to the next stage of the time-lapse (Baldwin, Kong, Huang, Guo, Wong, Li 2008).

Some of the 4D tools used for simulation are ProjectWise Navigator by Bentley, Project 4D ConstructSim by CommonPoint, Visual Simulation by Innovaya, JetStream Timeliner by Navisworks, Synchro 4D by Synchro ltd and Virtual Construction by VICO Software. Figure 1.3 shows an example of schedule simulation using Synchro 4D.

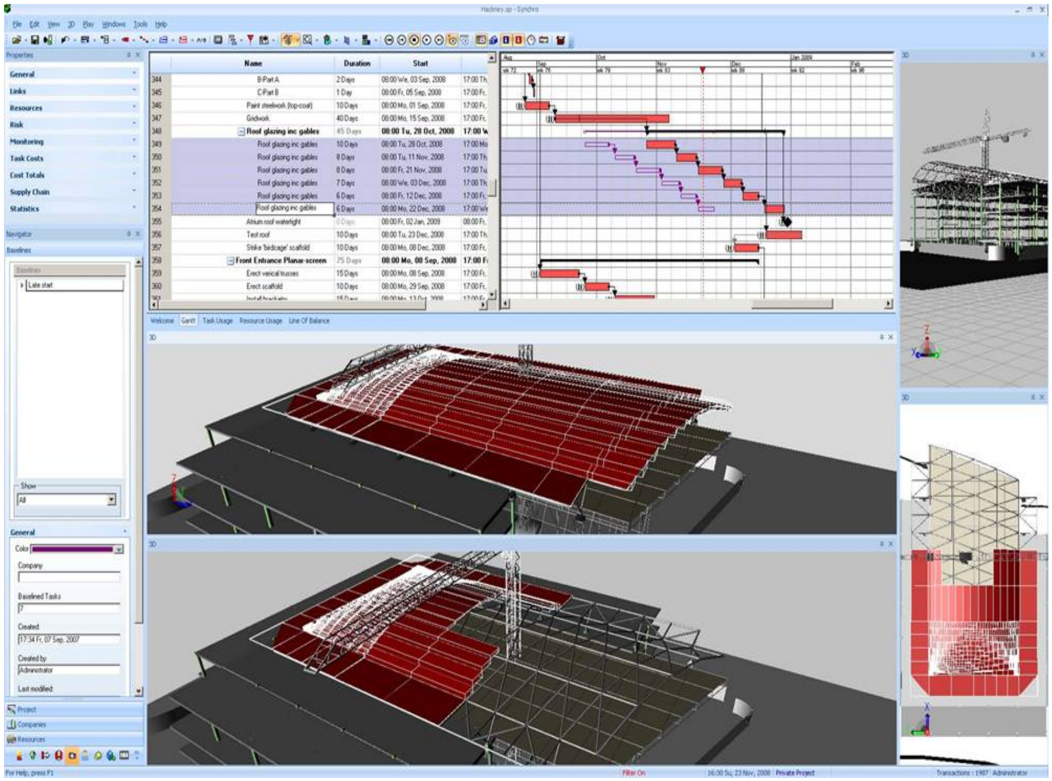

Figure 2.4 Example of 4D Simulation using Synchro 4D

CHAPTER 3

Building Information Modeling

Few years ago the only option available for designers to create drawings was regular CAD software applications. New 3D CAD programs are coming to market which not only have geometry information but also material information. This new generation of CAD software is referred to as Building Information Modeling (BIM). It represents elements in 3D and contains rich information about the materials.

This chapter presents an overview of what BIM technology and briefly discusses the main advantages of BIM in construction industry and the interoperability options. The chapter concludes by discusses the future of BIM in construction industry.

3.1. Building Information Modeling (BIM)

The Associated General Contractors (AGC) of America defines BIM as “Building Information Modeling is the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users’ needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility.”

“Key to the success of a building information model is its ability to encapsulate, organize, and relate information for both user and machine-readable approaches. These relationships must be at the detail level, relating, for example, a door to its frame or even a nut to a bolt, while maintaining relationships from a detailed level to a world view."

National BIM Standards

Krygiel and Nies (2008) discuss the endless range of possibilities using BIM. Figure 3.1 gives a summary of BIM features and interrelatioship possible between them. Some of these features are discussed in the later section.

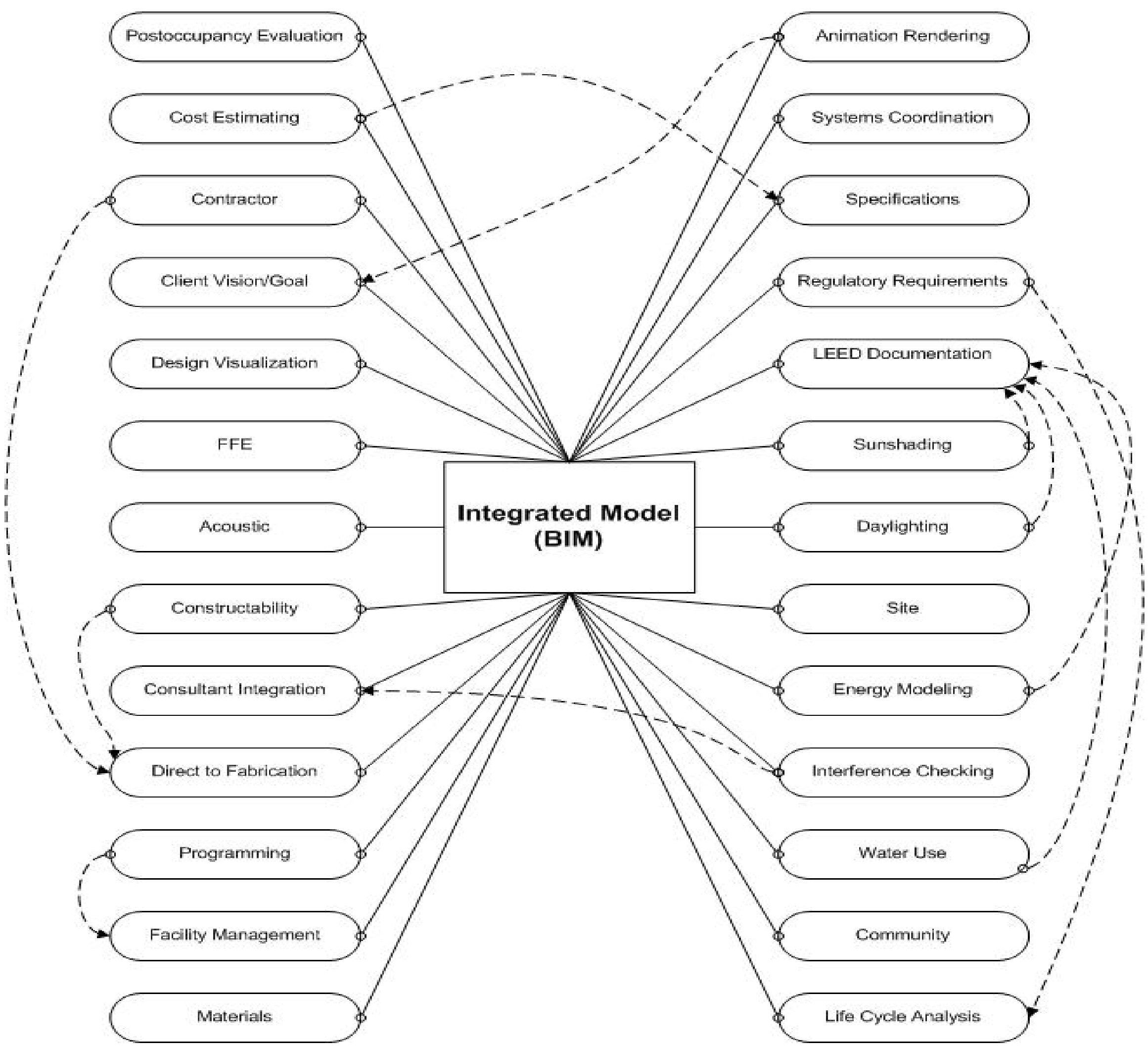

Figure 3.1 Building Information Modeling Roadmap by Krygiel and Nies 2008

The software applications available to create a BIM are Bentley Architecture, Graphisoft AchiCAD, Tekla, Vector Works ARCHITECT, Autodesk Revit and Architectural Desktop etc. For the purpose of this research Autodesk Revit Architecture was used to create a building information model of the project.

A considerable amount of money and time are spent to generate critical assessment information about a proposed design including cost estimates, energy use analysis, structural details etc. paper based documentation and traditional methods do no prioritized such analysis and thus they are normally done last when it is already too late to make important changes. All these things are not done during the design phase which ultimately causes huge discrepancy in what was the initial building and what is the end result. Building information modeling provides such critical information during the design phase which helps in modifying the building design. There is more effective document coordination and review of options available with a fraction of the cost as compared to paper based documentation.

Following is a summary of advantages of using building information modeling in construction:

- Increased speed of delivery (time saved)
- Better coordination (fewer errors)
- Decreased costs (money saved)
- Greater productivity, higher-quality work
- New revenue and business opportunities

3.2. BIM vs. CAD

Building information modeling is the new way of construction management which reduces monetary losses, schedule delays and improves coordination by minimizing communication errors and misinterpretation of project. The main difference between CAD and BIM is the intelligence associated with every element in BIM. A wall in CAD is nothing more than two parallel lines and has no information about the wall structure. BIM on the other hand stores information and a wall in BIM has all the information about its structure, type, area, volume etc as shown in Figure 3.2. Such information help in creating cost estimate and schedule. BIM helps the designer to avoid repetitive and redundant manual work thus allowing the designer more time to think about the design.

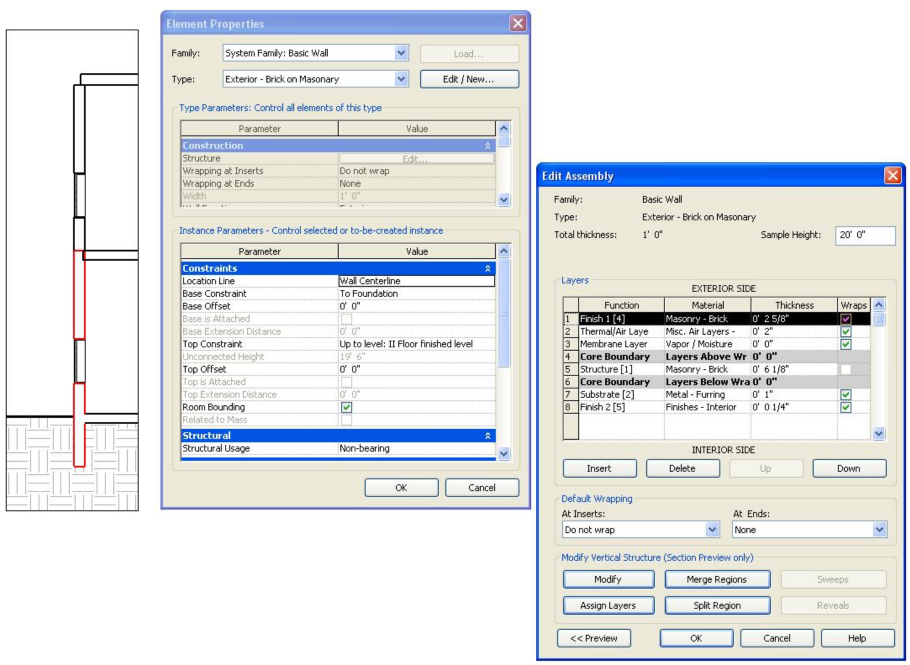

Figure 3.2 Cross section of wall containing information about wall in Revit

Another major difference between CAD and BIM is the way they work. CAD works with a number of layers and there is a lot of manual repetitive work associated with creating a cad drawing. If a change is made in cad it results in changes in all views and documents. BIM is parametric. If a change is made in BIM it is like a ripple effect. All the changes are made on its own in all the views.

Apart from drawing, drafting and documentation the major advantage of BIM which the construction industry is now realizing are the byproducts of the model. Once a model is created it can be used for a lot of other purposes too. Some of the uses of BIM are energy analysis, cost estimation, visualization, clash and conflict detection, pre planning of the project, sequence and scheduling etc. All these advantages result in cost reduction, better project management, time saving and better quality. BIM is helping in achieving the main objectives which are build faster, better, safer & at less cost

3.3. Interoperability in BIM

Interoperability can be defined as "ability of two or more systems or elements to exchange information and to use the information that has been exchanged" (IEEE 2006). It depicts the need to pass data between applications allowing multiple types of applications to contribute to the work at hand. Interoperability is required because there is no software or tool which can independently do all the tasks associated with building design and productions. Interoperability should not result in loss of data while exchange.

The formats available for communicating building information model are APIs, IFCs, XML, DWG, DXF, DWF, ODBC and even PDF. Figure 3.3 shows the options available in Revit for exporting the model. Some of the most popular interoperability options are discussed in the following section. For the purpose of this research Revit API was used to exchange information because of its ability to provide a very close link between building information model and application developed.

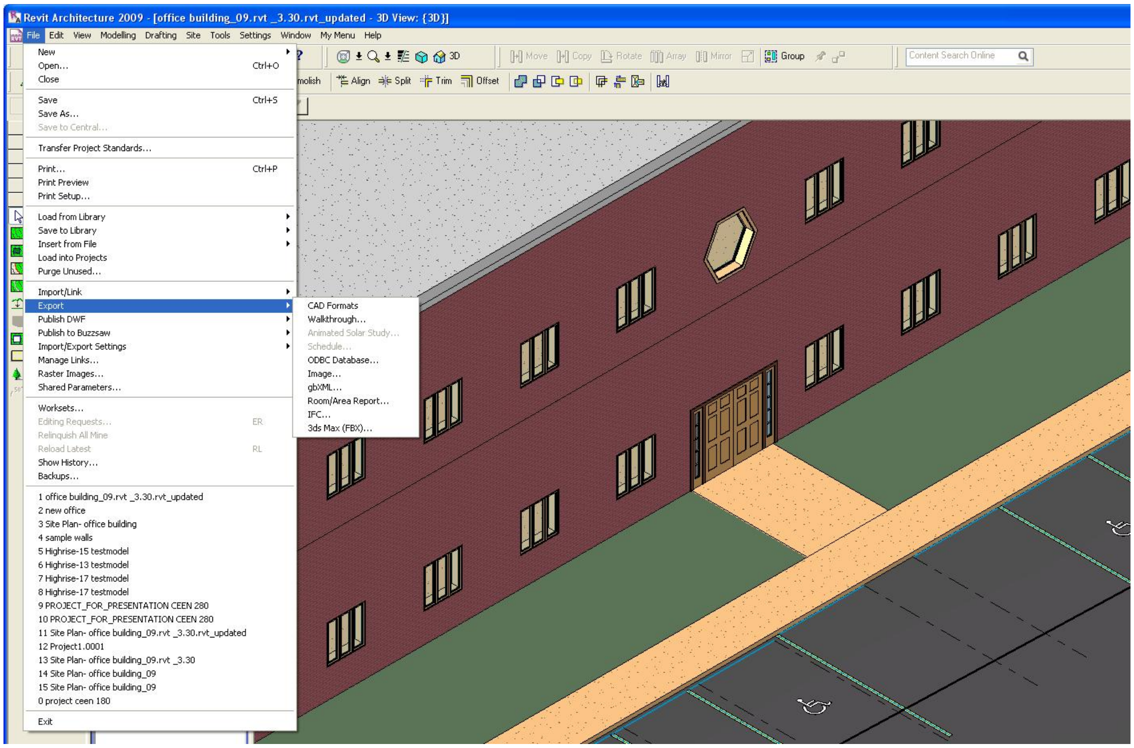

Figure 3.3 Various interoperability options available in Revit

3.3.1. Application Programming Interface (API)

API makes it possible for programmers to develop programs consistent with the Windows operating system and user interface. Instead of individuals writing the code to create components of the Windows operating system, such as forms, command buttons, and menus, you can call the appropriate functions in the Windows API and let the operating system create those components. (http://msdn.microsoft.com/en-us/library/aa165081 (office.10).aspx)

An integration based on an API offers a very close link between software applications and is often termed “ dynamic” because the API enables software application to interact with each other directly. For example, the Revit API allows independent software developers to create software programs that can access elements in the Revit building information model. Application develpers can use the API to query and change element properties, and also add and modify some elements.

Add-on software programs created by independent application developers provide extended BIM capabilities for specialized building application. API based application that ineterct directly with the BIM solution is a very effective method of linking building information model to the application because of the close integration provided by API.

3.3.2. IFC

Industry Foundation Class (IFC) is a building product data model for building planning and design, construction and management. It was developed by IAI (International alliance for interoperability). IFC was developed to create a large set of consistent data representation of building information for exchange between various software applications. It was designed to address all building information over the whole building life cycle, from feasibility and planning through design, construction to occupancy and operation. It is written in EXPRESS. It is an object oriented data model based on class definition representing the elements, processes, shapes etc that are used by software application during a construction or facility management project. The objects used in the exchange of information by IFC are nested with in a deep sub entity tree for example a wall has following hierarchical order:

IfcRoot -> IfcObjectDefinition -> IfcProduct -> IfcElement -> IfcBuilding Element -> IfcWall

The process of data transfer with the help of IFC can be explained in the following example. If there are two applications viz. Application A (source) and Application B (receiving) then application A's translator extracts information from the entities and assigns an IFC class to it. These IFC objects are then converted into a text file format defined by ISO-STEP Part 21. The receiving Application B converts this text file again to an IFC object reference it represents and then converts the IFC objects into native data structure for use.

3.3.3. XML

Extensible Markup Language (XML) is another way of exchanging information. It provides a common format to express data structures and content. It is an extension to HTML, the language used to send information over the internet. XML is different from HTML. It is designed to transfer data and not displays it. Unlike HTML, XML do not have predefined tags. It has user defined tags to specify an intended meaning for data transmitted, allowing user-defined schemas. Also, XML transfers and stores data and emphasizes on what the data is where as HTML displays data and focuses on how the data looks.

3.3.4. DWF

Design Web Format (DWF) by Autodesk and is an easy way of information exchange other than IFC or XML. DWF facilitates exchange of intelligent design data and also allows anyone to add objects, classes, views, and behavior. This web formats facilitate the information sharing and reviewing by providing markup and query capabilities. Data exchanged is fully navigable, can be selected and queried but cannot be edited. This format does not have domain specific schemas, rather they have schemas with general classes of entities e.g. geometric polygonal and solid entities and markup objects and sheet objects.

3.3.5. ODBC

The ODBC (open database connectivity) standard is a database access method that provides a vendor-neutral common ground between applications and databases. Essentially a vehicle for accessing data from relational tables of rows and columns, ODBC has been used in commercial applications for more than a decade and is a proven, established data transmission method. ODBC uses a middle layer, called a database driver that acts as a translator between an application and a database. As long as the software programs on both sides of the driver support ODBC, specialized programming or interfaces are not necessary. That reduces the cost of the application integration and ongoing product support. (Rundell, 2004)

3.4. Applications of BIM

Following sections give a brief description of most common uses of building information modeling in construction projects such as conflict and clash detection, quantity takeoff and cost estimation, construction sequencing, facilities management, visualization, fabrication, energy analysis.

3.4.1. Conflict resolutions and clash detection

Clash detection and conflict resolution is one of the most popular applications of BIM at present. This allows users to identify the elements in the 3D building information model which interfere with each other or occupy same space. In traditional method the clashes and conflicts were identified by overlaying individual system drawings on a light table. This method is time consuming, manual and error prone and requires all the drawings to be current. Building Information model clash detection is an intelligent system and it combines geometry clash detections with semantic and rule based clash detection. It allows contractors to check clash detection between specified systems for example clashes between mechanical and structural systems. Clash detection can be performed in two ways first either by BIM integrating tools or by clash detection provided by the BIM design tools. BIM integrating tools allow users to import a 3D model.

3.4.2. Quantity takeoff and Cost Estimation

Quantity takeoff and cost estimation is another area which can be immensely benefited from Building Information Models of the building. Although, there is no tool which can automate the whole process completely but BIM reduces a considerable amount of manual work and thus provide the estimator more time to analyze the building and cost and increases productivity and efficiency.

BIM designing tools have inbuilt cost estimation features. Material quantities are automatically extracted and change when any changes are made in the model. There are a number of BIM tools available. Autodesk Revit is the software used to create the model or this research. Autodesk Revit creates a building information model such that the computer identifies the model as a building and not a 2d sketch. For example element such as walls, foundation, and floor are not just few lines drawn but they are assemblies made of real materials which can be viewed if a section is cut. Another BIM tool SketchUp, do not define object type and thus quantities are not available in SketchUp.

Quantity takeoff with Building information models provide consistent information less prone to human errors. No BIM tool can provide a complete building estimation automatically from a model but it can reduce considerable amount of manual work. Building Information Model can help visualize the building. Although, it cannot generate a complete estimate of the building yet it can help reduce the laborious manual takeoff and thus help estimators by giving more time to optimize prices from subcontractors and suppliers.

Quantity takeoff using a BIM can be done by one o the following methods:

- By exporting the building object quantities to estimating software's. This can be done by extracting the building elements from within Revit and sending it to an estimating tool.
- By Linking the BIM tool directly to the estimating software for example software's like Sage Timberline by Innovaya or U.S. Cost or Graphisoft Estimator.
- By using a BIM quantity takeoff tool which imports data from a BIM tool e.g. Exactal, Innovaya and OnCenter.

3.4.3. Facilities Management

Building Information modeling has the capability to serve every sector of the construction industry which is fueling its adaptation. BIM is not only beneficial for new construction projects but it tremendously helpful for renovations, space planning and maintenance operations. BIM will allow the facility managers to follow the life cycle of the building more efficiently. It is a tool which can increase the efficiency of the building maintenance for post occupancy.

Existing facility management tools rely on polygonal 2D information to represent spaces. Facility management with BIM is in its infancy stage. Only recently some tools have been developed and made available in the market for facility management purposes such as Autodesk FM Desktop which is a BIM facility tool. Interoperability provided by BIM will be a big benefit achieved from BIM for facility management group.

Space management is done with DWF technology. This technology allows a smooth exchange of information of building data and the recipient does not need to have the native software in which the building model was created. Facility management is managing the operations throughout the building life. It is the responsibility of the Facility management to ensure services like air conditioning, electric power, lights, cleaning, security, life safety systems, building monitoring systems are all working in good condition for the occupants of the building.

3.4.4. Visualization

Visualizing an architectural design often relies on envisioning the building based on orthogonal drawings, a small-scale physical model or an artist's sketch or watercolor.

Visualizations such as these can be hampered by the viewer's ability to mentally interpret 2D drawings, the static nature of medium and, in the case of models or artist's renderings, the cost to produce them. Computer-based renderings expand the visual context of a design concept for more effective validation and communication.

Design visualizations are an exceptional medium to accurately visualize, thoroughly study, and effectively communicate building designs. BIM is making their creation even more efficient. The ease and fidelity of transferring the Revit building information model to visualization software applications such as 3ds Max, significantly reduces the time and cost to produce the visualization. Linking the Revit building information model to 3ds Max further minimizes the time required to coordinate the architectural design and the visualization.

Visualization facilitates collaboration and coordination amongst the project team members. Visualization techniques such as walkthroughs, photorealistic rendering and 3D views are widely used for the visualization of the projects. Tools such as Revit have built in visualization capabilities. The interoperability between various software applications facilitates use and reuse of the models created by the designers. Visualization of the project before the construction starts is an effective way of streamlining the pre planning of the projects. It helps in identifying the problems that may arise during the construction. Capabilities such as clash detection and conflict resolution by visualization is helping construction managers save money and time and delivering better quality.

But, ultimately, it is the details embodied in the building information model that ensures that the resulting visualization is a true reflection of the architect's vision.

3.4.5. Fabrication

Computer aided modeling techniques have been used by various industries such as automobile industries for years for accuracy and better quantity. Construction industry has also started realizing the importance of computer aided modeling due to increasing complexity in designs of building. Today there is a need to test the building model also prior to actual construction due to complex designs, better quality needs, scarcity of resources and need for faster production.

Fabrication and preparation of shop drawings involves constant modification and updating of drawings and documents. These constant changes result in inaccuracy and inconsistency which cause loss of money, time and quality. These inaccuracies in drawings are determined only during the erection starts at the construction site. Building information modeling helps create an efficient and accurate design. BIM provides a parametric solution to the fabricators. Any change made anywhere in the BIM model is update d in all the view on its own and eliminates inconsistency in data. It behaves like ripple effect in water. This parametric modeling reduces redundancy and eliminates manual updating. It is also helping fabricators in visualization of the project and faster quantity take off.

Some of the main advantages of BIM for fabricators include generation of multiple alternatives in less time with less money without any compromise in quality and consistency of the data, clash detection and conflict resolution which saves money by pre detecting the problems that may arise during construction. Clash detections for hard clashes and soft clashes facilitate the fabricator to make necessary changes in the design and drawing prior to construction and reduce change orders and schedule delays. There is a considerable time saving in producing shop drawings and material takeoff calculations.

3.4.6. Energy Analysis Using BIM

According to the US Energy Information Administration, buildings in the United States account for 30% of the world's energy and 60% of the world's electricity, making United States the primary consumer of energy in the world.(Krygiel, Nies, 2008). There is a need of sustainable construction for energy efficiency and conservation. New and emerging tools allow a user to submit data from project BIMs to test energy-saving ideas and see results quickly. This will help teams make energy-conscious decisions early in design – when those decisions have greatest impact on the building's life cycle. (Stumpf, Brucker, 2007)

For energy analysis using BIM one needs

- BIM Model of the project
- Ability to transfer information from one application (BIM) to other (energy simulation). Green Building XML schema called gbXML is an industry standard transfer file format that can be read by many energy modeling applications currently available on the market. (Krygiel and Nies, 2008)

- Energy simulations package: The right tool for the analysis can vary based on skill level, ability to digest the results, time available, and the current phase of the project. (Krygiel and Nies, 2008).

Krygiel and Nies (2008) provide following list of applications that aid in informing the designs for sustainable solutions which are utilized at different levels and different phases of design:

- IES<VE> (http://www.iesve.com)
- Ecotect (http://www.ecotect.com)
- Green Building Studio (http://www.greenbuildingstudio.com)
- eQUEST (http://www.doe2.com/equest/)
- EnergyPlus(http://energyplus.gov)
- Daysim(http://www.daysim.com)
- Radiance (http://radsite.lbl.gov/radiance/index.html)
- Climate Consultant (http://newton.aud.ucla.edu/energy-design-tools/)
- WUFI-ORNL/IBP (http://web.ornl.gov/sci/btc/apps/mositure/)
- Microsoft Excel (http://www.microsoft.com/office)

3.4.7. Construction Sequencings

Building information model are now being used for sequencing the construction projects effectively. It not only brings up any resource or space conflicts that may arise on the site during actual construction it also helps identify the resources required, material ordering and delivery schedule. This research focuses on developing an intuitive way of using the information available in building information models and transfers it to scheduling software to minimize tedious time consuming manual work.

3.5. Future of Construction Industry with BIM

BIM is the future of construction. It is bringing about drastic process changes. A survey conducted in 2007 depicted that more than 74% of US architectural firms are now using BIM out of which 34% used BIM for intelligent analysis and not just drawing generation. With cost of computers and cost of processing going down and need of better quality and higher productivity, BIM will be used as a common practice the way 2D cad drawings are used right now. Construction projects such as healthcare, commercial, government owned, education buildings etc are already demanding design firms to develop projects based on BIM models. With Growing popularity of green buildings and sustainability being a popular concern among such clients, BIM is receiving its much deserved importance in the process. LEED accreditation also gives some points to the buildings which use BIM in the process.

Contractors and design firms have been working on the basis of empirical rules developed with experience regarding schedules, cost estimates, post occupancy issues and overall life cycle of the building. BIM with 4D & 5D (cost estimation) CAD tools are now changing the way construction is done. 4D CAD tools for visualization, clash detection and space conflict resolution are becoming common practices in site offices. BIM does all the redundant manual works for the designers and allows them to spend more time on improving the design. Also, firms are realizing the benefits of preparing documentation using BIM. These benefits will be primary drivers in the acceptance of BIM technology.

BIM is also reshaping the educational system in construction. One of the main factors that are hampering the adoption of BIM is the fact that not many people are capable of using this technology. There is an educational gap which needs to be addressed. Many universities have modified their curriculum to accommodate BIM education in the under graduate level courses. It is clear that students who will graduate with BIM knowledge and capability to effectively use it will fuel innovative design trends and better construction process. With knowledge of BIM, sky is the limit for innovation.

The future of BIM in construction industry is very bright. With benefits like better coordination, fewer errors, higher productivity, savings in costs and time and better quality, BIM will become an indispensable tool in coming years. It will also provide new revenue and business opportunities. Yet lack of trained person, construction regulations and ownership of BIM model are some of the challenges need to be addressed for its faster acceptance.

CHAPTER 4

Virtual Reality, Cognitive Theories and Interactive Visualization

This chapter provides an overview of literature related to cognitive theories, virtual reality and its application in construction, and interactive visualization.

4.1. Cognitive Theories - Investigation of Human information processing

Cognitive science deals with the processes of learning, retention, logical reasoning and problem solving in human brain. For software designers it is helpful to understand how human brain works to design more effective computer application interfaces. The main goal of human-computer interface is to convey information. Visualization of construction projects is an effective way of communicating information and ideas to all stakeholders in the life cycle of the project. People have always tried to convey information through pictures, images and illustration because of its effective communicative ability. Humans relate more to visual aids than text and the saying “a picture is worth thousand words” shows the importance of visualization.

Human information processing models consist of memories and processors. It is the interaction between memories and processors which help human brain process information. There are three types of memories namely sensory memory, short term or working memory and long term memory and three types or processors which are perpetual, cognition and motor processors. A simplified model of human information processing by Dov Te’eni, Jane Carey and Ping Zhang (2007) is shown in the following Figure 5-1. The processors and memories operate differently for verbal and spatial information. Attention is needed to facilitate and control this cognitive system.

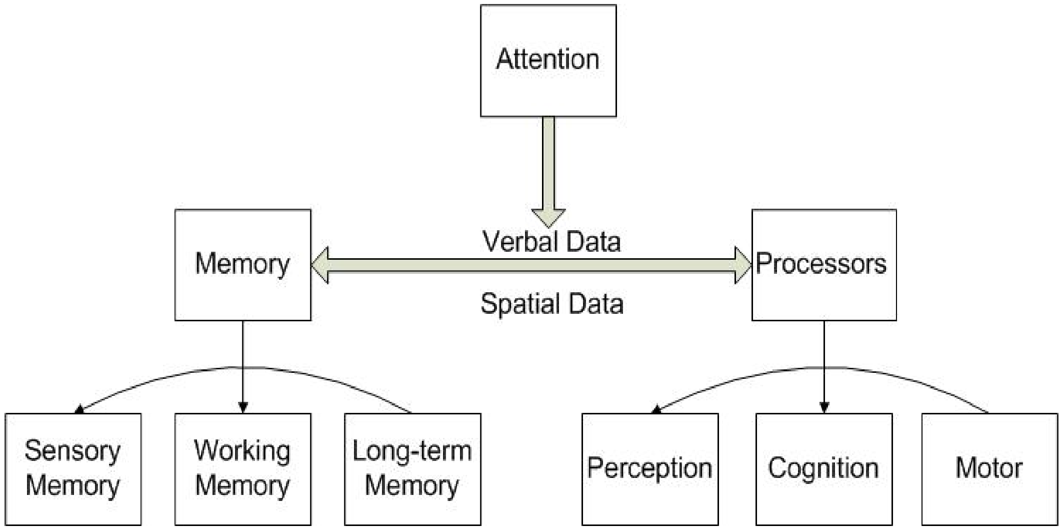

Figure 4.1 A simplified model of human information processing by Te'eni, Carey and Zhang (2007)

The three types of memories may be described as follows:

- **Sensory Memory:** This memory is based on stimuli processed through the senses such as smell, sights, touch, taste and sound. It is retrieved for two or three seconds. The content of this memory is constantly overwritten because of the huge size of data for example while interactive visualization the data keep changing and so does the memory.

- **Short Term Memory (Working memory):** This memory works just like a computer RAM but it loses its content unless being refreshed every 200ms and has a low capacity. It is used by the human brain to attend to information. It consists of two sub systems. Auticulatory System, which hold information by rehearsing it sub-vocally and Phonological system which stores auditory information.

- **Long Term Memory:** Long term memory is the amount of knowledge and skills human brain holds permanently. It is the result of conditioning. It is different from short term memory in terms of the period information can be stored but short term memory with repetition and reasoning can be transferred into long term memory.

Each of the processors shown in Figure 4.1 is responsible for a specific function. These processors work with memories and facilitate human brain information processing. Following are the main functions of individual processors:

- **Perceptual Processor:** This processor main function is to perceive information. It senses, detects, and accepts input from the external world and stores parts of input in the working memory.

- **Cognitive Processor:** This processor interprets and manipulates the input from perceptual processor. The main function of this processor is to aid in decision making.

- **Motor Processor:** This processor is responsible for interpreting cognitive decisions into physical actions.

To design a more cognitively effective user interface, it is very important to understand the function of the memories and processors together. Research in the field of cognitive science and human-computer interaction has shown some of the limitations of human brain when processing information. Some of the limitations discussed by Dov Te’eni, Jane Carey and Ping Zhang (2007) are as follows:

1. The processors can process data within approximately 100 milliseconds which means the user will not notice screen changes that fall within an interval of 100 milliseconds.

2. The capacity of the working memory is roughly five to seven chunks of data that can be retained for 10 to 20 seconds, i.e., the user cannot be expected to work with more than seven chunks of information simultaneously. Displaying more chunks mean that the user will concentrate on some parts of the screen, ignoring other parts.

3. The capacity and retention of long term memory is practically unlimited although retrieval may be difficult which means retrieval of the information that is not expected to be in the working memory will probably degrade both speed and accuracy information processing.

It is important to consider how users will perceive actions and behaviors, if they can communicate with the interface without much memory/cognitive load, what information they need to interpret and respond to the software in a desired way. Some of the principles of cognitive science used in designing the application are: (1) people interact more effectively with 3D virtual worlds which mimic the real world very closely, (2) people are resistant to reading manuals or training guides. ; They want to start working immediately.

Keeping such principles in mind the visualization of the scheduling process is done by the Visual scheduling Application. Users do not have to deal with a list of hundreds of activities for sequencing and scheduling a project. The application takes the users in virtual 3D model of the project and works how human brain processes information.

4.2. Virtual Reality

Virtual reality (VR), also called “virtual environment”, “synthetic environment,” “virtual world”, “artificial reality” is a technology which allows users to interact with a computer simulated environment which is a simulation of the real world or imaginary world. The use of immersive VR displays has primarily been limited to specialized research labs and those with large computing budgets, such as the military. Development of inexpensive hardware and software VR products in recent years has brought virtual reality within the reach of average researcher (Bell and Fogler 1995).

Definition of Virtual Reality

“The use of integrated technologies that provide multimodal display of and interaction with information in real time, enabling a user or users to occupy, navigate, and manipulate a computer generated environment” (R Bowen Loftin, Jim X. Chen, Larry Rosenblum, 2005). “VR includes graphics applications that allow users to walk through a simulated environment and, possibly, to interact with objects in it.” (Wang 2007)

Four key elements of virtual reality which enhance the simulation process are Virtual world, Immersion, Multimodal displays and interactivity:

Virtual World: “A virtual world is the content of a given medium. It may exist solely in the mind of its originator or be broadcast in such a way that it can be shared with others. A virtual world can exist without being displayed in a virtual reality system (i.e. an integrated collection of hardware, software, and content assembled for producing virtual reality experiences) - much like play or film scripts exist independently of specific instances of their performance.” (W.R. Sherman, A.B. Craig 2003).

Immersion: “it refers to what is, in principle, a quantifiable description of technology. It includes the extent to which the computer displays are extensive, surrounding, inclusive, vivid and matching. The displays are more extensive the more sensory systems that they accommodate” (Slater, Linakis, Usoh and Kooper, 1996)

Sensory Feedback: “Sensory feedback is an ingredient essential to virtual reality. The VR system provides direct sensory feedback to the participants based on their physical position. In most cases it is the visual sense that receives feedback, although virtual reality environments do exist that display exclusive haptic (touch) experiences. Achieving immediate interactive feedback requires the use of a high-speed computer as a mediating device” (W.R. Sherman, A.B. Craig 2003).

Interactivity: “The ability to affect a computer-based world describes one form of interactivity. Another form is the ability to change one’s viewpoint within a world. Interactivity fiction can be defines in terms of the user/players ability to interact with a world by changing locations, picking up objects and setting them down, flipping switches, and so on. Virtual reality is more closely associated with the ability of the participant to move physically within the world, obtaining a new vantage point through movements of the head” (W.R. Sherman, A.B. Craig 2003).

4.2.1 Virtual Reality in construction planning and scheduling

Products such as airplanes, cars and buildings are similar in that humans interact with them in an environment defined by the product. (Thorpe, Buswell, Soar and Gibb, 2008). In automobile and aerospace industry, highly pervasive applications of digital tools enable the integration of geometric condition, structural analysis, simulation, systems and manufacturing process and life cycle and business management in to a single, all-encompassing ‘process dashboard’, which delivers an overall improvement in value of at least 50% overall aspects of design and fabrication, across the entity supply chain. (Riese 2008).

Till recent years the use of virtual prototyping in construction industry was very limited but now researchers are trying to use same principles of virtual reality or virtual prototyping for building construction also. This virtual prototyping extends building information management and product modeling to allow construction organizations to model the construction process, to explore different construction methods and to enable both the client and supplier organizations to visualize how and when construction will take place. (Baldwin, Kong, Huang, Guo, Wong, Li 2008)

Traditional ways of generating a schedule limit the utilization of the 3D model and the potential benefits of the 4D model. Just like using the 2D drawing, schedulers still need to create the activities mentally, and link them to their related 3D components later. They can’t generate a schedule activity by selecting its corresponding component in a 3D model, which can translate their thinking into schedule activities directly (Wang 2007). 4D CAD models on the other hand rely heavily on the availability of full plan or schedule information to provide a graphical simulation of the project schedule. (Baldwin, Kong, Huang, Guo, Wong, Li 2008)

The main advantages of using virtual reality in construction are its capability to represent complex building components as a three dimensional graphical object. This helps the user in better visualizing a project than 2D drawing. Virtual reality is also superior to miniature models in showing design details because of its ability to provide the user virtual walkthroughs inside or outside the virtual building. Virtual reality also enables the users to discuss project problems before the real construction is implemented which supports collaborative planning and improves communication. (Hadikusumo, Rowlinson, 1999).

Immersive as well as non-immersive methods are used to visualize complex construction projects. Non immersive methods include desktop and input devices such as keyboard and mouse to interact with the 3D model of the project. An example of immersive virtual reality system is CAVE which is an automatic virtual environment. It is a theatre which measures 10’x10’x 9’ in a room which measures 35’x25’13’. It is made up of three rear projection screens for the walls and there is a down projection screen for the floor. A user’s head and hand are tracked with electromagnetic sensors. Stereographic’ LCD stereo shutter glasses are used to provide user 3D visual effect. (Wang 2007)

In this research virtual prototyping of the CAD model is done by extracting the geometry and material properties of the elements. Microsoft DirectX Library is used to create a virtual environment using the extracted information. Interactive visualization is done using first and third person cameras. Sequencing of activities is done while walking inside the virtual prototype of the building. This methodology is more effective for optimization of construction schedules and visualization of project during early planning stage.

4.3. Interactive Visualization

Visualization is transformation of data from one form to another form. These changes can be geometric transformation of the data in which the input geometry is changed but no changes are made in the topology of the data structure or attribute transformation in which the data attributes are altered or Topological transformation in which the topology is changed in the input data but not the geometry. By such manipulation of the data, realistic digital prototypes of the engineered product or process can be created. It facilitates collaboration and coordination amongst the project team members. Visualization techniques such as walkthroughs, photorealistic rendering and 3D views are widely used for the visualization of construction projects. Next step of visualization is interactive visualization. Such visualization provides immediate feedback to the user as they navigate and visualize building and depict the real world situation more closely.

Research is being carried out at Marquette University to enable interactive visualization in construction projects. This is a part of research which facilitates interactive visualization and visual scheduling for construction projects. This method of visualization of construction projects is different from visualization in the form of generating a sequence of images. It helps in interactively controlling the virtual camera for 3D navigation. This interactive visualization provides immediate feedback to the user as the parameters change and helps in further modification of the model.

CAD models or now BIM models prototype buildings and equipment and enable interactive visualization. They consist of a large number of elements and are geometrically complex. They are represented as polygons or higher order primitive and consist of millions of such primitives. For visualizing such prototypes, the functional as well as spatial organization of the components is maintained. Interactive visualization of such 3D models requires rendering at higher rates as the parameters change which places a lot of burden on the processing system. But with the advancement in computer technology there are a number of options available to speed up the process. These include using more powerful machines or clusters of computers.

Model simplification or hierarchical model representation is another approach to facilitate the fast rendering needed for interactive applications. Model simplification builds a multi resolution hierarchy from a complex model and enables the program to dynamically adjust itself at interactive rates and places fewer burdens on the processing system while rendering.

CHAPTER 5

Scheduling Application Architecture

The available methods of scheduling require a lot of manual work and data entry into the scheduling software for visualization of schedule and construction process. Sequencing of activities from a large list of activities is a very time consuming and tedious job. To minimize data entry and provide visualization at initial planning stage, a visual scheduling application is developed which interacts with a CAD program and a scheduling program and allows users to visually schedule the project. This chapter provides an overview of the application. It discusses how data is stored for interactive visualization. It also explains interaction of the Visual Scheduling Application with Autodesk Revit 2009 CAD program and Microsoft Project scheduling program.

5.1. Visual Scheduling Application

The application is developed for two way communications between Revit Architecture 2009 for model information extraction, Microsoft Project for schedule preparation and a database for project information storage. The application and its components are shown in Figure 5.1 and are discussed in detail in the following sections. This application interacts with Revit for extracting project geometry and element material information. Using this information and Microsoft DirectX graphics library a virtual prototype of the project is created (Van Verth, Bishop 2004). This allows users to interact with the virtual environment by navigating inside and outside the 3D model. First and third person cameras are developed for interaction with the 3D model. Users can select elements by clicking the element.

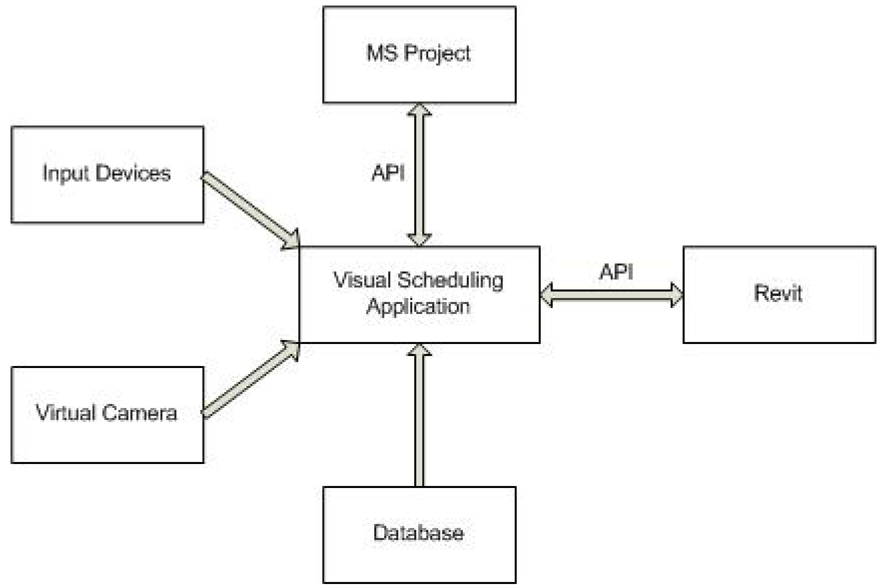

Figure 5.1 Visual Scheduling Application Architecture

To provide interactive visualization this application saves a lot of data. Data storage of the application is discussed in detail in section 6.2 Data Structure which explains how data is stored by the application to provide fast access and rendering at interactive rates. The application uses perspective view to project 3D model and directional lighting is used to make elements visible. Each of these topics is discussed in detail in the following sections.

The program interacts with Microsoft Project to enable visual scheduling of the elements. The interaction is done by using Microsoft Project API. It is a two way communication i.e. the visualization application can send element information to MS Project and it can read schedule information from MS Project. The interaction of Visualization application with MS Project is discussed in detail in section 5.1.5.

5.1.1. Database Structure

Points and vectors are the building blocks of interactive digital world. Points represent locations in space, which can be used either as measurements on the surface of an object to approximate the object's shape (this approximation is called Model) or as simply the position of a particular object. Vectors on the other hand represent the difference or displacement between two points. They are used to build lines, planes and polygons which store geometric data. Points are grouped together to form polygons and triangles which facilitate rendering and other computational purposes. A polygon is made up of a set of vertices (points) and edges (line segments). Triangles (three vertices) are the most commonly used polygons used to store geometric data and rendering purposes. All polygon information and material properties of a building can be read from a Revit model and must be stored in memory for rendering, scheduling and navigational purposes. Figure 5.2 shows the database schema designed for storage and retrieval of model data. The purpose of each table in the database is explained below:

Project Table: Project table contains all the information about the project. It stores project name, project id, type of Revit program used, for example, Revit Architecture, MEP or Structure. This information is required because if elements are imported from different Revit types it is important to know what element belongs to what type of program for data management. It also stores the information regarding Revit version, i.e., if the version of Revit used is 2008 or 2009. BBoxBase and BBoxheight information is also stored in this table. This information represents the model bounding box. Model bounding box is necessary for scaling and showing the model on the computer screen.

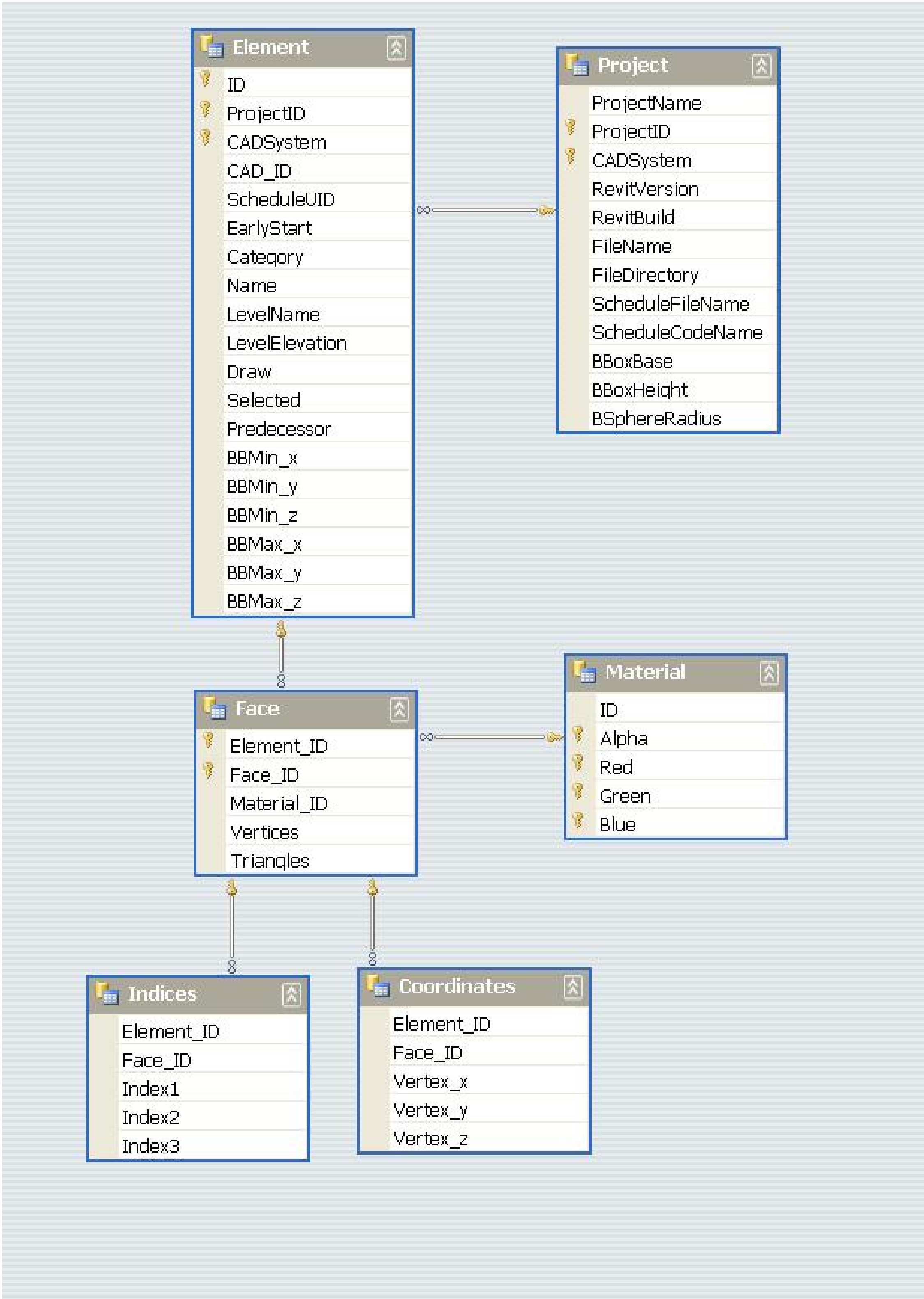

Figure 5.2 Database Structure

Element Table: Element Table stores and manages information regarding individual elements. This information include element id, CAD_ID which is the id given by cad program (Revit in this case), Scheduled id which is id given by MS Project when an item is scheduled. Every element has a unique id which is key property in this database. Revit has properties for each element and the database stores this information. They include element category and name. Similar to project Table, element Table also stores information about an element's bounding box coordinates. This allows determining which element is clicked by the user.

Face Table: A Face Table is used to store information regarding the faces that belong to an element. Every element has a number of faces and the number is not the same for various elements; for example, the number of faces in a wall is different from the number of faces in a wall with window so there is a need of a table which stores information about element faces. The table relates an element with its faces.

Material Table: Currently, Revit does not export element textures or material; only an element's color is exported. The color of an element's material is stored in the Material Table. A color has three components: Red, Green and Blue (RGB). Another component used along with RGB is Alpha component. Alpha value shows the transparency of the element. Alpha component does not represent any specific color but it represents how the combined color interacts with other colors. When alpha is at its maximum value (say 1.0) the color of the surface is independent of any object behind it where as when its value is at its minimum say 0.0 the RGB colors of the surface are ignored and the object becomes invisible just like a pane of clear glass and at an intermediate level say 0.5 the colors of two objects blend together. This property is used in the application to assign partial transparency to the window panes for more realistic representation in 3D.

Indices and Coordinates Tables: These tables contain information regarding individual indices and vertex coordinates. They also store element id and face id in order to determine to what face and element a coordinate or index belongs.

5.1.2. Virtual Viewer or Camera

In order to view objects in the virtual world, we need to present the notion of the viewer. This could be the main character's viewpoint in a first person shooter, or an over the shoulder view in a third person adventure game, or it could be a zoomed out wide shot in a strategy game. These properties can be encapsulated into a single entity commonly called virtual viewer or camera (Van Verth, Bishop 2004). Virtual viewer or a camera is a combination of the position of the eye and direction in which the viewer is looking. This controls which object lies in the current view. As shown in Figure 5.3, the virtual camera in the 3D is defined by the following three vectors:

- View direction vector determines the direction in which the viewer is looking.
- View Up vector is towards the up side of the screen
- View Side vector is towards the right or left side of the screen.

All these vectors are represented in the world frame using these three vectors together with the view position, the view frame or the view space relative to the world coordinate system.

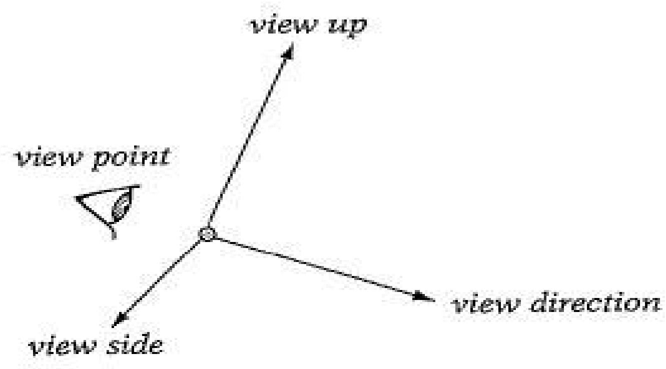

Figure 5.3 View frame relative to the world frame by Van Verth, Bishop 2004

5.1.2.1. Perspective Projection:

Virtual Building Constructor uses perspective projection for drawing the elements and information extracted from Revit. Figure 5.4 shows how perspective projection mimics viewpoint of real world most closely as it represents how an image is perceived by the eyes. For perspective projection the line segments which are farther from the viewer are drawn smaller than similar line segments that are closer to the viewer.

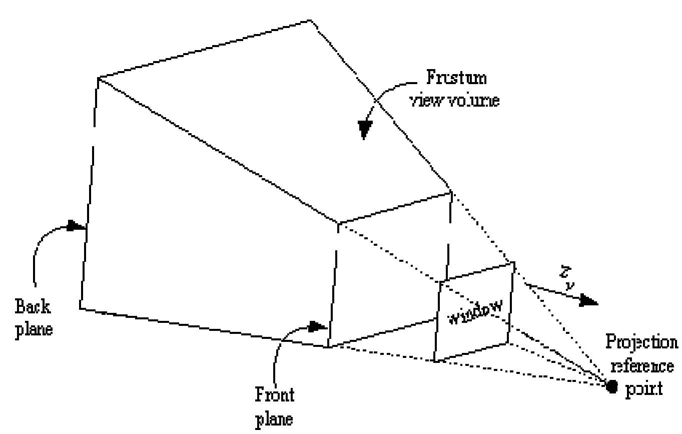

Figure 5.4 Perspective projection by Van Verth, Bishop 2004

5.1.3.2. Light

In this study directional lights are used to illuminate objects. Directional lights act like the sun light. Thus, it is also called infinite light source. Just like sun is at an infinite distance from the earth, this light is placed at an infinite distance and rays of light coming from this source are parallel to each other irrespective of where the 3D model is placed in the space. Each element in the 3D space is a made of a triangle mesh or a group of triangles. The interaction between the light direction and the position of a surface's normal determines how the surface is lit.

5.1.3. Interaction with Autodesk Revit Architecture

Interaction with Revit can be done in a number of ways. Some of the interoperability options available are Revit API, DWG, DXF, XML, ODBC and IFC. The Visual Scheduling Application interfaces with Revit using Revit API in C# programming language. Interaction with Revit using its API offers a direct, dynamic link between the application and Revit. Revit API facilitates extraction of information from a model and allows to query the model or to modify model elements. Using Revit API one can also add new elements to a model. The visualization application extracts not only geometry of the building elements but also their material properties.

Visual Scheduling Application uses Revit's external application functionality for extracting element geometry and material properties from Revit. This is done by creating an object that implements the Revit API's IExternalApplication interface. The IExternalApplication interface has two abstract methods, OnStartup() and OnShutdown(). Visual Scheduling Application overrides OnStartup() method for element extraction. The following section explains Revit's object model map. The top level classes in the Revit object model are Application and Document classes.

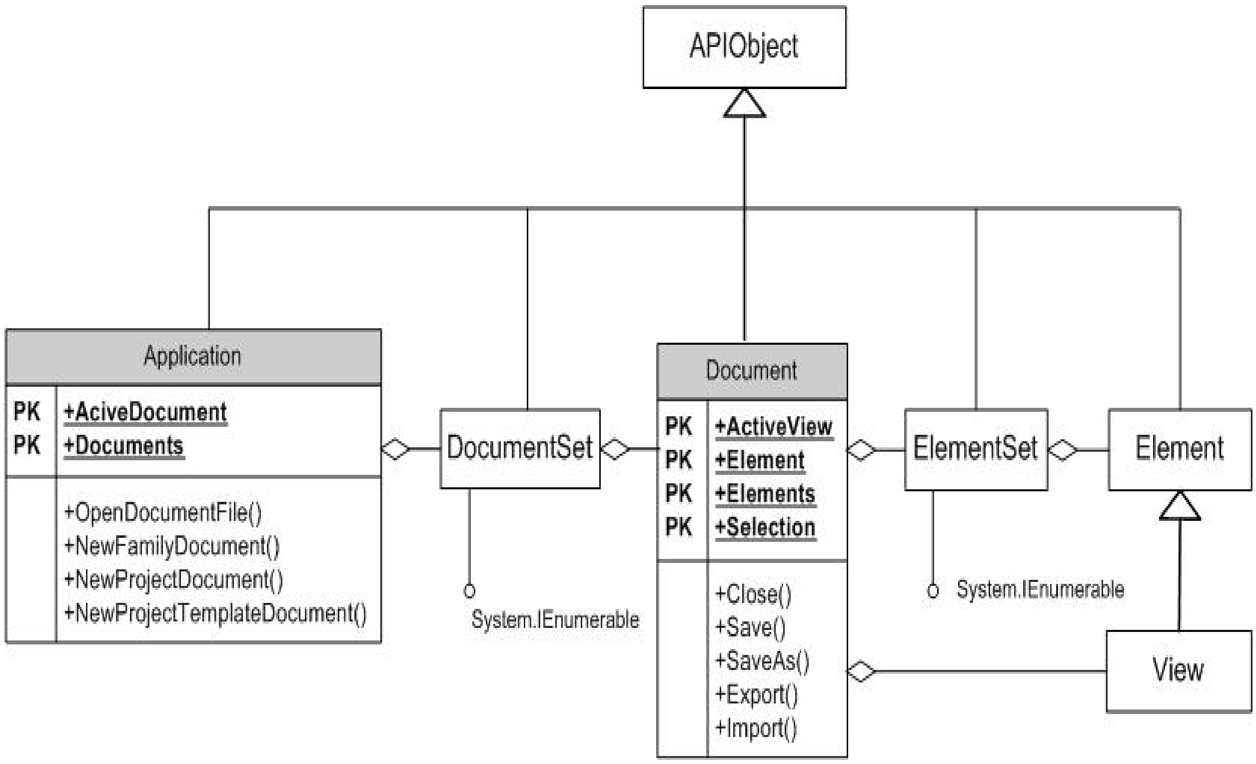

Figure 5.5 Application-Document-View-Element diagram (Revit 2008 API User Manual)

Application Object: It refers to an individual Revit session, providing access to documents, options, and other application wide data settings. The object properties include version name, number and build of application. It provides methods to open and create documents.

Document Object: Document Object is the Revit file representing the building model. In Revit one can have a number of projects and views of the project open simultaneously.

“Document stores the Revit Elements, manages the data, and updates multiple data views” (Revit 2008 API User Manual).

Elements: An element is an individual item in a building model for example a door, wall or a view. Revit elements are categorized in six groups as shown in Figure. 5.5

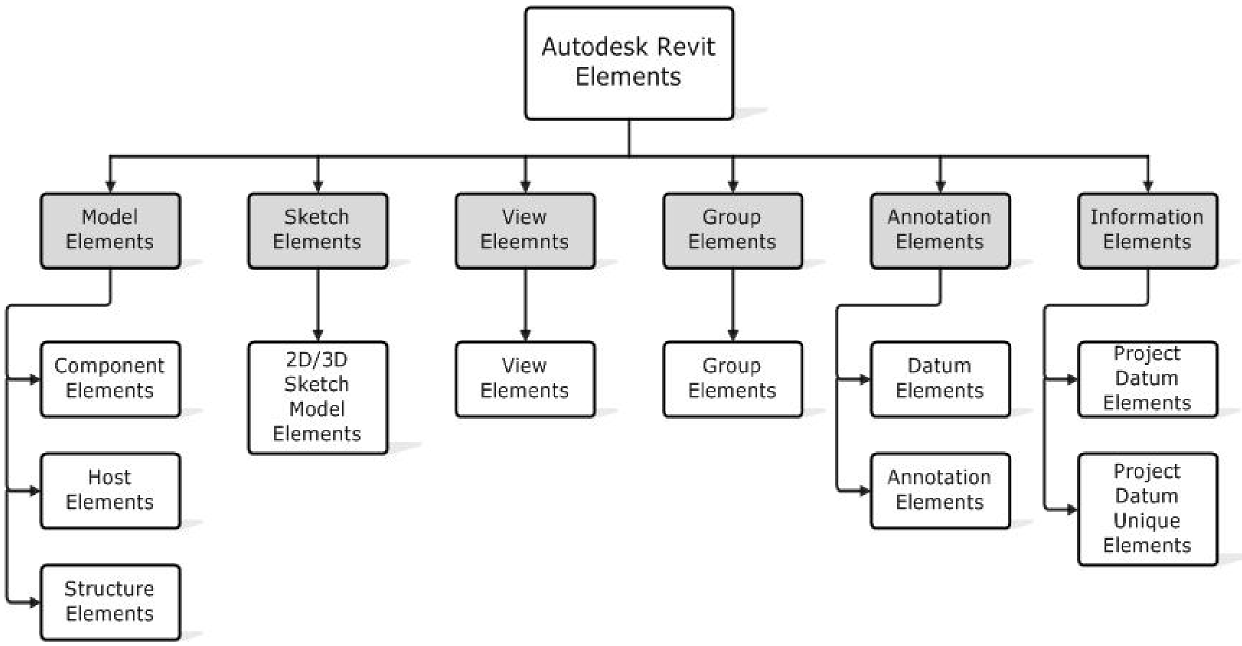

Figure 5.6 Element Classification Diagram (Revit 2008 API User Manual)

- **Model Elements:** These are the elements which exist in a building project and are classified as component elements such as family objects, host elements such as roof, ceiling and floor or Structure elements which are used in Revit Structure.
- **Sketch Elements:** These are temporary items which are used to sketch 2D/3D forms such as SketchPlanes, sketch etc.
- **View Elements:** These are abstract elements and represent the way user interacts with other objects in Revit.

- **Group Elements:** These elements represent the assistant Elements such as Array and Group objects in Revit
- **Annotation Elements:** These represent the elements which contain non- physical items that are visible. These elements show the 2D components that maintain scale on paper and are only visible in one view.
- **Information Elements:** These elements contain non-physical invisible items used to store project and application data.

Elements are also classified in terms of Category, Family, Symbol and Instance

- **Category:** Categories is a general class with helps in determining the type of element. It is subdivided as model category and annotation category. Model category includes beams, columns, doors, windows and walls. Dimensions, grids, levels and text notes fall under annotation category.
- **Family:** Families are classes of Elements within a category and it groups elements with common properties, identical use or if they have similar graphical representation. Families are categorized as system families and component families. System families are families which are provided by Revit and cannot be loaded or created such as walls, dimensions, roofs, floors, slabs and levels where as Component families are the families which can be loaded into the projects or can be created by using family templates.
- **Symbol:** Symbols are the non visible elements used to define instances. They are called Types in the user interface. For example a specific size of door in door family or Type can be a style for dimensions such as linear or angular.

- **Instance:** Instances are objects with specific location in the building (model instances) or on a drawing sheet (annotation instances). Instances represent transformed identical copies of a symbol. For example, if a building contains 20 windows of a particular type, there is one symbol with 20 instances.

Views: Views are images produced from a Revit model with access to data stored in the document. They can be graphic such as plans or text such as schedules. Each view is generated by projecting a three dimensional object onto a two dimensional projection plane.

5.1.4. Input Devices

The input devices facilitate navigation and interaction with the 3D model once it has been created by the graphics engine. The common input devices used for interactive visualization are keyboard, mouse, game pads and gloves which facilitate navigation in the 3D model. Game pads make navigation easier and have been used by many visualization applications such as video games to provide easier navigation. Gloves are used in immersive visualization where a user can manipulate things by moving or grabbing objects in the virtual environment. The graphics engine developed in this research uses keyboard and mouse as input devices.

5.1.5. Interaction with Microsoft Project

MS Project interaction component facilitates a two way communication between the building model and its schedule. This is done through the MS Project API. Using MS Project API, one can transfer model elements to MS Project for scheduling and also a schedule can be read from MS project for 4D Simulation. Figure 5.6 shows the application object model map for MS Project. Application object represents the entire project application. It contains application wide settings and options, properties that return top-level objects such as ActiveProject. It also contains methods that act on application-wide elements, such as views, selections, editing actions etc. Under application is Projects collection which contains a number of project objects.

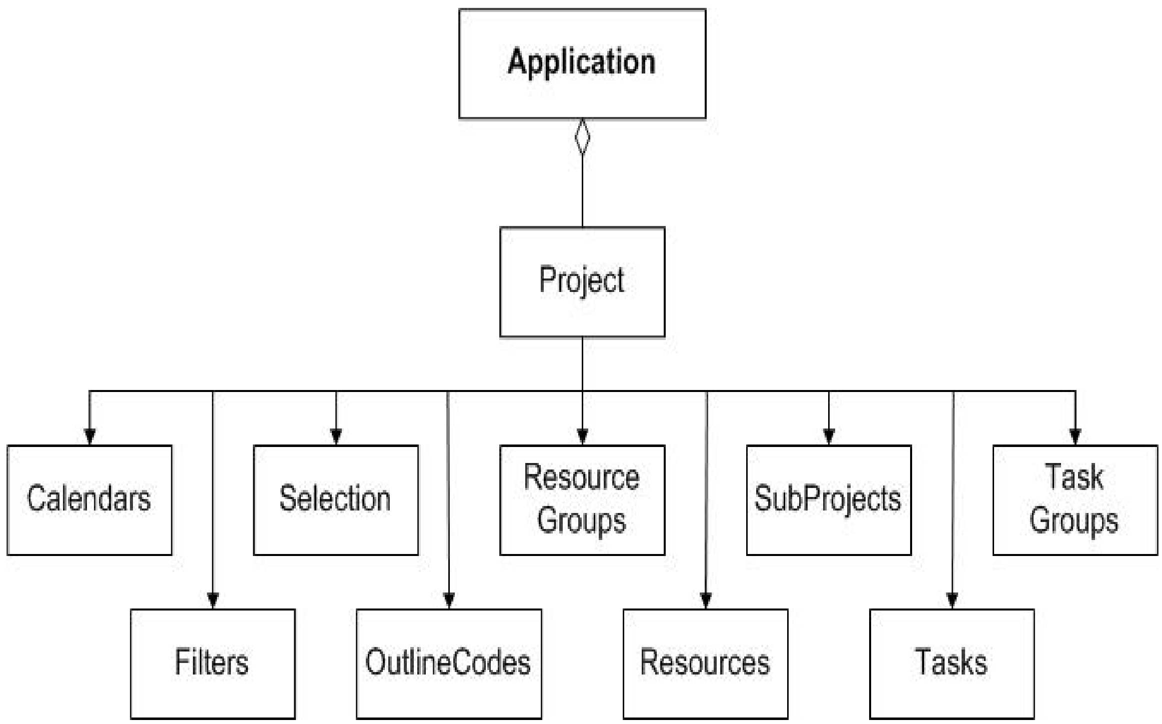

Figure 5.7 Microsoft Project Object Model Map

Calendar is a collection of calendar objects. These calendar objects represent calendars or a calendar for a resource or project. In this research default calendar is used. Filter is a collection of Filter object which are used to sort or filter the schedule for example the schedule can be filtered for critical tasks. Selection object represent the selection in active project. There is no collection for selection object.

OutlineCodes are used to organize the project in different levels. OutlineCodes is a collection of outline codes in the project file. The outline values for a project can be set using OutlineCodes 1-10 properties. Resource Groups is a collection of all resource based group definitions. This collection contains group definition objects and group criteria collection. Resources contain a collection of resource objects. It can be a child of a Project, task or selection.

SubProjects contain a collection of subprojects. These subprojects can be combined together to form one project, this collection contains subproject, project and task. Task is a collection of task objects and TaskGroup is a collection of task-based group definitions.

5.2 Summary

Visual Scheduling Application is developed for two way communication between Revit Architecture 2009 for model information extraction, Microsoft Project for schedule preparation and a database for project information storage.

The application interfaces with Revit using Revit API. This is done by creating an object that implements the Revit API's IExternalApplication interface. An external application is added to Revit in the form of Menu using C Sharp coding. This external application runs over Revit and extracts not only the geometry but also the material properties of the element which are then used by Microsoft DirectX Library to generate a virtual environment and virtual prototype of the building project for interaction.

The application interacts with Microsoft Project using its API. To visually schedule the building, it opens office application and creates a project document in it. The elements from the virtual prototype are added to the schedule by selecting and sending to MS Project. Outlines levels are based on the sixteen divisions of CSI. Every division is an outline level. This allows the scheduler to organize the schedule automatically. The sequence of the schedule is the order in which elements are selected and sent to MS Project.

CHAPTER 6

Case Study

This chapter presents description of visual scheduling approach adopted for scheduling the building used as case study. The chapter gives a brief description of the building project used and discusses in detail the basic components of the Visual Scheduling Application interface. It concludes by presenting in detail the step by step procedure to visually schedule a building.

6.1. Introduction

A commercial warehouse building is used for the case study. This building is divided into two parts. One part is the ware house and second part is the office area. It has three levels.

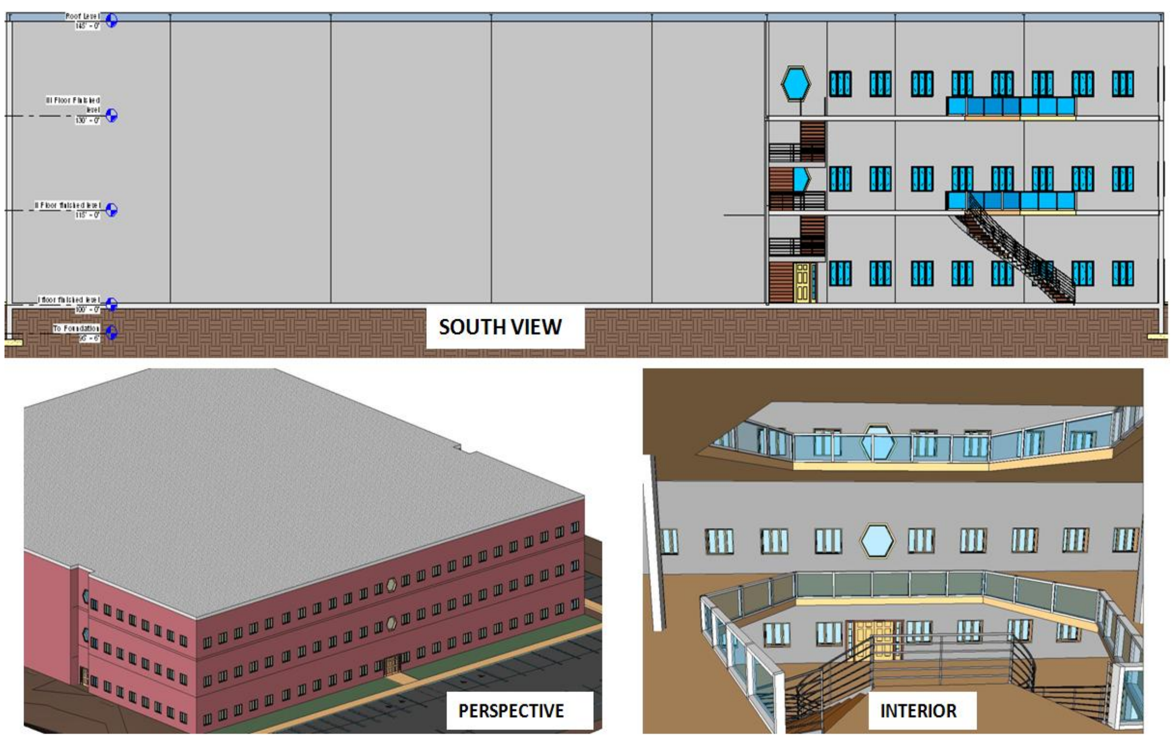

Figure 6.1 Different views of warehouse project used as case study

6.2. Basic Components of the Interface

The Visual Scheduling Application allows grouping of 3D elements into construction assemblies, create activity tasks visually, and visual sequencing of the activities. It is based on how human brain perceives and processes information and how they interact with the 3D world. Incorporating the cognitive science in the design of the user interface, it becomes easier to understand the application and the interface is intuitive. It is developed by incorporating Revit Architecture 2009 for (3D Model) and MS Project (for scheduling) and writing a program from scratch using Microsoft DirectX graphics Library. The interface consists of a Revit element extractor window, a 3D visualization window, scheduler pop up window and a number of buttons which facilitate visual scheduling. Each of these components of the interface is discussed in detail in the following sub sections.

6.2.1. Revit Element Extractor

Revit element extractor interface deals with extracting all Revit elements from the 3D model. This interface extracts not only the geometry of the building elements but also the material properties of it. This is an external application, added as a menu which runs over Revit and. After extracting the elements the application creates a directory to save the project. The 3D elements are saved as xml file which is then imported in the next stage for 3d visualization.

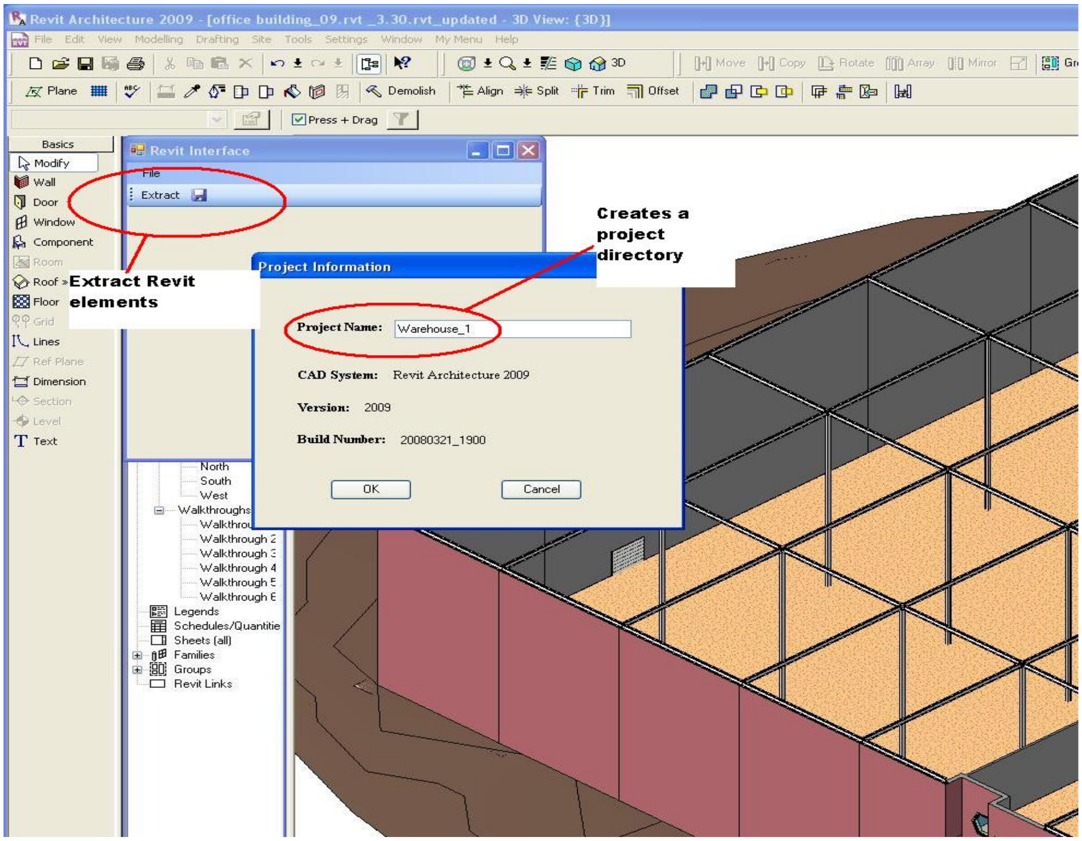

Figure 6.2 Revit Element Extractor

6.2.2. 3D Visualization and Scheduling Window

This interface allows user to visually interact with the 3D model and schedule it. It allows users to create activities by grouping elements, sequence those activities, assign predecessors and everything is done visually. The main functiona of the interface are discussed as follows:

Navigation: Navigation inside and outside the 3D model is done by 1st and 3rd person cameras available. The first person camera available allows the user to walk inside and around the building. The navigation is done using mouse and keyboard. To move forward the right key is pressed down. To look around the building left key is press down and the mouse is moved to look in the desired direction. To look up and down both left and right keys are pressed down. It should be checked that the navigate option is clicked and not the “select” button.

Element Selection: Element selection for scheduling is done by clicking on “select” and “task” simultaneously. It enables the selection mode. When an element is selected in the 3D window it is highlighted to show the selection. More than one element can be selected together to form a group of elements as one task and can be sent to MS project. It is possible that user wants to select all similar items but on a particular level. The application allows users to select similar items either in the whole building or on a particular level. For example while scheduling windows one may want to select all windows and schedule it as a task or may want to schedule windows on level 1 as one task and windows on level 2 as another task. With a selection option available, which allows users to select all similar items on a particular level or in the building as a whole makes selection easier for the scheduler and facilitates faster scheduling.

Predecessor Selection: Predecessor selection is similar to selecting the task activity. In this case also “predecessor” and “select” buttons should be enabled to select elements or group of elements as predecessor. An element can be selected as a predecessor only if it has been already scheduled.

Remove and Reset Option: These options are provided for the ease of navigation and selection. Some elements hide or are covered by other elements while navigation. Since this is a visual scheduling one must be able to see all elements as and when needed. Remove option removes the elements and make the covered elements visible. For example while scheduling footings, it is required to remove the floor slab and the finished ground surface. Reset option resets everything to default after using the remove option.

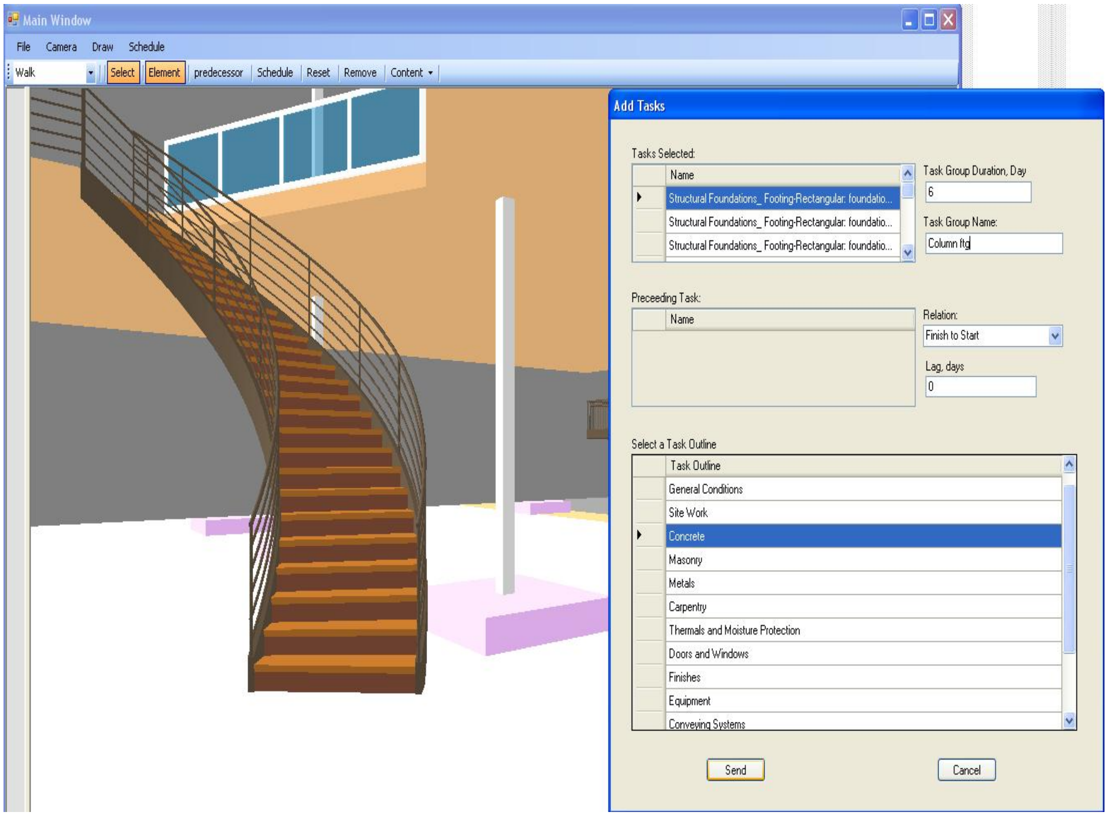

Figure 6.3 3D Visualization and Scheduling Window

Schedule Task: After selecting the elements which constitute one task, properties such as the duration of the task, the relationship and lag time can be entered. The scheduling window also shows a list of elements selected as task and as predecessors before sending it to MS Project. User can select under which outline task they want to send the task.

Draw Schedule: This option allows user to draw schedule up to a specific date. It helps in visualization o the project step by step in details.

Synchronize: The program has checks which do not allow rescheduling building elements if they have been already scheduled and sent to MS Project. If the user attempts to schedule an element that is already scheduled, the program gives a message that the element has already been scheduled. To modify a schedule, a user can delete one or more scheduled tasks inside Microsoft Project program. To allow the deleted tasks to be rescheduled, the user must click Synchronize button to synchronize the application database with the Microsoft Project database.

6.2.3. MS project Interface:

MS Project interface facilitates a two way communication between model and schedule. One can transfer elements to MS Project for scheduling and also a schedule can be read from MS project for 4D Simulation.

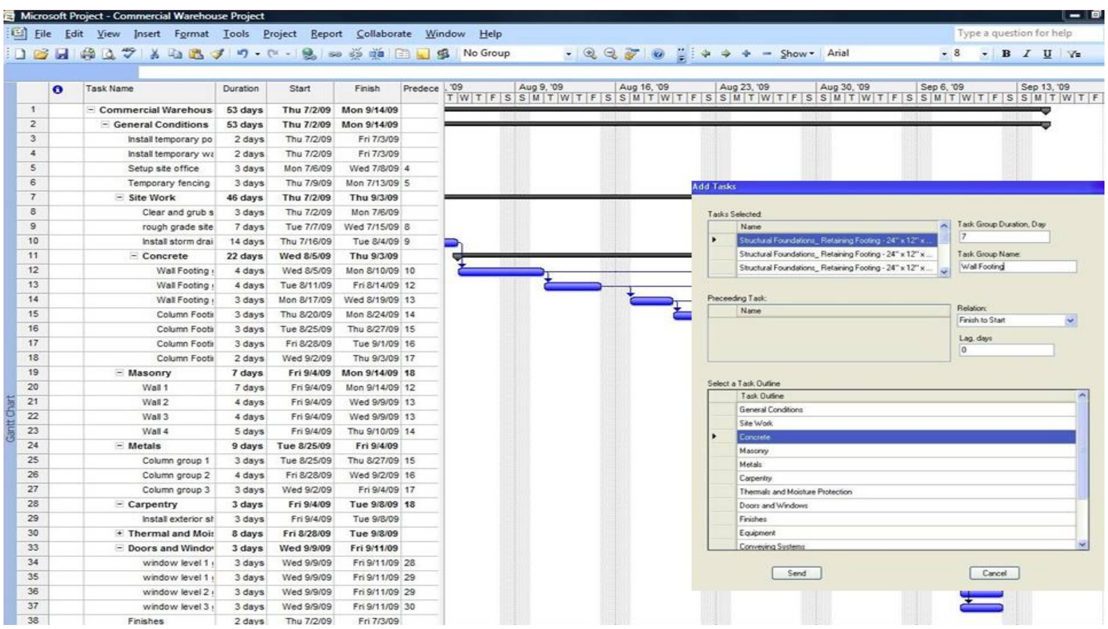

Figure 6.4 MS Project Interface

6.3. Step by step description of visual scheduling approach:

This section provides a step by step procedure that was adopted to visually schedule the commercial warehouse building.

Step 1: Extract elements from Revit

To start Visual Scheduling the 3D model file should be opened with the visualization program. For this case study the 3D model was created using Autodesk Revit 2009. The element extractor is an application written which runs on top of the CAD software. It then creates a directory and saves the project element in XML format. After extraction the user does not need the parent software which created 3D Model.

Figure 6.5 Step-1 Extract revit elements, Step-2 Open 3D model using Visual Scheduling Application

Step 2: Open the 3D model for visualization

In this step, user can open the xml file of the 3d model. Visualization of the project can be done by navigating around or inside the building using camera options available. The orbit camera allows user to navigate around the building and have a bird's view projection of the building. Walk camera takes user inside and around the building. Visualization helps in identifying how one wants to start the building construction. Instead of visualizing in mind one can see everything on the screen. It helps the designer in communicating their ideas to the stake holders just the way they think.

Step 3: Create an activity/ group of activities.

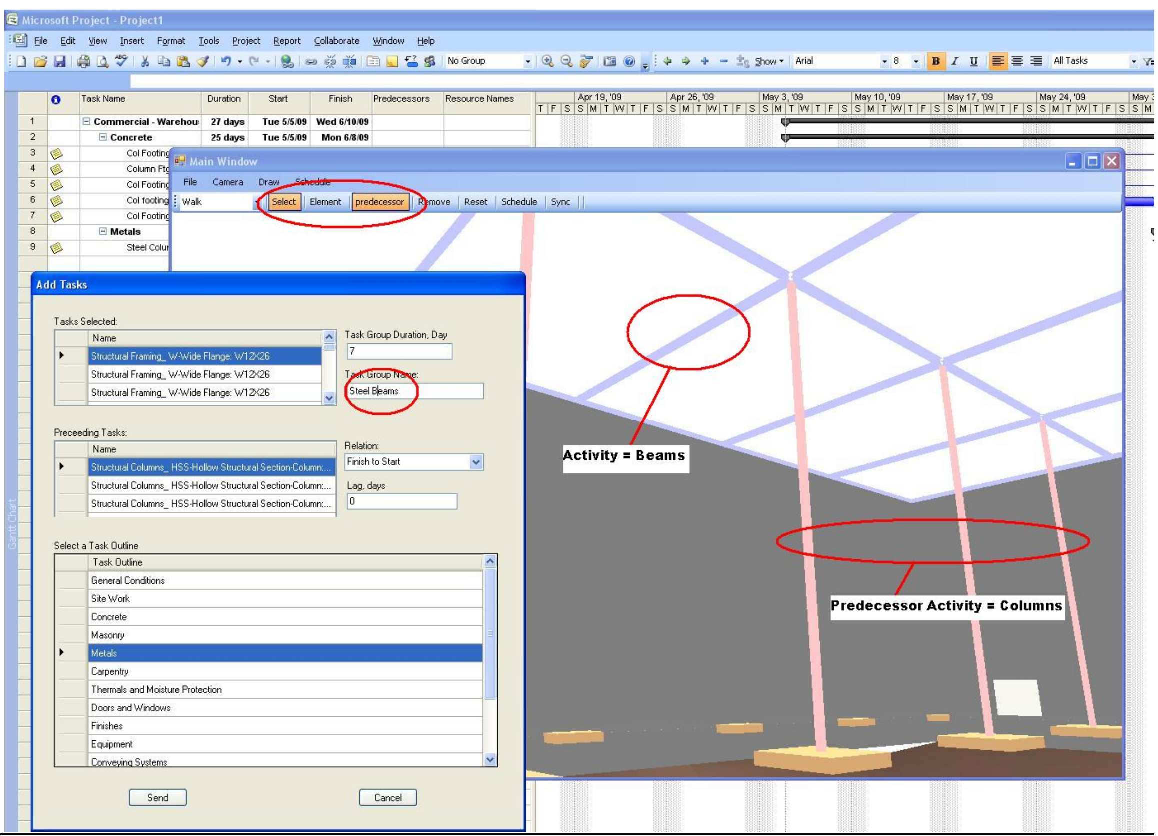

Figure 6.6 Activity and Predecessor Selection

After opening 3D model one should create a new schedule. By clicking this option the program opens a new MS Project file. The project name in the file is the name with which the 3D model file was saved. Now scheduler can decide how he/she wants to schedule the building. The program is flexible to accommodate every scheduler’s style. To create an activity, the user needs to switch to selection mode and click on “select” and “task”. Now user can select any number of items to make one activity. When an element is selected the program highlights it and the user can see what is selected. For ease of selection program provides an option which allows user to select similar items either in the building or on the same level. For example if an activity consist of windows on level one, user does not need to select individual window one by one but click on the option of select windows on the same floor. On the other hand if an activity consists of windows in the whole building, the user need to just select one window and click on the option select similar items in the building. After selection is done the user should click on “Schedule” for further action. This opens a pop up window which is the scheduling interface.

Step 4: Enter Duration and Lag Time

The user can define the relationship between activities and also enter the duration. Duration is a subjective figure. One can calculate duration but it is different for different users and different projects. It is more based on experience than on calculation. In this preliminary version of the program, no calculations are made for the duration but this functionality will be available in the future version of this program. Right now it allows users to use their experience and enter duration for the activity. The program also allows user to take into account any lag time expected for the activity. A text box takes user input for lag time and modifies the schedule in MS Project accordingly.

Step 5: Select Predecessor and Relationship between activities.

VBC also allows users to choose predecessor and the relationship between activities. Choosing predecessors is similar to selecting elements to create activity. User should click on “Select” and “Predecessor” to begin selection. After the activity and its predecessor in selected click on “schedule” and Schedule pop up window opens. This window shows the element and predecessors selected in a scroll list. It also allows user to choose a relationship between activity and predecessor as a drop down list. User can select the desired relationship option for the activity and predecessor.

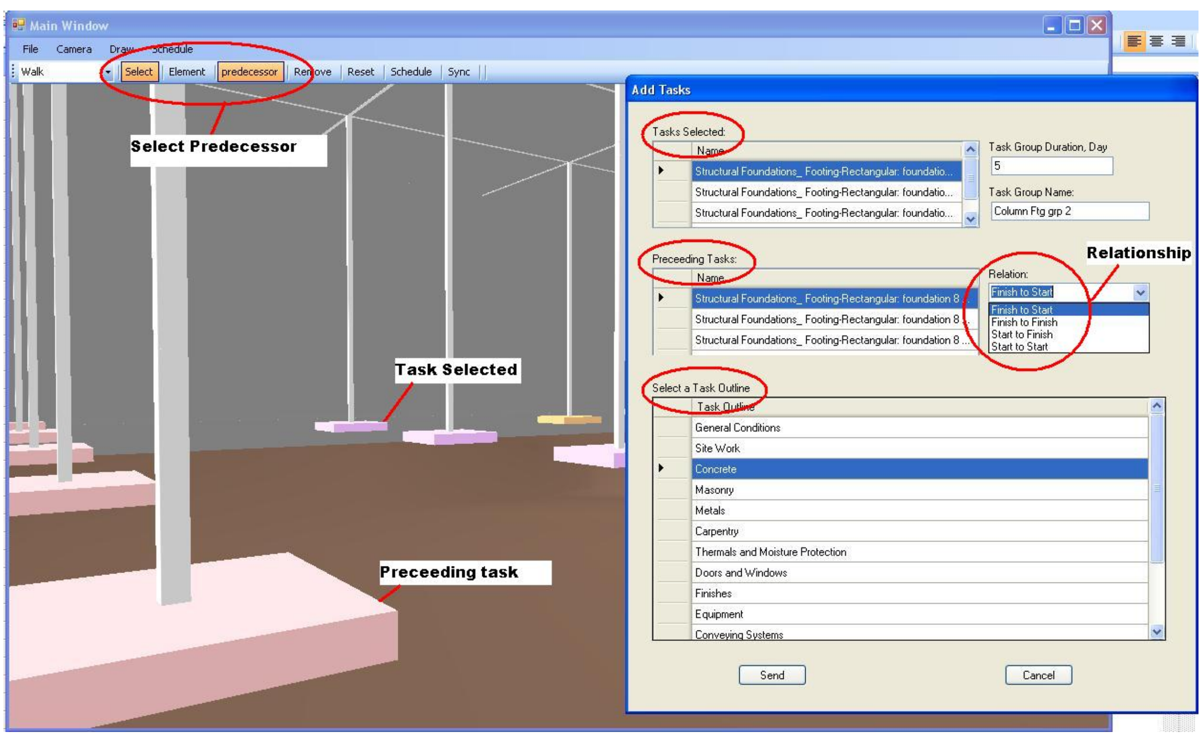

Figure 6.7 Selection of task outline and relationship between activities after activity and predecessor selection

Step 6: Select Summary Task/ Task outline

To make the schedule organized the program users WBS. Activities are arranges in different levels. Intermediate levels represent sub tasks and lowest levels represent work packages. The topmost level is the Project summary and show the duration for complete project. Second level is the summary task which represents summary of sub activities and the total duration required to finish that task. For example “Concrete Work” is the summary task which involves subtasks like foundation walls, slabs etc. The program provides a basic outline summary task list and user can select the summary task from this list.

Step 7: Send Schedule to MS project.

Once the elements are selected to create activity and select predecessors, duration, relationship and lag time is entered in the schedule window the information can be sent to MS project. This creates a schedule for the project.

CHAPTER 7

Summary, Conclusions and Future Research

This chapter provides a brief description of research summary, research contributions, research limitations and recommendations for future research in visual scheduling.

7.1. Research Summary

The goal of this research was to make sequencing of project activities simpler and more intuitive, and to provide visualization of the project at an early planning stage. The developed program transfers most of the information from a 3D CAD model to scheduling software and reduces manual time consuming data entry. To obtain 4D visualization of a construction project a schedule is required by the 4D simulation software to link with the 3D model. It is very difficult and time consuming to schedule a project looking at a list of project activities and elements. This study provides a visual approach for sequencing activities by walking inside the virtual building and selecting elements during the walkthrough.

A graphics application was developed using Microsoft DirectX library to assist the visual scheduling process. Both geometry and material information extracted from a Revit CAD model is used to create the virtual environment and generate a 3D model of the project. Both first and third person cameras are available for navigation and interaction with the 3D model. Users can walk around and inside the virtual building for visualization of the project and visually sequence the activities by selecting tasks and predecessors while walking in the building. This approach is based on the findings of modern cognitive theories which emphasize visualization in the form of images or walkthroughs helpful for reducing the load on user's memory. Less recollection is necessary when sequencing activities visually as compared to sequencing them using a long list of tasks. The methodology was validated by undertaking a case study and scheduling a Warehouse Project using Visual Scheduling Application.

The Visual scheduling approach was then demonstrated to contractors and industry professionals for their feedback about the methodology. According to the contractors consulted, the developed methodology simplifies the process and saves time. Some of the suggestions made for improving the software were implemented in the many revisions that the software went through; those suggestions which required more time and resources than was available for this study were documented to be pursued in the future.

7.2. Research Contributions

1. **Visual Interface for Scheduling:** Visual sequencing of construction activities is provided by giving visual aids to the scheduler thereby making the process more intuitive and simple. This application transfers the necessary project information from an architectural CAD model to scheduling software and streamlines sequencing and organizing project activities. This eliminates the tedious and time consuming manual data entry steps to create a construction project schedule. Extraction, organizing, sequencing and transferring of project elements to scheduling software is performed during a walkthrough of the 3D model. The research provides an assessment of effectiveness of visual scheduling and

feasibility of applying it to real-world projects based on feedbacks from experienced industry professionals and contractors.

2. **Visual Scheduling Application as an Educational Tool:** According to Wang (2007), "It requires special skills and experience to read 2D drawings and relate it to the schedule. Such schedules force planners to visualize and interpret the activity sequence in their minds. Also, some planners will have different interpretations of the same schedule, which makes it difficult to communicate and discuss whether a certain problem actually existed or not." It is very difficult for a student to understand scheduling by mentally visualizing what is being taught about scheduling. Visual Scheduling Application can be used as an effective educational tool for students who have no experience in scheduling.
3. **Foundation for future research and improvements: T**his research provides a good foundation for developing educational tools in the future. It provides a simplified approach for sequencing activities in a construction project. In project management area, this research can be extended by adding functionalities such as resource allocation, activity duration estimating, cash flow analysis, and calendar and staff allocations. For collaborative work, computer network capabilities can be added to the software.

7.3. Limitations

1. This approach is about visually sequencing project activities as the scheduler walks inside the virtual model. Scheduling of construction projects involves defining construction methods and tasks, sequencing of tasks, resource allocation, resource leveling, activity duration estimating, cash flow analysis, and calendar

and staff allocations. The scope of the study was limited to only activity sequencing because of time and resource constraints.

2. Considerable amount of computer memory and processing power is required for interactive walkthrough and scheduling. Computer resources set the limit for the size of the project that can be scheduled with the proposed approach.
3. This is a visual approach for scheduling construction projects. Scheduling is done by walking inside the virtual prototype of the building and selecting elements. Navigating insides the building model using mouse and keyboard may be difficult for some users.

7.4. Future Research

1. Adding functionality which allows selecting a portion or a section of an element. For example a slab may not be poured in a day. Functionality can be added which facilitates selection a section of an element and allow breaking an element in parts and scheduling each part as a separate task for creating more realistic schedules.
2. Adding functionalities such as resource allocation, resource leveling, activity duration estimating, cash flow reporting, and calendar and staff allocations.
3. Computer network capability can be added to facilitate collaboration among project members for better communication of ideas.

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Appendix - A

Scheduling Terminology

Task. A task is an individual unit of work that may combine with other tasks to complete an activity or be independent work items. Task can be thought of as the separate work unit items that collectively need to be done to finish each activity sufficiently enough to start the next activity.

Activity. Activities are single identifiable work step in the total project production. Groups of tasks combined to finish a job item are activities.

Activity Number. Number assigned to each activity. These numbers are sequential.

Activity list. List of work items for a project. Also the work breakdown structure.

Activity Duration. Elapsed time to perform an activity. Start to finish.

Arrow diagram. CPM network diagramming method using arrows to show activities interrelationship and the flow of job logic.

Event. An event is the exact day at which an activity is just starting or finishing. An activity is always preceded by an event and followed by a sequential event.

Event Diagram. The most common event system uses circles at the end of each activity arrow. These circles are places at the junction o the arrows and they represents the event

Milestone. Date on the schedule predetermined for a phase or important occurrence is scheduled to take place.

Early start date. Earliest date an activity can start.

Late start date. Latest date an activity can start.

Early finish date. Earliest date an activity will be completed without float.

Late finish date. Latest date an activity will be complete without any negative float.

I-J number. The letter I designated symbol for the tail of an arrow start of the activity , and the letter j designated symbol of the head of an arrow(finish o the activity).

Float. Measure of available scheduling leeway time on any activity's completion.

Free Float. Time that activity finish can delay an event without affecting the succeeding activity's start day.

Total Float. Measure of available spare time or scheduling leeway available on all activities completion. Total sum of all free float.

Negative float. Time a critical activity is late meeting its finish event.

Phases. These are groups of activities that will happen in a logical order, precede or succeed on another or happen simultaneously. Phases are arranged in divisions with sequential velocity management. Phases are supposed to flow into each other smoothly on time with no problems.

Constraints. A constraint is a potential real world limitation or a tactic o the scheduler in creating a float window during monthly recycling of the schedule that can delay the start of activities or tasks.

Job logic. This is the sequential relationship between activities, identified and defined during prescheduled planning these relationships consist of the necessary time and sequential order of construction operation throughout the project.

Logic diagram. Arrow diagram of complete project network schedule, or a cross section of an area of production.

Time-Scaled Chart. Logic diagram with a time scale.

Velocity diagram. Velocity diagram means a straight line, time scheduled flow chart. The purpose of the velocity diagram is to determine the most efficient paths to joining the activities in total operational network scope.

Velocity network schedule. This is the culmination stage of cpm. All the preceding scheduling elements are computed into a master network plan for the entire projects scheduling including post project closeout.

PERT. Programming evaluation research technique. Normally used by the military and defense industry contractors.

PDM. A schedule using the precedence diagramming method.