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4D Dynamic Construction Management and Visualization Software: 1. Development

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Abstract

With the increasing complexity of modern construction projects, there is a pressing need on higher degree of assistance from computer in order to accomplish effective planning and management. This paper delineates the previous development and implementation of a prototype four-dimensional Site Management Model (4DSMM), with the objectives to address the requirement for linking scheduling data to a three-dimensional computer graphics building model and to furnish the capability for planners to view graphic simulations of the construction process at any prospective specified date. Through the development and various real site trials in these few years, this prototype model extends 4D technology into areas of resource management and site space utilization, in addition to planning of building construction solely. In this study, a new information system platform, Graphics for Construction and Site Utilization (GCPSU), has been developed to implement the model 4DSMM. The characteristics of the prototype system, including the integration of dynamic resource management at the project level and decision-making support, and the underlying techniques, employed in the model to facilitate and tailor the construction management practice, are presented.

Keywords 4D Site Management, Construction Planning, Scheduling, Visualization

Introduction

Computer-assisted tools in format of two-dimensional diagrams, such as bar charts or critical path network charts, which lack in spatial features of the actual construction, have conventionally been employed to represent construction schedules. The pertinent resource and workspace requirements, which are not shown explicitly on the bar chart, are usually coordinated mentally. A visual representation of construction site, including the progress of the buildings and status of the use of site space as time elapses, will not be available. Thus, planners have to rely on their experience and intuition, imagination and judgment to extract data from paper-based design documents and to decide upon the appropriate method of construction, its timings and the site usage layout.

On the other hand, during the past two decades, advances in three-dimensional (3D) computer-aided design (CAD) technologies have furnished the opportunity for enterprises to apply 3D models to manage construction information in projects, via viewing their static realistic images. However, these 3D models by themselves, without the ability to display the exact status of a project at a specified period, furnish little assistance in progress control. There are no data integration and interaction between the 3D model, schedule information and other data. In order to produce a construction schedule from 3D drawings, planners have to envision the sequence of construction in their mind. This is a very difficult task since workspace logistics, and the utilization of resources and equipment are, by their very nature, highly dynamic. In practice, most site organizations often plan their works based on the inception site layout and utilization drawings, which are rarely updated during the project duration. Thus, in real terms, site managers have not been fully benefited from recent advancements in computer technology.

It is generally recognized that comprehensive construction planning and efficient site utilization are very significant in the site management of building construction. The increasing complexity of modern construction projects, coupled with the increasing number of involved parties, require more effective planning and communication. Four-dimensional (4D) technology is capable of attaching time information to the traditional static 3D model, thus allowing planners to view construction progress or schedule in a 4D environment. 4D visualization tools can demonstrate the entire construction progress in a vivid way and show potential conflicts in a construction site. Planners can also practice what-if analysis to assess and compare several planning options in order to select a better strategy. Owing to the significant potentials of 4D-CAD, several studies have been made on this newly generated field during the past decade.

Retik *et al.* (1990) discussed the possible use of computer graphics as a scheduling tool. Williams (1996) generated a 4D movie or animation film of a series of activity queues to help understand the construction plan realistically. Collier and Fischer (1996) linked layers in a 3D-CAD model to construction activities in a construction project. McKinney *et al.* (1996) presented a prototype 4D tool to allow planners to manually generate CAD, schedule, and 4D content. Adjei-Kumi and Retik (1997) presented a library-based 4D model for planning and visualizing the construction plan. McKinney and Fischer (1998) gave an overview on generating, evaluating and visualizing construction schedules with CAD tools. Liston *et al.* (1998) developed a 4D-CAD visual decision support tool for construction planners, with visual cues for quick identification of problem areas. Staub-French *et al.* (1999) illustrated that 4D simulation was better for construction planning than Gantt charts or CPM schedules. Koo and Fischer (2000) showed that 4D models are effective in evaluating the executability of a construction schedule and highlighted the need for improvements to 4D tools. Kamat and Martinez (2001) described a system to enable spatially and chronologically accurate 3D visualization of specific construction operations. Kamat and Martinez (2002) capitalized on a computer graphics technology based on the concept of the scene graph. Chau *et al.* (2003) implemented a 4D management approach to construction planning and site space utilization. Dawood *et al.* (2003) reported on the development of an integrated database for 4D construction process simulation.

Resource management is conventionally addressed by algorithmic tools solely. Son and Skibniewski (1999) employed a hybrid multiheuristic approach for resource leveling problem in construction engineering. Chau *et al.* (2002) developed a database schema, supported by data warehousing and decision support system, in order to implement construction resource management. Staub-French *et al.* (2003) formalized the ontology to represent estimators rationale for relating features of building product models to construction activities and associated construction resources to calculate construction costs. Castro-Lacouture and Skibniewski (2003) applied e-Work models for the automation of construction materials management systems. The construction site space can also be viewed as a type of resource. Tommelein and Zouein (1993) simulated the interactive dynamic space-time layout planning for resource management on construction sites. Reley and Sanvido (1997) modeled the space planning for mechanical, electrical, plumbing and fire protection trades in multi-story building construction. Akinci *et al.* (2002) presented mechanisms that automatically generate project-specific work spaces from a generic work space ontology.

In summary, all the existing 4D systems are tailored to relate 3D models and construction schedule with a specific database solely. The 4D research is lacking in the development of an integrated system incorporating other useful construction aspects such as resource management, linking different types of data sources, and fully automatic two-way data exchange between adjustments of a 4D state and scheduling data. Thus there is a need for the use of 4D tools to incorporate other construction aspects, such as resource management and cost assessment. 4D tools can play a key role and become an imperative link in the collaborative Architecture, Engineering, Construction (A/E/C) practice loop towards the implementation of paperless construction environment. All participants of a construction project are able not only to inspect 3D model through the project data network, but also to recognize the actual construction progress in time to adjust construction schedules, and to evaluate resource utilization in a specified duration, thereby contributing to better resource planning.

This paper delineates the implementation of a 4D site management model into the platform, 4D Graphics for Construction and Site Utilization (acronym 4D-GCPSU), by linking the 3D model with the project activity schedule. Each activity is suitably annotated with its resource requirements including material, equipment, labor, workspace and cost. The key objective is to develop software that is capable of furnishing assistance in site management, planning and communication, in particular in flexible short term re-planning and adjustments to detailed plans. Since the performance of any system can only be gauged by practical applications, a companion paper is written to delineate some insight and experience on the on-site use of this prototype system for a warehouse superstructure in Hong Kong (Chau *et al.*, 2004).

Descriptions of 4D-GCPSU

4DSMM comprises mainly a 3D model of the project and a construction schedule. Besides 4D visualization, the model incorporates the 4D concept into fields of construction resource management and dynamic site planning, by furnishing construction progress information and performing a number of management functions over space and time. 4D-GCPSU provides an information platform that couples the project schedule and dynamic site plan with the project 3D model to implement the purpose of site management, covering construction planning, analysis of resource requirement for each construction activity, assignment of construction materials, equipment and labor, evaluation of cost as well as generation of site layouts. Thus, project managers can adjust resources plans in accordance with the changes of schedule in a timely manner. 4D-GCPSU is built on commercial applications of AutoDesk AutoCAD and ObjectARX development platform. Figure 1 depicts the structure of 4D-GCPSUl.

Characteristics of 4D-GCPSU

4D Visualization and Simulation

The 4D concept, which encapsulates the addition of a time-based set of construction activities to the 3D model, remains the key objective of the model. In 4DSMM, when performing 4D simulation, the original schedule can be created and synchronized fully automatically to all 3D objects and components via the WBS. This is based on the built-in Start-Finish dependence relationships and the state of the object at that specific time defined in the WBS and the activity templates at the level of two week look-ahead schedule. The synchronization process is immediate and its accuracy has been verified by real application. The requirement to link each activity with the 3D model "explicitly" or manually in many previous 4D applications is thus eliminated. These operations are mostly replaced by importing a set of activity templates and property codes so that works required by users are significantly reduced. Figure 2 shows a portion of the key property codes in a tree style. An advantage is that 3D objects are no longer linked directly to their activities, but rather through a WBS node, which comprises a queue of sub-nodes of activities and allows the activity queue to be modified in an independent manner. Since activity information is retrieved and integrated with 3D objects to formulate the 4D state only during 4D visualization processing, the modification on the isolated activity information will not affect the 3D objects.

Component-Based Architecture

With the recent fast development of information technology applications, future extensibility and adaptation to new technology becomes a significant concern for any software. Although 4DSMM was designed originally to implement the 4D concept with practical verification of feasibility on site, its scope has been widened to incorporate resource management and site usage layout and more features will also be anticipated in the future. In order to maintain up to date with emerging concepts and technologies, the architecture of 4DSMM has been tailored to allow greater flexibility. 4D-GCPSU applies an open and component-based architecture through its capability to link different types of data sources, such as different database format, AutoCAD format, Visual Basic object, different scheduling software, as shown in Figure 1, to adapt to future technologies.

4D-GCPSU is developed to become an application suite of several productive applications and many utilities, processing a variety of tasks on a construction site, such as planning and visualization, resource calculating and tracking, and the provision of decision-making support. All applications share the same user interface and action mode, thus furnishing a similar user environment for users to switch amongst different applications. Some common middle-layer interfaces are introduced to separate function providers and clients. In other words, each function group is encapsulated in one single component for supporting these common interfaces. In this way, the removal of a component of the model will not affect functions of other modules. The interfaces are required to be supported by the new module, whose task may be to implement a new concept, import a new technology, or even extend to a new domain problem. These middle layers are tailored to be platform-independent. Many commercial planning applications can be supported and the early investment and training experience of its users can thus be adequately protected.

Work Breakdown Structure (WBS)

In order to cope with the current complex environment and fast changing technologies, more data and linkages are inserted and processed in the model. Yet, these may induce modifications to other parts or even to the whole architecture of the model. In order to avoid sequences of modifications, a dynamic mechanism to combine data from different modules becomes a feasible solution. A Work Breakdown Structure (WBS) is capable to furnish easy extension of other modules, future applications and dynamic resource computation without affecting existing systems. In 4DSMM, WBS is used not only as a bridge between schedule information and the 3D model, but also becomes the core of the entire model, through which other types of information, such as resources can be linked dynamically. The WBS code is built and identified with nominated name in such a hierarchy to delineate the outline structure of a construction project in a tree style through coding rules representing the level of details, as shown in Figure 2. In this way, the representation is simple, more comprehensible, and extensible in the future. Each item in 4DSMM, for instance structural element or resource plan, is assigned a WBS property which is attached to one or more WBS nodes, and then in turn to the whole model. In this way, each module will not only post its data to others by adding extra properties to the WBS node without regard to how and by whom they will be used, but is also able to obtain data from other modules via WBS nodes.

User-friendly WBS Editor

WBS has been employed by many planning applications for organization of the data. It is usually quite time-consuming to build the entire WBS tree, especially when activity level nodes are involved. Efforts are required by planners to create activity nodes for each construction element and to establish the task dependences among activity nodes for 4D visualization. 4D-GCPSU facilitates this task through its user-friendly WBS editor, a screenshot of which is shown in Figure 3. The pre-defined activity template, an example of which is shown in Figure 4, renders it possible to input a series of activities automatically for a specified structure type together with sequences and dependencies. This template is predefined during the software development based on previous construction projects and can be altered by users to suit their specific requirements. Moreover, a platform-independent middle layer component is employed for commercial planning software. If users consider it more convenient and familiar, they can utilize other commercial schedule software to create the WBS tree. Modifications in external planning applications will then be reflected immediately in the WBS editor.

Two-Way Data Exchange Mechanism

4D-GCPSU includes a two-way data exchange mechanism that links any adjustment of a 4D state on graphic screen to automatic revision of the start-finish timing and dependence or vice versa. This characteristic enables users to access schedule management functions even in AutoCAD graphic environment, without switching to other schedule applications. The capability of representation of scheduling on a vivid 3D graphic platform, as opposed to the traditional 2D bar chart, is desirable for both construction planners and project managers. When the 4D state with schedule property is changed in the 3D graphic environment via clicking a 3D element on screen, an evaluation on the validity of the modification will be undertaken by the system. If the revision is found to be not in conflict with any other scheduling data or constraints, the 4D visualization model is then updated simultaneously with the bar chart revised automatically. The new 4D construction state will be regenerated based on the updated scheduling information. There is no need to switch between 4D visualization environment and schedule software manually. This simplifies the working procedure substantially, especially in performing what-if analyses. Likewise, if a change is made on the 2D schedule bar chart, revision to the status of the entire 4D model is also reflected automatically.

Compatibility with Multiple Data Format

Recent advances in computer technology make 4D technology available even to small-scale construction enterprises. In order to maximize earlier effort and investment in a system, it is desirable to couple different types of data source and to serve a host of commercial users under different deployment environments. As a matter of fact, many business companies possess multiple types of data storage, including desktop databases, large SQL databases, and XML-based databases. Thus, a universal data access method, for multiple types of data source that might reside on different platforms as well as for emerging future types of data source, is preferable. Our experience and work illustrate that this is possible via the development of a common interface. In this regard, 4D-GCPSU provides adequate degree of flexibility.

The flowchart for linking of different data sources with a common interface is shown in Figure 5. A host library that implements a data source linking component is first installed into the user's system registry. When a new simulated workspace on a construction site is set up, 4D-GCPSU lists all installed components and launches the selected host library to start a wizard to generate the necessary files. During the formation of a workspace, 4D-GCPSU verifies the corresponding type of data source component for that workspace. The host library is then loaded dynamically and a function is called to link to the workspace data source, via a pre-defined interface.

Common Interface for Popular Scheduling Applications

At present, 4D-GCPSU does not furnish its own planning tool, but is linked via a common interface so that several popular commercial planning applications may be utilized to manage and operate the schedule information. In order to facilitate data exchange between 4D-GCPSU and existing planning tools, a middle layer is developed as the common interface for each type of planning application. Each 4D-GCPSU module can access planning data through this interface, in spite of which planning tool, is currently used in the background. Currently 4D-GCPSU provides middle layers for Microsoft Project 98, Microsoft Project 2000 and a basic schedule engine developed with this program. The middle layer, being written in Visual Basic and implemented in Windows DLL mode, will be loaded dynamically on the basis of the adopted schedule application. Although 3D-CAD models are increasingly available in IFC-format (industry foundation class) (IAI, 1998), it is not employed here because the representations within the existing format does not cover all the micro-level activity requirements in our case.

Universal Model on Resource Management

Resource utilization is an important topic in construction management and any project manager has to consider what resources (material, equipment, labor and others) will be used, and when resources should be acquired and delivered. A feasible resource plan should be adapted to the latest changes in schedule, which are highly dynamic and often affected by many uncertainties. A 4D environment that combines 3D model, schedule information and resource management can provide much assistance to a project manager in this regard. 4DSMM links resource management functions to schedule information in order to process resource issues dynamically. Resource requirements are computed precisely by 4D model because it links the real 3D objects, which provide quantity information, with timing data. For each activity, the construction manager is informed on which types of resource are needed and where and when they are needed. When integrated with the supply chain, the prototype system can provide advices on management of material stocks, generation of purchases and tracking of order status.

In order to streamline resource management, a set of resource stencils is introduced in 4DSMM. The predefined resource stencil is the component to aid in the resource management process, to define the resource utilization and relationship data for each resource involved, and to integrate between the 4D model and various construction resources. The stencil has two typical components: definition of a structural element type; and, resource entries for each unit of that element type. Any structural element or site level facility generated in a 3D environment contains a resource index property related to the resource stencil. The stencil gives type and quantities of materials, equipment needed, and how many workers are needed. Previous experience of construction enterprises, customized to reflect the actual situation for typical projects, is gleaned. In order to maintain extensibility, a universal model is employed for different types of resource, including materials, equipment and labor.

Each type of resources is viewed as a general resource item, related to a standard type of structural element with given quantity requirements. Every element is assigned a standard element reference when it is created in a 3D environment. With the provision of quantities for each type of structural element from the 3D model, this stencil can immediately generate the resource requirement throughout the time schedule.

Computation of Dynamic Resource Requirement

When there are frequent modifications to the schedule, it is not easy to keep resource requirements under control. 4D-GCPSU is capable to facilitate this task since the static 3D model can provide workload data for all structural elements and site layout facilities. Moreover, the 4D model can identify all elements to be constructed within any period. With the aid of pre-defined resource stencils, resource requirement for a specified future period can be computed dynamically which reflects the latest requirement of the project. A wizard is designed in the Resource Manager to perform this computation. When resource costs are input, the wizard will output individual cost for material, equipment and labor. The computation results can be saved as a reference plan or converted to a resource plan directly.

Site Space Utilization

In order to assist in accomplishing efficient site space utilization (Reley and Sanvido, 1997; Tommelein and Zouein, 1993; Akinci *et al.*, 2002), the construction site space is also viewed as a type of resource in 4DSMM. Similar to other structural elements, 3D objects for construction equipment, such as crane or hoist, are added to the 3D model. Storage, lay down, or assembly areas also have their own 3D reference. Site facilities are also displayed in 4D simulation to show the status of the entire site versus time, including facility locations and storages of permanent and temporary components. By tracking material status, 4DSMM displays the contents at site storage locations with presentation in a 3D environment. 4DSMM is able to evaluate site plans and give feasible advice on how to store and how much time is involved in transporting those resources within the site at any specified time.

Workflow in 4D-GCPSU

An integrated working environment is tailored for construction planners in 4D-GCPSU. It covers the workflow throughout the duration of a construction project, from the generation of the 3D model and the schedule plan to 4D visualization and resource management. Depending upon the desired management purposes, a variety of tools are furnished by the 4D-GCPSU platform: the Workspace Manager for manipulation of general workspace information; the Dictionary Manager for management of resource stencils; and, the Resource Manager for control of various resources. In order to have smooth transition between different applications, each module in the 4D-GCPSU suite shares the same user interface and operating modes. Moreover, whilst 4D-GCPSU is designed to be a stand-alone application suite, it takes advantages of popular commercially-available platforms. For example, AutoDesk AutoCAD 2000® has been chosen as the graphics subsystem for some modules incorporating a set of 3D modeling tools and 4D visualization applets. Figure 6 displays the workflow of 4D-GCPSU.

Formation of Workspace

The Workspace Manager is an intuitive integrated environment employed in 4D-GCPSU to process and save construction data in each project as a Workspace in several pertinent files. Wizards are employed to assist users to create a new workspace for different types of data source. The main role of the Workspace Manager is for input of construction information, including those on building, floor, segment, element, activity levels and WBS, prior to the generation of the 3D model. The formation of a new workspace comprises compilation of data on building, floors and segments. A common user interface is furnished to all tools in the Workspace Manager. During the operation of the Manager, a dynamic help panel, which provides instant tips and recommendation on ensuing operation, is displayed on the right hand side of the screen.

Generation of 3D model

The temporal representation of a static 3D model is able to demonstrate the actual progress at any previous date, the current progress, as well as the anticipated progress at any prospective date up to the completion date. 4D-GCPSU has the capability to facilitate the generation of a 3D model by furnishing a series of utilities. Standard structural elements can be easily defined by users using the specified geometric parameters in the Workspace Manager. They can then draw and place actual elements as desired by applying these standard elements with just simple clicking or dragging Windows-type operations. Several basic structural types, such as wall, beam, floor, column, door, window, and so on, are already defined directly. Users can also add other types of element manually into the control within 4D-GCPSU so that any user-defined object can be inserted into the 4D model. Moreover, the object-oriented programming technique adopted here allows the attachment of textual or numeric properties to any 3D object. These 3D models are organized in a hierarchical manner, with the entire workspace at the top level and detailed elements at sub-levels, namely, workspace, building, floor, insitu/precast area, column, wall, beam, and so on. Furthermore, in order to assist in the evaluation of site layout, construction equipments are also incorporated into the 3D model with graphical representation and are in turn linked to schedule data.

Creation of WBS with Scheduling Information

WBS is employed to define the entire workspace structure in tree-like manner, with each node having a WBS code property. The whole structure of the construction project is described by these code properties. WBS data are highly bound to the schedule information. In fact, many commercially-available scheduling software, such as Microsoft Project, use a WBS to organize their data. The WBS editor in the Workspace Manager facilitates the editing work to a WBS tree, by generating sub-nodes of activities for some element nodes based on existing activity templates and automatically setting their initial Start-Finish dependence. Moreover, a background interface engine is developed in order to interface synchronously with the external planning software. By employing the WBS structure, users can adjust the schedule information either in the WBS editor or in the external planning software depending on their individual familiarity with the type of working environment. Some code segments are designed to ensure that all external modifications will be fed back to the Workspace Manager simultaneously.

4D Visualization Controller

The classification of 3D objects is in terms of structure groups having different WBS properties. These properties affect directly how schedule information is extracted from external planning application data. When performing 4D simulation, the visualization controller will automatically search the proper activities for each element and hence it is not required to link each related activity to a 3D element. Hence, the user needs not worry about changing any pertinent relationship between 3D element and its activities during modification to any activities of an element. The usual requirement of “explicit” or manual operations to link an activity with the 3D model in other 4D tools is avoided.

Moreover, it is possible to import external graphic elements to 4D-GCPSU, which greatly enhance the flexibility of the system. In order to share the advantages of 4D visualization, users can generate any 2D or 3D element and import it to a structural group that is linked to WBS. Thus, a quick preview of the construction site with temporal relationship can be acquired through the set of conventional 2D construction drawings prior to the generation of the complex 3D model.

Users can choose an element on the graphic screen, scrutinize the start-finish timing and dependence, and revise as deemed necessary. Through the two-way management mode, the revision will automatically be synchronized in the external planning application, leading in turn to adjustment of the time properties of all related elements. The usual practices to first switch to the external planning application for modification of a 2D bar chart and then to refresh the drawing are no longer required. This user-friendly operation mode enables planning of re-scheduling operations to be processed in a 3D environment and facilitates evaluation of alterative construction plans.

Definition of Resource Stencils

The quantities for each element, as well as quantities of resources to be consumed in any specified period, can be computed accurately to within 10% in the 3D model corresponding to the schedule data. This has been verified through various real site trials, with the assumptions of general site conditions, including gentle/not too congested work space and good access conditions. The computation procedure for the quantities for each element as well as quantities of resources to be consumed in any specified period is dynamic in that resource utilization computation will be updated automatically whenever the schedule plan is modified or if the 3D model or the design is revised. Conventionally, it is difficult for a project manager to acquire such information directly. The 4D environment, with the 4D model coupled to the real 3D object and the corresponding schedule via the WBS linkage, facilitate the project manager to forecast the quantities for each resource precisely.

Resource Plan Scenarios

Construction planners can formulate a number of resource plan scenarios in the Resource Manager, on the basis of the computed resource requirements. Both types and quantities of material can be specified in these plans, which will be mainly employed as a guideline for resource management throughout the project duration. If one of these plans is finally adopted, order forms can be made by the system to pertinent suppliers. Afterward, when these ordered resources are delivered to the construction site, a storage entry form will be generated. A major task of the Resource Manager is to monitor the entire resource management procedure and to track and constantly update the status of each resource item including: what percentage of a resource plan has been completed; which order form is outstanding; any storage space available on the site; and, a list of all available materials in stock. The consumption log of each resource maintained by the Resource Manager comprises statistical charts and graphs which will be helpful to support decision-making. Comparison of different resource utilization plans can be made against user, time, or location.

Assistance to Decision-Making

Knowledge and experience that are acquired from previously completed projects may help to accomplish successful project management and effective decision-making in a new project. It is expected that the next generation of 4D tools will need to process a larger volume of data. Problems on data storage, data sharing and dynamic data exchanging between different applications during the life-cycle of construction management, especially in processing complex data types and sources in resource management, should be properly addressed. Thus, existing data are organized and converted into useful information, or knowledge, through the integration of a Data Warehouse and a Decision Support System (DSS).

The contents of a data warehouse may be a replica of data from a source or the results of preprocessed queries, such as "Where is a particular material consumed on the specified building?" The DSS is implemented in a star schema, which is a specific type of database design employed to support analytical processing. A star schema comprises two types of table: fact tables; and, dimension tables. Fact tables contain the quantitative or factual data about an entity whilst dimension tables hold descriptive data that reflect the dimensions of an entity. By using certain predefined and user-defined links between the fact and dimension tables within the star schema and constraints on the data, Structural Query Languages (SQL) queries can then output the required information. Microsoft SQL Sever is adopted as the data warehousing platform. Previous project data are entered into data warehousing system in order to assist in decision-making. If more historical data are supplied, more precise results will be acquired. Users are required to supply, acquire, and glean data about the current construction project into the computer-based model. Based on the user specified requests, the data warehousing system will analyze those historical data and attempt to establish the relationships, which will in turn be used by the DSS to furnish advice.

Conclusions

In this paper, the 4D site management model previously developed, 4DSMM, incorporating resource management and site space utilization, has been presented. Based on 4DSMM, a powerful information platform system, 4D-GCPSU has been successfully developed. The way on how to link 4D technology to the full spectrum of construction management activities is demonstrated. The integration of a WBS, 3D model, scheduling, resource stencils, decision support tools, and other design and developing strategies is capable of furnishing useful assistance to construction planners. The prototype model may require a large amount of data input for large projects which lead to large computer files and slow processing, as evidenced from the site trial (Chau et al., 2004). This, however, will not be a long term problem, given the recent advancement of computer technology. It is believed that 4D-CAD technology will have strong potentials and will impose significant impact on construction management practice. A feasible research direction will be on the extension of the 4D model, by adding construction-specific components such as scaffolding, roads, etc. A web-based collaborative system merging 4D technology into an entire A/E/C working environment may also be explored. Moreover, an appropriate method to evaluate current construction plans, including time, space and resource can be incorporated, so as to locate potential areas where problems may occur.

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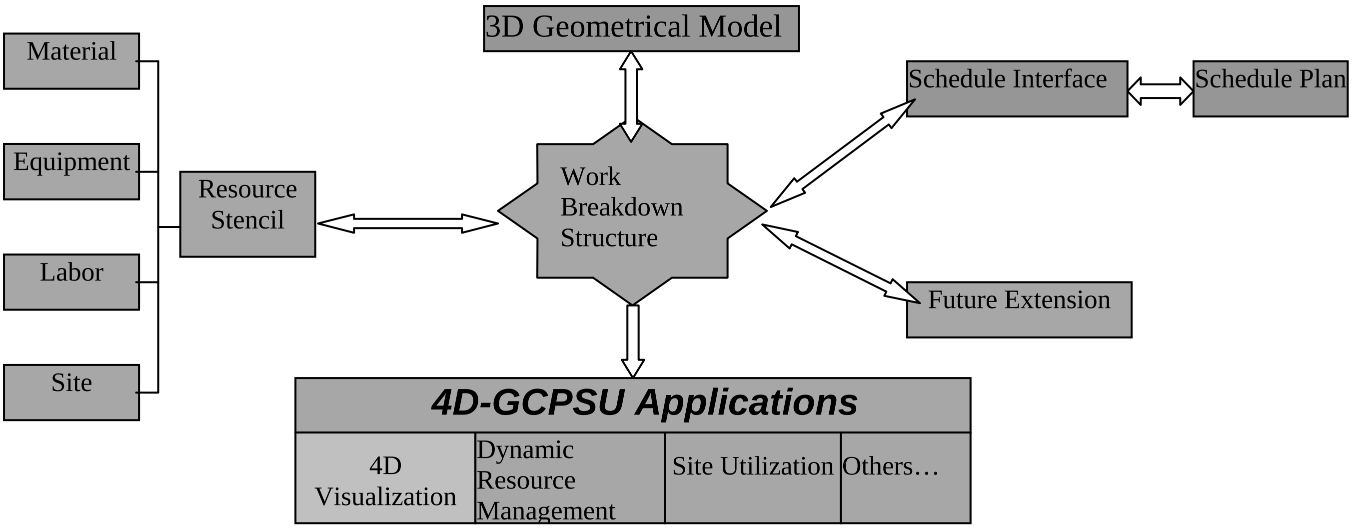

Figure 1. Structure of 4D-GCPSU

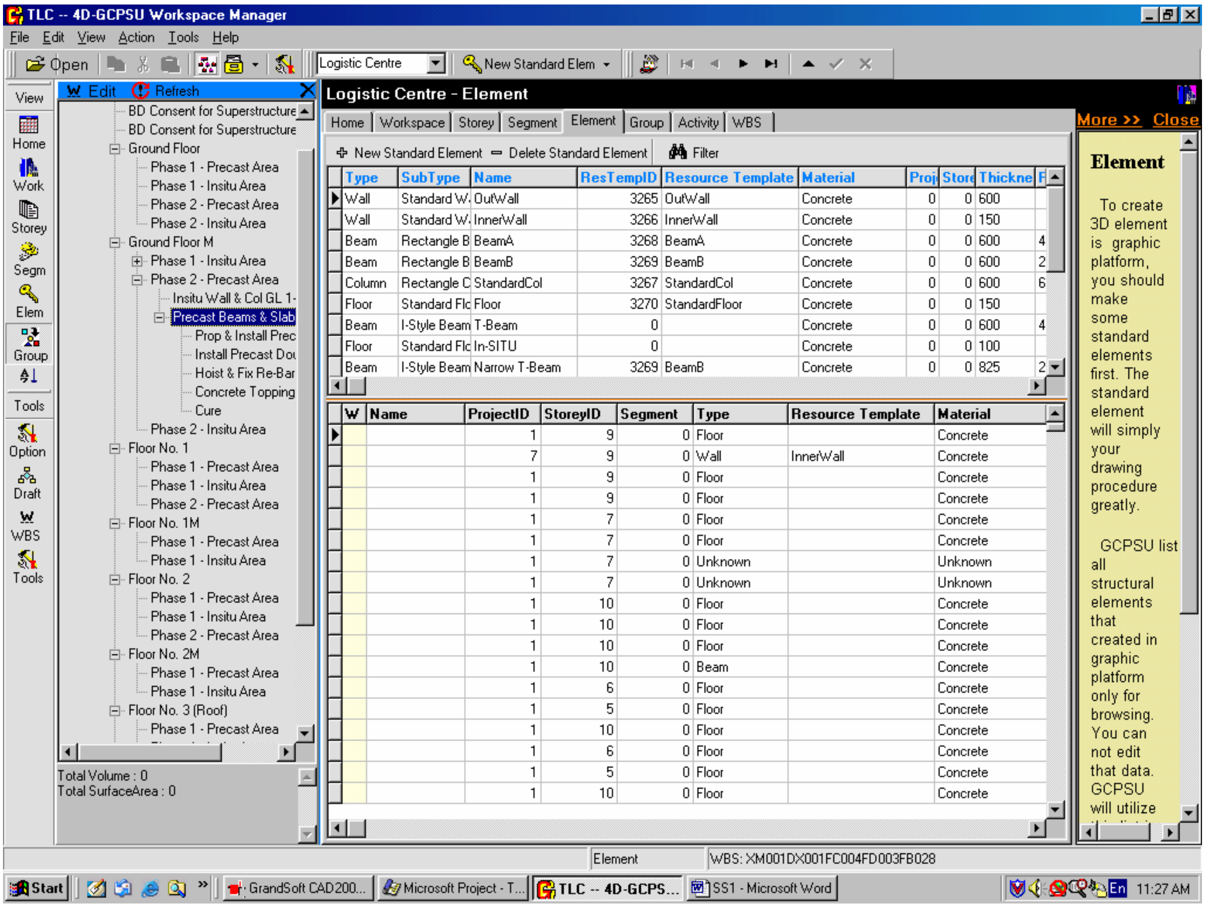

Figure 2. A portion of the key property codes in a tree style

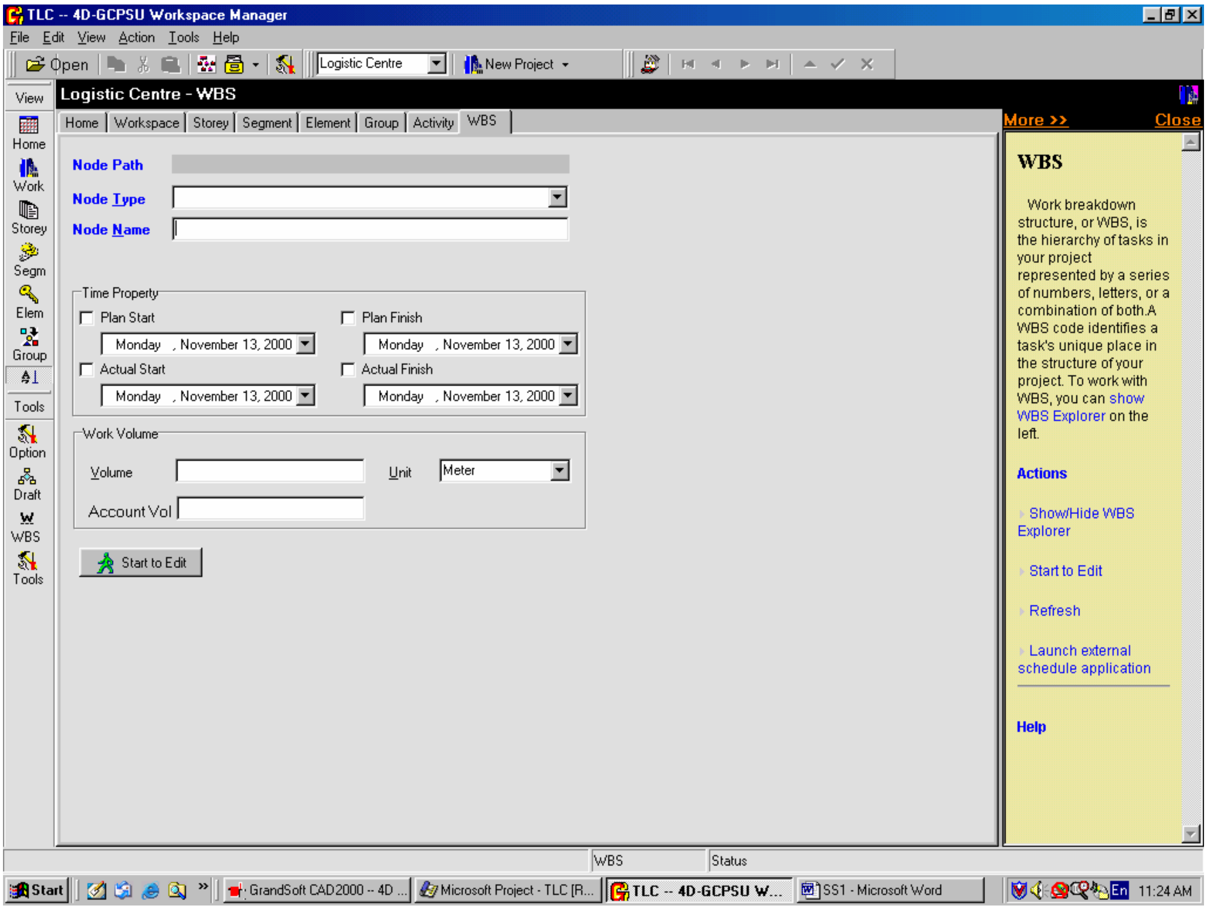

Figure 3. A screenshot of the WBS Editor

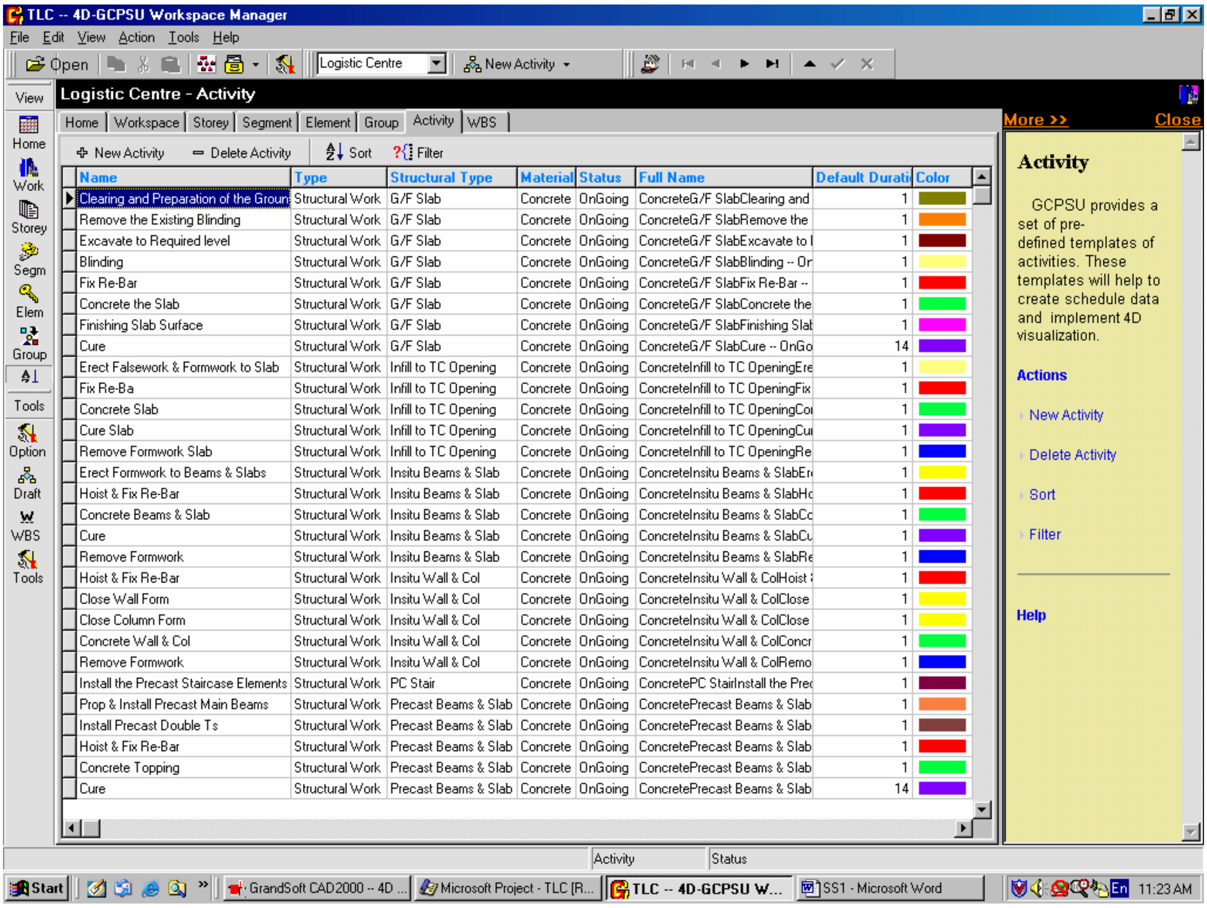

Figure 4. An example of the predefined activity template

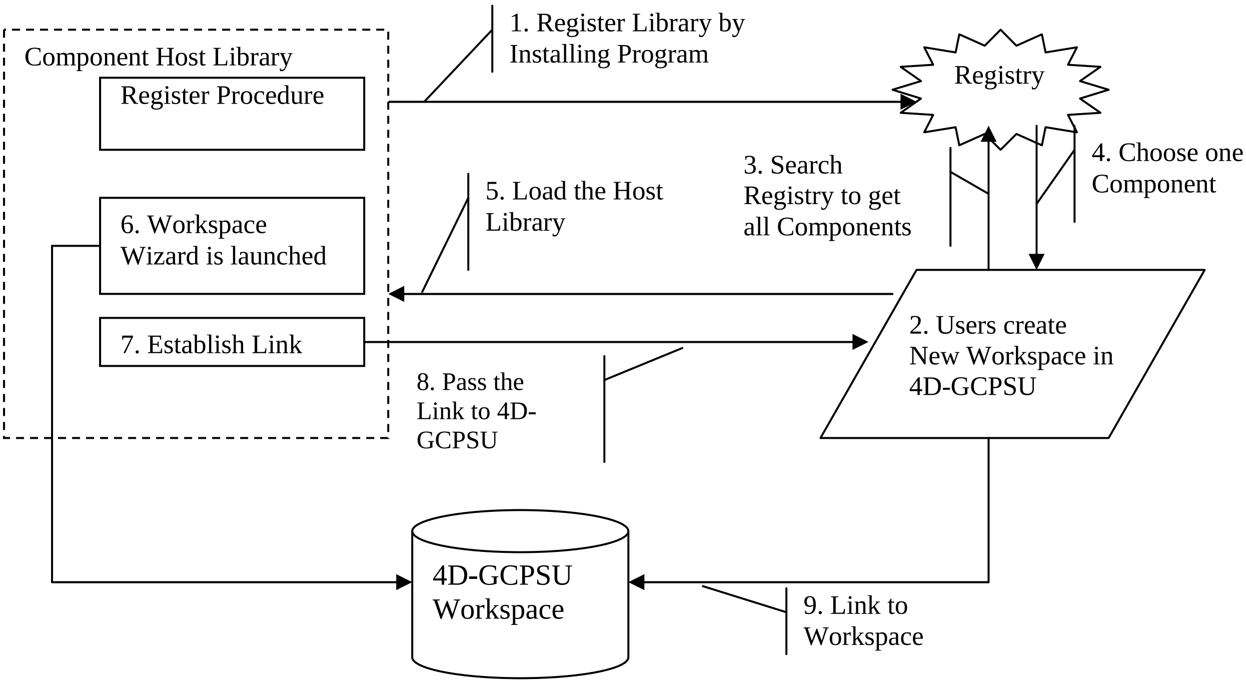

Figure 5. Flowchart for linking of different data sources with a common interface

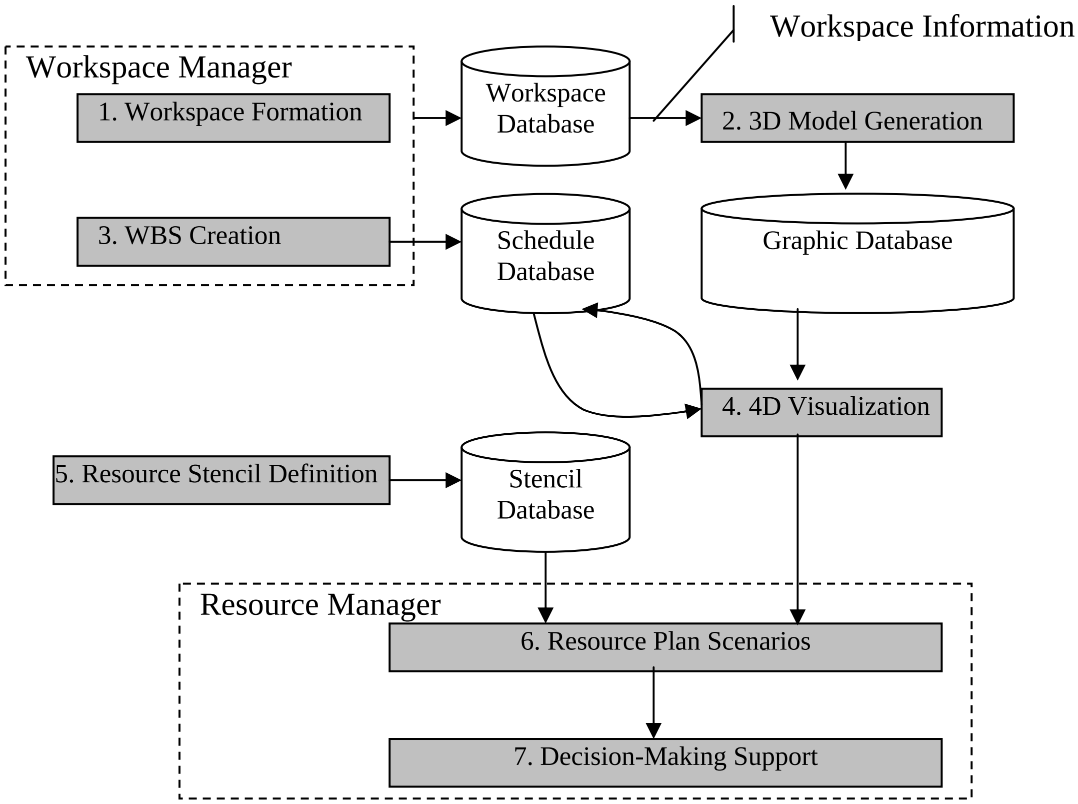

Figure 6. Workflow of GCPSU