



Visualization for decision making in construction planning

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ABSTRACT

This paper describes a new approach for planning and monitoring of construction projects. This approach is a result of two lines of research, which investigated the ways of and benefits from the integration of Computer Graphics and Artificial Intelligence tools within construction processes. The approach is based on visualisation of situations and/or solutions generated by a computerised system during the planning process. The implementation of the approach is outlined. The examples of visualisation are provided and discussed. The further development is proposed and conclusions are drawn.

INTRODUCTION

There is no doubt that one picture is worth a thousand words. For construction planning the question is not only how, but also (and mainly) what to visualise. Existing computerised design tools (i.e. CAD systems) are basically developed for designers to deal with a *product* design (i.e. drawing or 3D modelling of a building or structure). While the construction planning tasks (scheduling, time-cost forecasts, etc.) are a construction *process* design. Similar to the product design, the generation of the construction process is based on heuristic knowledge and its results are unique for every project. The difference is that these results (i.e. time schedule) are rather a sequence of events than physical objects and, therefore, it is more difficult to validate and evaluate them. Therefore, the visualisation may not only facilitate the validation and evaluation

of the generated process, but also support further decision making (i.e. recourse allocation, progress monitoring, etc.), based on it.

Computer graphics development has proposed a variety of visualisation tools and techniques (see Brodie [1], Earnshaw and Wiseman [2]). There are already several different either explicit or implicit ways of integrating computer graphics with artificial intelligence tools in civil engineering. They can be viewed according to the aims of the usage. The obvious one is the graphical illustration of final results. In this case a decision to fire graphic procedures or take off predefined graphic solutions is made as a result of data elaboration or calculations. Typical examples are the RETWALL system (see Siller [3]), which allows the choice of kind of retaining wall, from 10 possible, and the drawing of it, and the GERT system (see Cornick and Bull [4]), which pulls out suggested solutions for gypsum wall connection details.

A different case is where a decision is made by the user as a result of visual examination of graphic pictures displayed by a computer. PLATFORM II (see Levitt et al. [5]) presents planned schedules in the form of Gantt charts to allow a user to do a solution validation. SABA (see Ligget [6]) displays suggested facility layouts. The system, that is described in Guena and Zreik [7], allows checking of the opening directions of doors in a given layout.

Realistic representation of the design alternatives or solutions becomes necessary where manipulation of the words and symbols carrying out graphical meanings is a vehicle for generation of a new design. Examples can be seen in Akin et al. [8], Bijl [9], Gero et al. [10], and many others. The development here is based on logic (e.g. PROLOG) or object-oriented languages (see Bourdeau [11], Keirouz et al. [12]). These allow us to build intelligent systems using logic representation of graphical and geometrical information. The synthesis of a new design (the system's output) is obtained as a collection of words and symbols or primitives (objects). The connection of the formers with graphical entities is a way for visual representation of the solution (see OPS/83 in Kano [13] for displaying simulation by Gantt chart or Oxman and Gero [14] for kitchen layout design).

Geometric and spatial reasoning is a relatively new and very powerful approach (see Woodwark [15]). This approach is based on defining the connections between the geometrical representation of design objects (location, dimensions, etc.), spatial relationships (composition, hierarchy, sequence, etc.) and their (the objects') functional roles. Therefore, visualisation and further manipulation of objects could be, for example, based on their geometry, but decisions may be made on functional attributes. The examples of these approaches are described in Fenves and Baker [16] for structural design and in

Woodbury and Oppenheim [17] and Giraud and Hanrot [18] for architectural design.

Two different patterns of visualisation for the construction planning are demonstrated below. Their further implementation is discussed later.

PLANNING AND MONITORING OF CONSTRUCTION PROJECTS

Interactive visualisation of the construction process

Perhaps the most potentially useful application of computer graphics in design is the possibility of a three-dimensional representation of projects or their particular details in the same manner as has been conventionally done with cardboard, wood or plastic physical models. Once such a model was created, it was possible for a designer or his client to observe its features from different angles, or even "walk through" its various parts.

In a similar manner the 3D graphics may be applied as an aid for visual simulation of a construction project progress. The planner, the contractor or the owner can observe the simulated project or "walk through it", when performed with different methods, or at various stages of its execution. The ability to show a real picture of the work progress, indicating deviation from the planned schedule, is very valuable for the senior managerial staff, especially those dealing with co-ordination of and resource allocation for several projects concurrently. To 'grasp' a visual status of several projects is not only easier but also quicker. The example on Fig. 1 shows how project status can be presented at various project stages. This approach is based on visualisation of basic activities of construction processes, as suggested in Retik et al.[19] for multi-storey residential buildings. Each of the activities has, as their attributes, the planned start, the duration, their graphical and geometrical representation and their location in the project space. Each activity is composed from a parametric 'library' of basic elements such as walls, columns, windows, etc., created for this purposes and as a result could be adapted to the desired dimensions and position.

This kind of representation can help not only the convenient visual validation and simulation of the project progress but also creates new possibilities, not available by conventional methods, for the planning process itself. During the monitoring of the construction progress, the deviation from the planned schedule may be shown by using a different colour. As a result, the planner may not only notice a delay in a particular activity but also see the actual place of this delay. Moreover, a knowledge-based expert system can be integrated within the 'managerial' part of the system, advising what actions may be taken to avoid such a situation.



ACTIVITY	DATE	Jn	Jl	Ag	Sp	Oc	Ne	De	Jr	Fb	Mr	Ap	May
		86	86	86	86	86	86	86	87	87	87	87	87
1 ERECTION OF COLUMNS		1	1	1	1	1	1	1	1	1	1	1	1
2 ERECTION OF EXTERIOR WALLS		1	1	1	1	1	1	1	1	1	1	1	1
3 ERECTION OF HORIZONTAL SLABS		1	1	1	1	1	1	1	1	1	1	1	1
4 EXTERIOR WALL FINISHING		1	1	1	1	1	1	1	1	1	1	1	1
3 INTERIOR WALL FINISHING		1	1	1	1	1	1	1	1	1	1	1	1
4 FLOOR FINISHING		1	1	1	1	1	1	1	1	1	1	1	1

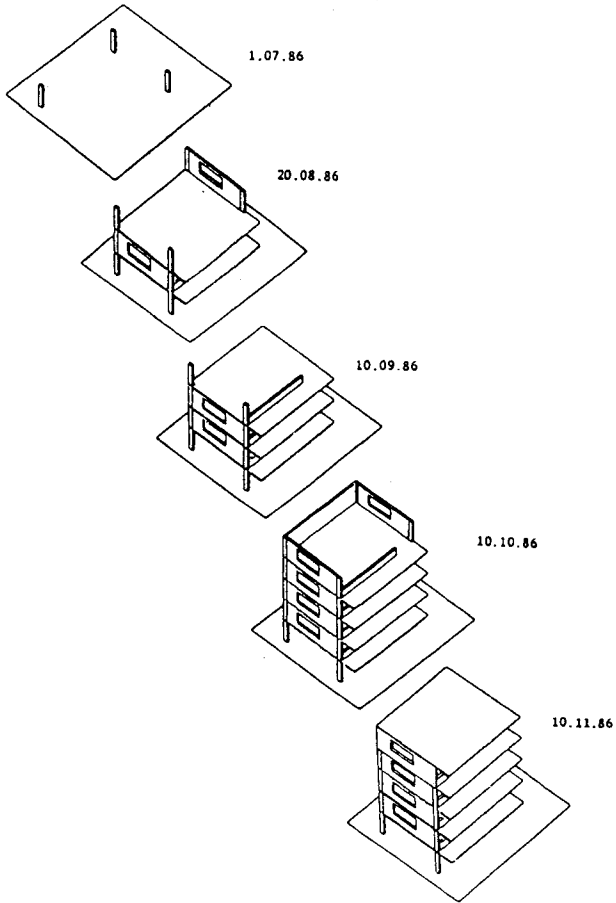


Figure 1. Construction Schedule Visualisation (from Retik et al. [19])

Graphic representation illustrated in Fig. 1, in conjunction with a regular bar chart, may be used in a similar manner in conjunction with a network, line of balance or any other technique. In such cases, it will present, in a visual form, those features which can assist the planner or site manager in a better perception of the construction process. For example, the system can present, in a graphical form, the activities on a critical path, or any other path (with network) or the progress of a specific work team (with lines of balance). Representation of such selected features can be requested by the planner from the managerial part of the system, appropriately programmed for this purpose.

Further development of the above approach may lead to the different realisation of the planning and monitoring tasks. The idea is to use dynamic visual status of all project activities during whole construction processes. For that, it is necessary to present the comprehensive picture of the project including new construction (structures, buildings, etc.), landscape development and site organisation with plant and facilities (see Fig. 2) and to schedule them. The visual status of construction work progress related to the site organisation is very important to the project managers. The possibility to check and compare visually several alternatives for plant and facilities location on the *site* and also to validate them in *time* may help to achieve better solutions.

Different levels of 'project picture' details are needed during the project implementation phases. For that, each building may be presented by work elements or segments which may be, for example, a structure erection or finishing works of a complete building floor section. Every segment should be associated with a group of activities. As a result, each segment may be later represented separately in more detail with its various composing activities or through the activities of each of its major trades, or responsibility groups - e.g. concreting, piping, etc., each of them monitored separately for its actual versus planned status (see Fig. 3).

One of the possibilities for achieving this multi-level planning is to present project data hierarchically. In this case, once the project is updated on the lowest level the result may be seen on all higher levels. To provide flexibility in defining hierarchy the 'hammock' approach may be used on every level, connecting a group of activities to one section or segment on the above level, consequently, a group of segments to a building, etc. (see Fig. 4). To avoid too much detail and make a picture understandable, every level can be connected to a *different* set of the parametric library of the graphical elements. For example, at the project level the following library elements may be necessary for generating the project picture: roads and approach ways; storage facilities, storage areas, etc.; cranes and rails; auxiliary structures; etc.

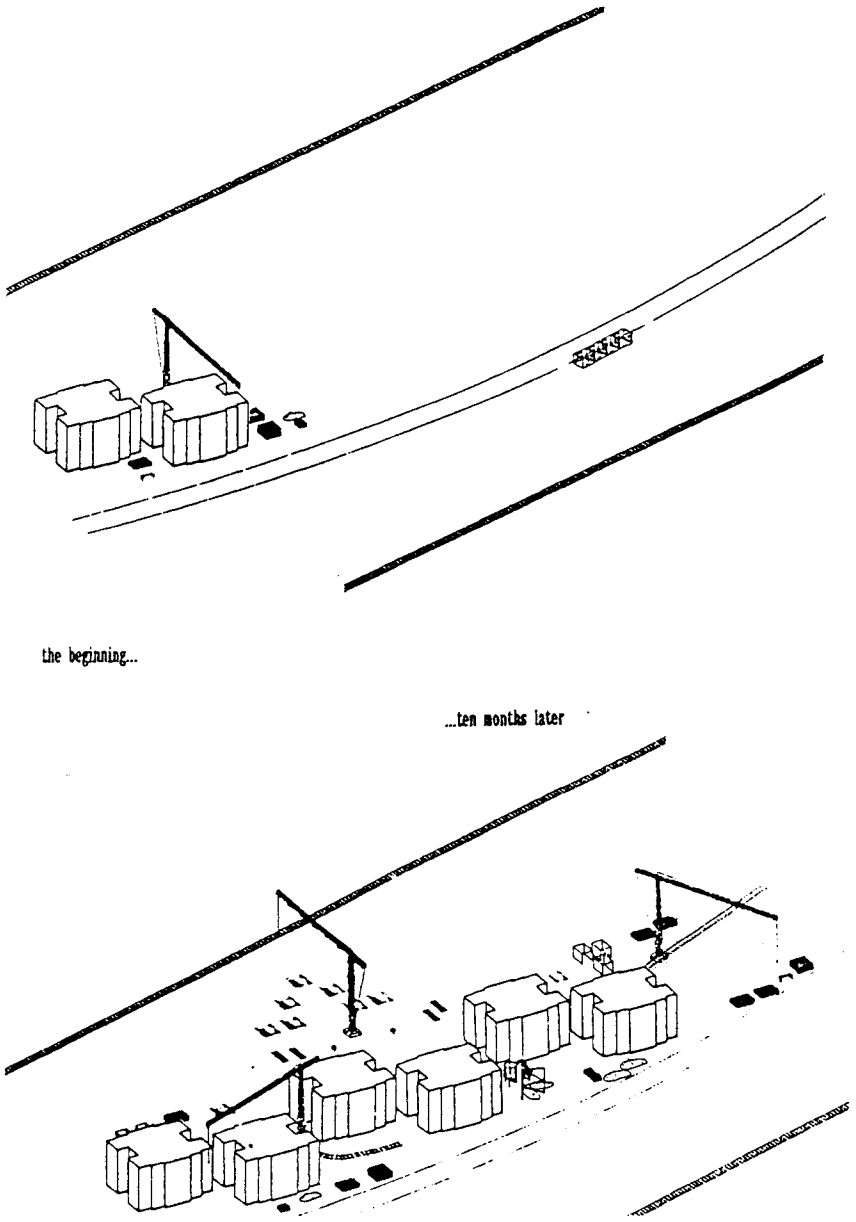


Figure 2. Example of Visual Monitoring of Construction Work Progress

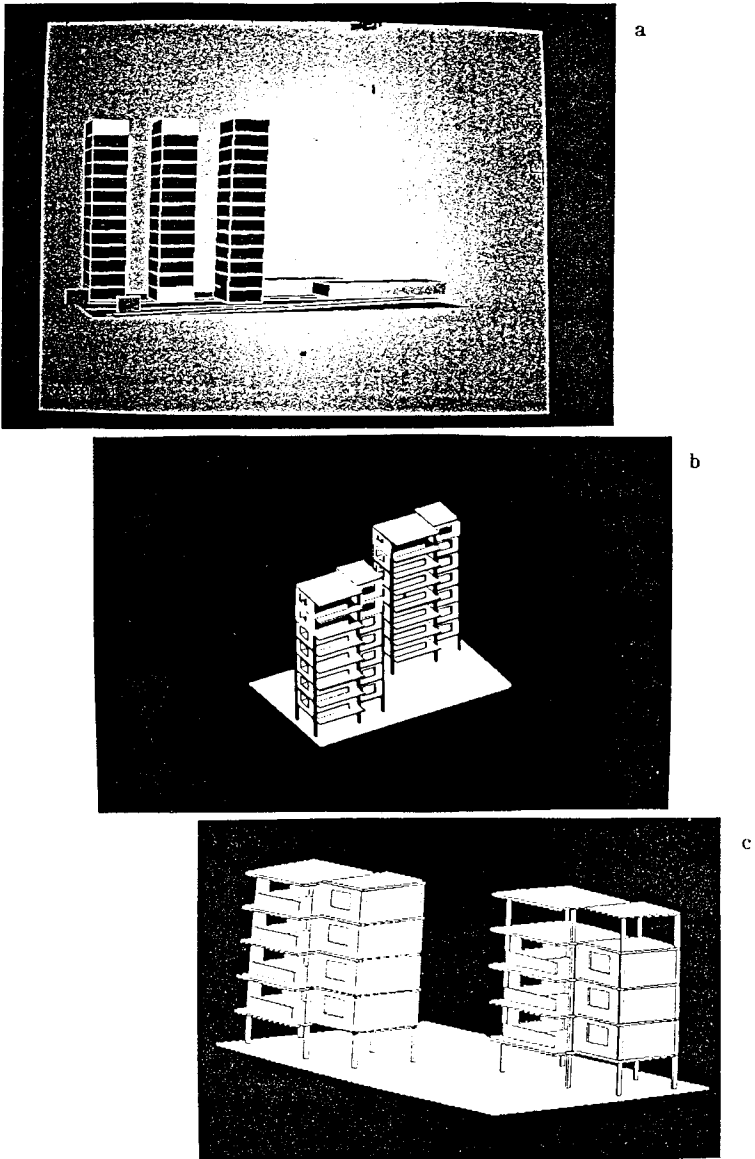


Figure 3. Different Levels of Project Visualisation:

- (a) segment level
- (b) activity level
- (c) selected activities

The library elements can be very schematic, although providing enough realistic visual presentation (see Fig. 2). The adjustment of the elements to the project context may be done through the dimension parameters once the project is set up. The actual location of the elements during the project should be related to the project progress similar to the activities schedule (see Retik et al. [19]).

The buildings and structures on the segment level (see Fig. 3a) can be created from simple 3D parametric boxes or prisms. Their dimensions and visualisation images (colour, texture, etc) should be variables of the composing activities of their groups (segments). The relationships between the visual status and the work progress may be achieved through simple production rules or, in the case of the object-oriented approach, through message passing.

Activity level (see Fig. 3b) is a basis for planning and monitoring tasks. These tasks may be handled by existing project management packages, providing output to the upper level through the program interface. Setting up a project and breaking it down into activities should be primarily based on managerial criteria and actual needs (resources, available work gangs, work places, etc.). The decision which activities to monitor visually (some projects may have several hundred activities) will probably be based upon importance of the specific activities in the project context or whether they are subcontracted or not, etc.

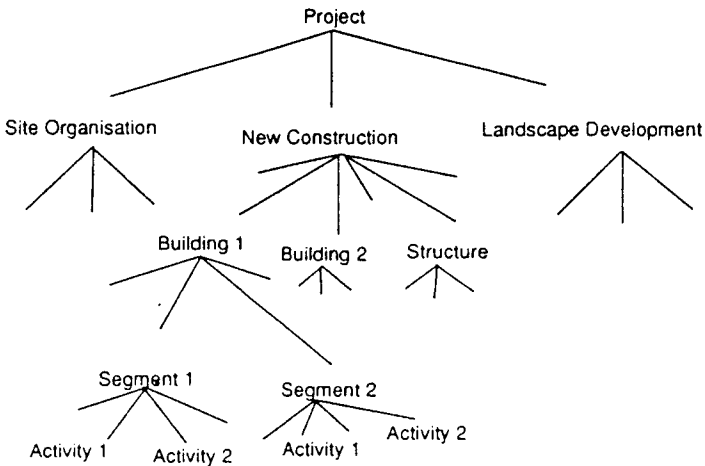


Figure 4. Hierarchical Representation of Project

Non interactive visualisation of the construction process

It is not always useful to visualise the construction process interactively. An example for such a situation is demonstrated further by the case of intelligent stochastic simulation of cost-time forecasting in Marston et al. [20]. In this case the *in situ* heuristic knowledge is integrated within the system for decision and action making during each cycle of the simulation process, if and when interference occurs in the work sequence.

The system prototype which is based on the above approach, consists of two main parts dealing with: (a) plan generation and (b) work process simulation. Plan generation involves (i) break down of work description into activities, (ii) establishing order and pace of the work as well as (iii) allocation of appropriate resources as materials, labour and tradesmen and plant and equipment. Once the time schedule is generated the simulation process may be started.

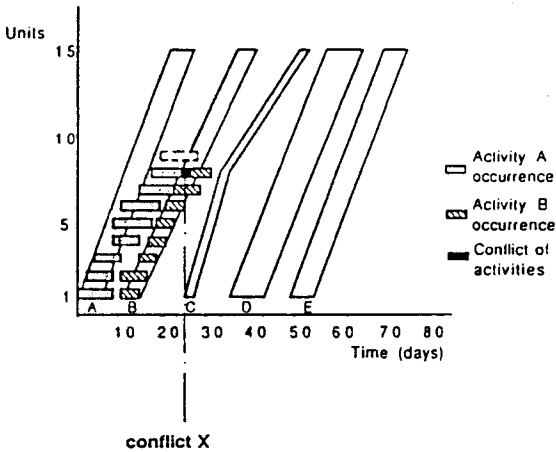
At this stage, the site production process is simulated by the Monte Carlo method. 'Actual' values of productivity rates are drawn randomly from probability distributions defined according to work context, load and domain. The resulting 'actual' duration of the involved activities is recorded. Progress is monitored to identify where departures from the plan cause interferences between activities or unacceptable delay, and management decisions are simulated to take corrective action where necessary. At the end of each simulation iteration, the 'actual' duration and cost is calculated, prior to a further simulation run being commenced. After completing a preset number of iterations (about 100), the final results are computed and reported.

Result representation, analysis and visualisation The primary outputs of the system - probabilistic estimates of total project cost and duration - can be presented both graphically and numerically. Various additional outputs may be produced for the purposes of explanation and validation including a graphical representation of the operational plan, reports on the decision responses to interferences and delays, and a facility to produce a trace of any simulation run.

One of the questions that appeared as a result of the simulation was how one can control decision making processes or know what kind of decisions were made and when. It is not realistic of course to visualise simulation processes interactively, showing every scenario a hundred times. Moreover, it is not necessary even since the decision will be made only when the interference has occurred. Therefore, only the conflict situations may be stored in the computer memory. Visualisation of the activities' interference may be achieved by graphic representation of a schedule such as line of balance graphs with the description of the decisions that were made. Evaluation of simulation results as well as their validity may be done later on. Because a large number of simulation cycles



are necessary to achieve representative cost-time distributions, conflict situations will be stored in the computer memory together with the decisions taken. 'Post-mortem' analysis will then be possible (see Fig. 5).



CONFLICT X:

DECISION: increase the gang size of the activity A by one labour for a week

IMPLICATION: add to the 'extra-cost' slot the following value:
 $40 \text{ hours} * (\text{spec-lab-cost-p/h})$

Figure 5. Example of 'post-mortem' analysis

DISCUSSION OF APPLICATION ASPECTS

The application aspect of the interactive multi-level visualisation approach in the former section (see Figs 2,3) deserves further discussion.

The creation of a three-dimensional image for each element may be quite an involved task in a real life project consisting of hundreds of different work items. As noted before, such processes can be largely facilitated by the creation of a library of composing elements such as walls, windows, columns, slabs, etc. Nevertheless, even then the amount of work can be quite extensive, especially in large projects. The task may be quite simple however, if the project



is anyway designed with the aid of 3D computer graphics - and has the desired image for the work items created in this process for different design purposes. In such a case, it would be enough to code each work element and the associated activity so that they could be properly referred to and recalled by the managerial part of the computerised system. It is not always a straight forward approach to relate a work element to an activity, but some abstraction/simplification may be done. On the other hand, the effort may be paid off in a complicated project where 'walk through' facilities will be necessary to explore project status on the activity level.

Some difficulties may arise with certain work elements which are invisible or not entirely compatible with the activities allocated for their execution. For example, activities such as formwork erection for concrete pouring, or excavating for foundations, would not be normally represented in a 3D building design. They can be added however, without difficulty as an auxiliary activity, coded in conjunction with the work piece they are to produce and represented by a different colour, shading, texture or annotation.

Another problem, especially at activity level, is the wealth of the graphical information contained even in a simple project - skeleton, fixtures, finishes, mechanical, electrical systems, etc., which can completely blur the image of the building under construction on a regular computer screen. A window in the screen may contain a symbolic representation of all or only special or subcontracted trades to be monitored acting as a checklist in the control process.

CONCLUSIONS

Visualisation of a building project may assist a schedule planner or user in a better perception of the construction work progress. The advantages of this representation may be more emphasised in large scale projects where the approach can be extended to monitoring not only the construction process itself, but also all auxiliary activities including on site plant and equipment. Here not only different locations of construction equipment and temporary facilities in space may be checked, but also be *traced in time*. In this case, especially in projects where heavy plant is used, delays and interferences may be prevented.

Monitoring of the work progress in large projects may follow whole work packages which can be subsequently separated into individual work items. It can also focus on individual work trades. The use of a graphical representation of the construction process is very much facilitated if the project is also designed with the aid of a 3-dimensional graphical system.



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