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Implementation of Visualization as Planning and Scheduling Tool in Construction

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Abstract
During the last decade, extensive research efforts have been made on the development of 4-dimensional (4D) models (space + time) which integrate computer graphics of 3-dimensional (3D) geometrical models to scheduling data with a view to generating graphic visualization of construction processes for planning and decision making purposes. Nevertheless, these 4D applications to construction planning are often limited to the component level of a building. Their major drawback is the lack of pragmatic site management features, such as analysis of resource requirements for individual construction activity, generation of site facility layouts, quantification of construction materials and cost evaluation over a specified time period. The objective of this study on 4D graphics for construction planning and site utilization (acronym 4D-GCPSU) is mainly to furnish a solution to the aforementioned problem. In this paper, our works on 4D model in a broader site management context aiming to assists planners to deal with day to day activities are delineated. The prospective requirements for 4D application to support practical use on site management are also highlighted.

Keywords:
3D geometrical model, 4D visualization, construction planning, construction scheduling, site management, site utilization

Introduction

It is generally recognized that, amongst other factors, thorough planning and efficacious site utilization are of utmost significance in the site management of building as well as civil engineering construction. Nowadays the nature of the project is becoming increasingly complex, involving more and more parties. As such, a more stringent standard on planning and communication is entailed. Up to the present moment, the stipulations of a typical building construction project are conveyed to the successful contractor mainly through paper-based working drawings. The planning staff of the contractor are often required to interpret these working drawings to formulate a project schedule relating various types of construction activities under the project. In doing so, the planners have to consider the resources requirements including human, material, plant as well as site facilities incurred under the project. They have to incorporate in their mind appropriate workspace logistics, logical construction sequence, and economic resources utilization within a spatial and time domain.

Moreover, although the site organization and usage plan is largely dependent on the construction schedule, these site layout drawings are often only prepared at the inception of the project and then not updated any more to reflect the dynamism on site. As such, they are virtually separated from the planning and scheduling system. On the other hand, construction plans generated mainly by computer-based tools are usually represented as bar charts or critical path method network charts. These types of tools are not capable to display the spatial construction features as well as the pertinent resource and workspace requirements, which are envisioned only in the mind of the planners. They do not furnish data integration or visual representation of the project versus time, such as project progress and status of site space usage. As such, planners can only glean information from design documents to adopt the appropriate construction scheme and site facility layout, on the basis of their intuition, experience, judgement and heuristic. It can be said that the potential assistance they can receive from the computer has not been fully exploited.

In order to develop advanced planning techniques, many researchers have devoted efforts on the concept of 4-dimensional model, which incorporates the time dimension into the concept of 3D visualization. Retik et al. (1990) explored the potential application of computer graphics to construction scheduling and outlined the possible features of the tool. McKinney et al. (1996) developed a 4D-CAD tool, which provides visual and communicative usage on the construction design process. Collier and Fischer (1996) used the 4D modeling of the San Mateo County Hospital as an example of visual-based scheduling. Williams (1996) represented the construction plan graphically with a 4D-Planner in response to project visualization, simulation, and communication needs. Adjei-Kumi and Retik (1997) reported a library-based 4D model PROVISYS for planning and visualizing the construction plan in a virtual reality. McKinney and Fischer (1998) presented and evaluated a 4D application integrating the usage of several software including AutoCAD, Primavera, Jacobus Simulation Toolkit and Walkthru. McKinney et al. (1998) delineated a construction example to illustrate how feature extraction of 4D-CAD models can help identify construction problems. Kamat and Martinez (2001) described a general purpose 3D visualization system on construction operations.

In this paper, the study on 4D graphics for construction planning and site utilization (acronym 4D-GCPSU) is delineated. A 4D site management model to incorporate a 3D geometrical model together with a project activity schedule has been proposed. Specifically, the construction activity is annotated with the pertinent requirements on resources including human, material and equipment. It is found that construction planning and communication at site management level often entails flexible short term re-planning. In order to cater for this need, the major objective of this study is thus to furnish a 4D graphical visualization capability for construction planning purposes. Moreover, the model incorporates other useful aspects of site management comprising the construction schedule with resources allocation, site facilities layout, site workspace usage as well as cost estimation.

Features of 4D Site Management Model

The study on 4D-GCPSU mainly focuses on the generation of a 4D model, which comprises a 3D geometrical model of a construction project together with its associated schedule. Its actual implementation, 4D site management model (4DSMM), involves the framework of integrating the 4D model with other computer-based techniques for site management. In so doing, it enriches construction features of the 4D model with the capability to perform a variety of site management functions over spatial and temporal domains. In essence, the 4DSMM furnishes a comprehensive environment that links the 3D geometrical model, the dynamic site plan together with the construction schedule. It accomplishes the entire purpose of site management incorporating construction planning, resource analysis for individual activity, site layout generation, material allocation and cost breakdown. The following are the key features of the 4DSMM:

(a) Conventional site planning

The conventional site management procedure, construction schedule and graphical site facility layout, which are already used to site planners, are included in the 4DSMM as far as practicable. In the prototype system, the bar chart representing the project schedule and the graphical site plan drawing can be generated, modified and displayed in a convenient fashion.

(b) Representation of 3D geometrical model
Based on the geometrical data input together with the graphical user interface (GUI), 4DSMM is able to produce the 3D model of the building project and permit the visualization of almost all 3D model components from different angles of view.

(c) 4D visualization
The 4D simulation for a specific construction project can be generated automatically via integrating the 3D geometrical model with the associated activity schedule. Under the model, the visualization of building construction at the activity level together with 3D site space utilization at any specific instant can be displayed through playing forward or backward within the time period.

(d) Integration of symbolic and graphical data
Some of the key characteristics of the 4DSMM are to evaluate the resources requirements including labor, material, equipment and to assess the requisite cost for a specific time interval through integrating symbolic and graphical data. The model is able to compare and rank different feasible construction plans via the knowledge base of the 4DSMM.

(e) Linkage between geometrical model and schedule
Under the system, the linkage between the 3D geometrical model and the project schedule is designed to be bi-directional. As such, the user can modify the construction plan either through the 3D graphical environment or through the conventional bar chart scheduling environment, as he/she desires to do so. Suppose that certain construction activity in the 4D simulation of a construction project is modified graphically on the screen, the bar schedule on that specific activity will be automatically adjusted in a synchronized manner. On the other hand, if the project schedule is altered, the corresponding 4D model will be modified simultaneously. Moreover, if either one of the aforementioned modifications takes place, the estimate on allocation of resources requirements will also be updated to reflect the real scenario.

This prototype system, in essence, furnishes construction managers a useful tool to manage and plan the site throughout the building cycle. It allows planners to envisage details of prospective work, to visually foresee potential constructability problems and to visualize how alternative construction sequences affect decision criteria including material, labor and cost, prior to making the final decision. As such, certain degree of optimization on undertaking the prevalent ever-complicated construction work can be accomplished at ease.

Structure of 4D Site Management Model

One of the main tasks of the 4D site management model is to identify and then organize different types of data. As such, the model algorithm should be structured such that it is able to integrate all spatial and temporal data for construction site planning and management purposes. Besides, consistency of information within the system amongst the 3D geometrical model, project schedule and resources requirements should be effected. Figure 1 depicts the structure of the 4D site management model, which is basically divided into the following four components.

- 3D Geometrical Model

The 3D geometrical model comprises a host of graphical objects representing entities to be constructed or those related directly to construction activities. These objects are in general categorized into three types, namely, real structural elements, operational objects and temporary facilities. Structural elements can be further sub-divided into different groups of building components, depending upon their locations within the entire structure. Operational objects, displayed by image patterns of different graphical textures, are employed to represent a diversity of activities that are progressing at a specific building element. Installing falsework, erecting formwork, steel fixing and concreting are typical examples of operational objects. Temporary facilities are defined as construction-related entities that are of temporary nature and that will not be part of the completed structure. Typical examples include mechanical equipment, material storage areas and other temporary site space usage such as site office.

- Information of Construction Planning

This component contains data concerning the duration of individual construction activity, sequence relationships amongst various activities and symbolic site plan details. It is the principal source of information for the generation of the bar chart project schedule.

- Construction Processor

One of the main tasks of the construction processor is to integrate the 3D geometrical model with the construction planning information in order to generate the 4D simulation model. Besides, it has to ensure that data feedback from the 4D construction model will correspondingly synchronize the scheduling information prior to re-generation of the 4D model. The central role of the construction processor as the key instrument of data exchange should be clearly noted. Other tasks of the construction processor are to animate simulation of activities, to evaluate the resources requirements for a specific construction activity such as labor, material, equipment, workspace, cost and to represent site facilities layout versus time dynamically.

- 4D Construction Model

The integration of spatial representation through a 3D geometrical model depicting the state of a project at a specific stage, with temporal representation through a project construction schedule, constitute a 4D construction model. It is generated on the basis of the 3D model and a mathematical representation of the behavior of various entities including building components and temporary facilities under the project throughout the construction period. It is represented dynamically as a series of graphics, under which differences in states of the entities are reflected via changes of their respective visual attributes. Here a 4D state can be defined as any specific graphic display of the project in a 3D format referring to a particular instant. In this system, the 4D construction model integrates the 4D state with the annotation of pertinent construction features including human, material, plant, workspace and cost. The information are then further processed for 4D simulation, workspace analysis, resource computation and cost forecast.

Identification and Flow of Information

It can be seen that data manipulation is very crucial to the success of the system. This is apparent since a major task of the 4D site management model is to manipulate a host of graphical data representing the 3D geometrical model, non-graphical schedule information as well as resource data. In particular, the integration of graphical data with a variety of non-graphical schedule information should be accomplished on the basis of their associated space-time relationships as well as the appropriate dynamic exchange. By comprising a knowledge base for construction management, the GCPSU database furnishes a data structure for bi-directional manipulation of information flow amongst resource data management, the 4D model and the construction schedule of the project. Details to elucidate the key identification and flow of information in the 4D site management model are depicted in the following sections.

- Generation of 4D construction model from input data

The first requirement for the generation of 4D construction model of a specific construction project is the creation of a 3D geometrical model. The construction processor takes the command here to transform graphical representation of components in the 3D model to symbolic representation, which can be termed component representation for all structural elements as well as temporary site facilities under the project. It then generates requisite construction activities from bottom to top hierarchical level, together with their associated relationships amongst individual structural element of the 3D geometrical model. This is performed in accordance with generally recognized construction technology and the method statement stored in a knowledge base, which is termed construction discipline module. Also in accordance with construction discipline module, the requisite temporary facilities are represented under the site layout plan. At the conclusion of this process, the construction processor creates an initial information of construction planning for the project.

The bar chart schedule of the project is then set up when the initial information of construction planning is conveyed automatically into the scheduling environment for manipulation and validation. The schedule data, after refinement, becomes the initial construction plan trial. It is then dynamically conveyed back into the construction processor for final compilation and generation of the 4D construction model. The construction processor integrates the component representation data with the information of this initial construction plan trial. It results in a mathematical representation of the behavior of the component representation entities, which reflects the dynamic visual attribute of individual object. At the present moment, in the prototype system, there are three types of visual attribute, namely: 1) visible, 2) visible plus specific activity image, 3) invisible. Through the knowledge stored in the construction discipline, the construction processor furnishes the construction feature for each entity. This representation is termed as the process representation. In essence, it delineates the space-time relationship between the 3D geometrical model and the information of construction planning. The 4D visualization is then performed to create the 4D model. Based on the process representation, the construction processor evaluates each object including structural component or site facility to establish the graphical variation of 3D geometrical model in daily construction operation. In other words, the construction processor is the module that is responsible to determine for every instant whether a structural element is visible, visible plus a specific operational object, or invisible, and whether a temporary facility is visible or invisible. In order to establish the 4D construction model, the construction processor incorporates all graphical as well as non-graphical data during this process in a form of construction annotation.

- Verification and feedback from 4D construction model

It is desirable that when modification of a 4D state takes place on the graphic screen for 4D-GCPSU, the updated scheduling information can also be reflected simultaneously. One of the major difficulties in accomplishing reverse data flow is the incapability of an individual 4D state in itself to represent the activity relationships as well as the temporal attribute. In order to overcome this difficulty, a new algorithm is adopted for the 4D site management model. Through the GUI and the alteration of the visual attribute for the pertinent objects, the displayed activities in a simulation of the 4D state representing the construction for a specific instant can be prolonged, shortened, advanced, postponed or paused. These operations allow adjustment of the 4D state, after which the project scheduling data can be updated.

Under this algorithm, several assumptions are used in order to re-set the temporal attribute and the activity relationships subsequent to adjustment of the 4D state. The major assumptions are, namely: 1) the adjustment will only affect the ensuing activities but not the previous ones, 2) the number of construction activities will remain unchanged, 3) the predecessor and successor relationships amongst various activities will not be altered, 4) if the temporal attribute of an activity has been altered, its new value comprising the duration, start/finish time, and connectivity time with all successors as well as predecessors will need to be supplied by the user, 5) the data on connectivity time between successors and predecessors of the activities will remain unchanged.

The mechanism for data feedback from the 4D construction model is based on the aforementioned assumptions. As such, when any requests on the adjustment of the 4D state in the 4D construction model are received through the GUI, the construction processor will decide whether it is legitimate or not. If it is considered legitimate, the construction processor will modify the pertinent process representation and the construction planning information regarding the associated activities or site facilities in accordance with the construction discipline. If the temporal attribute of any activity is modified during this process, the construction processor will check the impact of the modification on all ensuing activities. Moreover, the bar chart project schedule will be updated at the same time during this process. Last but not least, the construction processor will manipulate updated scheduling data to re-generate both 4D construction model as well as process representation. If the modification is considered illegitimate, the construction processor will restore the original 4D construction model.

Implementation and application of 4D-GCPSU System

With the prevalent usage of Windows platform and the availability of personal computers in site office, it is decided that 4D-GCPSU be developed and implemented on a pentium microcomputer. The programming languages used are mainly Visual C++ and AutoCAD ObjectARX. AutoCAD is adopted as the graphics environment whilst Microsoft Project98 is chosen as the project scheduling tool which is synchronously linked to the 4D-GCPSU. The composition of the 4D-GCPSU system is shown in Figure 2. Principally, the system comprises four segments that interchange data amongst themselves through the Dynamic Data exchange facilities. AutoCAD furnishes a graphical programming environment for the planner to generate a 3D geometrical model regarding the construction project whilst Microsoft Project displays a bar chart scheduling environment relating all the pertinent construction activities from the project inception to completion. The GCPSU database can be considered the root of the 4D-GCPSU system since it is basically the knowledge base that encapsulates all the working details concerning the project. The central and essential segment of the 4D-GCPSU system is the 4D-GCPSU center, which takes up a diversity of functions including linkage amongst other segments, user interface, 4D site management, and practical project management. Figure 3 shows the opening menu of GPCSU. Figure 4 displays a sample screen of GPCSU linking 3D geometrical model and schedule whilst Figure 5 shows a sample screen of GPCSU effecting 4D visualization.

In order to verify and validate the performance of the prototype system 4D-GCPSU, it was applied to the phase VI campus expansion site of the Hong Kong Polytechnic University during the actual construction of the project. It was a multi-building project, which comprised over 25,000 square meters of new building floor area. The construction period for the structural works was from August 1999 to March 2000. In order to assess the appropriateness of the extent of the involving data, the entire structural construction was traced in details by using 4D-GCPSU. Throughout the exercise, comments made by the site staff, who were jointly operating the prototype system on the project, were incorporated. The verification assisted to gauge the application of 4D-GCPSU in daily site planning work and to enhance the practicability of the software at the same time.

The insights gleaned from this case study demonstrated both successes and weaknesses of the present tool. It was confirmed that the product of this computer application was really desired by the industry practitioners. However, the generation as well as continuously update of both micro programme and detailed 3D CAD drawings were very laborious and the file size that resulted was so huge that it was very slow to process. Anyhow, it furnishes future directions for further enhancement of the tool. More details of the experience gained from this exercise will be the subject of a separate paper.

Conclusions

Through the exploration of the problems that may often arise from the existing means of construction planning, a new 4D site management model has been proposed in this paper. Moreover, the prospective requirements for 4D application to support practical use on site management have also been highlighted. 4D-GCPSU, representing the actual implementation of the model to link a 3D geometrical model with scheduling data, is demonstrated to have the capability to overcome drawbacks of conventional means in construction planning. This comprehensive computing system embraces the activity schedule, the pertinent resource allocation as well as site layout planning at any specified time interval. This tool can facilitate the planning process, foresee any site problem prior to occurrence and thus enhance the quality of site management. The recent fast advancements in computing technology have brought about more user-friendly, comprehensive and integrated site management tools, which at the same time entail higher management standards on the part of the planners. The study on 4D visualization practice has certainly far-reaching impacts in the field of construction management. It is anticipated that 4D-GCPSU will be further evolved incorporating novel technology as it arises.

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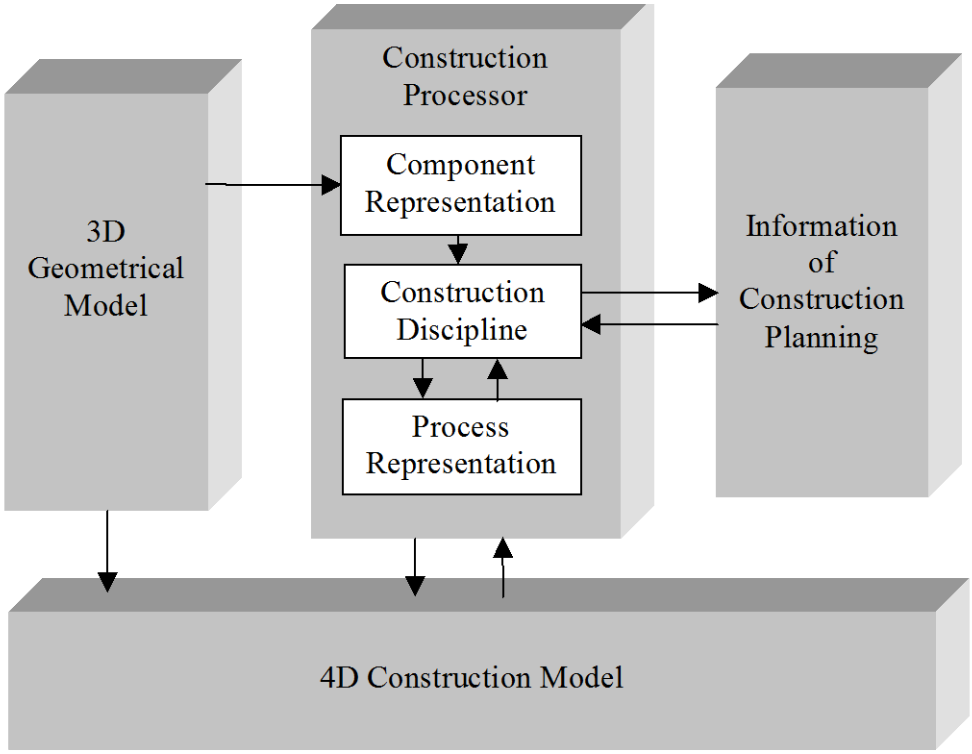

Figure 1. Structure of 4D Site Management Model

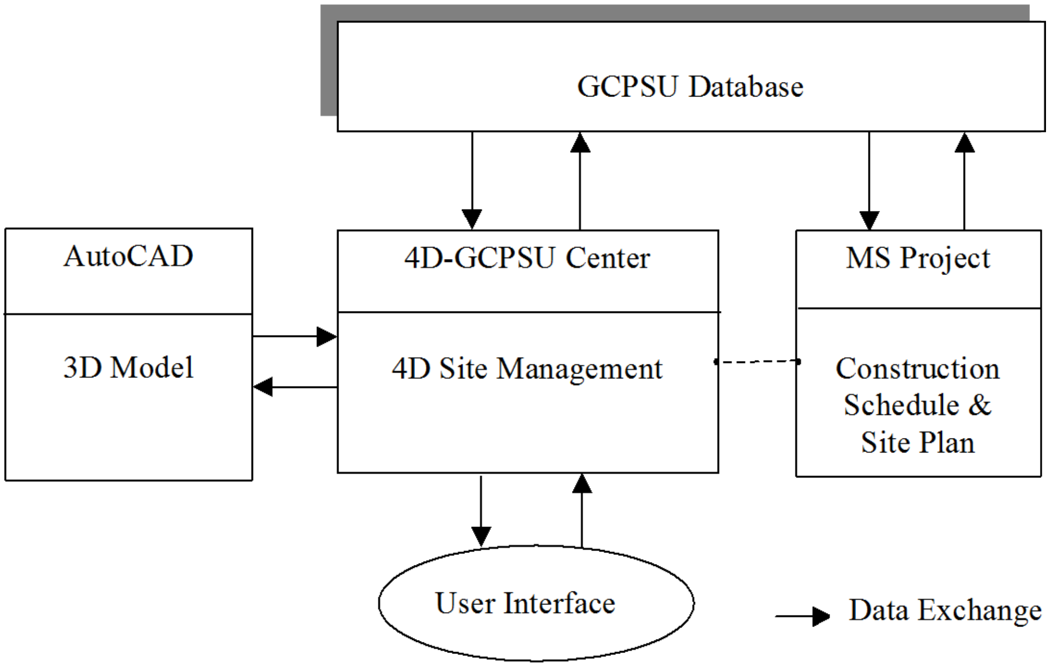

Figure 2. Composition of 4D-GCPSU

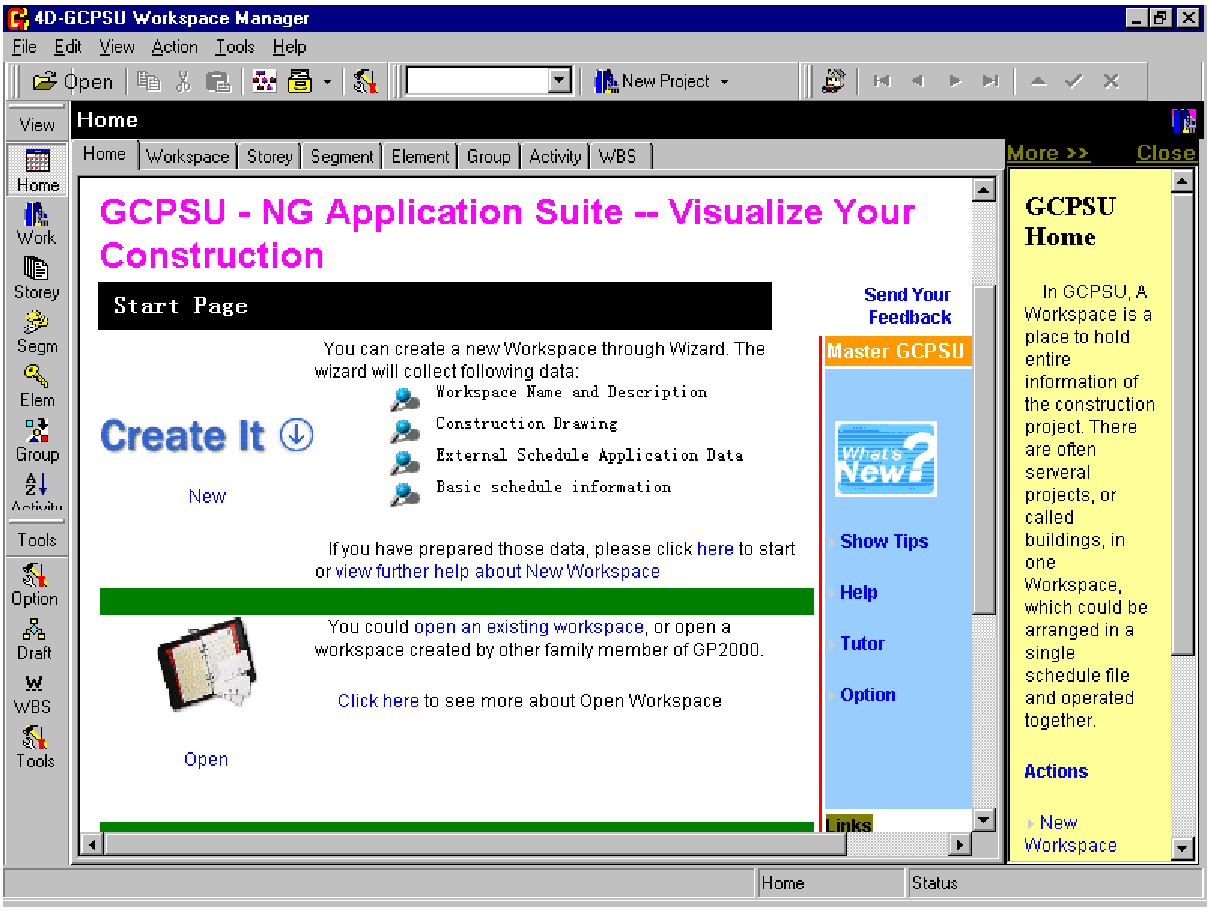

Figure 3. Opening menu of GPCSU

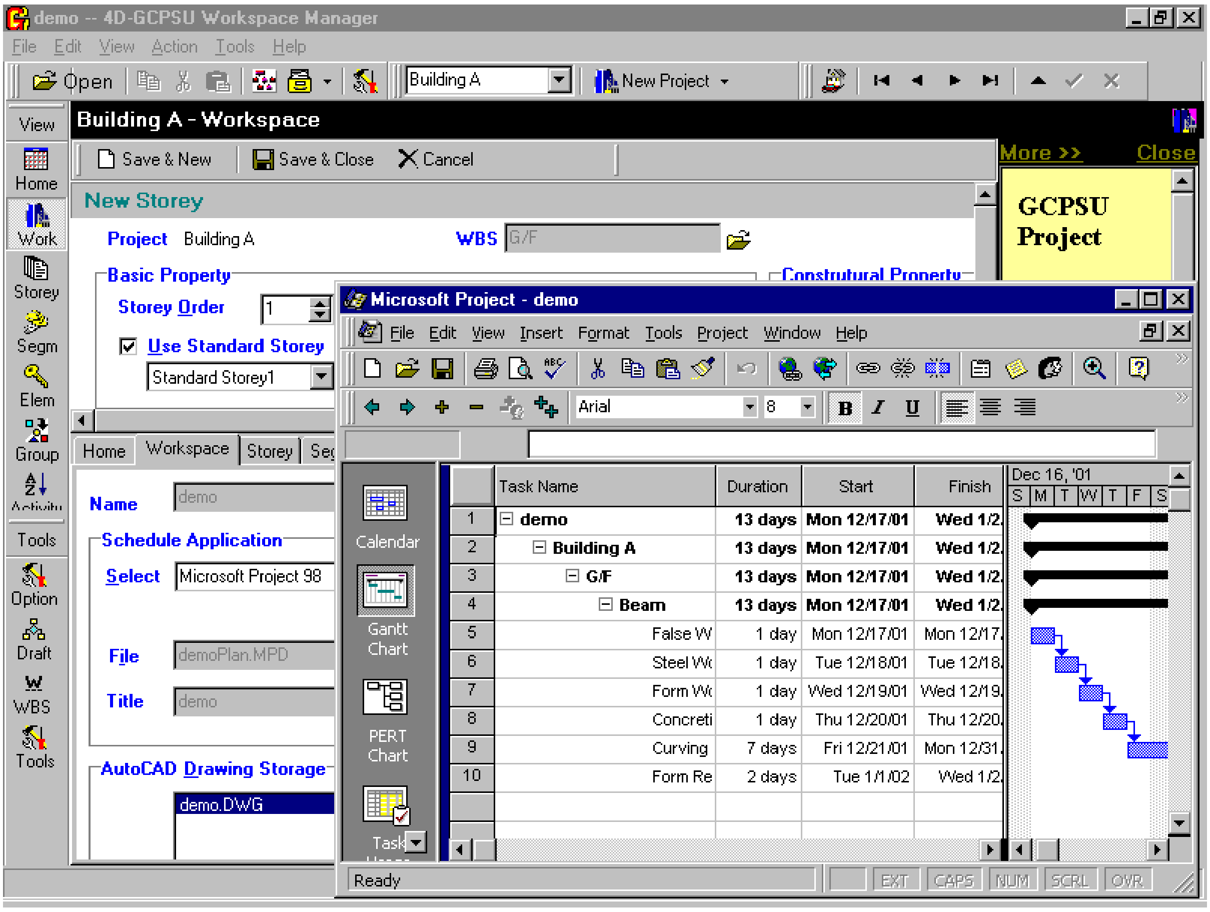

Figure 4. Sample screen of GPCSU linking 3D geometrical model and schedule

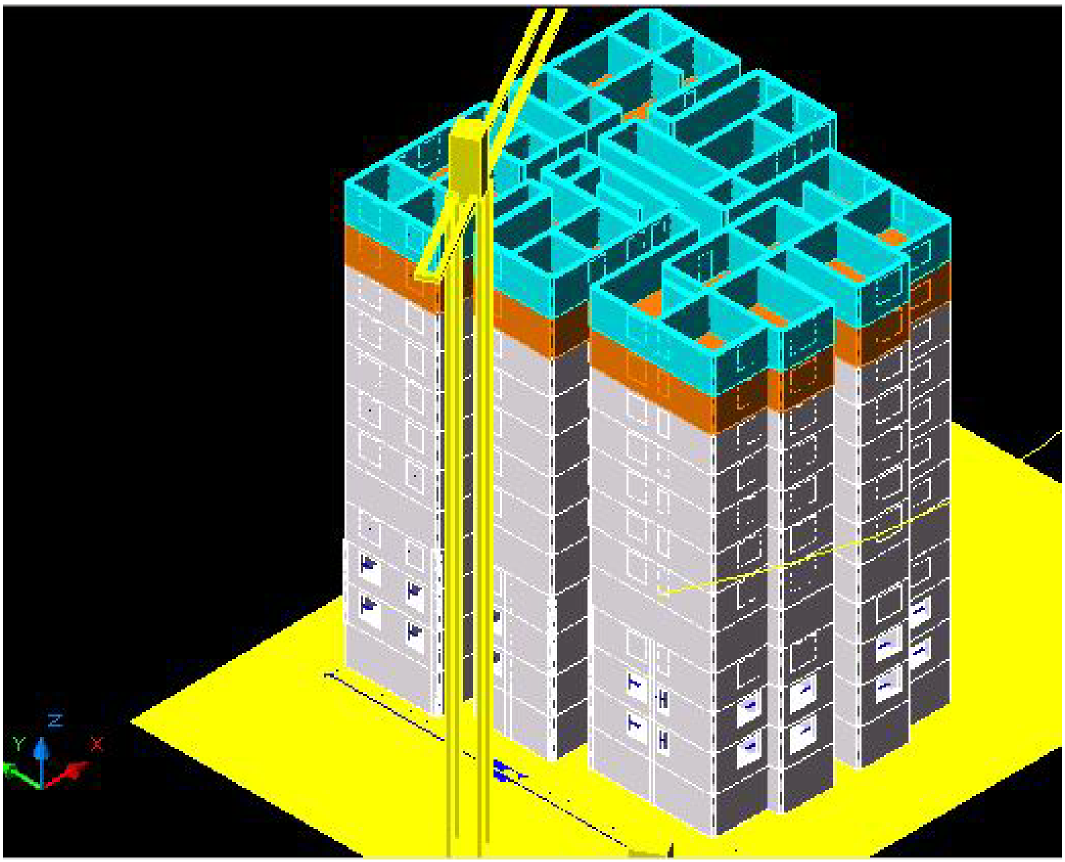

Figure 5. Sample screen of GPCSU effecting 4D visualization