4D CONSTRUCTION SEQUENCE PLANNING – NEW PROCESS AND DATA MODEL

Jan Tulke[1], Jochen Hanff[2]

[1] *Bauhaus-University Weimar, Dept. Informatics in Construction, Germany*
[2] *HOCHTIEF ViCon GmbH,Essen, Germany*

ABSTRACT: Model based working is only just getting introduced in the construction sector to support design and project management.

In particular, construction sequence planning as one of the key processes in a construction project can benefit from model based working. Since the time schedule defines sequences of activities and allocates resources such as material and labour, it plays an important role in optimizing and managing a construction project. In this respect, model based working can offer more to construction sequence planning than just a visualisation of the construction sequences, in which the term '4D simulation' is today commonly understood.

Still, available 4D simulation software packages do not engage in the scheduling work but require major additional effort after the time schedule has been finished. The links between the objects of the 3D CAD model and the activities of the time schedule have to be established manually, i.e. the user has to select certain objects and assign them to a related activity in the time schedule. Furthermore, a 4D simulation merely adds limited value due to a restriction to visualisation of construction sequences only.

This additional effort for creating the 4D simulation and limited benefit of having a visualisation of construction sequences only, seem to be the main drawbacks as a result of which 4D simulation still has not crossed the threshold to daily practice.

To significantly improve the efficiency of creating a 4D simulation this article presents a solution for creating time schedules and 4D simulations based on data stored in a building model.

KEYWORDS: 4D simulation, scheduling, construction planning, model based planning, building information model.

1 INTRODUCTION

Current planning processes in the construction industry are still mainly based on 2D drawings. On the other hand model based planning methods can improve communication among project stakeholders and help to avoid planning failures. They also enable continuous optimisation of the construction project already during early design phases by investigation of different design alternatives. Thus building models support the project team to make a qualified choice out of a range of possibilities.

A well known concept in this respect is the 4D simulation of construction sequences which is an adequate tool for visualizing inherently abstract and complex time scheduling data which are otherwise buried in deeply nested Gantt charts. Today's available 4D simulation software is in principle capable to generate visualisations which intuitively illustrate construction processes along the timeline. By linking the objects of a three dimensional model to the tasks in a time schedule, it helps to reduce major scheduling errors just by inspection and improves communication within the project team.

But even though advantages of 4D simulation are generally recognized, there are also some shortcomings because of which 4D simulations have not yet become daily practice in construction projects. The most important drawback within real scale construction projects is the lack of a concept to prepare the 4D simulation within appropriate time and in parallel to the creation of the construction schedule.

Today's 4D software packages mostly presuppose the existence of a complete time schedule and a related 3D CAD model with an adapted object granularity. These software packages offer manual or semi automatic methods for linking tasks of the time schedule to sets of CAD objects and provide means for a detailed definition of visualisations.

Following this concept, manually linking individual activities to CAD objects turns out to be a very time consuming and cumbersome task. Furthermore this task is generally not performed by the project scheduler because of a lack of integration of 4D functionalities into existing standard scheduling software. This degrades 4D planning to a non-interactive process, and issues encountered during evaluation of a 4D simulation are only addressed after the time schedule has been completed.

Another major drawback is that 4D simulation generates its value mostly from visualisation and inspection. Other

closely related dimensions like material or labour resources are usually not evaluated by 4D simulation packages.

In conclusion the step to daily practice could only be taken if the creation of a 4D simulation is significantly streamlined and closer integrated into the scheduling process, thus creating substantial benefits for the project scheduler. In addition further product information has to be incorporated into the simulation.

Since the creation of a time schedule is based on data already stored in a building model, using this data while creating the time schedule − combined with automatical linking of objects and activities − will generate additional benefits and substantially speed up the preparation of 4D simulations. As a result a 4D simulation could directly be used for supporting the scheduling work instead of just for validating it by subsequent plausibility checks.

This article presents a solution for creating time schedules and 4D simulations based on data stored in a three dimensional building model. To significantly improve the creation of a 4D simulation, we suggest a new approach which also takes the bill of quantities into account. If CAD objects are linked with quantities, selecting objects and evaluating the associated quantities instantly generates benefit for the scheduling process and also improves 4D simulation as well as resource planning. In the following we describe the impact on the scheduling process and the underlying data model. We also illustrate advantages and will give an example from a real-scale construction project.

2 TODAY'S 4D SIMULATION IN DETAIL

2.1 *Process*

A time schedule specifies the tasks to design and erect a building, the duration of these tasks and the relationships between the tasks. The duration of a task is based on quantities of the building which are mainly calculated on the basis of 2D drawings. In order to generate a 4D simulation, a three dimensional model has to be created. This is followed by the very time consuming manual or semi automatic linking of 3D objects to the tasks in the time schedule. During linking, adjustments of the CAD objects' granularity to the requirements of the time schedule are necessary; due to complexity of the CAD software, this involves CAD specialists in the 4D simulation process. After additional definition of visualisation parameters the 4D simulation can be inspected in a separate 4D viewer package.

As shown in figure 1, there are two lines in the process which both start from 2D drawings. One aims to deliver the geometrical representation of the project (3D CAD), the other aims to determine the duration of tasks and the relationships between tasks.
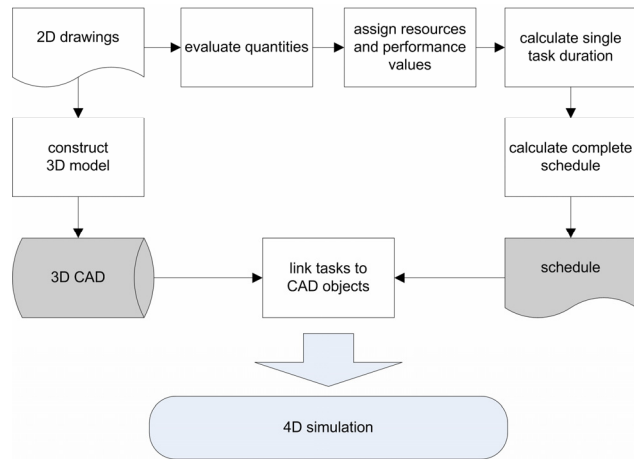

Figure 1. Today's 4D simulation process. All processes in both lines are performed manually.

Three software packages are involved in the creation of a 4D simulation (see Figure 2). A 3D CAD model and a construction schedule are created using standard software. Both packages do not interact and do not share any information. The data of both applications are exported separately to the 4D simulation package. This package provides means for linking both models, to define visualisation parameters and to control the simulation.

When applying this concept, vast potential inherent in computer models remains unexploited and a tremendous effort is required to perform validation of the completed schedule just by visualisation and inspection.

If a semi automatic concept is used, the linking itself is performed automatically based on rules. This speeds up the linking process but the user still has to manually assign attributes to each CAD object in order to link objects to activities in the time schedule.
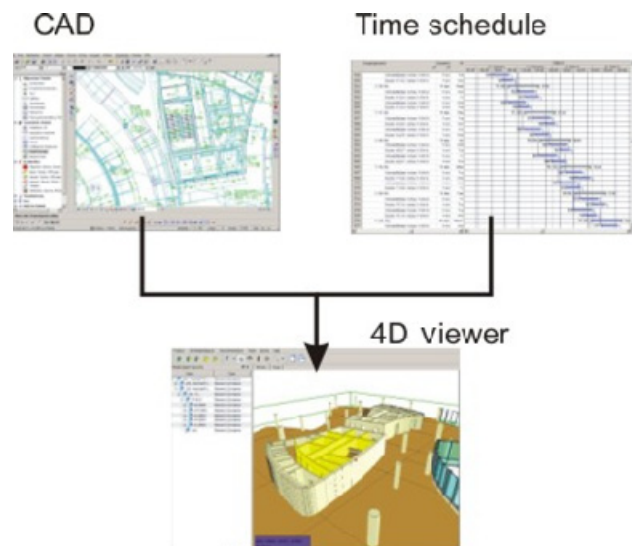

Figure 2. Involved software packages in today's 4D simulation approach.

If errors in the time schedule are detected, changes in the model or the time schedule are required or adjustments to the granularity of CAD objects are necessary and some of the links between CAD objects and activities have to be changed. Several revision loops are usually needed to

achieve the desired quality and precision of the time schedule and the related visualisation.

Each revision loop comprises the following tasks:
- adapting and refining the time schedule (project scheduler)
- changing the granularity of the 3D CAD model (CAD specialist)
- exporting data to the 4D simulation package
- linking the 3D model to the tasks of the construction schedule
- adjusting visualisation parameters
- running the 4D simulation

2.2 *Data model*

A 4D simulation visualizes construction sequences on task level. Each active task is visualised by highlighting associated construction elements. Tasks which can not be linked to construction elements, such as milestones or activities concerning design processes, are not visualised in a 4D simulation.

There also are some CAD objects which are not assigned to any task because they do not change during construction, e.g. the surrounding environment.

On the other hand, CAD objects can sometimes be assigned to several tasks to visualise different activities associated to the same construction elements. Figure 3 illustrates the relationships between objects in a CAD model and activities in a time schedule.
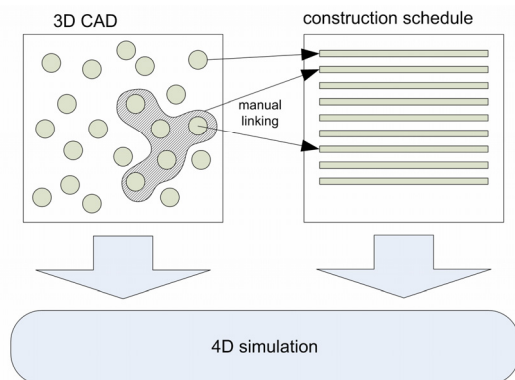

Figure 3. Relationships between CAD objects and schedule tasks.

The links are stored explicitly which means they have to be adjusted manually each time any change occurs either in the CAD model or in the time schedule.

Common 4D simulations provide a visualisation of construction sequences only. An evaluation of quantities or resources over time is not provided.

3 NEW APPROACH

3.1 *Process*

Building Information Models (BIMs) consist of three dimensional building elements with rich semantics and relationships between the elements. The elements store information about form, dimension, material etc. In this respect, geometry is just one part of the information provided by a BIM.

When assembling the time schedule of a project for each task the duration has to be determined. The duration depends on quantities and other parameters such as construction method, complexity of a project, boundary conditions, assigned personnel resources and equipment.

Using a BIM, the determination of task durations can be directly supported by selecting quantities from the model. The bill of quantities is derived from the building model by adding all partial contributions from individual CAD objects to one item in the bill of quantities. Besides quantities derived from the CAD model the estimator also adds manually collected quantities to the bill of quantities. These manually determined quantities are not included in a 3D model because to model these items as 3D objects would be too complex and time consuming.

The quantities – comprising both quantities from the model and manually added quantities – can be used to determine the duration of tasks. In order to use the objects and the quantities the data are stored in a relational database. Using a database enables the project scheduler to select quantities on task level by applying a standard query language (SQL). Based on CAD object properties the project scheduler can select only those quantities which satisfy certain restrictions such as type of objects (e.g. walls, columns, slabs), levels in the building (e.g. 1st and 2nd floor) or certain trades (e.g. concrete work, steel work). When selecting quantities from the database and storing the selection query for a certain task of the time schedule, the relationships between activities and CAD objects become gradually established and do not have to be introduced afterwards for a 4D simulation only. Using a query language results in a rule based linking of a model to a time schedule instead of linking objects to tasks by explicit selection. In contrast to the traditional way this approach for determination of task duration saves time and increases accuracy. Furthermore, resources and material consumption can be evaluated along the time line. Because of the rule based connection between the bill of quantities, CAD objects and activities, changes are easily handled and the 4D simulation can be updated automatically.
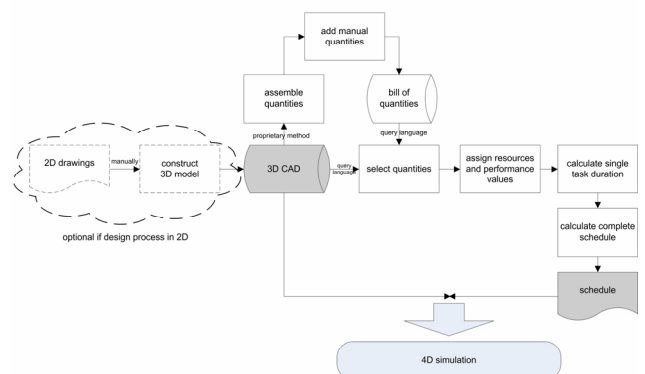
Figure 4 illustrates the process.

Figure 4. Preparation process of a 4D simulation in BIM context.

3.2 *Data model*

Figure 5 shows the software packages used to perform the process delineated in 3.1. Basically, the data flow can be divided into two parts: estimating and scheduling. In both parts primarily two software packages are used which exchange data with each other. In Figure 5 this communication is depicted as interface A and as interface B.

Interface A is an interface between a CAD system and a software application for creating a bill of quantities. In available software applications quantities are calculated from CAD objects and transferred to the bill of quantities using proprietary interfaces. The bill of quantities is created by an estimator.

Interface B illustrates the communication between a project database and an application for scheduling. Initially, the project database is populated with the CAD objects (attributes) and the calculated quantities. The time schedule is created by a project scheduler. The intersection between estimating and scheduling is the bill of quantities which is stored in the project database.
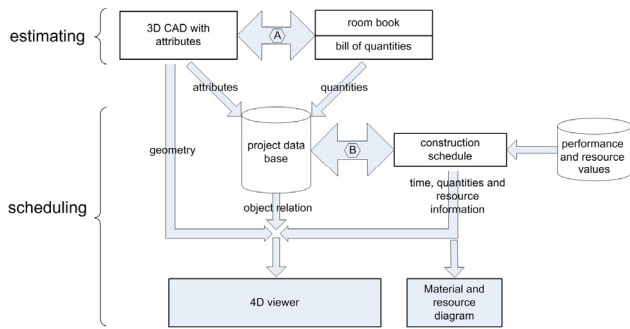

Figure 5. System components for support of model based scheduling.

The project scheduler specifies a rule to select a subset of the bill of quantities which is associated with an activity in the time schedule. Since the items of the bill of quantities are derived from the model and therefore implicitly linked to objects in the model, the properties of the 3D objects can be used to select this subset of the bill of quantities. The used properties can be a type of construction element, material, location or other. The rules are stored in the project database. The duration is calculated from the value of the selected quantities and a chosen performance factor. The duration of each activity, chosen parameters such as trade, performance factor and name of quantity items are written into the time schedule. Having this information in the time schedule enables the evaluation of material and resources along the time line.

Besides items in the bill of quantities which are derived from the 3D model, the bill of quantities also contains items which are added manually by the estimator. This is the case if the CAD model is not detailed enough or manual identification of quantities is faster, e.g. for complex facades. To visualize these items in a 4D simulation, some proxy objects have to be added to the building model. The link between an activity and the associated proxy objects has to be specified explicitly by the project scheduler.
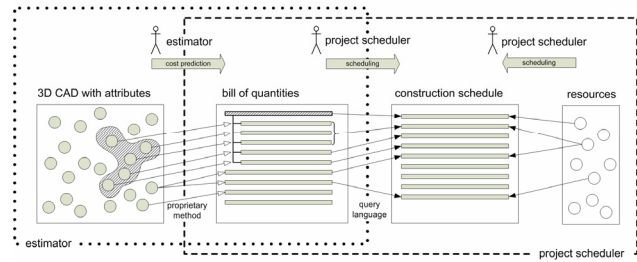

Figure 6. Relationships between the different data sets in the new 4D simulation approach.

During creation of the time schedule, the project database is gradually filled with links between quantities and activities in the time schedule. After the time schedule has been completed, the geometry information from the CAD system, the start and end dates of activities from the scheduling software and the object relations from the project database are exported to a 4D viewer.

As the links between activities and CAD objects are established in parallel to schedule creation, 4D simulations could possibly already be used by the project scheduler at any time during work to verify the preliminary schedule.

Figure 6 illustrates the relationship between the objects in the different software systems. It also shows the intersection of objects handled by the estimator and project scheduler.

4 EXAMPLE

The new 4D simulation approach has been tested on the model of the new corporate headquarters of the media group "Süddeutscher Verlag" in Munich, Germany. The project is a 28 storey high-rise office building with a total height of approximately 100 meters and a total floor area of 78,400 m². The construction period of this project is 36 months. The project website can be accessed at http://www.sv-hochhaus.de. Figure 7 shows the project as visualisation and during construction.

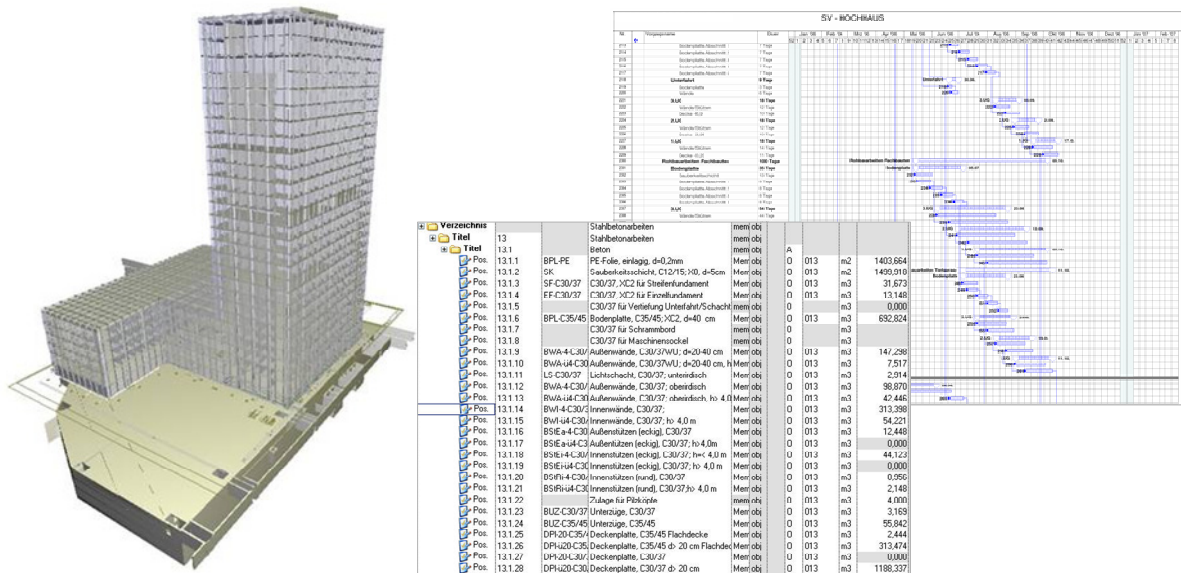Figure 7. Project visualisation and photo from on-site webcam.

Figure 8. 3D CAD model, bill of quantities and Gantt chart of construction schedule.

The CAD model consists of 40,000 objects and the construction schedule includes 800 tasks, 600 of which have been visualised in the 4D simulation. The bill of quantities contains 70,000 items (see Figure 8). The software tool used and the resulting 4D simulation are shown in figure 9 and 10.

To compare the work input required for creating a 4D simulation in this project, both the new and the old approach have been applied. The time schedule was already completed and was based on manually calculated quantities. Following the new approach, on task level, the manually calculated quantities could be verified by means of comparison with those derived from the model.

Linking CAD objects and tasks by explicit selection of objects took 4 working days.

In case of changes in the model, the creation of the 4D simulation takes the same period of time. Linking the model and the time schedule based on the database by using a query language took half a day. Setting up the database and exporting the model and the quantities to the database took an additional 4 hours Changes in the model only demands a reload of the data and the application of the rules stored in the database, which does not take more than a few minutes.

Comparing the quantities from the BIM and the quantities manually estimated for creating the time schedule, the BIM quantities proved to be more accurate.

If the linking had been performed in parallel to time schedule creation, additional time savings would have been generated because manual determination of quantities for predicting task duration would not have been necessary.
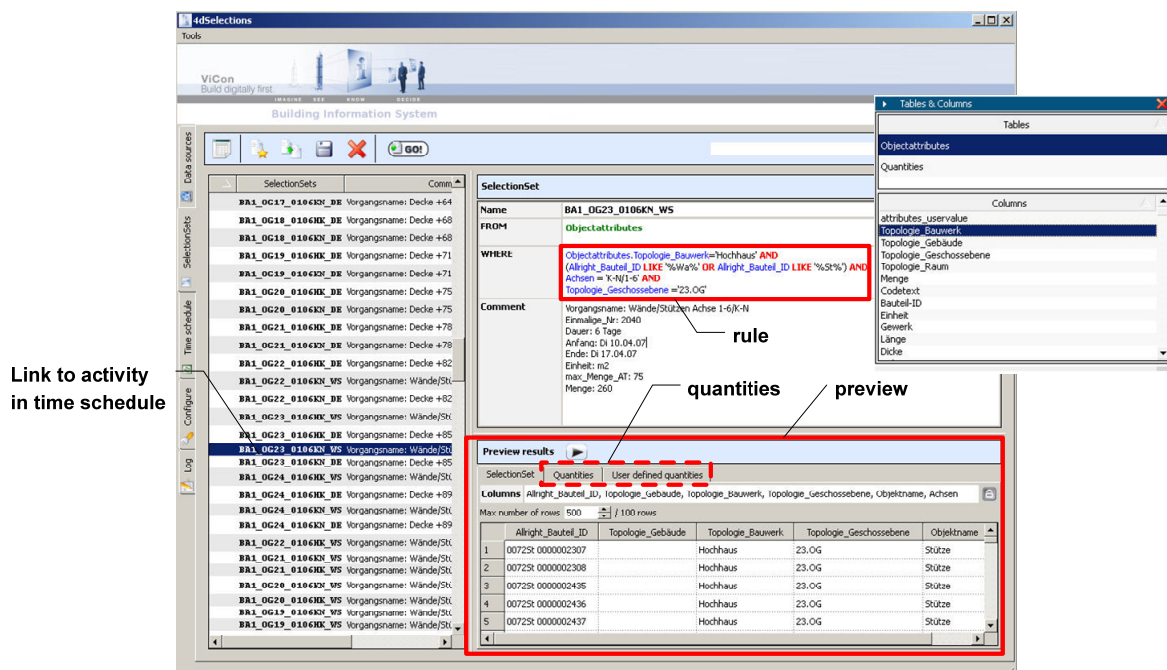

Figure 9. Selection of CAD objects and quantities based on SQL - preview of selected objects and quantities at the bottom.
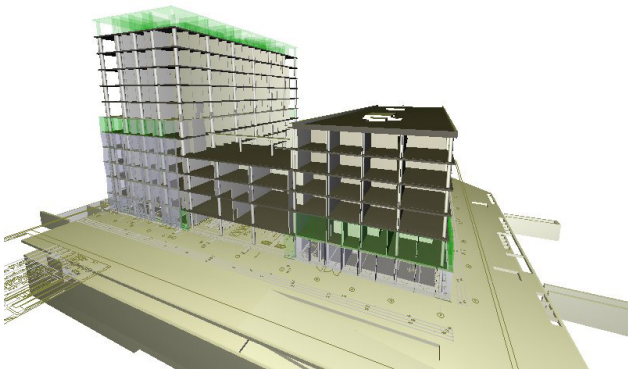
Figure 10. Snap-shot of resulting 4D simulation.

5 CONCLUSION

5.1 *Summary and future prospects*

The aim of the presented approach is to significantly speed up the preparation of 4D simulations by using 3D models and selecting objects with a standard query language like SQL. Another goal was to reveal additional benefits by a closer integration of the linking process into the scheduling practice. This should give the project scheduler an interactive and efficient tool to constantly verify his scheduling work.

The concept has been validated on a real-scale construction project. In addition, storing links between the product model (CAD/BIM) and process model (time schedule) enables quick updates of the 4D simulation in case of changes either in the model or the time schedule. Moreover, resource information incorporated in the schedule can be directly evaluated and the schedule adopted accordingly.

The new approach proved to significantly reduce the time and effort required to prepare a 4D simulation and will thus help to take the last step into daily practice. This is desirable because the consequent and interactive use of 4D simulation will definitely help the project scheduler to optimize construction processes to a much higher degree than today's 4D software does.

The highlighted advantages of the introduced concept are independent from the actual project size but especially for large projects with thousands of objects and processes the effort for creation and maintenance of the schedule is cut down significantly.

Once scheduling information is deeply rooted in the model data, several related evaluation and simulation possibilities open up, e.g.:
- resource planning (materials, labour, equipment, disposal)
- planning of site equipment (storage area, production area, crane area, logistics)
- comparison between "as-is" and "as-planned"
- payment schedule and billing support
- simulation of safety areas during construction
- simulation of evacuation paths during the construction phase
- changing traffic conditions

5.2 *Features still required*

Another major drawback in the 4D simulation process is that the granularity of the CAD objects has to be adapted to the requirements of the construction schedule. Because of the complexity of the software systems, CAD specialists are needed for this task. Project schedulers therefore are not always in a position to interactively investigate different schedule alternatives. To overcome this situation, an automatisation is needed which could divide up existing CAD objects and their related information according to schedule needs.

Further development is also necessary with regard to visualisation. Display, hide and highlight functions are not suitable for all processes. Scaling and moving of construction elements or equipment also has to be supported. Suitable representations for certain types of processes have to be developed as templates to further speed up the preparation of 4D simulations. In addition, useful concepts for easy visualisation of processes inside a building are still not included in today's software packages but would be of particular interest.

6 REFERENCES

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