

Chapter 4

Generating the 3D Models

4.1 Introduction

This chapter presents the important part of inputs of the integrated system. Several models used as input of the system were prepared by using CAD software in 3 dimensions (3D). These 3D models are classified in 3 categories as follows: 3D models of construction machines and equipment, 3D models of factory component, and 3D Models of temporary works.

After the 3D models were created by CAD software, these models were assigned characteristics and mechanisms necessary to convert the 3D static models from CAD to be the 3D dynamic models that simulate genuine action or movement. The characteristics and mechanisms of each model are different depending on its category or construction equipment classification. For example, the characteristics of the pile-driving machine are different from the characteristics of the excavator. Likewise the characteristics of the truck-crane are different from the characteristics of the tailor-truck.

4.2 The 3D Model Libraries

4.2.1 3D models of Construction Machines and Equipment

Machines and equipment selected as the input of the system are limited by machine sizes. The construction machine models selected to simulate the construction methods and sequences should be so large that they can significantly impact the construction process. This research was scoped in the case of factory construction. Thus, the important construction machines used in factory construction are as follows:

- *Excavators*
- *Truck cranes*
- *Pile driving machines*
- *Tailor trucks*
- *Dump trucks*
- *Concrete pumps*
- *Concrete mobile trucks*
- *Loaders*
- *Bull dozers*
- *Rollers*

4.2.2 3D Models of Factory-Building Components

The scope of this research was factory construction and was limited to structural and architectural works only. The structural and architectural works were divided into sub-activities of the factory as follows:

1) Structural works:

- *Pile work*
- *Excavating and back fill work*
- *RC footing work*
- *RC ground beam work*
- *RC column work*
- *Steel base-plate work*
- *Steel column work*
- *Roof structure (truss or beam) work*
- *Roofing work*
- *RC slab work*

2) Architectural works:

- *Wall and siding work*

4.2.3 3D Models of Temporary Works

The temporary works of factory construction should be considered in simulating the factory construction process because in many cases, they significantly affect the construction methods and sequences. The following temporary works were chosen for simulating factory construction:

- *Construction site fencing*
- *Site office and material store*
- *Labor camping*
- *Scaffolding*
- *Bracing members*

4.3 Modeling 3D Models by CAD Software

In this research, one part of the Integrated System (IS) inputs is the 3D models of factory construction that were presented above. The 3D models of construction machines, factory components and temporary works were generated by using CAD software called "AutoCAD version.2000". It is a famous Computer Aided Design (CAD) software and is

widely accepted in the construction business for preparing construction project designs and drawings. Nowadays, several designers use AutoCAD not only to prepare construction drawings but also to create the 3D models for many other purposes, such as making presentation their customers to visualize interesting area. The 3D models can be zoomed in, zoomed out and rotated to look at particular details. Moreover, the 3D models generated by AutoCAD can be transferred and imported into animation software conveniently. Therefore, AutoCAD do not required training in order to apply this software to develop the Virtual Reality (VR) system.

There are several menu commands in AutoCAD. However, they are simple, easy to learn and useful in generating 3D models. The commands shown in Figure 4.1 and Figure 4.2 are examples of AutoCAD commands used in generating the 3D models. Figure 4.3 shows a window of AutoCAD 2000 with a pulled-down menu, showing the drawing command.

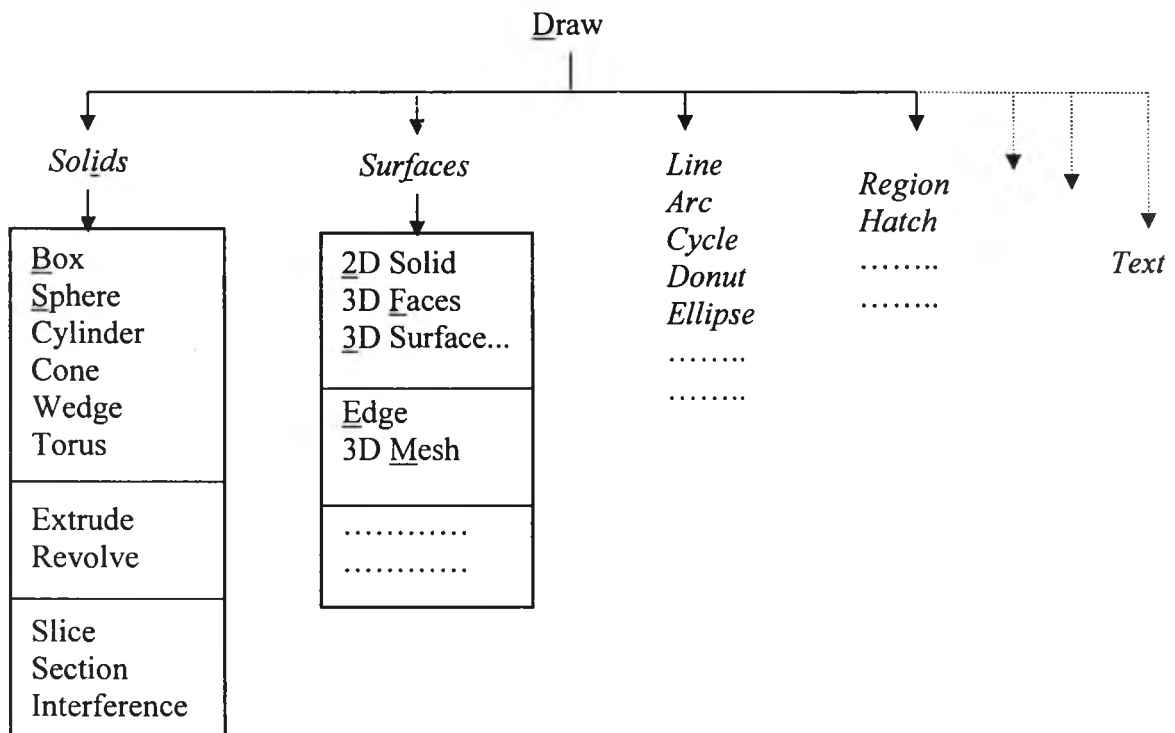


Figure 4.1: Examples of AutoCAD commands for creating the 3D models

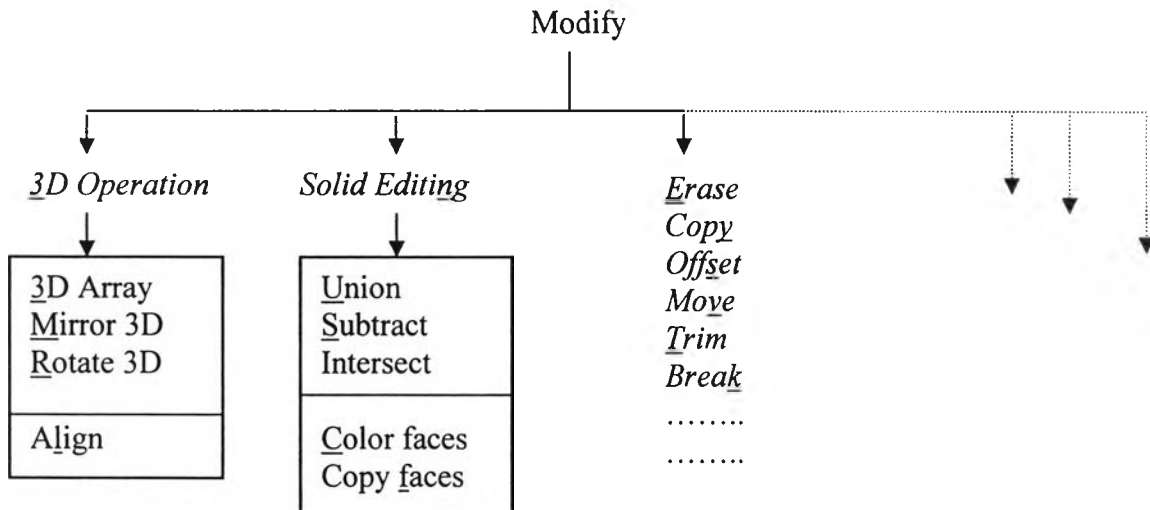


Figure 4.2: Examples of AutoCAD commands for modifying the 3D models

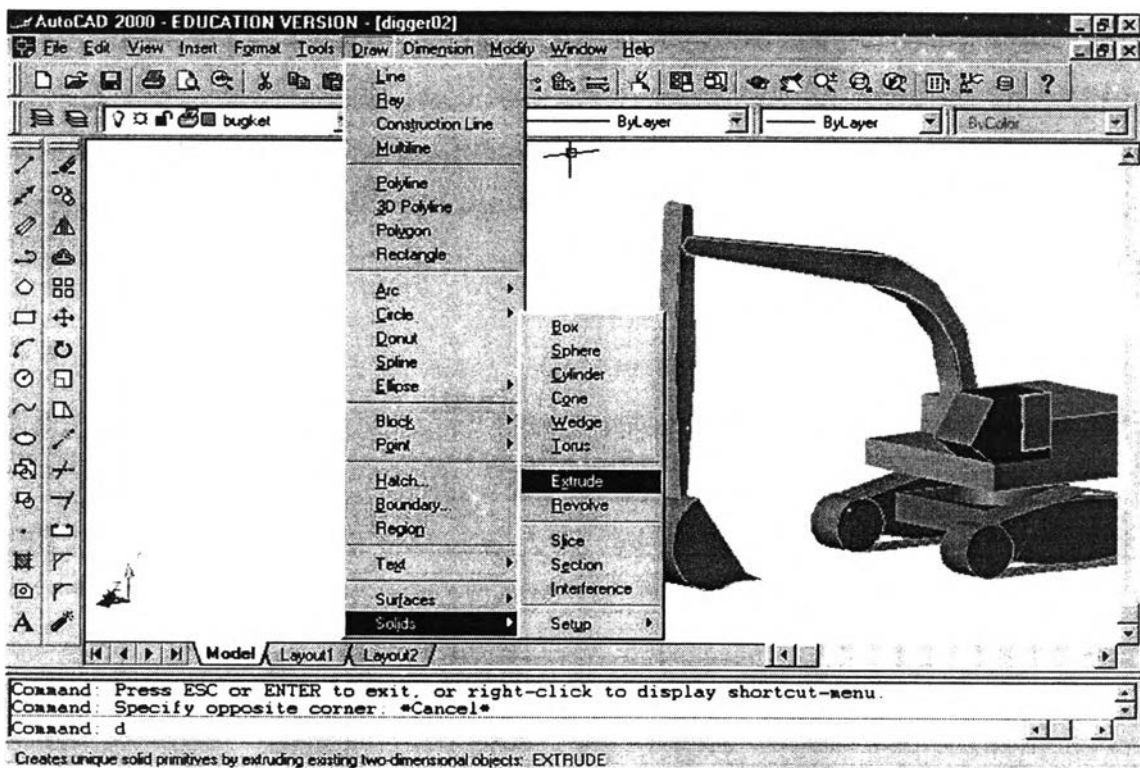


Figure 4.3: AutoCAD pull-down menu for creating the 3D models

4.3.1 The 3D Models of Construction Machines and Equipment

In this research, factory construction was used as a case study for studying the simulation of the construction process. Therefore, the important construction machine models (for factory construction) were created to be the system inputs. The following

steps are the sequences and methods of 3D modeling of construction machines: 1) collect the characteristic data of the machines (shape of components, dimensions, colors, and etc.) from the machine manuals and catalogs, 2) select only the main and important components or basic parts and neglect unnecessary details, 3) create the 3D models of the main components in certain scale by using 3D command in AutoCAD and only one main component is created in each layer, and 4) combine each main component together. These methods can be presented by flowchart as in Figure 4.4. The following examples of construction machines were selected for use as the machine models in factory-construction simulation.

Excavators or Backhoes

The characteristic data of excavators or backhoes were determined by using the data from the machine catalog and manual in Appendix 1. The basic parts or main components of the excavator can be divided into 5 parts: 1) Track-wheel, 2) Body and control- cabin, 3) First boom, 4) Second boom and 5) Bucket as shown in Figure 4.5.

The use of 3D commands in AutoCAD to create each basic part or main component is summarized in Table 4.1. Then, these main components were required to be combined together to form a 3D model of an excavator. Different sizes of excavators can be created in true-scale by varying the dimension of basic parts as shown in Figure 4.6

Table 4.1 Examples of 3D commands for creating the basic parts of excavator.

No.	Component	Layer Name	Color	Examples of AutoCAD Command
1	Bucket	Bucket	252	Draw – Arc, Line, Region, Solids, Extrude
2	First Boom	Boom01	40	Draw – Arc, Line, Region, Solids, Extrude
3	Second Boom	Boom02	40	Draw – Arc, Line, Region, Solids, Extrude
4	Body & control cabin	Body	40	Draw-solids, union, subtract
5	Track-wheel	Track	Black & 30	Draw-3D surfaces, Mesh, Solids, Cylinder

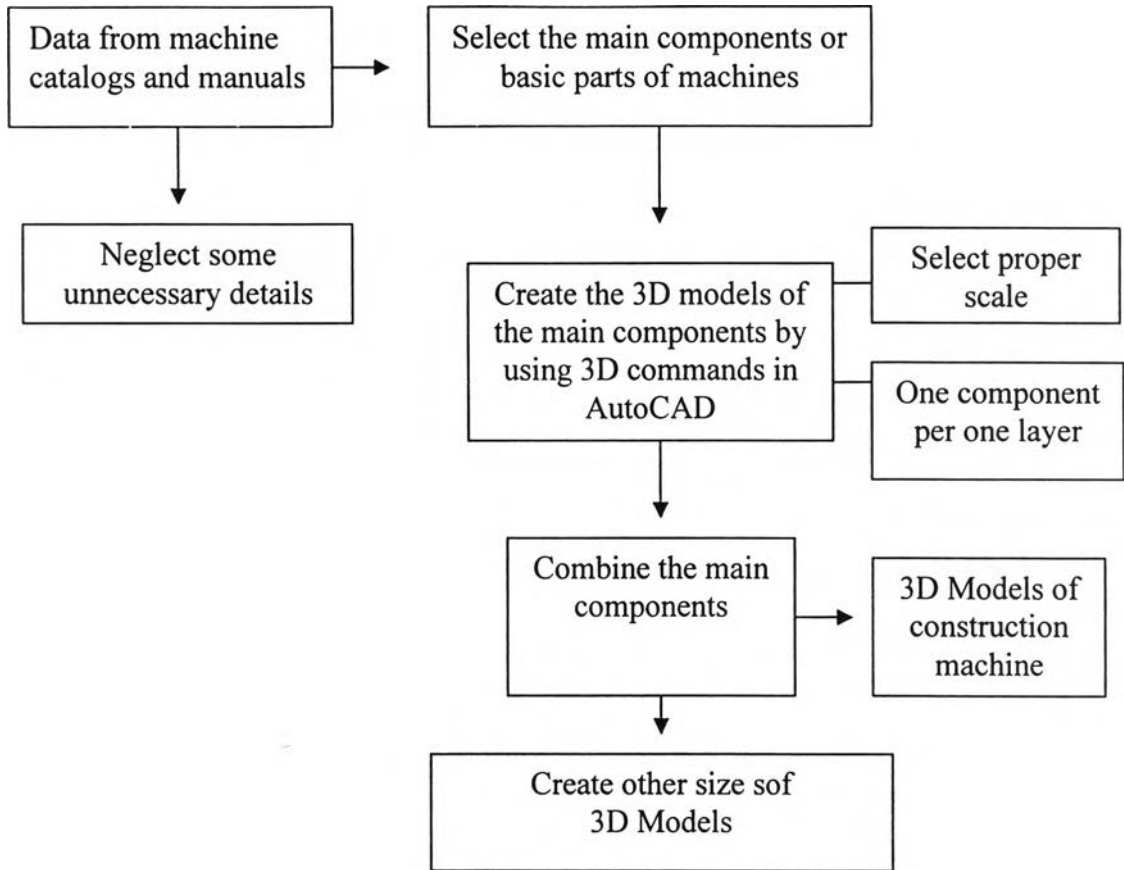


Figure 4.4: 3D modeling flowchart of construction machines

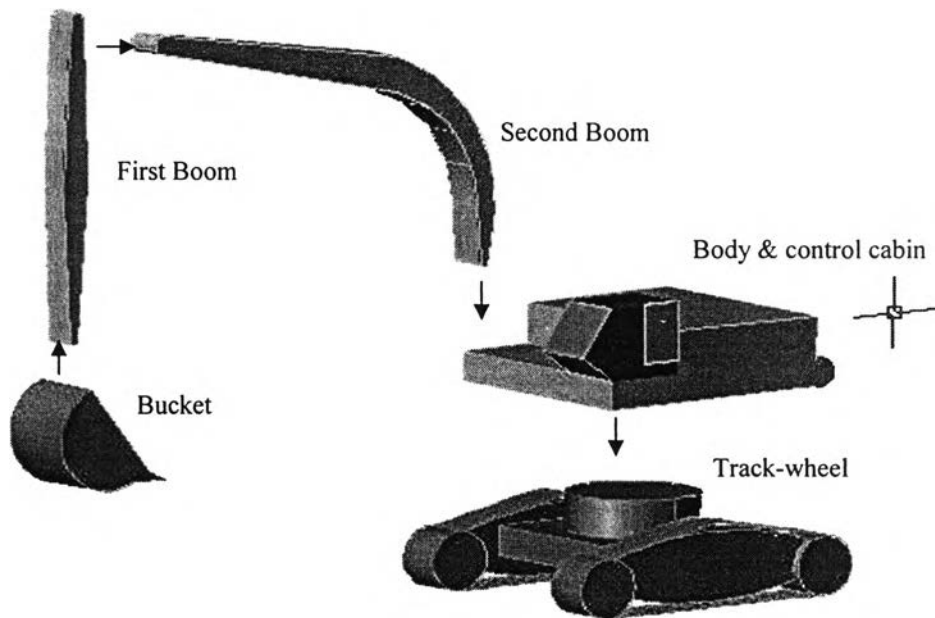
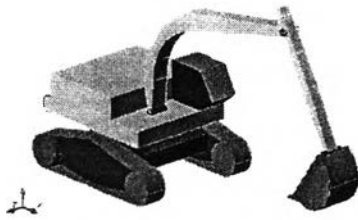
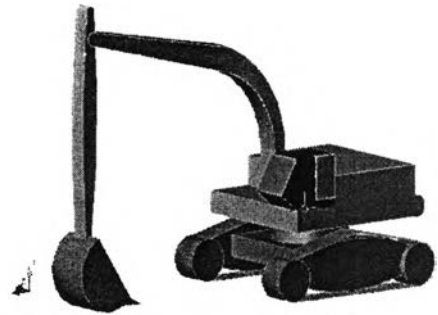


Figure 4.5: The main components and basic parts of an excavator model

Excavators



Excavator Model.1



Excavator Model.2

Figure 4.6: Different sizes of 3D models of an excavator created by AutoCAD 2000.

Mobile-Cranes

There are eight basic parts or main components of a mobile-crane: 1) Truck-wheels, 2) Truck-body, 3) Bracing-legs, 4) Crane-body and cabin control, 5) Base-boom, 6) middle-boom, 7) Tip-boom, and 8) Hook, as shown in Figure 4.7. The 3D commands and layers of AutoCAD used to create the truck-crane models were presented in Table 4.2. In addition, the different sizes of 3D models of the mobile-crane were created by varying the dimensions of the basic parts as shown in Figure 4.8

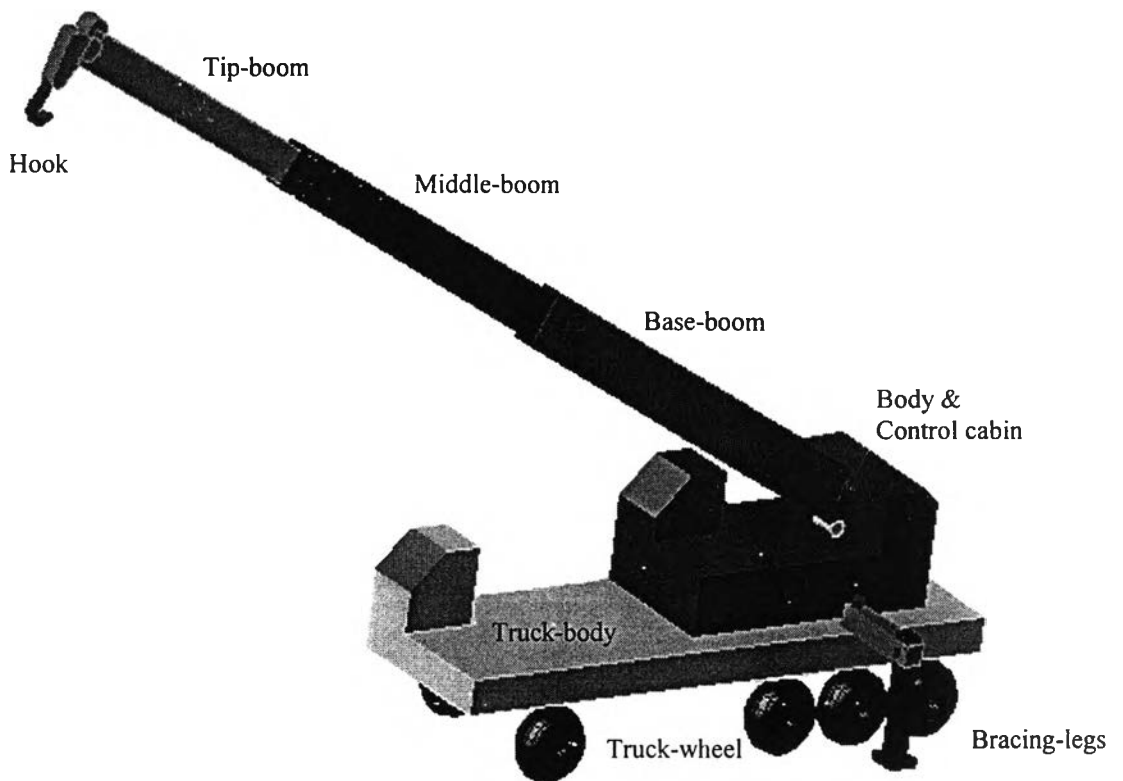
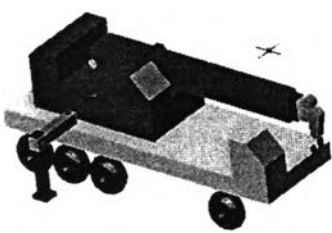


Figure 4.7: The main components or basic parts of a mobile-crane model.

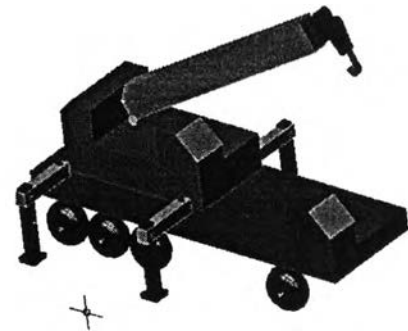
Table 4.2: Examples of 3D commands for creating the basic parts of a mobile-crane

No.	Component	Layer Name	Color	Examples of AutoCAD Command
1	Hook	Hook	Cyan	Draw – Arc, Line, Region, Solids, Extrude
2	Tip-boom	Boom01		Draw – Solids, box, Arc, Line, Region, Extrude
3	Middle-boom	Boom02		Draw-solids, box
4	Base-boom	Boom03	Blue	Draw-solids, box
5	Body & control cabin	Body	Red	Draw-solids, box, union, subtract
6	Truck-body	Truck	Yellow	Draw-solids, box, union, subtract
7	Bracing-legs	Leg	Orange	Draw-solids, box, union
8	Truck-wheel	Wheel	Black	Draw-3D surfaces, Mesh, Solids, Cylinder

Truck-crane



Mobile-crane model 1.



Mobile-crane model 2.

Figure 4.8: The different sizes of 3D models of mobile-cranes created by AutoCAD.

Pile-Driving Machines

The basic parts of a pile-driving machine are: 1) Hammer, 2) Tower, and 3) Rail, as shown in Figure 4.9. The 3D commands and layers of AutoCAD used in creating the pile-driving hammer models were presented in Table 4.3. The different sizes of 3D models of the pile-driving machines were created by changing the dimensions of the basic parts shown in Figure 4.10.

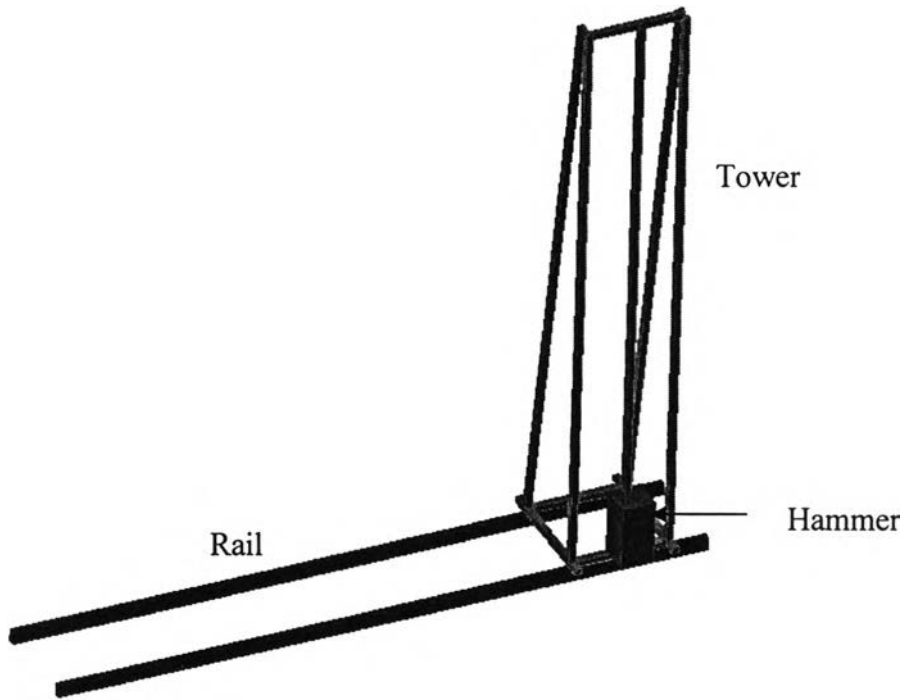
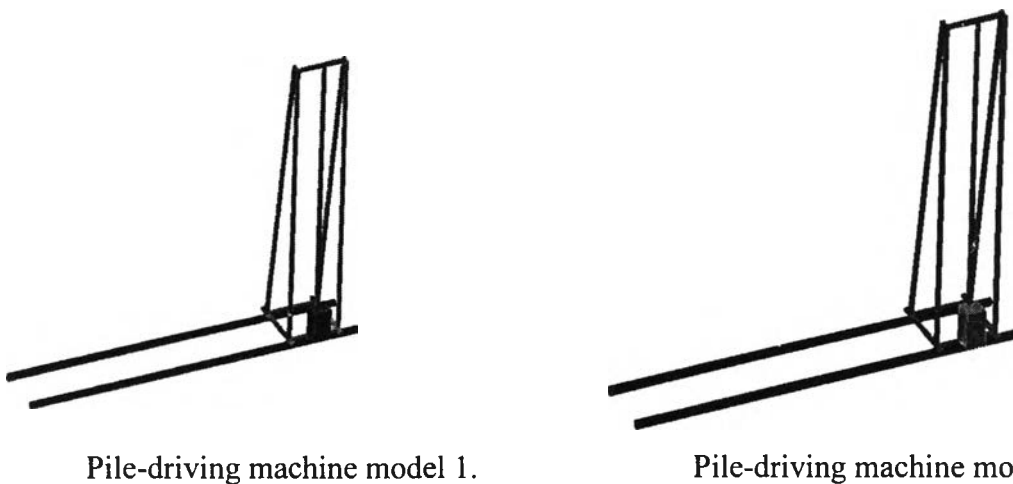


Fig.4.9: The main components of a pile-driving machine model.

Table 4.3: Examples of commands for creating the basic parts of pile-driving machines

No.	Component	Layer Name	Color	Examples of AutoCAD Command
1	Hammer	Hammer	Magenta	Draw-solids, Box
2	Tower	Tower	Green	Draw-solids, Box
3	Rail	Rail	Red	Draw-solids, Box

Moreover, static 3D models of other construction machines are also illustrated in Appendix 2.



Pile-driving machine model 1.

Pile-driving machine model 2.

Figure 4.10: The different sizes of 3D models of a pile-driving machine.

4.3.2 The 3D Models of Factory-Building

In this research, factory construction was chosen to be a case study of construction simulation using an integrated system because it has simple basic structures that cover the important components of the building. For this reason, factory construction is appropriate for use in preliminary study of building construction simulation.

The methods and sequences for creating 3D models of a factory are similar to the methods for 3D modeling of construction machines. The methods were demonstrated as follows: 1) Study the overall methods and sequences of factory construction, 2) Select the main structures and necessary components of the factory for creating the 3D models, 3) Create the 3D models of these structures and components using AutoCAD 2000.

The main structures and necessary components of factory building were divided into following parts: pile, excavating and back filling, RC footing, RC ground beam, RC column, steel base-plate, steel column, roof structure (Truss or Beam), roofing, RC slab, wall and siding, doors and windows. All of the components are presented in Figure 4.11.

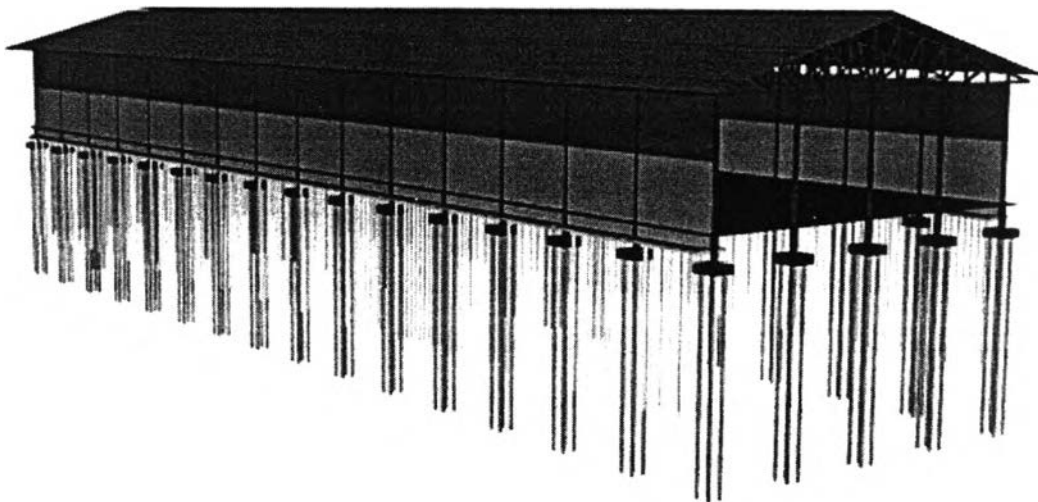


Figure 4.11: A 3D model of a factory building

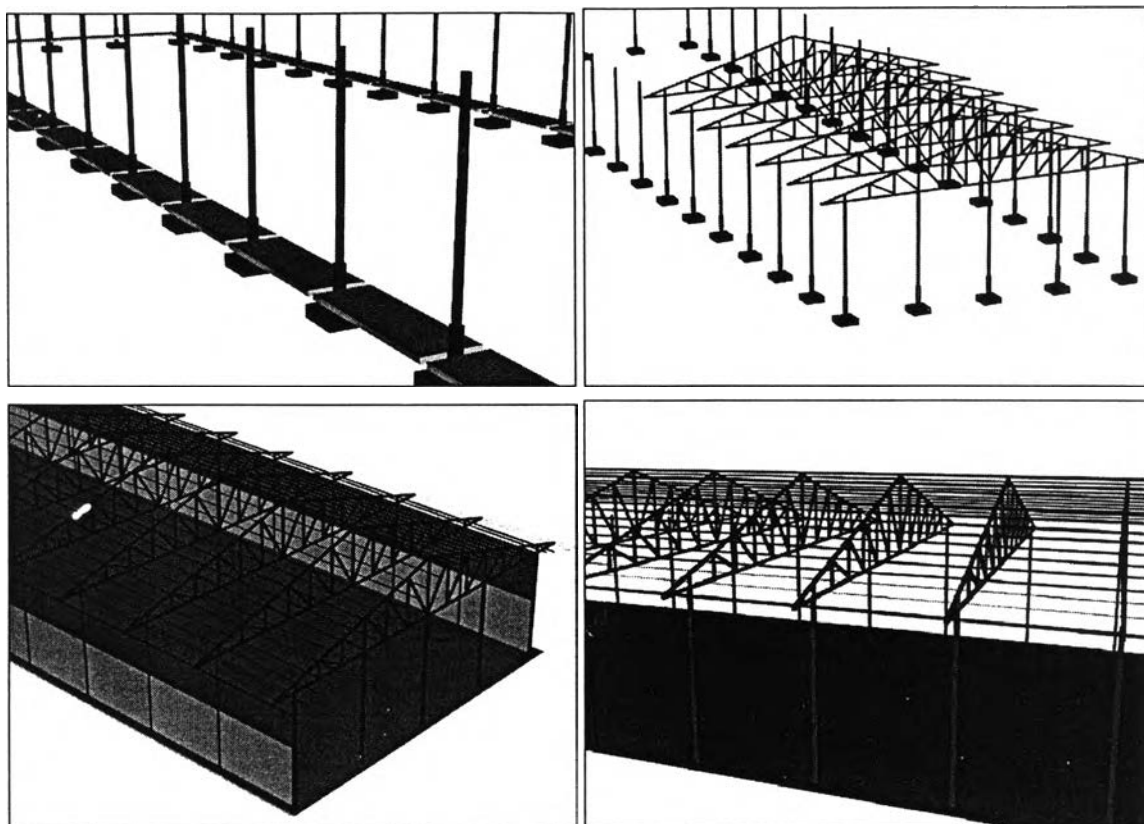


Figure 4.12: The 3D models of main components of a factory building.

In the Figure 4.12, there are four screens of displays the main components of factory building, which were generated by AutoCAD 2000.

4.3.3 The 3D Models of Facilities and Temporary Works

The facilities and temporary works are important parts of a construction project. There are several temporary works in the factory construction processes. However, only some temporary works have a significant impact on other construction activities. Thus, some temporary works affecting other activities should be considered and selected for simulating the construction processes. The following are examples of important temporary works involved in factory construction: 1) construction site fencing, 2) site office and material store 3) labor camp, 4) scaffolding, and 5) bracing members. They are shown in Figure 4.13.

4.4 Assigning Characteristics and Mechanisms of 3D Models

4.4.1 Software for Assigning Characteristics of 3D Models

The 3D software called “3D Studio MAX” distributed by AutoDesk Inc. was selected to assist in the assignment of the characteristics to the 3D models.

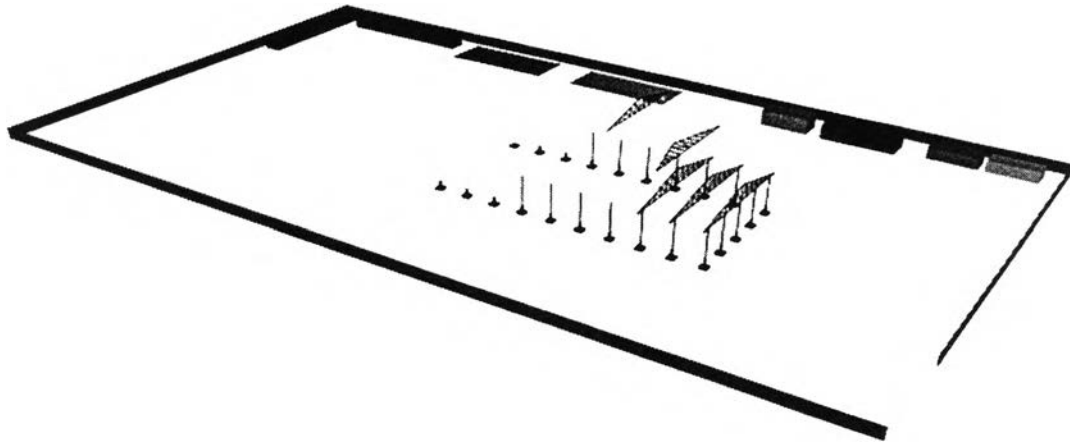


Figure 4.13: Examples of facilities and temporary works in a construction site.

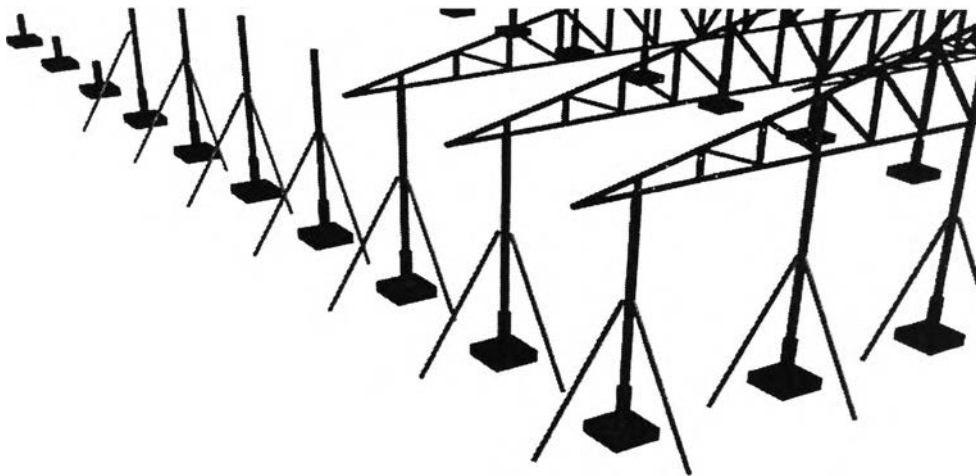


Figure 4.14: Column bracing: an example of temporary work.

4.4.2 Advantages of 3D software

When users apply 3D Studio MAX to generate the models or assign the characteristics of the models, they can use the 3D Studio MAX commands to rotate, zoom and walk-through for illustrating the different views of the models. In contrast, AutoCAD users cannot apply its commands to walk-through the model. They can apply CAD only to rotate and zoom in order to examine the details of the models. Moreover, the 3D Studio MAX can be applied to provide dynamic action to illustrate the actual movements of the 3D models.

4.4.3 Elementary Parts of Models in 3D Studio MAX

The elementary parts of 3D models in 3D visualizer consist of 1) structure, 2) pivot point, 3) name & color, and 4) property of surface.

4.5 Methodology of Characteristics and Mechanisms Assignment

When 3D Studio MAX was used as a tool to assign the characteristics of the 3D models, the methodology of assignment could be divided into the following steps.

4.5.1 Importing Components of 3D Models and Assigning Names

In order to assign the characteristics to the 3D models, after the models were created by the AutoCAD, they were imported into 3D Studio MAX by using the command in file operation panel (*File Import*) illustrated in Figure 4.15. Next, the name and color of the components were assigned by using the command panel (*Create*) in the rollout of name and color as shown in Figure 4.16.

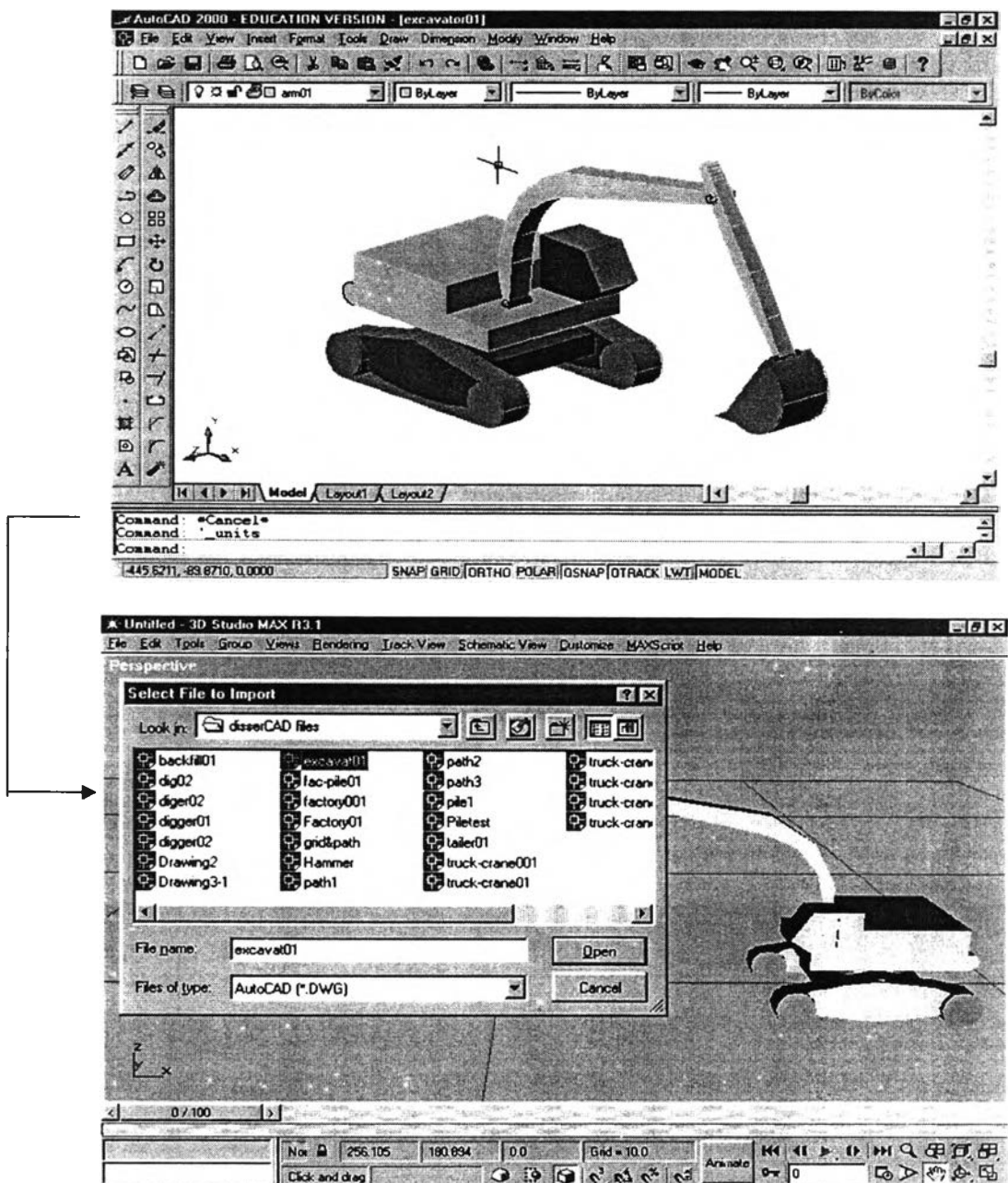


Figure 4.15: The 3D model of an excavator created by AutoCAD imported to 3DS MAX.

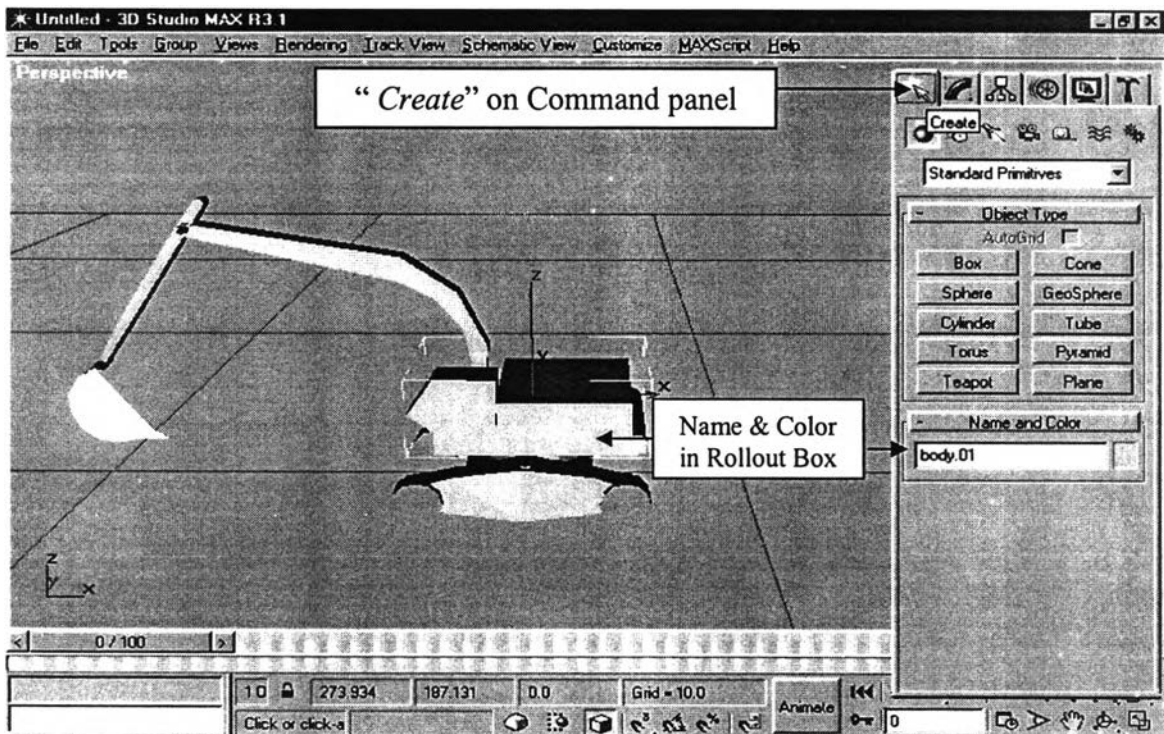


Figure 4.16: Command panel of 3D Studio MAX used to assign names and colors of the elements of the 3D model.

Name and color are important elementary parts of the 3D model in 3D Studio MAX (Lertsinthavanon, 2002).

4.5.2 Assigning Pivot Points to the Components

An important step in characteristic assignment is to assign pivot points to the components of the 3D models. A pivot point of the component is used as the center point of the component for rotation and movement. The method for assigning the pivot points of the components using the 3D Studio MAX command was shown in the following steps.

Step 1: Select the components of the 3D model that have been assigned a name and color already.

Step 2: Set up one point of the element that to be the center point of the component's rotation.

Step 3: Use the commands in the command panel and tab panel to assign the pivot point of the components. The command called "*Hierarchy*" on the command panel and the command called "*Align*" on tab panel were used for assigning the pivot point of the components, as shown in Figure 4.17. Pivot refers to "*defining the local center and coordinate system for each object*" (3DS MAX Reference).

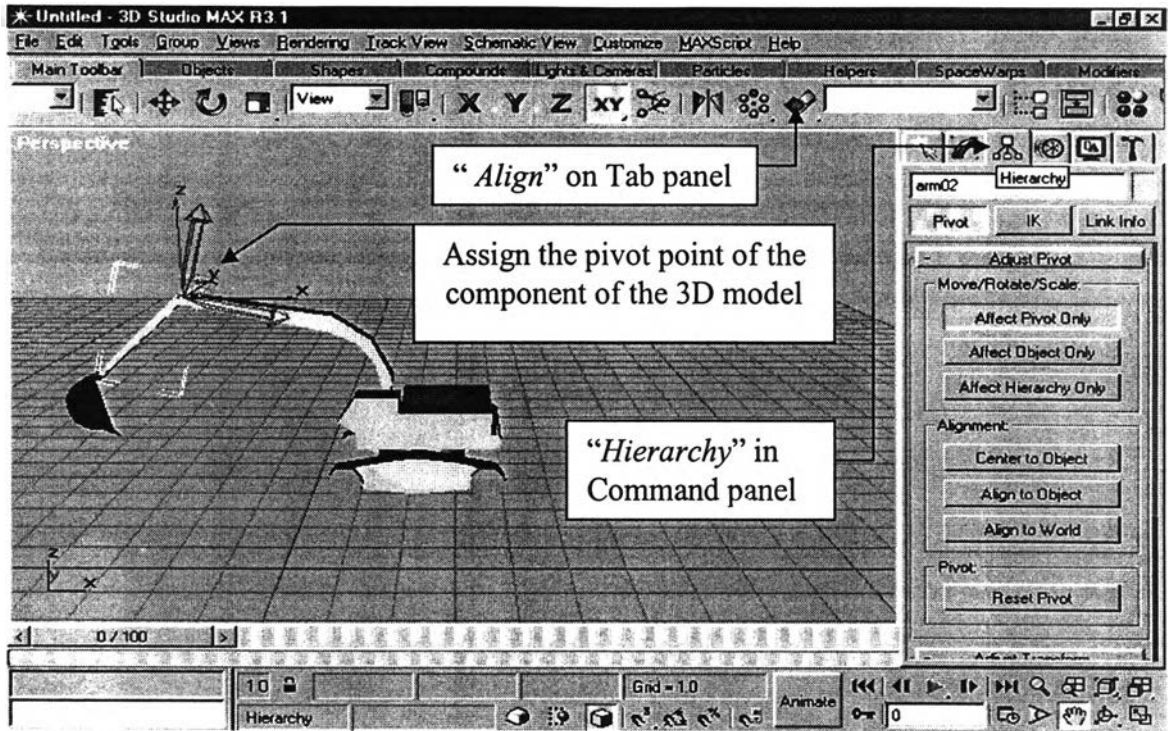


Figure 4.17 Commands on tab panel and command panel used for setting up the pivot point of the 3D model.

4.5.3 Assigning Relationships and Building Hierarchical Structures

After the components of the 3D models were assigned names, colors and pivot points, these components must be linked together so that one object is superior and controls the transformation of one or more subordinate objects or components. The linkage is unidirectional in that superior objects can control subordinates but subordinates have no effect on their superiors. This relationship structure is called a “*hierarchy*”. All components are parts of a hierarchy. An imaginary object named “*World*” is assigned to act as the root of everything in the scene. Therefore, if an object is not linked to any other object in the scene, it is considered a child of the “*World*”.

“*The family tree analogy*” is selected to describe the relationship between objects linked together in a hierarchy as shown in Figure 4.18. In the family tree, the object that controls one or more children is called “*Parent*”. A parent object is often controlled by another superior parent object. The object that was controlled by its parent was called “*Child*”. A child object can also be a parent to other children. The connection between a parent and its child is called “*Link*”. “*Link*” transmits position, rotation, and scale information from parent to child so that the children can be easily animated and transformed by moving, rotating, or scaling the parent.

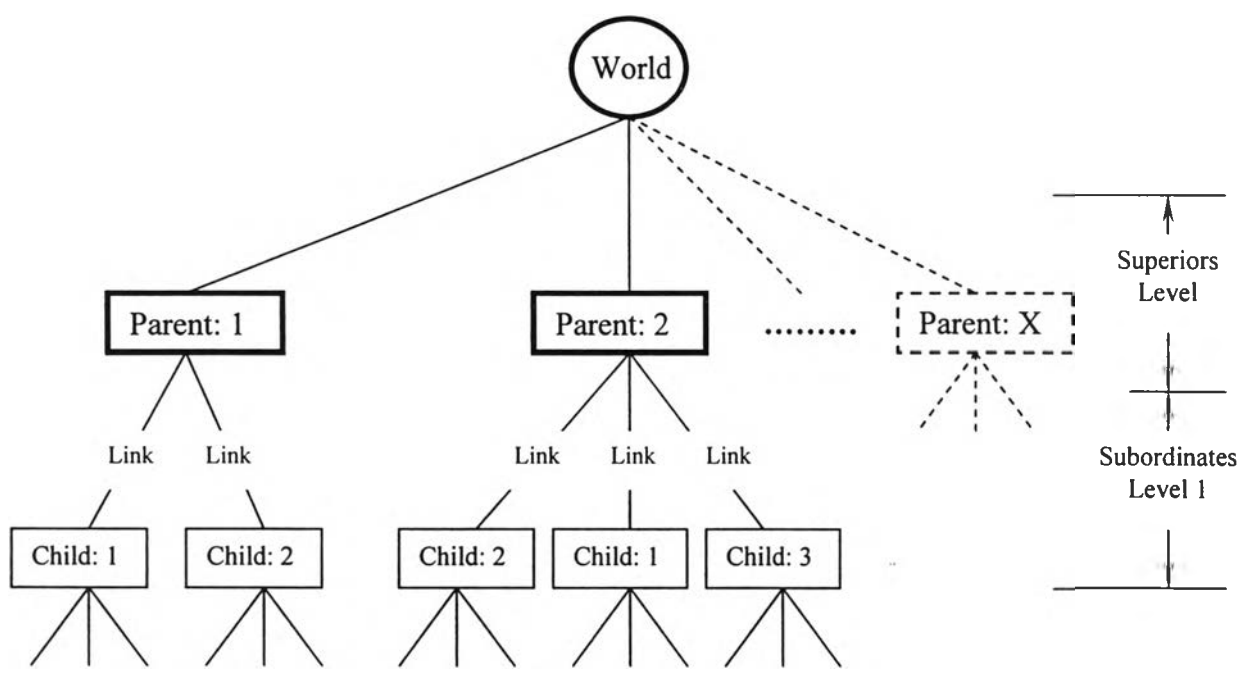


Figure 4.18: Family tree analogy

4.5.4 Linking Components of the Models

Object linking and hierarchical structures building are common techniques in computer modeling and animation. A child inherits the transformations (move, rotate, scale) applied to the parent, but the child's transformations have no effect on the parent. The “Link” and “Unlink” buttons on the left side of the main toolbar are used to make and break links between objects, respectively, as illustrated in Figure 4.19.

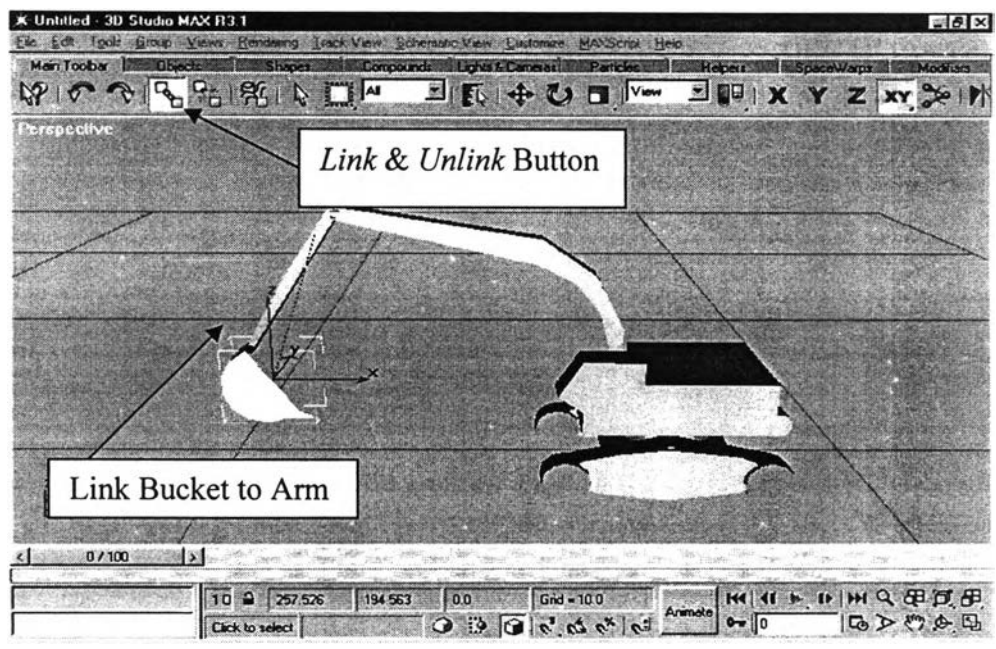


Figure 4.19: The Link/Unlink buttons used for linking/unlinking the 3D components

The methodology for assigning the characteristics and mechanisms of the 3D models can be summarized by using the flowchart as shown in Figure 4.20

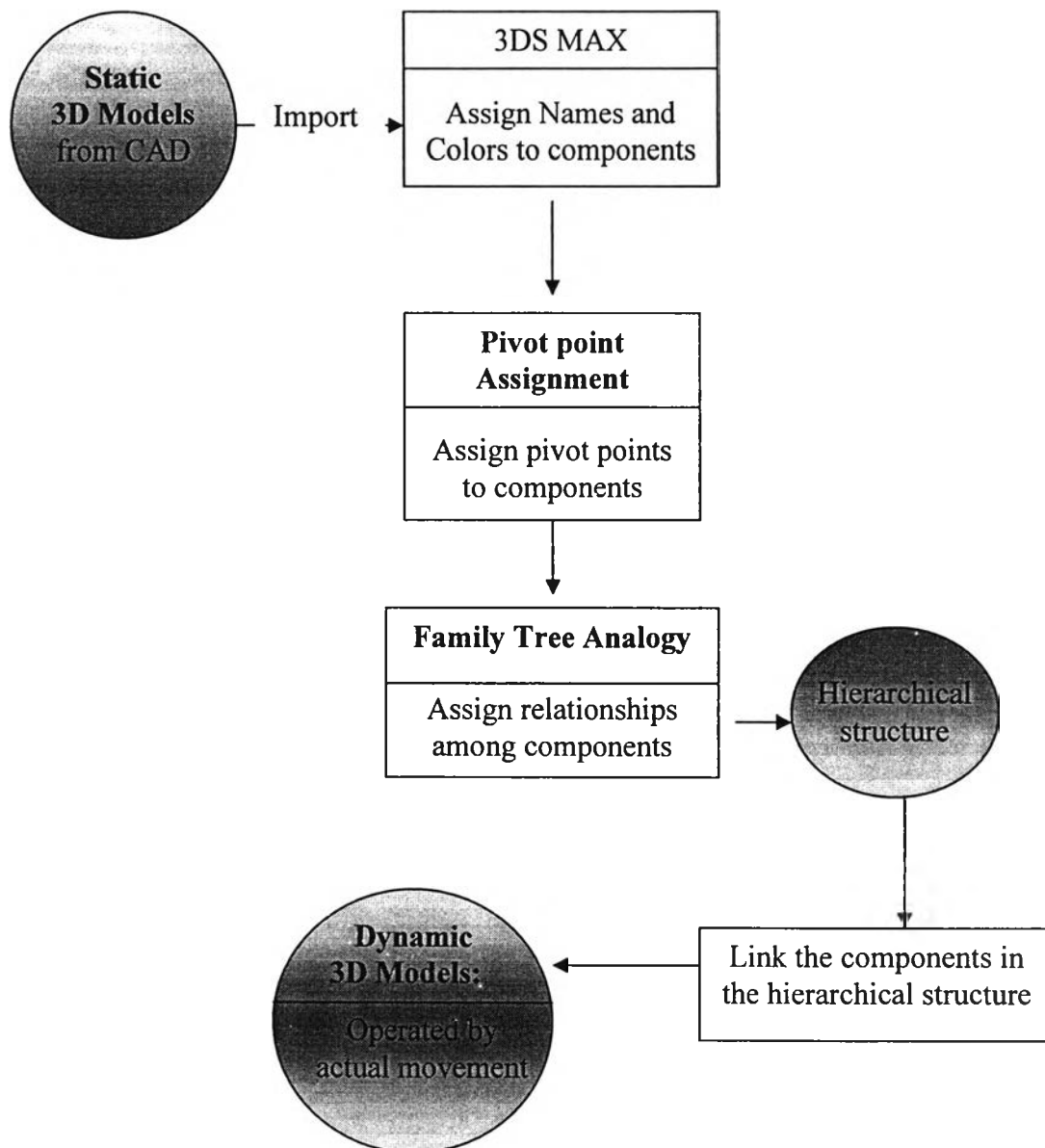


Figure 4.20: Flowchart for assigning the 3D model characteristics and mechanisms

4.6 Characteristics and Mechanisms of Construction Machines

In this chapter, the 3D models of construction machines that were created by CAD would be assigned their characteristics and mechanisms. Construction machines such as excavators, mobile-cranes and pile-driving machines have been assigned their characteristics and mechanisms using the above methodology.

Excavators

The method for assigning the excavator characteristics and mechanisms is described as follows:

- Components of the excavator

In Chapter 5, the excavator consists of five important components, namely 1) track-wheel, 2) body & cabin, 3) second arm, 4) first arm, and 5) bucket, as illustrated in Figure 4.21.

- Pivot points of the components

The pivot point of each component of the excavator is presented in the following figure (Figure 4.21). Each point was treated as a center-point for illustrating actual rotation and movement.

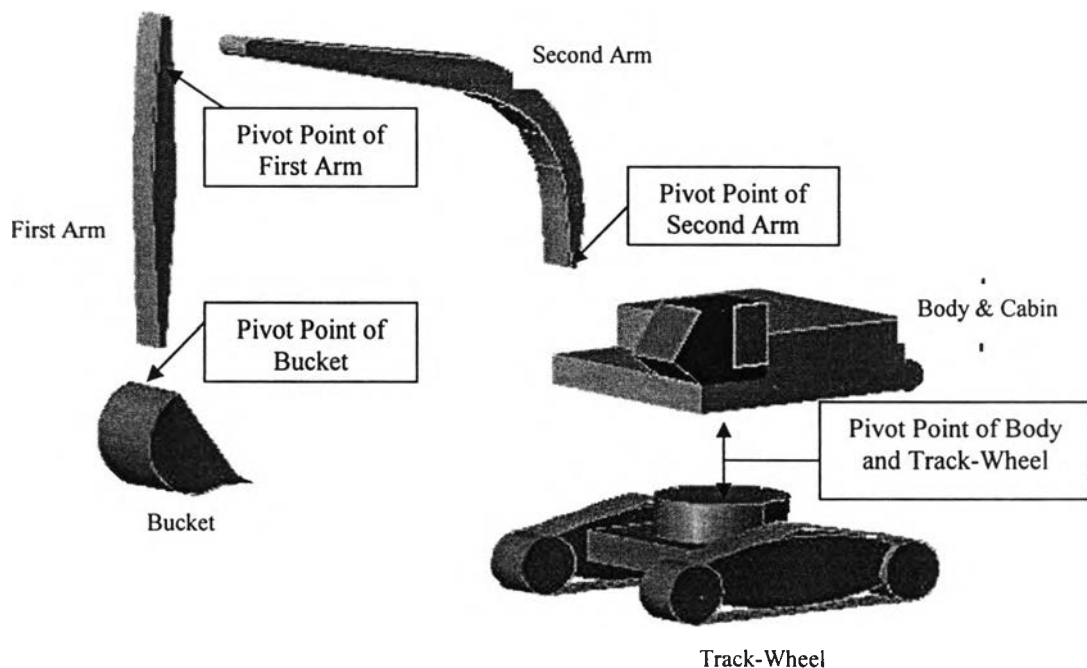


Figure 4.21: Names, colors and pivot points of excavator components

- Relationship among the components

After the pivot points of excavator were assigned, these components must be assigned relationship using a family-tree analogy and hierarchical structure. The hierarchical structure of the excavator as shown in Figure 4.22 can be explained by following relationship:

The bucket is assigned to be a child of the first arm, the first arm is a child of the second arm, the second arm is a child of the body, and the body is a child of the track-

wheel, respectively. The excavator's hierarchy consists of 5 levels, with the top superior of the hierarchy being the construction site, which was assigned to be the parent of the excavator and all other construction machines.

- *Components linking*

The linkage among the excavator components is described in Figure 4.23. It illustrates that the bucket was linked to the first arm, the first arm was linked to the second arm, the second arm was linked to the body, and the body was linked to the track-wheel, respectively.

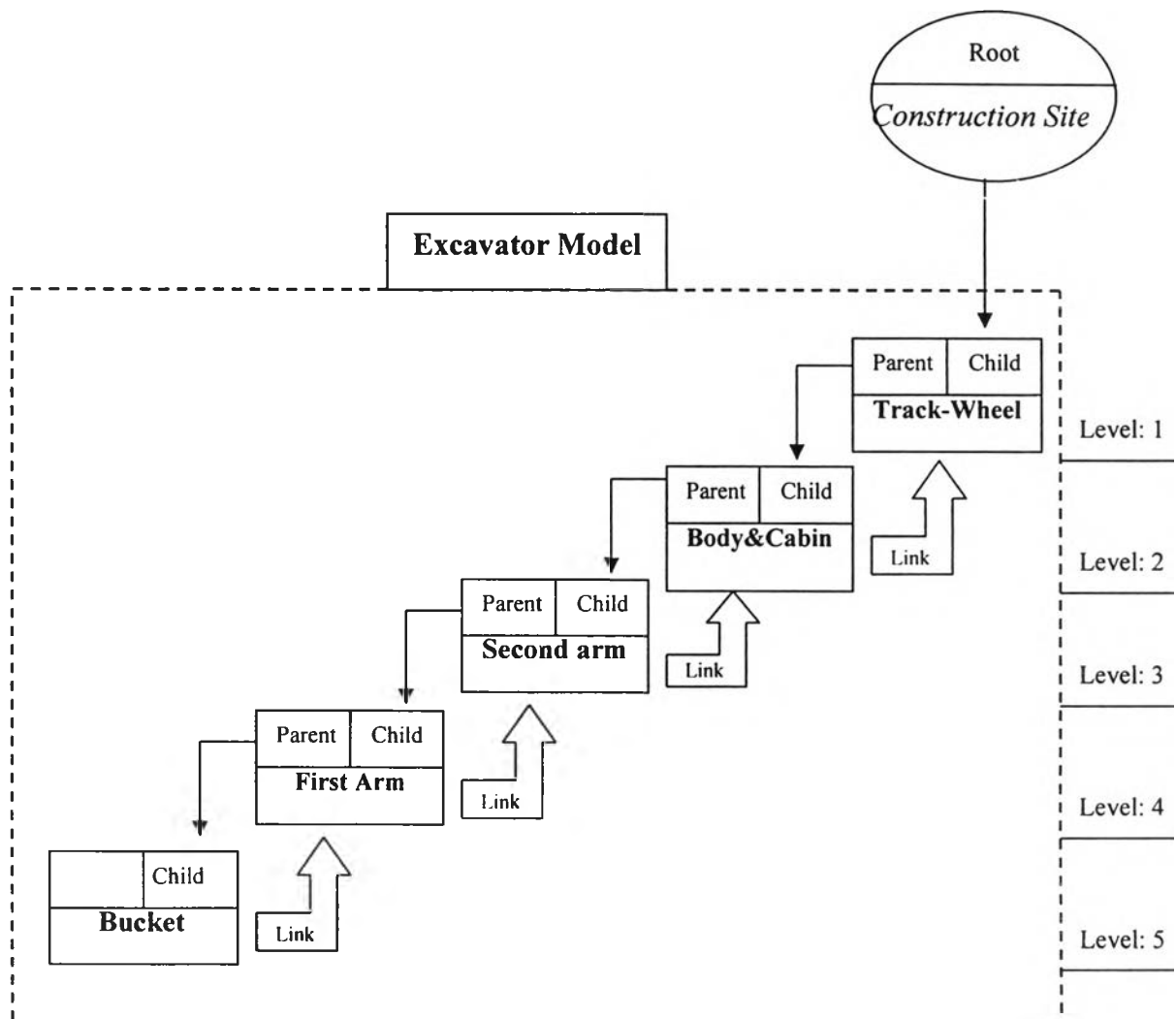


Figure 4.22: Family-tree and hierarchical structure of an excavator model

Pile-Driving Machines

The method for assigning the characteristics and mechanism of pile-driving machine is described as follows:

- Components of the pile-driving machine

The pile-driving hammer consists of three important components, namely 1) rail, 2) tower, and 3) hammer, which are illustrate in Figure 4.23.

- Pivot points of the components

The pivot point of each component of the pile-driving machine is presented in Figure 4.24. Each point was used as a center-point for illustrating actual rotation and movement.

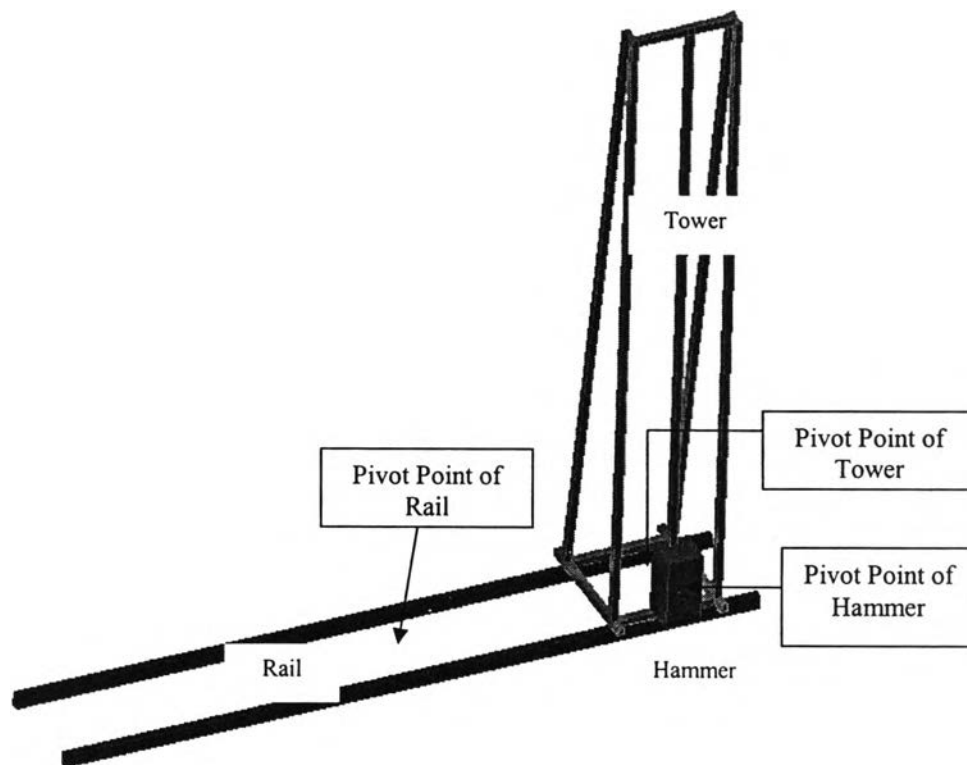


Figure 4.23: Names, colors and pivot points of pile-driving machine components

- Relationship among the components

After the pivot points of the pile-driving machine were assigned, these components must be assigned relationships using family-tree analogy and a hierarchical structure. The hierarchical structure of the pile-driving machine as shown in Figure 4.25 can be explained by the following relationship:

The hammer is assigned to be a child of the tower and the tower is a child of the rail, respectively. The pile-driving machine's hierarchy consists of 3 levels, with the top superior of the hierarchy being the construction site, which was assigned to be the parent of the pile-driving machine.

- *Components linking*

The linkage among the components of the pile-driving machine is described in Figure 4.24. It illustrates that the hammer was linked to the tower and the tower was linked to the rail, respectively.

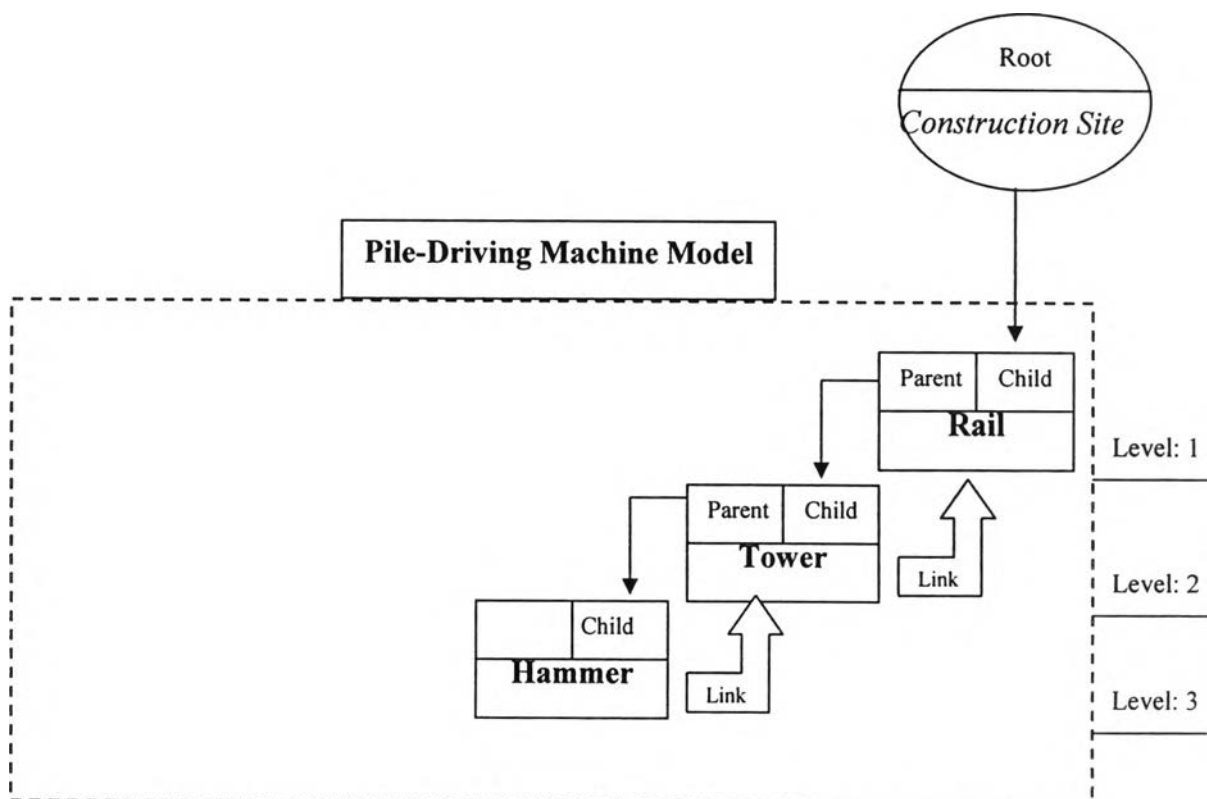


Figure 4.24: Family-tree and hierarchical structure of a pile-driving machine model

Mobile-crane

The method for assigning the mobile-crane characteristics is described as follows:

- *Components of the mobile-crane*

The truck-crane consists of eight important components, namely 1) truck-wheel, 2) truck-body, 3) body & cabin, 4) base-boom, 5) middle-boom, 6) tip-boom, and 7) hook, as illustrated in Figure 4.25.

- Pivot points of the components

The pivot point of each component of the mobile-crane is presented in the following Figure 4.27. Each point was used as a center-point for illustrating actual rotation and movement of the mobile-crane.

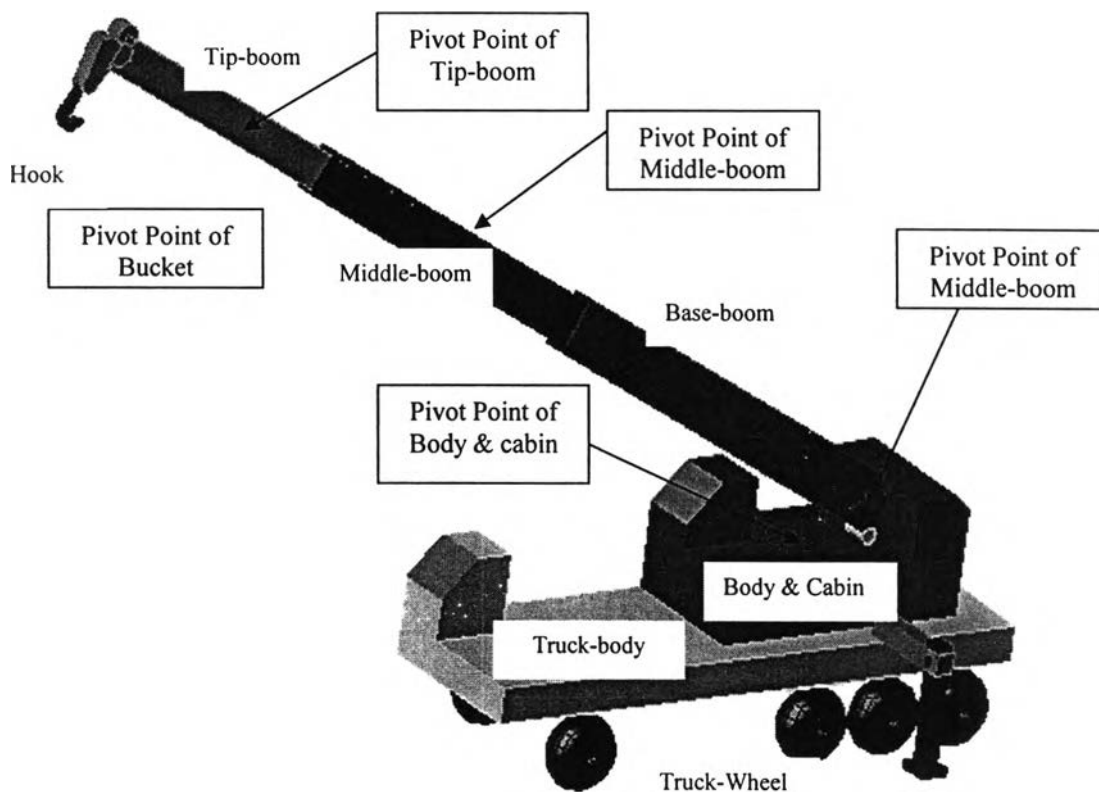


Figure 4.25: Names, colors and pivot points of mobile-crane components

- Relationship among the components

After the pivot points of mobile-crane were assigned, these components must be assigned the relationship by using family-tree analogy and hierarchical structure. The hierarchical structure of mobile-crane shown in Figure 4.27 can be explained as following relationship:

The truck-wheel is assigned to be a parent of the truck-body, the truck-body is a parent of body, the body is a parent of base-boom, the base-boom is a parent of middle-boom, the middle-boom is a parent of the tip-boom, and the tip-boom is a parent of the hook, respectively. The mobile-crane's hierarchy consists of 7 levels, with the top superior of hierarchy being the construction site, with was assigned to be the parent of the mobile-crane and all other construction machines.

- *Components linking*

The linkage among the components of the mobile-crane is described by the Figure 6.26. It illustrates that the hook was linked to the tip-boom, the tip-boom was linked to the middle boom, the middle-boom was linked to the base-boom, the base-boom and the bracing-legs were linked to the body, the body was linked to the truck-body, and the truck body was linked to the truck-wheel, respectively.

The linkages among the components of other construction machines are illustrated in Appendix 3.

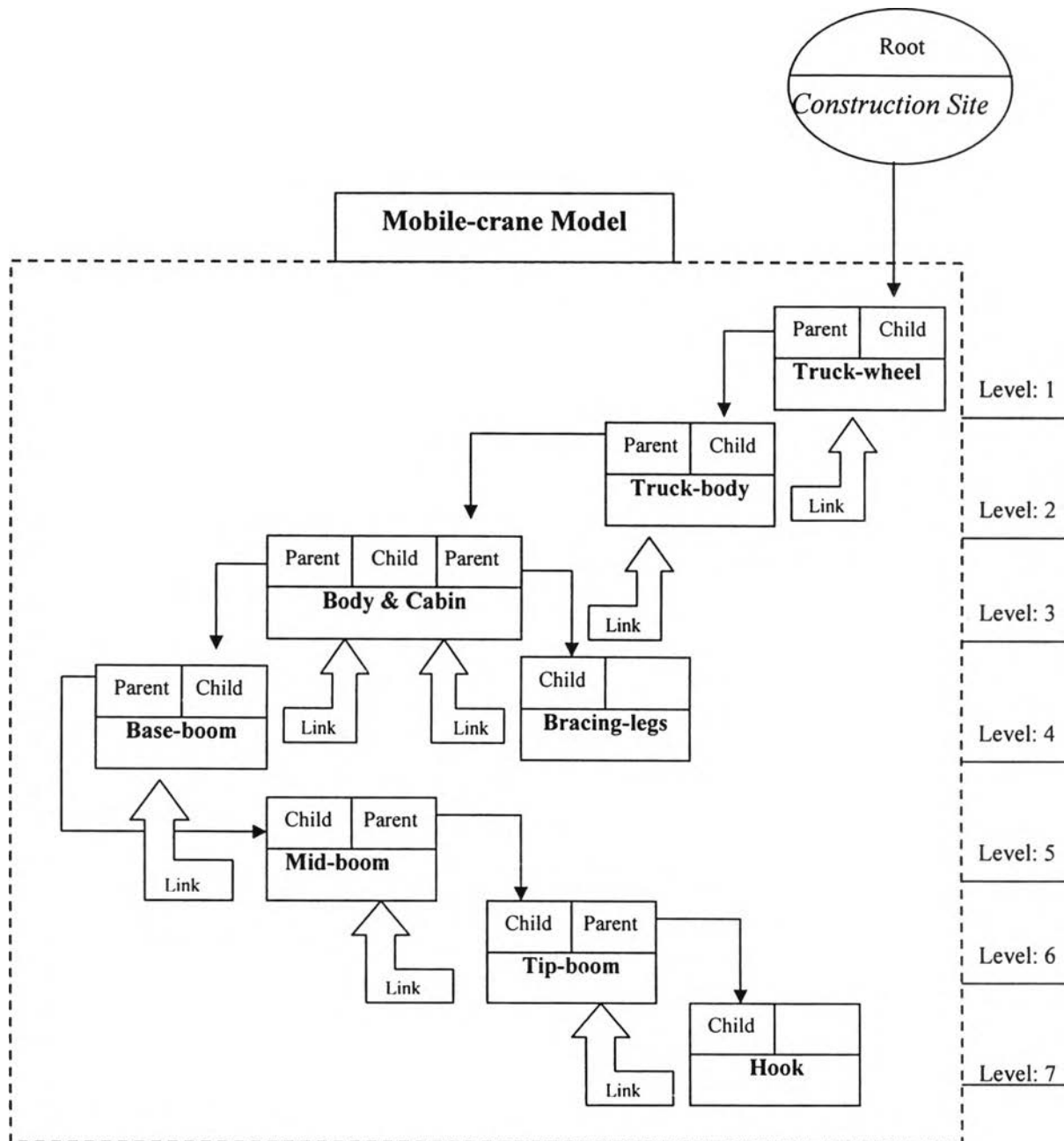


Figure 4.26: Family-tree and hierarchical structure of a mobile-crane model

4.7 Verifying the Characteristics and Mechanism of 3D Models

Before the dynamic 3D models of the construction machines can be used to operate the construction activities, the motion of these models should be verified. It should illustrate their real movements. The movement of these virtual models should be similar to the movement of the real construction machine. One method used to verify the characteristics and mechanisms of the 3D models is examining and considering the changes of the position and rotation of the components that were assigned to be parent and child in the hierarchical structure. If the children (or child) of a parent change the position together with the parent in the same direction, then the characteristics and mechanisms of the 3D models are correct.

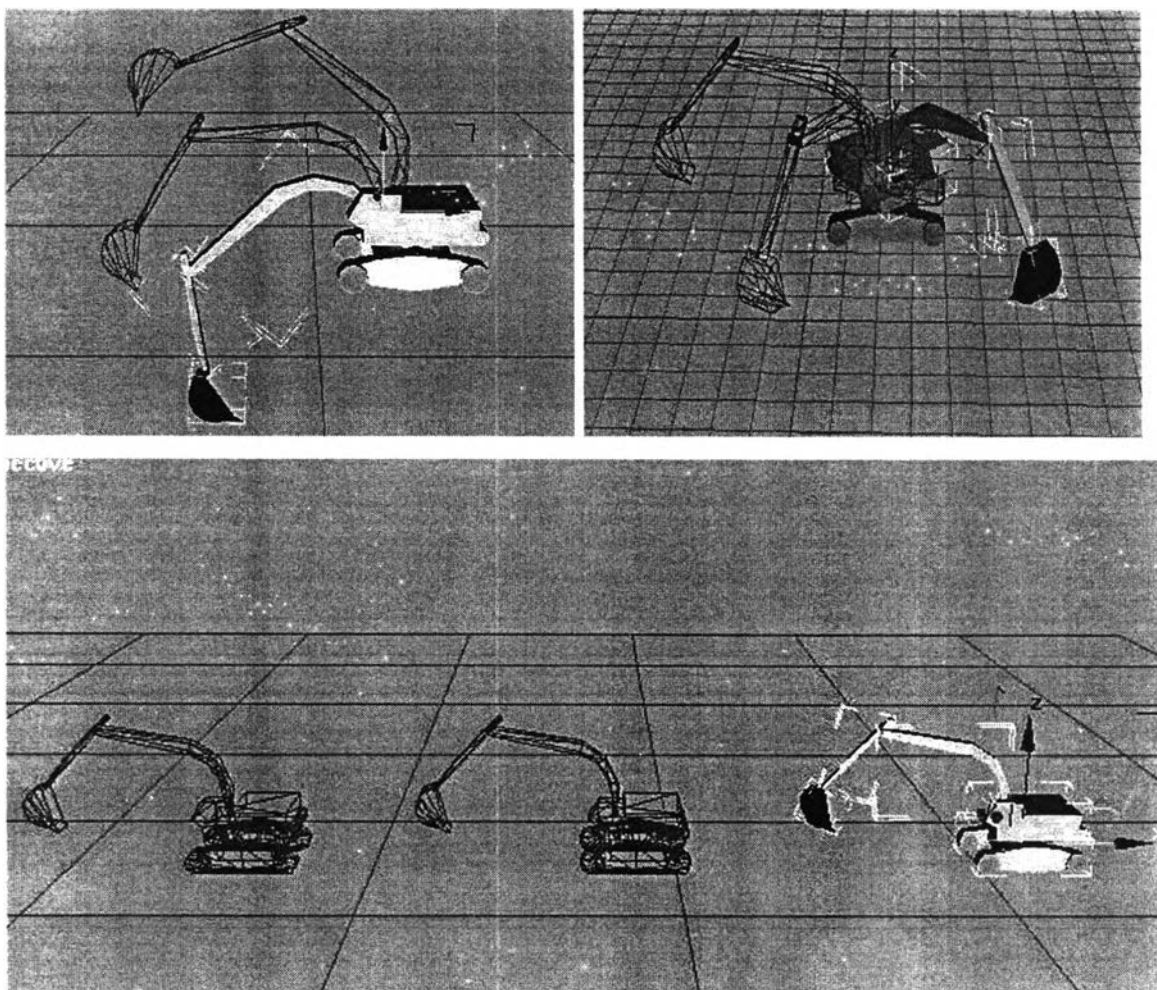


Figure 4.27: Verification of excavator characteristics and mechanisms

Verification of the excavator's characteristics and mechanisms is shown in Figure 4.27: 1) while the second arm of the excavator was rotated around the Y-axis, the bucket and the first arm always rotated together with second arm, 2) while the body of the

excavator was rotated around the Z-axis, the bucket, the first arm and the second arm always rotated together with the body, and 3) while the track-wheel of the excavator was moved in the direction of X-axis, the bucket, the first arm, the second arm and the body always moved together with track-wheel.

Verification of the pile-driving machine's characteristics and mechanisms as shown in Figure 4.28 is described by following examples: 1) the hammer can change its position in direction of the Z-axis with independent moving, 2) while the tower was moved in the direction of rail, the hammer always moved together with the tower, and 3) while the rail was moved in the X-direction, the hammer and the tower always moved together with the rail.

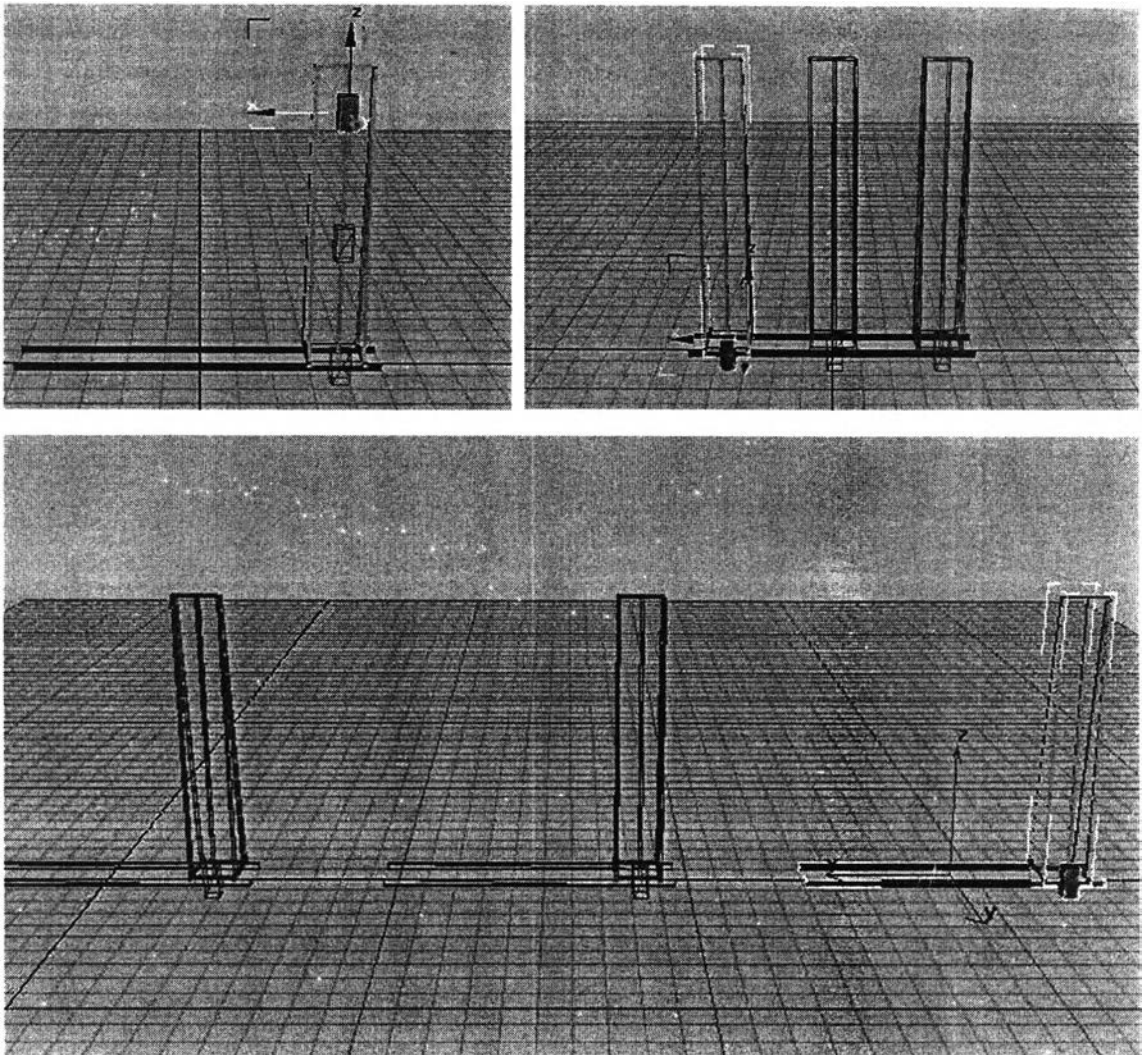


Figure 4.28: Verification of pile-driving machine characteristics and mechanisms

For the mobile-crane, while the parents in the hierarchical were rotated or moved, their child or children were already rotated or moved together with the parents, as shown in Figure 4.29.

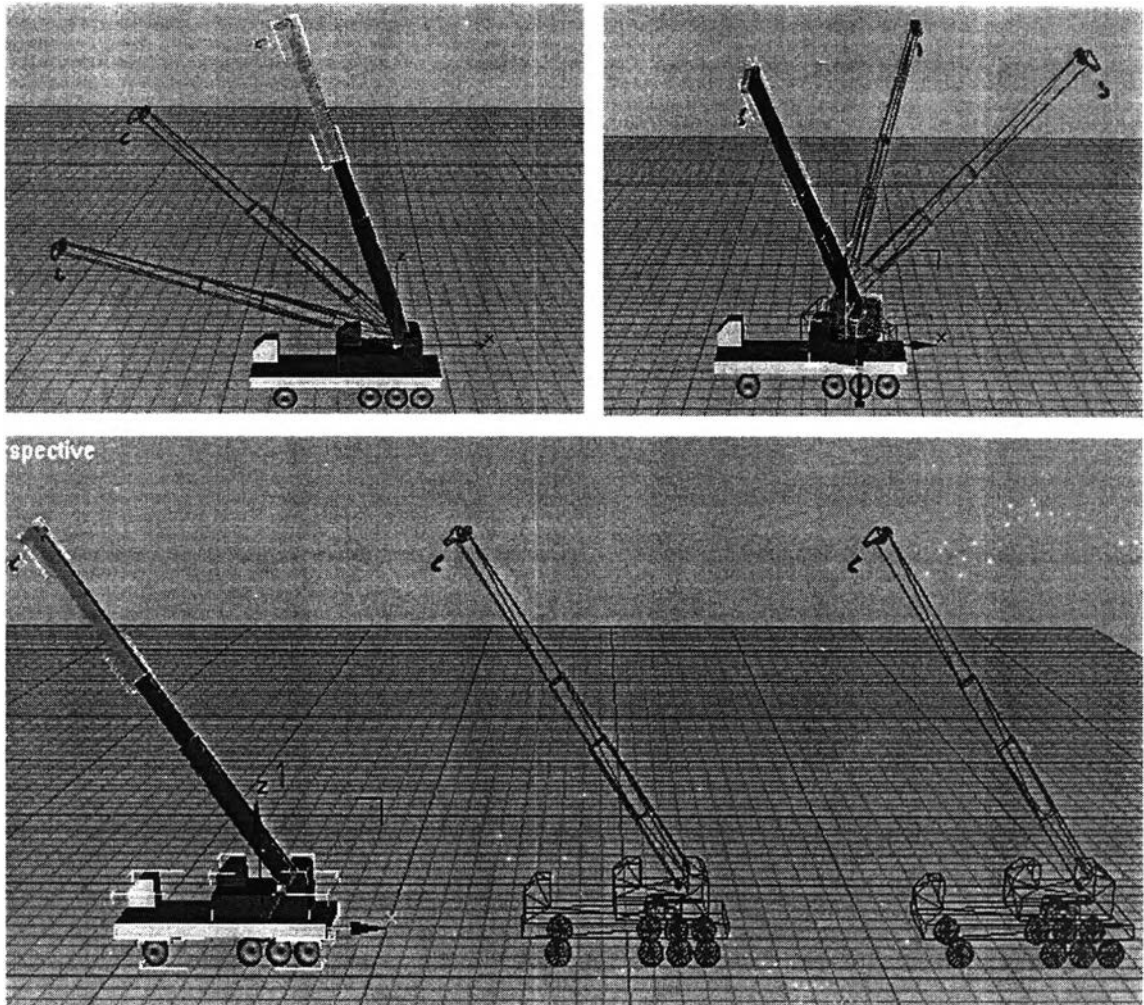


Figure 4.29: Verification of mobile-crane characteristics and mechanisms

4.8 Conclusion

In this chapter, the method of 3D modeling was explained by demonstrating the steps and sequences. The well-known CAD software called “AutoCAD version 2000” was used as a tool for creating the 3D models. Three types of 3D models were created by using this CAD software, namely 1) the main construction machines models, 2) the important components models of factory building, and 3) facilities and temporary work models. These 3D models have been used as important inputs of the Integrated System, which has been generated in this research.

The methodology of characteristics and mechanisms assignment consisted of the following steps: 1) import the components of the 3D models and assign names, 2) assign

the pivot points to the components, 3) assign the relationships and build hierarchical structures, and 4) link the components of the models. The 3D models of construction machines such as the excavator, pile-driving machine and mobile-crane were used as the examples of characteristics and mechanisms assignment. Furthermore, these 3D models were verified by examining their actions and movements, which should resemble the actions and movements of the real machines.