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Prof. Dr. rer.nat. Ernst Rank

Development of the 4D EarthworkViz Toolkit Applied in Road Construction

Diploma Thesis

Yilin Lu

Supervisor: Dipl.-Inf. Yang Ji

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Abstract

In this thesis a prototype of the so-called *4D EarthworkViz Toolkit* applied in road construction is developed. It visualizes the earthwork processes by combining a 3D road model and a 1D project schedule together. It realizes (1) the displaying of project real-time status, (2) the animation of the whole project procedure and (3) the user-interactive animation control.

Keywords: 4D, EarthworkViz Toolkit, 3D road model, project schedule, real-time status, Java3D, animation.

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Contents

1 Introduction

1.1 Motivation

The concept *four-dimensional (4D) technique* has become wide spread in building construction. In the past decades the 4D technology, which binds 3D models and their corresponding work schedules, has been developed rapidly, especially in the fields of construction and project management. Because of its convenience and high efficiency, the 4D technique has been already applied in the practice [1].

Engineers have already got many benefits by using 4D technique in a construction project: compared to traditional tools, e.g. 2D drawings on paper, it saves much time in project designing and controlling, provides increased productivity, improves project coordination capability. In reality, the 4D tools have achieved great success in recent years. *San Mateo Health Facility* [2] and *Construction Director* [3] are two real-world examples, in which 4D technique has been successfully applied. One of the latest known examples is, according to the news report, the 4D-CAD application in the construction of the Beijing National Stadium known during the 2008 Summer Olympics [4].

Now let’s come back to the expression *4D technique*. What is actually the meaning of 4D? And why 4D? As all the related persons involved in construction industry know, a construction project is a dynamic process with a high degree of complexity. Within the whole project period, there are dynamic relationships among the work duration, cost, resources and work space. Many of them are uncertain or random. Nowadays, the size of construction projects become more and more tremendous while the deadlines of project scheduling and project execution become closer and closer. It leads to the demand of highly efficient project planning and scheduling, within which the sequence of the work processes ought to be planned closely and might be temporarily overlapped. As an inevitable result of such a construction schedule, many work steps have to be coordinated at the same time. So it is important to properly distribute the work time and space on the construction site to gain a smooth workflow. An insufficient project schedule will probably make the whole workflow too vulnerable and will certainly lead to high cost.

Fortunately, the *4D technique* has been introduced into construction industry. This technology adds an extra *time* dimension to the 3D Computer Aided Design (CAD) technology, forming the 4D CAD model. 3D CAD is a technology which describes the geometric spatial properties of construction models. To go further, the 4D CAD is aimed at the characteristics of construction management, focusing on describing the construction progress of the project. The 4D CAD is a new development in the field of CAD techniques. From above we can see two key points in the applying of 4D CAD techniques: 1. 3D CAD model; 2. Used in construction scheduling management. To the point one, various 3D CAD tools have been developed in the past years. Then how to link the 3D CAD model with the project scheduling management is the problem this thesis is mostly concerned about, especially in civil engineering projects.

Project scheduling is a very important branch of construction process management, meanwhile it is a critical part related to the project cost controlling. The traditional tools are not unexpectedly abundant: Gantt Charts [5], Net Plan Analysis [6], Line of Balance [7], Histogram [8], etc. It seems that these tools are capable of meeting our needs. But the tradition has not considered that the complexity of construction processes has been increased enormously, for example, we would have put spider web-like cables and pipe network into a construction project; we would have arranged some professional team to dedicate decades-long time to do the management and maintenance work. In modern time, there might be hundreds of people and thousands of work tasks who and which are involved in a project. The engineers might come from different countries and communicate with each other through countless phone calls and emails, while at the same time new machines and technologies will be put into work. On the other hand, due to their own limits, the traditional tools are not able to accurately represent these high dynamic processes, and can not vividly express the complex relationships among the work processes. Furthermore, they can hardly solve the possible problems emerged during the workflows, not mentioning the possible emergencies occurred in the construction process. Therefore, it is meaningful to find a scientific, efficient, reasonable construction management tool for the current modern construction projects, especially for the great and complex ones. Since the traditional tools are unable to meet our demands, we have to turn our face to the new technology, namely, the help of the *4D technique*.

1.2 Problem

Concerning the construction industry, there have been great opportunities in recent years. Since the bankruptcy of the investment bank Lehman Brothers in September 2008, the whole world has been oppressed by the fear of economic recession. In order to stimulate the economy, most of the large countries announced to expanse the investment in the infrastructure construction and maintenance, especially in road construction [9]. These projects would benefit a lot from the employment of 4D tools. The following question is, which one shall we chose? Or if there were none, what kind of 4D tool can support the construction management in order to enhance the productivity on construction site? Though many pioneers have made great efforts in developing 4D tools, most of the models are successfully applied in the building constructions which possess great vertical height. For example, a new information system platform named 4D-MCPRU developed by the cooperation of the TsingHua University and the Hong Kong Polytechnic University [10].

If we directly apply the present 4D systems in the projects such as construction of highway or railway facilities, we will inevitably encounter difficulties, because such projects have their unique properties other than the vertical height. Firstly, they are located in a horizontal plane; secondly, they are linear or curvilinear geometric objects; thirdly, in practice, highways and railways are always constructed sequentially along the road’s meandering direction, thus, the work activities are subject to the elements of natural topography.

The available 4D software components have been designed to adapt the characteristics of the buildings which have vertical work zone, e.g. in high building construction. That means these buildings mostly have repetitive artificial segments. On the contrary, the horizontal construction projects are subject to the complex natural ground conditions. In the earthwork phase, to realize the designed purpose of a road, the natural soil should be cut or filled. Unfortunately, there was not any suitable 4D tool supporting infrastructure construction management.

Now we decided to develop a visualization toolkit *EarthworkViz* with Java3D. With this toolkit the data of the whole project can be integrated and linked with a 3D road model: the information of construction progress, time scheduling.

2 State-of-the-art

2.1 Introduction of road construction

Road construction has a long history. By about 10.000 B.C., rough pathways were used by human travelers [12]. With the explosion of the human population and the increasing migration in different regions, a great number of vehicles have been produced and correspondingly the modern road construction method has been developed.

2.1.1 An outline for a typical road construction process

There are many different road construction types. Different project may have different type. For an individual road the type of construction is subject to the following conditions:

- road design purpose (speed, traffic volume, etc.),
- geological and environmental conditions,
- available construction equipments,
- allowed budget and project duration.

Though in different road construction projects each step plays different roll and the relationship and interaction between the steps are not the same, a road construction project consists of a set of basic steps. They can be summarized as:

→ terrain survey and (pre) road design,

→ construction set-up (site clearance, dump site, equipment, etc.),

→ earthworks (excavation, transportation, filling and compaction),

→ bridge construction, if necessary,

→ drainage structures,

→ road pavement construction,

→ placement of road surfacing and road furniture,

→ landscaping,

→ release of the road.

2.1.2 A brief description of the construction steps

The first step of a road construction is *terrain survey and (pre) design activities*. It includes the property acquisition, public utility and property adjustments, cost estimates, pre-construction investigations, work planning and commencement. This step is very important and may take considerable time: the property acquisition may be a sensitive issue for involved land owners; the public utility adjustments in urban areas may be complex and extensive; before setting out to work the detailed cost estimates for all of the construction jobs are required; the geotechnical data and the ground conditions ought to be collected during the pre-construction investigation phase; the work schedule must be done prior the project commencement and should be periodically updated during the project progress. And after the site offices, the construction of compounds to ensure security for plant and materials and the rooms for the workers are established, the project will start off.

The following step is the *construction set-up*. Of course it is subject to the different condition of different projects. In general, the site will be cleared at first. The clearing work involves the removal of vegetation such as grass, brush, trees and stumps, as well as the removal of old buildings and structures. For these activities the equipments such as bulldozers, scrapers and graders may be put into use. The cleared material should be considerably treated, for example, timber may be burnt or transported away and disposed of as landfill and topsoil may be dug up and stored for future landscaping. After the clearing work, the centerline of the road can be established.

Then there comes the step of *earthworks*. As a common sense, the high ground should be excavated and the low ground should be filled to form the rough profile of the designed road, then the finished surface should be shaped to design levels, followed by excavating for the drainage works. In the cutting process the ground will be excavated to the depth necessary to reach the formation level and the un-refillable material according to geological conditions for the future work such as landfill will be carted away, meanwhile the haul suitable materials will be carted to the filling areas, if there is any excess cut material, it should be suitably disposed. In the fill areas, firstly, if there is water from depressions and any unsuitable underlying material, they should be drained and disposed, then the fill materials should be spread in horizontal layers not more than 250 mm thick, and these layers should be thoroughly compacted to required density.

Following the earthworks, there are still several steps to be accomplished such as *bridge construction, drainage structures, pavement construction* and finally the *placement of road surfacing* and *the release of the road* which are not supported in the purposed *EarthworkViz Toolkit*. In this toolkit only the earthworks step is involved.

2.2 2D and 3D road models

2.2.1 The delineation between 2D and 3D

Traditionally, designing drafts and working drawings are drawn on paper and consist of points, lines and planes, possibly in different colors. All of them were in 2D version, among which the most important are site plans and profiles. Due to the rapid development of computer science, the architects and engineers can create more realistic images of new buildings and other structures, the engineers can also make the blueprints with the help of computers. During the project designing phase, we can already see the aesthetically rendered pictures with 3D effects. But such 3D pictures are only used to show the final effect of the buildings and structures, and they will not help the detailed project designing and execution. On the side of engineers, many of them are still used to the traditional 2D drawings. Computers are only used as complementary tool to save the heavy repetitive manual work. In most cases, the construction designs still have to be expressed by the traditional 2D plans, though they are created by the computer-aided design software.

The problem is that even if we use the CAD software to create the 2D blueprints, they are still a bunch of abstract points and lines. For example, in the field of building construction, none of the 2D construction drawings itself can tell which lines represent walls, windows or doors; in the field of road construction, none of the 2D construction drawings itself can tell which lines represent travel lanes, gutters or drainages. They have to be defined by the engineers. If one geometric element in the horizontal alignment has been changed, the corresponding plans must be updated to ensure the consistence of the entire project plan. Even a small project might need hundreds of drawings. Minor changes also require significant cost and are time-consuming. Moreover, these drawings can not explicitly indicate construction costs. Engineers have to make bill of materials and update it with continuous progress of the project.

In the field of building construction, the concept of *Building Information Model (BIM)* was introduced by Professor *Charles M. Eastman* based on the term *Building Product Model* [13], which had been extensively used in the professor's later book [14]. This is a tremendous progress in the traditional CAD technology. These 3D BIM models are object-oriented. One can easily specify the building components and the interrelationships between them. If changes occur, the environmental elements will be changed correspondingly.

Nowadays, some of the powerful CAD systems [15] can generate 2D execution plans from 3D model in building construction. In Infrastructure construction, 3D CAD systems have not been applied widely. A recent research will be introduced in details in the section 2.2.2.

Actually the 2D drawings and 3D models are complementary to each other. The 2D drawings have their advantages: they reduce the design complexity; it is easy to link a project schedule to a 2D drawing, but it is difficult to directly link a schedule to a 3D model. Meanwhile, the 3D models can overcome most of the disadvantages of 2D drawings: The site plans and the profiles are not combined explicitly. One ought to imagine in the mind what the whole construction looks like. It is always difficult if he is not an experienced engineer. Moreover, the 2D drawings might be made by different people thus might be error-prone. There may be potential geometric conflicts among different drawings.

2.2.2 A current 3D road construction earthwork model

In road construction, the traditional method to design a road is to draw the horizontal alignment plan by determining the radius of each adjacent section's curvature and to draw the vertical alignment plan by determining the gradient adapted to the surveyed geometric condition and road designs. The road cross section profiles will be determined according to the national standards. In the current research efforts, a new road modeling and earthwork assessment system *ForBAU Integrator* has been developed to generate 3D road model from 2D road design plans [11].

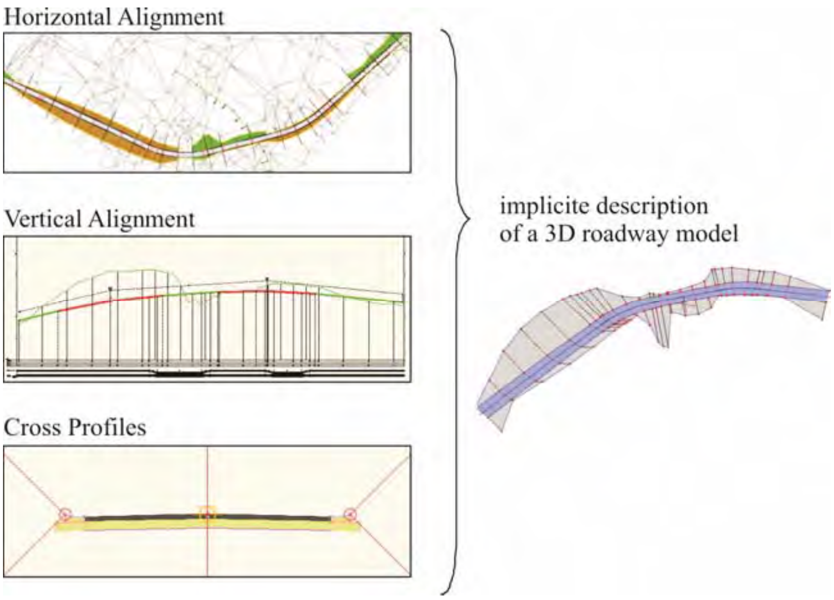

Figure 1: Relationship between 2D drawings and 3D model

The problem is that the 3D road geometric representation can't be used directly. It must be computed *(Figure 1)*. Another problem is how to merge the 3D road model with a digital terrain model (DTM). The 3D terrain model describes the surface of the construction area before the project starts. Such a terrain model will usually be created by surveyor with provider-specific modeling tools or with a road design tool. The terrain model can be described as data of a collection of points and the connections between theses points. The data exchange formats are provider-specific formats or as a part of the LandXML standard [16]. A further important 3D model is the subsoil model. It contains description of the subsoil layers. The subsoil layers are interpolated surface between the drill holes. The subsoil properties are linked with each subsoil layer. The *ForBAU Integrator* has been developed to integrate these models into one holistic model for generating the simulation source data.

In the earthwork phase, cutting and filling are of particular interest. The information of cutting and filling materials is stored in the 3D holistic road model. The traditional mass-calculation method is to calculate the volume of the materials to be excavated or to be filled between the two cross-section profiles by multiplying the average cutting or filling areas by the distance between two profiles.

A so-called *voxelization* algorithm has been developed to evaluate the 3D holistic model and to generate simulation source data *(Figure 2).* Firstly, the voxelization algorithm sets a 3D evaluation grid in the holistic model. Then, the algorithm evaluates each grid point, to which subsoil layer it belongs to. In the next step, a voxel structure will be created, and each voxel has a specified position and a specified subsoil property. Finally, only the voxels inside the road model will be exported to the simulation tool.

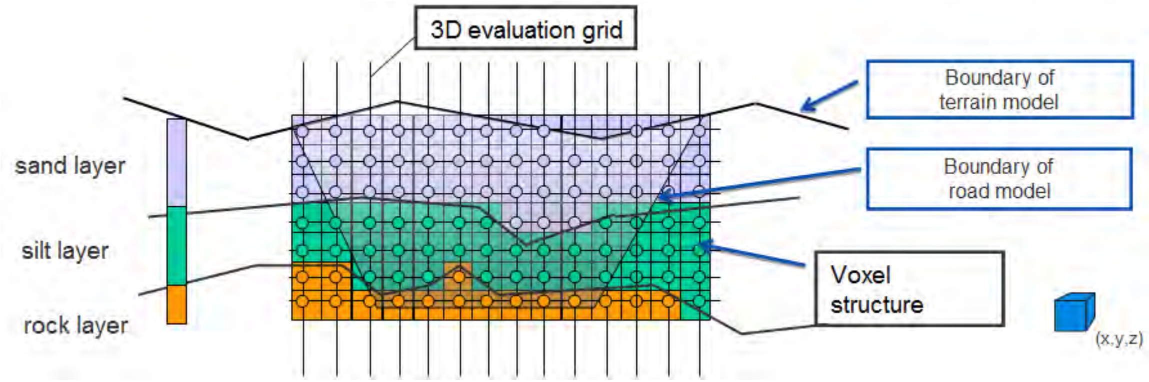

Figure 2: The voxelization algorithm

2.3 1D project time schedule

In practice there are two main targets to be fulfilled: Firstly, the project ought to be completed in the required time limit; secondly, also a particularly important task, is, the monitoring of the project cost. The past experience shows, that most of the original cost plans had been exceeded by the end of the projects.

Almost every project has a determined deadline. Even though the activities in a project can be moved a little and the deadline maybe not so strict, in most cases their tolerance is very limited. The strict following of the time schedule is somewhat the key of a successful project implementation.

Nowadays people use various techniques to make time schedules in the road construction. For example, the well-known *Gantt Charts* (activity-based scheduling method) [5] is widely adopted in Germany; meanwhile, the

Line-of-Balance scheduling (location-based scheduling method) [7] also has its own advantages and is accepted by many people.

2.3.1 Gantt Charts

This kind of time scheduling has been put into use for many years and is mature. The first known Gantt chart was developed in 1896 by *Karol Adamiecki*. *Adamiecki* did not publish his chart until 1931. The chart thus now bears the name of *Henry Gantt* (1861–1919), who designed his chart around the years 1910-1915 and popularized it in the West. In the 1980s, personal computers eased the creation and editing of elaborate Gantt Charts. Figure 3 shows a schematic example of Gantt Charts.

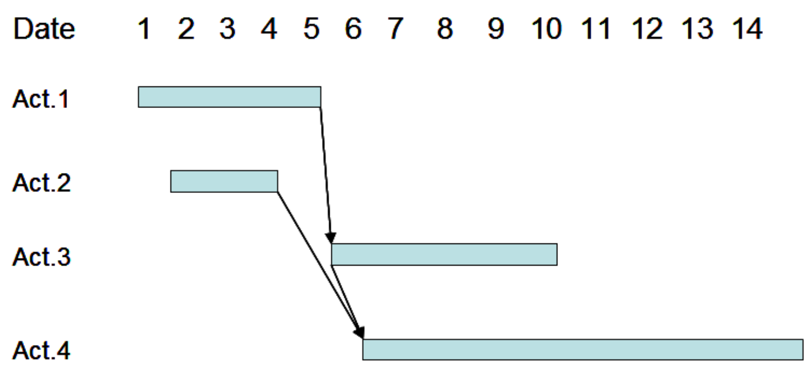

Figure 3: A schematic Gantt chart

To learn how to build a Gantt chart, firstly, one ought to know what the critical path method is. The Critical Path Method (CPM) is a mathematically based method to schedule activates in a project [6].

The duration of the whole project and the relationship among the hundreds of activities of this project play a decisive role in the total project cost. To a large extent, the CPM can be used to assist the project manager to find an optimal project schedule.

The real projects are always very complicated. They may contain hundreds of or thousands of activities. Some large projects may even have subprojects. To deal with all these activities at the same time is almost an impossible mission or it would probably take a lot of time and effort to accomplish this task. Obviously, every project has a set of critical activities, which influence the entire project progress and duration. Together the sequence of these critical activities is called the critical path. If all the activities on the critical path are identified and properly managed, the entire project would be under control. The final network is often presented in a bar chart known as Gantt chart that describes the proposed schedule of the project. This can be used as the master schedule, on which the plans of more specific nature such as detailed short-term plans are based.

In practice many construction companies use software tools to create the Gantt chart. Among them the *Microsoft Project (or MSP)* is most popular because of its high price-performance ratio. Some companies also use other commercial software such as *Powerproject* and *Superproject*. Both have much more powerful functionalities, but correspondingly, they are much more expensive.

2.3.2 Line-of-Balance method (LoB method)

Unlike Gantt Charts which is an activities-based planning method, the LoB technique is a scheduling method, which takes the positions of the linear construction site into account.

In the early 1970s the basic concepts of LoB have been firstly applied in the construction industry as a planning and scheduling method. Line-of-Balance is a graphical scheduling method for continuous flow of activities, which is especially suitable for construction projects because of their high degree of repetition, such as highways, high-rise buildings, long bridges, tunnels, pipelines network, etc. These construction projects exhibit repetitive characteristics. Each kind of them contains some certain basic units, which are repeated several times within the same project.

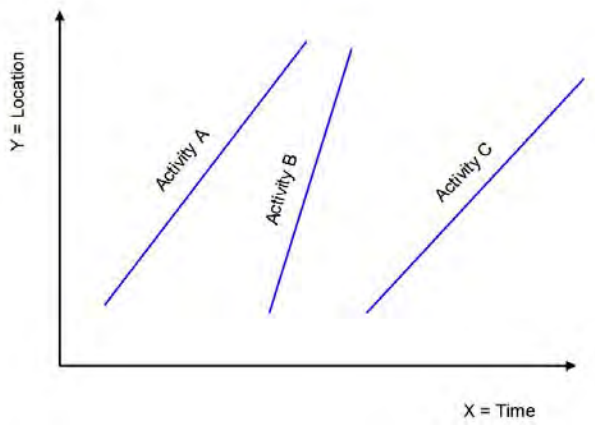

Figure 4: A schema of LoB

In Figure 4 the x-axis represents time, the y-axis represents number of units, length, area, volume or even the combination of all of them. In road construction, the y-axis represents the length of the finished road section. The LoB method assumes that within a limited period an activity has a constant production rate. With this assumption the work flow can be drawn as lines in a diagram. The slope of the line is just the production rate of an activity. It is expressed in terms of units per time.

In practice a project can hardly keep up with the planning entirely. The actual implementation can be drawn as the actual line next to the original planed line. This characteristic of the LoB allows the analysis of deviation of the project implementation. With the assumption of the same slope as the actual line the forecast of the implementation can be made by extending the actual line to the project end. The relationship between the forecast line and the original line can be easily observed. If there is any conflict or collision, the project scheduling would be adjusted or corrected or remade.

Actually in practice these location-based scheduling methods are not as popular as the activity-based ones. That doesn’t mean that the location-based planning is worse than the activity-based planning. There are many reasons. For example, people are already used to the early developed activity-based planning and tend to use it further. And the absence of strong software packages to support the realization of the location-based planning is another important reason.

Now there are on the market only a few commercial software packages available for the road construction. One example of them is *DynaRoad* [17]. DynaRoad is project management software specially developed for optimizing the costs related to earthworks. It supports to calculate mass balance and haul distances, and evaluate costs of different design and planning alternatives. It can also create optimized schedules and support the monitoring of actual hauls and the control of project progress.

2.3.3 Comparison of Gantt Charts and LoB

Advantages and limitations of Gantt Charts:

- Advantages:

After several decades of theoretical developing and practical applying in the industry the Gantt Charts have become a common technique for representing the phases and activities of a project work breakdown structure (WBS) and proven to be a very useful project management tool that provides a clear overview of the project scheduling.

They provide an excellent presentation tool to illustrate the whole project scheduling. The time is explicit and linear, all tasks are visible in relationship to others, the groups of milestones and deadlines are shown, and the individual resources scheduled to time is added to the charts as well.

They can show how much of the plan has been completed currently by displaying the status of an activity in the same or a parallel bar or with different colors. That means the status of the project can be under control of the project planner.

Gantt chart is the most favorite scheduling method to many people according to the strong tradition, especially to planners and executives, who are in charge of the construction scheduling.

- Limitations:

Gantt Charts cannot show the results of either an early or a late start in the activities. The technique of the earliest start date and the latest start date is difficult to be used, because there would be two sets of date for the same activity.

The Gantt chart does not reflect the true project status because some activities behind schedule sometimes do not mean that the whole project is behind schedule. And without special notations or colors the critical path is difficult to be recognized.
Gantt Charts do not show the different possibilities involved in performing the activity. If a project has several scheduling possibilities, it is hard to be shown in one single Gantt chart. Each possibility requires a redrawing of the Gantt chart.

The resource assignments cannot be easily integrated. Though the software packages used today have already included such functionalities, it doesn't look natural to the Gantt Charts method. Therefore the Gantt Charts do not represent the size of a project or the relative size of work elements. If two projects are the same number of days behind schedule, the larger project has a larger impact on resource utilization, yet the Gantt does not represent this difference.

Although Gantt Charts are useful and valuable for small projects that fit on a single sheet or screen, they can become quite large for projects with more than about 30 activities. Larger Gantt Charts may not be suitable for most computer displays. A related criticism is that Gantt Charts communicate relatively little information per unit area of display. That is, projects are often considerably more complex than can be communicated effectively with a Gantt chart.

Advantages and limitations of Line-of-Balance method:

- Advantages:

The presentation format of LoB is two-dimensional. Thus the project planners and managers can explicitly see the progress of the project scheduling and the actual project implementation status.

The actual line can be drawn next to the original planned line. The planner can easily recognize whether the project is behind schedule. The LoB is especially suitable for a linear and repetitive nature (It can also be used for non-repetitive construction project.)

The basic assumption of LoB for a linear project is that the rate of production of each activity is constant. To achieve the most efficient project implementation the optimum output rate of a crew of optimum size (so called *natural rhythm* of an activity) has to be considered. Any deviation from the rate will cause idle time for labour and equipment. With the help of LoB the planner can take charge of the project implementation and keep the project scheduling efficient.

Based on a combination of network technology, the LoB can easily perform the interrelationships and interdependencies of activities. The dependencies among activities include the time dependencies and the space dependencies. The LoB shows them explicitly.

The distribution of resources (labours and equipments) is particularly important to the project managers. They must not only know the total available resources but also make sure that the resources are distributed to the activities as smooth as possible. For example, if the hiring and firing of the crews are too frequently when the project manger does not have a clear overview of the human resources on construction site, it may cause delay of the whole project and unnecessary cost.

In a real project, resources are always limited. The LoB can also help to solve this problem.

The milestones and the critical path can be easily recognized in the LoB diagram.

The LoB provides better ways of analyzing different scheduling possibilities and different project durations. It may quickly check the schedule feasibility, provide the real-time report and optimize the control actions by choosing the LoB lines without conflicts. The risk of scheduling is reduced as well.

- Limitations:

Large projects always have a big number of activities. If the LoB scheduling is to be used in such projects, there would be a large LoB diagram with many lines in it. These lines may even crossover each other. It would be hard to be plotted or to be displayed on a screen. And the activities would be also very difficult to be recognized. That means, people can only see a total mess and thus the LoB scheduling loses its original advantages.

There is lack of efficient supporting software packages. It has become the biggest obstacle on the way of wide spreading of the LoB scheduling method. In road construction there are only a few commercial software packages on market and they are not as mature as the software for the Gantt chart.

Many of the project teams are reluctant to accept new ideas. People always prefer things they are familiar with. The focus on controlling the project, that the LoB brings, is new thinking for many project planners and managers. The accompanying greater transparency towards management and the client may scare some people.

Conclusion:

The two construction scheduling methods, activity-based Gantt Charts and location-based LoB, have their own advantages and limitations. The Gantt Charts are being applied in the construction industry since several decades and have been widely accepted by the project planners and managers. Yet it has fatal limitations because of its one-dimensional expression format. In comparison, the LoB scheduling has relatively many advantages, yet the lack of supporting software packages become the main obstacle in its developing and the wide acceptation.

Though through the comparison it seems that the LoB method might be better than the Gantt Charts method in road construction projects, the LoB method has not been widely accepted in the construction industry. In this thesis the Gantt Charts method will also be adopted.

2.4 4D road model

Similar to the situation of the 3D road models, most of the current 4D systems that have been already developed or are still under development are for high-building constructions whose 3D models consist of vertical and artificial elements. However, the demand of efficient 4D models for highways and railways rises urgently.

As previously mentioned, road construction has its own characteristics: it ought to be carried out in a horizontal work zone, it is located in a relative wide work area, the work processes are mostly non-repetitive, and the projects are subject to the natural topographical conditions (*Figure 5*).

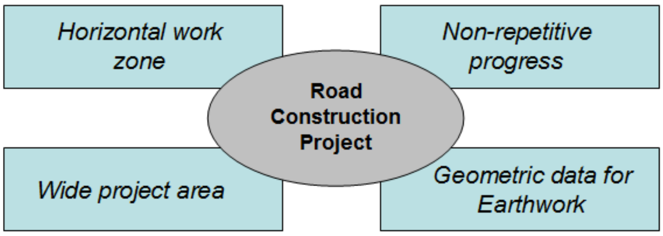

Figure 5: Characteristics of road construction projects

So far, mature 4D road models are currently rarely available. Most of the 4D systems have been developed for the high-building construction; there is still no efficient 4D model applied in the horizontal construction area. The available 4D systems focus on providing simple expression of 3D completion status of project schedules. In other words, most of the current 4D systems provide mainly visualization functionalities, and even though, the visualization function is not adequate, because the terrain model has not been fully divided according to a sophisticated time interval. Since project schedule and 3D models use different data exchange formats, it becomes difficult to link them. An interface should be established to make it, and this procedure is complicated.

The 4D tools suffer from some large restriction. The existing project schedule management softwares provide functionalities e.g. schedule progress control. But all of the available 4D software packages merely link the established 3D models with their corresponding time points. The project status at an arbitrary time point can not be shown. Because of the inadequate flexibility of the current 4D models, the schedule management functions become weak and the users are reluctant to apply 4D models on construction sites.

3 System design

3.1 Goal

The so-called 4D *EarthworkViz Toolkit* is intended to visualize the excavating and filling processes of the earthworks in road construction. The focus is to combine the 3D model with the 1D project schedule. Moreover, different visualization possibilities resulted from different schedule plans can be estimated and compared.

Actually in the real world many other factors must be considered to judge the quality of a project schedule, such as the on-site resources and labours, the logistic of the work flow, the total project costs, etc. To consider all of them would be a tremendous task, which is too complicated. In this thesis only the project duration would be taken into consideration and we account that a shorter duration would be better.

This toolkit ought to fulfill at least three targets: Firstly, the status of the earthwork processes in a road construction project at any arbitrary time point would be visualized in the form of 3D road model. Secondly, the earthwork transportation processes will be animated within a proportionally reduced time unit, to show people who wish to have an overview of the whole project, for instance, unprofessional persons such as project owners and clients, and professional persons such as the civil engineers and logistic managers. Thirdly, this 4D tool should allow the animation control by user interactively. That means the user can change or reset the link of 3D model to 1D project schedule. In a project, there might be more than one possible relationship or sequence among some activities, if the activities are not the critical ones. This 4D toolkit will be capable of visualizing all of the possibilities.

3.2 Simplified case

A real-world project is always tremendous and complicated, especially a road construction project. To develop the *4D EarthworkViz Toolkit*, it is better to start with the simplest case. As introduced in section 2.1, to construct a road, earthworks are a necessary step. There are two important types of activities, namely, cutting and filling. Some of the excavated earth materials can be reused for filling areas, some to the disposal, and the excess part, if there is any, to be sold or treated in another way.

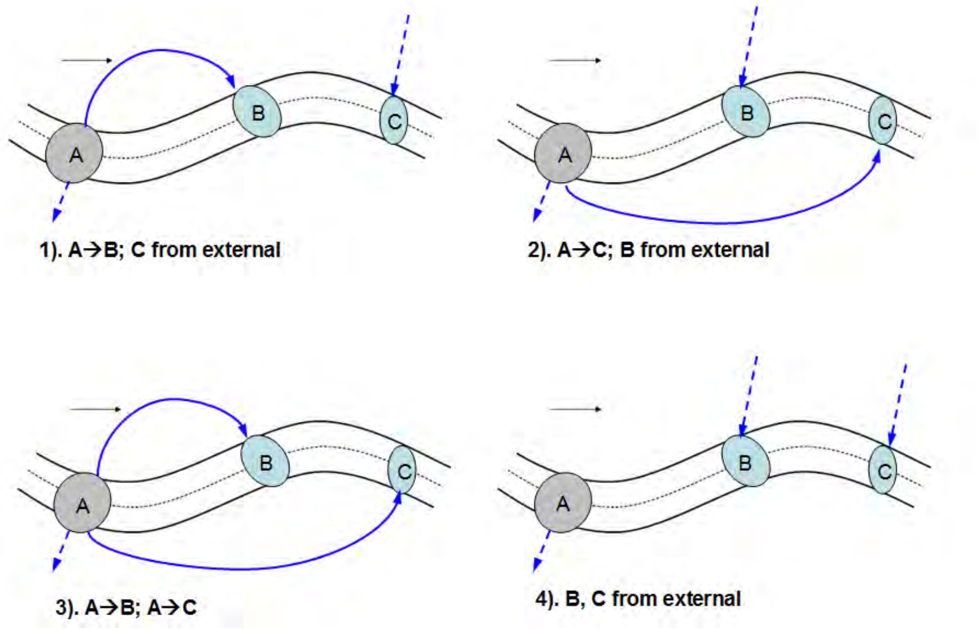

Figure 6: Four cases of the material movement among areas A, B and C

In a simple example (*Figure 6*), in the area A the earth should be excavated, the area B and C should be filled. There are some cases: The materials of A will transported only to B, or only to C, or to both B and C, or to neither of them, and the proportion of the amount to B and C can be different. It depends on many factors, for example, the distance between the cutting and filling areas, the transportation vehicles, the labors or the geometry conditions, etc. Among them the case 3 is the most interesting. In the following this case will be illustrated. The others can be visualized analogously. And commonly, we assume that the excavated volume of materials is equal to the sum of filling materials: $V_a = V_b + V_c$

3.2.1 Concept overview of 4D EarthworkViz Toolkit

The *4D EarthworkViz Toolkit* ought to be able to link the 3D geometry information of the road model to the 1D time information. The design concept is illustrated in Figure 7. The detailed data integration progress will be described in chapter 4.

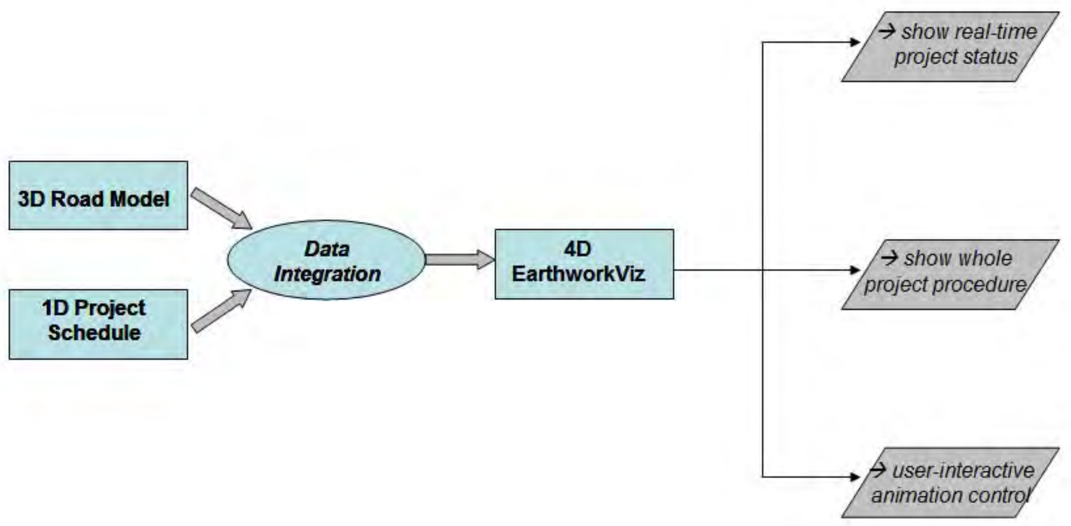

Figure 7: Concept overview of 4D EarthworkViz Toolkit

3.2.2 3D road model as one component of 4D road model

As mentioned in section 2.2.2, we will use the so-called *voxelization* algorithm to create our 3D earthwork model. That is, the earth material in a digital road model will be divided into some voxel sets and every set will be divided into voxels in cube-form which are small enough in adaption to the required time interval accuracy. And the material transportation in the real world will be transferred to the voxel appearing and disappearing progresses according to the project schedule. In the simple example, the area A will be treated as a voxel set, area B and area C analogously. Each set is divided into small voxels (*Figure 8*).

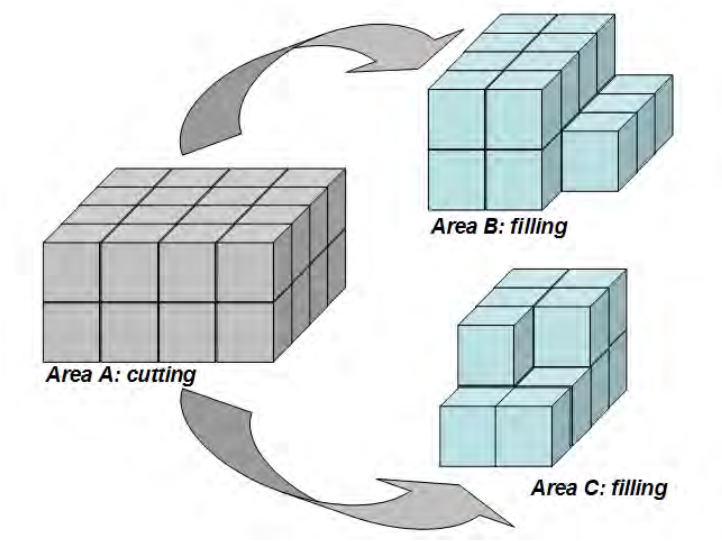

Figure 8: Simulation of the material movement among areas A, B and C

3.2.3 1D project schedule as another component of 4D road model

In this simple case, the excavation process in area A can be regarded as an activity, the filling processes in area B and C also as activities, respectively. We name the excavation of A the *Position 1 (Pos.1),* fillings in B and C *Position 2 (Pos.2)* and *Position 3 (Pos.3).* We assume that according to the pre-calculation of the whole project schedule, the Pos.1 should begin at time point t_{a1} and finish at t_{a2}, while the Pos.2 should begin at t_{b1} and finish at t_{b2}, the Pos.3 at t_{c1} and t_{c2}. The project schedule is represented in a Gantt chart format. The activities can be executed in a sequence or in parallel manner *(Figure 9)*.

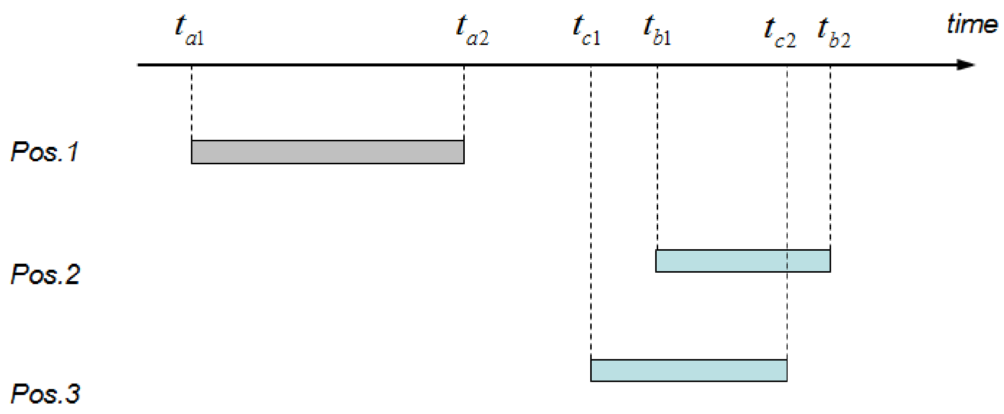

Figure 9: 1D project schedule in Gantt chart format

Actually almost each activity has a tolerant interval for the beginning and finishing time (*Figure 10*). That means, within this time tolerance, normally longer than the duration that an activity indeed needs, the bar can move forward or backward freely in the Gantt chart. The earliest beginning time point and the latest finishing time point can be calculated with the help of the Critical Path Method (CPM).

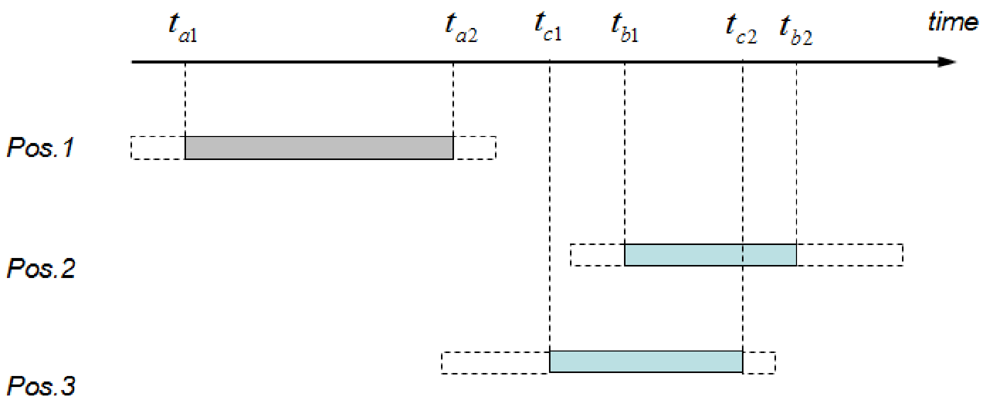

Figure 10: 1D project schedule in Gantt chart format with tolerant time interval

Therefore, there are actually many different project schedules to choose. With the *4D EarthworkViz Toolkit*, the different proposals can be visualized and calculated respectively and the results can be compared and the best would be selected.

3.3 Software Design Concept

3.3.1 The Model-View-Controller (MVC)

The implementation of the *4D EarthworkViZ Toolkit* is based on the *Model-View-Controller (MVC)* software design pattern. The MVC was firstly developed by Trygve Reenskaug in 1979 [18].

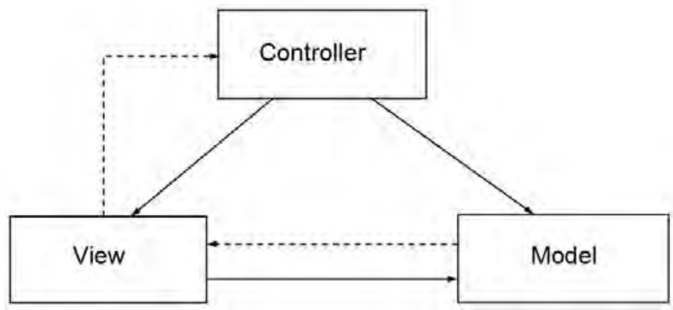

Figure 11: Concept of the MVC [18]

In the MVC, the *Model* represents a domain-specific data structure. When a model changes its state, its associated views will be informed by the *controller*. The *View* means the graphical representation of the data in the *Model*, and provides functionalities for user to edit the data interactively. The *Controller* receives user input data from the *View* and initiates a response by calling on model objects to perform the changes in the *View* [18]. The solid lines in Figure 11 represent direct associations and the dashed lines represent indirect associations. They constitute the control flow as follows: The user can interact with the user interface by e.g. pressing a keyboard or mouse button; the controller gets the input event from the user interface and translate it into the information that the model can understand; the model will be notified and result probably in a change of the state; the result will be responded to the view thus the view can render an appropriate user interface; and in the end, a new user action will cause a new control flow cycle.

3.3.2 Structure of the *EarthworkViz Toolkit*

The data of the geometry information of the road and terrain, which means the information of the voxels which are generated by the voxelization algorithm and exported from a holistic 3D model which consists of the 3D road model, the DTM and the subsoil model, as mentioned in section 2.2.2, is stored in XML files. The project schedule is made by Microsoft Office Project®. The data is the basis of the 4D visualization and should be linked to the 3D model. And the Java3D will be chosen as the implementation language to realize the *4D EarthworkViz Toolkit* (*Figure 12*).

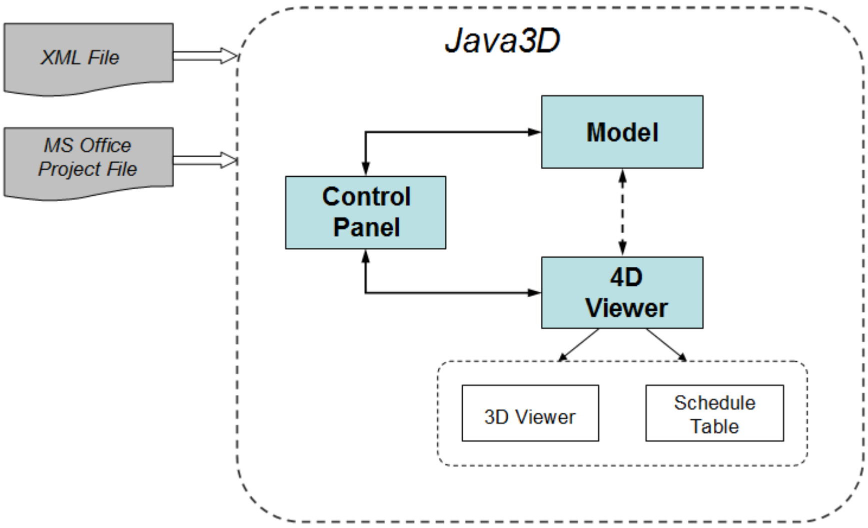

Figure 12: Structure of the 4D EarthworkViz Toolkit

The control flow will be realized by the Java Swing Components (JSlider, JButton and JTable). The details will be explained in chapter 4. Figure 13 demonstrates a real example.

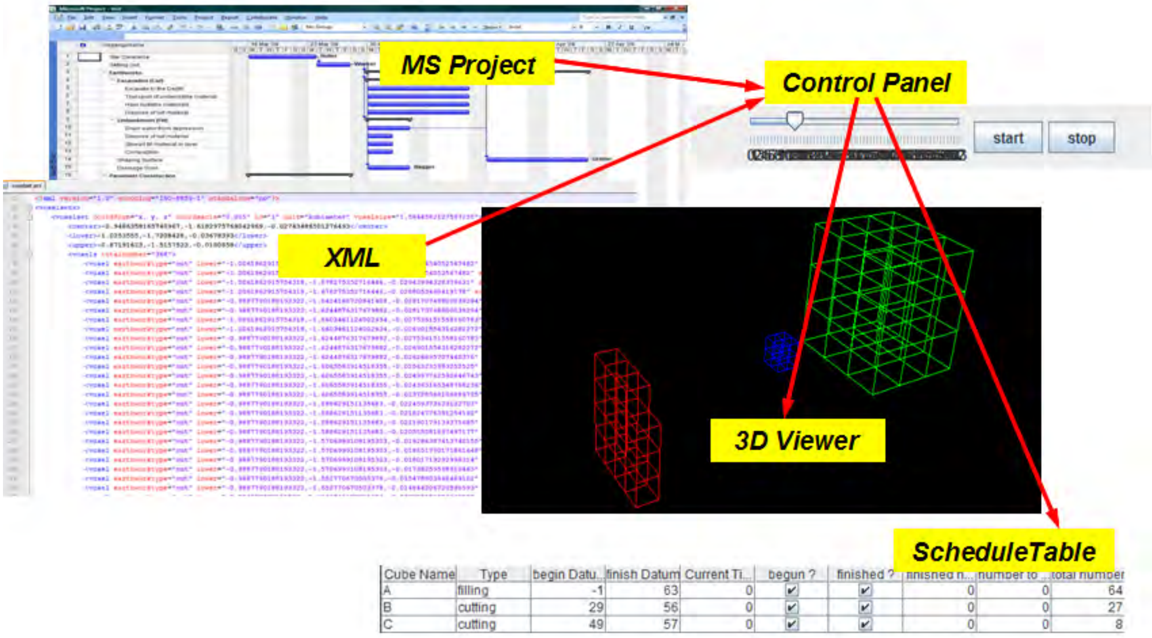

Figure 13: A real example

4 Technical implementation

4.1 Establishment of 3D road model

Few CAD software package has been developed to create 3D road models. With the help of XML standard, the geometry information can be stored and transported among different programming platforms. In our case, we will link the 3D geometry information of a road model from an existing project to the project schedule with the help of XML standard and the Java3D platform to create the 4D views.

4.1.1 Data linking with the help of XML

Here is some basic knowledge of the open standard XML (Extensible Markup Language) [19]. XML is a set of standardized rules produced by the W3C (World Wide Web Consortium) to encode documents electronically [19]. An XML document always begins with a declaration, containing some information about itself. An XML document is defined as a string of characters. The characters are divided into *markup* and *content*. They can be distinguished by simple syntactic rules [19].

The markup strings either begin with the character "<" and end with a ">", or begin with the character "&" and end with a ";". The other strings of characters which are not markup are content. There are still *tags*: There are three kinds of tags: start-tags, for example <section>, end-tags, for example </section>, and empty-element tags, for example <line-break/>. And the term *element* means a logical component of a document. One element either begins with a start-tag and ends with a matching end-tag, or consists only of an empty-element tag. The characters between the start- and end-tags, if any, are the element's content, and may contain markup, including other elements, which are called child elements. A markup construct consisting of a name/value pair that exists within a start-tag or empty-element tag is an attribute [19]. In Figure 14, a simple example of a XML document is illustrated.

```xml
<?xml version="1.0" encoding='UTF-8'?>
<painting>
  <img src="madonna.jpg" alt='Foligno Madonna, by Raphael'/>
  <caption>This is Raphael's "Foligno" Madonna, painted in
  <date>1511</date>-<date>1512</date>.</caption>
</painting>
```

Figure 14: A single but complete example XML example [19]

A 3D road model of an existing project has been created by the *ForBAU Integrator* mentioned in the section 2.2.2 and the earthwork data can be exported into an XML file (*Figure 15*).

```xml
voxelset.xml
<?xml version="1.0" encoding="ISO-8859-1" standalone="no"?>
<voxelsets>
    <voxelset coordform="x, y, z" coordsacle="0.005" id="1" unit="kubimeter" voxelsize="1.5844582127597255">
        <center>-0.9486358165740967,-1.6182975769042969,-0.02743486501276493</center>
        <lower>-1.0253555,-1.7208428,-0.03678393</lower>
        <upper>-0.87191623,-1.5157523,-0.0180858</upper>
        <voxels totalnumber="368">
            <voxel earthworktype="cut" lower="-1.0061862915754318,-1.6962045930325986,-0.03007454052567482" soildtype="sand" upper="-0.9887790188
            <voxel earthworktype="cut" lower="-1.0061862915754318,-1.678275352716446,-0.03007454052567482" soildtype="sand" upper="-0.9887790188
            <voxel earthworktype="cut" lower="-1.0061862915754318,-1.678275352716446,-0.02943994328379631" soildtype="sand" upper="-0.9887790188
            <voxel earthworktype="cut" lower="-1.0061862915754318,-1.678275352716446,-0.0288053460419178" soildtype="sand" upper="-0.988779018819
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6424168720841408,-0.028170748800039294" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6244876317679882,-0.028170748800039294" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-1.0061862915754318,-1.6603461124002934,-0.027536151558160783" soildtype="sand" upper="-0.98877901
            <voxel earthworktype="cut" lower="-1.0061862915754318,-1.6603461124002934,-0.026901554316282272" soildtype="sand" upper="-0.98877901
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6244876317679882,-0.027536151558160783" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6244876317679882,-0.026901554316282272" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6244876317679882,-0.02626695707440376" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6065583914518355,-0.02563235983252525" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6065583914518355,-0.024997762590646743" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6065583914518355,-0.024363165348768236" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.6065583914518355,-0.023728568106889725" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.588629151135683,-0.022459373623132703" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.588629151135683,-0.021824776381254192" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.588629151135683,-0.021190179139375685" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.588629151135683,-0.020555581897497177" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.5706999108195303,-0.019286387413740155" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.5706999108195303,-0.018651790171861648" soildtype="sand" upper="-0.97137174
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.5706999108195303,-0.01801719292998314" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.5706999108195303,-0.01738259568810463" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.552770670503378,-0.015478803962469102" soildtype="sand" upper="-0.971371746
            <voxel earthworktype="cut" lower="-0.9887790188193322,-1.552770670503378,-0.014844206720590593" soildtype="sand" upper="-0.971371746
```


Figure 15: A snapshot of the earthwork data in XML format

This file contains the geometry and material information of the road model, which has been divided into thirty voxel sets and each voxel set has been divided into several hundred small voxels. Each voxel set is in cube form. One cube is bounded by six square faces with three meeting at one vertex. If the coordinates of its upper and lower vertex are known, its location in space can be determined and its center point and volume can also be calculated. One can see that the coordinates of the center point, upper point, lower point and number of small voxels, which each voxel set contains, are listed within the element *voxelset*.

There is another child element of *voxelset*, the *voxels*. Its child elements are *voxel*. The attributes of a *voxel* include *earthworktype*, *lower, solidtype*, *upper*, etc. The *earthworktype* points out whether this voxel is to be excavated (*cut*) or filled (*filling*). The *lower* and *upper* are the x, y and z coordinates in the 3D coordinate system sequentially. The *solidetype* explains the earth material, whether it is *sand* or another (*any*). This *solidtype* attribute will not be used temporarily.

4.1.2 Java3D

Java3D is a scene graph-based 3D application programming interface (API) based on the Java platform [20]. Java3D is mostly an interface that encapsulates the graphics programming using a real, object-oriented concept [20]. It is easy for beginners to get started and the object-oriented concept makes itself more understandable. The other APIs of the Java2D language are completely compatible. So it is especially convenient and comfortable to Java programmers.

Java3D has a tree-form structure (*Figure 16*). The solid arrows represent parent-child relationship and the dashed arrows mean references. Loops among objects are illegal, but different branches of a scene graph can share the same referenced objects [21].

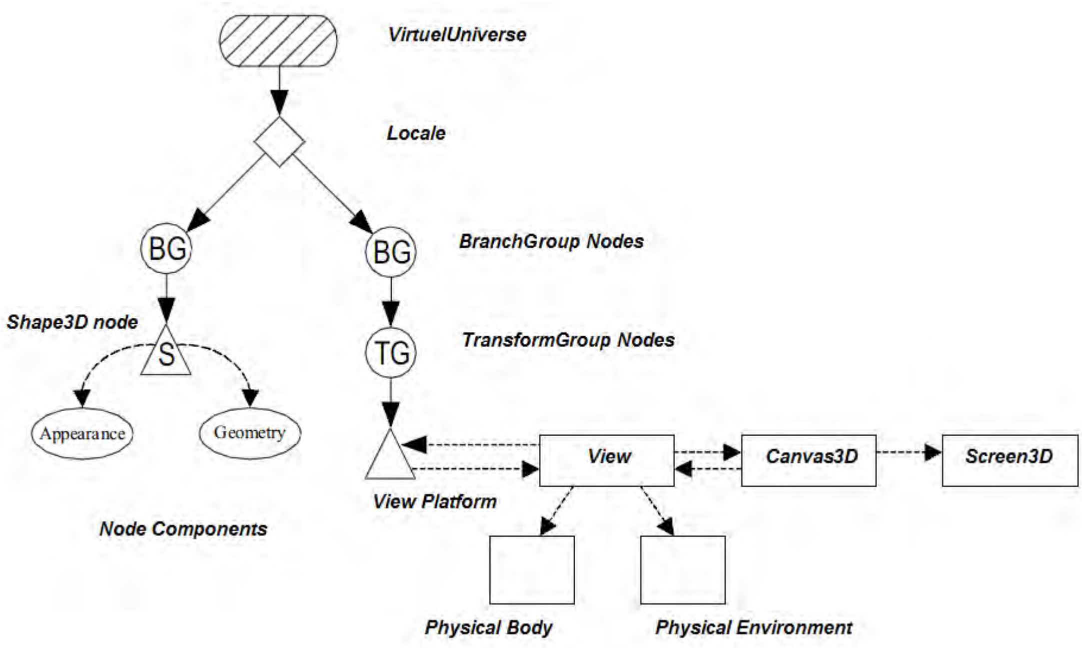

Figure 16: A Java3D scene graph example [21]

4.1.3 Definition of a single voxel

The length, width and height of each voxel could be defined to be different, and the volume of each voxel could be also different. In this work, they are of the same size for the convenience. We assume that the side length of each voxel would be equal to a, and the lower point has coordinates (x_1, y_1, z_1), the upper point has coordinates (x_2, y_2, z_2) (*Figure 17*).

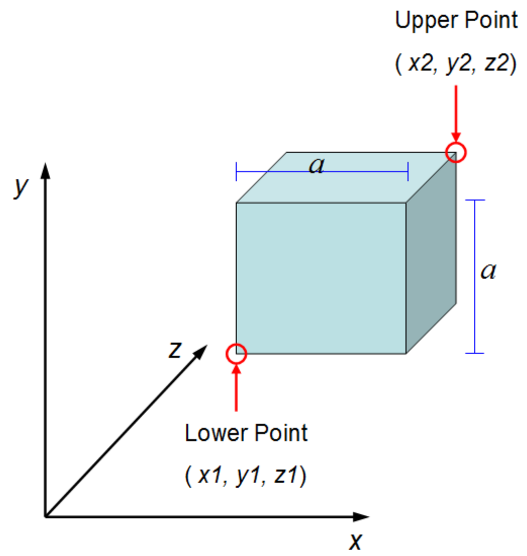

Figure 17: A single voxel

The other vertexes can be easily determined by the lower and upper point. For example, the vertex of front upper left corner can be represented by ($x_1, (y_1 + a), z_1$), the others analogously. At the same time, the volume V of the voxel is a^3.

Each voxel has extra characteristics such as color, transparency, etc. The voxels in cutting and filling areas can be set in different colors and the transparency can visualize the excavating and filling progress. If the value of transparency is set to one (1.0), that means the voxel is completely visible. If the factor is set to value zero (0.0), that means the voxel is completely invisible. Even though the voxel in the fact still exists, for the observers, it has been *disappeared* (*Figure 18*).

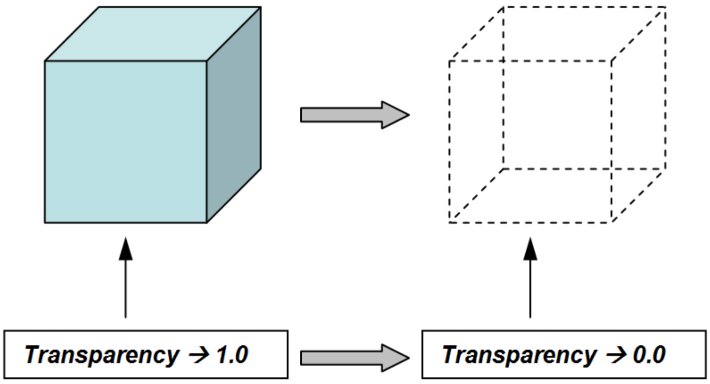

Figure 18: A single voxel with different transparency value

This function can be used for animating the transportation of earth materials. At the site the earth materials should be excavated from cutting areas and be transported to filling areas (*Figure 19*).

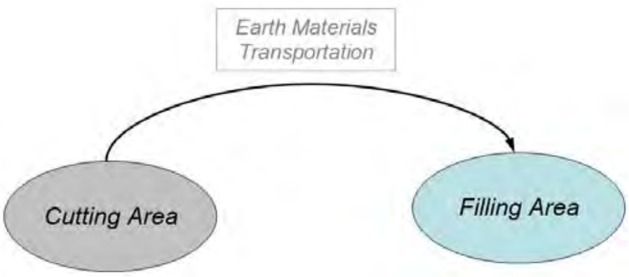

Figure 19: Material transportation from cutting area to filling area on-site

In the *4D EarthworkViz Toolkit*, the material movement process will be realized in the following way. Before the excavation process, the earth materials of cutting areas on-site are set to be solid with the transparency value equal to one ("*appeared*"), after excavation process, the transparency value equal to zero ("*disappeared*"), in filling areas vice verse (*Figure 20*).

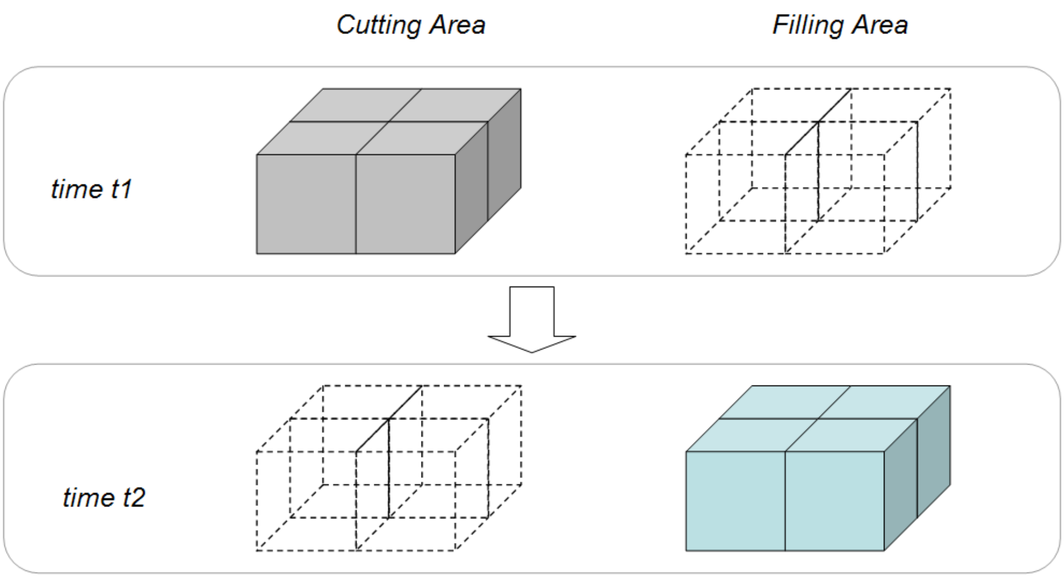

Figure 20: Visualization of excavating and filling progresses

4.2 4D visualization

The problem now is how to link the 1D project schedule to the 3D model to create a 4D model. The information of time schedule is stored in the MS Office Project® file. The useful information for us is the beginning and finishing date of each activity.

4.2.1 Setting up of 1D project schedule by MS Office Project®

Microsoft Office Project® is a software tool developed by Microsoft which is purposed to create Gantt chart based project schedules. Adopted in civil engineering, it can help the managers and civil engineers developing project plans, assigning resources to tasks, tracking progresses, managing budgets and analyzing workloads. The MS Project® will create a project schedule into a Gantt chart and the critical path will be also generated (*Figure 21*).

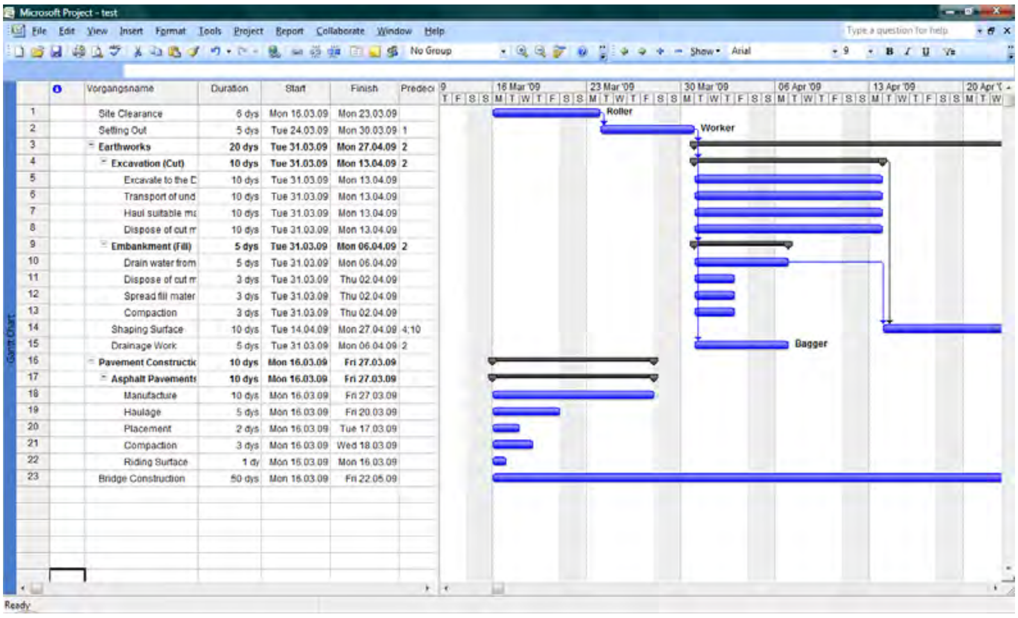

Figure 21: An example of project schedule in MS Project®

In the left part of the screenshot in Figure 21 we can input the name and work date of an activity, additionally pre- or follow-activity, if there is any. The Gantt chart and the critical path will be generated automatically in the right window. And the beginning and finishing date of each activity can be read from the file and imported into the 3D road model.

4.2.2 Control of single voxel with the help of Alpha class

Java3D API provides a class named *Alpha* which extends the *Component* class. The Alpha class provides methods which can convert the time value into an Alpha value. The alpha value of the class *Alpha* ranges from zero (0) to one (1). The most primary use of an Alpha object is to provide alpha value for *Interpolator* behaviors, which smoothly interpolate among the two extreme values (e.g. the alpha values) that an interpolator can produce. (*Figure 22*) [21]

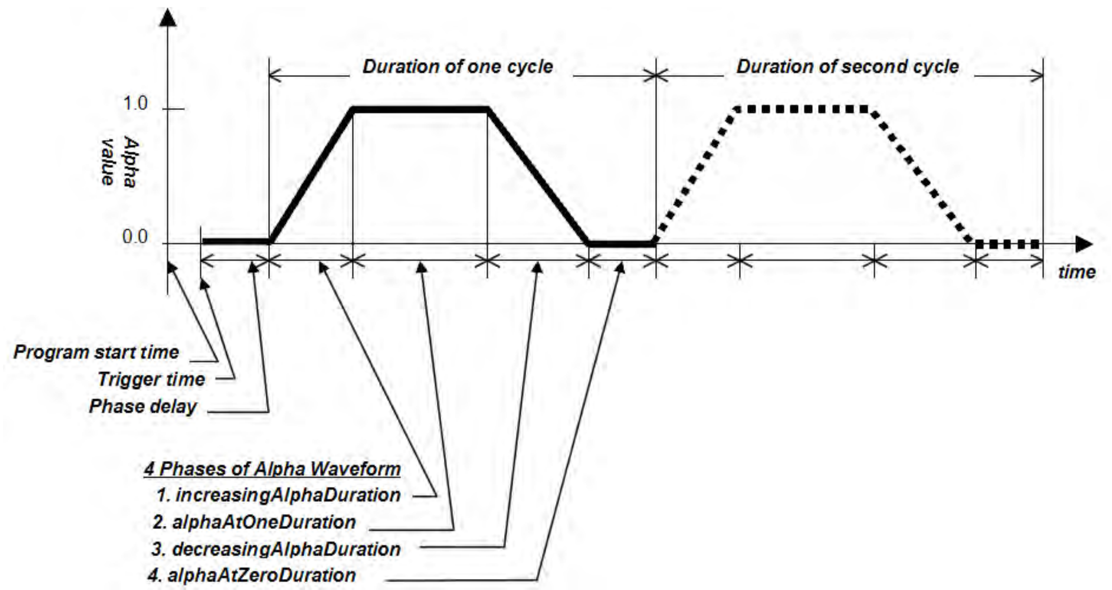

Figure 22: Phases of the Alpha waveform [21]

The first cycle of an Alpha object begins after *Trigger Time* and *Phase Delay*. The *Trigger Time* is defined as the time after the start time to the beginning of operating the Alpha object. After the *Phase Delay* duration, the waveforms of an Alpha object begin. One cycle has generally four phases, namely the *increasingAlphaDuration*, the *alphaAtOneDuration*, the *decreasingAlphaDuration* and the *alphaAtZeroDuration*. The cycle of an Alpha object may contain some of these four phases. There are a lot of different selection and combination options. One Alpha object may have only one cycle, repeat the cycles for several times or repeat the cycles continuously. In our case, we assume each voxel's appearance effect or disappearance effect with uniformed speed and that the voxel either appears once or disappears once. This means, that the Alpha object to control a single voxel has only one cycle, with only decreasing mode. The Alpha object can be referenced to the *TransparencyInterpolator* to realize the appearing process (*Figure 23*). The disappearing process can be realized analogously. [21]

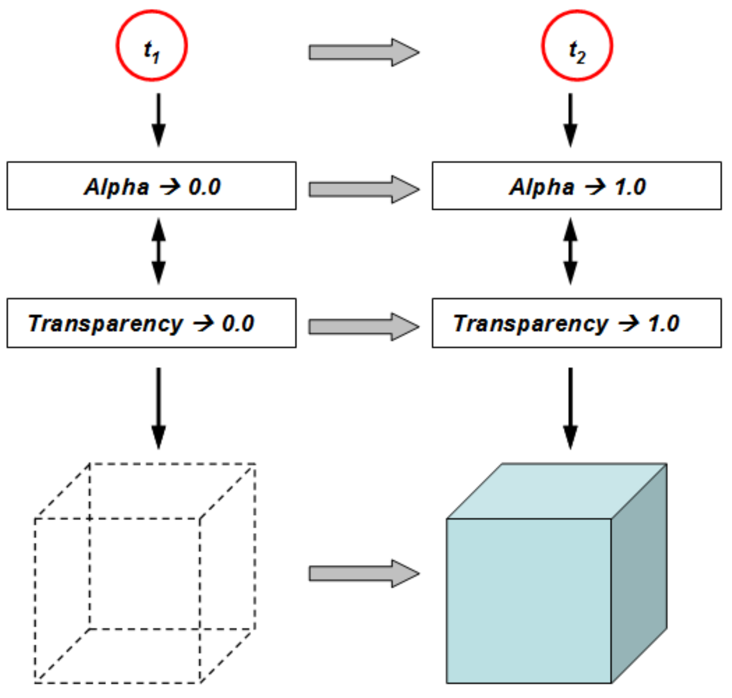

Figure 23: Appearing process controlled by Alpha parameter

The control of the disappearance or appearance time point located in the whole project schedule can be realized by determination of the *Trigger Time* parameter. The (t_1, t_2, t_3… t_n) are Trigger Time values of voxel 1, 2, 3… n, respectively (*Figure 24*).

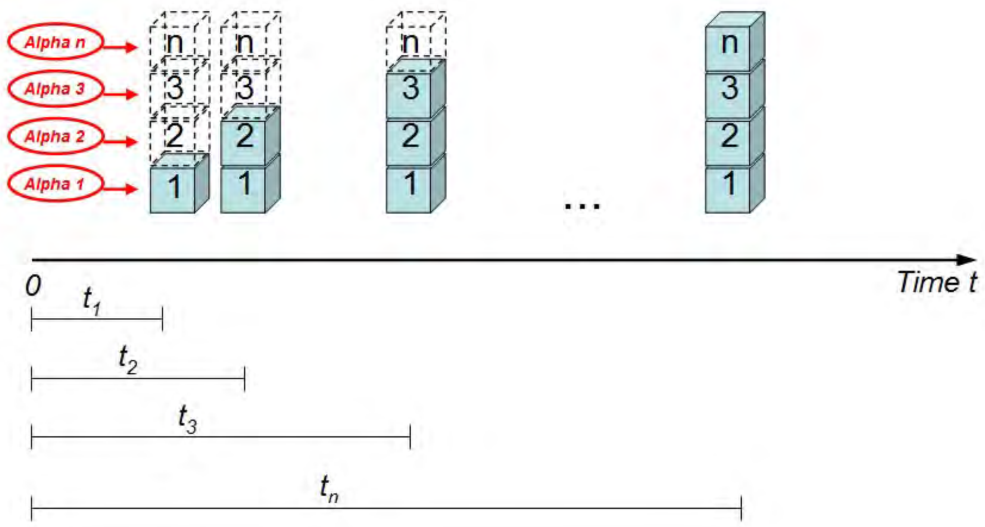

Figure 24: Voxels with different Trigger Time values

4.3 Visualization of project real-time status

The civil engineers, the supervisors of the project and the clients may want to have a look at how the project is going on. The real-time status of a project can be visualized by the *EarthworkViz Toolkit*.

As a part of Sun Microsystems' Java Foundation Classes (JFC), the Java *Swing* is an API (Application Programming Interface) which provides a graphical user interface (GUI) for Java programs. Since Java3D has been developed on Java Platform, the *Swing* is also applicable to Java3D.

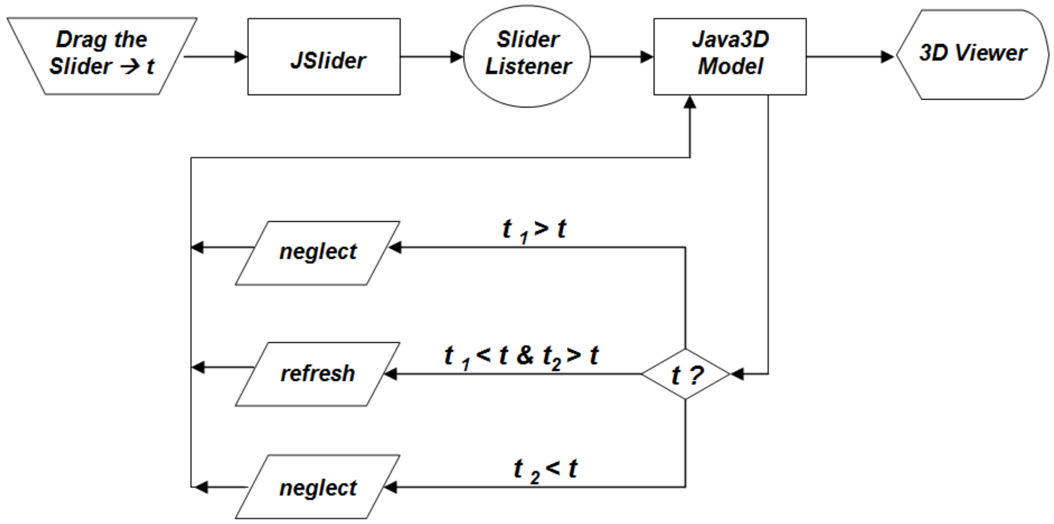

Figure 25: Control flow of the visualization of project real-time status

The *majorTickSpacing* and *minorTickSpacing* would be regarded as the time interval, for example, one month, one week, one day, one hour or even one minute, if necessary. The user gives a signal to the controller, for example, to drag the slider to the time point he wants, this information would be passed to the Java3D Model through a JSlider *EventListener*. The Java3D Model would firstly compare the time point t that the user inputs with the beginning time point t_1 and the finishing time point t_2 of each activity. Then it would decide whether to activate this activity or to neglect it. After all activities being calculated, the view of real-time status would be refreshed (*Figure 25*).

4.4 Animation of the whole project procedure

In some cases people may want to have an overview of the whole project and the 4D toolkit provides a function that can display the whole construction procedure with an animation. Analog section 4.3, but this time we use the Java Swing component of *JButton* to start and stop the visualization.

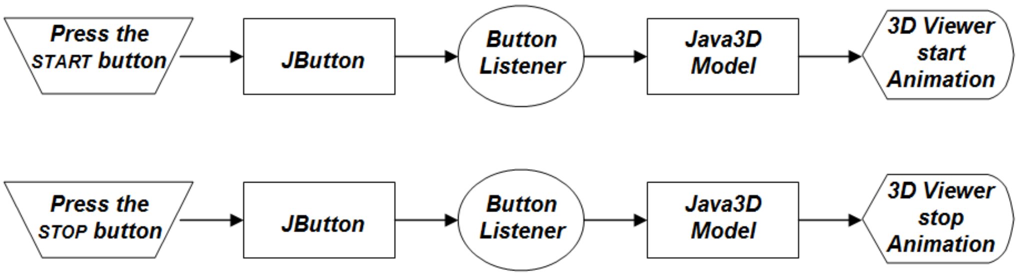

Figure 26: Control flow of the animation starting and stopping

When the user presses the *start* button, the JButton *EventListener* gives a signal to the Java3D model to tell it that the animation should be activated. When the user presses the *stop* button, the *EventListener* will pass a command to the Java3D model to stop the animation (*Figure 26*).

4.5 User-interactive animation control

The 4D toolkit has another function. It can visualize different project schedules and compare the results of work duration. In a construction project, there are activities which are not located on the critical path. The optional sequences and relationships among such activities are allowed to be changed. For example, in the earthwork step of a road construction project, the cutting material of cut area A could be carted to fill area B at first and then to fill area C, or vice versa, or in a parallel manner. The different project schedule will cause different 4D view. The 4D toolkit has been designed to visualize all of the project schedule possibilities.

Here the Java Swing component *JTable* will be used to allow the user to edit project schedule [22]. Every single activity will be indexed, e.g. "A→B, 100, 3" will be assigned the index 1, that means one hundred cubic meter earth material will be carted from cut area A to fill area B within three days. Each project schedule includes a different collection of activities. That means in the table each project schedule plan can be represented as a collection of indexes which are sorted in a pre-defined sequence. If the user changes the project schedule plan, the *EarthworkViz Toolkit* will compute once again and return the new result to the viewer (*Figure 27*). In this example, a project schedule may be the index combination "1,2" or the "3,4".

ScheduleTable

Index	Activity	Volume	Duration
1	A→B	100	5
2	A→C	20	1
3	A→C	50	3
4	A→B	70	4

Figure 27: Example of a JTable including different project schedules

The Figure 28 shows the work flow of the user-interactive animation control. The solid lines represent the same process as in the section 4.3, the dashed lines represent the reaction process according to the project schedule changes.

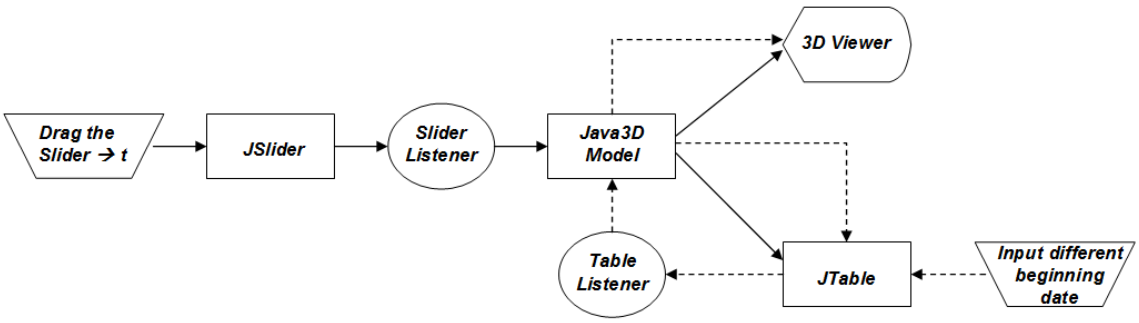

Figure 28: Control flow of the user-interactive animation control

5 Conclusion

5.1 Summary

In this thesis the development of a 4D *EarthworkViz Toolkit* to link the 3D road model to the 1D project schedule has been introduced. This 4D toolkit can now be applied in earthwork management in road construction projects.

The *4D EarthworkViz Toolkit* has been developed with the Java3D API. The original geometry information of the road and terrain that we need to make the visualization are stored in existing 3D earthwork assessment system *ForBAU Integrator*. The project schedules are created using MS Office Project. The data exchange among different software environments has been achieved with the help of XML standard.

The 4D visualization function is based on the so-called *voxelization* algorithm. According to this algorithm, the road model is divided into a limited number of voxel sets; each voxel set contains a limited number of voxels. Each voxel is defined as cube-formed volumetric element in three dimensional space. The size and location of each voxel can be different from one project to another. They ought to be determined according to different project requirements. Each voxel would be either excavated or be filled. The appearance and disappearance effects of every voxel along with the time advancing can be controlled by the

Alpha class and *Interpolator* provided by Java3D API. Each voxel is controlled by an individual Alpha object and this Alpha object is referenced by the Interpolator.

The Java *Swing API* provides the control panel and the schedule's table for the visualization. It will receive commands and respond result information between the control panel and the model. People can watch the results in the Java3D viewer and table.

With this toolkit the road model and the project schedule data are linked explicitly and dynamically. The real-time status of an arbitrary time point of the project schedule can be shown; the whole project construction procedure can be displayed and the different project schedules can be compared. The Figure 29 shows the brief work flow of the 4D toolkit.

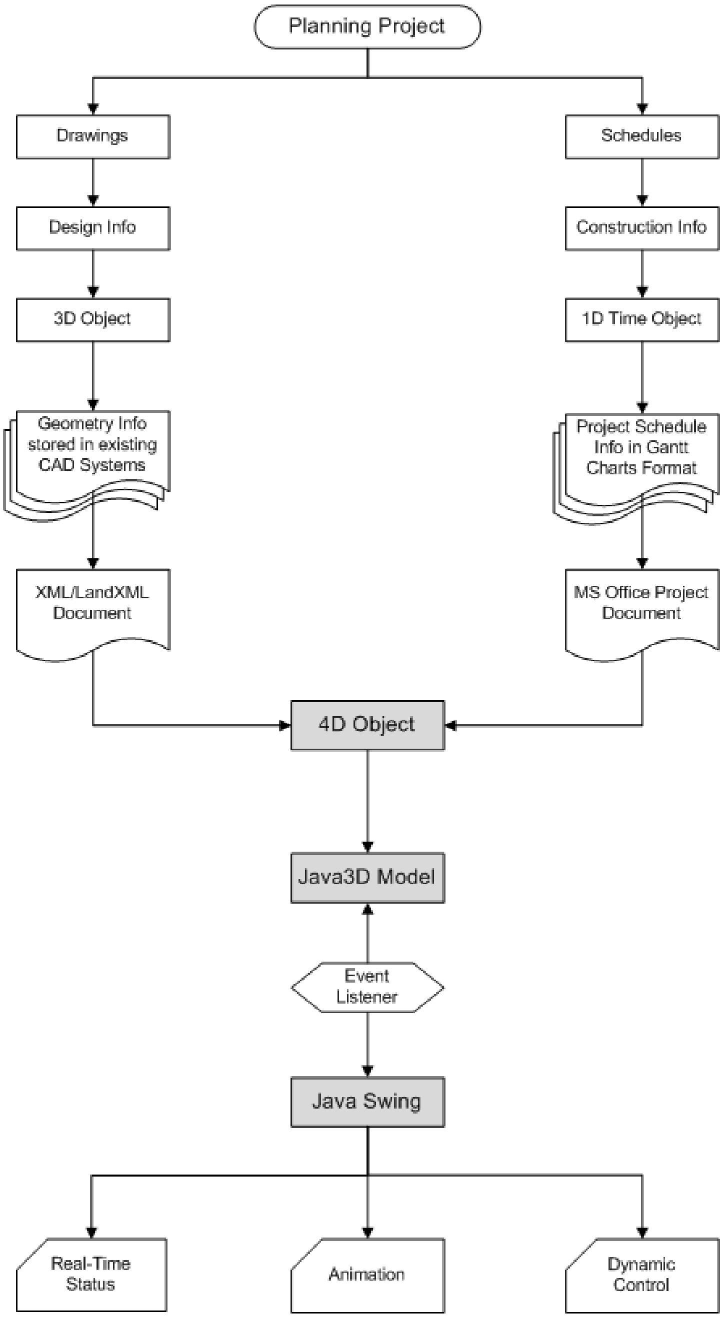

Figure 29: Summary flow diagram of the 4D EarthworkViz Toolkit

5.2 Evaluation

The *EarthworkViz Toolkit* combines the road model and the project schedule, thus the geometry information and the time information could be communicated. This communication channel was lacking in the past construction procedure.

It makes the project schedule with help of the 3d models more reasonable. The work which in the past required much imagination and experience is now explicitly rendered. And unlike the existing 4D systems only showing several status of different phases, the *EarthworkViz Toolkit* can show status of almost every moment, if the voxels have been considerably pre-defined.

It makes the project design more efficient. The work which in the past required much effort is now attained merely with several mouse and keyboard clicks.

And it makes the project design more flexible. The problems which in the past could only be discovered in the construction processes can now be found in the pre-designing phase. With the computational visualization more plans can be virtually executed with high efficiency.

5.3 Further thinking

This 4D visualization toolkit has only been developed including the geometry information and the time information. In the real world a road construction project always involves other aspects. Labors, transportation vehicles, resources and other on-site equipments and facilities must be assigned to each activity. Moreover, the labor protection laws must be considered. People don’t work every day. And if it happens to be bad weather, the construction has to pause. There must be emergency situations during some construction procedure, which ought to be considered as extra parameters. (*Figure 30*) Some teams have put effort in this field, for example, the 5D Initiative (Initiative of the European construction industry for the development of new IT tools for design, realization and operation of buildings and infrastructure) [23].

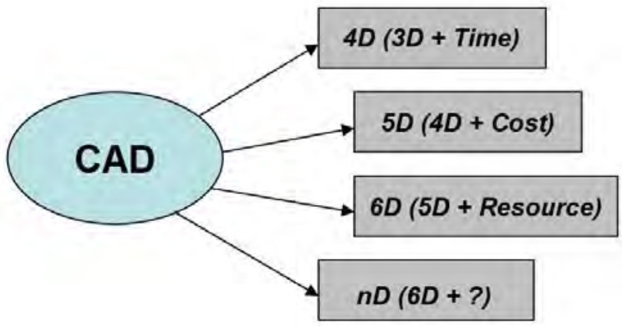

Figure 30: Extension of the CAD systems

There is also possibility to improve the automation of the 4D toolkit. For example, data such as resources has to be input manually. Every time the project schedule is modified, the database has to be manually updated and the resources, for instance, have to be manually assigned to the activities once more. We can imagine that the next generation of 4D CAD systems would be certainly more intelligent, e.g. a higher automation. They may link the model and database more flexible and may update themselves more automatically.

To make the 4D technique really applicable on the site, there is still a long way to go. The software must be more realistic and need to consider all aspects of a real construction project. The basic visualization function of earthworks in a road construction has been attained with the *4D EarthworkViz Toolkit*. We have reason to believe that it has a bright future.

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Erklärung

Ich versichere, dass ich die Arbeit ohne fremde Hilfe und ohne Benutzung anderer als der angegebenen Quellen angefertigt habe, und dass die Arbeit in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegen hat und von dieser als Teil einer Prüfungsleistung angenommen wurde. Alle Ausführungen, die wörtlich oder sinngemäß übernommen wurden, sind als solche gekennzeichnet.

München, den 30.11.2009

Yilin Lu