Implementation of logic for earthmoving processes with a game development engine

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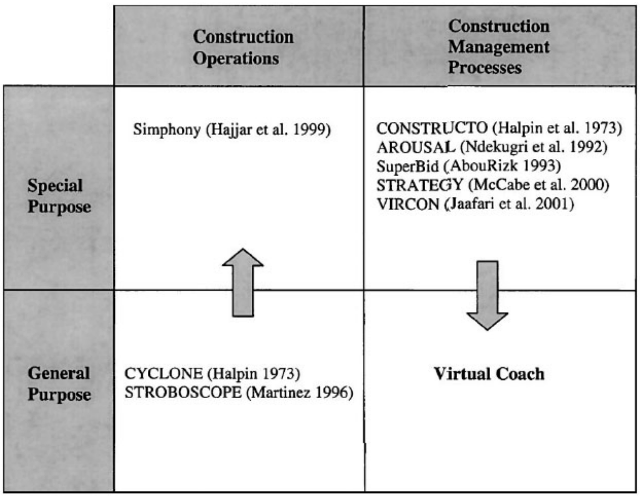
In modern industry for example the assembly of a car can be done in different ways or sequences. All may lead to success. Nevertheless manufacturers decide on one specific order of processes for the assembly. This order is designed and managed properly and is the result of deeper studies of the logic of the assembly. In the construction industry experiences on site have shown that logic of processes is difficult to be identified. Although there are areas where a logical order of processes can be presumed. This paper tries to setup logic for earthmoving processes and implement it within a computer game development engine. The result is an interactive computer game that allows the user to play the simulation of excavation in real-time.

1 INTRODUCTION

The rapid development of computer sciences in the last decades brought a lot of ideas about representing the physical reality with machine driven intelligence. However the practicability of the developed tools is yet limited to repetitive process types. Also in the construction area this problem is still being discussed and researched. This paper refers to some approaches for automation and simulation and shows a prototype for an interactive simulation based on computer game technologies.

2 AUTOMATION AND SIMULATION

First approaches for automation and simulation of construction processes assumed that process models could be described with deterministic dependencies. This led to the development of several theories that have been applied so far for representing constraints of processes on a timeline or in a graph. But when it comes to simulating and automating process models in construction it has been shown very early that deterministic approaches might not lead to success. Retik & Shapira (1999) show a VR-based simulation tool for planning site activities with both an integrated intelligent and non-intelligent interface. It indicates that the authors doubt an entirely automated system. Rojas & Mukherjee (2005) discuss some simulation environments developed since 1973 (Fig. 1) and show the relationship to their concept of an educational simulation tool (Virtual Coach). They also argue that the simulation languages used by some of the environments use ´activity cycle diagrams´ (ACDs). These ´discrete event models´ do not sufficiently consider the need for concurrent events in the process model. For this reason they designed ´virtual coach´ to be a ´cycle-based simulation´ with consideration of spontaneous interactions with the process model.



	Construction Operations	Construction Management Processes
Special Purpose	Simphony (Hajjar et al. 1999)	CONSTRUCTO (Halpin et al. 1973) AROUSAL (Ndekugri et al. 1992) SuperBid (AbouRizk 1993) STRATEGY (McCabe et al. 2000) VIRCON (Jaafari et al. 2001)
General Purpose	CYCLONE (Halpin 1973) STROBOSCOPE (Martinez 1996)	Virtual Coach

Figure 1. Relationship between virtual coach and other construction simulation environments (Rojas & Mukherjee 2005, p. 84)

From the practitioners point of view the solution suggested by Rojas & Mukherjee is preferable to simulation methods that work with ACDs. The speciality of construction processes is that there are not many ´hard` constraints. Therefore new approaches have to be pursued to develop tools that support the simulation of processes while dismissing logic and offering situational interaction.

To develop such a solution Bargstädt & Blickling (2004) proposed the use of interactive environments such as game development engines. These tools allow to model logic of processes in a way that users can interact with the model during runtime. An earthmoving process serves as an example. The concept also refers to earlier works on earthmoving processes done by Martinez & Ioannou (1999) and AbouRizk & Mather (2000).

3 LOGIC ISSUES IN SIMULATION

Martinez (1999) showed that the logic of processes for earthmoving could be described with ACDs. In Fig. 2 the boundary conditions of their approach are pointed out.

Conditions needed to start (1)	Activity (2)	Outcome of activity (3)
Pusher at push-point	*PushLoad*	Pusher ready to backtrack
Scraper at cut		Loaded scraper ready to haul
Pusher ready to backtrack	*Backtrack*	Pusher at push-point
Loaded scraper ready to haul	*Haul*	Loaded scraper ready to dump
Loaded scraper ready to dump	*DumpAndSpread*	Dumped soil Scraper ready to return to cut
Scraper ready to return to cut	*Return*	Scraper at cut

Figure 2. Activities, Required Conditions, and Outcomes for Scraper and Pusher Operations (Martinez 1999, p. 266).

The process has been divided into five main activities. These are ´PushLoad´, ´Backtrack´, ´Haul´, ´DumpAndSpread´ and ´Return´. Fig. 3 visualizes the concept in a graphical way.

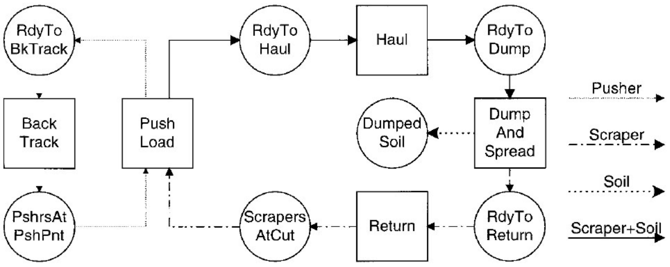


Figure 3. ACD for Scraper and Pusher Operation (Martinez 1999, p. 266).

Rojas (2005) mentioned: *´An activity cannot occur if the condition is not fulfilled and when it occurs it always produces the predicted outcome.´* (see Fig. 2). He further said that *´(..) discrete items change state as events occur in the simulation. The state of the model changes only when those events occur.´* This statement has led the authors to the idea of developing a tool that allows to change the state of the model through user interaction. To assure the most convenient way of deciding when and where the state of the model should be changed the user is supposed to get visual feedback from the virtual environment of the site. Besides he is supposed to ´steer´ the process model using mouse and keyboard.

The logic of the processes was also implemented using ACDs, but on a higher level of detail. The principle of the simulation is shown in Fig. 4.

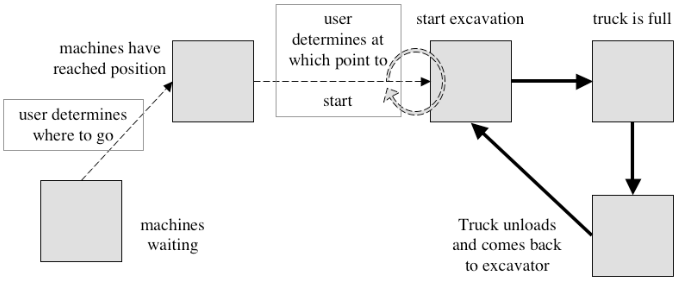


Figure 4. Simulation with user interaction in the virtual environment of the construction site

Before starting the excavation process the logic foresees that the user has to determine where to go with the machinery. This is quite an important question when planning the production process on a high level of detail. Most other research assumes abstract simulation models without reference to the geometry of the site. Associated to this Bargstädt & Blickling (2005a, 2005b) have pointed out that the change to a high level of detail in the process model requires analysis of the impact on simulation.

After the machines have reached their positions the user has to determine at which point the excavation process starts. Here it is necessary to tell the excavator where exactly the shovel should hit the ground if simulation runs on a high level of detail. To assure progress in simulation the interaction with the user is required because otherwise the system will not continue automatically and cannot decide where to continue excavation. This considers that these decisions are not logical but situational.

Following the simulation process in Fig. 4 it can be seen that the process of telling the excavator where to start is an iterative process for the user. After having decided where to hit the ground the excavator fills up the truck without user interaction. After that the next user input is expected. This dialogue game continues until the truck is filled up, which is calculated in the back on the basis of a simple mathematical term. After this the automated part of the simulation starts. The logic foresees that the excavator pauses while the truck drives to a determined place to dump the soil. After coming back the interactive sequence of telling the machine where to work is continued.

The implemented logic is attached to the geometric and material conditions of the virtual site. Changes in the 3D model of the site would result in necessary updates of the logic. If there were a river or other obstacles like marshy ground not only the geometry and material constraints but also the logic of processes need to be adapted.

A conclusion at this point is that logic of processes in construction can be hardly determined even if simulated on a high level of detail. Experiences from construction sites show that assumptions at an early stage that were explained to be ´logic constraints´ have been proven wrong when it came to execution. In construction processes only a few constraints are purely logic, whereas most ´constraints´ are given by economic consideration. If really needed a column can even be built underneath a ceiling after that ceiling already has been poured.

4 DEVELOPMENT OF A COMPUTER GAME PROTOTYPE

The use of computer game technology for simulation purposes has become more and more popular in the last years because of the progress in hardware development. Applications of these technologies mostly aim at education and training whereas technical simulations are mainly applied in association with collision detection or assembly. Especially the latter is interesting for the simulation of the assembly of a facility.

As a small section of the huge amount of possible scenarios during construction an earthmoving process has been chosen. That problem has been focus of research in many research works.

An idea of how logic can be built in the game development engine gives Fig. 5. It shows the logic that was implemented for the truck. It is only a detail of the whole system where a ´FiniteStateMachine´ was implemented. This pre-defined part of the engine is a Petri Net that runs the behavior of the truck.

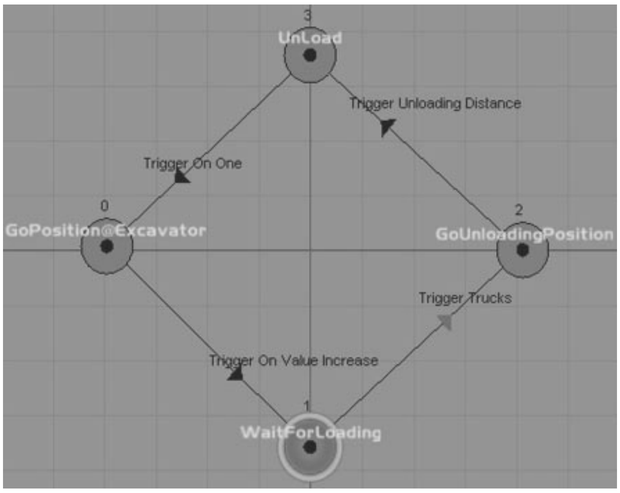


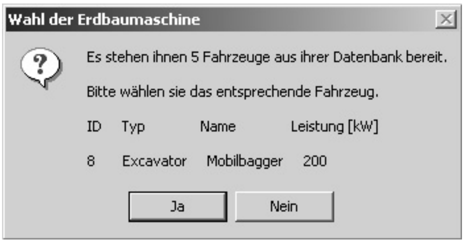
Figure 5. Truck logic in the game development environment

The game is simulated in real-time. The requirements are defined as follows:

1. Truck types, excavator and its equipment are selected out of a machinery database
2. The machinery database contains all detailed data on the chosen machines and equipment, e.g. cost/hour, max. load, weight, etc.
3. The user decides where to start the excavation
4. The virtual time is displayed in the application window as well as the buttons to start and stop duration recording during simulation
5. Input data are collected for later reuse in simulation: an external database is connected to the application so that all process parameters can be saved for later evaluation
6. The virtual construction site provides the user with geometrical data of the site; the objects should appear in a close to reality shape

The prototype requires thorough knowledge of the channel graph logic of the used game development engine. The application consists of several channel groups that merge to one big graph. Here only a few aspects of the graph are discussed.

One task 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 for the selection of machine types (see Fig. 6). The user goes through all the machines in the database and thus determines the configuration consisting of a specific excavator with shovel and a truck. The choice is important because there are some parameters (maximum load of truck, performance of excavator) that influence the efficiency of the loading game between excavator and truck. Here the user is free to decide which truck or excavator to choose. But he has to consider the maximum performance possible with the chosen configuration of machines. The selection process is kept open for users` decision.


Wahl der Erdbaumaschine

Es stehen ihnen 5 Fahrzeuge aus ihrer Datenbank bereit.

Bitte wählen sie das entsprechende Fahrzeug.

ID	Typ	Name	Leistung [kW]
8	Excavator	Mobilbagger	200

Figure 6. Start-up window with available trucks and excavators

In addition to the truck and the excavator the user can also choose specific equipment of the excavator, for example size and type of the excavator shovel. Only compatible equipment is offered by the database.

In the prototype the user can 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 yet been implemented. The further development foresees to give a specific point of the virtual construction site. The user indicates the position on the screen and the machine will move to that position.

In Fig. 7 that position is marked with a cube. 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 7) to excavation and loading.

Figure 7. Machines proceed to the cube according to user interaction

This switch is important for the database to register that a certain process phase has finished. At the beginning of the next phase the user needs to specify the position of the excavation area. This can be initiated by user input and causes the excavator to rotate the shovel to the chosen position. The excavation is again started by user input. After this the movements of the excavator are animated in real-time what is important for the correct determination of the process duration (see Fig. 8). After having performed all the necessary steps to fill up the truck, the truck leaves automatically and moves to the unloading point. Before that the system changes to phase process-dependent waiting for discharge (Ablaufbedingtes Warten durch Abladen), which is also recorded in the database.

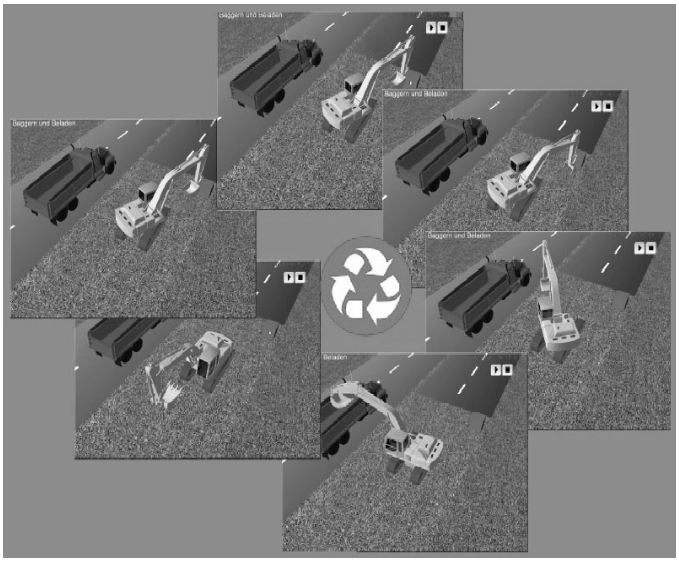


Figure 8. Excavator sequence after user has determined where to start with excavation

The process as described above can be executed in “registration mode” (process durations are instantly written in the database) or offline. Clicking the `play` button starts the registration 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 process durations. Fig. 9 shows an example of data written into the database.

ID	StartTime	EndTime	Duration	Process
1	16:44:26	16:45:09	00:00:43	Umsetzen
2	16:45:09	16:47:11	00:02:02	Baggern und Beladen
3	16:47:11	16:48:16	00:01:05	Ablaufbedingtes Warten durch Abladen
4	16:48:16	16:50:16	00:02:00	Baggern und Beladen
5	16:50:16	16:51:21	00:01:05	Ablaufbedingtes Warten durch Abladen
6	16:51:21	16:52:00	00:00:39	Baggern und Beladen
7	16:52:00	16:52:09	00:00:09	Umsetzen
8	16:52:09	16:53:30	00:01:21	Baggern und Beladen
9	16:53:30	16:54:32	00:01:02	Ablaufbedingtes Warten durch Abladen
10	16:54:32	16:56:32	00:02:00	Baggern und Beladen
11	16:56:32	16:57:35	00:01:03	Ablaufbedingtes Warten durch Abladen
12	16:57:35	16:58:32	00:00:57	Baggern und Beladen
13	16:58:32	16:58:41	00:00:09	Umsetzen
14	16:58:41	16:59:39	00:00:58	Baggern und Beladen
15	16:59:39	17:00:39	00:01:00	Ablaufbedingtes Warten durch Abladen
16	17:00:39	17:02:39	00:02:00	Baggern und Beladen
17	17:02:39	17:03:39	00:01:00	Ablaufbedingtes Warten durch Abladen
18	17:03:39	17:03:43	00:00:04	Baggern und Beladen

Figure 9. Example of data written to the external database

5 CONCLUSIONS

Simulation concepts in construction used to be based on common simulation techniques known from other industries. These concepts mostly work with deterministic approaches. This has motivated to search for solutions to bypass deterministic approaches. Thus flexible simulation models have to be developed that consider situational aspects in the process model. The question is, whether a simulation ´interrupted´ by human interaction can still be called a ´simulation´ in its original sense. Integrating human decision making leads to long simulation durations. It is not possible to ´calculate´ the simulation entirely by mathematical terms. For a big project it has been estimated that the total duration of the game might take more than one day. For this reason further research aims to minimize the human part although there will remain some crucial decisions that cannot be taken by computers.

Fig. 10 shows a part of the logic of the prototype. The whole graph is too extent and is therefore omitted. The figure shows the ´start channel group´. This is the starting point of the complete game logic. It gives an overview on the design of the whole application. The ´start project channel` is executed from left to right. The ´GetDatabaseInfo´ on the left side is responsible for the determination of the machinery equipment at the beginning of the game.

In future the representation of a general-purpose virtual construction site with imported geometry and pre-defined construction logic will be one point of interest in research. It has been shown that game development engines can be used for implementing logic of construction processes. However, efficiency in simulating the processes must be increased.

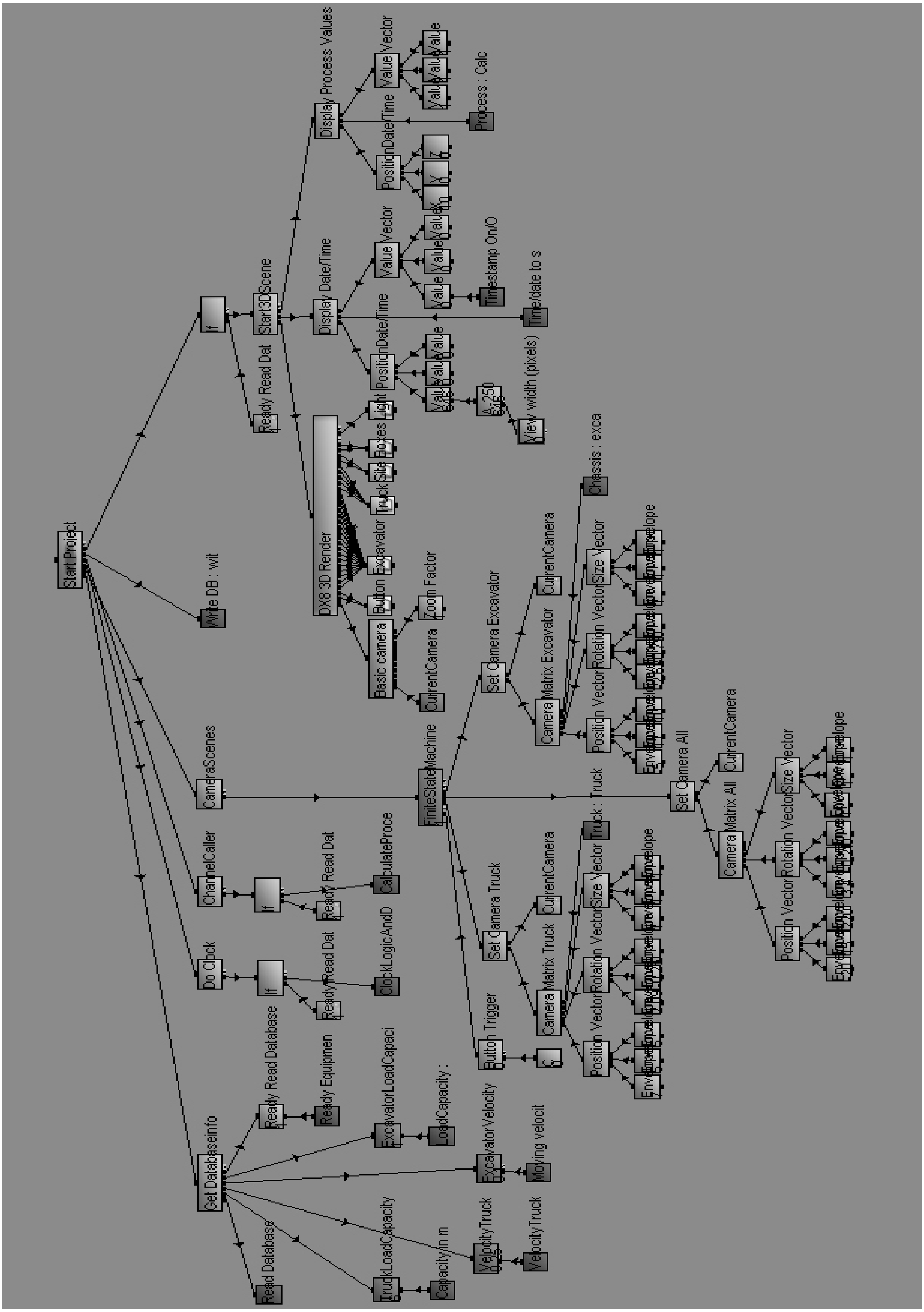


Figure 10. Overview on the concept of the prototype

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