THESIS

FOUR-DIMENSIONAL CONSTRUCTION PROJECT PLANNING WITH AUTOCAD

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GRADUATE SCHOOL, KASETSART UNIVERSITY
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THESIS APPROVAL

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THESIS

FOUR-DIMENSIONAL CONSTRUCTION PROJECT PLANNING WITH AUTOCAD

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A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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Wittaya Srisomboon 2008: Four-Dimensional Construction Project Planning with AutoCAD. Master of Engineering (Civil Engineering), Major Field: Civil Engineering, Department of Civil Engineering. Thesis Advisor: Mr. Suphawut Malaikrisanachalee, Ph.D. 88 pages.

Four-dimensional (4D) project planning system can effectively improve project planning, communication, coordination, visualization and simulation. 4D project planning system can be achieved by integrating a three-dimensional (3D) building model with project schedule.

This study investigates approach for implementing a 4D project planning system using AutoCAD together with Microsoft Project. System architecture, physical database model, and approach for converting AutoCAD's simple geometric objects to real construction objects as well as approach for linking the AutoCAD 3D solid model, project schedule from Microsoft Project and Microsoft Access are also presented. The eight-storey reinforced concrete parking building was used as a case study to simulate construction sequence as well as to detect time-space conflicts using the 4D project planning system that was developed.

Student's signature

Thesis Advisor's signature

11 / Jan / 2008

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Wittaya Srisomboon

September 2007

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LIST OF ABBREVIATIONS

CPM	=	Critical Path Method
MS Access	=	Microsoft Access
MS Project	=	Microsoft Project
ODBC	=	Open Database Connectivity
VBA	=	Visual Basic for Applications

FOUR-DIMENSIONAL CONSTRUCTION PROJECT PLANNING WITH AUTOCAD

INTRODUCTION

Project planning is the heart of project management because it provides integrated information that coordinates the work of all parties and should be completed before the project starts. Planning also facilitates the project control system to track the quantity, cost and time of work required to successfully complete the project. Benefits achieved from good project planning include increasing possibility to finish the project on time, no interruption of work, and reducing amount of rework. A major challenge for the construction project planner is to: 1) determine the sequence of all construction activities to be performed; 2) allocate the resources required for the execution of the activities appropriately; 3) foresee the use of available time and space effectively; and 4) make good plan to complete the project within the framework of budget.

Presently, construction planning relies on two-dimensional (2D) drawings, bar chart, Critical Path Method (CPM) along with planner's experience. Construction project consists of many inherent factors where ineffectiveness of project planning can lead to time and cost overruns (Kinley, 2007). Since each construction project is unique and dynamic in nature, unexpected problems may arise during construction phase. At the same time, due to increasing pressure for shorter delivery time, construction project planners are facing complex challenges.

Koo and Fischer (2000) stated that traditional bar chart and CPM schedules used as a project planning tool fail to provide information pertaining to the spatial aspects of construction project such as work spaces and material transportation path. Planners need to conceptualize the construction sequence in their minds by associating the components in the 2D drawings together with the related activities in the schedule. CPM and bar chart only convey what is built and when it is built.

Difficulty in interpretations about construction sequence depends on knowledge of each individual. In such situation, an inexperienced engineer may misunderstand the sequence and, consequently, misguide a foreman. Ciribini and Galimberti (2005) stated that CPM method does not consider the effects of overcrowding. For example, crews involved in non-critical tasks may impair the completion of other critical activities. Narendra (2005) stated that CPM networks are self-explanatory in describing only the temporal relationships between activities, but inherently discrepant in describing the spatial relationships between activities. This inconsistency in CPM networks is likely to cause spatial conflicts in construction schedules. Furthermore, poor planning in the construction activities can lead to many conflicts including:

1. Safety hazard conflict

Safety hazard conflict occurs when a hazard space generated by an activity conflicts with a labor crew space required by another activity. A hazard space is generated when an activity creates a hazardous situation such as falling objects and fire sparks. Therefore, when a hazard space conflicts with a labor crew space, it creates a hazard situation for the labor crew.

2. Damage conflict

Damage conflict occurs when a labor crew space or an equipment space or a hazard space required by an activity conflicts with the protected space required by another activity. A protected space is required to protect a component from damages for a certain period of time. For example, a protected space is needed around the component during the curing of concrete or drying of paint. Therefore, when a labor crew or equipment is assigned to the same area where the protected space is needed, it may damage the component that is being protected.

3. Congestion time-space conflict

Congestion time-space conflict occurs when a labor crew space or an equipment space required by an activity conflicts with another labor crew space or an equipment space or a temporary structure space or a building component space required by another activity. As shown in Figure 1, there are different levels of congestion. Some congestion cases create a constructability problem, in which the conflicting activities could not be performed concurrently as planned.

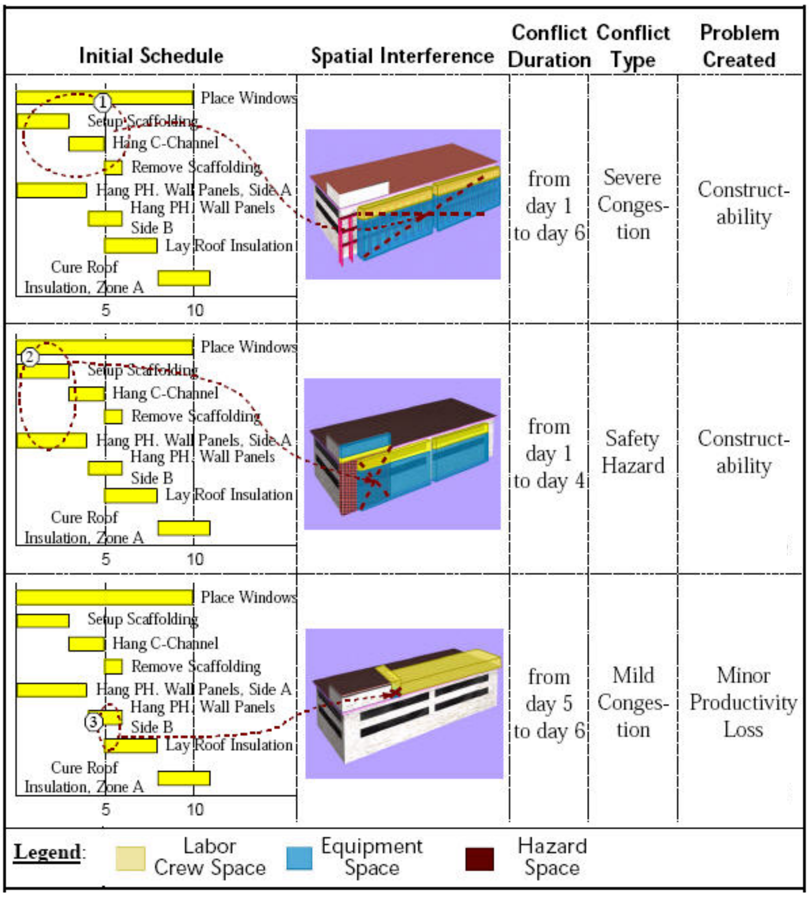


Figure 1 Different Types of Time-Space Conflicts Existing in the Schedule
Source: Akinci *et al.* (2000)

In summary, Akinci *et al*.(2000) demonstrated that appropriate changes in the construction method and good project planning is the effective way to eliminate above said conflicts which mainly arise due to time-space conflicts between activities. Nowadays the ability to visualize a project through a four-dimensional (4D) computer-aided design (CAD) model which a three-dimensional (3D) CAD model is linked with project schedule allows construction project planners to review and generate better construction plans. Several researchers (Koo and Fischer 2000, Staub-French and Khanzode 2007) have illustrated that use of 4D models can help to overcome the practical shortcomings of traditional CPM and bar chart schedules by:

1. Visualizing and interpreting construction sequence

The 4D model displays the actual project being built and shows the construction sequence through 3D model and corresponding to construction schedule.

2. Anticipating safety hazard situations

By viewing the 4D model, project planner can detect areas where accidents may occur and implement prevention measures such as placing warning signs, restricting access, or providing safety guards.

3. Conveying spatial constraint of a project

Traditionally, CPM project scheduling can only convey message about different construction activities what is built and when it is built (time). Supplement to this the 4D model can shows not only what is built and when it is built but also where it is built (space). The 4D model therefore allows users to verify whether a component of any activity can be physically placed or whether crews can work in a certain location or not. In other words, detecting time-space conflicts or previewing an accessibility problem is possible through the 4D model because it conveys the spatial implication of a component being placed at a certain time and location.

4. Communications among project participants

The 4D model provides a useful way to communicate with different project participants. Particularly it is useful for the owner who is not familiar with 2D drawings and CPM schedules. In this situation, the 4D model can generate real construction scenario showing the real sequence of work, time and space. This helps owner to better understand different components of activities and take decisions consequently. Information flow modality for communication and coordination among the project participants by using 4D model is shown in Figure 2.

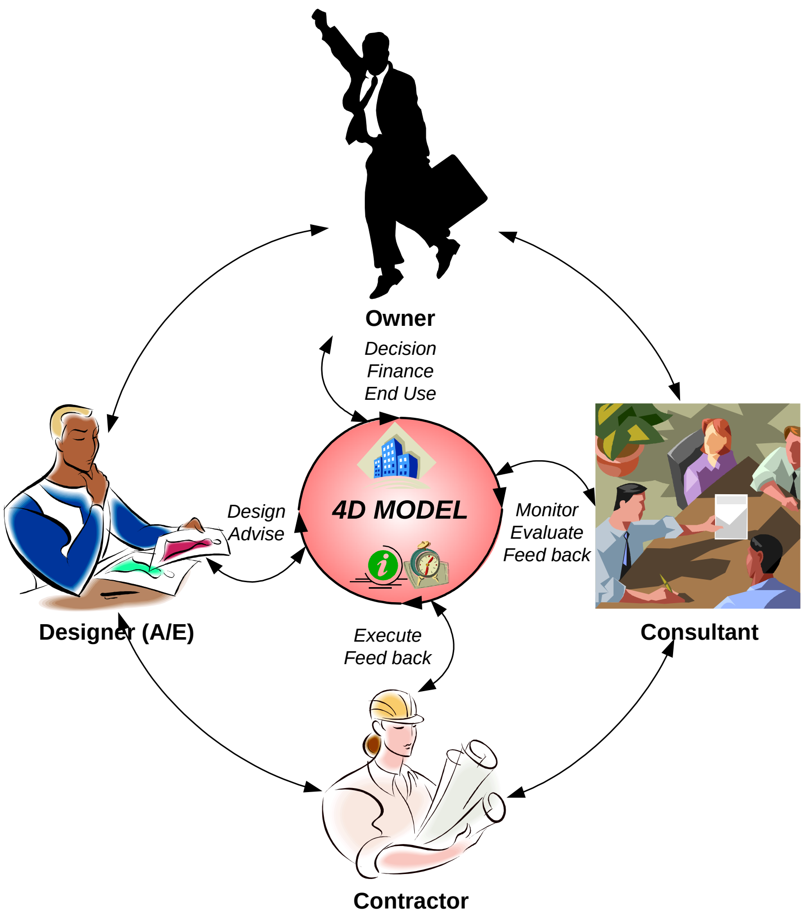
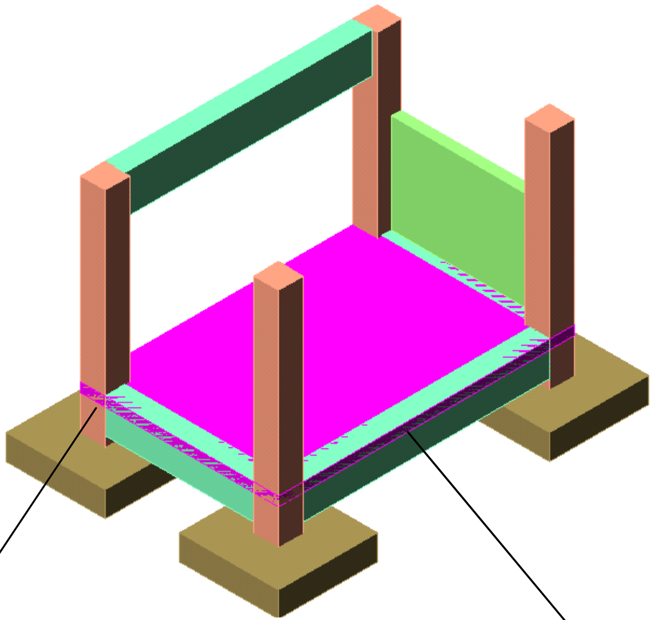


Figure 2 Use of 4D Model as Central Construction Communications Tool among the Project Participants

Statement of the problem

Although 4D tools are useful for visualizing, communicating, coordinating and simulating construction project activities, (Koo and Fischer, 1998) stated that there is the need for some functional improvements to make it possible to recognize the attributes and behavior of the individual objects of the 4D model as well as recognize the relationships among the different interrelated structural objects to make it more effective for project planning. In other words, a knowledge-based 4D tool must be able to recognize the characteristics of individual objects including its name, dimension, gridline, quantity, and material properties. Another vital aspect for project planning is to recognize the relationships among the different interrelated structural objects .For example slab is connected to beam, beam is connected and supported by column. These three structural objects are interrelated and hence their relationship must be recognized for effective project planning.

AutoCAD can be used to support 4D model by using the 3D modeling tool. AutoCAD maintains entity as simple geometric objects including line, polyline, polygon, solid, surface and wireframe. These simple geometric objects, however, convey only the spatial information (i.e., shape, coordinate, and volume) which facilitate for the object visualization and do not recognize structurally as used in real construction object as shown in Figure 3. It means that information provided by AutoCAD only is incomplete and hence ineffective because computer does not recognize what it is, and consequently user can not retrieve it for further application. This particular shortcoming leads to the ineffective communication between AutoCAD and its user as well as the potential development for analysis tool.



ObjectID	Coordinates	Layer name	StType	Gridline	Floor	Dimensions	Volume
213008	X_1,Y_1,Z_1	Beam_1st Fl.	?	?	?	?	0.50
213009	X_2,Y_2,Z_2	Column_1st Fl.	?	?	?	?	0.81

Figure 3 Simple Geometric Objects and Its Spatial Information by 3D Solid Model

OBJECTIVES

1. To convert simple geometric objects to real construction objects.

2. To develop 4D Project Planning System by integrating 3D construction model with schedule.

Scope

This study used the 8-storey reinforced-concrete structure parking building, located behind the office of the president, Kasetsart University (as seen in Figure 4) as the case study. The project duration was 330 days. Figures 5 through 8 illustrate site layout, front view, rear view, and side view respectively.

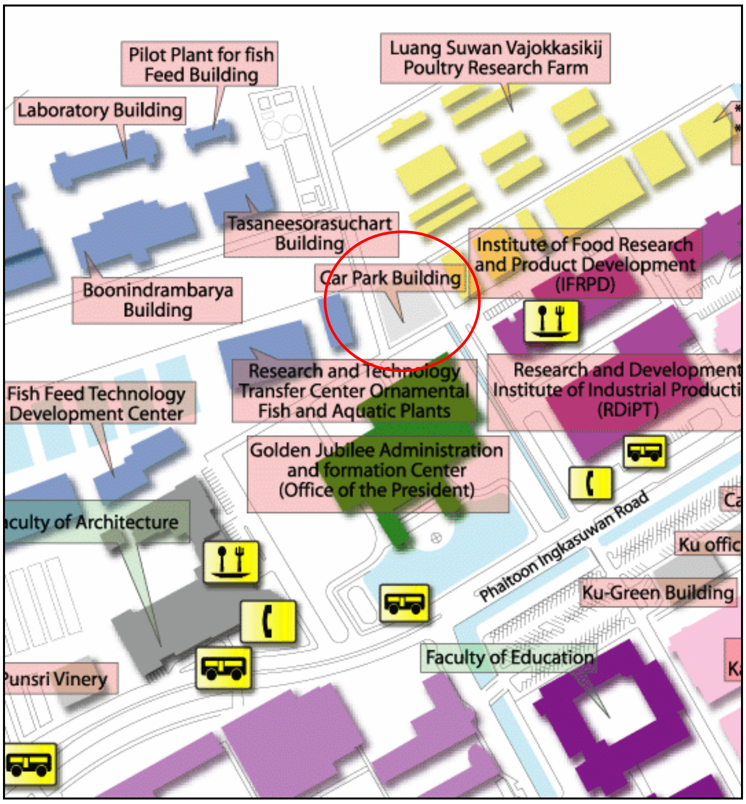


Figure 4 Location of Car Park Building

Source: Kasetsart University (2003)

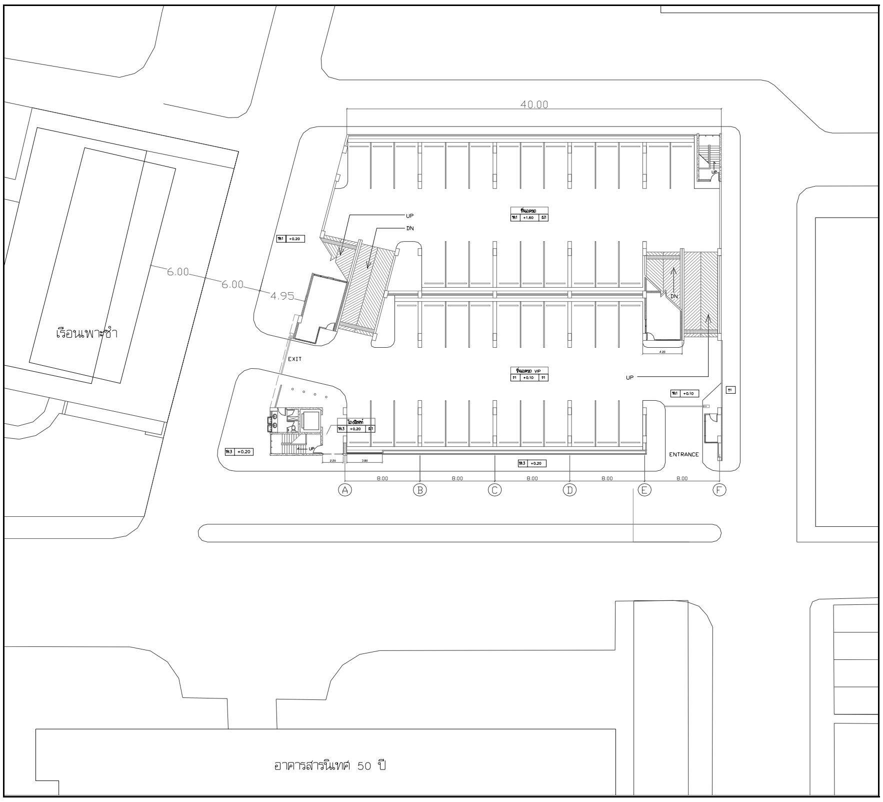


Figure 5 Site Layout

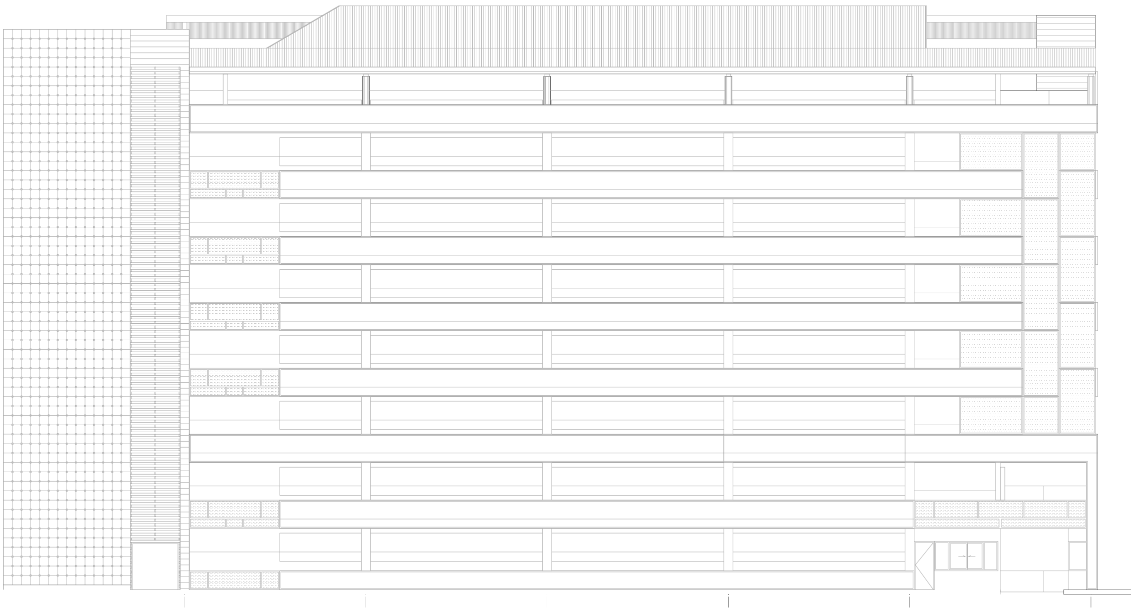


Figure 6 Front View

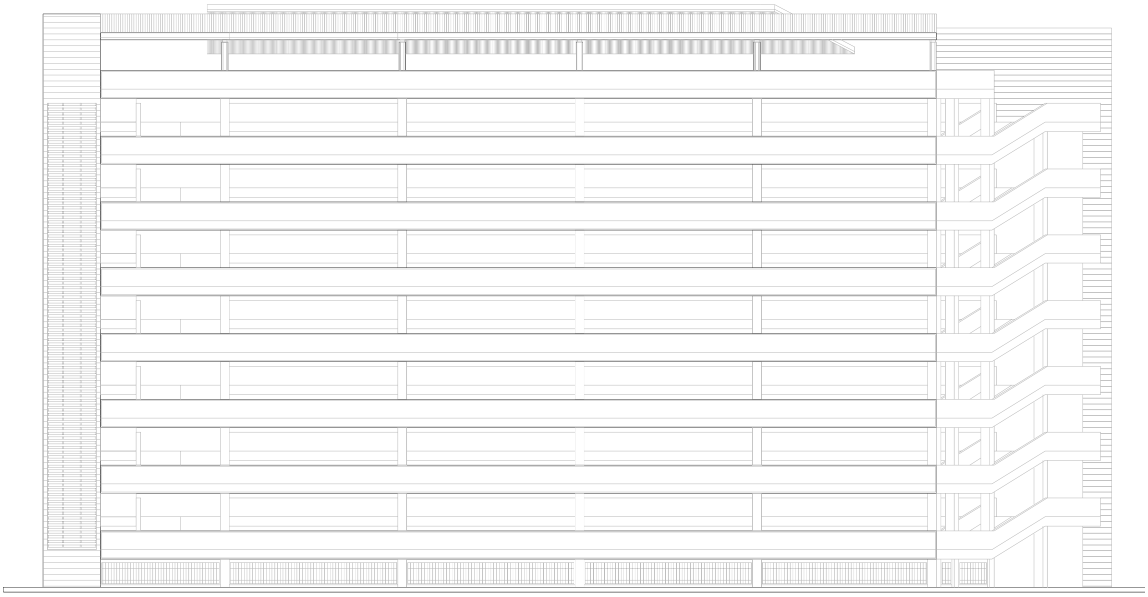


Figure 7 Rear View

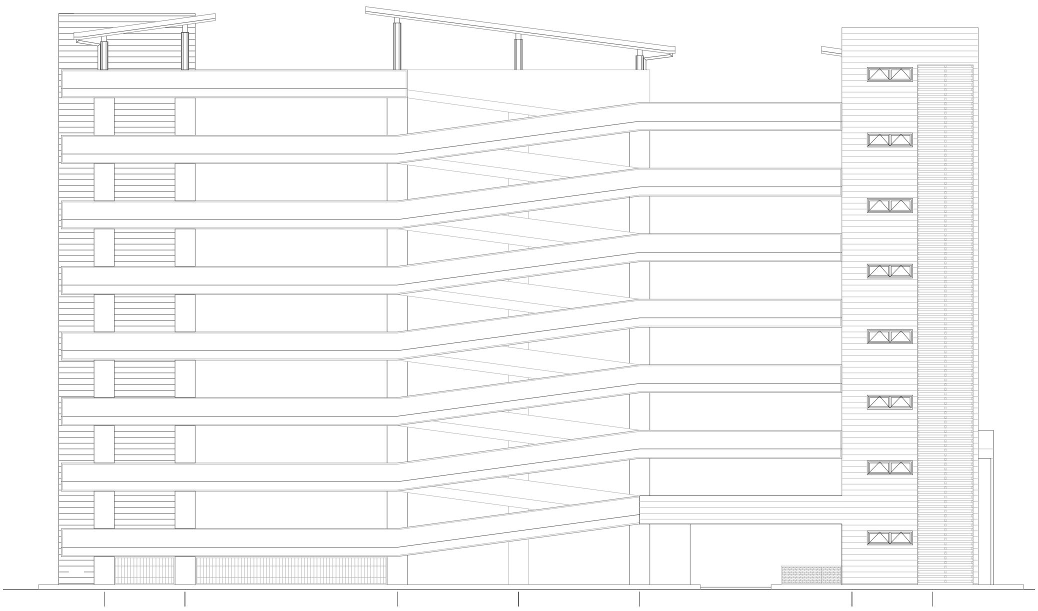


Figure 8 Side View

LITERATURE REVIEW

1. Past studies on 3D and 4D models

Koo and Fischer (2000) developed 4D model by linking CPM schedule (Primavera P3) with 3D CAD model (AutoCAD R14) through the Plantspace Schedule Simulator as shown in Figure 9 and used a commercial two-story office building project as their case study.

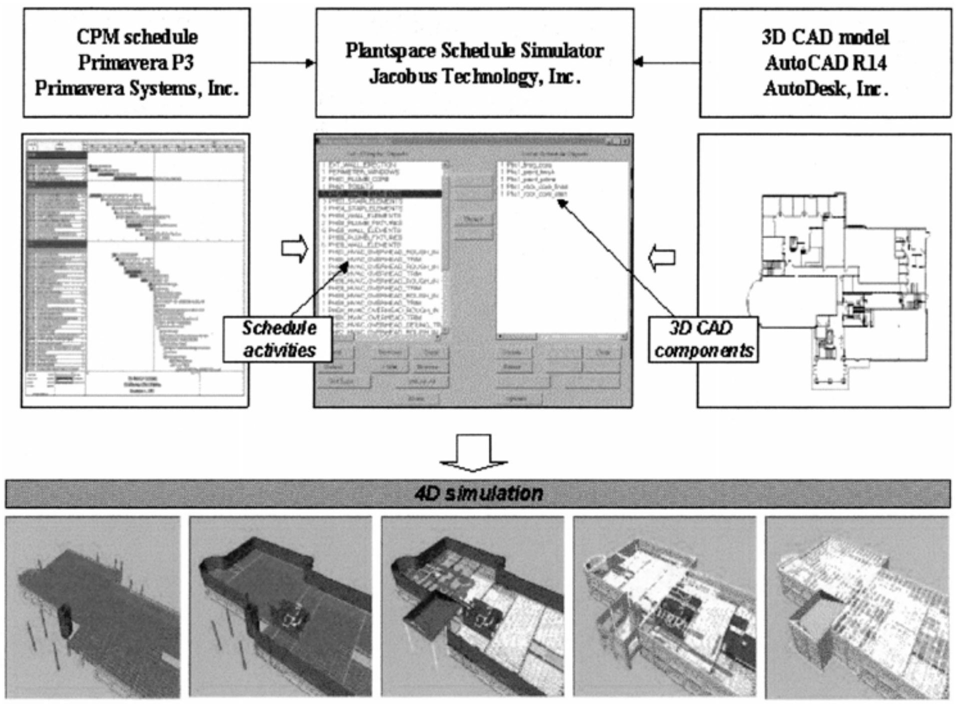


Figure 9 Overall System Architecture for 4D CAD Model Development
Source: Koo and Fischer (2000)

They summarized that the 4D model can minimize the conceptualization for project planner as it conveys the temporal and spatial aspects of planning information. The 4D model allows easier comprehension of the project plan and allows users to detect possible problems in the schedule. Through the case study, they discovered that the 4D model was particularly effective in determining the correctness of the schedule, conveying the spatial aspect, constraints of project components and their related activities. The 4D model also supports additional analyses regarding cost, productivity, safety, and resource allocation which can lead to more realistic schedules and cost estimates.

Dawood, Sriprasert and Mallasi (2003) developed approach and tool namely, ProVis as shown in Figure 10, for the simulation of building components and space availability for construction tasks according to the preliminary schedule. Users will be able to visually detect the problems related to logic of schedule and time-space conflicts by the assistance of this tool. ProVis prototype was controlled by Visual Basic for Applications (VBA) which embedded in AutoCAD 2000.This was a part of the VIRCON project. Processes for the VIRCON database and integration of interface among MS Access, AutoCAD and Microsoft Project are shown in Figure 11 and 12, respectively.

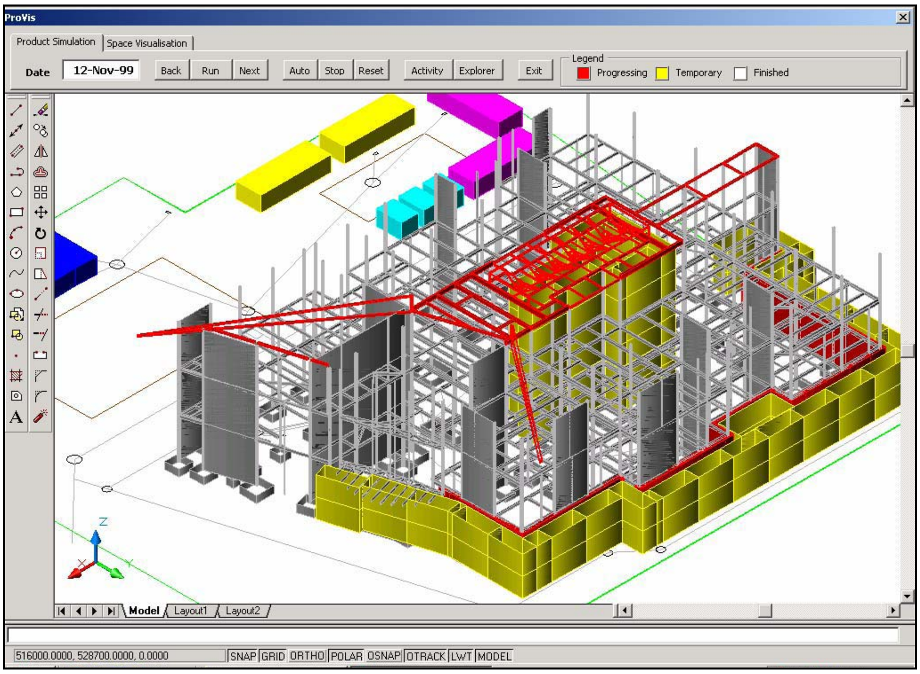


Figure 10 4D Visualization for Constructing Centuria Building

Source: Dawood *et al*. (2003)

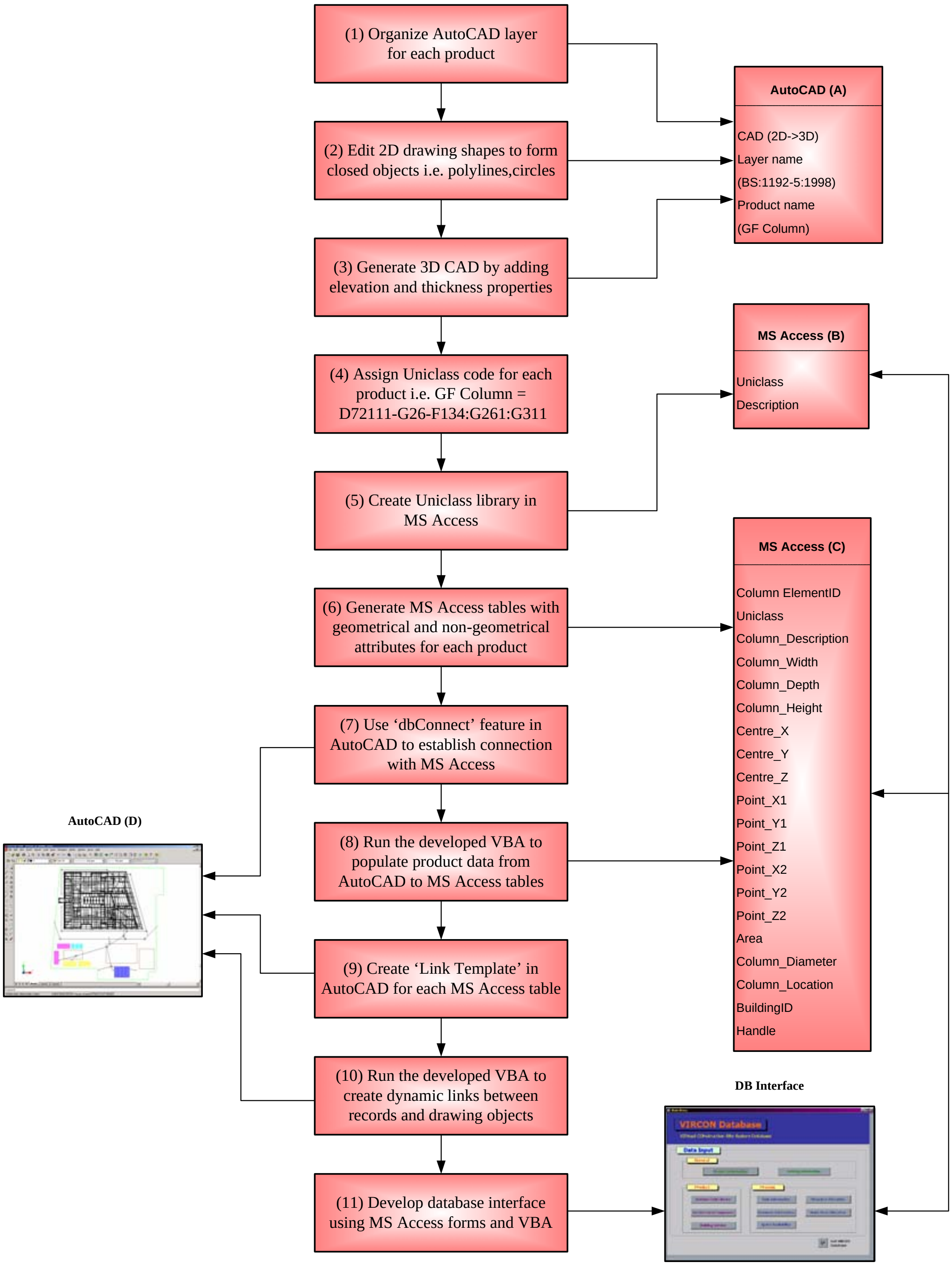


Figure 11 Processes for Populating Product Data to the VIRCON Database

Source: Dawood *et al.* (2003)

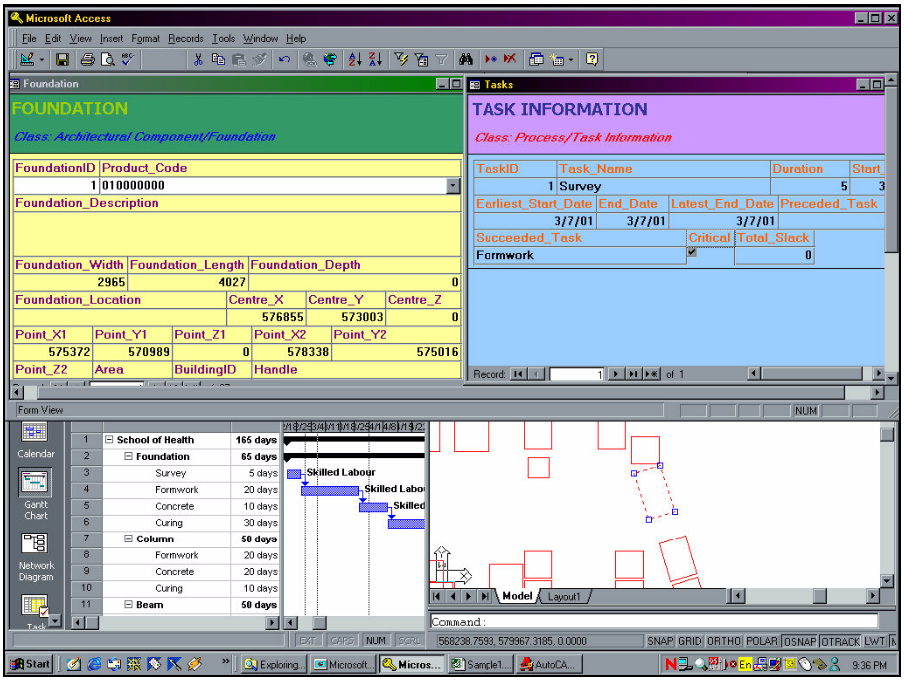


Figure 12 Integrated Interface among MS Access, AutoCAD and MS Project

Source: Dawood *et al.* (2003)

Chau *et al.* (2004) demonstrated that 4D visualization with a visual interface of layout of site facilities and allocation of resources along with the installed components can facilitate site planning and help construction managers streamline the site management. A prototype 4D visualization model has been developed and implemented to overcoming problems incurred in conventional construction planning methods and in incorporating practical site management features. This 4D visualization model, which links the 3D geometrical model with scheduling data, comprises the activity schedule, associated allocation of resources, and layout of site facilities at any projected instant as shown in Figure 13 and 14. There are many potential benefits of a 4D visualization system, including facilitating site planning and management, predicting the occurrence of any potential site problems, and streamlining the site management practices.

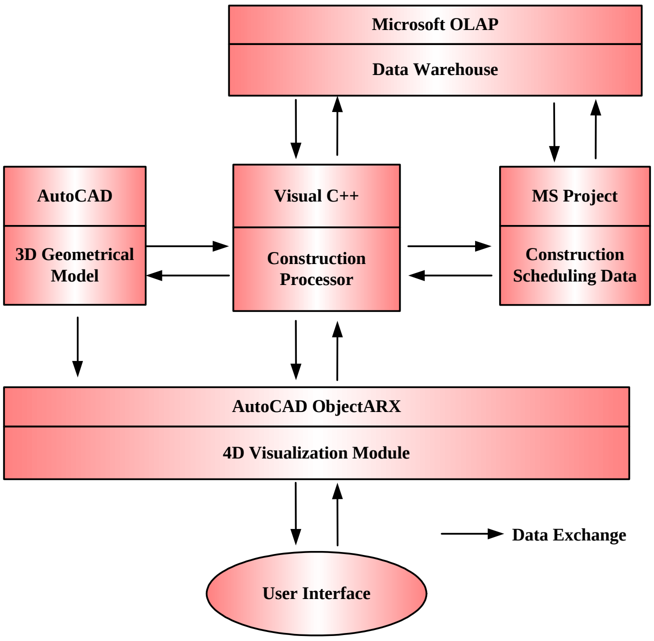


Figure 13 Architecture of 4D Visualization Model

Source: Chau *et al.* (2004)

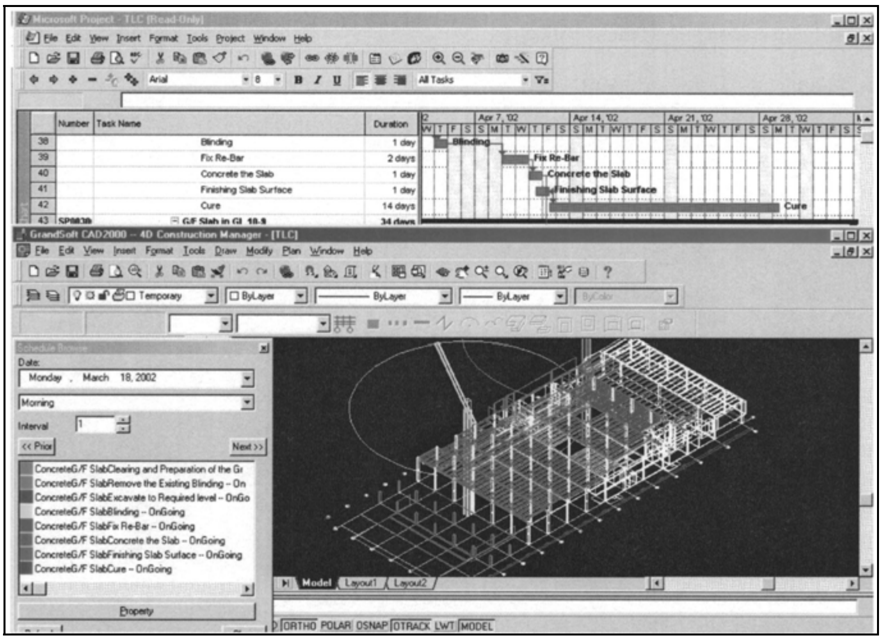


Figure 14 4D Visualization Linking 3D Geometrical Model with Schedule

Source: Chau *et al.* (2004)

Samuel João da *et al.* (2005) presented a 4D planning simulation of a building as shown in Figure 15. 4D planning development is illustrated as accomplished manually. It is proven that the manual procedure adopted in 4D planning simulation presents a lot of difficulty and little productivity. In this way, the 4D visualization is unviable on the building schedule. Therefore, it is extremely important that it makes a connection between software of planning and graphical visualization, namely Microsoft Project and AutoCAD, respectively. Finally they discussed that is possible to establish a connection between Microsoft Project and AutoCAD, allowing the integration and developing 4D planning, but this methodology needs to be analyzed with great care about software development specialists to check about its practical use.

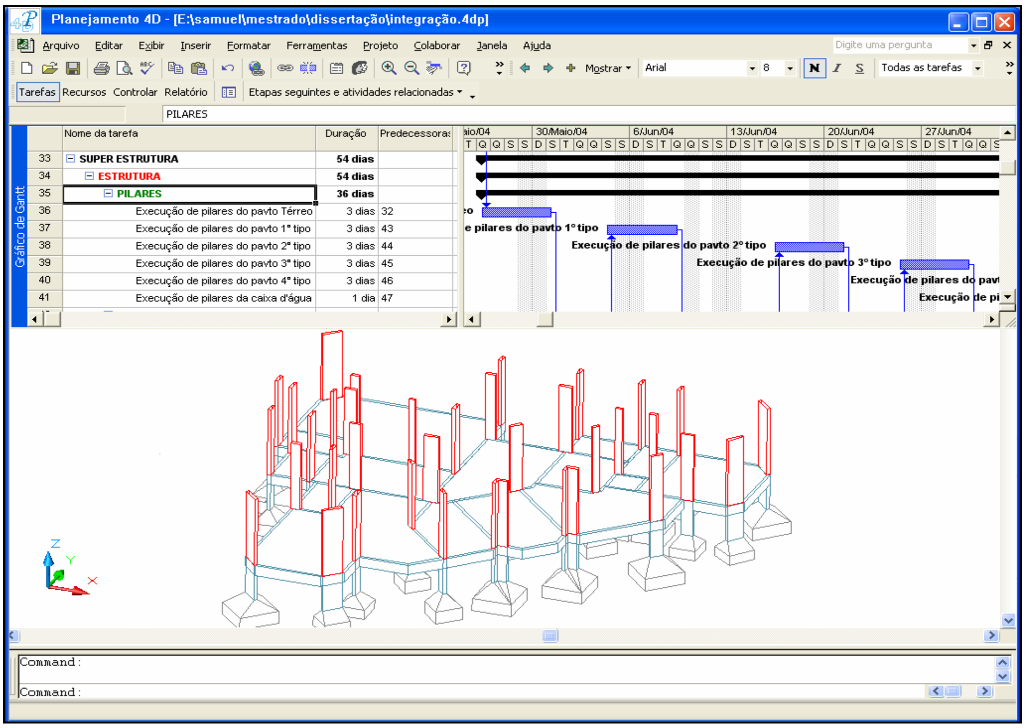


Figure 15 Integration of Microsoft Project and AutoCAD as 4D Planning Program

Source: Samuel João da *et al.* (2005)

2. 3D Modeling Tools

2.1 AutoCAD Series

The Autodesk Revit platform for building information modeling is an architectural design and documentation system that supports the design and architectural drawings and schedules required for a building project as shown in Figure 16. In the Autodesk Revit building model, every drawing sheet, 2D and 3D view, and schedule is a presentation of information from the same underlying building model database. As work in drawing and schedule views, Autodesk Revit collects information about the building project and coordinates this information across all other representations of the project. The Autodesk Revit parametric change engine automatically coordinates changes made anywhere in model views, drawing sheets, schedules, sections and plans.

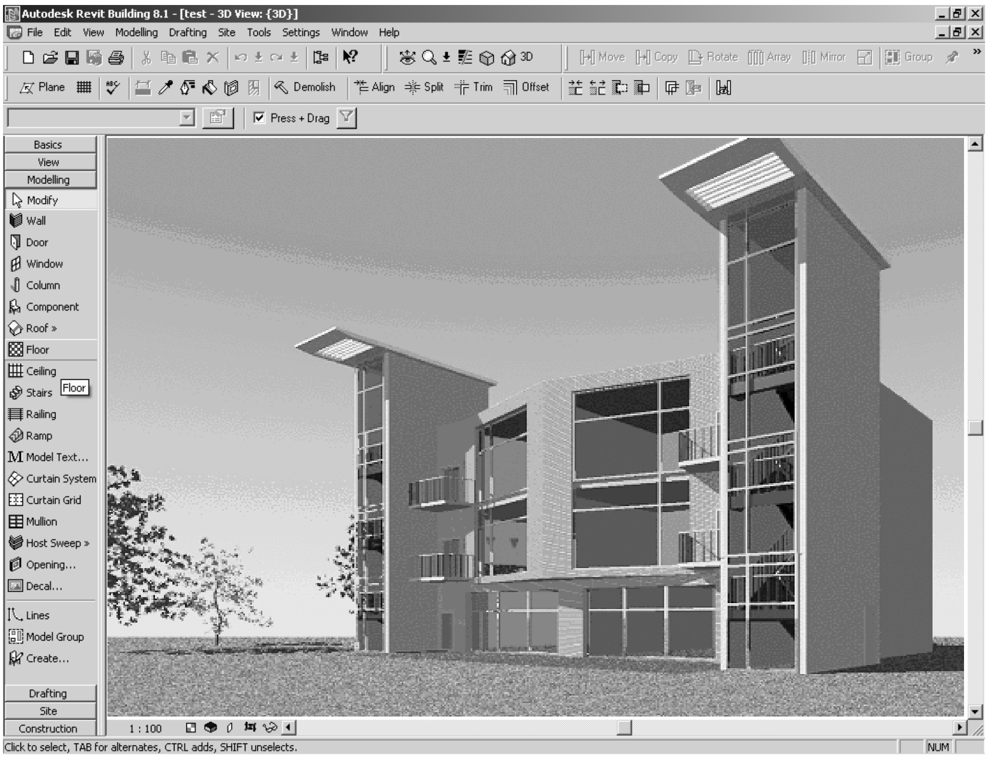


Figure 16 Sample screen of Autodesk Revit Building
Source: Autodesk Incorporated (2007)

AutoCAD is a suite of CAD software products for 2D and 3D design and drafting, developed and sold by Autodesk Inc, Modern AutoCAD includes a full set of basic solid modeling and 3D tools as shown in Figure 17, but lacks some of the more advanced capabilities of solid modeling applications. AutoCAD can co-exist with such products as a 2D drafting tool. AutoCAD is a vector graphics drawing program. It uses primitive entities such as lines, polylines, circles, arcs, and text as the foundation for more complex objects. AutoCAD supports a number of application programming interfaces (APIs) for customization and automation. These include AutoLISP, Visual LISP, VBA, .NET and ObjectARX. ObjectARX is a C++ class library, which was also the base for products extending AutoCAD functionality to specific fields, to create products such as Autodesk Architectural Desktop, AutoCAD Electrical and third-party AutoCAD-based applications.

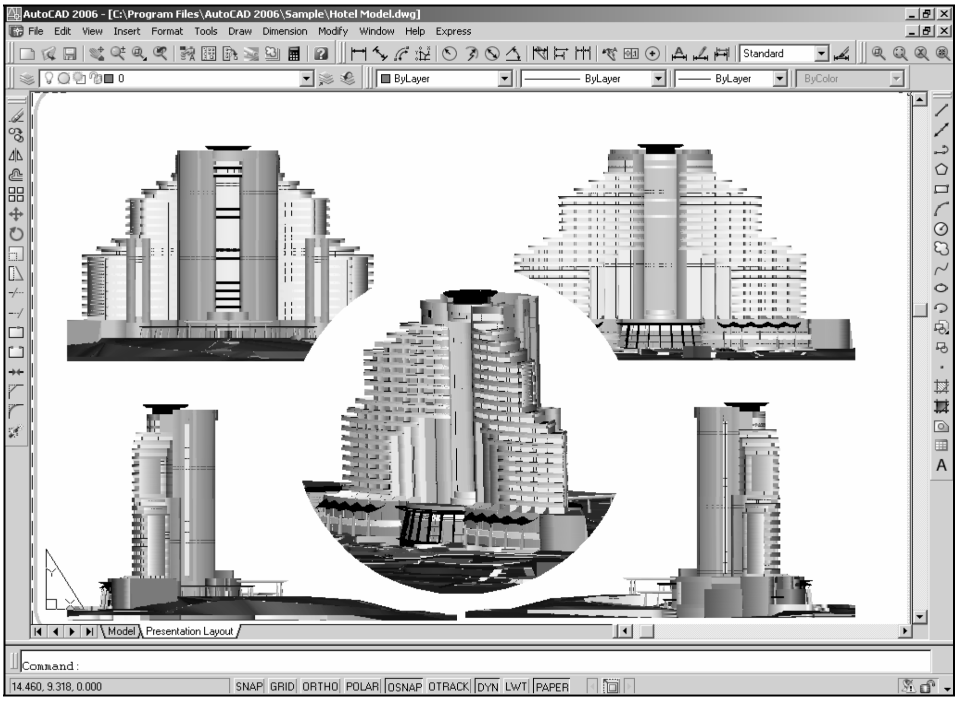


Figure 17 Sample screen of AutoCAD 2006

Source: Autodesk Incorporated (2006)

Autodesk Architectural Desktop has an integrated, robust set of architectural features and enhancements that reduce workflow inefficiencies and drafting inaccuracies that typically occur as a building design evolves through successive, iterative phases of development. Through the use of efficient 2D drafting tools, objects update dynamically to reflect design changes so that 3D building models can give you a comprehensive visual understanding of the design. Thus, productivity is increased and coordination of drawings improved where errors are minimized and design recycle times are reduced. The result is an intelligent drawing set that reduces costs during construction and provides increased value to the building owner as shown in Figure 18.

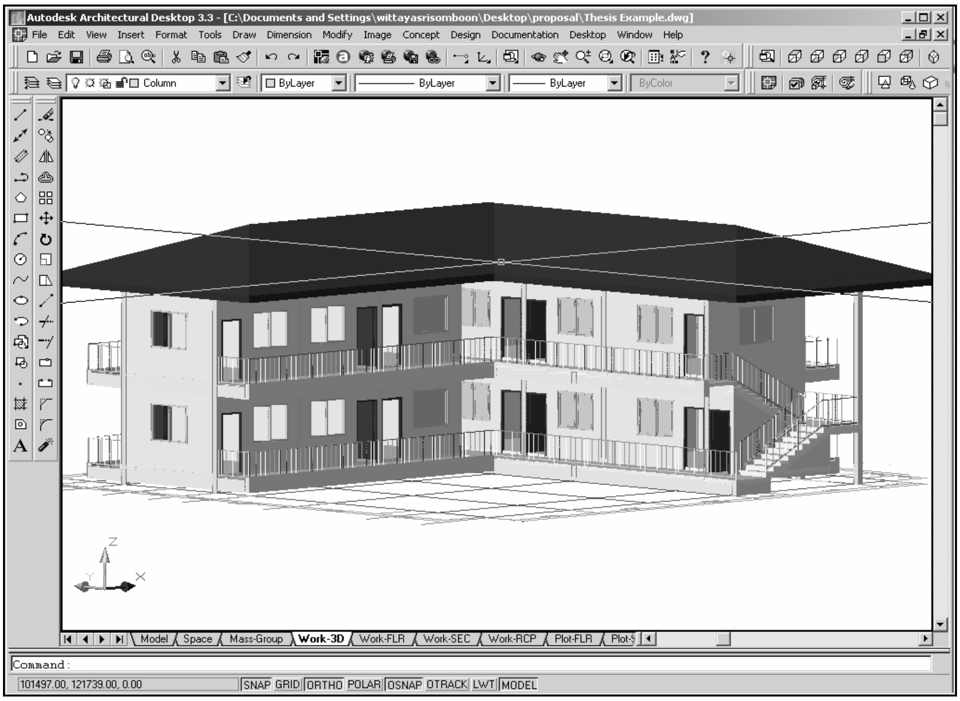


Figure 18 Sample screen of Autodesk Architectural Desktop
Source: Autodesk Incorporated (2004)

Autodesk Architectural Desktop provides a mature suite of tools for conceptual design, architectural design development, and construction documentation. New architectural and building design objects include wall objects, structural members, window objects, and curtain walls. These tools enable user to fully realize the benefits of the object-modeling approach. As a designer, user can work in 2D or 3D while using a streamlined interface that means ease-of-use and seamless integration with other Autodesk industry solutions.

2.2 Visual Reality Program

Maya is the powerful 3D modeling, animation and rendering solution. Maya is the most comprehensive package for producing 3D and 2D graphics. It's intuitive, customizable user interface and artist-friendly brush-based tools make Maya's industry-standard 3D features easy to learn and easy to use. Whether you are planning to completely migrate over to 3D or simply use it from time to time to compliment existing 2D work, you can benefit from Maya's quality, reliability and wide breadth of functionality.

Maya is currently being used to visualize models for industrial design, engineering and architecture, and then take them to the next level with 3D effects and animation.

2.3 Others

Java is an object-oriented programming language developed by James Gosling and colleagues at Sun Microsystems in the early 1990s. Unlike conventional languages which are generally designed either to be compiled to native (machine) code, or to be interpreted from source code at runtime, Java is intended to be compiled to a bytecode (though it can be compiled to native code with gcj), which is then run (generally using JIT compilation) by a machine. The language itself borrows much syntax from C and C++ but has a simpler object model and fewer low-level facilities. For example Java application is given in Figure 19.

Figure 19 Sample screen of Three-Dimension Model for BIM in Java Environment
Source: Sangkeaw (2007)

3. Construction Scheduling Tools

3.1 Primavera

Primavera which is the leader in project management solutions, delivers a project controls solution specifically developed to increase construction project management efficiency and speed, while reducing schedule delays and risk. Primavera project planner version is good example as shown in Figure 20. Primavera Project Planner version provides scheduling functions which include:

1. Critical Path Method
2. Free and total float calculation
3. Activity relationships: Finish to Start, Start to Start, Start to Finish and Finish to Finish
4. Time units in hours, days, weeks and months
5. S-curve for tracking progress

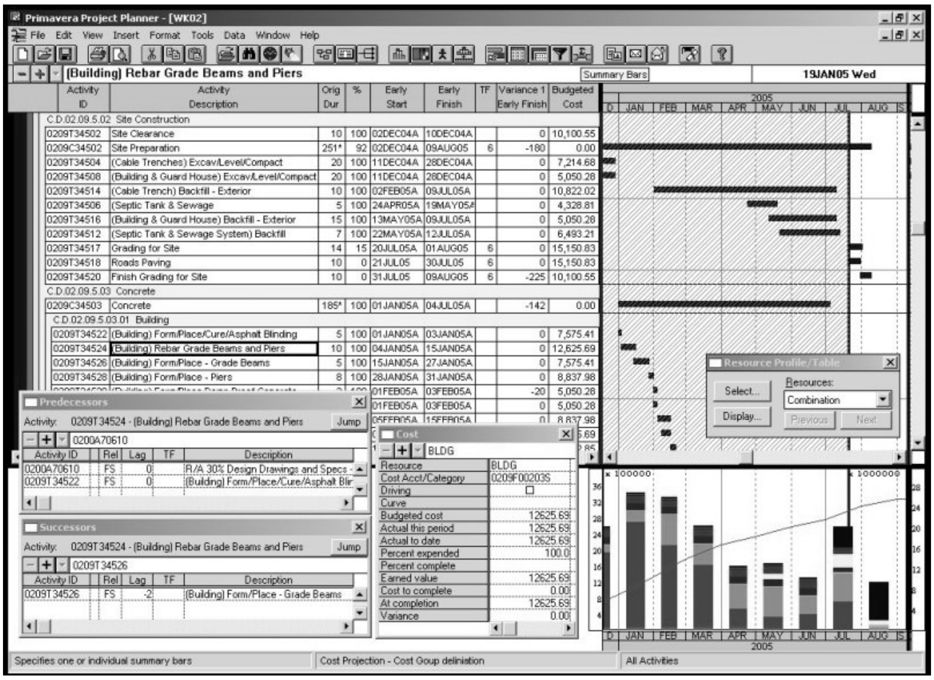


Figure 20 Sample Screen of Primavera Project Planner
Source: Jan Hlavacek (2007)

3.2 Microsoft Project

Microsoft Project is a project management software program developed and sold by Microsoft which is designed to assist project managers in developing plans, assigning resources to tasks, tracking progress, managing budgets and analyzing workloads. Schedules can be resource leveled, and chains are visualized in a bar chart. Additionally, Project can recognize different classes of users. These different classes of users can have differing access levels to projects, views, and other data as shown in Figure 21. Custom objects such as calendars, views, tables, filters and fields are stored in an enterprise global which is shared by all users.

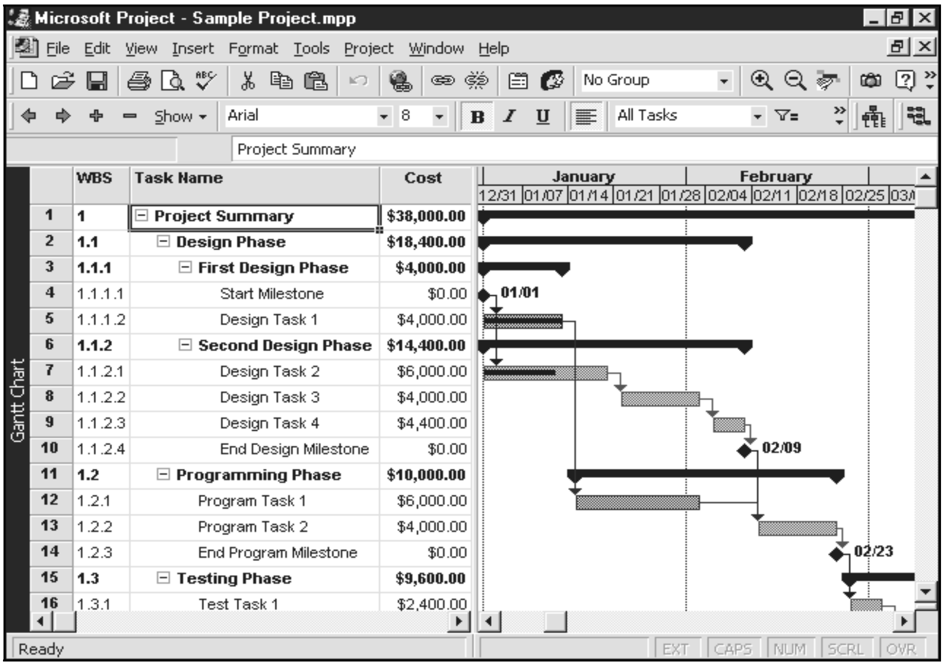


Figure 21 Sample screen of Microsoft Project

Source: Critical Tools Incorporated (2007)

RESEARCH METHODOLOGY

The research procedure is divided into five steps as described follow.

1. Literature review

Past studies on the application of 3D and 4D model for planning, scheduling and management of the construction projects were reviewed. The purpose of literature review is to gain knowledge on how 3D and 4D models can be used for solving problems related to temporal and spatial aspects of the overall project management. In application, 3D model helps to conceptualize various construction objects in its dimensions. 4D model has added benefit over the 3D model which is that it includes another vital dimension of the construction activities (i.e., time). Hence, 4D model is used to combine 3D model with the schedule and hence can be used for the complete visualization of the temporal and spatial aspects of the project activities to overcome the problem incurred to the traditional planning tools. However the functionality improvements of the 4D tool are further required to develop it as an effective analysis tool.

2. Selection and investigation of the case study project

For this study purpose the 8-storey parking building was selected as the case study because:

1) It is a high-rise building having repetitive activities and hence takes less time in generating the 3D building model.

2) The sample building has site space constraints having critical minimum space to stack the excess earth with only one access road. The overall site layout planning is also poor.

3) In most situations high-rise buildings are constructed in crowed urban area having limited space for the construction activities. Hence, the outcome of the research can be directly applied to the practical cases.

3. Develop approach and tool

By reviewing the past study on use and application of the different software package for project planning, it was found that a variety of different tools can be used for developing the 4D model including Primavera, Microsoft Project, AutoCAD, Java Microsoft Access, Microsoft OLAP, VBA and C++. This study, however, used Microsoft Project, AutoCAD, Microsoft Access, and VBA for developing the 4D model because they are well known and widely used.

The main concepts for the development of new approach are as follows:

1. AutoCAD 3D solid objects were assigned their attributes by using layer name, color, coordinate and elevation.
2. The activities that are critical and are in progress were presented by displaying red. Different colors are used to indicate other required properties of the structural component.
3. The 4D construction simulation is demonstrated by showing or hiding the layer in AutoCAD with corresponding start and finish date in Microsoft Project.
4. Microsoft Access is used as database for storing; 1) the temporal and logical information exported from Microsoft Project, 2) the spatial information exported from AutoCAD, and 3) reference table from data input form.
5. The connection among Microsoft Project, AutoCAD, and Microsoft Access is established by the tool named Open Database Connectivity (ODBC) (Dawood *et al.* 2001).
6. VBA is used for controlling the data connectivity and developing user interface by operating through VBA macro in AutoCAD.

4. 4D Project Planning Case Study

The new 4D model tool was applied to the case study project (i.e., 8-storey parking building) to verify whether it can be used in real practice. The 4D model tool was specifically as visualization, integration and analysis tool. Any gaps found on the use of approach and tools were repeatedly improved during the application.

5. Conclusion

After application of the 4D project planning system on the real case study, its' practical use as the planning tool, benefit from its use along with the limitation incurred were studied, analyzed and summarized. Based on the results recommendation for the further study in future for its improvement were outlined.

RESULTS AND DISCUSSIONS

The results of this study are presented into two sections. The first section illustrates the system analysis and development process and the second section illustrates the application of 4D project planning systems with the case study project as described below.

1. System Analysis and Development

1.1 System Architecture

Figure 22 illustrates the system architecture where Microsoft Access, AutoCAD and Microsoft Project are integrated through VBA.

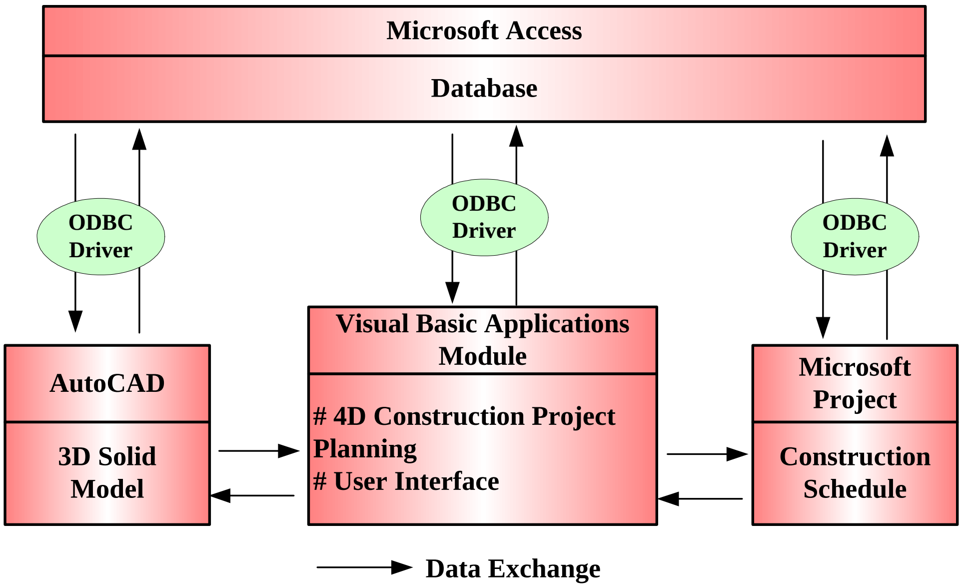


Figure 22 Conceptual Design for System Architecture of 4D Project Planning System

1.1.1 Database with Microsoft Access

Microsoft Access is used as database because it provides helpful functions that facilitate the data manipulation such as query, relationship, analysis, database maintenance, import and export data. Moreover, Microsoft Access is controlled by VBA macro which can operate on Microsoft Project and AutoCAD as well.

1.1.2 3D Solid Model in AutoCAD

Three types of 3D modeling are supported by AutoCAD: wireframe, surface and solid. Each type has its own creation and editing techniques. A solid object represents the entire volume of an object. Solids are the most informational complete and least ambiguous of the 3D modeling types. Complex solid shapes are also easier to generate and edit than wireframes and meshes. Furthermore, user can analyze solids for their mass properties (volume, moments of inertia, and center of gravity). In addition, user can export data about a solid object to applications such as numerical control (NC) milling or finite element method (FEM) analysis. By exploding a solid, user can break it down to mesh and wireframe objects.

User can use AutoCAD Color Index (ACI) to help for identifying objects visually and also assign the color of an object either by layer or by specifying its color explicitly, independent of layer. Assigning colors by layer makes it easy to identify each layer within model. Assigning colors explicitly provides additional distinctions between objects on the same layer. ACI is the standard colors used in AutoCAD. Each color is identified by an ACI number, an integer from 1 through 255. Standard color names are available only for colors 1 through 7: 1 Red, 2 Yellow, 3 Green, 4 Cyan, 5 Blue, 6 Magenta and 7 White or Black.

There are two coordinate systems used in AutoCAD for the entity reference; the first is a fixed system namely world coordinate system (WCS) and the second is a movable system namely user coordinate system (UCS). The WCS functions as the main co-ordinate system and UCS is useful for entering coordinates, defining drawing planes, and setting views of the entity. Since the UCS is the secondary co-ordinate system used for referencing the entity; changing the UCS only changes the orientation and tilt of the coordinate system and does not change viewpoint.

AutoCAD is used as the graphical programming tool by a construction planner while generating 3D solid model of the project. It is represented by various graphical construction components or other entities related to construction activities. The 3D solid model can be divided into three main categories: structural elements, operational objects and temporary facilities. Structural elements are footing, beam, column, slab, stair, ramp and wall. Operational objects are scaffolding, tower crane, and equipment. Temporary facilities are site office, space for material storage and resource paths.

1.1.3 Construction Schedule with Microsoft Project

Microsoft Project is an effective tool for project scheduling. It uses CPM network analysis technique and is best suited for scheduling of project activities with deterministic time duration. CPM based project scheduling is capable of effectively scheduling activities having wide range of (simple to complicated) relationships and displaying project information in the form of a bar chart which shows the temporal relationships among various construction activities from start to completion of the construction project. The schedule developed in Microsoft Project can be revised immediately as required using minimum effort and time. This updating facility helps to visualize the overall project at any time during its implementation.

1.1.4 Visual Basic for Applications Module

The 4D construction model provides a helpful construction planning tool that helps construction planner in making decisions. The 4D construction output is produced as a series of graphics based on the 3D solid model associated with construction schedule through developed VBA, illustration of attributes of building components and the locations of temporary site facilities. A variety of conditions with alternative construction sequences can be simulated.

Graphic User Interface was developed using VBA macro in AutoCAD environment. Graphic User Interface was divided into two parts; facilitating during data manipulation and generating 3D model; facilitating during data connectivity and construction simulation.

1.2 Algorithm Development

The algorithms were developed for the conversion of simple geometric objects to real construction objects. The algorithm conversion is accomplished in three distinct steps: 1) Identifying the type of structure; 2) Identifying the gridline; and 3) Identifying the floor. Figure 23 illustrates the procedure for identifying type of structure by using range of ACI for structure. For example 11, 13, 15, 17, 19, 21, 23, 25, 27 and 29 represent footing. In the first step, system reads the object color index from Microsoft Access. After that system verifies the object color index for each 3D solid object. If the object color index is 256, it means that 3D solid object is assigned as bylayer. Hence, the object color of this object is a layer color. Furthermore, the object colors vary depending on the user assignment (object color index: an integer from 1 through 255). Lastly, system matches the object color with color range (specified color index represents the type of structure as shown in Table 1).This process is repeated until the last object is read.

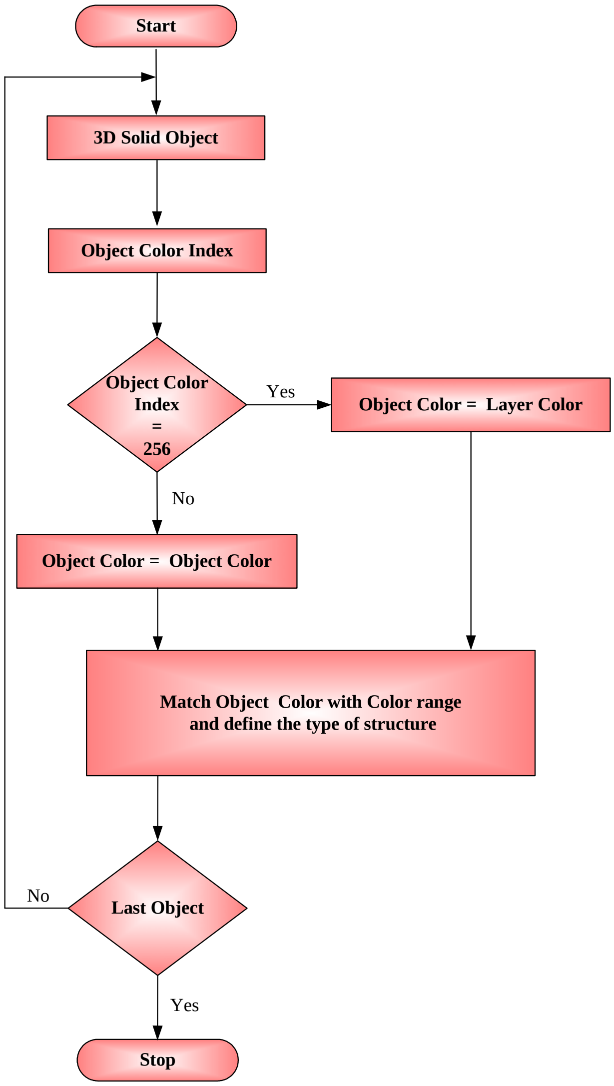


Figure 23 Identifying Type of Structure Algorithm

The following table is the color index of 3D solid object that defined the type of structure.

Table 1 Color Index of 3D Solid Object

Structure Type	**Color Index**
Pile	49, 59, 69, 79, 89
Footing	11, 13, 15, 17, 19, 21, 23, 25, 27, 29
Beam	201, 203, 205, 207, 209, 211, 213, 215, 217, 219, 221, 223, 225, 227, 229, 231, 233, 235, 237, 239
Column	161, 163, 165, 167, 169, 171, 173, 175, 177, 179, 181, 183, 185, 187, 189, 191, 193, 195, 197, 199
Slab	31, 33, 35, 37, 39, 151, 153, 155, 157, 159
Core Lift	43, 45, 53, 55
Wall	71, 81, 91
Stair	83, 111
Traffic Line	2, 94
Truss	245, 40
Steel Frame	51, 61
Panel	254
Net	249
Footpath	41
Door	252
Door Frame	247
Window	130
Window Frame	246
Site office	28
Material Storage	16
Stopper	106
Site office	3

Figure 24 illustrates the procedure for identifying gridline. In the first step, system reads the centroid in Microsoft Access database. After that system matches the centroid of object (X axis) for 3D solid object with reference gridline table. If the centroid of object (X axis) is matched, system matches the centroid of object (Y axis).In case it is matched, it means that these objects are located on the gridline. This assigns gridline of 3D solid object as reference gridline table. Furthermore, system goes to next record. In case of mismatches both X and Y axis, system identifies as N/A. This process is repeated until the last record is read.

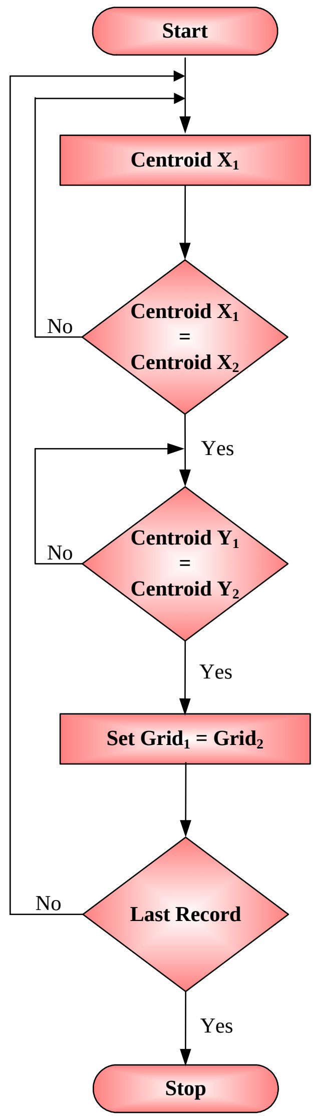


Figure 24 Identifying Gridline Algorithm

Figure 25 illustrates the procedure for identifying floor. In the first step, system reads the type of structure from Microsoft Access. After that system verifies the type of structure. If type of structure is column, then system goes to next algorithm (Figure 26). Another, system matches the maximum of Z axis (Upper boundary) for 3D solid object from reference elevation table in Microsoft Access and then system assigns the floor of 3D solid object as reference elevation table. This process is repeated until the last record is read.

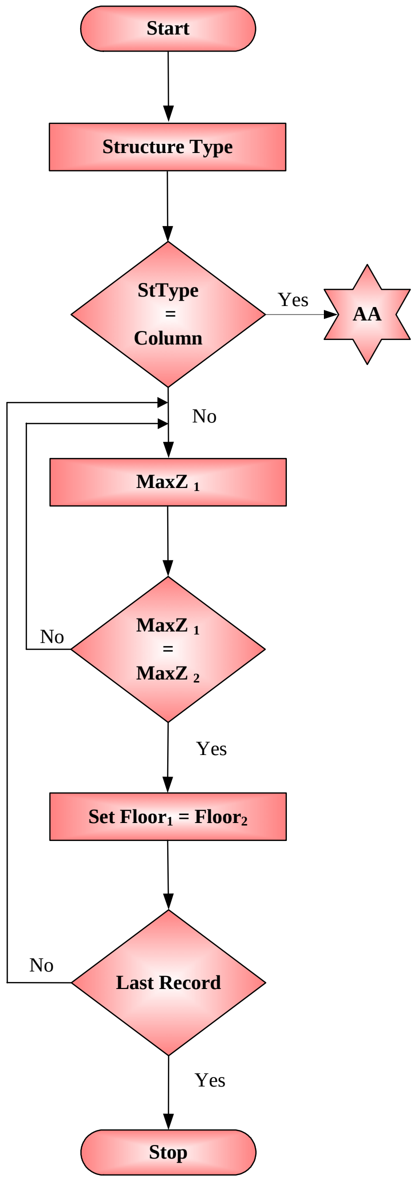


Figure 25 Identifying Floor Algorithm

Figure 26 illustrates the procedure for identifying floor of column. In the first step, system reads the minimum of Z axis (Lower boundary) from Microsoft Access for each 3D solid object. After that system matches the maximum of Z axis (Upper boundary) for 3D solid object from reference elevation table in Microsoft Access and then system assigns the floor of 3D solid object as reference elevation table (i.e., between n and n+1). This process is repeated until the last record is read.

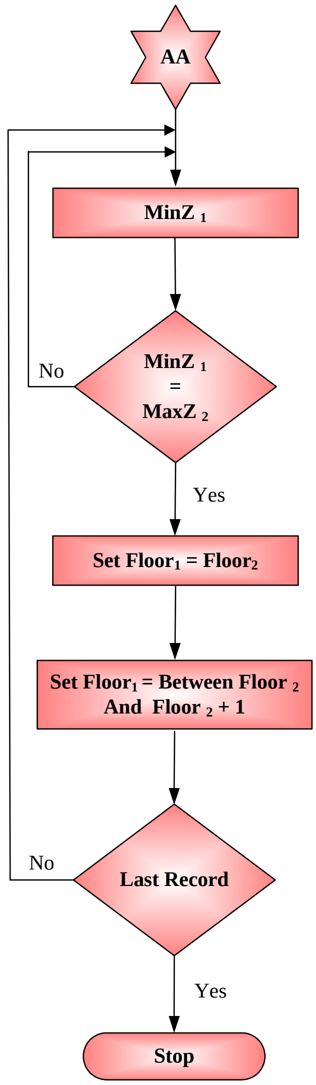


Figure 26 Identifying Floor Algorithm (Continued)

Figure 27 illustrates the procedure of the construction progress simulation. In the first step, the viewing date (A) is defined by user. After that system verifies for each activity with their start and finish dates. In case that the start date(B) is later than the viewing date it means that the activity has not yet started, hence it's corresponding layer should not be shown. In case that the start dates is earlier than the viewing date, there are two possibilities: the activity may be finished or it may be progressing. In the first case, the finish date (C) should be earlier than the viewing date. In this case the layer should be made visible. For the second case, the layer's color should be changed to red and then the layer should be made visible. This process is repeated until the last activity (layer's name) is read.

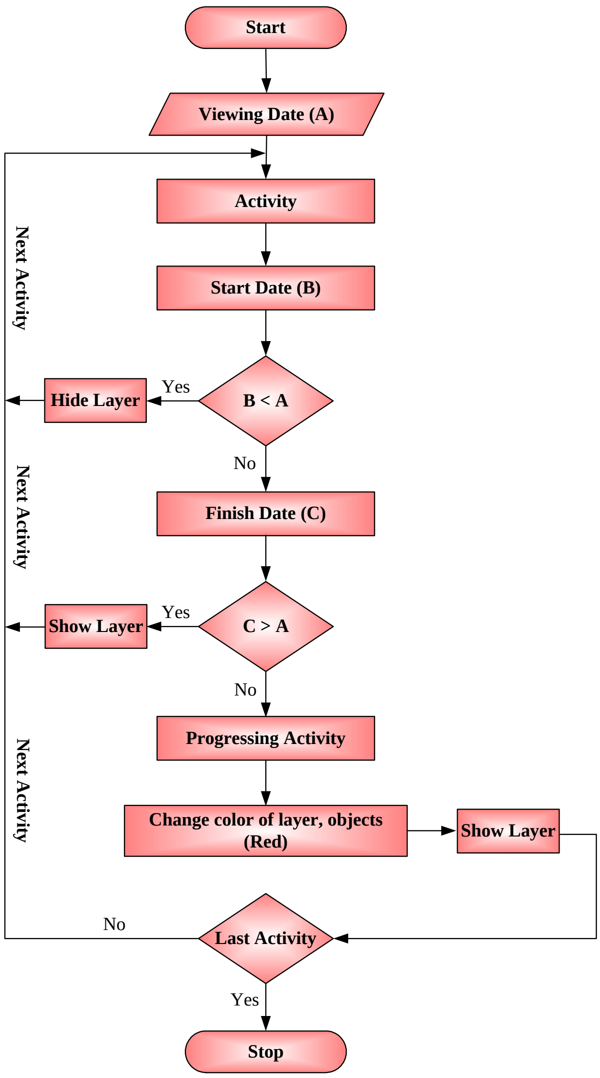


Figure 27 Simulation of Construction Progress Algorithm

1.3 System Implementation

Figure 28 illustrates the detailed design for system implementation of 4D project planning system. The process consists of eleven steps. The details of each step are described as follow.

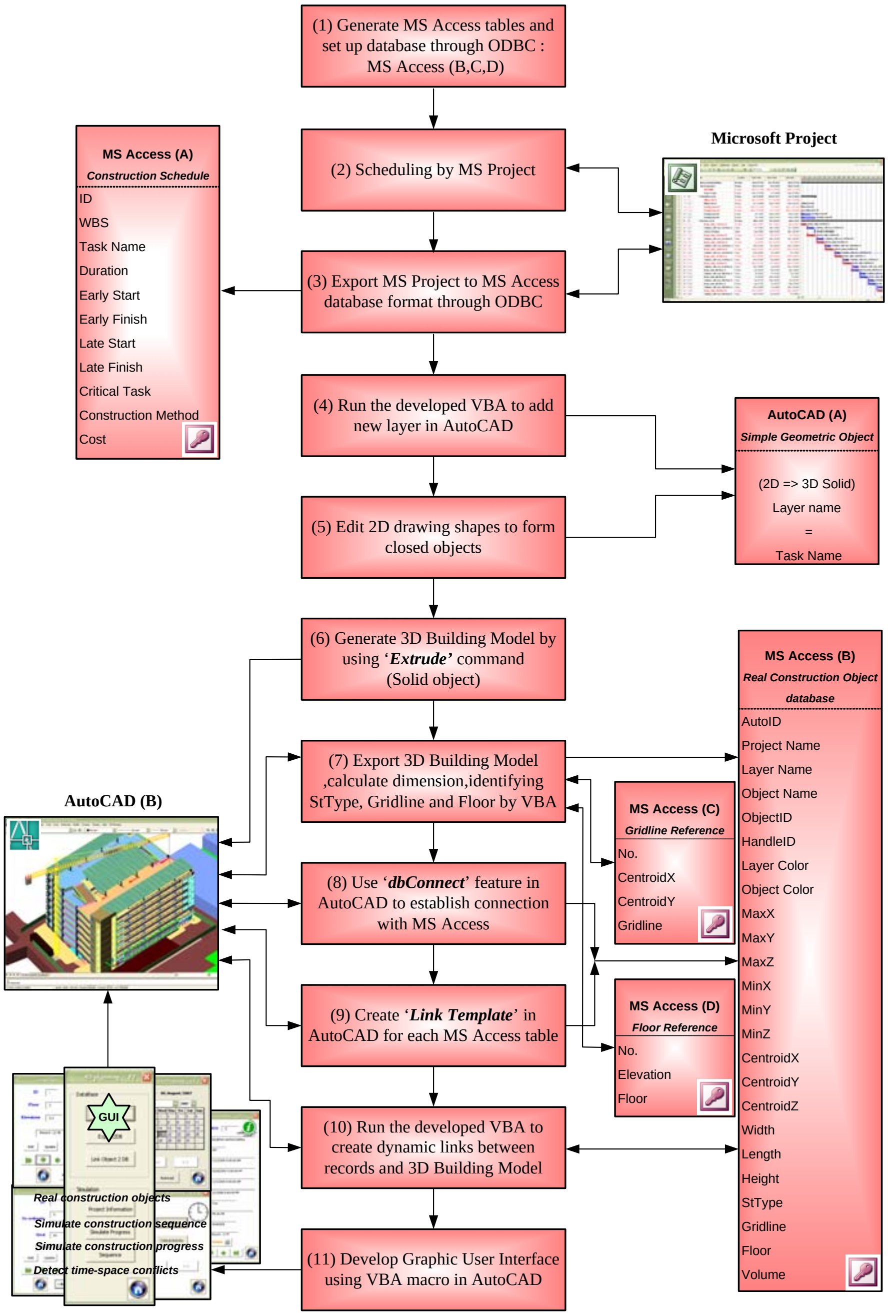


Figure 28 Detailed Design for System Implementation of 4D Project Planning System

1.3.1 Generate Microsoft Access tables and set up database through ODBC.

Microsoft Access table is used for storing: 1) the temporal and logical information exported from Microsoft Project; 2) the spatial information exported from AutoCAD 3D solid objects; and 3) reference gridline and elevation. These consisted of five tables: Consdb, Schedule, Sequence, ReferenceGridline, and ReferenceElevation as shown in Figure 29. Brief information about the tables are tabulated in Appendix B.

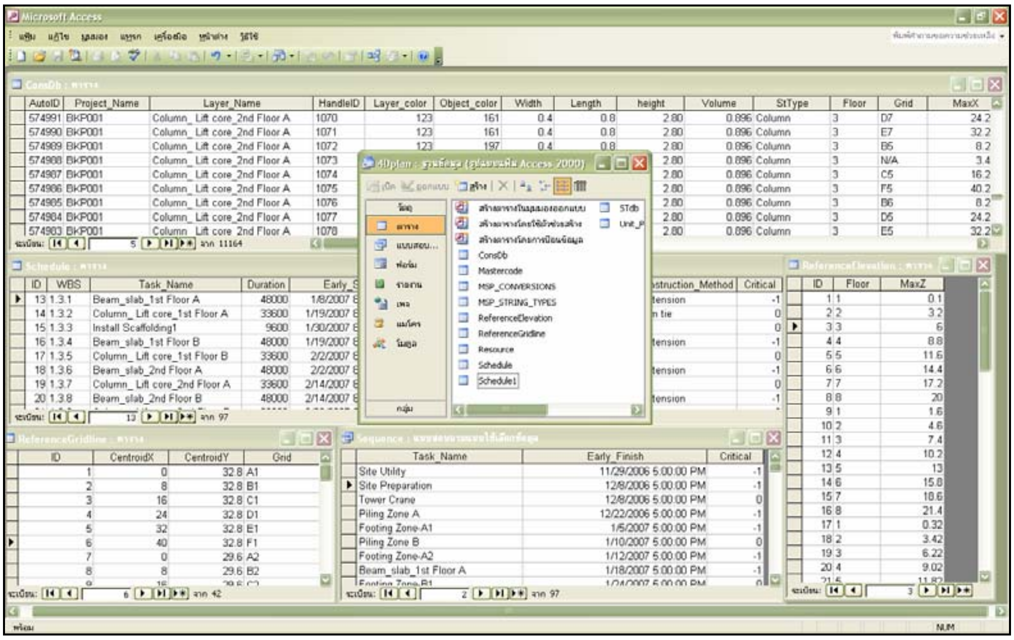


Figure 29 Table View in Microsoft Access Database

ODBC is a standard application programming interface (API) used to access data in relational databases. In order to use ODBC to access databases, user has to create a data source that associates a particular ODBC driver with a database and contains information.

The following steps describe how to create and configure data sources for use with the ODBC driver for a database.

1. On the Start menu (Windows), Control Panel, click Administrative Tools.

2. Run the ODBC Data Source Administrator as shown in Figure 30.

3. Select the ODBC data source type to be created or modified. An ODBC data source name (DSN) can be one of the following types:

3.1 File - A data source stored in a file that can be shared among all users who have the same ODBC drivers installed. These data sources need not be dedicated to a specific user or local to a computer.

3.2 User - A data source local to a computer and accessible only by the current user that created the data source.

3.3 System - A data source local to a computer but not dedicated to a specific user, so any user with appropriate privileges can access a system DSN. A System data source is visible to all users on a computer, including Windows NT services.

4. Select the Driver for a database from the list of drivers, set Advanced File DSN Creation Settings (driver-specific keywords) for a File data source type and click Add button as shown in Figure 31.

5. Specify the name and the location of ODBC Data Sources file and

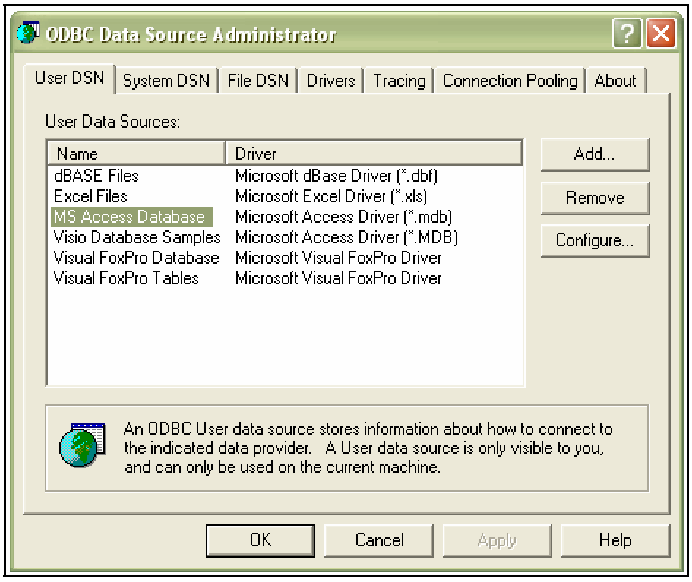


Figure 30 ODBC Data Source Administrator Form

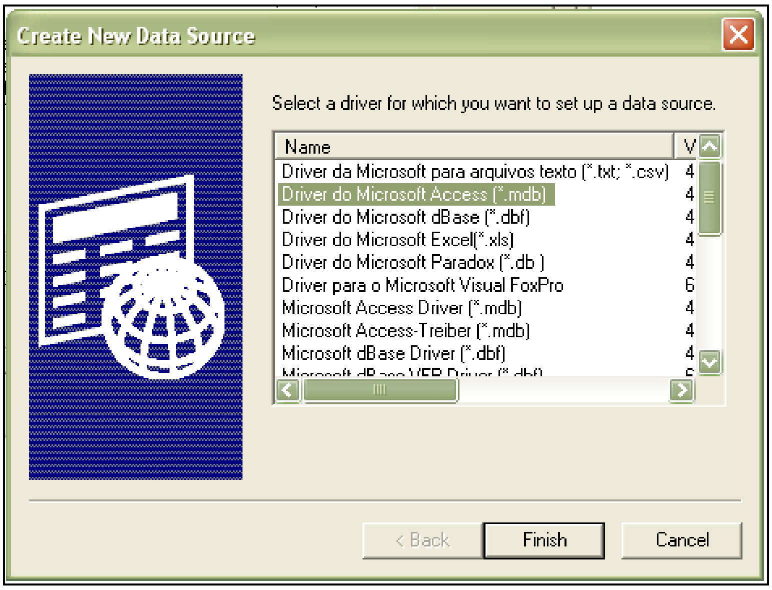


Figure 31 Create New Data Source Form

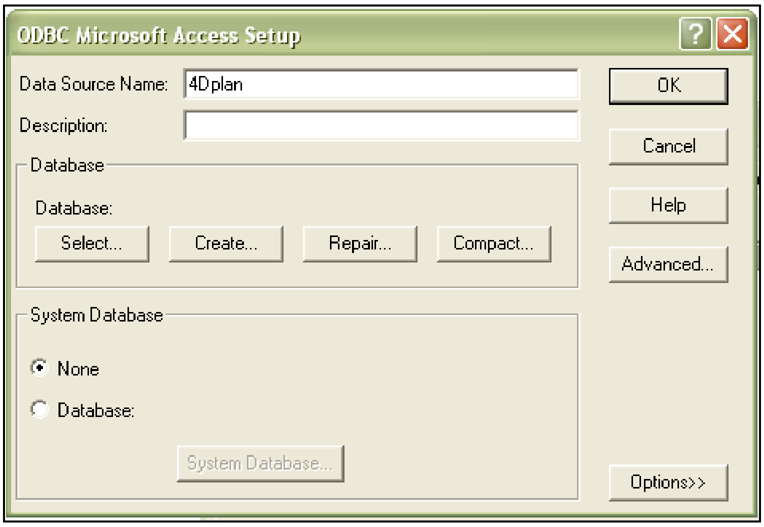


Figure 32 ODBC Microsoft Access Setup Form

1.3.2 Scheduling by using Microsoft Project

Fundamental data include work breakdown structure, task name, early start, duration, early finish, late start, late finish, predecessor, construction method, critical tasks and cost as shown in Figure 33. The temporal and logical information of construction project are used during the simulation purpose. There are construction sequence, construction progress and highlighting of critical task.

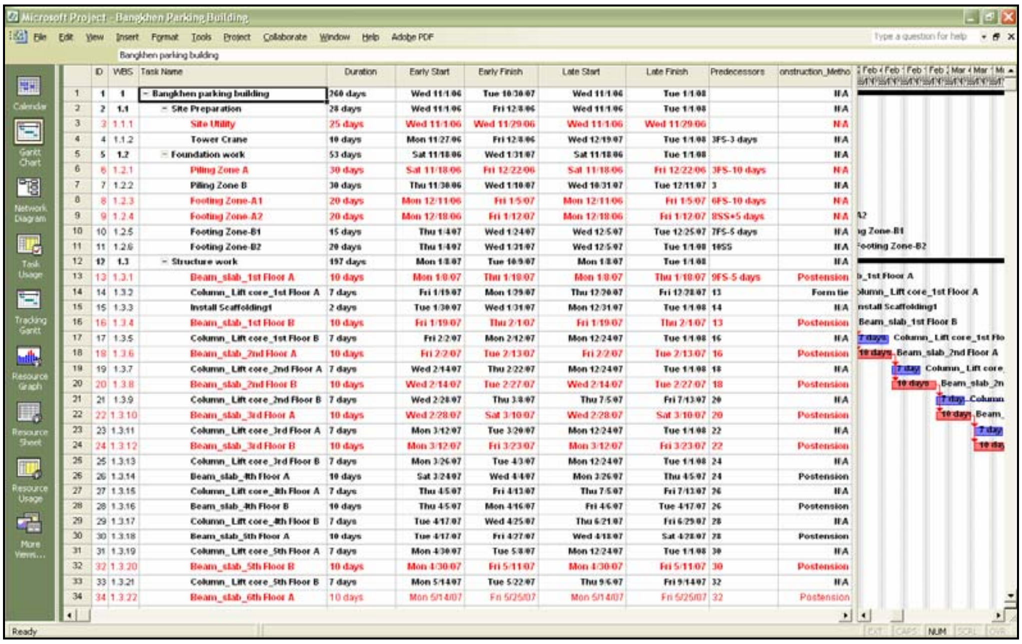


Figure 33 Sample screen of Microsoft Project

1.3.3 Export Microsoft Project to Microsoft Access database format through ODBC.

The following are steps which are used for exporting or updating the Bangkhen Parking Building to Microsoft Access database (4Dplan.mdb).

1. Open Bangkhen Parking Building.mpp file on Microsoft Project.
2. On the File menu, click Save As.
3. On the Save As Form as shown in Figure 34, click ODBC.
4. On Select Data Source menu shown in Figure 35, click Machine Data Source tab and select MS Access Database.
5. On Select Database Form shown in Figure 36, select 4Dplan database (4Dplan.mdb) file and click OK.
6. On Export Wizard-Map Selection form select 4Dplanning as shown in Figure 37, click Next.

7. On Export Wizard- Task Mapping add or edit Microsoft Project fields that are required to export the database and assign proper names in Database fields shown in Figure 38.Schedule (table name) appears in MS Access database (4Dplan.mdb)

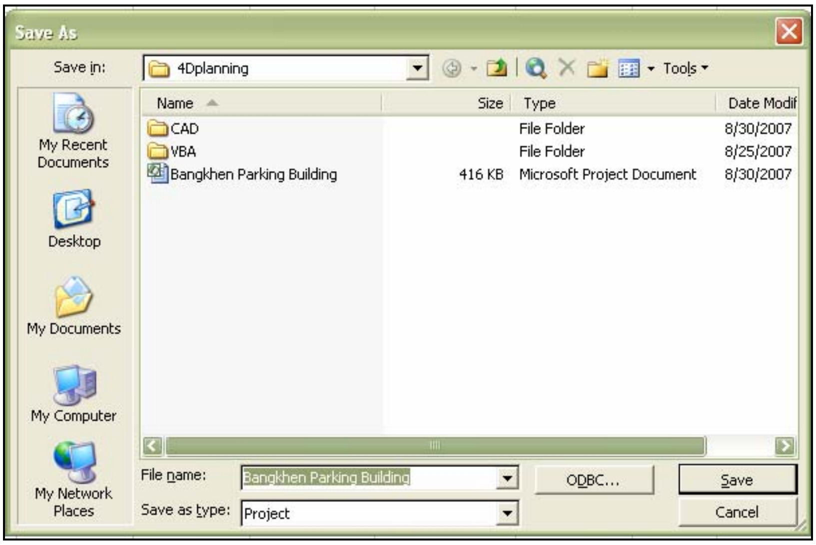


Figure 34 Save As Form in Microsoft Project

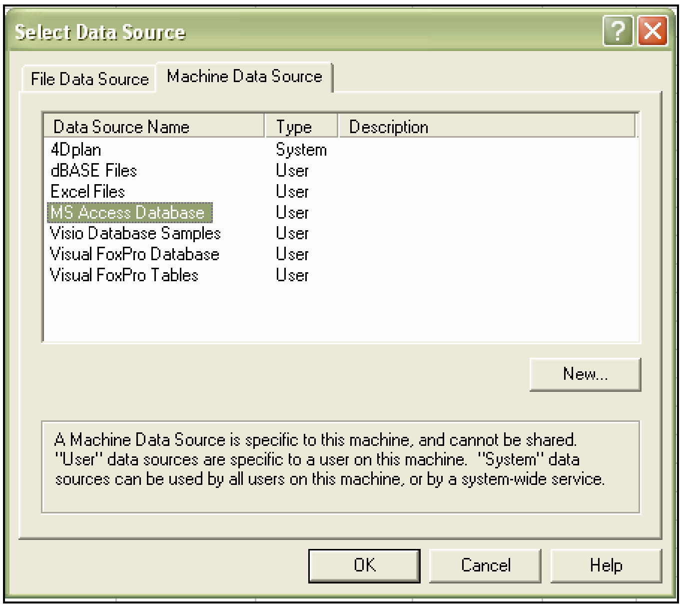


Figure 35 Select Data Source Form

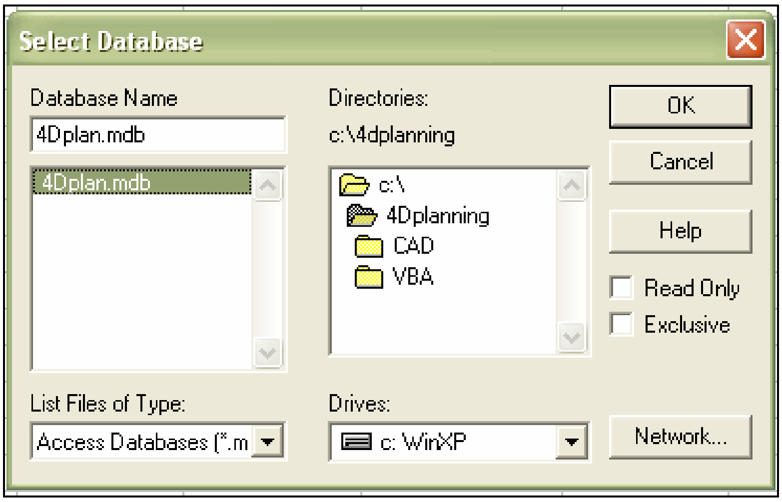


Figure 36 Select Database Form

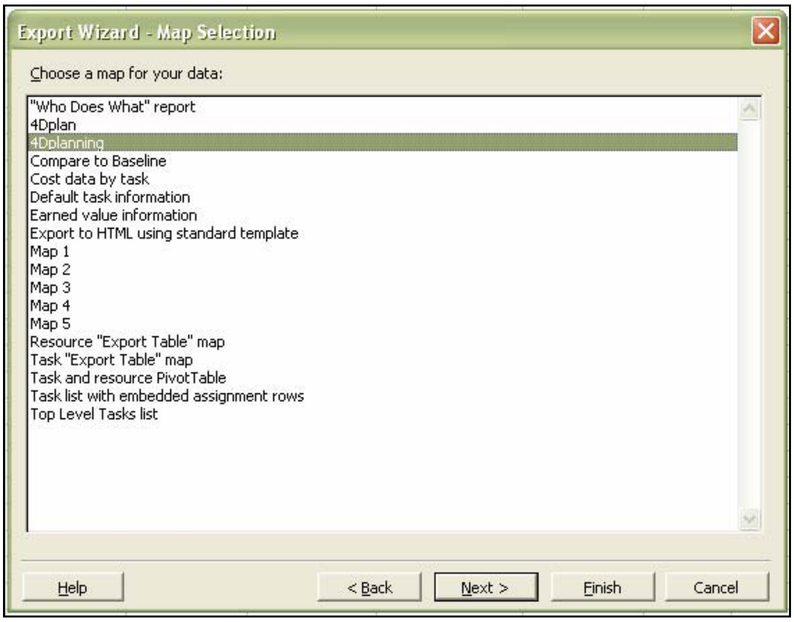


Figure 37 Export Wizard-Map Selection Form

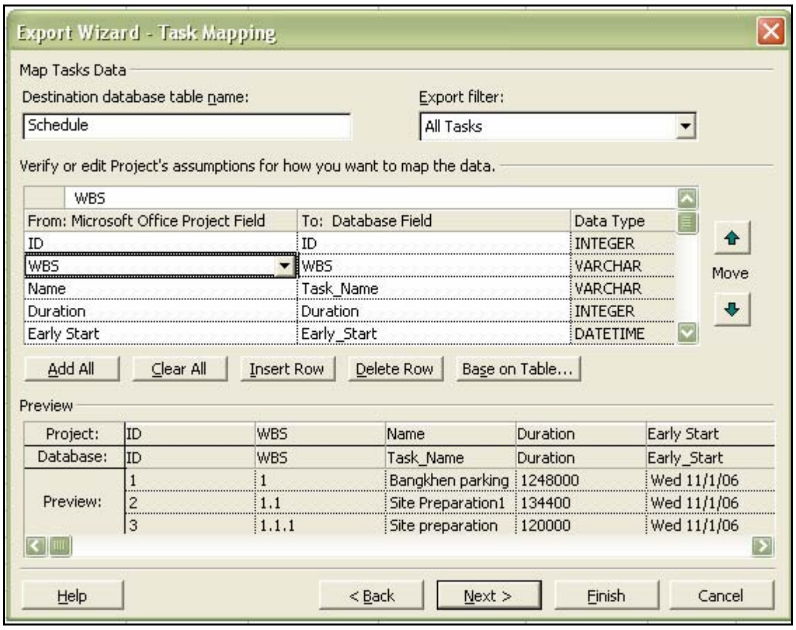


Figure 38 Export Wizard-Task Mapping Form

1.3.4 Run the developed VBA to add new layer in AutoCAD.

Layer name is used to control in the construction simulations. Therefore precise name is required. Developer created VBA for automatically adding new layer in AutoCAD. Layer name is assigned according to task name in MS Access (A).

1.3.5 Edit 2D drawing shapes to form the closed objects.

Before generating 3D solid model, the original 2D CAD drawings are created using various types of lines (i.e., broken lines and blocks), the shapes of the drawings have to be edited to form closed objects using polyline or polygon. It should be noted that this step is time consuming. In order to avoid this problem in future development of the database, an agreement with Design Company in producing all drawings in the closed objects should be done.

1.3.6 Generating 3D Building Model by using Extrude command in AutoCAD.

Three types of 3D modeling are supported: Wireframe, Surface and Solid. Each type has its own creation and editing techniques. In this system only solid object is exported to MS Access database. The Extrude command is used to convert 2D object to 3D solid object.

With Extrude command, user can create solids by extruding selected objects. User can extrude closed objects such as polylines, polygons, rectangles, circles, ellipses, closed splines, donuts, and regions. User cannot extrude 3D objects, objects contained within a block, polylines that have crossing or intersecting segments or polylines that are not closed. User can extrude an object along a path, or user can specify a height value and a tapered angle. Use Extrude to create a solid from a common profile of an object, such as a gear or sprocket. Extrude is particularly useful for objects that contain fillets, chamfers, and other details that might otherwise be difficult to reproduce except in a profile. If user creates a profile using lines or arcs, use the Join option of Pedit to convert them to a single polyline object or make them into a region before user uses Extrude command.

Figure 39 illustrates the 3D solid modeling by using Extrude command. User can execute Extrude command through Menu bar, click Draw, then click Solid, and click Extrude, Tool Bar (solids group) or Command line by key "Extrude". As seen in Figure 39, 2D rectangular is converted to 3D solid object (i.e., column). Any commands have text for communication with user. For example, in case of Extrude command user can see Select objects and Specify height of extrusion or [Path] respectively. To avoid the confusion of assigning the object color, while generating 3D construction model, user should be assigned the color index to object either bylayer or by specifying its color by using reference color index as detailed in Table 1.

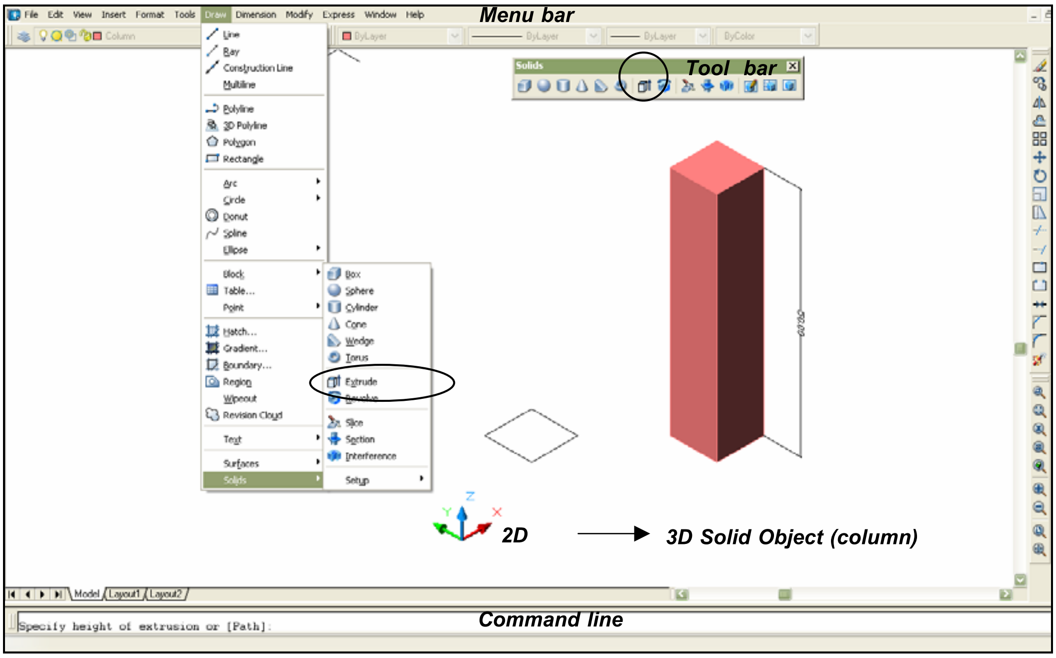


Figure 39 Generating 3D Solid Model by Using Extrude Command

The accuracy of 3D solid modeling is very important because the geometrical properties are used for the conversion of simple geometric objects to real construction objects such as layer name, object color, coordinate and elevation. User can check these by using Menu Bar, select Tool, then click Inquiry, and click Mass properties or on Command line by entering List command as shown in Figure 40 and 41.

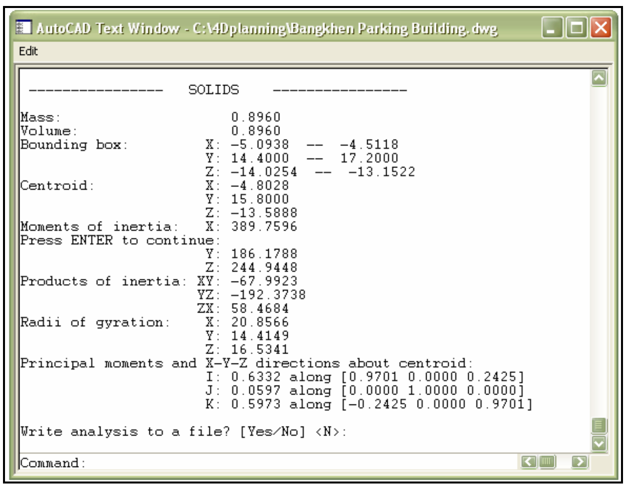


Figure 40 AutoCAD Text Window by Mass Properties Command

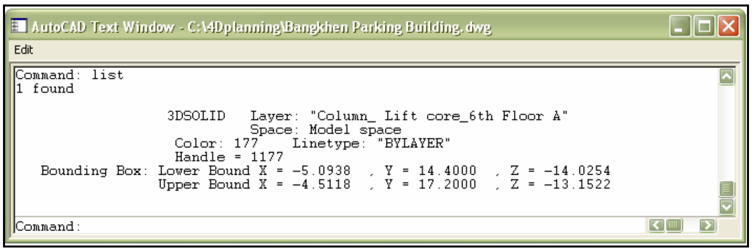


Figure 41 AutoCAD Text Window by List Command

1.3.7 Export 3D Building Model, calculate dimension, identify structure type, gridline and floor.

For this, firstly system exports the geometric data of 3D Building Model to MS Access (B). Secondly system automatically calculates object dimension using VBA developed by the author for this study. Width, length and thickness of objects are calculated by using difference of x, y, z coordinate values in WCS. Finally, system identifies structure type, gridline and floor number by using Color index, MS Access (C) and MS Access (D), respectively as reference for further process.

1.3.8 Use of 'dbConnect' feature in AutoCAD to establish connection with MS Access.

The steps for establishing connection are as follows.

1. From Tools menu select dbConnect and open the dbConnect Manager window as shown in Figure 42.
2. Right-click the Data Source and choose Configure Data Source.
3. Type "4Dplan" as the data source name and click OK. This opens the Data Link Properties dialog box. Then select Microsoft Jet 4.0 OLE DB Provider as shown in Figure 43 and 44.
4. Click Next, and enter the MS Access database file (*.mdb) in the path field. Click Test connection as shown in Figure 45.

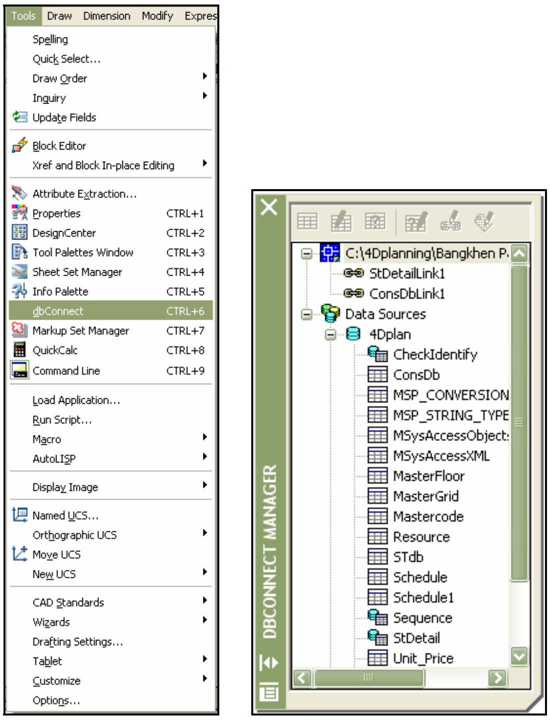


Figure 42 dbConnect Manager Form

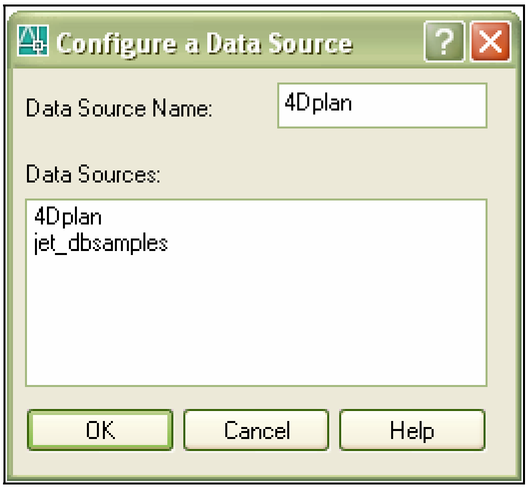


Figure 43 Configure a Data Source Form

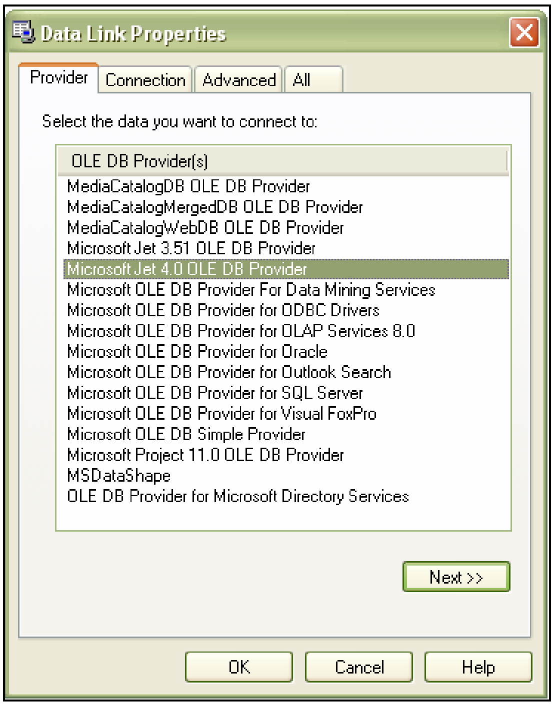


Figure 44 Data Link Properties Form

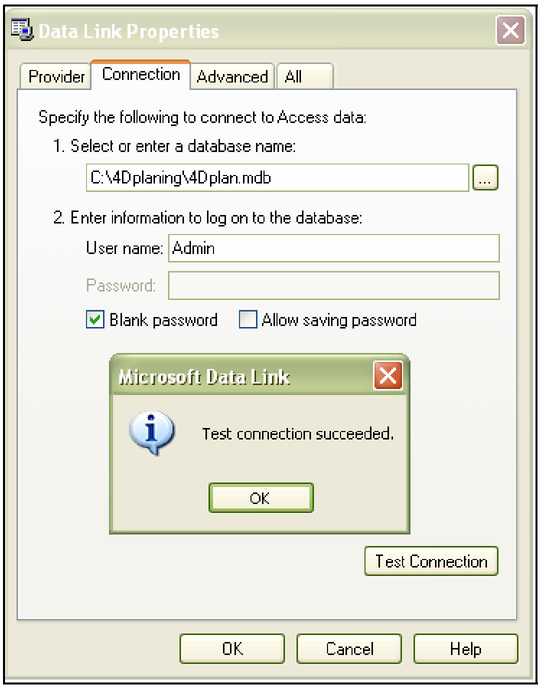


Figure 45 Data Link Properties and Test Connection Form

1.3.9 Create 'Link Template' in AutoCAD for each MS Access table

1. Right-Click the Consdb (table name) and select New Link Template and leave default link template name as shown in Figure 46.

2. Press continue to open the Link Template box and select the 'HandleID' as the unique key reference and click OK as shown in Figure 47.

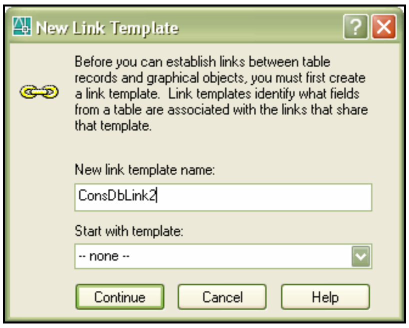


Figure 46 New Link Template Window

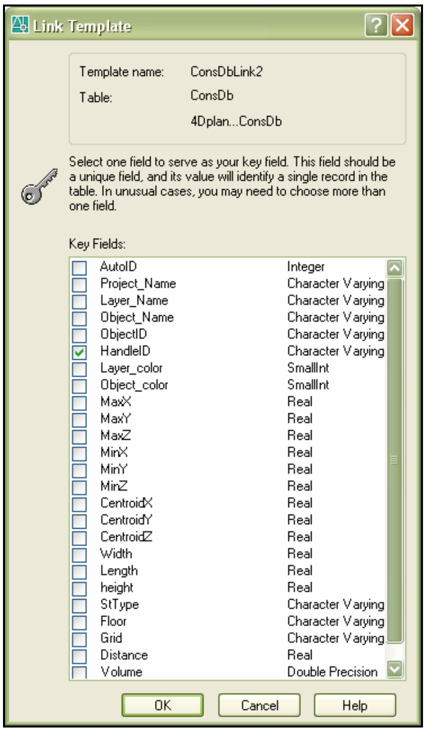


Figure 47 Link Template Window

1.3.10 Run the developed VBA to create dynamic links between records and 3D solid objects.

Continue from previous step (9), system automatically links the records in MS Access (B) with 3D solid objects by using primary key (HandleID) based on one to one relationship.

1.3.11 Develop Graphic User Interface using VBA macro in AutoCAD.

User can load VBA automatically each time when you run AutoCAD. Additionally, the Load Application command provides the Startup Suite option that automatically loads the specified applications through selection of file name Acvba.arx, clicking contents and adding VBA file as shown in Figure 48.

Figure 48 Load and Upload Applications Form

Graphic User Interfaces is divided into two sections; First, Graphic User Interface Group 1, the main concept of this is to facilitate during data manipulation and generating 3D model, as shown in Figure 49.

1. Button 1 Add Layer: Automatically add new layer as Task_Name in Schedule table exported from Microsoft Project.
2. Button 2 Open All Layers: Open all Layers in current drawing.
3. Button 3 Close All Layers: Close all Layers in current drawing
4. Button 4 Microsoft Project: Open Microsoft Project for updating and export.
5. Button 5 Microsoft Access: Open Microsoft Access
6. Button 6 Input Data: Data Input Form
   - 6.1 Level Data: View, Add, Update and Delete
   - 6.2 Gridline Data: View, Add, Update and Delete

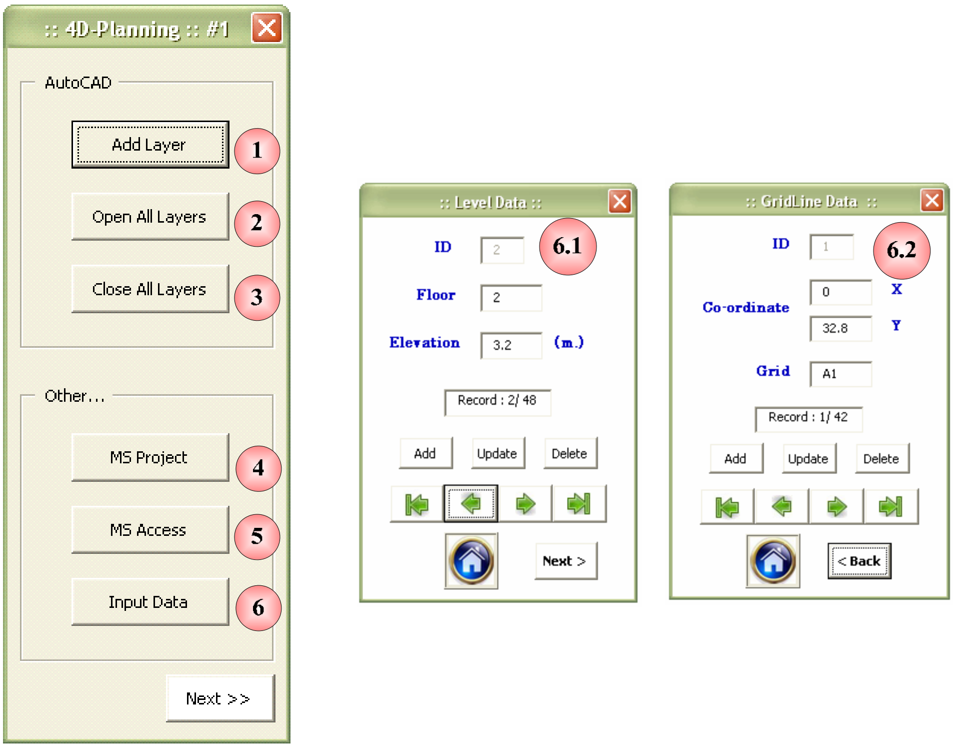


Figure 49 Graphic User Interface Group 1

Second, Graphic User Interface Group 2; the main concept of this is to facilitate during data connectivity and simulation, as shown in Figure 50.

1. Button 1 Microsoft Project: Open MS Project for exporting and updating.
2. Button 2 Export2DB: Export the geometrical data of 3D solid object to MS Access database (Consdb).
3. Button 3 Link object 2DB: Link 3D solid object with MS Access database (Consdb).
4. Button 4 Project Information: Open Project Information Form; this provides fundamental data from MS Project with 3D solid object.
5. Button 5 Simulation Progress: Open Construction Progress Form; this provides calendar for easy simulation.
6. Button 6 Sequence: Open Construction Sequence Form; this provides two alternatives, simulation the construction sequence with and without highlighting critical activity.

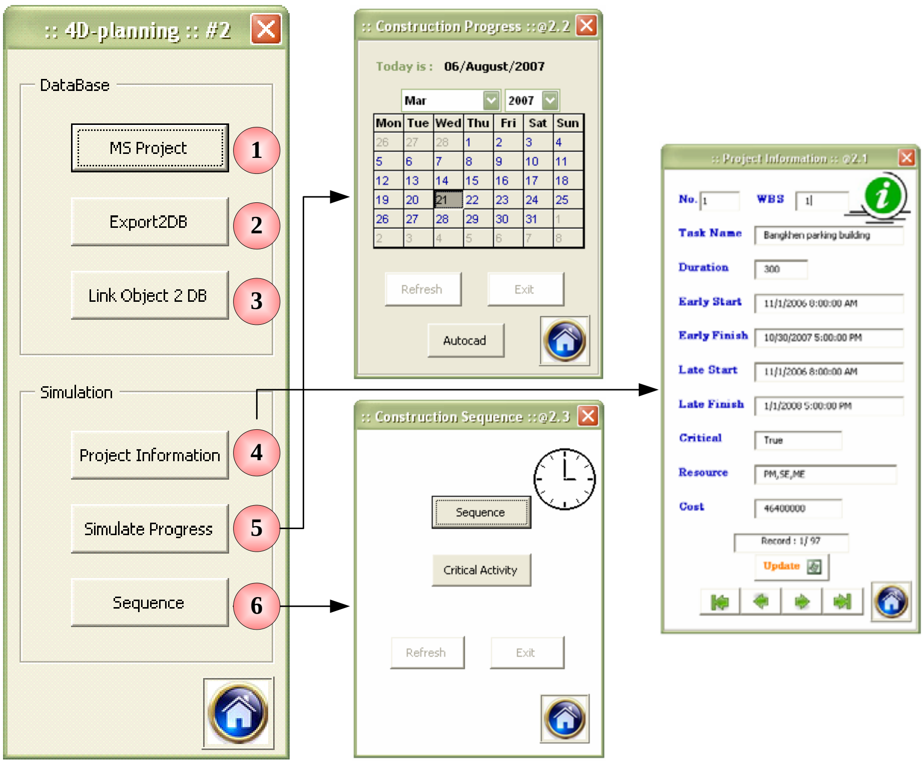


Figure 50 Graphic User Interface Group 2

2. Application of 4D Project Planning System with the case study

By using the 4D project planning system in the case study project, the benefits are summarized as follows:

2.1 Product of the conversion of simple geometric objects to real construction objects.

After finishing the conversion of simple geometric objects to real construction objects, planner can get the information about task name, type of the structure, gridline, floor number, its dimensions and volume. For example, in Figure 51 for object no. 1, Footing Zone-A2 is located on gridline no. C5, under ground elevation (UG), dimensions 3.2 X 3.2 X 1.2 meters and object volume 12.29 cubic meters, respectively. This information can be employed to calculate the formwork area, estimate the component cost and activity duration. Furthermore this allows easier understanding of the useful information about structure components required for construction execution (i.e., volume of concrete to be used for footing, beam, slab and column).

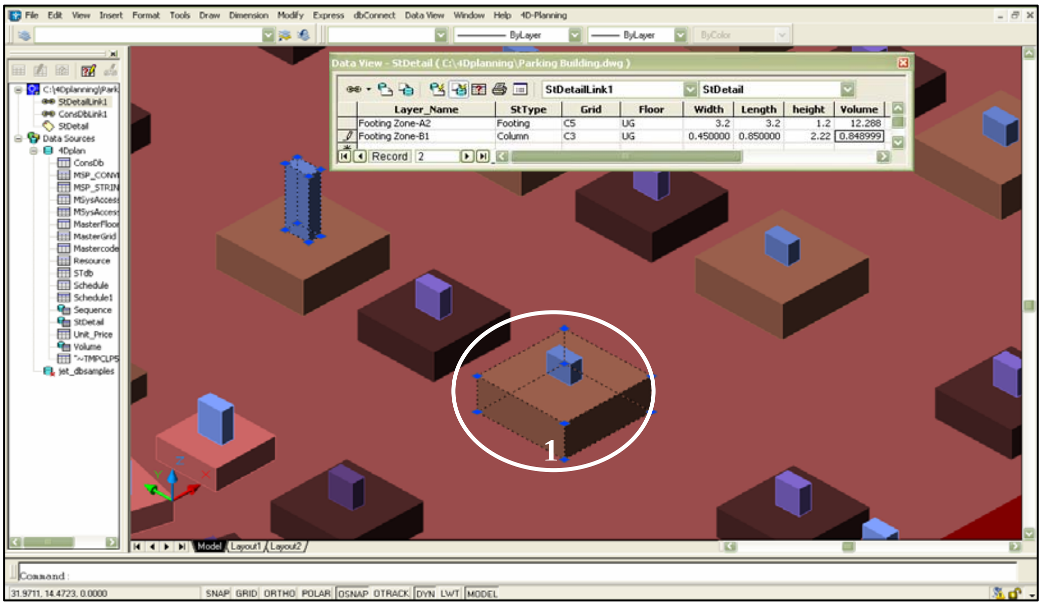


Figure 51 Data View Window in AutoCAD

In addition, AutoCAD provides a useful tool for searching the objects based on criteria that user specifies. There are Autoview linked objects in drawing, Autoview linked records in data view and query. These offers automatically view database table that are linked to objects or view graphical objects that are linked to database table.

2.2 Simulation of Construction Sequence

By viewing the 4D model, planner can see the sequence of activities clearly, based on original schedule by using early finish date as key. Planner also can virtually detect the construction problems prior to the start of the construction such as, time-space conflicts which cause delay. However, the problems detected vary according to the level of experience of the individual user. Modification of schedule is allowed for the better alternative. Moreover, critical activities are highlighted in red and displayed various views as well, as shown in Figure 52.

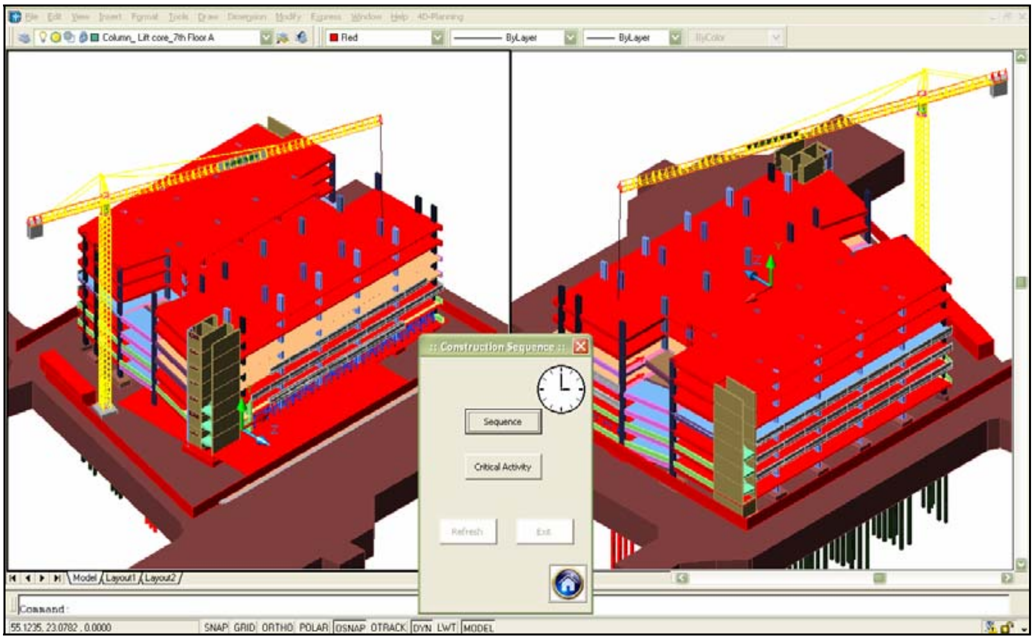


Figure 52 Sample screen of Simulation of Construction Sequence

2.3 Simulation of Construction Progress as Original Schedule

Planner can simulate the construction progress by directly clicking on calendar at any date throughout the project duration. The progressing activities are shown in red as shown in Figure 53. Planner can see its parallel occurrence (spatial relationships) as shown in Figure 54. This can extend to workspace planning, and help planner in decision-making, so as to guide subcontractor when to start their work without any interruption. Moreover, this also helps in the comparison of planned and actual progress at construction phase.

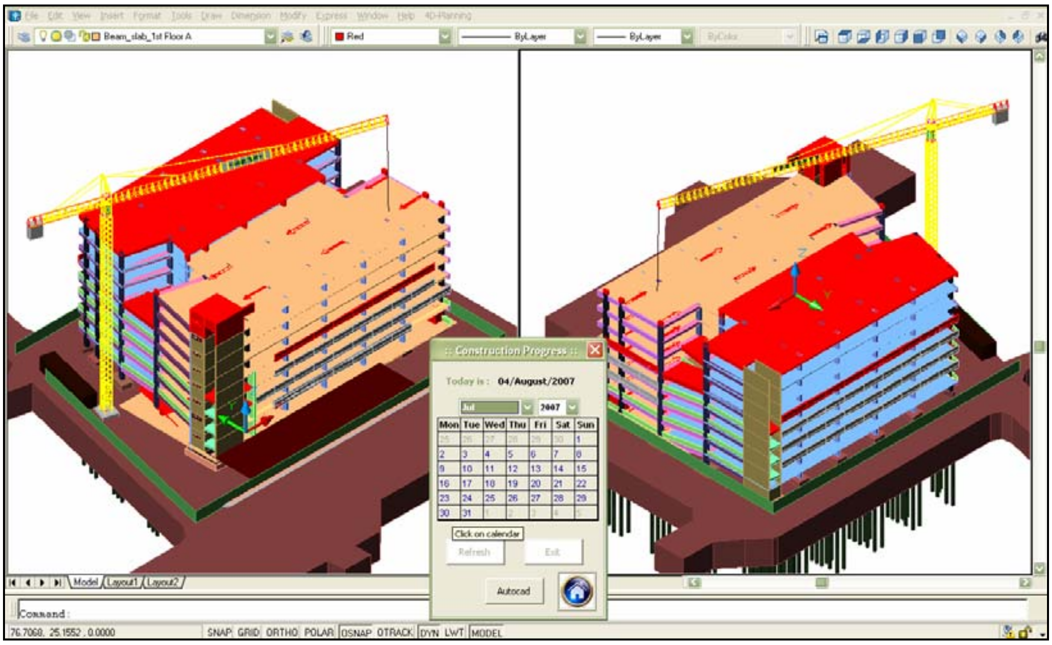


Figure 53 Sample screen of Simulation of Construction Progress

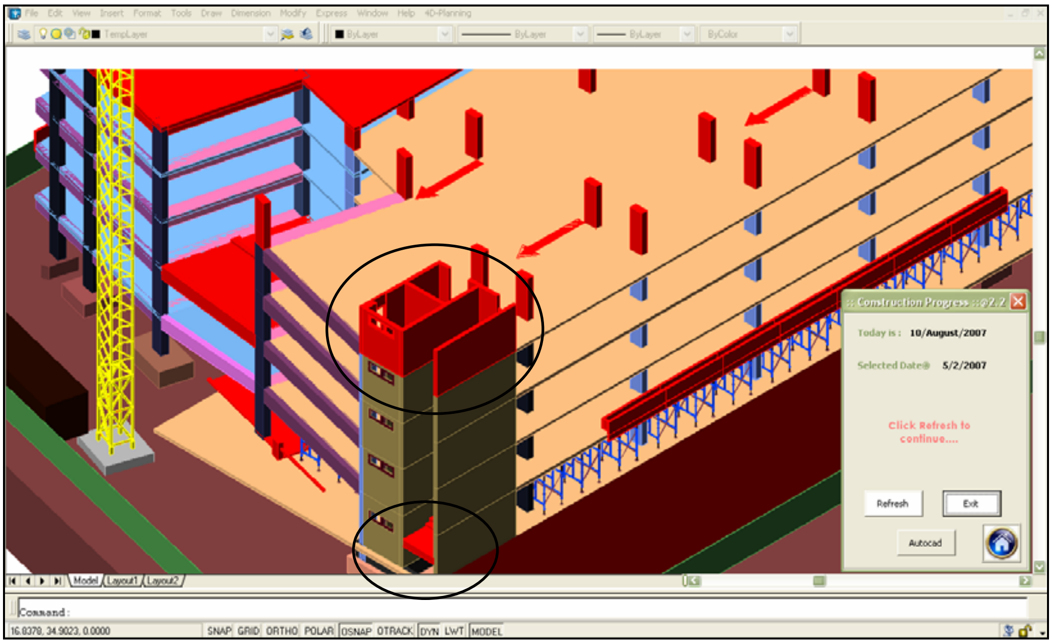


Figure 54 Sample screen of Time-Space Conflicts between Core Lift and Stair

2.4 Displaying construction schedule and 4D model concurrently

Displaying construction schedule as in the case of traditional planning tools CPM and bar chart does not give information about spatial aspects of the project. On the other hand, displaying 4D model of the object as in the 4D model does not give information about temporal and logical aspects. Actually construction schedule and 4D model are the supplement to each other for the complete visualization of the project in the single screen as shown in Figure 55 and Figure 56. Thus construction schedule and 4D model can be displayed concurrently for the quick and complete visualization of the project and its components. This is useful for precise project planning, scheduling, effective execution and monitoring.

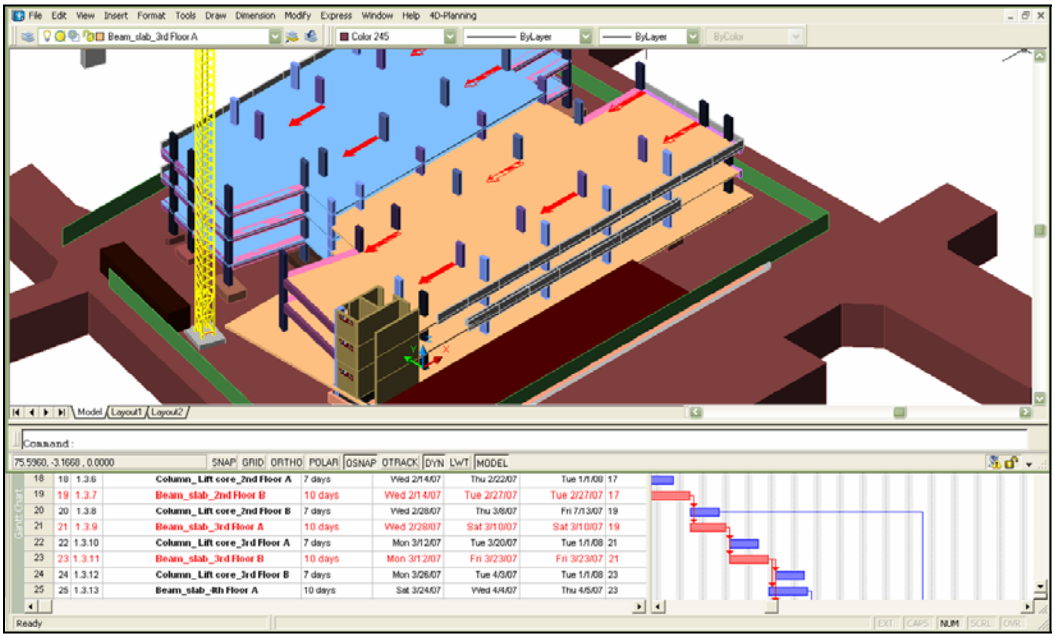


Figure 55 Sample screen Displaying Schedule and 4D Model Concurrently

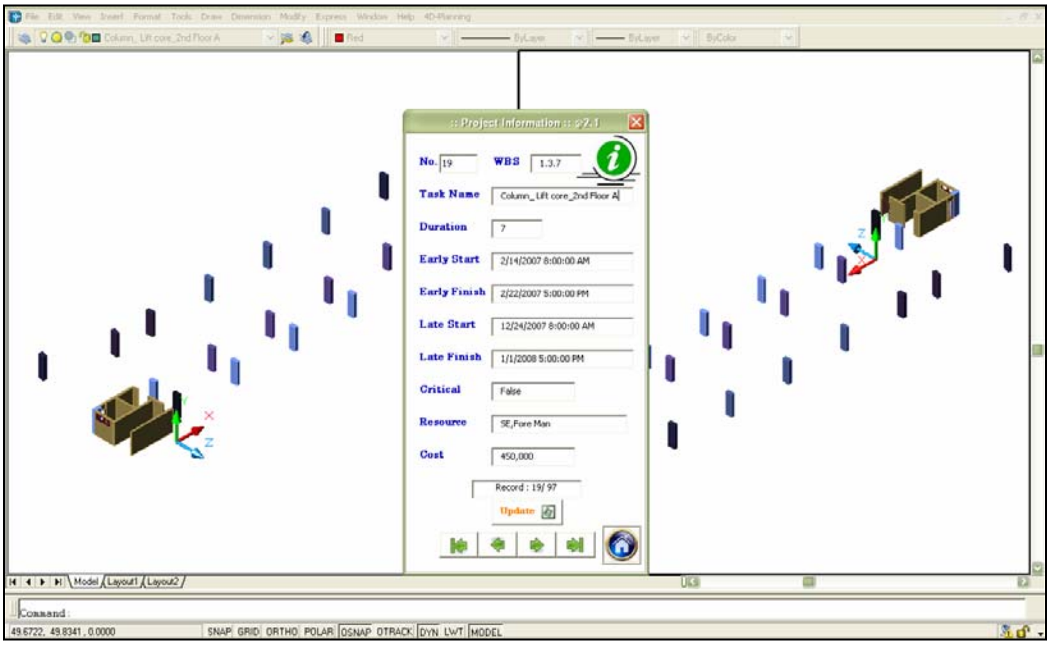


Figure 56 Sample screen of Linking between Construction Schedule and 3D Model

2.5 Allocation resource space on construction site

Planner can place temporary components and symbol in the 4D model. For example, scaffolding is not part of the actual building and does not always have to be model accurately, but needs to be employed to detect possible time-space conflicts. Hence, a simplified frame could be added in the 4D model directly to represent the installed scaffolding in schedule as shown in Figure 57. Direction of work flow is symbolized by arrow and service area of tower crane by circle as shown in Figure 58.

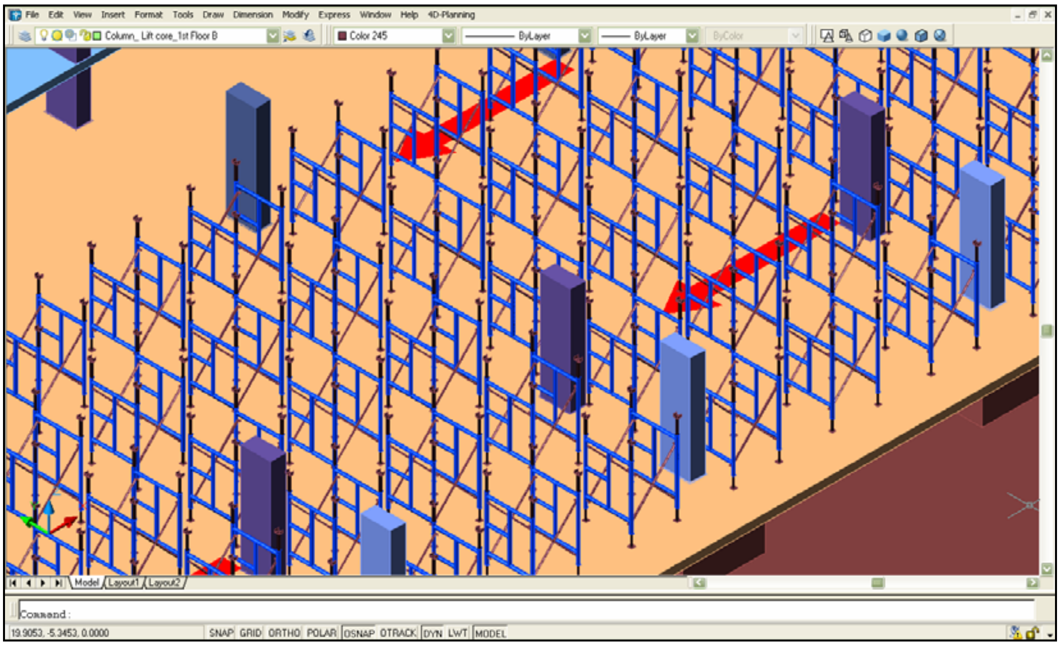


Figure 57 Sample screen of Temporary Components in the 4D Model

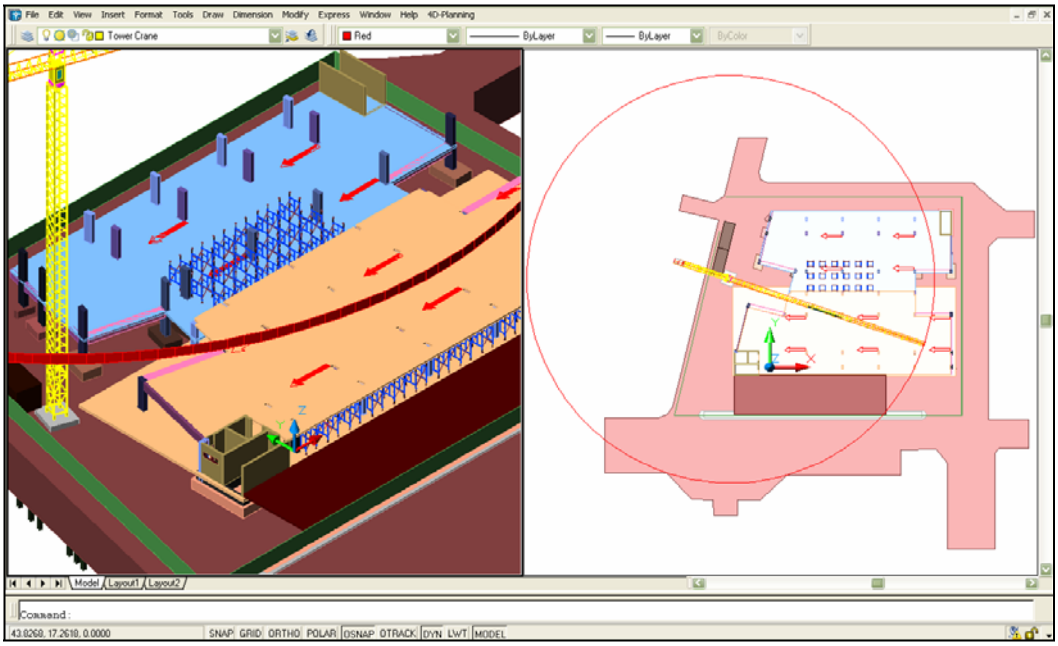


Figure 58 Sample screen Showing the Service Area of Tower Crane

2.6 Anticipating safety hazard situations

Since all construction projects are dynamic and many accidents occur due to unforeseeable human errors, it can be difficult for project planner to anticipate all the hazard areas existing on the construction site. By viewing the 4D model, planner can detect the hazardous area. For example, during the panel installation a fire spark due to welding may fall down on the working space as shown in Figure 59. In this case, planner can split the concurrent activities into subsequent activities or can add activities that represent the installation of safety equipment or prevention measures.

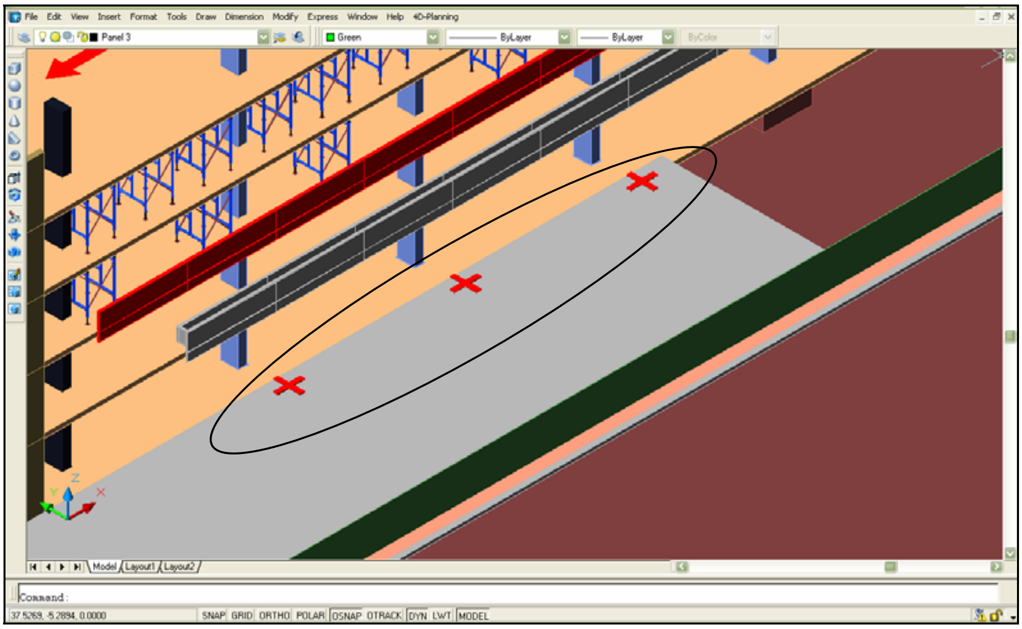


Figure 59 Sample screen Showing Hazardous Area due to Installing Panel

2.7 Project tracking by using S-Curve

Figure 60 illustrates the S-Curve which plotted the cumulative costs against time in Microsoft Excel. The cumulative costs are provided by multiplying the volume of objects with unit price. Early start and late start curves are the boundary. The status of project is tracked visually over time; it can be defined as behind schedule, on schedule and ahead of schedule.

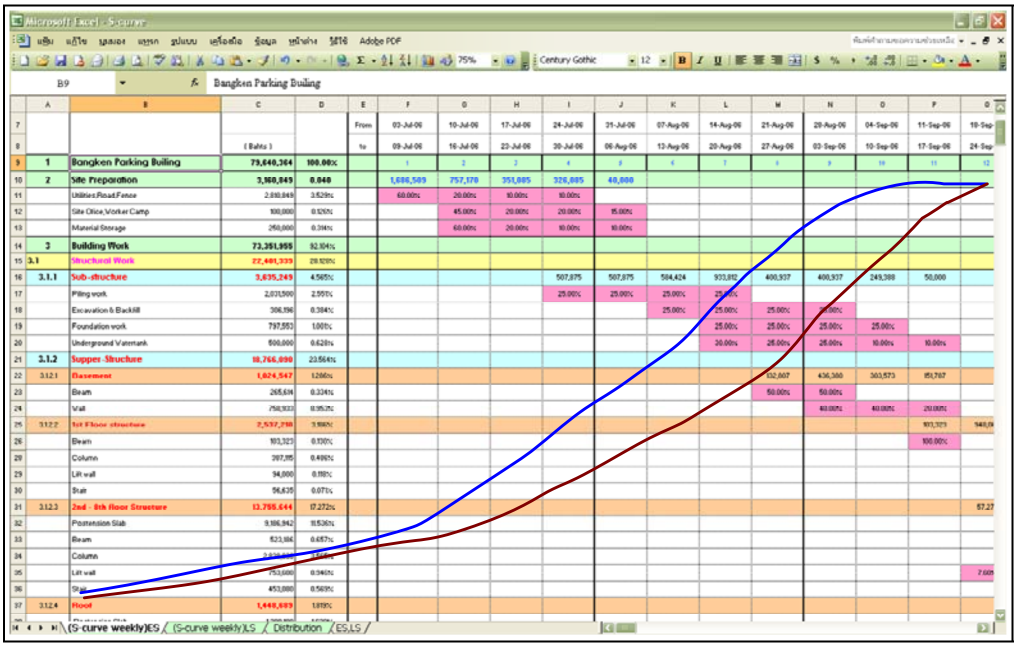


Figure 60 Sample screen Showing S-Curve in MS Excel

Based on the experience gained from the case study, Table 2 discusses the advantages of using a 4D project planning system. The discussion is presented with respect to the 4D model's facility to convey planning information as visualization, analysis and integration tool.

Table 2 Comparison between CPM Schedules and 2D Drawings with 4D Model

Items		CPM & 2D Drawings	4D Model	Remark
Visualization Tool	* Visualization and interpreting construction sequence	Force planners to visualize in their minds	Clearly interpretation, Allows the modification of better alternative.	Figure 52,53
	* Anticipating time-space conflicts	Difficult to detect	Identifies possible conflicts	Figure 52,53,54
	* Conveying the impact of changes in schedule	Difficult to detect	Clearly shows impact	Figure 53
	* Identifying building components	Does not provide support	Allows easier to identify	Figure 51
Analysis Tool	* Allocation resource space	Does not provide support	Allows easier to detect	Figure 57
	*Anticipating safety hazard situations	Does not provide support	Allows easier to allocate	Figure 59
	* Supporting the project tracking	Does not provide support	Provides easier to track	Figure 60
Integration Tool	* Communications among project participants	Limitation of individual experience	Communication via. medium, reduce gap of experience	
	* Providing feedback on design	Provides limited feedback	Encourages feedback	

CONCLUSION AND RECOMMENDATIONS

Conclusion

The 4D project planning system can be achieved by integrating the AutoCAD 3D solid model with project schedule. AutoCAD 3D solid model is a preferred approach because it is the most informational complete and least ambiguous of the 3D modeling type as well as user can analyze its mass property such as volume, bounding box and centroid. However AutoCAD maintains entity as simple geometric objects including line, polyline, polygon, solid, surface and wireframe that are not meaningful to project participants. These simple geometric objects are needed to be transformed to real construction objects. This transformation process can be achieved by using layer name, color, coordinate and elevation of each object in AutoCAD for identifying its attributes. Microsoft Project is used as scheduling tool, AutoCAD is used as 3D modeling tool, and Microsoft Access is used as database. Connection between Microsoft Project, AutoCAD and Microsoft Access are established through ODBC driver. Visual Basic for Applications program was developed to facilitate data manipulation, data connectivity, generating 3D model and construction simulation.

The 4D project planning system has multidimensional uses for the project planning. For example it provides the support to: communicate between the project participants, review the construction sequence, determine the completeness of the construction schedule by elimination of the time-space conflicts, visualize the construction progress, and facilitate the site layout planning. In addition, S-curve provided is useful for tracking the status of project during construction phase. In other words, 4D project planning system can be utilized during the project planning phase as a brainstorming tool by the planner to predict and solve potential problems that may arise in the future during construction phase of the project.

Regarding the use of 4D project planning system, there exist problems and limitations including:

1) Due to AutoCAD 3D solid objects can be exported only the minimum and maximum x, y, z coordinates. In case of objects which lie in oblique direction or irregular shape, these lead to produce an inaccurate dimension.

2) It is time-consuming to generate 3D solid model from 2D drawings. It is difficult to represent different activities such as painting and finishing work in 3D modeling. For large number of objects, the 3D model may take long time to process. To avoid the complication and long process time due to large number of objects, construction activities must be broken down in to smaller number of objects as per their specific uses.

Recommendations

Following are the future studies that can be undertaken to improve the 4D project planning system developed by developer to make it efficient, practical and useful to solve various problems during planning and construction phases of the project .

1. Developing a knowledge-based system that can automatically acquire relationships between standard building components, and determining the interference of workspace.

2. Dimensions and volume of objects can be utilized for the cost estimation by introducing the fifth dimension. This will lead to the planning of the entire project including its cost.

3. Repetitive schedule method (RSM) is alternative scheduling tool that can be integrated with 4D model tool. This will provide benefit for highway and housing project.

4. Before generating 3D model to match the level of detail in the schedule, it is important to set the purpose of the 4D model. Therefore the level of detail of the 3D model must be determined according to the type of problem that the user wants to

resolve through the 4D model. In case where time-space conflicts are detected, more detail model may be needed.

5. The activities used for developing 3D model should be named according to work breakdown structure, cost breakdown structure and organization breakdown structure for the entire project management.

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APPENDICES

Appendix A

System Requirement and File Checklists

System requirement

User should make sure that computer is provided with the latest ODBC drivers installed. The minimum basic hardware requirements are listed follow:

Processor: Intel processor 3.0 GHz or more.

Operating System: Microsoft Windows XP

RAM: 512 MB minimum.

Hard Drive Free Space: 100 MB

VGA Card

File checklists

The following table lists the files format and the description for each one that user will need before running the 4D project planning system.

Appendix Table A1 File checklists

File Name/Path	Description
C:\4Dplanning\4Dplan.mdb	The Microsoft Access database file for 4Dplan
C:\4Dplanning\VBA\4Dplanning.dvb	The AutoCAD VBA file project that contains the 4Dplanning VBA macros.
AutoCAD	AutoCAD 2006 or later version
Microsoft Project	Microsoft Project 2003
Microsoft Access	Microsoft Access 2003

Appendix B

Data Dictionary

Appendix Table B1 Geometrical Data of 3D Solid Object

Table Name : Consdb

Description : Geometrical data is exported from 3D Solid Object in AutoCAD

Field	Description
AutoID	Auto Number
Project Name	Name of project
Layer Name	Name of Layer in AutoCAD
Object_Name	Name of Object in AutoCAD Ex. AcDb3dSolid
ObjectID	The object identification of the AutoCAD entity that the specified object is associated with.
HandleID	The name of an entity with a specific handle, handles are unique within a drawing.
Layer_color	Color of Layer defined as integer (1-256)
Object_color	Color of object defined as integer (1-256)
MaxX	The 3D WCS coordinate specifying the maximum point of the object's bounding box.(X axis)
MaxY	The 3D WCS coordinate specifying the maximum point of the object's bounding box.(Y axis)
MaxZ	The 3D WCS coordinate specifying the maximum point of the object's bounding box. (Z axis)
MinX	The 3D WCS coordinate specifying the minimum point of the object's bounding box.(X axis)
MinY	The 3D WCS coordinate specifying the minimum point of the object's bounding box.(Y axis)
MinZ	The 3D WCS coordinate specifying the minimum point of the object's bounding box.(Z axis)
CentroidX	Centroid of object (X axis)

Appendix Table B1 (continued)

Field	**Description**
CentroidZ	Centroid of object (Z axis)
Width	Width of object
Length	Length of object
Height	Height of object
StType	Type of Structure Ex. Footing, Beam, Column etc…
Floor	Elevation of object defined as floor number
Distance	Distance of object's centroid from origin(X0,Y0,Z0)
Volume	Volume of object

Appendix Table B2 Construction Scheduling Data

Table Name : Schedule

Description : The temporal and logical information that is exported from Microsoft Project.

Field	**Description**
ID	Auto Number
WBS	Work Breakdown Structure
Task_Name	Name of task
Duration	The amount of working time from the start to finish of task
Early_Start	The earliest date that a task could possibly begin.(ES)
Early_Finish	The earliest date that a task could possibly finish.(EF)
Late_Start	The latest date that a task can start without delaying the finish of the project.(LS)

Appendix Table B2 (Continued)

Field	Description
Late_Finish	The latest date that a task can finish without delaying the finish of the project.(LF)
Critical_Task	A task that must be completed on schedule for the project to finish on time.
Cost	Total cost
Construction Method	Construction Method

Appendix Table B3 Reference Elevation

Table Name : ReferenceElevation

Description : Elevation for defining the floor number of building components. (Specify by user)

Field	Description
ID	Auto Number
Elevation	Elevation
Floor	Floor number

Appendix Table B4 Reference Gridline

Table Name : ReferenceGridline

Description : Gridline for defining the gridline of building components. (Specify by user)

Field	**Description**
ID	Auto Number
Coordinate X	Centroid of object (X axis)
Coordinate Y	Centroid of object (Y axis)
Gridline	Gridline name ex. A1,B2 etc.

Appendix C

AutoCAD Glossary

<u>Bylayer</u>

A special object property used to specify that the object inherits the color or linetype associated with its layer. Specifies that new objects assume the color assigned to the layer on which you create them. When Bylayer is selected, the color of the current layer is displayed in the old and new color swatches.

<u>Command line</u>

A text area reserved for keyboard input, prompts, and messages.

<u>Extrusion</u>

A 3D solid created by sweeping an object that encloses an area along a linear path.

<u>Handle</u>

A unique alphanumeric tag for an object in the program's database. A handle is persistent (stays the same) in a drawing for the lifetime of the object.

<u>Layer</u>

A logical grouping of data that are like transparent acetate overlays on a drawing. User can view layers individually or in combination.

<u>ObjectARX</u> (AutoCAD Runtime Extension)

A compiled-language programming environment for developing AutoCAD applications.

<u>UCS</u> (User Coordinate System)

A user-defined coordinate system that defines the orientation of the X, Y, and Z axes in 3D space. The UCS determines the default placement of geometry in a drawing.

<u>WCS</u> (World Coordinate System)

In the WCS, the *X* axis is horizontal, the *Y* axis is vertical, and the *Z* axis is perpendicular to the *XY* plane. The origin is where the *X* and *Y* axes intersect (0,0) in the lower-left corner of the drawing.

Appendix D

Example Source Code

```
Public Sub Export_Object_To_Database()

'Variables for AutoCAD objects
Dim SolidSelection As AcadSelectionSet
Dim SolidObject As Acad3DSolid
Dim EntLayers As AcadLayers
Dim EntLayer As AcadLayer
Dim nLayer As Integer
Dim LayerName As String
Dim ProjectName As String
Dim StartPro As Long
Dim ReInputBox As Long

'3Dsolid
Dim group1Code(0 To 1) As Integer
Dim data1Value(0 To 1) As Variant

'Variables for ADO Objects
Dim wsPath As String
Dim conString As String
Dim db As New ADODB.Connection
Dim minExt As Variant
Dim maxExt As Variant

Dim SolidRS As New ADODB.Recordset

'Connect to the database
wsPath = ThisDrawing.Application.Preferences.Files.WorkspacePath
'MsgBox "=>" & wsPath
conString = "File Name=" & wsPath & "\4DPlan.udl"
 db.Open conString
If Err <> 0 Then
MsgBox "Could not open 4DPlan.udl"
   Exit Sub
End If
```

```
db.Execute "DELETE FROM ConsDb "

'Open the one recordset
SolidRS.Open "ConsDb", db, adOpenDynamic, adLockOptimistic ', adCmdTable

If Err <> 0 Then
MsgBox "Could not open ConsDb recordSet"
   Exit Sub
End If

'Make sure the Recordset supports Addnew

If Not SolidRS.Supports(adAddNew) Then
   MsgBox "Cannot add records to the SolidRecordset."
   Exit Sub
End If

ProjectName = InputBox("Enter your Project Name", "<# Project Name #>", "Project Name")

    If ProjectName = "" Then GoTo ReturnInputBox

    GoTo StartPro

ReturnInputBox:
 ProjectName = InputBox("Enter your Project Name", "<# Project Name #>", " Project Name
")
 Exit Sub

StartPro:

 Set SolidObject = ThisDrawing.ModelSpace.Add3dsolid ("SSet0")

'Get the selection set of all Solid in the current drawing
   ThisDrawing.SelectionSets("SolidSet").Delete
Set SolidSelection = ThisDrawing.SelectionSets("SolidSet")
```

```
    If Err <> 0 Then
        Set SolidSelection = ThisDrawing.SelectionSets.Add("SolidSet")
    End If

    Set EntLayers = ThisDrawing.Layers

        CloseLayer99 ‘Sub code

         For nLayer = 0 To EntLayers.Count - 1

         Set EntLayer = EntLayers(nLayer)
         EntLayer.LayerOn = True
         LayerName = EntLayer.Name
         Debug.Print "No." & nLayer; vbCrLf; LayerName

group1Code(0) = 0
data1Value(0) = "3DSOLID"
group1Code(1) = 8
data1Value(1) = LayerName
SolidSelection.Clear
SolidSelection.Select acSelectionSetAll, , , group1Code, data1Value

'Loop through the selection and add the Solid data to the database

For Each SolidObject In SolidSelection

'Add a new blank record
SolidObject.GetBoundingBox minExt, maxExt
SolidRS.AddNew

'Set the field values
SolidRS!Project_Name = ProjectName
SolidRS!HandleID = SolidObject.Handle
SolidRS!Object_Name = SolidObject.ObjectName
SolidRS!objectId = SolidObject.objectId
```

```
SolidRS!Layer_Name = data1Value(1)
SolidRS!Task_Name = data1Value(1)
SolidRS!Object_color = SolidObject.color
SolidRS!Layer_color = EntLayer.color
SolidRS!MaxX = Round(maxExt(0), 3)
SolidRS!MaxY = Round(maxExt(1), 3)
SolidRS!MaxZ = Round(maxExt(2), 3)
SolidRS!MinX = Round(minExt(0), 3)
SolidRS!MinY = Round(minExt(1), 3)
SolidRS!MinZ = Round(minExt(2), 3)
SolidRS!CentroidX = SolidObject.Centroid(0)
SolidRS!CentroidY = SolidObject.Centroid(1)
SolidRS!CentroidZ = SolidObject.Centroid(2) 'Indicate
SolidRS!width = Round(Sqr((maxExt(0) - minExt(0)) ^ 2), 2)
SolidRS!length = Round(Sqr((maxExt(1) - minExt(1)) ^ 2), 2)
SolidRS!Object_height = Round(Sqr((maxExt(2) - minExt(2)) ^ 2), 2) SolidRS!Volume =
Round(SolidObject.Volume, 3)

SolidRS!Floor = "N/A"
SolidRS!Grid = "N/A"


 Dim ObjectColor As Integer
 Dim LayerColor As Integer

    'Should not use these Indexcolor (10,12,20,22,240) Red group

   If SolidRS!Object_color = 256 Then
            ObjectColor = SolidRS!Layer_color

            GoTo Categorize:

            End If

    If SolidRS!Object_color = 0 Then  'ByBlock 0
```

```
        ObjectColor = SolidRS!Layer_color

        GoTo Categorize:

        End If

 If SolidRS!Object_color = 49 or 59 Or 69 Or 79 Or 89 Or 11 Or 13 Or 15 Or 17 Or 19 Or 21 Or 23 Or 25 Or 27 Or 29 Or 201 Or 203 Or 205 Or 207 Or 209 Or 211 Or 213 Or 215 Or 217 Or 219 Or 221 Or 223 Or 225 Or 227 Or 229 Or 231 Or 233 Or 235 Or 237 Or 239 Or 161 Or 163 Or 165 Or 167 Or 169 Or 171 Or 173 Or 175 Or 177 Or 179 Or 181 Or 183 Or 185 Or 187 Or 189 Or 191 Or 193 Or 195 Or 197 Or 199 Or 31 Or 33 Or 35 Or 37 Or 39 Or 151 Or 153 Or 155 Or 157 Or 159 Or 254 Or 83 Or 111 Or 43 Or 45 Or 53 Or 55 Or 51 Or 61 Or 103 Or 113 Or 123 Or 133 Or 143 Or 106 Or 94 Or 41 Or 247 Or 235 Or 245 Or 30 Or 249 Or 71 Or 81 Or 91 Or 2 Or 28 Or 16

Then
      ObjectColor = SolidRS!Object_color

Categorize:

    Select Case ObjectColor

      Case 49, 59, 69, 79, 89
       SolidRS!StType = "Pile"

       Case 11, 13, 15, 17, 19, 21, 23, 25, 27, 29
       SolidRS!StType = "Footing"

       Case 201, 203, 205, 207, 209, 211, 213, 215, 217, 219, 221, 223, 225, 227, 229, 231, 233, 235, 237, 239
       SolidRS!StType = "Beam"

       Case 161, 163, 165, 167, 169, 171, 173, 175, 177, 179, 181, 183, 185, 187, 189, 191, 193, 195, 197, 199
       SolidRS!StType = "Column"
```

Case 31, 33, 35, 37, 39, 151, 153, 155, 157, 159
SolidRS!StType = "Slab"

Case 71, 81, 91
SolidRS!StType = "Wall"

Case 254
SolidRS!StType = "Panel"

Case 83, 111
SolidRS!StType = "Stair"

Case 43, 45, 53, 55
SolidRS!StType = "Core Lift"

Case 51, 61
SolidRS!StType = "Steel Frame"

Case 103, 113, 123, 133, 143
SolidRS!StType = "Metal Sheet"

Case 249
SolidRS!StType = "Net"

Case 41
SolidRS!StType = "Footpath"

Case 245, 40
SolidRS!StType = "Truss"

Case 207
SolidRS!StType = "Door"

```
        Case 247
        SolidRS!StType = "Door Frame"

        Case 207
        SolidRS!StType = "Window"

        Case 235
        SolidRS!StType = "Window Frame"

        Case 2, 94
        SolidRS!StType = "Traffic Line"

        Case 28
        SolidRS!StType = "Site office"

        Case 16
        SolidRS!StType = "Store"

        Case 106
        SolidRS!StType = "Stopper"

        Case Else
        SolidRS!StType = "N/A"

        End Select
        End If

Next 'Object in selectionset

SolidRS.Update

    Next  'Next Layer

'Close the recordset and the databasae connection
SolidRS.Close
```

```
db.Close

MsgBox "Export Objects To Database Finished :*)"

   SpecifyGrid99 'Sub code
   SpecifyFloor99 'Sub code
ThisDrawing.Regen acAllViewports

End Sub
```

CIRRICULUM VITAE

NAME	: Mr. Wittaya Srisomboon		
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