Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

DETERMINATION OF PROCESS DURATIONS ON VIRTUAL CONSTRUCTION SITES

Hans-Joachim Bargstädt

Chair of Construction Engineering and Management
Marienstr. 7A
Bauhaus University Weimar
99423 Weimar, Germany

Arno Blickling

Chair of Construction Engineering and Management
Marienstr. 7A
Bauhaus University Weimar
99423 Weimar, Germany

ABSTRACT

The paper analyses the application of 3D gaming technologies in the simulation of processes associated with human resources and machinery on construction sites in order to determine process costs. It addresses the problem of detailing in process simulation. The authors outline special boundary conditions for the simulation of cost-relevant resource processes on virtual construction sites.

The approach considers different needs for detailing in process simulation during the planning and building phase. For simulation of process costs on a construction site (contractors view) the level of detail has to be set to high. A prototype for determination of process durations (and hereby process costs) developed at the Bauhaus University Weimar is presented as a result of ongoing researches on detailing in process simulation. It shows the method of process cost determination on a high level of detail (game between excavator and truck) through interaction with the virtual environment of the site.

1 INTRODUCTION

The increased use of 3D technologies during the lifecycle of a building has brought up lots of new approaches for planning and simulating construction processes. In association with the developments in other industries the construction sector is on its way to reengineer the working processes step by step on the basis of product lifecycle management (PLM/PDM) technologies (Bargstädt 2003). As these technologies are applied in the automotive sector one can look for a close similarity between the two industries. Besides, the process reengineering in construction should be accomplished in such a way that every process in the production chain can be reengineered using 3D technology. Till now the impetus was mainly on planning processes and also on site progress simulation, controlling or constructability reasoning (Cleveland 1989, Retik 1999, Li 2003, Dawood 2002, Fischer 1998, Cheok 2000). At the Bauhaus University Weimar the focus during the last year was set on reengineering the processes for cost estimation from the contractors point of view (Bargstädt 2004).

The research is based on the use of interactive virtual reality environments known from the computer gaming technology. Those tools provide the developer with predefined algorithms that can be used for process simulation and interactivity. One big advantage is the possibility to setup the logic for the behavior of the application objects without programming. This paper investigates the application of gaming software development tools with the focus on process simulation in virtual worlds with specific focus on cost estimation. It will also be discussed on which level of detail the individual steps in the construction process should be simulated. Finally, a prototype for determination of process durations is presented and discussed.

2 PROCESS SIMULATION

When comparing process simulation in the stationary industry with that in the construction industry some big differences exist. The processes in the common industry are characterized by:

- High precision: cost estimation for a new product development in the automotive industry goes parallel with the virtual simulation of the complete production process in order to determine labor costs and to assure process quality (see figure 1, Bauhaus University, Weimar). As the whole assembly process is simulated, the fault rate in determination of process durations is quite low and the risk of overlooking some process steps is equally low.
- Setup of production planning systems (PPS): these systems assure a high level of detail in process simulation. Because of the shortened time-to-market of a product developers are forced to intensify time and knowledge in the product development before it is launched. Later changes are difficult and high in price as the PPS has got to be

adapted and reconfigured. Mistakes in the PPS result in costly call-backs for example of car models after detection of dangerous functional deficits.

- Constant quality of processes: as the personnel often can be kept as a team from project to project the quality of production processes can be assured in a better way. After having defined a default production process for a certain product this process can be applied by many employees and can be optimized with increasing experience.

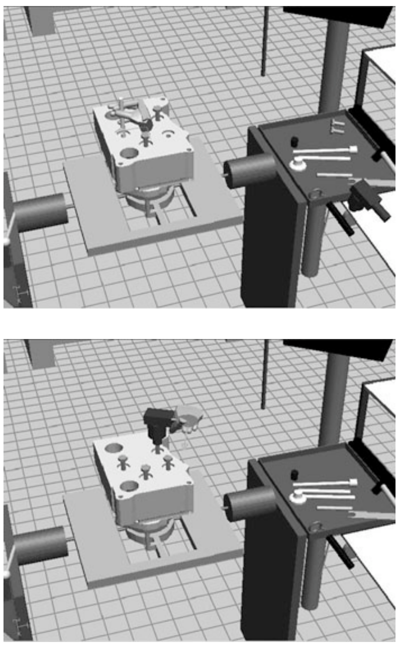


Figure 1: assembly of parts (automotive sector)

In comparison to these three arguments the process simulation in the construction industry is characterized by the following:

- Low precision: it is regarded as too complex to simulate the whole production process in advance. Besides there is nobody who takes over the role of the ´product developer´ or ´product manager´ known from other industries. Therefore the process of production is not simulated in detail in advance. As a consequence the fault rate in any production process model is higher, nobody really pre-defines the complete production process. The precision of process modeling and simulation in other industries rises from year to year but the construction industry is still unchanged. As nobody has yet defined detailed processes the data used for estimation of process lengths are average numbers taken from single surveys or from knowledge systems.
- No specific PPS: even if a lot of efforts is taken to setup a system for production planning in the beginning of a site, practice has shown that the system will often be neglected after some period of time. The main reason is that changes in the production process model are not rare but everyday business on the construction site. Therefore PPS known from the common industry are not made for use in construction. Immediate changes in process simulation should be self-understood in a system suitable for the construction industry. In changing the process simulation also the cost estimation should be up-dated automatically.
- The quality of processes varies: as teams sometimes need to be established instantly the quality of the processes may vary with people that have different levels of experience. A constant process quality can hardly be assured. It is difficult to define default processes as the boundary conditions change from site to site. Therefore the cost estimation must somehow consider the experience and the skills of the team. Why do good teams perform less efficient on certain sites as compared to some other sites? This insight is accessible when the level of detail in process simulation and documentation is increased. To improve process quality in construction it is necessary to benchmark the status quo. This should be made by simulating and monitoring the planned and the as-built process chain of a certain number of projects to gain data for analysis. The benchmarking will detect gaps between planned and as-built processes. If the specific reasons for losses in efficiency can be detected it will be possible to setup a reengineering concept for future construction processes.

The comparison showed that in the construction industry the optimization of process modeling and process simulation is crucial for higher efficiency in process quality and process controlling. A concept for production process simulation has to consider that 4D-modeling itself does not fulfill all requirements of interactivity and documentation needed. The aim of research is to handle and combine the huge amount of the single process steps in order to simulate the process costs. Therefore we first have to analyze and define different levels of detailing. What comprises high level of detail and what is a low level and which level should be used in order to determine process costs?

3 LEVEL OF DETAIL IN SIMULATION

With the current development of 4D software tools the quality of process simulation is much improving. As a consequence today the application of 4D has already increased productivity (Bergsten 2003). Nevertheless there are still many problems to solve to make the use of the systems more efficient. Koo and Fischer (see Bergsten 2003) mention the deficits in simply setting up alternative scenarios in an acceptable amount of time. Also the simulation of non-physical constraints is not yet solved. Bergsten mentions the problem of detailing in process simulation saying that ´(..) it is important to specify the types of operation and the level at which detailing a 4D concept provides the most benefit.´ It means the necessity to classify the process types to be simulated (should only the production be simulated or also other processes like site visits of surveyors?) and to choose a level of detail before simulating. Especially the latter decision has a significant effect on the complexity of the process simulation and the amount of rendered data for the performance of the simulation system. The following two examples visualize different levels of detailing in process modeling.

3.1 Different levels of detailing

It seems obvious that the owner of a project has a different view on the project than an architect or the contractor. Therefore only the data necessary for the owners` decision making should be visualized by choosing a role from a predefined set of roles. The following example (figure 2) shows the simulation of the site progress for a simple housing.

The level of detail in simulation is chosen to fit the needs of the owner who wants to see the progress milestones. The owner is merely interested in the detailed production process of every single construction unit. He wants to get some basic lines to be able to detect major deviations when checking the site while the contractor wants to know in detail the reasons for the deviation. The main steps of the site progress may be simulated in only a few steps as follows. The next sequence of simulation steps in figure 3 shows another level of detail that might fit the needs of the foreman on the construction site in front of his working place. Instead of using drawings he might take a look on the screen of his mobile device to see what comes next in the production. Now the detailing is augmented so that the foreman can see which material is needed and how the working process might proceed. Here the different qualities in process execution may become visible. It depends on how experienced a worker is to estimate how much time a process would take. As we can see from above there is a need to determine in which detail site progress has to be simulated. Yet the maximum level of detail is not achieved. The requirements of the contractor to determine the expected costs from the simulated process need to be incorporated into level of detail.

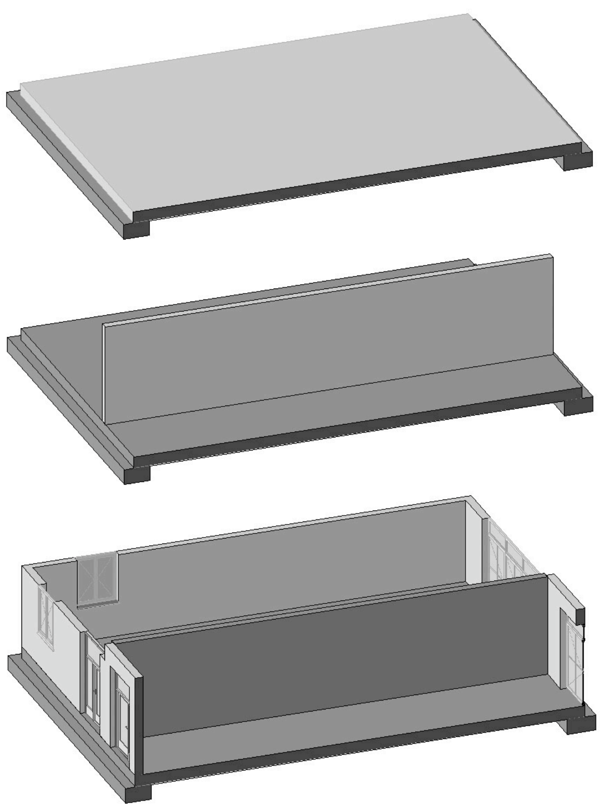
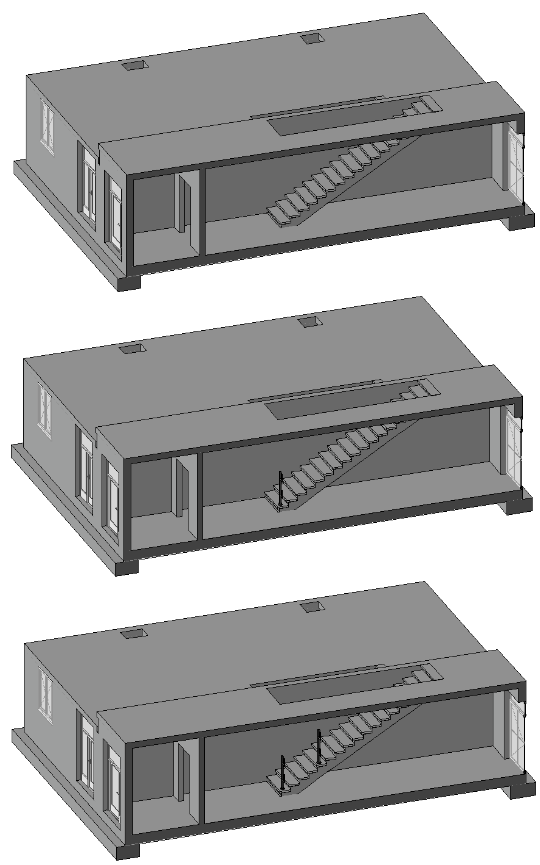


Figure 2: low level of detail in simulation



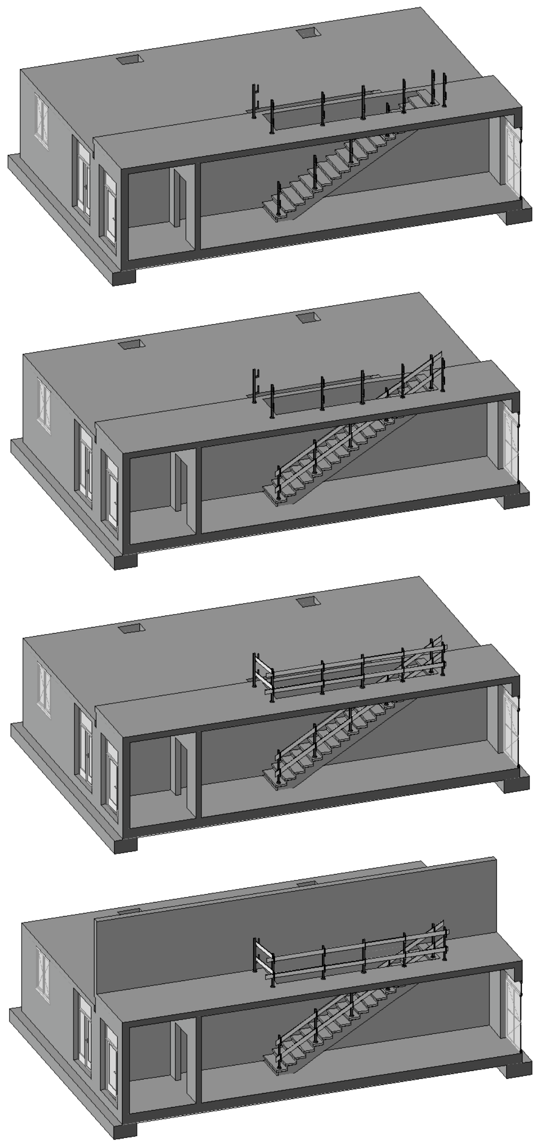


Figure 3: medium level of detail in simulation

Here we face an increased complexity because of two reasons: first the simulator needs deep knowledge of construction processes and simulation technologies; second the near-real environment prompts the user to simulate the entire chain of construction processes rendering the simulation process inefficient. Even if it at a first glance this appears inefficient the approach for the prototype foresees that the level of detail in process simulation fulfills the requirements as described below.

3.2 Requirements of detailing in order to determine process costs

4D modeling is an effective method to visualize site progress by linking the 3D geometry of the model with the chronological activities on a time schedule. This approach may be useful for users who are not building experts or engineers or who look for a holistic view of the project. On the other hand the engineer as a specialist or the worker on the construction site need to simulate less elements but with a maximum level of detail in process simulation. Therefore, they need the possibility to blend out the simulated processes of other disciplines that might hinder their work. If this is not done, the rendering time for the process simulation needed is longer because building parts that are not necessary are rendered as well. In the example shown in figure 3 a lot of other processes may run simultaneously with the simulated processes. While working on the problem shown in our example the worker need not see the simulation for the construction of a concrete wall that might be of interest for another worker working on the site. For this reason the first requirement of detailing from the estimators point of view is the possibility to make a selection of processes to be simulated.

The second requirement of detailing is to reduce the amount of processes to shorten simulation time for the estimator. An example might be the process of driving a nail into wood. It is clear that the worker needs a tool for that. The process of getting that tool for example can be estimated automatically after having determined some boundary conditions for the site such as distance to the tool magazine.

Finally, the third requirement of detailing is the definition of a ´leading process´: the process with a high influence on the production process chain and its efficiency. When one compares, for example, the construction process of a masonry wall first with stones provided at the working place (crane lift directly to working place) and second with the process of building the same wall in a cellar (no crane access), the process of getting the stones is a ´leading process´ because it has a big impact on working efficiency and the production chain is strongly dependent from it. By linking all ´leading processes´ together it is possible to decrease the amount of simulation steps in estimation. The ´leading process´ of a VR-based simulation is comparable to the critical path in a time schedule.

3.3 Results regarding cost estimation

Simulation of production processes on the site is not the same as 4D modeling. 4D modeling is rather comparable to the animation of site progress but is not enough to simulate the production process. For cost estimation we need to simulate the production process on a high level of detail to determine process durations. Today this process is limited to the imagination and expertise of the estimator. This method can be improved by simulating the production process in a virtual environment using game technology. With these requirements in the background a method is proposed as under.

4 SIMULATING COST ESTIMATION

In the following chapter the estimation of labor costs in virtual environments on a high level of detail is discussed. In association with the latest research at the Chair of Construction Engineering and Management at the Bauhaus University in Weimar (Bargstädt 2003, Bargstädt 2004) this concept foresees the simulation of every used resource in virtual reality. That means `avatars` are used for simulating human resource activities in virtual reality. In this connection, reference could be made to the research at the Department of Building and Real Estate at the Hong Kong Polytechnic University and the Department of Civil Engineering at Tsinghua University in Beijing (Li 2003). This paper integrates avatars in the virtual environment of the construction site. It refers to an experiment that investigated benefits from using VR in supporting assembly planning. It was found out that ´(..) planners spent much longer time in the traditional engineering environment than in the VR environment.´ Li also refers to other researchers who investigated management systems in VR with impetus on performance management and evaluation of productivity. In association with this Li proposes a knowledge-based VR system called Virtual Construction Laboratory (VCL). This system is said to enable the planner to conduct virtual experiments of innovative construction technologies and processes. The approach aims to gain productivity rates and resource usage information from the system. Correlated with VCL the approach in this paper discusses the simulation of human resource activities on a high level of detail to determine process durations and associated process costs during simulation of production processes. By doing so the labor costs can be estimated while playing the production process on a site as a computer game by linking resources with processes (Bargstädt 2004). A main question is concerning the accuracy of the process chain. The cost estimation process in construction foresees that the estimator determines a specific time-based effort for the related working process, for example hours/m2 or hours/m3. In establishing such estimation values it is assumed that an average worker needs this value. This theoretical assumption doesn't consider the following aspects in an accurate way:

1. Risks and variations in the working environment
2. Adjacent production steps that may influence productivity, e.g. distance to specific resources such as electric power, water, material or site equipment
3. Accessibility of working place, e.g. use of elevators in high-rise building

The above list can yield a large number of constraints that depend on the building type, the topology of the site, the infrastructure and so on. To be able to estimate time durations it is necessary to consider a maximum number of such aspects. The method of playing the production process in the estimators` imagination to approximate durations is not very reliable for the future estimation of process durations. Here the use of VR environments might play a remarkable role as this technology makes it possible to visualize the production process step by step even for other persons. With the proposed solution the huge amount of single process steps needs to be simulated in order to define an ideal production process. Yet it is unclear on which level of detail the simulation should be developed. Till now research was focused on the visualization of the construction progress rather than on the single process steps done by single workers. Nevertheless Li (Li 2003) admits thinking about simulating virtual humans when integrating avatars directly into the virtual reality environment. This step is a possibility to escape from fuzzy benchmarking methods. A concept for future estimation and controlling is given in figure 4. The output of the logic simulation of processes on a high level of detail delivers precious data about process durations and quality.

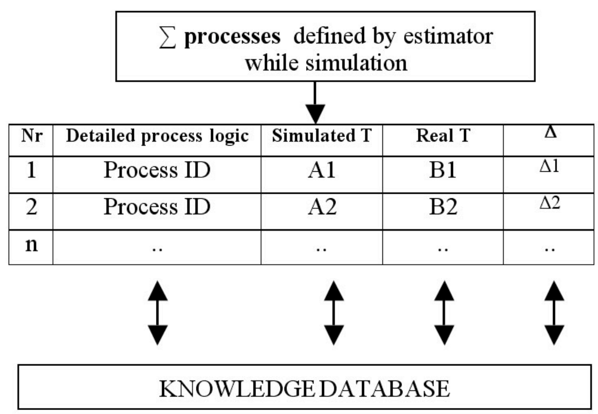


Figure 4: benchmarking in process durations

The first and most difficult question to answer is how to handle the big amount of processes. It has not yet been investigated how long the simulation of all the production processes in virtual environments on a high level of detail will take. It depends on the willingness of construction industry to accept the use of VR for cost estimation. When using pre-defined algorithms for process simulation it depends on the amount of algorithms pro-vided. Game development tools come with a large collection of pre-defined algorithms but not all fulfill the specific needs of construction. Let us for the time being assume that these construction-specific algorithms have already been developed and are offered in our game development tool. In this case the estimator can navigate through the list of algorithms and choose one to connect it to the avatars in the virtual environment. The estimation of one single process will take only a few seconds.

Research aims to connect virtual products with their particular algorithms so that they can be used for simulation directly after taking them from the virtual warehouse library. Thus the huge amount of processes that need to be simulated by the estimator can be standardized and reduced.

The second important question is the method for simulating the process logic. This problem can partly be solved using pre-defined algorithms delivered with game soft-ware tools. These algorithms simulate almost all processes in VR that human beings and other objects from reality can accomplish in reality. Nevertheless there is potential for optimization, for example through logic combination of algorithms such as walking and carrying a stone at the same time. As an example for process logic may serve the masonry work. The process `build masonry of type x` requires repetitive steps in the process chain. It is assumed that the worker is standing at his working place and the stones are stored a few meters away from him. To build the wall he needs to walk to the position where he can get stones from the pile, take some stones and go back. Then he places them in the wall after having added some mortar. As this is a repetitive process with a certain number of variables the process logic for `build masonry of type x` can be developed. The position of the stones is one of the variables that need to be determined.

5 PRESENTATION OF THE PROTOTYPE

To show a possible result from the template of a prototype avatar with intelligent motion logic we use Virtools® and Quest3D®. As Virtools® comes with an additional programming interface (C++) for development of theme-specific algorithms Quest3D® advertises to de-liver full simulation functionality without any code programming. The latter will be sufficient for the setup of small prototypes for the simulation of avatars working on a construction site. For more complex simulations on a high level of detail it will be necessary to develop construction-specific algorithms with Virtools® or a comparable tool. Li (Li 2003) refers to the laborer database used in the VCL to visualize construction specific production processes. When visualizing concrete works the occupied laborers were shown in the virtual environment as avatars. Even if this approach is worth to be pursued today these VR tools are only capable of simulating `(..) major building objects and processes`, as Li mentions. In the case of cost estimation the avatar receives a certain process as a ´mission´ from the estimator. Then the process is simulated while simultaneously the calculation of process duration and costs is performed by the system.

As a first prototype we have built a simple channel graph with Quest3D® for the movement of workers on a construction site. The aim of the prototype is to setup an environment where two objects on a simple field can be moved by the user performing a specific action on the keyboard or mouse. That action should be understood as the order to move to a certain point of the field. A further aim is to setup a virtual time system so that the machine can measure the time needed for the movement process. The movement from point A to B in this context corresponds to the ´single process step´ to be performed by the worker. To calculate the time for the process we need the virtual time system that counts the seconds from the start to the end of the movement. This data has to be written in an external database connected to the virtual environment for later analysis. For example, one can find out how much time the workers will have to spend walking around on the site because of inefficient logistics or material supply. With the functionalities implemented today we can already move the ´human resources´ on the field through interaction with the user. As a first experience we can say that the dimension of the graph for this simple action is already quite huge. The complete graph consists of several parts with each part being responsible for a specific functionality such as colors, backgrounds, camera view or collision detection. As an example figure 5 shows a simple part of the graph responsible for the interaction with the user via mouse input. In the graph we can see that with clicking the left mouse button on a particular place in the field one of the objects (ball in front = worker 1) moves from the original position to the position clicked. The same happens if the right mouse button is clicked. The picture above shows an early stage in the complete bifurcation of the whole graph.

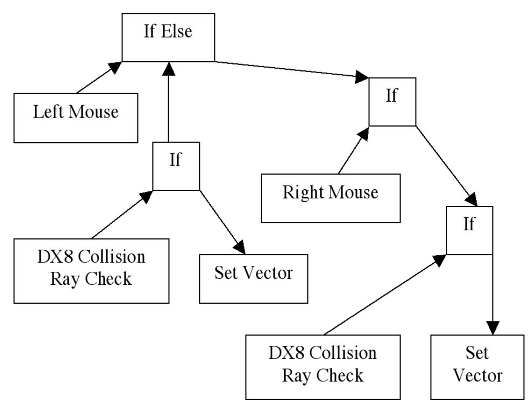


Figure 5: channel graph for user interaction (prototype)

Located behind the ´DX8 Collision Ray Check´ channel is a complete pre-defined channel graph that needs different input information, for example the name of the objects whose collision should be detected. Figure 6 shows a screenshot of the prototype in its first stage.

The two balls (= 2 workers) lie on the grey field (construction site area). The black cube is the marker for the next position to move. When worker 1 moves from point A to point B the time is recorded in the external database as described in figure 4. In this first prototype the impetus was not on accurate computer graphics but rather on testing the libraries with pre-defined algorithms for setting up a process model for the movement of the human resources.

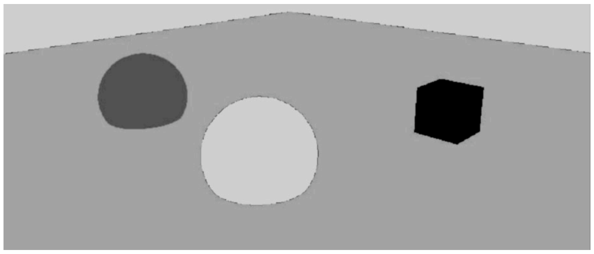


Figure 6: view on the first prototype in the game engine

After the experience from this very simple prototype the method was applied in a more complex environment. Here the game between an excavator and a truck had to be simulated in real-time. For this the requirements were defined as follows:

1. selection of excavator and truck types out of a machinery database
2. machinery database contains all detail data on the chosen machine, e.g. cost/hour, max. load, weight, etc.
3. use of the logic from the first prototype to handle movements of objects in the virtual environment
4. the virtual time should be displayed in the application window as well as the buttons to start and stop duration recording during simulation
5. an external database is connected to the application so that the determined durations can be saved for later evaluation
6. the virtual construction site should provide the user with basic geometrical data on the site, that means the object should appear in a close to reality shape

The second prototype requires deeper knowledge of the channel graph logic. All in all the application consists of several channel groups which merge to one big graph. It is not possible to show the whole graph as the complexity is too high. In the following only some aspects of the graph are discussed.

One problem was to set up a \`virtual time system\`. This system is supposed to assure the real-time character of the application. The movements of the truck and the excavator should be as fast as in reality. The velocity of the excavator in comparison to the truck is much slower, which means that the truck has to wait for the excavator from time to time. This should be considered in the virtual environment as if it were reality to assure the authenticity of the system. The actual time should be displayed for the user. Figure 7 shows a part of the \`clock channel\` as implemented in the application.

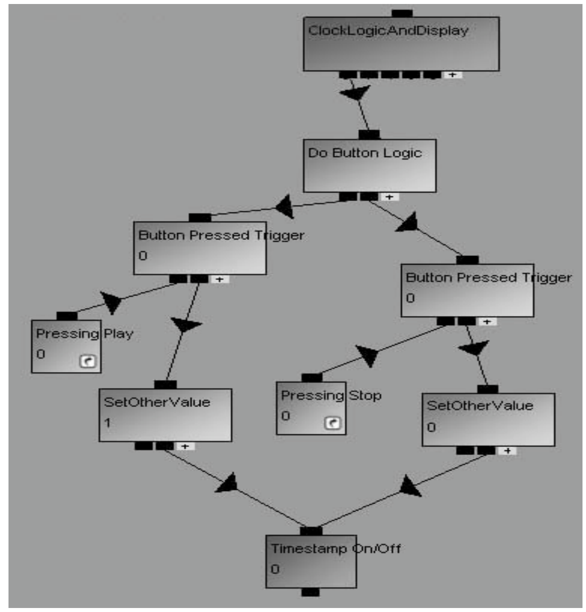


Figure 7: channel graph for the ′virtual clock system\`

The figure displays simple button logic for the \`start\` and \`stop\` button. A further problem was the implementation of the logic for the determination of the machines to be used for simulation. After the start of the application the system asks first for the machine types. The user can click through all the machines in the database and thus determine the configuration consisting of one excavator and one truck. The choice is important because there are some parameters (e.g. maximum load of truck, performance of excavator) that influence the efficiency of the collaboration between excavator and truck. Here the system lets the user decide which truck or excavator to choose but considers the maximum performance possible with the chosen configuration of machines. Here the selection process is kept open for human decision instead of decisions automatically generated by the system. At the moment the latter is considered to be too complex and less efficient.

Figures 8-11 show screenshots of the application. Figure 8 shows the startup window with the menu of available trucks and excavators.

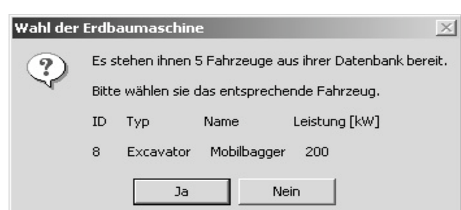


Figure 8: user dialog during choice of excavator

In addition to the truck and the excavator the user can also choose specific equipment of the excavator, e.g. size and type of the excavator shovel. Of course only compatible equipment is offered by the database.

Figure 9 shows the situation after the determination of excavator, equipment and truck. In this prototype the user can only vary the geometrical position of the working environment. Yet for the time being the shown excavation is only a `play process` because other logic has not been implemented.

Figure 9: startup window of simulation tool

The next step foresees the determination of a point on the ground of the virtual construction site. The user indicates the position on the screen where then the machine will move to. In figure 10 this position is marked by a cube.

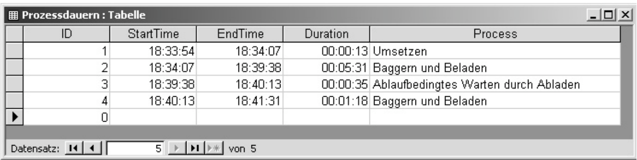
Figure 10: machines move to `cube location´

After having reached the desired position both machines stop and wait for further user input. In the actual construction phase the user can switch from hauling (`Umsetzen` in figure 10) to dig and load. This change in phases is important for the database to register that a certain process type is finished. After each phase the time system saves the process duration and waits for the next process to begin. After having changed the phase the user needs to specify the position of the digging area. This can be initiated by user input and causes the excavator to rotate the shovel to the chosen position. The dig process can also be started by user input. After this the movements of the excavator are animated in real-time which is important for the correct determination of the process duration. Here the prototype is not designed to consider changes in the geometry of the ground area after the shovel has hit the ground. This problem was yet considered as too complex. After having performed all the necessary steps to fill up the truck (the truck can only leave when filled up completely), it moves automatically to the unloading point. Before that the phase changes to process-dependent waiting for discharge (Ablaufbedingtes Warten durch Abladen in figure 11) which is another process phase to be considered in the database.

Figure 11: filled up truck moves to unloading point

The process as described above can be executed in “simulation mode” (process durations are instantly written in the database) or offline. Clicking the `play` button starts the simulation mode. The actual process phase is identified and written into the database together with the starting/ending time of the process and its ID. The database then calculates the difference between starting and ending time and thus the process duration. Figure 12 shows an example of data written into the database.

In this early state of the second prototype `leading processes` are not implemented. Therefore the user has to initiate the change in phases manually by interacting with the system. With the data shown in figure 12 the prototype has achieved its aim. The process durations can now be multiplied by the cost parameter of the single objects (e.g. EUR/h) in the virtual environment to determine the resource costs for certain processes.


Prozessdauern : Tabelle

ID	StartTime	EndTime	Duration	Process
1	18:33:54	18:34:07	00:00:13	Umsetzen
2	18:34:07	18:39:38	00:05:31	Baggern und Beladen
3	18:39:38	18:40:13	00:00:35	Ablaufbedingtes Warten durch Abladen
4	18:40:13	18:41:31	00:01:18	Baggern und Beladen
0				

Datensatz: 5 von 5

Figure 12: processes and durations in the database

As one can see the process duration for dig and load (Bagern und Beladen in figure 12) is 5:31 minutes which is quite a long time to wait for in front of a computer screen. However, this is the `real` time the excavator will need for executing the process. The commitment to `real` time process simulation is due to the necessity to simulate some process types in the construction area in one by one steps. This is relevant especially for highly specialized process steps with a short duration but a big effect on the quality of the product, for example in bridge engineering. Even if not considered in this work it is clear that the coexistence of non-simulated and simulated processes is necessary to avoid long waiting times. In this context a time accelerator can be a possible solution to compress the simulation velocity. On the other hand it has not been investigated yet which effect this might have on the logic, because when accelerating time some decisions have to be made automatically without user input. A possible solution can be to let the estimator define boundary conditions through definition of leading processes and then let the logic of the leading processes define the highly-detailed process steps automatically. In this case a logic has to be developed for every leading process. Ongoing researches at the Bauhaus University work on the development of a logic for masonry work as a first example.

6 PROS AND CONS

The paper summarizes current research on gaming technology at the chair of Construction Engineering and Management at the Bauhaus University Weimar both from the game developers and the construction managers point of view. After these first experiences using the pre-defined algorithms we can evaluate the pros and the cons of the method as follows.

6.1 Cons

One disadvantage of the method described in chapter 5 is the duration of the estimation process for the user of the system. If the level of detail is at its maximum and there is no possibility to minimize the amount of processes to be simulated the estimated total time for playing ´one cost estimation game´ is quite long compared to the today cost estimation process. A possible solution will be to minimize the amount of processes to be simulated manually and to reroute a maximum number of processes to the computer where those processes can be simulated automatically on the basis of pre-defined logic.

Furthermore the library of pre-defined algorithms is not yet adapted to the specific needs of the construction industry. This requires the development of every single process step from the beginning on to the reusable channel graph. Once the graph is developed it can be reused. If reusability is possible the development of construction-specific graphs is a worthwhile investment.

6.2 Pros

The major advantage gained from a virtual construction site is the quality of the visualized process. In the very first prototype (balls and cube) this advantage is not observable because the environment is yet too simple. By simulating on a higher level of detail we obtain close-to-reality data which allows to make more reliable assumptions on the real process durations. This takes risk out of the cost estimation process and leads to a more accurate cost estimation.

Furthermore the proposed estimation method combines process simulation with process cost estimation. As the virtual time system allows to record the duration of processes the total time for certain process categories (e.g. answers the question: how much time have we spent on `digging and loading` or `changing position`?) can be analyzed easily. Also the process costs can be calculated by the computer derived from the process simulation during the play of the game. Today the cost estimation process is separate from the simulation process which costs a lot of time and may lead to misunderstandings between cost estimator and the site manager. Through the merge of these two processes precious time can be saved.

The cost estimator is forced to think deeper about possible problems in the production chain because the virtual environment communicates problems immediately and closer to reality because of its visual interface.

With the technology it is also possible to pause the cost estimation process in real-time for a while and continue it later. This is relevant when the estimator needs to leave the working place for a short time.

A great advantage of the system is the ease of use for other persons who get involved into the construction process in a later phase of the project. In a short time those users can watch the pre-planned construction process and use it as guidance.

7 CONCLUSIONS

Virtual reality in construction calls for reengineering the construction processes accurately, especially for the purpose of reliable cost estimation and controlling. Even if today process simulation and thus determination of process durations and costs are not very detailed the ongoing development of new VR-based approaches will facilitate that higher level of detailing in construction process simulation. With the tool from above new applications of virtual environments in construction are possible such as controlling on a daily basis directly on the construction site. It is expected that the ease of use together with the `game character` of the method will lead to a higher acceptance of computer based methods on construction sites. The presented ideas and concepts will be pursued at the chair of Construction Engineering and Management at the Bauhaus University Weimar. The aim is also to bundle the worldwide approaches for construction process simulation correlated with cost estimation and controlling and – in future – also with transportation and logistics in order to establish a valuable basis for the construction industry. A further focus will also be set on the development of process logic for site-relevant construction process simulation.

REFERENCES

Bargstädt, H.-J., Blickling, A. 2003. Unit-oriented tendering and calculation of buildings using data generated by the method of Integrated Product Lifecycle management (PLM/PDM) of buildings, IABSE-Symposium Metropolitan Habitats and Infrastructure, Shanghai 2004. Available via http://www.uni-weimar.de/Bauing/baubet/personen/blickling_engl.html [accessed April 13, 2005].

Bargstädt, H.-J., Blickling, A. 2004: Effective cost estimate and construction processes with 3D interactive technologies: Towards a virtual world of construction sites, Xth International Conference on Computing in Civil and Building Engineering ICCCBE, Weimar, June 2-4, 2004. Available via http://www.uni-weimar.de/Bauing/baubet/personen/blickling_engl.html [accessed April 13, 2005].

Bergsten, S. 2003. Using 4D CAD in the Design and Management of Vertical Extensions to Existing Buildings. In: Construction Process Improvement (ed. Atkin, Brian; Borgbrant, Jan; Josephson, Per-Erik) 2003, Blackwell Science, Oxford, pp.266-277

Cheok, G.S., Stone, W.C., Lipman, R.R., Witzgall, C. 2000. Ladars for construction assessment and update. In: Automation in Construction, No. 9, 2000, pp 463-4

Cleveland, A.B. Jr. 1989. Real-Time Animation of Construction Activities, Proc. of Construction Congress I - Excellence in the Constructed Project, 1989, San Francisco, CA: ASCE, 238-243

Dawood, N., Sriprasert, E., Mallasi, Z., Hobbs, B. 2002. Development of an integrated informa-tion resource base for 4D/VR construction processes simulation. In: Automation in Construction, 12 (2002), pp 123-131

Fischer, M., Staub, S. 1998. Constructability reasoning based on a 4D facility model, Structural Engineering Worldwide, CD-ROM Proceedings, 1998, Elsevier Science Ltd.

Li, H., Ma, Z., Shen, Q., Kong, S. 2003. Virtual experiment of innovative construction operations. In: Automation in Construction, Volume 12, Issue 5, September 2003, Pages 561-575

Retik, A., Shapira, A. 1999. VR-based planning of construction site activities. In: Automation in Construction, No. 8, 1999, pp 671-680

AUTHOR BIOGRAPHIES

HANS-JOACHIM BARGSTÄDT is professor and head of the chair of Construction Engineering and Management at Bauhaus University Weimar, Germany. His research interests include virtual construction sites, simulation and 4D modeling in construction, supply chain management and logistics in construction as well as aspects of international project management. His e-mail address is <hans-joachim.bargstaedt@bauing.uni-weimar.de> and his Web address is <www.uni-weimar.de/Bauing/baubet/index.html>.

ARNO BLICKLING is an assistant researcher at the chair of Construction Engineering and Management at Bauhaus University Weimar. Before he was construction manager in a contractor. His research interests include the application of game development tools for process simulation on virtual construction sites. His e-mail address is <arno.blickling@bauing.uni-weimar.de> and his Web address is <www.uni-weimar.de/Bauing/baubet/personen/blickling_engl.html>.