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Expert System for Construction Site Layouts
Système expert pour l'aménagement de chantiers de construction
Expertensystem zur Planung von Baustellen

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SUMMARY
ESBE is the hybrid object-oriented expert system for the optimization of construction site layout. It combines a hybrid system, consisting of an expert system and mathematical facility layout algorithms, the construction site database, the CAD component and the user-interface/3D-visualization component. Several aspects of the integration and realization of the latter in ESBE are discussed.

RÉSUMÉ
ESBE est un système expert hybride à orientation objet, destiné à l'aménagement de chantiers de construction. Il comporte un système hybride constitué d'un système expert et d'algorithmes mathématiques de planification d'installation, d'une banque de données de chantier, d'une composante de conception assistée par ordinateur (CAO), ainsi que d'une interface d'utilisateur / composante de visualisation tridimensionnelle. Les auteurs exposent différents aspects de l'intégration et de la réalisation de cette dernière composante pour ESBE.

ZUSAMMENFASSUNG
ESBE ist ein hybrides, objektorientiertes Expertensystem zur Planung von optimalen Baustellenlayouts. Es enthält ein hybrides System, bestehend aus Expertensystem und mathematischen Facility-Layout-Algorithmen, Baustellendatenbank, CAD-Komponente sowie als Benützerschnittstelle / 3D-Visualisierungskomponente. Es werden einige Aspekte der Integration und der Realisierung dieser letzteren Komponente in ESBE diskutiert.

1. INTRODUCTION

Despite the fact that the turnover of a large-scale construction site is that of a medium sized factory and "construction" means "transportation", only a few mathematical methods or other advanced information technologies treat the problem of finding an optimal realisation of the site plant. In contrast to this, other industries are using these modern methods to minimize cost, workload and time.

At the first glance, many reasons can be named why these modern methods have not yet been considered for the construction site. In this settings we must deal with a very complex dynamic process, which differs extremely from the process in a factory.

Because of these problems a hybrid object-oriented expert system called ESBE is being developed. The objective is the interactive generation of an optimized construction site layout. The task is the dimensioning and the arrangement of the individual construction site facilities. ESBE consists of three major parts: an object-oriented construction site database which contains general and company specific data of the construction site facilities and the building data; a hybrid system with mathematical optimization algorithms and an expert system (knowledge based system) as well as a well-tailored user-interface with a 3D visualization component.

The aggregation of the uncertain knowledge is realized using a combination of fuzzy and probability functions. Outputs of this expert system are the recommended type and amount of the different construction site facilities and a ranking of the appropriate areas (rectangles) to place the facilities. These areas serve as input to the mathematical algorithms, computing the optimal positions of the facilities inside these restricted areas. Both parts are realized using the object oriented language EIFFEL.

The user interface / 3D-visualization are the part of ESBE, that interacts with the user. They decide whether ESBE will be accepted by the user on the construction site which means how successful the system will be in practice. The paper describes the interfaces to the other components of ESBE and how it has been realized.

2. WHY TO TAKE THE EFFORT TO REALIZE A WELL TAILORED USER-INTERFACE / 3D-VISUALIZATION COMPONENT ?

In our opinion, the human factor is still playing the major part in almost every design step for an user-interface. There are many reasons to take big efforts especially in developing a 3D-visualization component, some of which are:

- user acceptance
  A three-dimensional image can be interpreted easier by the user than two-dimensional solutions used so far, because three dimensions correspond better to reality. Another problem is the loss of information of a three-to-two projection.

- trace of the building process
  Another feature is that the building process on the construction site can be traced on the screen in time-discrete steps. A two-dimensional top view cannot show the changing of

the height of an object, so the three-dimensional issue becomes attractive. It shows, for example, that the crane has to have a specific height at one discrete time period, because the front wall is higher than the rest of the building.

lack of information / data obtained by the user
The hybrid components of ESBE, i.e. the expert system and the mathematical optimization algorithms, cannot consider specific aspects of the construction site. Therefore the user, e.g. the construction site manager, is needed. Using the 3D-visualization component, he can introduce facts like the topology of the construction site, which is hardly possible using two-dimensional images.

3. HOW TO FEED THE USER-INTERFACE / 3D-VISUALIZATION COMPONENT

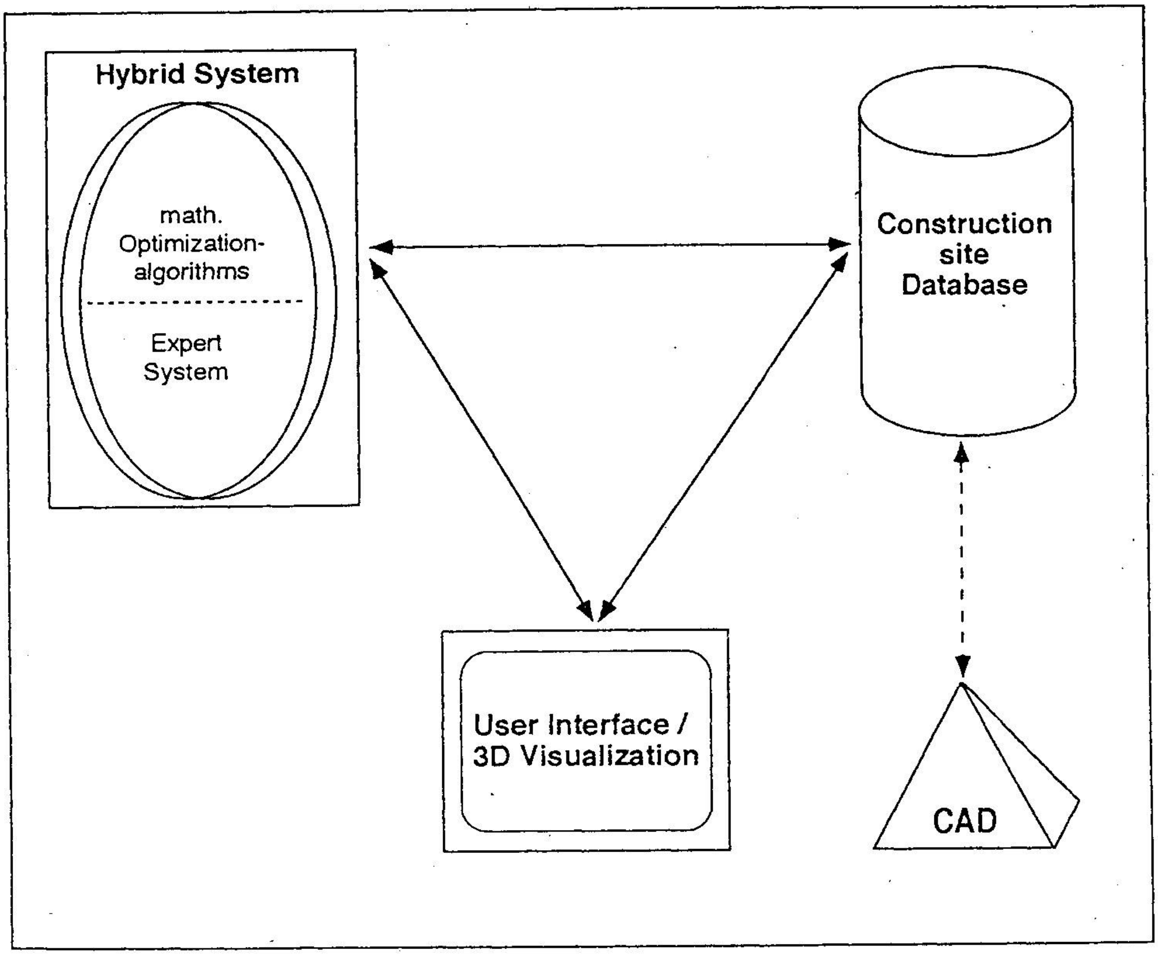

Fig. 1 Concept of ESBE

Fig. 1 shows, that the user-interface / 3D-visualization component has internal interfaces to the construction site database and to the hybrid system, which consists of the expert system and the mathematical optimization algorithms. The database contains building data fed by the CAD component. Asynchronous inter process communication (IPC) is implemented between the different components to ensure a fast data exchange.

3.1 The construction site database

So far, we have realized the database using the relational DBMS INGRES. To make the objects of the hybrid system persistent, they must be cracked down to entities in order to integrate them in the rDBMS. The next step will be to replace the rDBMS INGRES with an object-oriented database.

The project data can be separated into three major data blocs:

- main project data
  It contains general information about the project, e.g. address of the construction site etc.

- execution independent data
  It can be divided up into construction site data, e.g. site area, and the building divided up into construction units (cubes), coming from the CAD system.

- execution dependent data
  It is determined by the marker, like the project scheduling etc.

As a result, we get the individual jobs which are necessary to build the execution units and to optimize the construction layout: place, time and quantity.

The calculated and optimized layout at discrete time periods with all construction site facilities and the building can be retrieved from the database by the 3D-visualization component. The user-interface gives access to the whole database, e.g. the data sheet of a used crane.

3.1.1. The CAD component

The CAD component provides building data with its geometric, material and spatial aspects. Realizing this we used the so-called *element-method*. For this, the building has to be divided up into construction units (cubes), which are stored in a construction unit catalogue. The needed materials and their quantity are assigned to the construction units. The building itself will be reduced into execution units, which are assigned to the corresponding construction units and their local places in the building. Thus the geometrical and material aspects of the building is given. This information is fed into the highly integrated database.

3.2 The hybrid system

The hybrid system consists of the mathematical optimization algorithms and the expert system. The user-interface / 3D-visualization have the following fast communication over IPC with the hybrid system:

- compute layout for a specific time period

- layout computed; layout can be accessed in the database

- questions from the expert system to the user

- changing the position of a construction site element by the user

- etc.

The hybrid system will process a new construction layout, update the database and send the updated data back to the user-interface / 3D-visualization component.

4. HOW TO REALIZE THE USER-INTERFACE / 3D-VISUALIZATION COMPONENT

We used object-oriented analysis and modelling techniques to design ESBE. To realize the different components we chose the object-oriented programming language EIFFEL. The different components, the database, the hybrid system, the user-interface / 3D-visualization are separate processes. The are running on a RISC-workstation under the operating system UNIX.

We wanted to realize the user-interface / 3D-visualization component by using standardized tools to ensure portability.

Therefore OSF/Motif had been chosen for the user-interface. It supports network transparency, the optimized use of the workstation-network etc.

The visualization component is developed with PHIGS (the Programmer's Hierarchical Interactive Graphics System). It is a high level graphical library used to display and interact with three-dimensional (3D) images. As a standard approved by the International Organisation for Standardization (ISO), it offers portability to many different computers using different operating systems and window systems. We are using PHIGS PLUS, which is an enhancement of PHIGS, and already part of the standard. With the advent of the PEX protocol, developed by the M.I.T. X Consortium, PHIGS can be used to drive graphics display over the network.

The three-dimensional construction site is displayed in a variable PHIGS-Window under the graphical interface OSF/Motif.

5. HOW TO WORK WITH THE USER-INTERFACE / 3D-VISUALIZATION COMPONENT

A suitable user-interface with a 3D-visualization component has been developed. It gives the user the possibility to take a realistic view at the optimized construction site. The items in the following sub-chapters have been realized to help the user work with the 3D-visualization component. Some of these items are shown in the enclosed Fig. 2, 3 and 4. The ESBE main menu is always displayed in the top right corner. It contains the following options:

- determine project number

- optimize construction site

- activate ESBE database menu
- modify construction site facility
- select explanation component
- end of session

Below the ESBE main menu Fig. 2 shows the activated ESBE database menu. Fig. 3 shows a crane data sheet retrieved from the database. Technical and economical information, like the weight and the abbreviation of the chosen crane, are given. Even the working-load of the chosen crane is displayed under the PHIGS-window. All these information can be called by the user and their are required by the hybrid system to optimize the construction site. The user can select a discrete time to look at the construction site by using the time bar, which is displayed at the bottom of Fig. 2 and 4. In this case he chooses the 51th week. He can change between day, week and month.

The following sub-chapters demonstrate, what the user can do with the 3D-visualization component. Fig. 2, 3 and 4 show a PHIGS-window under OSF/Motif displaying a small construction site to demonstrate some of the given items.

5.1. Looking at the construction site from different viewpoints

PHIGS gives the opportunity to look at the construction site from different viewpoints. The following items have been realized so far:

- zooming
  The user can extend or reduce the picture of the construction site by simply moving the mouse. Fig. 4 shows for example a reduced construction site.
- moving
  The user can move the construction site to any direction by simply moving the mouse.
- rotate
  The construction site can be rotated around the centre of the world coordinate system by simply moving the mouse. Fig. 3 shows a side view and Fig. 4 a slant of the construction site.
- helicopter flight
  The user can simulate a helicopter flight over the construction site using the mouse. Fig. 2 shows this view.

5.2. Tracking the construction process

By changing the time on the time bar you can watch the progress of the construction and the needed machinery according to it. This is a big advantage because now you can plan your work by doing (simulating) it. Problems that normally appear only while construction is running can be discovered earlier and you can react to the problematic situation immediately by changing the schedule or other factors.

5.3 Animation of facility elements

Animation of the particular construction site facility elements, especially the cranes. This helps to see, if machines interfere with each other or with the building when they are working.

5.4 Changing the position of facility elements

To automate everything is a big hazard and not very useful, the user should take the final decision where to place the particular elements. Thus he can change the position of an element by simply activating the element with a mouse click. Now he points to the location and the element will turn to its new position. At that stage the user can activate a new optimization with the fixed location of the element.

5.5 Activation of the construction process

By giving a start and end time and a discrete time interval it is possible to track the progress of completing step by step. Thus the user can watch a "movie" of the construction progress.

5.6 Simulating a realistic walk over and through the construction site

The user can define his height and by using cursors he can walk in any direction over and through the construction site. Also he can change his view by using the mouse.

6. CONCLUSION

First tests using ESBE to optimize small construction sites show that we are on the right track, but still a lot of research has to be done on the different components, especially on the hybrid system. Nevertheless we have developed the user-interface / 3D-visualization component in parallel, because it has in our opinion a big impact on the entire system. We do not want to develop a fully automated system generating not changeable layouts. We want and need the interaction with the user giving hints, answering questions, playing on the computer, simulating etc., and all this in a demanding, attractive, almost with the greatest of ease to involve the user in the whole system.

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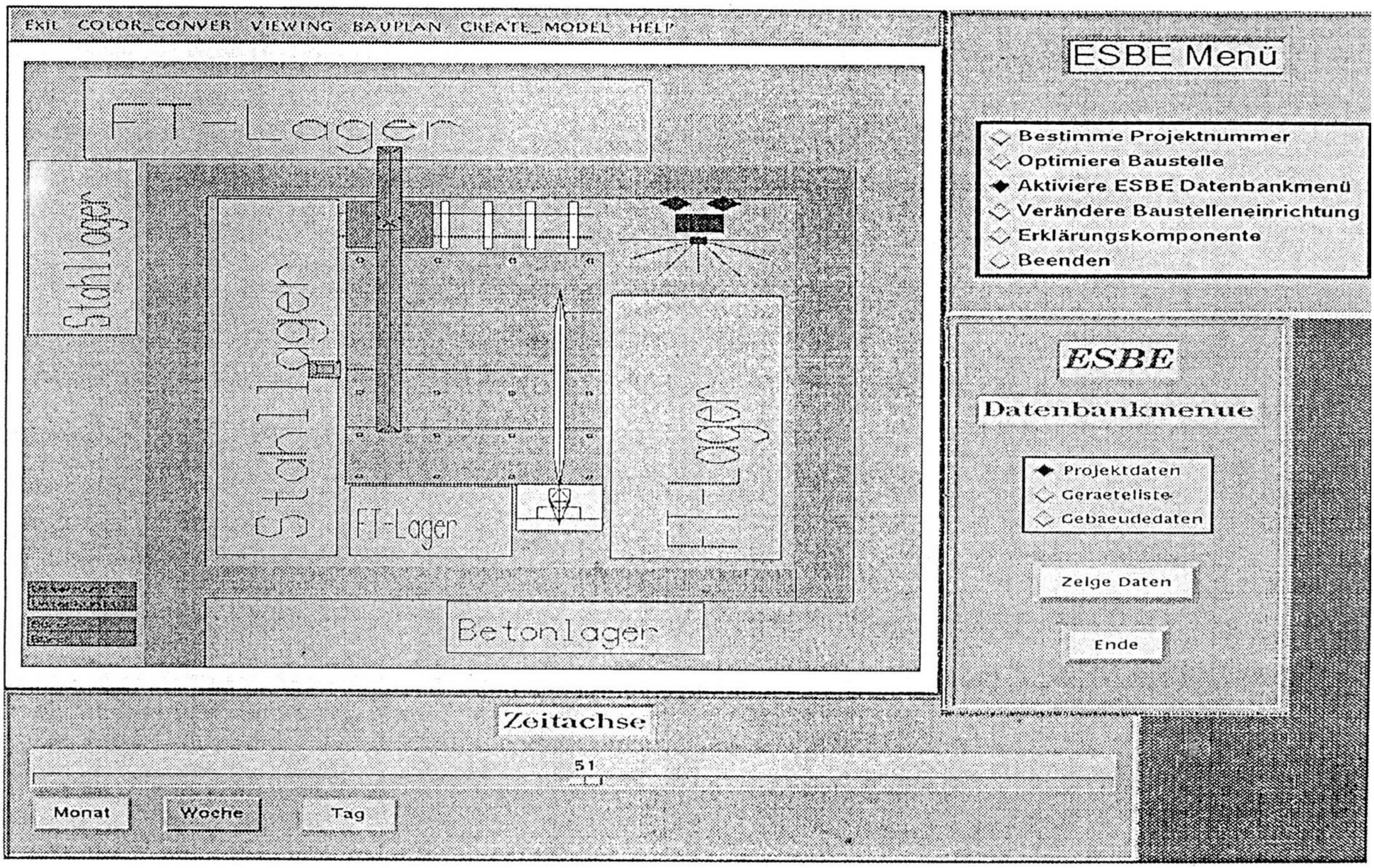


Fig. 2 Screen mask of ESBE

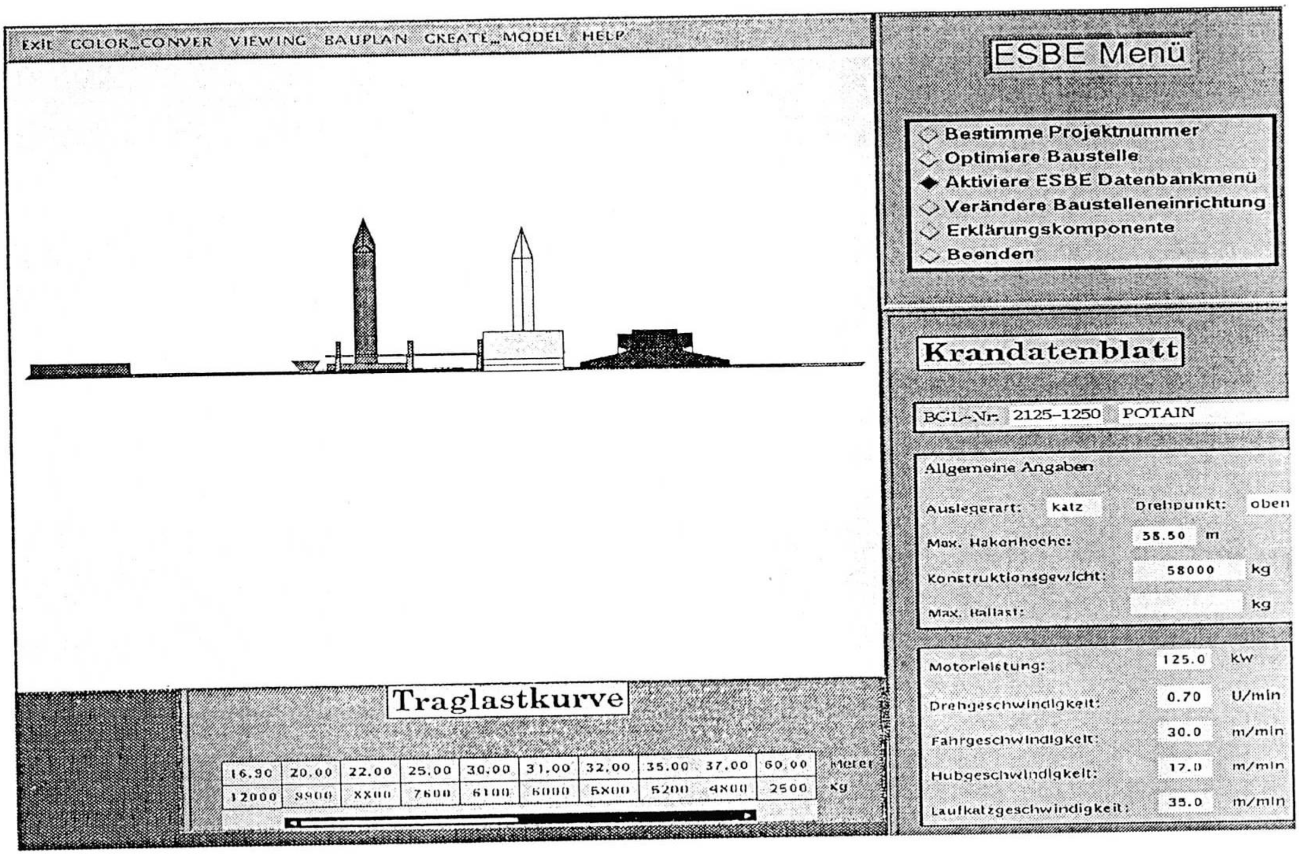


Fig. 3 Screen mask of ESBE

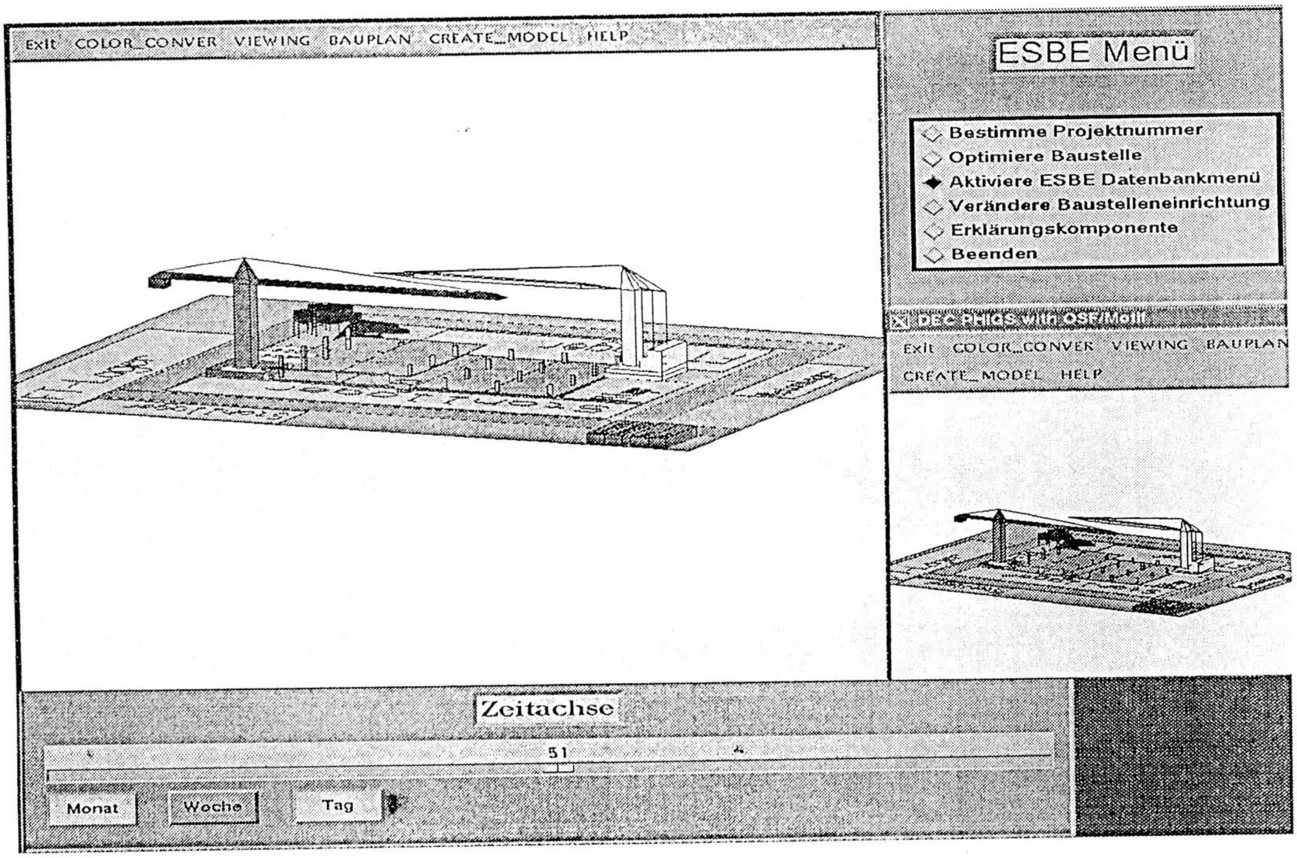
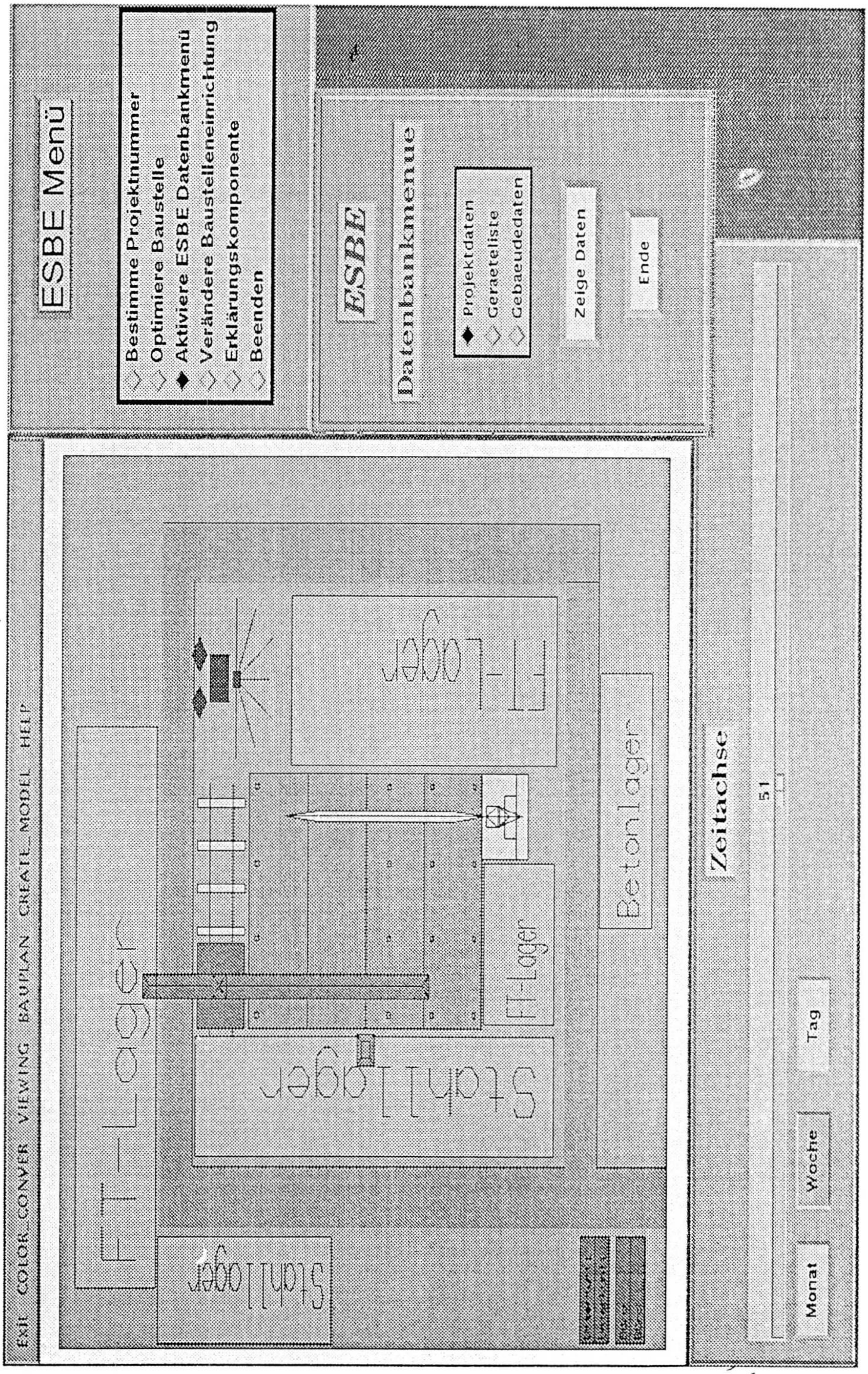


Fig. 4 Screen mask of ESBE



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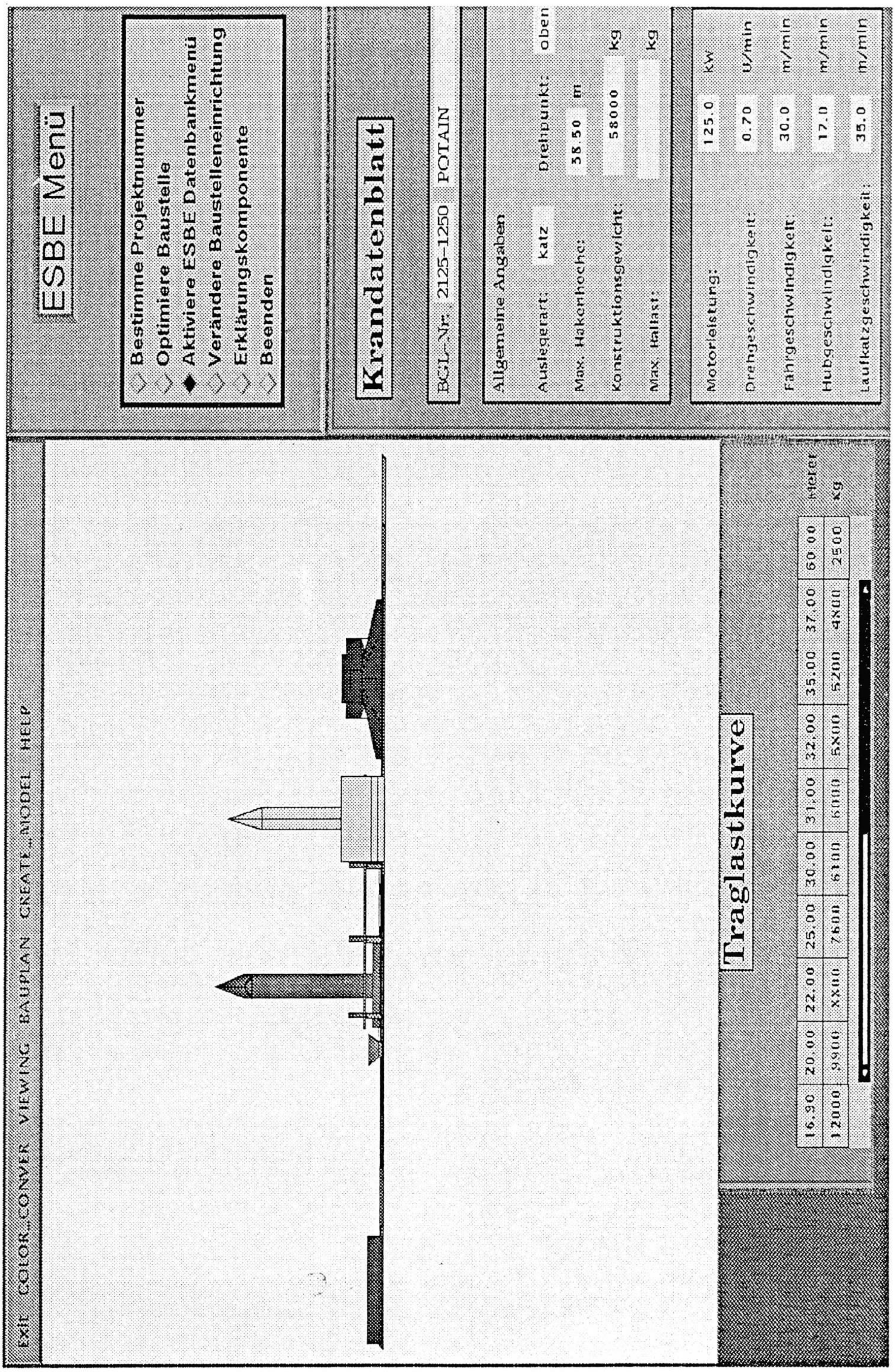

Fig. 3 Screen mask of ESBE

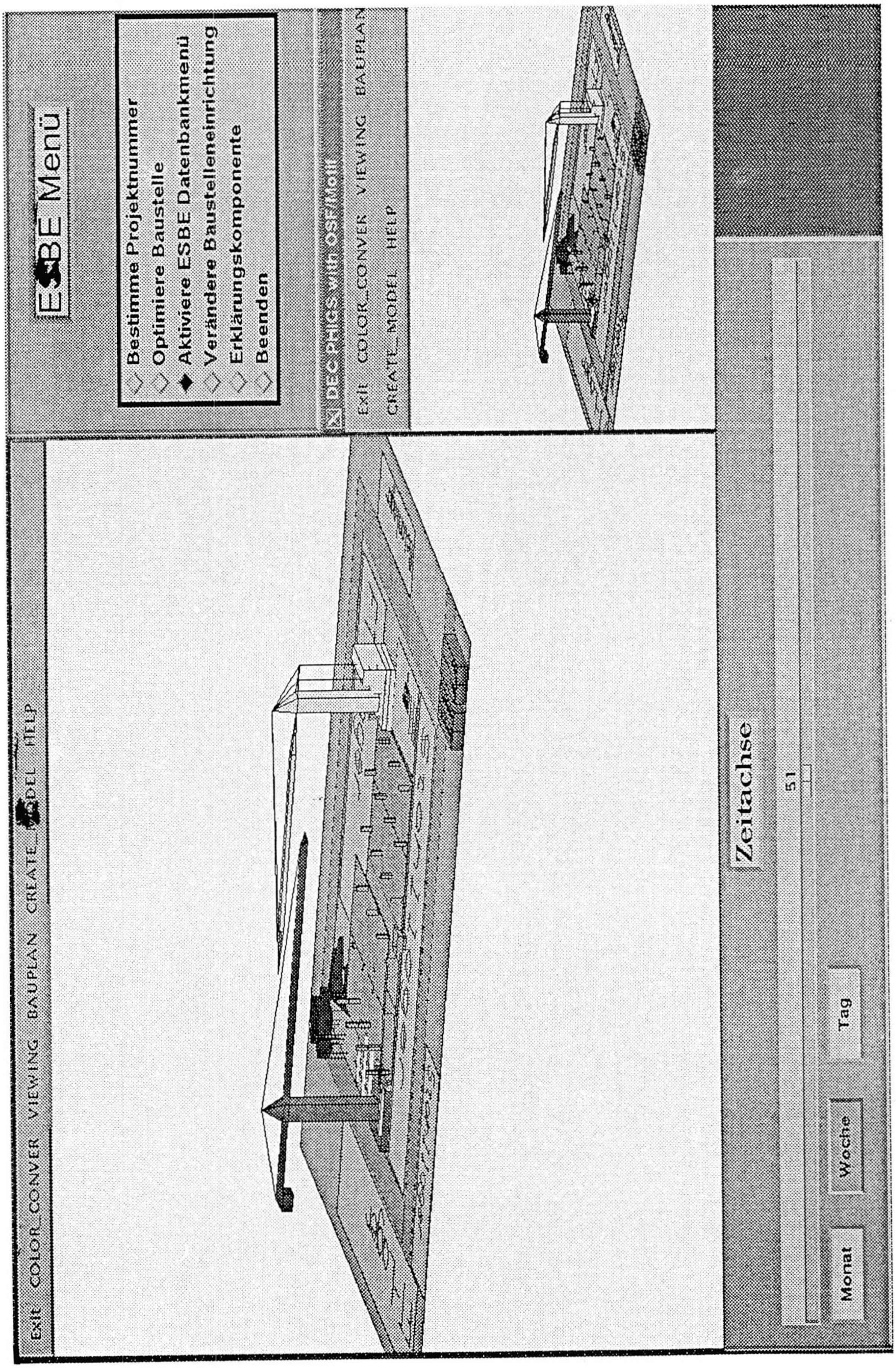

Fig. 4 Screen mask of ESBE