Simulation and Gaming in Construction Business

Design of a module-oriented modeling approach based on system dynamics and its prototypical implementation in research and education

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„Sometimes you need a lot of courage to lean far out of the window,

but finally, you will see more than others."

(own experience, 2009)

Abstract

The development and application of simulations with the purpose to explore systems and their innate, partly dynamic structures has established itself, among others, in the areas of natural sciences, business studies and political sciences. This similarly applies to business games used in the field of further education to support understanding of complex relationships, especially in business studies. Both always have a model in common which serves as starting point for the development.

Hence, the aim of this research project is the development and practical testing of a module-oriented modeling approach, which can be used both in the simulation of multi-causal and dynamic relationships on different levels of the construction industry and in educational games employed in academic and further education. Out of this primary aim, numerous research contributions emerged in the field of modeling, simulation and educational games.

The successful conceptual design of a module-oriented development framework for domain specific system-dynamic libraries (SDL approach) demonstrates that it is quite reasonable and possible to connect the development of simulations and business games. Thereby, knowledge synergies are created which enable the interdisciplinary development of simulations and business games.

Compared to other fields, significantly less implementations of simulations or business games exist in the construction industry. Therefore, the approach introduced here can provide a valuable contribution to promote further developments, e.g. the explanation of the risk situation of a company, the identification and evaluation of project risks, endangered operational procedures on various functional levels or to improve the understanding of the decision making process in detail.

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Contents

Nomenclature

AMA	American Management Association
AMCA	atom-molecule-component-approach
ASIM	Arbeitsgemeinschaft Simulation
BRTV	Federal Collective Agreement for the Building Industry (Bundesrahmentarifvertrag für das Baugewerbe)
CCD	Construction Company Dynamics
CD	construction dynamics
CDL	Construction Dynamics Library
CLA	commuter learning approach
CLD	causal-loop-diagram
CMD	Construction Market Dynamics
CMS	Content-Management-System
CPD	Construction Project Dynamics
CPFS	Construction Project Flight Simulator
CRM	course-relationship-method
CYCLONE	CYCLic Operation NEtwork
ERM	entity relationship model
FDG	Forensic Decision Game
GNU	GNU's Not Unix
GPL	General Public License
GPMAF	General Purpose Multi-Agent Framework
GUI	graphical user interface
MIT	Massachusetts Institute of Technology

MLA	multi-level analysis
NTUA	National Technical University of Athens
OE	Operational Environment
ORO	Operation Research Office
PGM	probabilistic graphic models
PLE	personal learning edition
PO	Process Ontology
RAND	Research ANd Development
SD	system dynamics
SDL	system dynamics library
SFD	stock-flow-diagram
SKA	synergetic knowledge absorption
SMP	shared modeling platform
SWD	swarm web development
TBOC	Training Brain Operations Center
TRADOC	U.S. Army Training and Doctrine Command
UCLA	University of California, Los Angeles
UML	Unified Modelling Language
USDML	Unified System Dynamics Modelling Language
VDI	Association of German Engineers (Verein Deutscher Ingenieure e.V.)

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1 Introduction

The following section explains the fundamentals which are seen as indispensible for the understanding of the paper as a whole. However, this chapter does not claim to offer a comprehensive and highly detailed overview of the issues comprised in the research, but aims at introducing the relationships of the different domains to make them available for the further chapters of this academic paper. At first the motivation and the general aim of this dissertation are described, followed by central definitions and characterizing features. Then the background knowledge required for the overall understanding is presented in appropriate brevity. Furthermore, the final delineation between this reserach project and other research areas is clarified on the basis of the purpose and previously introduced content. Lastly the approach and the methodology of the research project are developed, reflected in the structure of the paper.

1.1 Motivation and aim

The development and application of simulations with the purpose to explore systems and their innate, partly dynamic structures has established itself, among others, in the areas of natural sciences, business studies and political sciences. This similarly applies to business games used in the field of further education to support understanding of complex relationships, especially in business studies. Both always have a model in common which serves as starting point for the development.

Simulation models are complex descriptions of reality to aid the exploration of multi causal processes within a system. In contrast to that, business game models are especially characterized by the emulation of reality in a substantially reduced complexity. This reductionism is necessary and sensible for teaching purposes, but such business game models can hardly be employed for a valid simulation of the same reality. Therefore, the development of a purely simulation-oriented model on the one hand, necessarily very detailed due to the included structural relationships and interdependencies, can be juxtaposed to the business game model on the other hand, which, apart from the extracts taken from reality, has to consider numerous additional didactical aspects like the pedagogical framework, the required competencies and the intended teaching and learning aims.

As both human resources and financial expenses required for the development and implementation of simulations as well as business games can be quite substantial, it appears sensible to merge one of the most complex phases – the modeling.

Especially in this context, the development of a module-oriented model offers the following advantages:

- At least one reduced business game can be extracted from a simulation created for scientific purposes.
- Module-oriented simulations can be executed on the basis of the complete reality depicted therein or part of it.
- The module-oriented model allows the design of variable and versatile business games.
- As both simulation and business game have a common basis, insights gained from the simulation can be applied to the business game and vice versa.

Consequently, the development of only one model offers considerable and numerous possibilities of application. This, in turn, results in the following central aim of this research project:

> The aim of this research project is the development and practical testing of a module-oriented modeling approach, which can be used both in the simulation of multi causal and dynamic relationships on different levels of the construction industry as well as in business games for academic education and further training.

1.2 Definition of central terms

The terms simulation, business game and their possible variations are used synonymously in literature and practical application alike.[1] Therefore it appears necessary to inspect the two terms and define them for further handling in the paper.

1.2.1 Simulation

Generally stated, a simulation allows to emulate selected events or whole systems in a simplified manner.[2] Here the primary aim is more to answer questions than to understand processes.[3] Due to the potentially high degree of complexity[4], a simulation is devised to illustrate systems, the relationships and the multiple interdependencies between the included individual elements in detail. This maximum of realism is generally independent of the individuals who use the simulation.[5]

These relationships are also, among other sources, found in the VDI (The Association of German Engineers) guideline “Simulation of logistics, material flow and production systems”[6], in which simulations are understood as the emulation of a system with its dynamic processes in an experimental model to achieve insights which can be transferred to reality.[7]

[1] cf. Golombiewski (1995)
[2] cf. Wenzel (2004)
[3] cf. Taylor & Walford (1974)
[4] cf. ibid.
[5] cf. Kriz (2000)
[6] in German: Simulation von Logistik-, Materialfluss- und Produktionssystemen
[7] cf. VDI 3633-1 (2010)

In summary, the term simulation describes the precise emulation of a real situation with the aim to gain insights, but without the intention to serve as teaching method directly.

1.2.2 Business game

Apart from the term business game itself, numerous other terms are in existence, e.g. action plan game, management game, educational game, simulation game, planning game, simulation exercise[8].

Accordingly, there are equally numerous definitions which, due to their varying background, lead to partly synonymous, partly conflicting perspectives and viewpoints. Nonetheless, it appears to be common understanding that business games primarily pursue teaching aims.

Comparable to simulations, business games should also appear as realistic as possible, with the one difference that the depicted environment is based on assumptions only.[9] This hypothetical and virtual world dominantly provides conflict and problem settings[10] in which participants need to prove themselves[11] depending on the specific objective target.

Hence, business games emphasize the activities and decision-taking[12] and thereby the experiencing of consequences arising out of the decisions and the general conduct of the persons in charge[13]. These relationships can also be found in the U.S. Army Modeling & Simulation Glossary. There a simulation game is a simulation in which the participants seek to achieve some agreed-upon objective within an established set of rules[14]. Primarily due to the use of simulation games in the U.S. Army, the objective may not be to compete, but to evaluate the participants, increase their knowledge concerning the emulated scenario, or achieve other goals.

All in all, a business game is primarily a teaching and learning method which allows participants to gain experience by (collaborative) action in conflict and problem settings within a virtual, but realistically emulated excerpt adopted from reality.[15]

1.3 Characterizing features

Based on the aforementioned definitions, the fundamental terms needed for this research paper like model, system, simulation and business game as well as their sub terms are to be considered further and need to be put in a context and relation to each other. As the concept of a model is the central item of this paper, it is necessary to discuss it in more detail in the following.

[8] cf. Steffens (1972), Rohn (1964), Bollermann (1975), Scheitlin (1975), Kaiser (1976), John & Walther (1981), Schmidt (1988), Manthey (1990), Anderson & Lawton (2008)
[9] cf. Geuting (1992), von Fürstenberg (1993)
[10] cf. Rebmann (2001)
[11] cf. ibid.
[12] cf. Blötz (2005)
[13] cf. Taylor & Walford (1974)
[14] cf. U.S.Army (2013)
[15] In how far the findings of this paper extend these previously accepted fundamentals of a definition for business games will be summarized in chapter 7.

1.3.1 Model

The term model is ambiguous[16] and is used frequently as well as with multiple meanings[17]. In general, every emulation of an original can be labeled a model.[18] Models serve the purpose of cognitive insight (pragmatic function) on the one hand and inform about certain relations regarding an existing or future original (semantic function) on the other hand.[19]

Even though numerous definitions are potentially available, e.g. due to the fact that the term model is exposed to different viewpoints in the domains of engineering, economics, psychology, philosophy and other sciences, the definitions offered by Stoff (1969) and Stachowiak (1973) are seen as the most commonly accepted ones because of their relatively general character.

According to Stoff (1969), models can be categorized into material models and cognitive models. Stoff understands material models to be e.g. analogy models, structural models, models with mechanical, dynamic, kinematic and other physically similar representations of an original as well as drafts and diagrams which show a spatial similarity to the original. Cognitive models, however, are drawing models (symbolic models), graphic presentations, maps, sketches and also visual (iconic) models, according to Stoff.

Stachowiak (1973) classifies the term model into graphic and technical models and semantic models. In graphic models, which are predominantly defined by two-dimensional descriptive and spatial images of the original[20], photographs, illustrations, diagrams and different types of graphs depict relationships and interdependencies within an overall structure. Currently, such models are applied as probabilistic graphic models, in which every knot represents one random variable (or a group of random variables) and the connections between these variables express probabilistic relationships.[21]

Although this categorization appears similar to the material models following Stoff, it differs in the aspect that Stoff explicitly classifies images as cognitive models if they are not strictly true to the original whereas Stachowiak regards these as diagrams, figures or graphs in the widest sense.

The mainly three-dimensional technical models, according to Stachowiak, are to be seen as spatiotemporal and material-energetic representations of originals[22]. One potential use of these models is the model of a flying body for studies in a wind tunnel[23], testing facilities for the testing of materials like the life span and durability of road surfaces made of different materials[24] (Stoff and Stachowiak agree in this).

According to Stachowiak semantic models are abstract, formal descriptions and representations of an excerpt taken from reality. The transition of the graphical as well as the technical model

[16] cf. Giesen & Schmid (1976)
[17] cf. Harbordt (1974)
[18] cf. Dörner (1984)
[19] cf. Busse (1998)
[20] cf.Stachowiak (1973)
[21] cf. Bishop (2006)
[22] cf. Stachowiak (1973)
[23] cf. ibid.
[24] cf. ibid.

to the explicitly semantic model is smooth and flowing[25]. Hence, this model is found in, e.g., software engineering as a preliminary step before the concrete technical implementation in the data modeling. Different modeling languages exist for the creation of such semantic data models, of which the entity relationship model (ERM), which can be used as basis for a standardized viewing of data[26], is the most widespread. Therefore the semantic models following Stachowiak can be seen as synonymous to the cognitive models proposed by Stoff.

Models are principally defined by three fundamental features: 1) the visual representation, 2) the reduction and 3) the pragmatic feature.

Regarding the visual representation, it can be stated that models are always representations of natural or artificial originals[27]. Depending on the according purpose of the realization, models therefore are required to be sufficiently similar to the original system[28]. Usually models do not comprise all properties of the original they represent[29], as stated by the feature of reduction. This means that less important attributes of the original are omitted by the model designer and the original is thereby narrowed down to typical and relevant influence factors, data, properties, events, information, structures and so on. The pragmatic feature expresses that models cannot always be allocated to an original as it exists in reality, because the model fulfills its substituting function with a limited scope on selected theoretical or real operations[30]. Consequently, the model can contain elements which are not given in the original.

Salzmann (1976) expands these considerations in regard to business game models. He added the features accentuation, transparency, intentionality and instrumentality to the business game model.[31]. While the first two of the listed features contain only minor elements of innovation, the feature of intentionality suggests that a business game model is always developed for a specific aim. This aim can be teaching or education, but also a forecast of the development of future market conduct. The feature of instrumentality includes this consideration. It expresses the idea that each business game follows an intention or serves a function. Buddensiek et al. (1980) focused especially on the intention of education and training and assigned the following training functions to the models:

- elucidating specific nontransparent structures of an original (structuring function),
- clarifying complex relationships (heuristic function),
- making learning content available which is not accessible in the original (substitute function),
- introducing alternatives to an existing reality (anticipation function),
- questioning an available reality from a real-utopian perspective (function of critique of ideology),

[25] cf. Stachowiak (1973)
[26] cf. Chen (1976)
[27] cf. Stachowiak (1973)
[28] cf. Sauerbier (1999)
[29] cf. Stachowiak (1973)
[30] cf. ibid.
[31] cf. Salzmann (1976)

- offering the learner a training possibility for a specific behavior needed in future situations (training function)

Models are structured in themselves by allocating each subject a structured set of potential attributes, i.e. characterizing features.[32]

Hence, abstract statements can be expressed as mathematical functions in models on the basis of attributes respective predicates. As a whole, these statements can form and display a system[33]. This background is applied in the conception of models, chapter 3 starting p. 42.

1.3.2 System

Attributes and predicates represent so-called process variables in a system. According to Forrester (1972a), a system is a multitude of parts (components) which are in relation to each other and interact for a common purpose. Kramer & Neculau (1998) postulate a similar view, stating that it is only possible to call something a system when several process variables are connected to each other and form an ordered whole. Usually it is possible to find one or more process variables which can be identified as independent values and others which are dependent values and influenced by the former.[34]

Systems are normally illustrated with the help of larger quantities of attribute and predicate classes[35]. Thus, a model can also be seen as a system.[36] Each system is described with the help of the environment, the behavior function and the structure[37]

The elements of a system can be seen as systems themselves, even on a lower level[38], i.e. they form a subsystem. Then a system can consist of several subsystems which in turn contain a certain number of elements respective units. If components cannot be divided any further, they are seen as elements.[39]

The interaction within a system is effected by the links between the elements contained in the system, i.e. they are connected to each other by a characteristic system structure.[40] The relationships between the individual components influence the system as a whole and, depending on the behavior pattern of the model, create variable impulses.

Especially in relation to business games, Böhret & Wordelmann (1975) regard these impulses as a method to observe and analyse the developments of varying inputs (system states) within

[32] Attributes here mean characteristics and properties of individuals, relations between individuals, properties of properties, properties of relations etc. (cf Stachowiak (1973)). Attributes are linguistically expressed with predicates (cf ibid.)

[33] Similar relationships are communicated by in the U.S. Army Modeling & Simulation Glossary: A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process (cf. U.S.Army (2013))

[34] cf. Kramer & Neculau (1998)

[35] cf. Stachowiak (1973)

[36] cf. Harbordt (1974)

[37] cf. Kaaz (1972)

[38] cf. Krüger (1975)

[39] cf. Niemeyer (1977)

[40] cf. Bossel (2004)

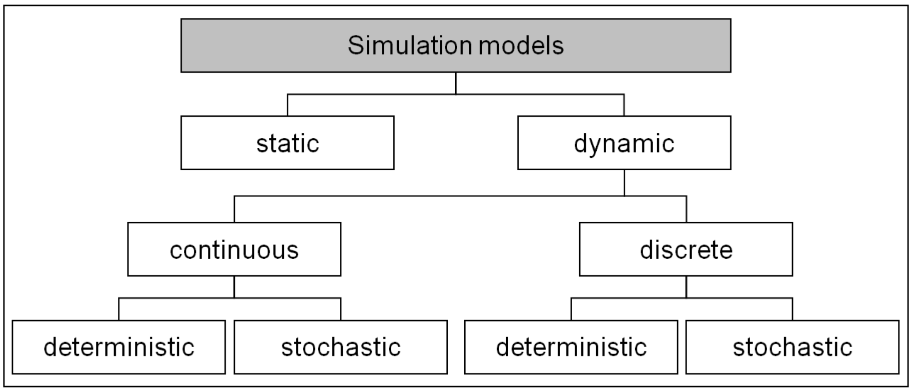


Figure 1.1: Simulation models

dynamic models.

Summing up, systems are composed of the following parts: a) elements, b) subsystems, c) relationships between the elements respective the subsystems.

1.3.3 Simulation

Following Sauerbier (1999), a simulation is the execution of calculations in a model, transforming input values into output values. Based on the previously introduced terms, the simulation thereby represents an imitation of real processes using mathematical models. Simulations can be classified in different types:

- examination method,
- medium of representation,
- intended purpose and
- transition of state.[41]

It is especially the classification through the transition of state which is of central interest for this research project (figure 1.1).

A static model is a reproduction with no changes of state. This means that such a model represents a system which displays reality at a specific point of time only. In the end such a system contains only constant attributes, so-called state constants[42].

In contrast to that, a dynamic model comprises time-dependent changes of state (state variables)[43]. Although a distinction can be made between static and dynamic models, the definition of the term simulation, which is communicated through the Modeling & Simulation Glossary of the (U.S.) Army Modeling and Simulation Office, seems to be contrary in this context. This definition considers especially the aspect of time: "A simulation is a method for implementing a model over time."[44]. Based on this, only dynamic models should be a basis for simulations. Static models

[41] cf. Page (1999)
[42] cf. Niemeyer (1973)
[43] cf. ibid.
[44] cf. U.S.Army (2013)

are entirely absent here and are not considered in this definition. As state variables change with the progress of time, it is possible to distinguish between continuous or discrete changes of state. Within the continuous model, which can contain one or more differential equations to depict the relation between the progress of time and changes of the state variables[45], state variables change continuously. In a discrete model, however, state variables change at specific points of time, i.e. event-oriented.

In a deterministic simulation the reactions to specific input are explicitly set[46] and the input values thereby clearly determine the simulation results[47], Lastly, the stochastic simulation describes the input values with the help of probability distributions[48].

1.3.4 Business game

The business game is supposed to describe learning content, e.g. processes within a marketing oriented corporation. As these are usually highly complex and not easily accessible for noninvolved persons, only selected relevant sections are focused. This modeling follows the principle of isolating abstraction[49], in which the relevant section is isolated from the overall concept of reality and intentionally simplified but without altering the significantly influential elements of reality. When developing business game models, it is important to depict these elements in the right scales and with the correct reciprocal effects. It has to be conveyed to the target group in how far the individual factors affect proceedings and how they influence each other.

The vast range of variation in the existing models[50] offers a remarkable incentive for the participants, because even though certain rules set a firm framework, the participants can navigate and act without constraints within it. Here the aspect of playing a game gains significant meaning. By taking over the position of an entrepreneur, the players enter a competitive situation and confront the other groups of players. Therefore this teaching and learning method has specific advantages. Especially the initiation of the participant's independent activities, i.e. acting or reacting, explaining to others, hands-on practice and the discussion of it results already in a significant increase of the teaching and learning success[51] (for details refere to table 8.6 on p. 160).

Several different areas exist within the course of a business game (figure 1.2). The default starting point is the action area, in which every player or each group of players is informed about the initial situation. After the screening of this information, the first round begins. Each round consists of an action and a reaction phase. In the action phase, the player groups develop their desired course of action according to the situation at the beginning of each round and communicate their taken decisions to the system, using the available input and command options

[45] cf. Liebl (1995); Sauerbier (1999)
[46] cf. Page (1999)
[47] cf. Sauerbier (1999)
[48] cf. Page (1999)
[49] cf. Kosiol (1961)
[50] A classification of business game models is shown in table 8.8 on p. 161.
[51] cf. Karl (2013)

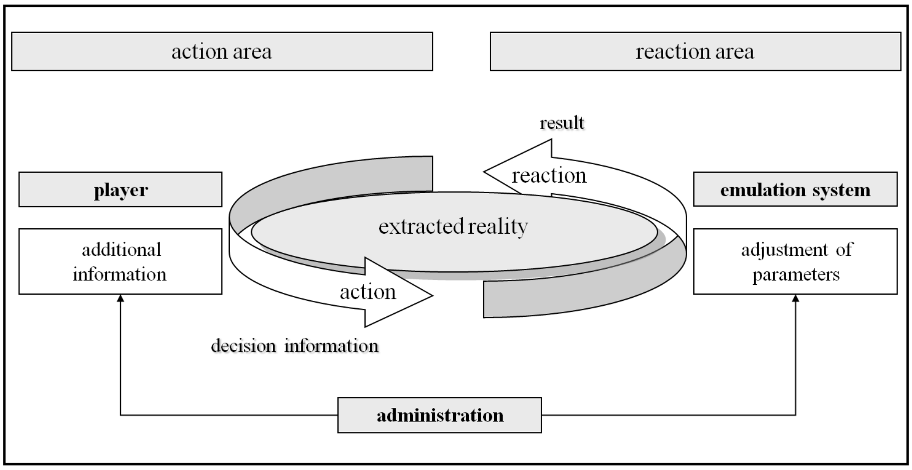


Figure 1.2: Flow chart of a business game

and facilities. After the decision information has been related to the system, the reaction phase begins. Now the emulation system uses the parameters preconfigured by the game supervisors to evaluate the received player's decision information and delivers the result information back to the players.

It is just these described relations which enable business games on the one hand to gain insights into the interactions within the depicted and emulated extract of reality, on the other hand to provide data which is helpful for decision-based simulations. Therefore business games can, apart from the aforementioned primary application as teaching and learning method, also be regarded as a scientific method to gain further insight by analyzing the interactions of the involved participants. The reasonable and meaningful combination of simulation and business game requires a more differentiated consideration of the main aspects which both concepts have in common, discussed in the following chapter.

1.4 Relationship between model, simulation and business game

The synonymous use of the terms simulation and business game (p. 9) may partly be traced back to sources like Geilhardt (1995), who stated that a business game always includes a simulation.

This general statement requires closer inspection: indeed, a business game always includes a certain kind of simulation (To make a clearer distinction in the context of a business game the term emulation will be used instead of simulation in the following.). This, however, is not due to an exact emulation of reality, but more because of a model which has been adapted to the business game purposes and thereby allows to depict a specifically chosen extract of reality. According to Gehring (1992), the relationship of model and simulation is the following: the simulation illustrates processes of real systems in a model. Therefore the model, which can either be employed in a comprehensive or reduced form, is generally to be seen as integral part both of simulation and business game (figure 1.3).

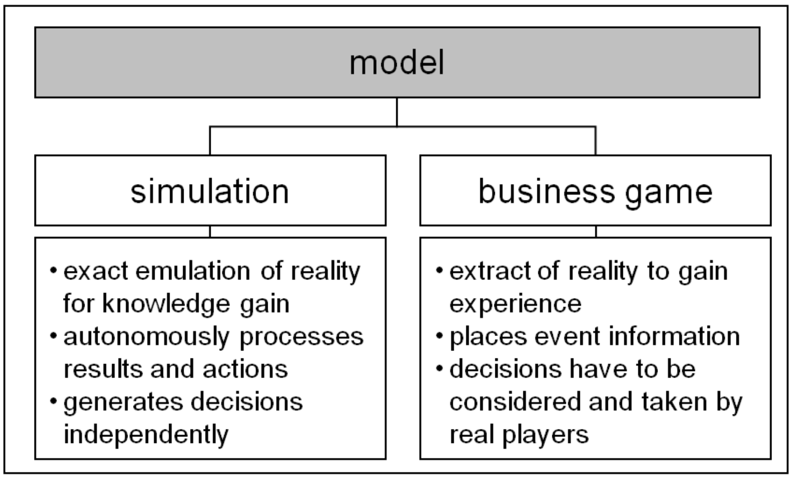


Figure 1.3: Relationship between simulation and business game

Therefore, the modeling claims a central position both in the conceptualization of simulations as well as business games. A further aspect in common is the existence of an action and a reaction area (figure 1.2, p. 16). The decisive difference is the allocation of the two areas. On the one hand, a simulation does not only display the event information in the reaction area, but also autonomously processes the tasks of the active agents in the simulation and generates their decisions. On the other hand, the system of a business game only places the event information at the disposal of the users, the decisions have to be considered and taken by the real players themselves.

1.5 Background of simulation and business game

To discuss the background of simulation and business game in the following section, it appears necessary to focus both on the general background of the concepts as well as the developments of this field. This also includes the highly relevant discussion of the previous development of these two areas in the construction industry, addressed in a separate section.

1.5.1 General background

Historically, both simulation and business game can be traced back to early, tactical war games originally found in the Asian region. The term game itself has a history which has developed with the passing of centuries. One of the first discussions of this term is the essay "Homo Ludens"[52] published by the dutch cultural historian Huizinga in 1938. His essay postulated the following definition of the game:

Looking at it from outside, one can call the game a free activity, and although seen as “not meant in this way” and outside regular life, it still engrosses the player completely. This activity

[52] latin: the playing human, in contrast to "homo oeconomicus", cf. Franz (2004)

is not tied to financial interests, no additional benefit is acquired, it takes place within its own set time frame and in its own set space, strictly following specific rules and regulations.[53]

Following this definition, Huizinga regards a game as a a) present activity in a b) closed imaginary space which c) follows specific conventions. Similar definitions were also proposed by Caillois (1958) and Heckhausen (1973), whereas the latter explicitly talks about quasi-reality.

Even today, these three prerequisites can still be derived from the definitions of simulation and business game. This means that the background and the development of simulation and business game are closely related and, as a consequence, exert much influence on each other. Taking into account Huizinga's definition, who stated that a game is not tied to financial interests or additional benefit, newer definitions consider a specific aim as part of a game, like Costikyan (1994) who sees a game as a form of art in which participants, termed players, make decisions in order to manage resources through game tokens in the pursuit of a goal.[54] Important to mention is the fact that Costikyan's definition is mainly focused on roleplaying and computer games. Nevertheless, it gives an insight how the definition of the term game has developed through the years and further how important the achievement of a specific goal appears at the present time.

In the following, several important historical stages will be introduced which have had crucial influence on the development of simulations, business games and even current roleplaying or computer games.

It is unknown which game sparked the initial impulse. Several sources mention the Indian war game Chaturango and the Persian chess[55], others mention the Chinese board game Wei-Hai as a historical beginning[56]. A general consensus exists, however, regarding the military origin of these games. War operations of two conflicting parties were staged on boards to emulate different dispositions for further developments. Later, these war games developed from a pure gaining of insights to a training method. The game play of the first documented war games was determined by the underlying model only, which caused them to be called rigid war games.

In 1644, Christoph Weikhmann, patrician and business magnate in Ulm, developed one of the first rigid war games called "Königs-Spiel" (King's Game), in which two opponents played against each other with 30 pieces, following 14 rules of movement.[57] With this King's Game, following principles of chess, Weikhmann's explicit aim was to display in brief and easy teaching political and military axiomata[58] in which several characters or pieces were employed to depict a whole royal suite. Emphasis was less on conflict and hostilities, but more on the opportunity for the players to try out different roles like marshal, councilor or courier. Therefore Weickhmann‘s work probably represents the *first politically-oriented simulation.*

[53]cf. Huizinga (1965)
[54]Some years later, Costikyan revised his general definition of a game into a functional definition in which he stated, that a game is an interactive structure of endogenous meaning that requires players to struggle toward a goal (cf. Costikyan (2001)). Again, the goal is a central component.
[55]cf. Rohn (1964), Schmidt (1988)
[56]cf. Freudenreich (1979)
[57]cf. Hartl-Prager (1972)
[58]cf. Weickhmann (1664)

A more complex design of a war game for the training of young Prussian officers was developed by Georg Vintarius in 1798 with a topographic map divided in 3.600 spaces[59]. However, the enormous complexity and the abundant 60 pages of rules lead to the failure of the teaching intentions. This is one of the first documented works in which the relation between complexity and teaching/ learning success demonstrated its significance, a relation which had to be considered by following war and business games as well.

Due to the lack of topographic display possibilities in previously developed war games, Kriegs- und Domänenrat[60] Leopold George Baron von Reiswitz (Reiswitz sen.) used a sandbox to demonstrate the desired terrain in 1811.[61]. One year later, in 1812, Reiswitz sen. developed the *first analogue simulator*: a chest of drawers which contained the shaped terrain in solid state.[62].

Lieutenant Georg Heinrich Rudolf von Reiswitz (Reiswitz jun.) developed his father's war game further and defined, apart from other details, troop movements true to scale, depending on the arm of service.[63] Based on ballistic experiments, he also calculated and defined the effects of the weapons being part of the war game. Here he also extended the use of dice to account for deviations from the calculated reference values.

All in all it can be stated that the model of the war game devised by Reiswitz jun. is based on empiricism and chance alike and thereby appears to be the first *stochastically oriented simulation*.

Even though the model established by Reiswitz jun. was recommended to all Prussian officers as training tool and, beyond that, influenced developments of later war games (among others, the American war game devised by William Roscoe Livermore, major of the U.S. Army Corps of Engineers)[64], it was not widely accepted and employed due to its complexity and the considerable number of rules.[65].

Further progress was achieved by the Prussian major general Julius von Verdy du Vernois in 1876. He adopted the sandbox model of Reisswitz sen., but appointed an impartial referee for the evaluation of the game rounds, the so-called Leitender (similar to leader or manager) or Vertrauter (confidant)[66]. This way the war game attained a higher flexibility and liveliness, leading to a higher motivation of the learners[67]. Verdy du Vernois developed one of the *first free war games*, which allowed the game management to exert guiding influence in the game play itself. Furthermore, this model considered both the independent evaluation of the game success as well as the motivation of the participants. The theoretical considerations of Julius von Verdy du Vernois and his war game have been influencing this training method until today. In this context, hardly a publication can be found in this context which does not quote him[68].

[59] cf. Hartl-Prager (1972)
[60] There is no appropriate translation available for this German title.
[61] cf. von Hilgers (2000)
[62] cf. Reiswitz (1811)
[63] cf. Reiswitz (1824)
[64] for details please refer to Livermore (1879)
[65] cf. Hartl-Prager (1972)
[66] cf. von Verdy du Vernois (1876)
[67] cf. Hartl-Prager (1972)
[68] cf. Lenoir & Lowood (2003)

More decisive breakthroughs in development took place at the beginning of the twentieth century. Germany and the USA are to be mentioned here, as they tried to gain military advantages in future or imminent armed conflicts with the help of testing alternative strategies and the strategic and tactical training of their military decision-makers. Additionally, potential scenarios were simulated to anticipate future developments on the political level.

In 1929, Erich von Manstein, staff officer (at that time, later field marshal) and responsible for the organization of a war game, predicted that increasing political conflicts would lead to a Polish attack on East Prussia or Upper Silesia[69]. Von Manstein proposed to extend the purely military orientation of the war game by political aspects, so that political and military leaders could learn from each other. Therefore, high-ranking members of the Foreign Office played the roles of the President of the League of Nations as well as the Polish and German foreign ministers. This approach is remarkable, as it added a political perspective to the previously only military simulations and thereby pursued Weikhmann's nearly 300 years old concept.

Before the Second World War, it was mostly singular potential scenarios which were planned with the help of military simulations and games, but especially in Germany whole campaigns were meticulously planned and simulated with a view to the Second World War. In 1939 the German army began the operative planning of operation “Barbarossa”[70], with the help of war games, the operation which was later realized in the war against the Soviet Union in 1941. The German army theoretically prepared an invasion of England with war simulations as well.[71] The resulting operation “Seelöwe“ (Sea lion), however, was never realized due to numerous reasons[72].

It was not only in Germany that war simulations became routine preparation for larger military operations. Another example is the Japanese attack on Pearl Harbour at the end of 1941. Here, the “Total War Research Institute”, founded in 1940, was staffed with high-ranking specialists[73] who took over the roles of military and political involved parties to research advantages and disadvantages of certain tactics[74] for this operation in advance.

After 1940, numerous war games were developed for the different branches of the military forces in the USA as well.[75] Based on their successes in the military context, the simulations found their way into economically oriented areas, too. The management simulation ”The Money Game”[76], devised by Ralph Norman Angell[77] in Great Britain in 1912[78], and the ”Organisation

[69] cf. Goldhamer & Speier (1959)
[70] cf. Deist (1993)
[71] cf. Klee (1958)
[72] cf. ibid.
[73] cf. Goldhamer & Speier (1959)
[74] for details please refer to Specht (1957)
[75] A detailed overview of the development can be found in the appendix starting p. 155. An example of recent U.S. military applications of models and simulations can be found at TBOC - Training Brain Operations Center, which is the operations center for the U.S. Army's Training Brain. Under the direction of the U.S. Army Training and Doctrine Command (TRADOC) G-2, TBOC is part of the G-2 Operational Environment (OE) Enterprise (for more details refer to http://tboc.army.mil).
[76] A card game for four or more players, earliest copyright for prototype 1912, patented 1928
[77] knighthood awarded in 1931: Sir Ralph Norman Angell (author; Nobel Peace Prize winner in 1933)
[78] for details please refer to Angell (1912) or Angell (1928)

of Production Game"[79], developed by M. Bierstein in the Leningrad textile factory in 1932, can be listed as the *first economically oriented business games*. The game theory achieved further progress. von Neumann & Morgenstern (1944) laid the decisive foundation.[80] The introduction of electronic data processing and the use of computers provided more and more extensive areas of application, both for the simulation and the business game. Now it was possible to input the data and process it faster than before, thereby accelerating simulation processes significantly and reducing the quantity of wrong decisions or calculation errors.

A further milestone was set by the RAND Corporation in 1955[81], which developed a business game that considered both economical and logistic aspects. This business game, developed on behalf of the US Air Force, contained not only military aspects, but also the cost effectiveness of storage facilities and supply provision.[82] The American Management Association (AMA) recruited employees of the RAND Corporation in 1956, and involved the Naval War College, of which "War Gaming" is an integral part since 1887, as well as IBM experts[83] to develop the business game "Top Management Decision Simulation"[84] for the training of executive staff members. This represented the *first business game with exclusively economic orientation*[85], integrating all operational areas[86].

The successful corporate business game "Business Management Game" was created by Andlinger und Greene[87] in the same year. It can be seen as a pioneer in its field because it was played on a board in contrast to the business game of the AMA[88]

As a consequence, a significant number of management games were developed in the fifties and sixties to train the managing of corporations. Apart from the Japanese top management simulation model 625-B[89], several business games were developed especially in the USA, e.g.:

- the management game of the Lockheed Missiles and Space Division/ 1953[90],
- the Carnegie Tech Management Game/ 1957[91],
- the UCLA Executive Decision Game/ 1957[92],
- a simulation of operative production tasks by the General Electric Simulation Laboratory/ 1958[93].

Further evidence of business games is listed by Ricciardi et al. (1957). The breakthrough of

[79] cf. Klabbers (2006)
[80] cf. von Neumann & Morgenstern (1944)
[81] Abella (2008) critically discusses the past and the present of the RAND Corporation in detail.
[82] cf. Rohn (1964)
[83] cf. Hausrath (1972)
[84] for details please refer to Ricciardi et al. (1957)
[85] cf. Rohn (1964)
[86] cf. Klabbers & Gust (2008), available as technical contribution on CD-ROM in Blötz (2008)
[87] for details please refer to Andlinger (1958)
[88] cf. Klabbers (2006)
[89] cf. ibid.
[90] cf. Burck (1964)
[91] cf. Hausrath (1972)
[92] cf. ibid.
[93] cf. Silk (1958)

business games in the USA took place in 1960/61. The popularity of business games is clearly shown with the data compiled by Hausrath (1972):

- Remington Rand Univac study: senior management executives of 95 corporations confirm the use of business games.
- more than 2.000 management trainees of Boeing Airplane have participated in business games.
- more than 3.600 staff members participated in the Minneapolis-Honeywell in-house training TOP BRASS GAME. 250 executive managers participated in the PILLSBURY IN-HOUSE GAME.
- several top management executives of the private economy participated in business games at the Army Management School: 600 in LOGSIM[94] and 264 in FORT SIMULATION[95].
- 15.000 mid- and high-level executives participated in the AMERICAN TELEGRAPH AND TELEPHONE COMPANY'S FINANCIAL MANAGEMENT GAME.

Until 1980, more than 2000 simulations and business games for training purposes were listed in the USA by Horn & Cleves (1980).

1.5.2 Simulation and business gaming in Germany

The development in Germany can hardly be compared with the rapid development in the USA. Especially the collaboration and mergers of civil and military facilities supported simulations and business games considerably in the USA[96].

While business games were integrated relatively quickly even into school curricula in the USA, in Germany they were not used before the sixties. In the former GDR, business games were frequently and widely used at universities[97]. Since the end of the sixties, the business game has established itself in Germany first in the context of vocational training, later also as a method for additional and further training in the public administration.[98]

The concept was increasingly discussed in the middle of the eighties, especially by Bleicher and Rohn. Moreover, Bleicher and Rohn significantly furthered the growing acceptance and use of business games in Germany with their trend-setting contributions[99].

In the year 1988, in German-speaking countries alone more than 300 simulations and business games existed, according to Rohn (1988)[100]. Compared to the catalogue of simulations and business games compiled by Horn & Cleves (1980), the very different dissemination and distribution

[94] a logistics business game developed by the Army Operation Research Office
[95] a computer-aided logistics business game developed by the Army Management School
[96] An example is the Army Operation Research Office (ORO) founded in the year 1950, which was affiliated with the Johns Hopkins University in Baltimore, Maryland.
[97] cf. Siebecke (1995)
[98] cf. Böhret & Wordelmann
[99] e.g. Bleicher (1962), Rohn (1964), Bleicher (1965), Rohn (1988), Rohn (1995)
[100] cf. Rohn (1988), part 1: 166, part 2: 143

Table 1.1: TOP 10 of contributions per country in ”Simulation and Gaming” (1970-2013)

rank	country	amount of contributions
1	USA	843
2	England	82
3	Canada	71
4	Netherlands	70
5	France	29
6	Germany	27
7	Israel	26
8	Japan	22
9	Australia	20
10	Finnland	16

of this method in comparison to the USA becomes evident again. Nevertheless, the interest in topics related to simulations or business games is quite high compared to other countries.

This becomes apparent when looking at the contributions in the English journal ”Simulation and Gaming”. From the journal‘s founding in 1970 to the year 2013, more than 843 articles were published by American authors. With this the USA clearly take the first place in the ranking of all contributions. In the same period, Germany’s contributions amount to only 27. Germany achieves the sixth place, narrowly exceeding the output of Israel with 26 contributions (for details please refer to table 1.1). Leaving the English-speaking countries out of the statistics, Germany manages to take the third rank in comparison to the remaining countries.

The German authors were especially productive in the years 1972 (number: 2, topic: urban and regional development), 1986 (2, administration simulation/ complex problem solution aided by simulation), 2005 (2, corporation reputation in business games), 2006 (2, theory-oriented evaluation for the design and research in business game and simulation/ processes of collective bargaining), 2009 (2, development of microworld/ theory-oriented evaluation in practice) and 2013 (2, both about climate change and Simulation/Gaming). On average, German authors published one article every second year in ”Simulation and Gaming”, whereas the USA published 20 and England, achieving the second place, published 2 per year. It appears that simulation and business game is still seen as a subject of scientific interest and research in the international context, especially in the USA, England and Canada. The fact alone that Germany takes place six in the final ranking of contributions shows that a professional discussion of these topics, started in the eighties, still continues today.

1.5.3 Development in the construction industry

The previously mentioned close relation and therefore high influence on each other of simulation and business game becomes especially apparent in the sector of construction, where Halpin's works served as a starting point for a number of research projects both in the context of construction simulations and in the field of user-friendly modeling alike. Based on his dissertation[101], Halpin developed the process simulation CYCLONE (CYCLic Operation NEtwork) at the University of Illinois, a simulation which allowed the graphical display and simulation of discrete systems, taking into account deterministic or stochastic variables in the process.[102] Beyond the simulation CYCLONE, Halpin & Woodhead developed the business game CONSTRUCTO, in which the effects of weather and productivity of the project management were issues of central interest.[103] Borcherding (1977) developed a similar simulation like CYCLONE at the University of Texas, whereas several further developed projects were more influenced by CYCLONE. Lluch & Halpin (1981) developed a CYCLONE version for workstation computers at the Georgia Institute of Technology (MicroCYCLONE). The INSIGHT system, developed by Paulson (1987) at Stanford University, was based on the same elements as CYCLONE, with the difference of an additional interactive interface. Based on this, Touran (1981) connected the automatic link-up of real data with INSIGHT. Lastly, the work of Chang & Carr (1987) requires reference here, as they expanded the CYCLONE concept with additional application areas of resource usage at the University of Michigan.

In the following years, Tommelein emerged as a major developer of implementable systems and tools. Worth mentioning is the SightPlan system, a system dealing with the layout of construction site facilities which was developed during her dissertation at Stanford University.[104] Beyond that, Tommelein linked the previous simulation approach to the lean principles already in 1989 and applied this concept in practice to the pipeline construction.[105] The influence of these research contributions in the field of simulation is reflected in the later works, e.g. in Choo et al. (1999) or Choo et al. (2004). Likewise in the year 1989, Tommelein et al. developed a simple business game called Parade Game, which was designed to illustrate the relationships between work flow of partial performances and the overall performance.[106]

Further evidence for the close link between the research of simulation and the business game development becomes especially noticeable with the considerate influence of CYCLONE and CONSTRUCTO, on whose foundation more business games with orientation to the construction industry were created. The work of AbouRizk (1992) from the University of Alberta, Edmonton, should be mentioned, who combined the concept of CONSTRUCTO with aspects taken from project management to a business game called "SuperBid". This development was continued in the field of construction management processes in the following years, among others with these

[101] cf. Halpin (1973)
[102] cf. Halpin (1977)
[103] cf. Halpin & Woodhead (1973), Halpin & Woodhead (1976)
[104] cf. Tommelein et al. (1987), Tommelein et al. (1989) and Tommelein (1989b)
[105] cf. Tommelein (1989a)
[106] cf. Tommelein et al. (1989)

works:

- AROUSAL: a flexible simulator reproducing the context of decision-taking in a building company[107]
- STRATEGY: a simulation environment modeling the construction process for training purposes[108]
- ICMLS: an interactive and adaptive teaching environment for the training of students in the field of construction process engineering [109]
- VIRCON: combination of traditional construction planning with 3D/4D models[110]
- The Equipment Replacemant Game: multiplayer simulation game which simulated the influence of different purchasing and selling strategies for equipment on the economic success of a building company[111]
- GPMAF: general multi-agent software tool for training in the construction operation[112]

Just as in the USA, simulations and business games for the construction industry gained more and more attention in Germany in the seventies and eighties.

Gehbauer (1974), for instance, realized that a simulation model can serve as a valuable support for the determination of performances and the combination of devices both in practice and under stochastic random influences.

A general overview of the state of simulations in the construction industry is given in Franz (2003). The possible applications range from the simulation of complex workflows like excavator-truck-operations and concrete-mixer-truck-crane-queues[113] to the simulation of earthworks procedures[114]. The further developments in Germany are characterized by the following works, among others:

- Chahrour (2007): integration of CAD and simulation on the basis of product models in earthworks
- Weber (2007): simulation of logistics processes of construction sites on the basis of 3D-CAD data
- Zamzow (2008): application of the construction progress simulation for the evaluation of stressed spatial structures in the construction process
- Günthner & Kraul (2008): process simulation for the planning of construction projects taking the example of a subway station
- Steinhauer (2008): planning of complex assembly procedures with the help of constraint-based simulations

[107] cf. Ndekugri & Lansley (1992)
[108] cf. McCabe et al. (2000)
[109] cf. Sawhney et al. (2001)
[110] cf. Jaafari et al. (2001)
[111] cf. Nassar (2002)
[112] cf. Mukherjee et al. (2004)
[113] cf. Franz (1989)
[114] cf. Gehbauer (1974)

- König & Beißert (2008): expansion of constraint-based simulation approach on the basis of STS
- Voigtmann & Bargstädt (2008): simulation of construction logistics processes in interior works
- Kugler (2012): CAD integrated modeling of agent-based simulation models for the construction progress simulation in surface engineering
- Alexander (2013): quantitative assessment of risks and simulation of their effects on the progress of a construction project

Current research, for instance at the Bauhaus-Universität Weimar, the University of Kassel and the Leibniz Universität Hannover as well as the conferences taking place in the context of simulations, among others in cooperation with the ASIM - Arbeitsgemeinschaft Simulation (Workinggroup Simulation) and the Arbeitsgruppe Unikatprozesse (Workinggroup Unique Processes) in the Fachgruppe Simulation in Produktion und Logistik (professional group simulation in production and logistics), suggest that the main focus of the simulation is on the construction progress, i.e. the emulation of operative construction processes.

Aspects of construction economics and strategy, however, appear to be more of subordinate interest. The same seems to be true for the simulation of construction industry, which is addressed mostly in business games, but less in simulations.

According to Rohn (1988), eight business games, which explicitly targeted the challenges of the construction industry, existed in Germany in 1988 alone.[115] Further eight business games existed with the central topics of the planning, construction and operation of facilities as well as urban development.[116] So the construction-specific business games covered 5% of all the existing business games.

Decisive influence on the development and wider distribution of corporate business games for the german construction industry was exerted by Danielzik (1986) with the business simulation "Bauwirtschaft" (construction industry), which still appears to be the basis for further business simulations in this field[117].

Following Blötz (2008), in German-speaking countries alone more than 550 business games are known[118].

How many business simulations are currently employed in the field of academic and further training of construction management cannot be determined with certainty at this point of time. This fact is reason for further research activities, whose results are displayed in chapter 2.1 starting page 30.

[115] cf. Rohn (1988): Simulation Bauindustrie; Baumarkt Simulation; Bauwirtschaft; AUBABAU/Autobahn; BAUMA2/Baumarkt I/II; BAUMAWI/Baumarkt; MARCONI; WOHNBAU/Wohnungsbau

[116] cf. Rohn (1988): Brown Boveri Anlagespiel, p. 15; Netzplan, p. 105; CUPSW, p. 177; DISPLAY, p. 177; FUSSZON/Fussgängerbereiche, p. 181; STAPLAN/Stadtplanung, p. 203; SU3, p. 205; UB21, p. 209

[117] e.g. von Lentzke et al. (2006)

[118] board games 116, team games with computer 171, team games without computer 50, single player games 50, online/internet & intranet games 62, remote business game competitions 22, freeform games 29 and behavioral/psychological or roleplaying games 54

1.6 Delineation of the research project

This research project concentrates on the sector of the construction industry. Within the scope of the study, the areas construction operation, project management, business management as well as economics are main points of interest. Therefore the module-oriented approach of modeling, the model conceptualization and partly the prototypical implementation both of the simulation and the business game display according orientation. The primary interest is more in decision-taking, less in planning and the optimization of the construction progress. Due to this, models and simulations from further areas like, e.g. the construction engineering, are not within the scope of this research.

1.7 Approach and methodology

Based on the previously listed aims, the approach falls into four basic phases: (1) literature research, (2) specification of the requirements, (3) implementation, (4) prototypical application (figure 1.4).

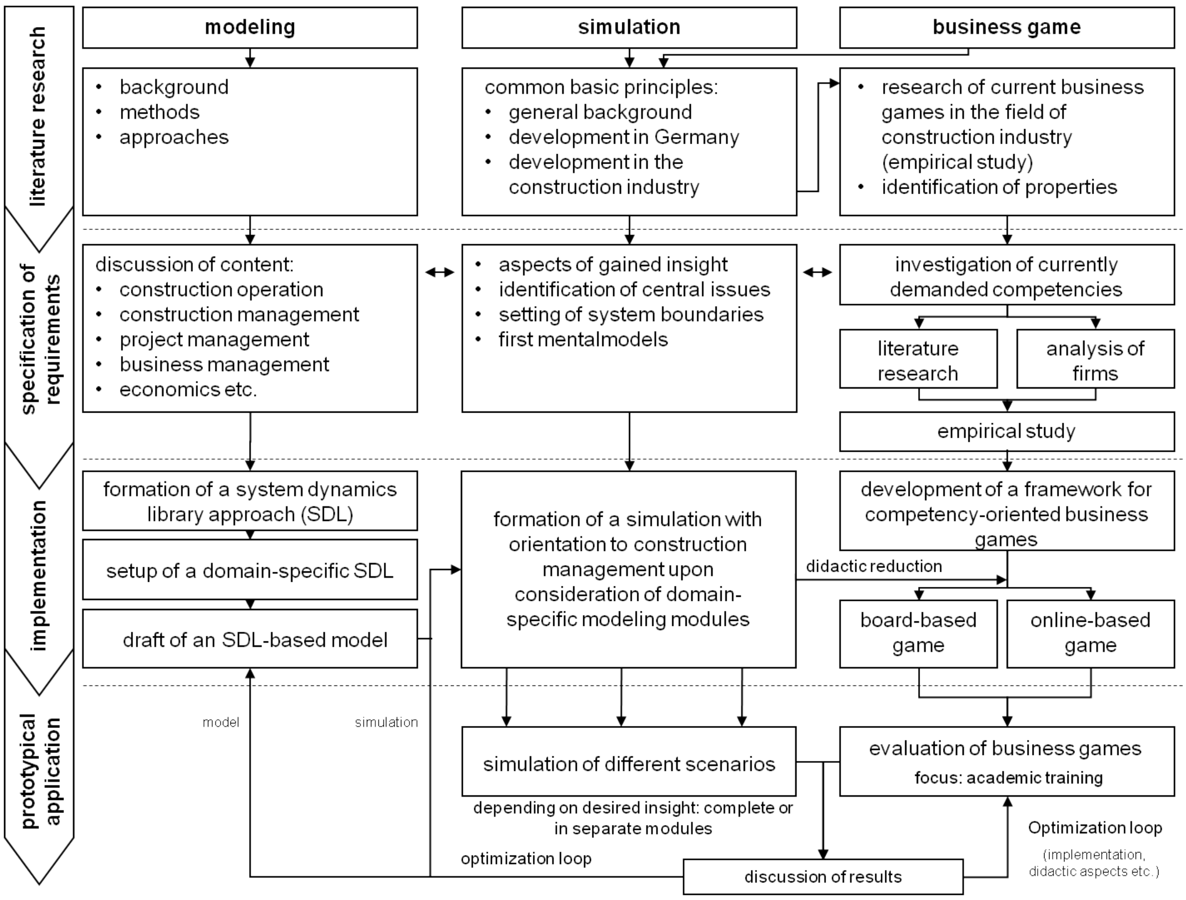


Figure 1.4: Approach and methodology of the research project

Within the four phases, the research is parallel in the fields of modeling, simulation and business gaming. To specify the aims, a thorough literature research and a critical discussion of the fundamentals of the abovementioned topics is required in the first phase. As already stated in chapter 1.5.3 starting p. 24, there is no current and valid overview of the business games used in the academic training of construction management. For this reason, an empirical study is carried out in the first phase to elucidate the current situation of business games in the field of construction industry at German universities and institutions of higher education.

The requirements for the three subdomains are specified in the second phase. These are based on a content-related discussion in the area of modeling on the one hand, and an empirical study in the field of business games in the construction industry on the other hand. In the field of simulations, the major insights to be gained are identified in this phase. Then, the results are the basis to devise a formal development framework in the third phase, the phase of implementation, with which dynamic module-oriented[119] models can be created.

The development framework is used to create models which are transferred into suitable simulation software and provide the foundation for the development of business games. The simulation is realized with the help of the System Dynamics (SD) approach, as this method lends itself to a holistic analysis and simulation of complex and dynamic systems[120].

The business simulation is extracted from the previously developed simulation models on the basis of a modular didactic reduction and focuses especially the academic and further training. It is formulated both as a board-based and an online-based solution. Considering the current discussion of competency acquisition in the academic training, a framework needs to be developed for competency-oriented business games to provide the basis for the implementation.

Finally, in the last phase, the phase of prototypical application, different scenarios are simulated and both the board-based and the online-based business simulations are evaluated. In the end, the discussion of the results should help to locate flaws and inconsistencies and allow the adjustment of the model, the simulation or the implementation of the business game in the first optimization loop.

1.8 Structure of the research paper

This research paper is divided in seven chapters. Chapter 1 introduces the motivation and the background of this research project. It illustrates the background of the central terms simulation and business game as well as their relation to each other and describes the approach and methodology. The results of an empirical study of academic training with business games in the field of construction management are introduced in chapter 2. The conceptualization of a formal dynamic modeling approach with module-orientation is described in chapter 3. Based on the aforementioned, first models are developed in chapter 4. Different subdomains are compiled

[119] Modules are generally seen as model elements with an internal operational logic of their own (VDI 3633 (1996)).Therefore modules can also be seen as subsystems within a system.

[120] cf. Forrester (1972b)

graphically and mathematically to be implemented in a simulation software and two business games in chapter 5. The results of the prototypical implementation are shown in the following chapter 6, both for the simulation and the online business game. Here the gained insights of several simulation scenarios and the evaluation of the business game are discussed. Finally, chapter 7 summarizes and discusses the results of the research project, places them in a larger context and suggests further research activities in this field.

2 Business games in the training of construction industry

The number of available business games targeting specifically the construction industry appears relatively small when compared to business games with economic orientation.[1]

This problem can be traced back to the fact that business games developed for the consumer and industrial goods markets usually provide little help for this domain as the construction industry mostly produces unique copies only.[2] Construction companies normally have limited influence on the product design or the employed building materials. This framework is mostly set by the client, just like the construction method. As a general rule, the construction companies are only the executive agents and follow the according directions and requirements of the employer. Business games for the construction industry need to consider this problem setting and emulate the actual decision-making processes of this industry in a suitable manner.[3]

In the following, an empirical study illustrates how many business games are employed in the academic training of the German construction industry and how they can be classified. To allow the categorization and discussion of the currently used business games, they are classified according to following pairs of opposites: general - functional, universal - specific, basic - complex, deterministic - stochastic, interactive - isolated, free - rigid, dynamic - static, manual - EDP-supported, open - closed. The properties of these dichotomies are briefly summarized and introduced in table 8.8 at p. 161.

2.1 Empirical research of business games in the construction industry

The empirical study PlanBauDE: Current state of business games in the field of construction industry at German universities and institutions of higher education[4] pursues a quantitative and qualitative goal. On the one hand, it has to be determined how often and widespread business games are employed in the academic field of construction industry in order to ascertain the current significance of the business game method especially in this field. On the other hand, the qualitative approach aims at elucidating which teaching and learning goals are pursued with

[1] e.g. Q-Key (total quality management), TOPSIM - General Management (corporate management), SimulTrain$^{(R)}$ (project management), HeiCON (management in retail businesses), MARGA (industry corporation), DIMAXX (service provider), CROCUS (cross-cultural management) and others listed in Blötz (2008)

[2] cf. Bauer (2007)

[3] cf. Danielzik (1986)

[4] carried out by the author in the year 2010

the business games in this context. The latter should consider the discussion of competency development in Europe initiated by the so called Bologna process.

Therefore, technical data of the business games is retrieved in this study and the evaluation of the applied business game comprises consideration of the intended competencies. The former considers the classification of business games introduced in table 8.8. The intended competencies are acquired using a catalog of competencies compiled specifically for this purpose. The competencies which are currently requested for engineers in the field of the construction industry are factored into this catalog. On the one hand it is based on an analysis of internationally active building contractors[5], on the other hand on detailed and thorough literature research[6].

The resulting catalog of competencies contains 35 competencies in five areas:[7] (1) methodological competencies, (2) expertise, (3) social and communicative competencies, (4) personal competencies, (5) activity-related and implementational-related competencies.

Within the scope of this research, 63 chairs of construction industry (universities and institutions of higher education) were invited to participate in an online survey. All in all, 47 subjects opened the questionnaire and 40 of them completed it in the end. 16 institutions used a business game, equivalent to a quarter of the German chairs of construction industry at universities and institutions of higher education. All subjects of this group reported particulars about their institutions. According to the accumulated answers, 4 universities and 12 universities of applied sciences use business games in the academic education of construction industry. Remarkably and against the historical development of business games in Germany, the use of business games with orientation towards the construction industry is more widespread in western Germany and especially in North Rhine-Westphalia (figure 2.1).

16 subjects contributed the following particulars about the basis for the employed business games:

- in-house development (8)
- business game models following Danielzik (1986) (4)
- TOPSIM series (3) (TOPSIM Project Management (2), Topsim Easy Start-Up (1))
- other basis (1)

Of the individually devised developments, 5 were created in cooperation with[8]:

- commercial enterprises (4)
- universities or institutions of higher education (2)
- government authorities (1)

Only one institution used pre-configured components (e.g. open source applications and others[9]

[5] cf. Karl (2010)

[6] A more detailed overview of the individual competencies can be found in table 8.5 starting p. 164

[7] The same catalog is used in later sections of the paper and also in the empirical study KompBauDE: Competencies for the construction industry - A survey to determine current competency requirements for civil engineers. The qualitative evaluation of competencies in this study is of significant importance for the competency-oriented reduction of the general model in chapter 5.2.3 starting p. 119

[8] multiple answers were permitted

[9] Available options were: content management systems, chat scripts, groupware tools, portal systems, social networking tools, user management tools, virtual communities, email systems and discussion boards.

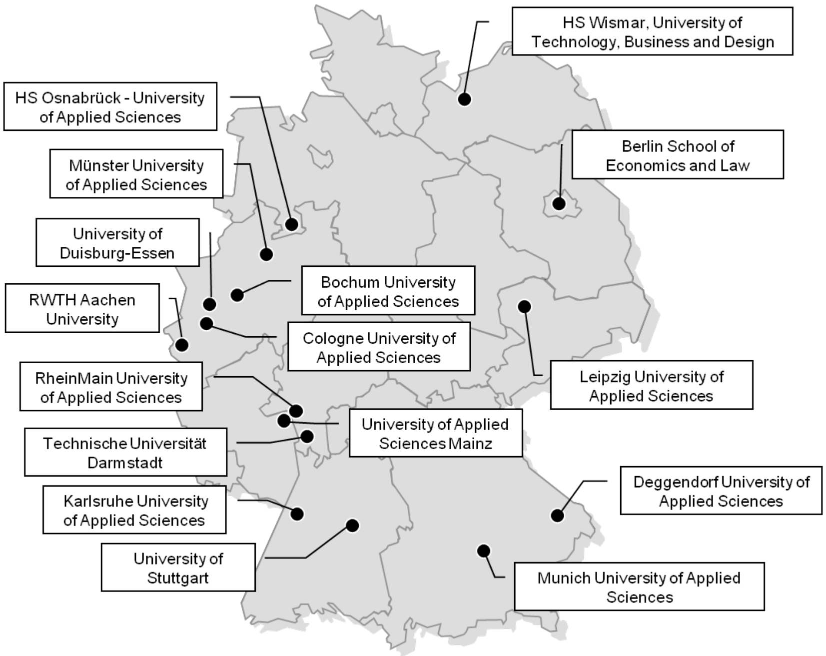


Figure 2.1: Distribution of business games with orientation to the construction industry in Germany

in form of a content management system (CMS) for the creation of their in-house developments, whereas 6 institutions explicitly claimed individually tailored developments.

This commitment seems to be reflected in the costs of development. Participants entered development costs of up to 100.000 Euro. Furthermore, the costs for the execution of one business game session were listed with up to 2.000 Euro. The business games of 6 subjects reproduced a national market of the construction industry only. In contrast, 7 business games did not include a dedicated market at all. The reproduction of an EU-wide or even international market of the construction industry was negated by nearly all participants. One exception was a business game based on a model which allowed to apply it in other market settings as well.

The following details were given in regard to the target group of the according business game[10]:

- students only (1,4)
- partly engineers (construction managers, project leaders and others) (3,47)
- partly or no management personnel (managing directors and others) (3,87)
- partly or no business start-ups (3,87)
- no pupils (3,93)
- no others (4,0)

The predominant application with the target group of students can be differentiated in more detail by examining the phase of the studies in which the business game was used for the first

[10]mean value in brackets; multiple answers were permitted; scaling: exclusively (1), predominantly (2), partly (3), none (4)

time[11]:

- bachelor program (advanced studies) (9)
- master program (5)
- bachelor program (fundamentals) (2)
- further training on university-level (1)
- complementary or post-graduate studies (0)
- other: diploma (1), in-house training (1)

Apparently, business games are mostly used for students in advanced phases of bachelor programs or master programs. It should be possible to derive the content-related quality of business games with the help of their competency-orientation. To achieve a largely independent and unrestricted feedback, the competencies to be addressed in the business games were categorized in the three groups of utmost importance, high importance and regular importance. These groups were determined with the help of three open questions (table 2.1) before the evaluation of the competency catalog (table 2.2).

Table 2.1: Intended competencies (open questions)

Intended competencies[12]		
utmost importance	high importance	regular importance
methodological competency (2x)	social competency (2x)	social competency (team work) (2x)
calculation (2x)	awareness of interrelations	personal competency (2x)
competency in field of construction industry	methodological competency (presentation)	corporate competency
construction management competencies	professional competence	learning by doing
awareness of interdependencies between constructional operations	independence	selection and evaluation of relevant information
understanding of economic relationships	vocational qualification	division of labor
management of a corporation	organisation	
expertise in the field and subject-specific practice	creation of a management information system	
decision-making	contractual experience and understanding	
orientation in the professional field		

It appears that the acquisition of methodological competency, the awareness of relationships and the transfer of subject-specific competency are the main intentions of employed business games. Similar interpretations can be derived from the catalog of competencies, which was evaluated by

[11] multiple answers were permitted
[12] n = 13; there is no horizontal relation or ranking in this overview

12 subjects in regard to the most promoted competencies in the equivalent business game. All in all, the following prioritization of the queried areas of competency can be established[13]:

- predominantly methodological competencies (2,3),
- predominantly to partly activity- and implementation-based competencies (2,8),
- partly social and communicative competencies (3,0),
- partly personal competencies (3,2),
- partly expertise resp. professional competencies (3,4).

Compared to the open questions, a general prioritization of the methodological competencies can be found again. The professional competencies, however, display a very different picture compared to the free text answers. Although, according to the free text answers, it is skills and qualifications in the area of calculation, construction industry and business management which should be developed in the employed business games, a detailed query shows that the professional competencies are seen as lower-ranking than the other types of competencies. A detailed juxtaposition of the individual competencies is shown in table 2.2.

On closer inspection it appears that at least the construction-oriented competencies can still be listed among the most prioritized aims. All further subject-specific competencies are rather found in the medium range of the prioritization. Furthermore, 8 of the identified 35 competencies are not supposed to be addressed by the business game. On the contrary, according to statements of the test subjects a major proportion (77%) of the demanded competencies should be promoted by the business game method. If the general advantages of business games (table 8.6 on p. 160) are included, it appears that at least 80% of the predominantly intended competencies can be achieved with the use of the business game method. This result demonstrates which expectations the users have of the business game method and which significant contribution business games can offer in the training and teaching of construction industry. All in all the business game method seems to have a high significance in the academic training, at least for those who know and use it. This conclusion can also be drawn from further free text answers:

- The business game is a very important didactic tool for us. (P8)
- The business games are very well accepted by the students. (P47)
- In the meantime, it [the business game, note from the author] belongs to the standard training in the according degree programs. (P5)

Even though this positive opinion prevails among the users of business games, the business games do not seem to have established themselves on a larger scale in the training of construction industry. Reasons for this may be the high development costs. Development costs of up to 100.000 Euro have been determined within the scope of this study, figures which appear rather realistic when juxtaposed to the calculations of Rohn (1995), who listed costs between 80.000 and 300.000 Deutschmarks for the development of one business game, depending on its complexity. To finalize this investigation, the individual business games used in the training of construction

[13] n = 12; mean value in brackets; scaling: exclusively (1), predominantly (2), partly (3) , none (4)

industry are briefly introduced in the following and discussed thereafter.

Table 2.2: Intended competencies (catalog)

Intended competencies[14]		
predominantly	partly	none
recognition of relations and interdependencies* (1,83)	flexibility* (2,50)	emotionality* (3,50)
decision-making ability* (1,92)	initiative* (2,50)	awareness of sustainability (3,67)
capacity for teamwork* (2,00)	creativity and innovative ability* (2,75)	awareness of global economic relations (3,67)
interdisciplinary thinking* (2,08)	economic competencies (2,75)	ethics awareness (3,75)
communication skills* (2,08)	skills of risk avoidance (2,83)	abilities of project development (3,83)
operational competencies (2,24)	representative and presentational abilities (3,00)	public relation skills (3,92)
motivation* (2,29)	conflict-solving readiness* (3,08)	awareness of the life cycle of estate and buildings (4,00)
analytic thinking* (2,33)	capacity to work under pressure* (3,08)	professional and discipline-specific English (4,00)
structured thinking* (2,33)	optimism* (3,08)	
anticipation of future developments* (2,42)	openness* (3,17)	
project communication management (2,42)	problem-solving skill in construction site management (3,25)	
	negotiating skills* (3,25)	
	risk awareness (3,25)	
	mobility (3,27)	
	personnel management (3,33)	
	contractual competencies (3,42)	

[14] n = 12; mean value in brackets; scaling: exclusively (1), predominantly (2), partly (3) , none (4); competencies marked with * can generally be covered by business games

2.1.1 Showcase introduction of currently employed business games[15]

2.1.1.1 Bauwirtschaft

Table 2.3: Properties Bauwirtschaft

Name	Bauwirtschaft **since** 1985
Institution(s)	Cologne University of Applied Sciences, University of Duisburg-Essen, Deggendorf University of Applied Sciences
Model	general, universal, complex, stochastic, interactive, dynamic, EDP-supported, closed
Short description	
The business game Bauwirtschaft was developed by Danielzik (1986) and is a computer-supported team business game devised specifically for the construction industry. Several teams of players take over the management of medium-size construction businesses and compete for projects within a virtual market. Apart from construction-specific aspects like the calculation of offers, participants need to consider economic factors like uninterrupted availability of sufficient liquidity.	
Primary competency objectives	
Awareness of interrelations, competency in field of construction industry, social competency, creation of a management information system (MIS), selection and evaluation of relevant information	
Primary target group(s)	
only/ mostly students	

2.1.1.2 Unternehmensplanspiel Bau

Table 2.4: Properties Unternehmensplanspiel Bau

Name	Unternehmensplanspiel Bau **since** 2001
Institution(s)	Münster University of Applied Sciences
Modell	specific, complex, stochastic, interactive, dynamic, EDP-supported, open
Short description	
Inspired by the concept of Danielzik (1986), the Münster University of Applied Sciences developed a database-supported business game for their training of construction industry. In this business game, groups of students are responsible for the leadership of construction businesses. Tasks like preparatory work, audit and assurance (cost accounting and results accounts) as well as observation and analysis of the market need to be carried out to compete against other competitors in the virtual market.	
Primary competency objectives	
awareness of interdependencies between constructional operations, social competency	
Primary target group(s)	
mostly students and engineers	

[15] The listed information is mostly taken from answers to the survey. Only those business games are listed for which sufficient information could be gained from the questionnaire. They are ordered chronologically according to their first year of application.

2.1.1.3 BawiPLAN

Table 2.5: Properties BawiPLAN

Name	BawiPLAN **since** 2006
Institution(s)	Leipzig University of Applied Sciences
Model	functional, interactive, free, static, EDP-supported, open
Short description	
BawiPLAN is based on PHP and MySQL. The business game is complemented by an internet platform based on Microsoft Sharepoint. This is supposed to accommodate the trend to online business games. The basis for BawiPLAN is provided by the business game "Baumarkt" (for details see von Lentzke et al. (2006)) which itself appears to be significantly inspired by Danielzik's business game Bauwirtschaft published twenty years ago. The business game BawiPLAN is offered in every semester in the elective module for construction engineers but also for industrial engineers with construction as chosen area of concentration.	
Primary competency objectives	
competency in field of construction industry, social competency, corporate competency	
Primary target group(s)	
mostly students, partly engineers	

2.1.1.4 Unternehmensplanspiel

Table 2.6: Properties Unternehmensplanspiel

Name	Unternehmensplanspiel **since** 2006
Institution	Bochum University of Applied Sciences
Model	basic, deterministic, interactive, rigid, static, EDP-supported, closed
Short description	
This business game was developed at the Bochum University of Applied Sciences as a cooperation between the department of construction industry and management and the faculty of economics. Here, participants again need to run a construction business and compete against other students in a virtual market. Students cooperate in small teams to learn entrepreneurial activities in the areas of order acquisition (invitation and acceptance of tenders), tender preparation as well as order processing. One declared aim is to convey knowledge of the procedures and mechanisms in the construction industry to the participants.	
Primary competency objectives	
calculation, organisation, division of labor	
Primary target group(s)	
students only	

2.1.1.5 Virtual Construction Company Competition

Table 2.7: Properties Virtual Construction Company Competition

Name	Virtual Construction Company Competition (vc^3) **since** 2008
Institution	University of Stuttgart
Model	interactive, free, dynamic, EDP-supported, open
Short description	
This business game is based on a research project devised in 2007 and emulates the management of a construction company. Similarly to other concepts, participants lead construction companies in time-lapse for several years. A virtual market offers the platform for the competition with other students. Primary aim of this business game is the awareness of interrelations between relevant individual aspects and learn to take decision of a construction company oneself. This business game was originally developed for the consolidation of the subject construction industry at the University of Stuttgart. Currently it is available to all learners and lecturers in the field of construction industry at that institution.	
Primary competency objectives	
management of a corporation, independence	
Primary target group(s)	
students only, partly pupils, engineers, management personnel, founders of new businesses	

2.1.1.6 TOPSIM Project Management

Table 2.8: Properties TOPSIM – Project Management

Name	TOPSIM Project Management **since** 2008 resp. 2010
Institution(s)	RWTH Aachen University respectively Karlsruhe University of Applied Sciences
Model	general, specific, basic, stochastic, isolated, rigid, dynamic, EDP-supported, closed
Short description	
This business game transfers fundamental methods of project management. The project itself is the construction of a rollercoaster. For this, time factors and resources need to be considered accordingly, just as project structure, costs and finances, network techniques etc. The participants are given the task to plan the construction of the rollercoaster for a theme park and accompany this project until the final handing over. Here the participants learn the main tasks of a project manager, get insights into established and proven methods of project planning and implementation and experience the limits and possibilities of project management.	
Primary competency objectives	
Training of methodological, subject-specific and personal competency	
Primary target group(s)	
students only, partly engineers (RWTH Aachen University)	

2.1.1.7 TOPSIM Easy Start-Up

Table 2.9: Properties Topsim Easy Start-Up

Name	Topsim Easy Start-Up **since** k.A.
Institution(s)	Berlin School of Economics and Law
Model	general, universal, basic, deterministic, EDP-supported
Short description	
Central aspect of this relatively easy business game is the founding of a new company which manufactures and markets products for leisure activities. The typical phases of a start-up are emulated. Each of these phases contains specific economic, technical and social challenges. Special focus is on the coping of information complexity and the training of entrepreneurial thinking and acting. The participants are supposed to learn the use of established management methods and instruments for the decision-making processes.	
Primary competency objectives	
understanding of economic relationships, methodological competency, social competency	
Primary target group(s)	
students only	

2.2 Discussion

In general and first of all it has to be considered that the previously introduced business games were selected and developed to include especially the competency aims defined by the users of the business game (please refer to table 2.1, p. 33). For this reason, the introduced business games can be regarded as mostly viable for the training in the field of construction industry.

On closer inspection, and particularly in regard to the intended competencies on the basis of the competency catalog evaluated by the test subjects (please refer to table 2.2, p. 35), the dominantly targeted construction-oriented as well as economic competencies are implemented in the business games developed specifically for the construction industry. The latter is true for business games of the TOPSIM series as well, but of course here the construction-specific aspects are not in the main focus of interest.

All assessed business games contribute to the demanded competency in the management of project communication, be it in form of face-to-face interaction or with the support of new media.

It appears more difficult, however, to further the partly intended competencies like risk avoidance, problem-solving skills in the construction management or the contractual competencies with the hitherto existing business games in a comprehensive manner. The integration and consideration of statistically-established factors which influence the results of many business games can aid in the emulation of risks, but the participants are not necessarily forced to discuss these issues thoroughly. Therefore, tangible risks, their effects and potential countermeasures needed to be considered in the business game models in detail. This offers participants the chance to react to the externally changed reality within the time frame of the proceeding game.This is similarly true for the problem-solving skills in the area of construction management.

Due to their general orientation, the business games of the TOPSIM series cannot be expected to fulfill the demand for contractual competencies specifically relevant in the field of the construction industry. On the other hand, aspects of building contract law are - in general - incorporated in the five construction-oriented business games. However, a more comprehensive dealing with contract law would require the different types of contracts and their relevant content to be explicitly considered and integrated into the business game model to emulate their according effects and allow the intended learning success.

Beyond that, the explicit inclusion of risks, problems in the operative construction business and aspects of construction law assisted the training of risk propensity (respectively the skill of risk avoidance) more than in previous business games.

The promotion of mobility, listed by the test subjects as partly intended and being a central aspect in the implementation of the Bologna process[16], can only be achieved to a lesser extent by the established business games, as their scope does not include a geographically extensive orientation of the construction industry. Consequently the participants do not have the opportunity to act in an unknown or foreign market (or multiple markets) in order to explore specific characteristics of, e.g., neighboring countries. Depending on the design of the business game, this also affected the abovementioned explicit inclusion of local risks, problem settings in the local operative construction business as well as the building contracts of the corresponding projects.

Another partly intended aim was the training of representative or presentational skills. This aim was dominantly addressed with the participants' presentation at the end of a business game session. To allow more extensive improvement of these skills, participants should be encouraged and allowed to present and introduce specific sections of their plans and progress at different points of time during the session. This could include the entrepreneurial targets at the beginning of the session, further on a marketing concept of the corporation or the presentation of a project for the principal etc. This is, necessarily, dependent on the availability of time resources in the devised time frame of the business game.

To sum up, it appears to be a valid claim that at least the five business games with orientation towards the construction industry cover the fundamental and most important areas and needs and therefore - in contrast to the business games with purely economic orientation - represent progress in this domain. Nevertheless, a full achievement of the intended competencies which have been elucidated and listed in the catalog of competencies cannot be detected yet.

The test subjects seem to expect more from the business game method or the business game itself than it can potentially achieve. The use of business games is not per se the one and only solution for action- and competency-oriented teaching and learning. A thorough reflection of the intended teaching and learning aims is always required in this context. It has to be carried out on the basis of a detailed definition of the problem setting which will define the required type of action. This, in turn, has direct influence on design and configuration of the business game. This study has identified several demands which users make on business games in this domain.

[16] cf. HRK-Service-Stelle-Bologna (2007)

To satisfy these demands alone, business game models for the construction industry need to feature the following properties:

- illustration of relevant factors and their relations in the context of the construction industry,
- integration of economic aspects,
- modeling of risks, their effects and potential countermeasures,
- involvement of different construction contracts including their relevant content,
- consideration of problem settings and their solutions in construction business operations,
- inclusion of construction markets not limited to national limits only,
- integration of additional competency-oriented teaching and learning methods for the support of further skills and qualifications

Finally, the study illustrated that domain-specific business games basically always follow the same aims, independent of the institution for which they are developed. Therefore, cooperations between different institutions can be regarded as very reasonable. The shared and collaborative development of business games which are used at the different institutions either independently or in parallel (shared business game sessions, e.g. using online-based business games) can be an approach to reduce at least the substantial development costs of the individual involved parties.

3 Design of a module-oriented modeling approach based on system dynamics

The main aim of this chapter is to develop an approach for modular simulation models which can be applied both in research and in teaching. In doing so, the models should be designed in a modular way, to flexibly allow for further developments. Building on separate components, a library will be set up, allowing for new elements to be embedded in it or for the existing ones to be adjusted or extended respectively.

For the simulation this is meaningful in two ways: insights can be gained both from using a single element and from the sensible combination of several interacting elements. This fact should also support the design of business games, in which distinct components can be sensibly combined in modules, following the logic of intended teaching and learning objectives. The module-oriented approach developed here is based on the System Dynamics method which is introduced in the following chapter.

3.1 System Dynamics

System Dynamics (SD) is a system oriented and computer-based problem-solving approach for explicit mathematical models[1], addressing the analysis and design of decision-making rules (policies). Jay W. Forrester is considered to be the founder of the System Dynamics approach. Working at the Massachusetts Institute of Technology (MIT) at the end of 1950s, he linked the Feedback Control Theory[2] with the Computer Science and Business Management[3]. Forrester's research findings in the field of theoretical dynamics and in the systemic behavior of industrial companies[4] were also applied in other scientific fields and thus the generic term System Dynamics was coined. This approach applies to dynamic problems characterized by change over time, interdependence of system components, information feedback and cyclical causality. As these occur in every complex system, be it social, industrial, economic or ecological[5], they also apply to teaching, research and decision-making theory. The next sub-chapter offers a short overview

[1] cf. Milling (1996)
[2] for details see Doyle et al. (1992)
[3] cf. Hafeez et al. (2004)
[4] this is the reason why it was published for the first time with the term "industial dynamics" (cf. Forrester (1961))
[5] cf. Richardson (1991)

of the background and the basics of this approach[6].

3.1.1 Background

SD is an approach that attempts to comprehend the behavior of complex systems over time. It addresses feedback loops and time lags affecting the whole system. For this purpose, quantitative and qualitative models are developed, which can, due to their inner structural properties and data, reproduce the real system under examination as accurately as possible.

As opposed to considering separate isolated variables and their development, the SD approach is focusing on the interdependency of various factors and variables over a time sequence. Compared to other methods, e.g. the econometric approach[7] in which variables are given over the whole of a prediction period, an initial state is defined in SD by determining the starting points for all variables[8], which will dynamically change across time through manipulation of main parameters in form of endogenous pulses.

This is therefore a cyclical self-updating model throughout the simulation process[9]. Due to the causal links between the several variables, both dynamic as well as time-lagged interdependencies can be observed, thus allowing a deeper understanding of the system. In this respect, SD is a suitable method for the detailed analysis of complex dynamic problems. The analysis of the problem structure and of the reactions it causes provides for insights on long-term effective decision-making rules.

Because of its universal formalism, SD offers a wide range of applications in various fields. Especially the complex economic field requires such a systemic approach for an adequate modeling.[10] The SD method is therefore highly suitable for the modeling and simulation of markets, productions and companies.

The SD models clearly distinguish between stock- and flow-variables. Stock variables represent the current state of the system, for example the amount of produced goods.

In contrast, flow variables have a changing effect, for example the amount of produced goods per hour. All SD models consist mainly of these two sorts of variables, whereby all elements are inserted in the model with given values (initial values), so that the future system states can be processed.

Such a model is subsequently further refined, until the real system is captured as accurately as possible respectively needed. The computer-simulation of the system addresses the inner structure with regard to nonlinearities, feedback structures and complexity. The simulation of various interventions should deepen the understanding of the system under examination

[6] Detailed descriptions and discussions of System Dynamics can be found in Forrester (1961), Forrester (1968), Forrester (1969), Forrester (1971b), Forrester (1972a), Forrester (1972b), Sterman (2000) and Sterman (2004)

[7] econometric models are part of empirical economic research and attempt to elucidate economic and structural relationships as well as test economic hypotheses. For details refer to Eckey et al. (2011).

[8] cf. Schwarz & Ewaldt (2002)

[9] cf. Weber & Schwarz (2007)

[10] cf. Gold (2005)

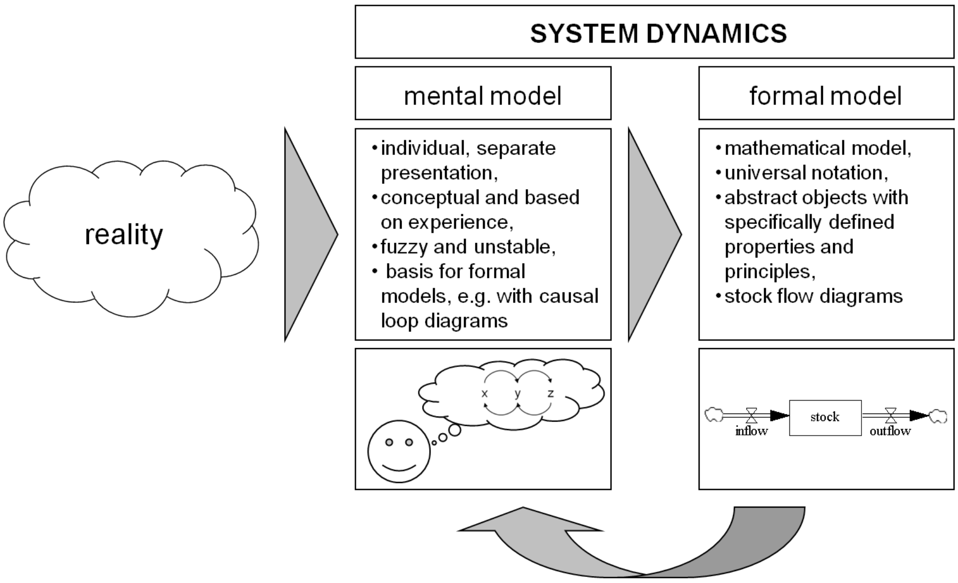


Figure 3.1: Relationship between mental and formal models

and conclusively explain decision-making rules for the system governance or for interventions. Nevertheless, this is legitimately only a model, meaning an abstraction of the reality. That is why, depending on the purpose of the simulation, the model should be designed so as to explicitly incorporate relevant aspects, whereas less relevant ones are to be simplified if not even disregarded. The expert knowledge of the modeler is therefore paramount for the design of such models.[11] Despite the necessary abstraction, the model should remain realistic and depending on its aim, should provide insights about the system structure even to SD-laymen. Consequently, the representations of the model should be formally clearly outlined, to facilitate the design, analysis and presentation of the real system part.

3.1.2 Excursus: mental and formal models

In the process of modeling, a basic distinction between mental and formal models must be made (figure 3.1).

The term mental models is often used to describe the cognitive structures of individuals and was coined in the early 70s by Johnson-Laird (1983). They are defining structures as inner, differentiated representations complementing the logic application and consequently the ability to draw conclusions.[12] Mental models are therefore to be considered as more or less exact thought patterns about the connection between specific situations.[13] Senge (2003) understands mental models as inner representations of the nature of things, e.g. pictures, assumptions and stories that trigger one's own interpretation of the world and determine one's behavior. This is one of

[11]for further details regarding the simulation of systems, refer to Sterman (2004)
[12]cf. Johnson-Laird (1983), Baron (2000)
[13]cf. Johnson-Laird (1983)

the reasons why Forrester criticized mental models as fuzzy, incomplete and imprecise.[14] Even more so, mental models change over time within an individual[15], thus leaving out feedback, time lags and accumulations[16].

Doyle & Ford (1999) also have a similar perspective. According to them, the mental model of a dynamic system is a relatively durable and accessible but limited inner conceptual representation of an outer past, present or future system, the structure of which parallels the perceived system structure.

Even though, according to Strohhecker (2008), mental models are constantly under plausibility controls by the learning processes, the latter render them rather unstable and are therefore to be seen as inaccurate and not (without information loss) interchangeable. Only to a limited extent can they be subject to examination and evaluation, as they offer only a rough estimate of the relationship between the influencing variables.[17]

To sum up, mental models appear to be better suited for the representation of smaller systems. As they are largely based on an inner, individual and consequently mainly subjective perspective, an unbiased transfer and communication is to be regarded as problematic. This is not least because of the fact that mental models exclusively emerge and exist in the mind and therefore are frequently not formally documented. Consequently, the mental models themselves as well as the gained insights are difficult to reproduce. Especially when taking into consideration the state of the art quality requirements for scientific knowledge gain[18], the exclusive use of mental models is ill-suited for complex dynamic systems.

On the other hand, mental models are quite suitable to serve as a basis for the design of formal models (see chapter 3.1.4.1). Formal models are primarily based on the mental representation of at least one individual, but are designed and documented following a formal approach and universal notations. Such a model consists of abstract objects with pre-defined properties, for which certain rules (axioms) apply.[19]

The basic structure of a formal model can, for example, emerge from the predicate logic. Such a formally designed model results from reality either by abstraction or by detail accumulation and eventually becomes accessible for mathematical processing. Therefore, these models are more than an individual conceptual representation of reality.

Through the use of formalism, everyone can reach an understanding of the system structure, predict possible development trends, identify potential interferences and thus perform effective interventions in the system. Following this line of argument, formal models are to be preferred when examining complex systems, as they can assist the optimization of mental models and consequently the assessment and decision-making capabilities.

[14] cf. Forrester (1971a)
[15] cf. ibid
[16] cf. Sterman (1994)
[17] cf. Strohhecker (2008)
[18] among others objectivity, comprehensibility, verifiability, reliability and validity
[19] this aspect was already discussed in general according to Stachowiak (1973) on pp. 13

When modeling, one should follow Valéry (1937), to whom simplicity deemed wrong and complexity unsuitable, meaning that mental models are not to be too simplistic, whereas formal models must not be too complex. The Bonini-paradox[20], which describes the difficulties of designing complex system models and simulations, expresses a similar idea[21]. Starbuck (1976) explained this paradox in the 70s by stating that the more exhaustive the complex system models are, the less comprehensible they become. This means that the more realistic the models, the more difficult the task of understanding them. As a consequence, the real processes on which the models are based cannot be entirely understood. This fact makes it even more difficult to locate the decision-making dispositions. Summing up, the system dynamics formal modeling approach offers numerous advantages but bears some limitations nonetheless.

3.1.3 Advantages and limitations

As is common for all other models, the system dynamics model is also subject to simplifications.[22] Therefore it is necessary to determine from the very beginning, which excerpt of reality will be examined for which purpose, so as to be able to identify the relevant and indispensible aspects, elements, interdependencies and forms of actions later on in the process of modeling. A subsequent model validation should be able to remove any uncertainty whether the model does not adequately reproduce the real system behavior in all its aspects[23].

As stated earlier in this work, the system dynamics approach can be applied in the fields of research, teaching and decision-making. These three fields are not entirely separate, but the boundaries between them can be blurred.

In the field of **research**, system dynamics models are based on physical laws or on problem-solving theories amended by empirical findings respectively.[24] Such models are precise, objective and verifiable[25], especially because of their symbolic and formal language, thus meeting the stringent quality requirements of science and research. Irrespective of this aspect, the quality of the prediction of the future is a major challenge for system dynamics as for any other simulation technique used as a scientific prediction method. Even the most elaborate models cannot guarantee entirely precise predictions.[26] The theories and the assumed interdependencies on which the system dynamics model is based are valid until the derived hypotheses and findings are empirically disproved.[27]

The system dynamics models can prove valuable in the field of **teaching** by elucidating causalities and interdependencies and making them comprehensible. Thus, such models are both operators and accelerators of teaching and learning processes (function of a catalyst), both concerning

[20] named after Professor Charles P. Bonini (Stanford Graduate School of Business)
[21] for details refer to Bonini (1963)
[22] cf. Senge (2003)
[23] cf. Bossel (2004)
[24] cf. Nienhüser (1996), Sterman (2004), Ogata (2004), Weller (2007)
[25] cf. Strohhecker (2008)
[26] cf. Eggers (1991)
[27] cf. Picot et al. (2008)

changes of behavior (single-loop learning[28]) and the adjustment of mental models (double-loop learning[29]).

In this context, it is especially the graphical representation of the interdependencies that facilitates the understanding of the system.[30] Despite these advantages, it must be stated that system dynamics models are useful but not sufficient for better learning in themselves.[31] During teaching and learning processes, these models and their simulations should be regarded as complementary to the teaching and learning methods already in use and not as their substitutes.

As experiments based on system dynamics models are supposed to lead to informed decisions and decision-making rules[32], they are often used in the field of **decision-making**. They can contribute to solving several problems[33] by summarizing fractions of the model to a holistic overall pattern, thus offering a more comprehensive representation of the decision-making problem.[34] A wide range of possible action dispositions can be tested with a system dynamics model in order to find the best possible solution within the given interdependencies. This happens without performing trials on the original material[35], which would be partly impossible anyway. These decision-making experiments are consequently relatively cost[36] and time efficient, bearing neither risks nor real consequences.[37] At the same time, a system dynamics model can restore the initial system state, similar to a flight simulator for pilots.[38]

In order to be reliable enough as an application for decision-making, the model should not contain any mathematical inaccuracies.[39] For the performance of a decision-making experiment with a system dynamics model, sufficiently precise quantitative data is required. Reference should be made to the fact that the data can often only be estimated or defined within ranges of values, which in turn causes[40] and increases[41] the transfer of inaccuracies into the system.

[28]This expression was coined by Argyris (1985) and describes a learning process to reach current aims within the framework of existing mental models, i.e. interpret the information feedback with the help of the existing mental models (cf. Sterman (2004)).

[29]This term was also coined by Argyris (1985). Here, the information feedback of the real world does not only change decisions within existing decision-making rules, but also displays reciprocal effects and changes the underlying mental models. (cf. Sterman (1994), Moxnes (2000), Moxnes (2004), Sterman (2004), Sterman & Sweeney (2007), Wheat (2007), Strohhecker (2008))

[30]cf. Hafeez et al. (2004)

[31]cf. Strohhecker (2008)

[32]cf. Forrester (1961)

[33]cf. Strohhecker (2008)

[34]cf. Hafeez et al. (2004), Strohhecker (2008)

[35]cf. Bossel (2004)

[36]Even though the identification and representation of real and relevant interdependencies as well as the following creation of a model are time-consuming and can take, depending on the problem setting, a few weeks up to two years (cf. Strohhecker (2008)), it is assumed that experiments are more cost-intensive in the reality.

[37]cf. Kramer & Neculau (1998),

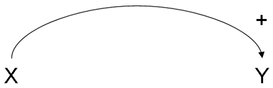
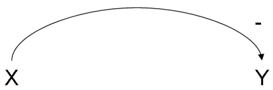
[38]cf. Strohhecker (2008)

[39]cf. Milling (1981)

[40]cf. Coyle (2000)

[41]see Hamilton (1980) for the quantification of qualitative variables

Table 3.1: Definitions and examples for relationships in CLD

symbol	denomination	meaning	equation
	positive causal relationship	X increases, Y increases as well or X decreases and Y decreases as well	$Y = \int_{t_0}^{t}(X + ...)ds + Y_{t_0} \frac{t}{dt}$
	negative causal relationship	X increases, Y decreases or X decreases and Y increases	$Y = \int_{t_0}^{t}(-X + ...)ds + Y_{t_0} \frac{t}{dt}$

3.1.4 Graphic representations and constitutive elements

As briefly mentioned in chapter 3.1.1 on page 43, different representations can generally be distinguished in general: on the one hand, the Causal-Loop-Diagrams (CLD), which enable a qualitative study of dynamic systems and on the other hand the Stock-Flow-Diagrams (SFD), which are used in quantitative studies.

The specific advantage of CLD is the relatively straightforward way of visualizing system structures and causalities as well as the prediction representation of expected qualitative system behavior. For a detailed quantitative study of dynamic systems, SFD will be used.

3.1.4.1 Causal-Loop-Diagrams (CLD)

CLD have long been a standard practice within the SD-approach. Today they are mostly used before the simulation analysis to aid in the representation of the basic causal mechanisms at work.[42] CLD is therefore to be defined as a qualitative visualization of the interdependencies between different elements. Such a diagram consists of a set of nods which link the various elements or variables to each other. The relationships between the variables, visualized by means of arrows, can be labeled as positive or negative (table 3.1).

CLDs help to identify whether the initial pulse[43] within a system will be reinforced or dampened. To determine which of the two will occur, the value of one variable X will, for example, be increased at one of the nods. At the other remaining nods, the variables which are influenced by the initial pulse are examined in regard to increases or decreases. A CLD is considered reinforcing or escalating when it retains its sign after the initial pulse and at the end of the

[42] cf. Binder et al. (2004)

[43] Here a pulse is not seen as a physical parameter, but more like in electrical engineering – a single, temporally limited and transient effect or a periodically repeated series of effects (refer to Rint (1953) and Schröder et al. (1972) for details).

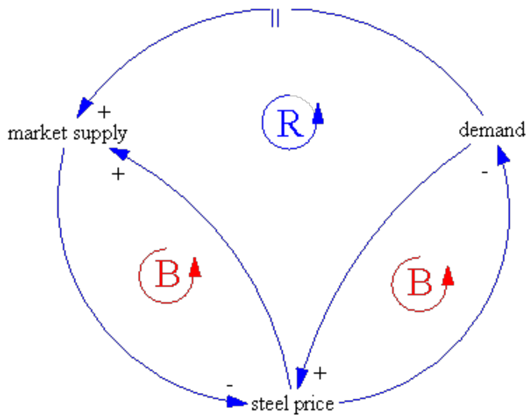


Figure 3.2: Example of a causal loop diagram

simulation. If the final pulse is contrary to the initial one, this is an indicator that the system has a stabilizing effect. Thus, reinforcing or escalating systems can either be identified by their exclusively positive links or by an even number of negative links. Stabilizing systems, however, display an uneven number of negative links. It is expected that reinforcing systems result in an exponential increase or decrease, while stabilizing systems converge rather to a certain value. Consequently, determining whether a system is reinforcing or stabilizing is an important step for the prediction of dynamic system behavior at an early stage.

A simple example will demonstrate that a positive causal link is identified by two variables changing in the same direction. This means that an increase of the variable X at the initial nod directly causes an increase of the value of the dependent variable Y as well. On the other hand, a negative causal link means that both variables X and Y will change in opposite directions: if the X value increases at the initial nod, the dependent Y value will decrease and vice versa.

With regard to the causal relation between steel price, market supply and demand (figure 3.2), it can be observed that a rising demand causes higher prices, while a lower demand has a dampening effect. This is an example of a positive causal link, also named stabilizing loop system (balancing). A rising demand also increases the supply. The effect is time-lagged, represented in the figure by two parallel lines across the linking arrow. An increased supply, on the other hand, has a dampening effect on the steel price, representing a negative causal link or escalating loop system (reinforcing). Taken as a whole, the cycle demand-supply-steel-price is thus an escalating causal loop system.

This example serves the illustration of the difference between linear cause-and-effect chains and CLDs. In CLDs, the effects are also influencing their cause. Nevertheless, CLDs are neither comprehensive[44] nor definitive, but should rather be considered tentative.[45]

Using different scenarios, CLDs can depict causal links to elucidate the influence of specific factors on long-term trends, but these do not distinguish between stock variables and flow

[44] cf. Sterman (2004)
[45] cf. ibid.

Table 3.2: Example of a stock-flow-diagram

<table>
<tr><td>Diagram</td><td>
</td></tr>
<tr><td>Equation</td><td>$stock(t) = \int_{t_0}^{t} inflow(s) - outflow(s) + stock\frac{t}{dt}$</td></tr>
</table>

variables[46] and therefore are generally ill-suited for valid quantitative analyses. For the latter, stock-flow-diagrams are applied.

3.1.4.2 Stock-Flow-Diagrams (SFD)

As opposed to CLD, SFD distinguishes between stock variables (levels, stocks) and flow variables (flows, rates). Stocks are state variables, building the resource base like goods, machines or personnel, usually displayed in the SD-notation as rectangles. Stock variables change their values through flow variables (in- and outflow). The values of the stock variables are continuously changing over time, even when the share of flow variables, displayed in the SD notation as double line arrows, change discontinuously. The change intensity of such an in- or outflow is displayed as a valve (table 3.2).

Hence, flow variables influence the values of stock variables. Contrary to stock variables, the value of a flow variable does not depend on prior values, but on its related stock variable in the system, where applicable together with exogenous factors like auxiliary or constant variables.[47] The set of all dynamic equations creates a system of non-linear differential equations simultaneously computing the change for each variable through integration across time in the relevant period.[48]

An example from masonry will be used to illustrate the design of an SFD and the contained SD-elements on the one hand and to allow a short qualitative analysis on the other hand. A conscious decision has been made to omit an explicit description of the differential equations in this context. In the first example (Figure 3.3), the stock variable is the *work to do*.

The stock variable *work to do* means here that a specific number of square meters of brickwork should be performed. This stock variable is defined by the *production* taking place, represented as flow variable, meaning that over time, the required amount decreases. In this example the stock variable should be regarded as a source out of which flows the “amount of brickwork“. In this case it is irrelevant what happens with the produced good, displayed in the SD-notation as a cloud at the end of the production process. This symbol is therefore marking the system boundaries of the model. Here the production is being exogenously influenced by a number of *workers* with a specific productivity, displayed by the *working time value*. Both *workers* and the *working time value* are constant variables.

[46] cf. ibid.
[47] It is especially important for the construction of SFDs to distinguish the stock and flow variables. A helpful tool is the virtual halt or freeze of a system. Here, stock variables still display values whereas flow variables are devoid of values. For further details refer to Sterman (2004).
[48] cf. Niemeyer (1977)

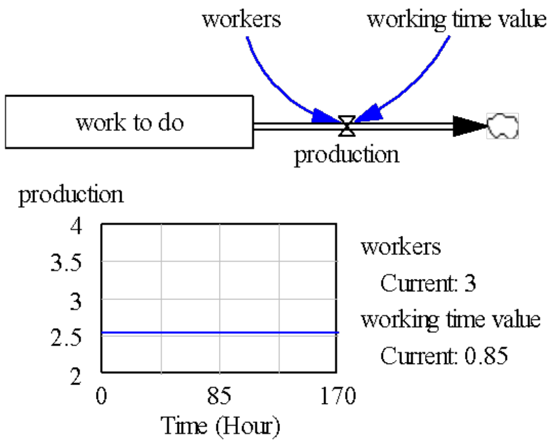


Figure 3.3: Example 1 – Wall construction work

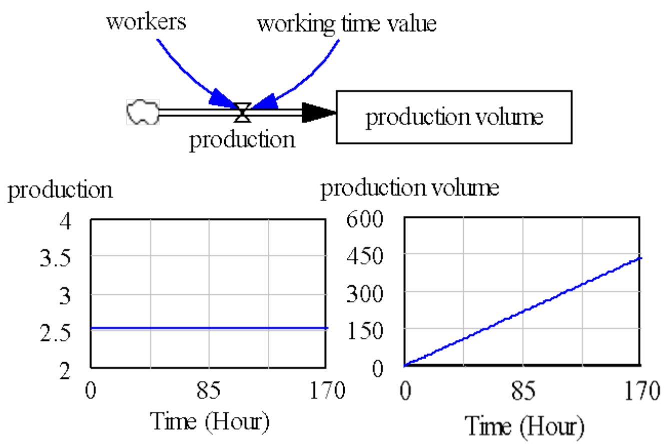


Figure 3.4: Example 2 – Production output wall construction

For the sake of the qualitative analysis, the *work to do* is set to the value of 450 m^2. The simulation time runs for 170 h. The number of *workers* is set to three and the *working time value* amounts to 0,85 m^2/h. The expected result of production is 2,55 m^2/h. But how much brickwork will have been completed at the end of the simulation? To answer this query, the stock variable *production* is to be examined. In general, the system boundaries at the end of *production* can also be set at the beginning and the stock variable at the end. In this case the stock variable is the *production volume* (figure 3.4).

The simulation demonstrates that with identical initial values 433,5 m^2 of brickwork will have been completed after 170 h. With regularly recurring tasks, an effect of adjustment to the job or *work experience effects* can reasonably be assumed. The extent to which the *production* is influenced by such effects should also be examined.

To this mean, the initially constant variable *working time value* will be upgraded and extended (figure 3.5). It is assumed for the given example, that after 40 h the productivity increases by 30% and persists at this level for the rest of the simulation period.

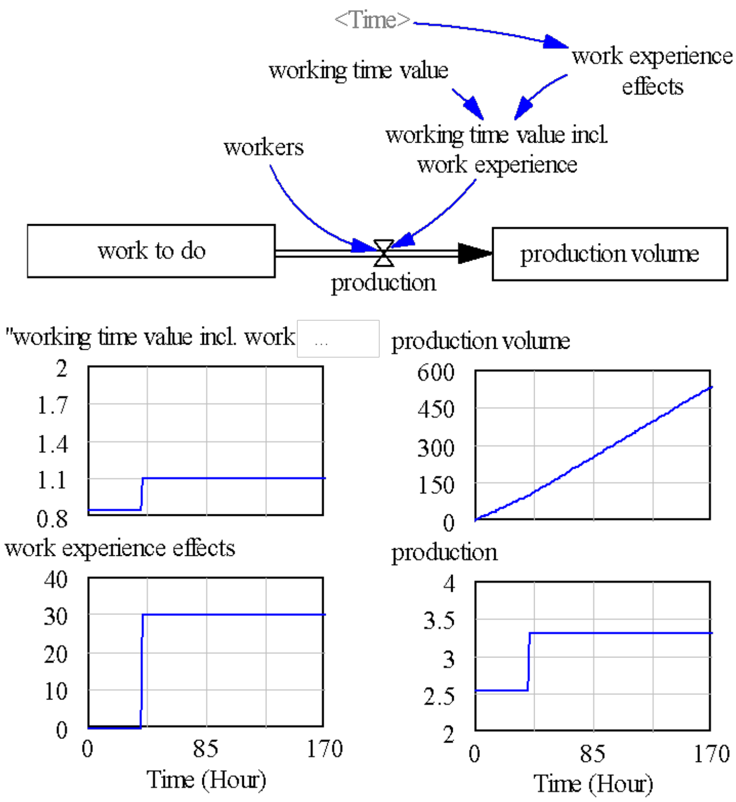


Figure 3.5: Example 3 – Example 2 including gained experience

The system boundary in the example is replaced at the beginning of the flow variable with the stock variable *work to do*. The diagrams clearly show that the *work experience effects* directly influence the variable *working time value incl. work experience* as well as the *production*. Nonetheless, the production level increases to the time t = 40 h only moderately. Interestingly, at time t = 170 h, a production level of approximately 533 m^2 has been performed. The legitimate question is thus, by which time the requested level of 450 m^2 will be reached. To this end, a termination criterion will be defined as shown in the final example (figure 3.6).

Apart from this, it is assumed that at the time t = 85 h additional 12 *workers* will be available. Along with the moderate rise in *production* because of the *work experience effects*, a steep increase of the production level occurs at time t = 85 h. Under the given conditions, 450 m^2 of brickwork are reached here in a time t = 98 h.

With the help of the examples, the elements existing within an SFD and their mechanisms of action ought to be introduced. Beyond that, the following should become comprehensible:

- The purpose of the simulation must be determined before the design of a simulation. (see example 1 & 2).
- It is advantageous to design a rough model first and to develop it gradually and subsequently (example 2 & 3).
- In order to identify the background and reasons for the occurrence of specific influences, the ceteris paribus clause is to be used in the qualitative analysis, meaning that only one element should be changed at a time (example 3 & 4).

Among others, it is these aspects which will be considered in chapter 3.3.6, starting on page 64, in the preparation of a formal conceptual approach for modeling and simulating dynamic systems.

3.2 System Dynamics in the field of construction

The SD approach became particularly widespread in the 1980s in such fields as project management, shipbuilding, defense and aviation[49]. Therefore there are numerous SD-models in the various fields of stationary industry that are largely universally transferable. According to Bauer (2007), the special feature of the construction industry is that it is a processing industry without own production site. The buildings are made in make-to-order production at a requested location and various stakeholders are involved. Because of the one of a kind production in the non-stationary industry, the transfer of existing models from the stationary industry proves difficult. John D. Sterman also acknowledged this distinct feature of the construction industry in the 90s and related it to the SD approach. According to Sterman (1992), construction projects are highly complex and dynamic and consist of numerous interdependent elements, various feedback loops and non-linear relations and feature both “hard” and “soft” data.

[49] cf. Roberts (1978), Cooper (1980), Reichelt & Sterman (1990)

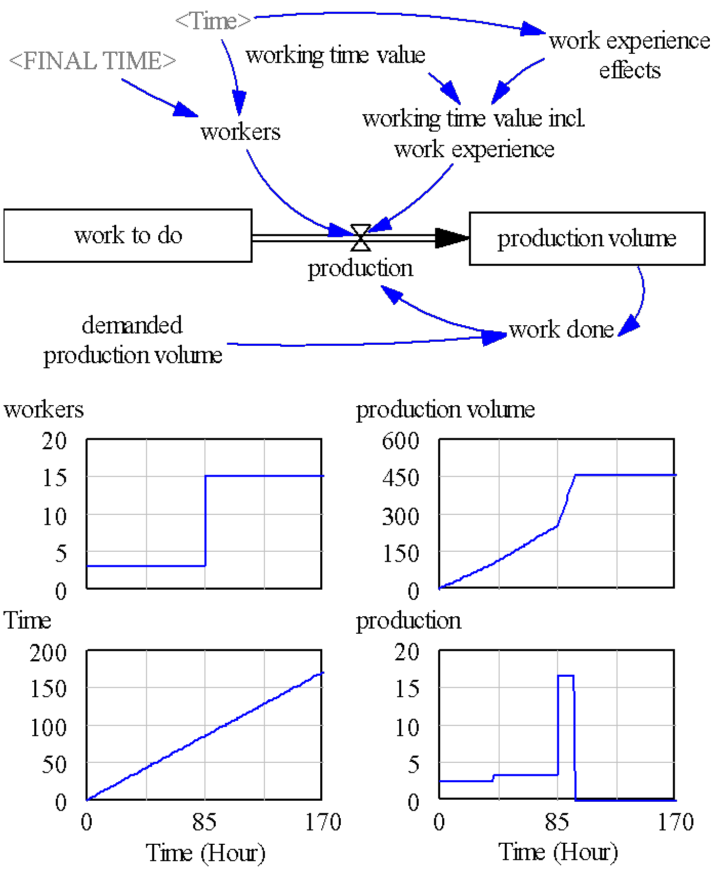


Figure 3.6: Example 4 – Example 3 including additional workforce and end of project

Irrespective of the different research areas construction engineers are working on, a set of established methods and procedures can be observed in the construction practice. These methods and procedures are based on research findings and norms or have been transferred and adapted from other fields; the long-term effective ones form a code of practice readily available when needed. This fact should be taken into consideration when applying methods from other domains.

Although many researchers apply the SD-approach to problem-solving in the field of construction[50], there is currently no systematic approach to make the design of SD models practicable and applicable on the one hand, and to support the universal usability of construction-specific models on the other hand.

The obstacles frequently encountered when attempting to introduce or apply simulations in the field of construction today, prove the necessity of such a systematic universal approach. An empirical study[51] identifies these obstacles as lack of know-how, excessive costs and the increased effort associated with the application of the model. Hence, a readily applicable modeling approach would be helpful in both closing the gap between existing knowledge and the expertise required by the simulation and in reducing the modeling costs. Such an approach is not only justifiable by the mentioned obstacles it is supposed to overcome, but also by the fact that most test subjects would consider making increased use of simulations in their companies, extending the field of application of the approach beyond the usual field of research and development. Further, the approach appears especially promising in the management of organizational strategy and human resources. Here, the simulation is mainly regarded as a method to cut costs and minimize potential risks.

Despite the few basic elements it consists of (stock- and flow values, variables, auxiliary variables, constant variables), the SD approach seems to be seen in the literature as well as in its applications more as a “special method”. The design of a specific method and of a feasible framework for the modeling and simulation of dynamic systems can contribute sensibly in this context, as it provides a purpose-oriented, useful and immediate access to system dynamics simulations within a domain.

3.3 Domain-specific libraries of simulation modules

Even though SD models are used in various fields of science to gain more insights, both theory and practice of theses simulations are rather difficult to comprehend for externals or third parties without previous SD knowledge. The SD approach may be well-known in many branches of science[52], but for a comprehensive discussion – for instance to be able to develop valid and

[50]e.g. Chang et al. (1991), Ogunlana et al. (1995), Ibbs & Liu (2005), Mbiti (2008), Mawdesley & Al-Jibouri (2010), Skribans (2010), Hou et al. (2011)

[51]Study SimBauDE: the current use of simulations in the German construction industry, carried out by the author in the year 2012 with 33 participating construction companies (91 invited). The author acknowledges the assistance and support of Mr. Philipp Louven, M.Sc. in the data acquisition.

[52]Hübner-Dick (1980) for example, who researches possibilities and limitations of system dynamics in the analysis of international politics.

functioning models and simulations independently – both a detailed and thorough study of the theoretical relationships and an intensive search for previous models, which are potentially suitable for integration into the intended model, deems necessary. In addition to that, previously developed SD models quite often acquire their reputation within their specific area of a single domain only. Currently it appears to be inevitable that previously existing models (independent of their scientific subject) and their contained elements can hardly be integrated into new models. One significant reason can be the lack of a viable possibility to exchange existing SD models within a domain or even beyond it. This seems to point to the necessity to develop a general and feasible method to classify SD models as well as their contained components and units to make them available for other modelers. One possibility is the development of domain-specific libraries of simulation models, called system dynamics libraries in the following.

3.3.1 System Dynamics Libraries

Following the nomenclatura of chemistry, a system dynamics library (SDL) is based on an atom-molecule-component-approach (abbreviated: AMCA). Therefore such a library consists of the following three fundamental entities (E): Atom (a), Molecule (m) and Component[53] (c).

An atom is the smallest entity[54] which can still be characterized in a model. To these units belong all single entities which exist independently and without external influence inside a model. Following general model theory, atoms have defined attributes and properties[55]. Atoms cannot cause system changes by themselves only, but may do so in combination with other entities existing in a model. Consequently, all discrete entities are atoms, e.g. stock and flow variables, (auxiliary) variables and constants. A coupling of atoms forms a molecule[56], which gains its properties through the interaction of its atoms. The linking of molecules results in a component or a module which has a case-sensitive internal processing logic. The combination of atoms, molecules and components results in a comprehensive model.

As the application of system dynamics models is supposed to lead to more consolidated decisions and decision-making rules[57], the decision-making level (D) is included as well in the approach introduced here. Therefore the operative, the tactical and the strategic decision-making level are equally comprised. The operative level contains mostly the physical realization and the implementation of tasks. On the tactical level, the processes and the organization within a corporation play a central role whereas the position and the targets of the corporation in the market are central focus of the strategic level.

To derive effective decision-making rules for various functional areas (F) within a company with the help of a holistic system analysis of complex dynamic problem settings, it appears sensible to include the following areas: strategy and organization (SO), research and development (RD),

[53]in contrast to the nomenclatura of chemistry the term molecular substance is not used here
[54]cf. Nic et al. (2006)
[55]cf. Stachowiak (1973)
[56]cf. Nic et al. (2006)
[57]cf. Forrester (1961)

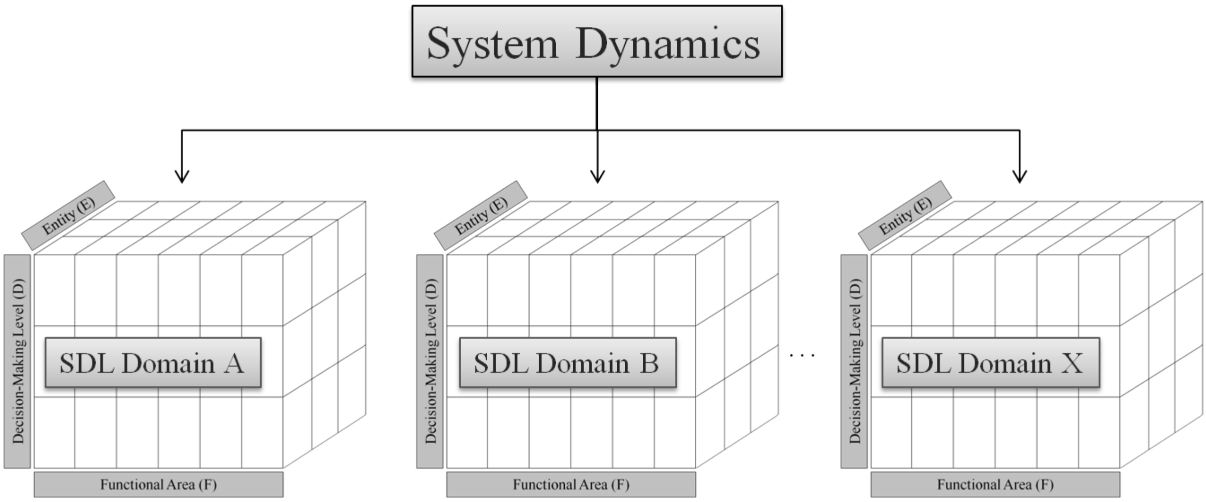


Figure 3.7: Concept of System Dynamics Libraries (SDL)

finance and governance (FG), marketing and sales (MS), human resources and leadership (HL), as well as operations and procurement (OP).[58]

With the help of such a system (figure 3.7), different SDL can be developed on the basis of the SD approach. These libraries offer a helpful transfer potential for their own domain, but also make units available beyond their own domain and allow the integration in their branch of science with little or no adaptations. This classification of units creates a high degree of universality and reusability. Previously developed entities for a specific decision-making level or functional level can be used in other levels with potentially little or no adaptations.

Using this approach does not only mean that new entities in development can be classified systematically, but existing models (independent of the domain they were developed for) can be analyzed methodically, the separate entities can be extracted and made available in a specific SDL. Thus, an SDL can be continuously complemented by controlled and systematic examination of SD models.

Atoms and molecules represent the universal entities in an SDL, whereas components were already assigned a fixed point of reference within a precise problem setting in a specific level. The boundaries between the different levels can be blurred, depending on the selected system limitations and the desired scale. If, for example, a company is modeled as a whole on the strategic level, considering details or individual processes of the work flow deem inappropriate.[59] In this case a molecule or a component, which was developed in detail for the operative level, can be reduced to an atom in a model of the strategic level. Here, the attribute required for the new model will be derived as a time-dependent function from the previous entity. If the need to inspect the behavior of this atom in more detail is identified later on, it can effortlessly be expanded to the previous stage.

[58]The structure of the functional areas follows van Assen et al. (2011)
[59]cf. Troitzsch (2004)

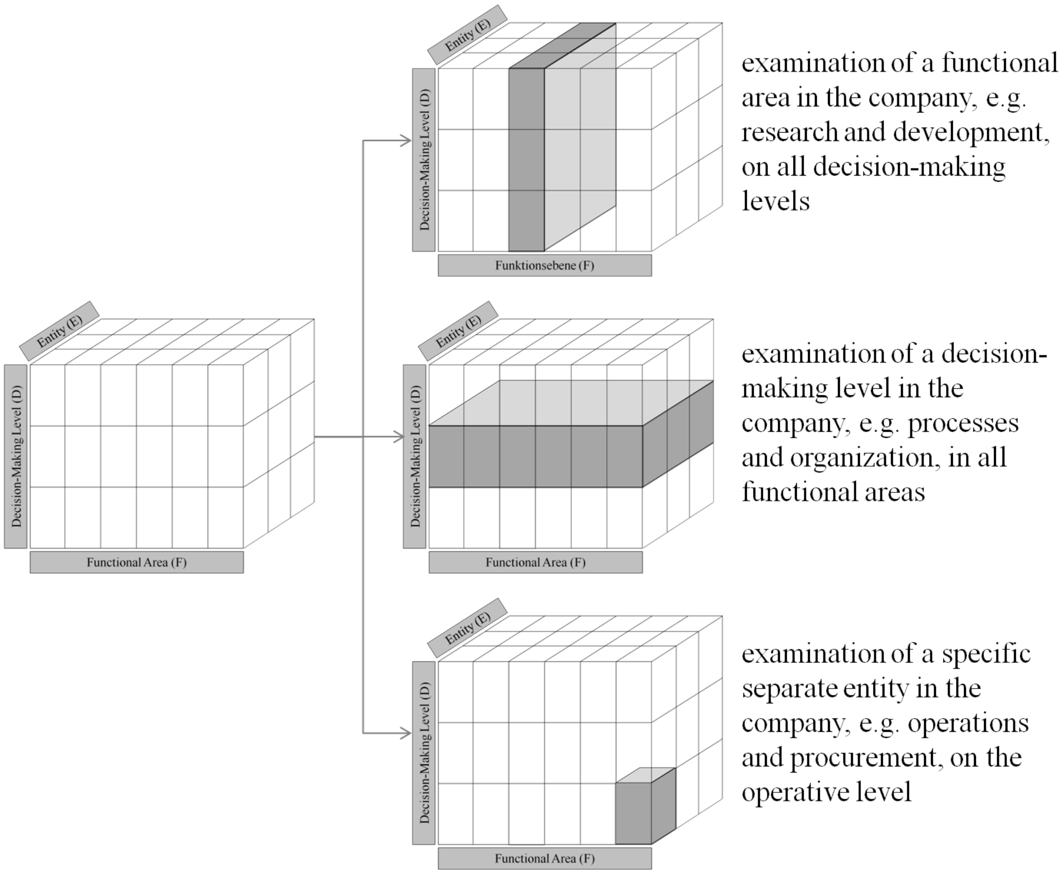


Figure 3.8: Possibilities of analysis with the SDL approach

3.3.2 Synergistic modeling and simulation using SDL

As the SD approach comprises both the decision-making level and the functional area of a company, this approach offers a formal basis for the synergistic modeling and simulation within a domain. Consequently, the consistent development of a company-specific SDL leads to numerous possibilities of analysis (figure 3.8).

With the help of already available reference models adapted to the individual processes, activities and data of a company within a necessary customizing process, the division managers, e.g., of functional areas, are put in the position to analyze their area of responsibility in due consideration of several other levels of decision-making in the company. The inclusion of SDL units from more than only one functional or decision-making level can lead to a) the development of more informed decisions and choices, which consider interests of other decision-makers in the company, b) new insights, which can illustrate the previously unknown far-reaching scale of an evaluated decision, c) the detection of potential conflicts which can be counteracted in advance and d) the development of argumentation to convince individuals both in the own functional area but also from other involved decision-making levels that the targeted decision is sensible and appropriate. However, these exemplary possibilities of application depend on an SDL which is properly maintained by all departments in the company.

In addition to the possibilities mentioned above, such a synergistic modeling approach will lead to further substantial benefits. As already mentioned in chapter 3.1 on page 46, a model is only valid until the gained hypotheses and insights are disproven on empirical basis. This means that the gained results do not necessarily have to be true, whether due to analytical, formal or fact-based logic relationships. Both the units deemed relevant for the model and the links among these are subject to assumptions of at least one individual. Therefore it is true for such models as well, that wrong premises like units and/or erroneous deductions in form of links between the units may imply wrong conclusions. Strictly spoken, a model can only be accepted as true after it was definitely verified. Usually this would suggest an empirical study in form of a long-term observation of real relationships and behaviors, the results of which can be juxtaposed to the results of the simulation afterwards.[60]

This point shows the decisive advantage of the synergistic modeling approach with which the model designer will be able to build a feasible link between simulation and decision game. If, ideally, a game has been established in parallel to the simulation and is based on the identical model (e.g. developed out of an SDL), the "time lapse" function of the game can help to form an empirical basis from the behaviors and decisions of the participants. A thorough analysis of the decisions made in the game forms an empirical basis to assist in a first verification resp. falsification of the model. Hence, a falsification based on these premises can help to improve the quality of the simulation model as a whole but without the need to monitor the whole period of observation in real time.

Based on this approach, the first step to develop SDL units is the localization of relevant entities, which need to be formally and explicitly described according to the specific aim of the model. This description is achieved with the SDL process ontology, devised specifically for such purpose and described in the following chapter.

3.3.3 SDL Process Ontology

Each entity of the SDL is structured in itself in a specifically laid-out process ontology (PO)[61]. In the first stage, the SDL PO lists the resources included in a specific process. These are subdivided in, e.g., material, tools (e.g. equipment or machinery), personnel and capital as well as the dependencies between the individual resources (figure 3.9).

This means that atoms, for instance, can be allocated to the monitored resources. These resources contain the properties allotted to the atoms which, in turn, results in a dependency on the according functional areas. The second stage SDL PO integrates the previously defined objects of

[60] further details regarding these aspects are discussed in Karl (2014)

[61] The term ontology (the study and categories of being) originates from philosophy but is, in computer sciences, frequently seen as a clearly separated and formally structured description and illustration of terms, components etc. and their relation to each other in a given area of interest. Such ontologies are often employed for the organized exchange of knowledge (e.g. knowledge representation in the section of artificial intelligence). In contrast to taxonomies, which only display a hierarchical sub-categorization only, ontologies are in the position to depict relationships between the individual terms. For further details, please refer to, Uschold & Grüninger (1996), Oberle et al. (2009), among others.

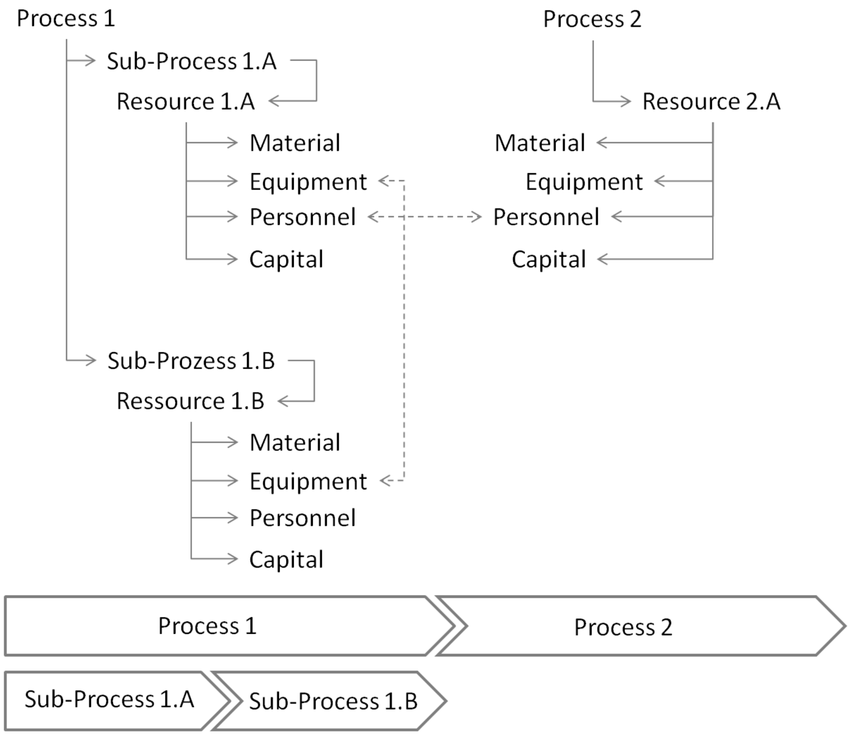


Figure 3.9: SDL Process Ontology

the first stage within a larger context and therefore creates a relationship between the individual processes. As a consequence, the previously introduced molecules consider the resources and properties of the atoms in a larger scale and allow the illustration of processes. These represent cost- and production-oriented activities and are summarized as process chains in the components. Hence, the application of a PO predefines the first inner structure of a domain-specific SDL, thereby allowing model developers to quickly locate the required elements for the respective model purpose and include them in their individual models.

On the basis of the SDL PO, first formally distinct and transferable networks of processes, objects and interdependencies are designed and can be drafted in more detail with the help of a specific SDL notation.

3.3.4 SDL notation

Fundamentally important for the systematic expansion of an already developed SDL, an according notation[62] is as elementary as the structured basis supplied by the PO. The separate units are defined as follows:[63]

[62]The notation aims at the possibility to establish SDL as database-supported libraries in the long term.
[63]This notation accounts especially for the formal predicate logic. To facilitate the denominations, each entity is assigned a unique identification number (uid) within its own field. With the assistance of further attached uids, the development respectively the affiliation of an entity within a group can be understood in the future.

Atom:

$$a_{R,,uidn.\dots uidm} := a\left(D, p, F(p)\right) \in f(p)\ [u(p)] \tag{3.1}$$

Molecule:

$$m_{P,uidn.\dots uidm} := m\left(D, F(p), \sum_k (a_k), \sum_l (m_l)\right) \in f(p)\ [u(p)] \tag{3.2}$$

Component:

$$c_{P,uidn.\dots uidm} := c\left(D, \sum_j (Fp_j), \sum_k (a_k), \sum_l (m_l), \sum_m (c_m)\right) \in f(p)\ [\sum_j (up_j)] \tag{3.3}$$

mit:

D = decision-making level $\in [CMD, CCD, CPD]$;

p = predicate $\in [property\ 1, ..., property\ i]$ with i$\in \mathbb{N}$;

F(p) = function $\in [SO, RD, FG, MS, HL, OP]$;

f(p) = form $\in [stock, flow, const, var, system]$;

u(p) = unit $\in [SI - unit, currency - unit, ...]$;

R = resource $\in [MA = material, DE = device, WO = worker, CA = capital, ST = storage]$[64];

P = process $\in [PL = planning, SF = site\,facilities, EA = earthworks, SC = shell\,construction]$;

uidn = unique identification number n $\in \mathbb{N}$;

uidm = unique identification number m $\in \mathbb{N}$;

k = uid of included atom;

l = uid of included molecule;

j = uid of included component;

It is necessary to keep in mind, that a predicate p can be a conglomerate of different properties, e.g. the resource material can contain a quality, a weight and a price (arity of three). Hence, if an atom consists of a predicate with an arity of x and is subject to an itemization process in modeling, it needs to be broken down to further independent atoms with an arity of one to allow its use in the following simulation. Within a simulation, an atom is always required to be downgraded until it describes only one property. According to the first example in chapter 3.1.4.2 on page 51, the notation is demonstrated as follows:

$$worker:\ a_{WO,1} := a\left(CPD, number, OP\right) \in const\ [qty.] \tag{3.4}$$

$$working\ time\ value:\ a_{WO,2} := a\left(CPD, working\ time\ value, OP\right) \in const\ [m^2/h] \tag{3.5}$$

[64]In case an atom is used as auxiliary variable in the model, AUX = auxiliary is used

$$work\ to\ do:\ a_{MA,1} := a\,(CPD, quantity\ of\ work, OP) \in stock\ [m^2] \tag{3.6}$$

$$production:\ a_{MA,2} := a\,(CPD, quantity\ of\ production, OP) \in flow\ [m^2/h] \tag{3.7}$$

$$production:\ m_{SC,1} := m\,(CPD, OP, a_{WO,1} a_{,WO,2}) \in flow\ [m^2/h] \tag{3.8}$$

As can be seen, the flow variable *production* can appear as molecule or as an atom in an SDL. Indeed, the entity *production* is dependent on the atoms *worker* and *working time value* and consequently represents a molecule. Equally correct is the fact that this flow variable – on closer and separate inspection – qualifies as one smallest identifiable entity as it can neither cause any system changes on its own, nor exists the necessity to influence exogenously.

This described situation is only based on the fact that the modeling of entities using the SDL approach may need to consider the occurrences of feedback. Three cases can be distinguished in general (figure 3.10). In the first case, the bottom-up method[65] helps to form a molecule out of three already existing atoms. Here, two atoms influence the third one (e.g. var + const → var, var + const → flow, var + const → stock). The second case presupposes the existence of at least two more atoms, of whose coaction a previously unknown third atom is created. This means that one further atom was created during the construction of a molecule. The third case represents a recursive form, in which the implementation of the top-down-method[66] transforms an existing atom into a molecule. For this, possible influences on the atom were identified. The result of this observation is the creation of more atoms.

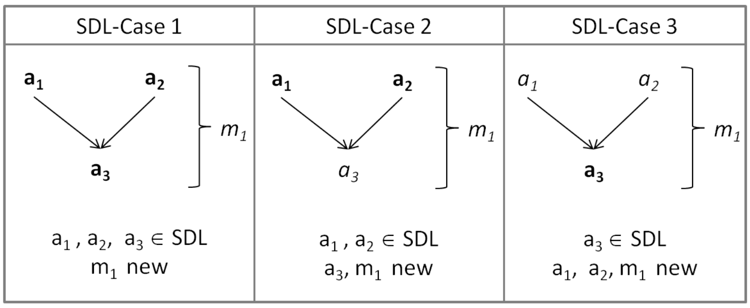


Figure 3.10: SDL model cases

As models on the basis of an SDL can be of substantial size and complexity – depending on the problem setting and the desired insights – a unified graphic mode of representation is introduced in the following. It can be used to facilitate the observer's understanding of complex models and elucidate the main features of an SDL-based model.

[65]abstraction in increments following VDI 3633 (1996)
[66]itemization in increments following VDI 3633 (1996)

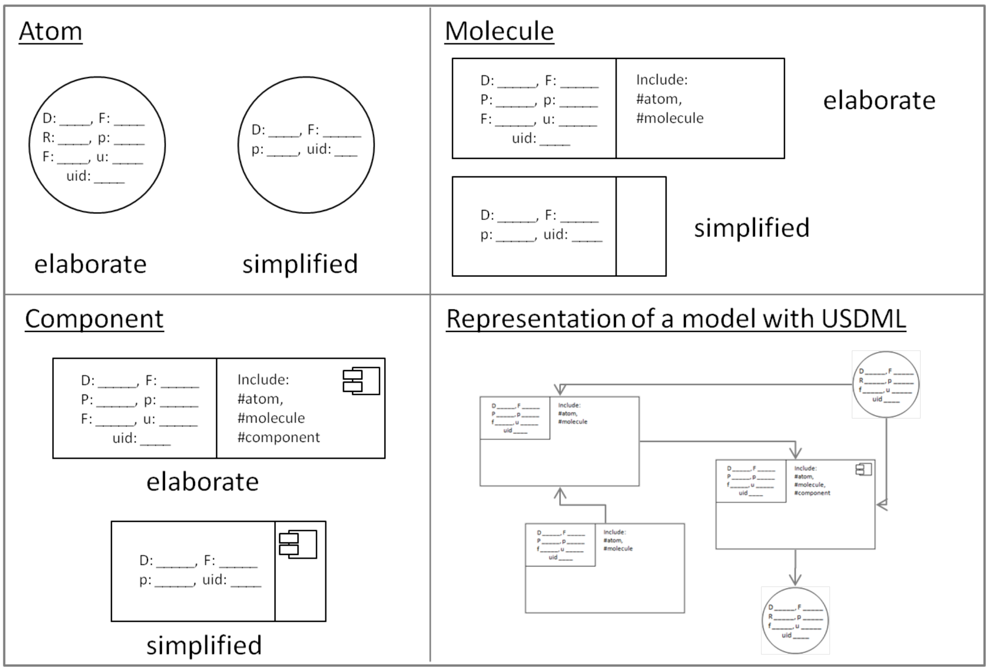


Figure 3.11: Overview of notation USDML

3.3.5 Unified System Dynamics Modelling Language

Although the SD approach provides two generally applicable and straightforward comprehensible modes of presentation to the user (CLD, refer to p. 48 and SFD, refer to p. 50), the introduction of a distinct modeling language appears sensible both for the support of the systematic expansion of SDL and for the improved understanding of the complex models and their underlying system. This modeling language is based on the concept of the already existing Unified Modeling Language (UML)[67] and adopts especially the presentation modes of the UML object, class and component diagrams. Thus, a specific symbol is assigned to each of these three basic units of an SDL (atom, molecule, component) which conveys information to the observer (figure 3.11).

Based on the SDL notation, the Unified System Dynamics Modeling Language (USDML) offers both a simplified and an elaborate presentation. The elaborate and more detailed presentation displays seven information units: 1. decision-making level (D), 2. functional area (F), 3. resource (R) respectively process (P), 4. property (p), 5. form (f), 6. unit (u) and 7. unique identification number (uid). In contrast to that, the simplified presentation consists of four necessary information units: 1. decision-making level (D), 2. functional area (F), 3. property (p) and 4. unique identification number (uid).

The four hitherto introduced methods and procedures of the SDL approach are supposed to enable model designers to develop decision-based simulations as well as educational games in the long term.

[67] A graphic modeling language for the specification, construction and documentation of software elements and other systems.

3.3.6 Modeling and simulation with the SDL

In this research project, the top-down method is dominantly applied in the model creation processes. The advantage of this approach, seen in contrast to the bottom-up method, is the applicability of the top-down method both in the modeling process itself and in the system analysis. In the modeling procedure, this preferred method is used to refine sections of the model in accordance to the specific problem setting. At first, some sections are modeled on a high level of abstraction, in which selected subsections are treated as black boxes[68]. After that, each black box is subject to an individual and detailed modeling. Within these generated subsystems (consisting of at least one mathematical function), simulations are conducted and their results can either be seen individually or their input/output behavior can be used as basis for the superordinate model (application of a bottom-up method[69] for an incremental summary of results gained from the black boxes.).

To prepare the following examinations, a development framework is introduced for the modeling and simulation of dynamic systems; it includes the SDL approach[70]. In general, the modeling and the subsequent simulation including the presentation of the results and their discussion is formally separated in six phases. In this classification, the modeling comprises 1) identification and formulation of problem setting, 2) compilation of effect relationships and 3) differentiation of model concept. In the area of simulation, the three remaining phases can be found: 4) preparation and implementation of simulation, 5) presentation of results and lastly 6) discussion of results. Figure 3.12 depicts this development framework. It contains reasonable steps of the overall procedure, recommendations regarding their implementation as well as the preferred and intended results of the phases.

According to the development framework, the hitherto developed model should be transferred into suitable simulation software in phase four. To address this aim, the following chapter is concerned with the aspect of the software selection for the SD simulation. First, the current state of available computer programs is considered, then one software product is selected and used in the subsequent procedures.

3.3.7 Software selection for the SD simulation

When choosing the most appropriate modeling software, the difference of qualitative or quantitative perspective needs to be considered. A qualitative view focuses exclusively the cause-effect relationships. Here, the system structure, the relationships and the influences of individual factors on each other are of dominant interest. The system behavior can be analyzed, but numerically-oriented predictions can only be achieved with the help of a quantitative perspective.

First it has to be decided whether the qualitative model design should be followed by a simulation,

[68] A model in system theory in which a unit-step response processes the input of a system and returns the feedback of the system on its environment (output) (cf. VDI 3633 (1996))

[69] cf. VDI 3633 (1996)

[70] on basis of VDI 3633 (1996), Bossel (2004) and Sterman (2004)

Development framework for modeling and simulation including the SDL approach

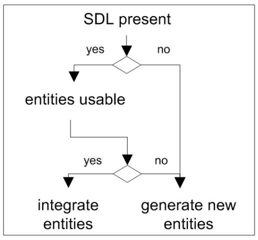
	Step of procedure	Why is it necessary?	What is to be done?	Output
1. Identification of problem setting	definition of model objective (what, which motivation), formulation of written model , system building (black boxes)	specification of targeted knowledge gain, identification of substantial system variables and effect relationships, definition of system limits	written description of model and first reduction of reality	text models
2.Determination of effect relationships	block diagram as sum of all black boxes, identification and illustration of first relevant effect relationships (system variables and effects/influences)	illustration of first draft of system structure, derive statements on potential behavior, execution of qualitative research	derivation of written model description (only direct effects, isolated consideration, ceteris paribus condition), numerical inspection, mathematical analysis, effect matrix, Vester's "paper computer"	first mental models as block diagrams, effect relationship diagrams, e.g. causal loop diagrams or others
3. Differentiation of model concept	SDL PO for the identification of essential key variables, parameters (fixed system parameters), state variables (storage variables), modifier (interim/auxiliary variables)	generation of context and relationships between the individual processes within a model	successive differentiation of previously developed mental system and structuring in processes, sub-processes and involved resources	tables, allocation network etc.
	development/ extention of an SDL 	long-term minimization of development efforts by re-utilization of already developed (possibly from other domains) units, first direct access to subsequent SD simulation, facilitated integration of new entities in different functional areas and decision-taking levels, basis for a computer model which can be simulated	first formal illustration of variables in the model (according to SDL PO defined classification), recursive or iterative formulation of variables following AMC approach	first general equations based on the SDL notation, grouped according to SDL PO, decision level and functional area
	USDML presentation of the general model	identification of relationships and missing units	summary of SDL entities into overall and general model	USDML diagram
4. Sim. preparation/ implementation	determination and presentation of differential equations, validation and model validity respectively check of system stability/ integrity	acquisition of reliable qualitative results, testing of model validity, potentially optimization of model	collection of valid and reliable data, transfer model into an appropriate simulation software (potential viewing of partial models and subsequent linking)	mathematical equations and simulation results
5. Presentation of results	evaluation of simulation results for gaining insights	comparison of simulation results to original model purpose	graphical preparation and/or generation of animations	tables, charts, diagrams, animations and other forms
6. Discussion of results	identification of significant results	specification of result effects on a) model purpose, b) other questions	discussion of the significant results and connecting to central question	text and graphical representations, if necessary

Figure 3.12: Modeling and simulation with SDL

which attempts to gain insights and result in predictions using concrete (real or realistic) data. If this is not the case, all software programs which can generate texts and at least rudimentary graphics could in principal be used to display models. Taking into account the aim of this research, only those programs are considered in the following selection of software, which can run simulations taking system dynamics into account[71].

In general, all of the inspected software solutions can develop SD models for the analyses of markets, products or business processes in companies. Due to the target group for which the following models should be developed (research, education and industry), emphasis of the final choice is placed on the identification of an efficient, competitive and universally applicable software without any limitations. Independent of offered version with time limitations or other restrictions, the programs Mapsim, NetLOGO 5.0.1, Sphinx SD Tools 0.7b, SystemDynamics 1.3 and Vensim are eligible for the desired purposes. To guarantee a long-term availability and usability of the models, it has to be ensured that the selected software is sufficiently supported and can also be expanded with additional functions to carry out further analyses and simulations on the basis of the developed models.

Of these above-mentioned software products, especially the program Vensim appears to be suitable. Developers and suppliers of Vensim, Ventana Systems, Inc., work with SD-based simulations since the middle of the 1980s and can currently be seen as established in the market. The PLE version of Vensim (personal learning edition) is fully functional and at no charge for the personal use respectively for research and teaching. Furthermore, it is equally possible to export models developed with Vensim to other programs, e.g., Forio Simulations. Beyond this, models from other programs, e.g. from Stella and ithink, can be imported by Vensim with the help of an interface program. The functions contained in the PLE version of Vensim are suitable for basic or complex system dynamic models. A future expansion of functions like, e.g. Sensitivity Simulations with the Monte Carlo method and Live Data Connections can already be integrated with the PLE Plus version. Further functions are offered by the version Vensim Professional and Vensim DSS[72]. The latter offers a development tool which helps to construct so-called management flight simulators. Subsequently, these can be used as independent applications. In all above-mentioned version of the software, the models created with the PLE version can be imported and integrated. Therefore, the PLE version will be used both for the following modeling as well as the simulation later on.

[71] A list of the currently available SD software can be found in the tables 8.9 to 8.11 in the appendix on page 162 and following.

[72] Decision Support System, for details about DSS please refer to, e.g. Sauter (2010) and Turban (2011)

4 Exemplary development of a model

Apart from the concept of a domain-specific SDL, which is based on the SD approach and called construction dynamic library (CDL, figure 4.1), a cadre of module-oriented models should be created in this research project. Within the CDL, three significant areas are in the central focus: (1) the construction project[1] (2) the construction company[2] and (3) the construction market[3]. The CDL is supposed to enable users to depict both the construction industry and all involved parties in a network of linked operational, economic and market-dynamic processes.

These models and the included units are to offer the basis for further developments and should be summarized using the term construction dynamics (CD). The design of the different units will be shown in detail in the following to demonstrate the practical development of the CDL, taking the operative level (CPD) as an example. As the modeling of CD units is a recursive process (refer to figure 3.12 on page 65), the development of the exemplary units is also intentionally illustrated in this form. As a consequence, the potentially missing atoms needed in chapter 4.6 on page 75 and the equally lacking units in chapter 4.7 on page 88, respectively, are going to be modeled within these chapters. As the formal approach is analogue both on the tactical as well as the strategic level, an explicit illustration of the development process on these levels is deliberately omitted.

4.1 Purpose of the model

A project model is supposed to be generated on the operative level while applying the SDL approach. The aim is to have a project model which can display connections and dependencies or predict, both correctly and qualitatively, tendencies and dynamics of developments. These predictions should be formed on the basis of, e.g., risks in the construction operation itself, volatilities of labor or operating costs as well as the potential influence of experience and necessary on-the-job training required by the personnel of a construction site in a surface construction project. Additionally, elementary supply chains will be shown in the project model to allow examination of their influence on the project. Primarily intended orientation of the model *construction project* are the involved costs. The following questions should be answered with the help of the model and the subsequent simulation:

- How do the costs change with the passing of time?

[1] Construction Project Dynamics (CPD)
[2] Construction Company Dynamics (CCD)
[3] Construction Market Dynamics (CMD)

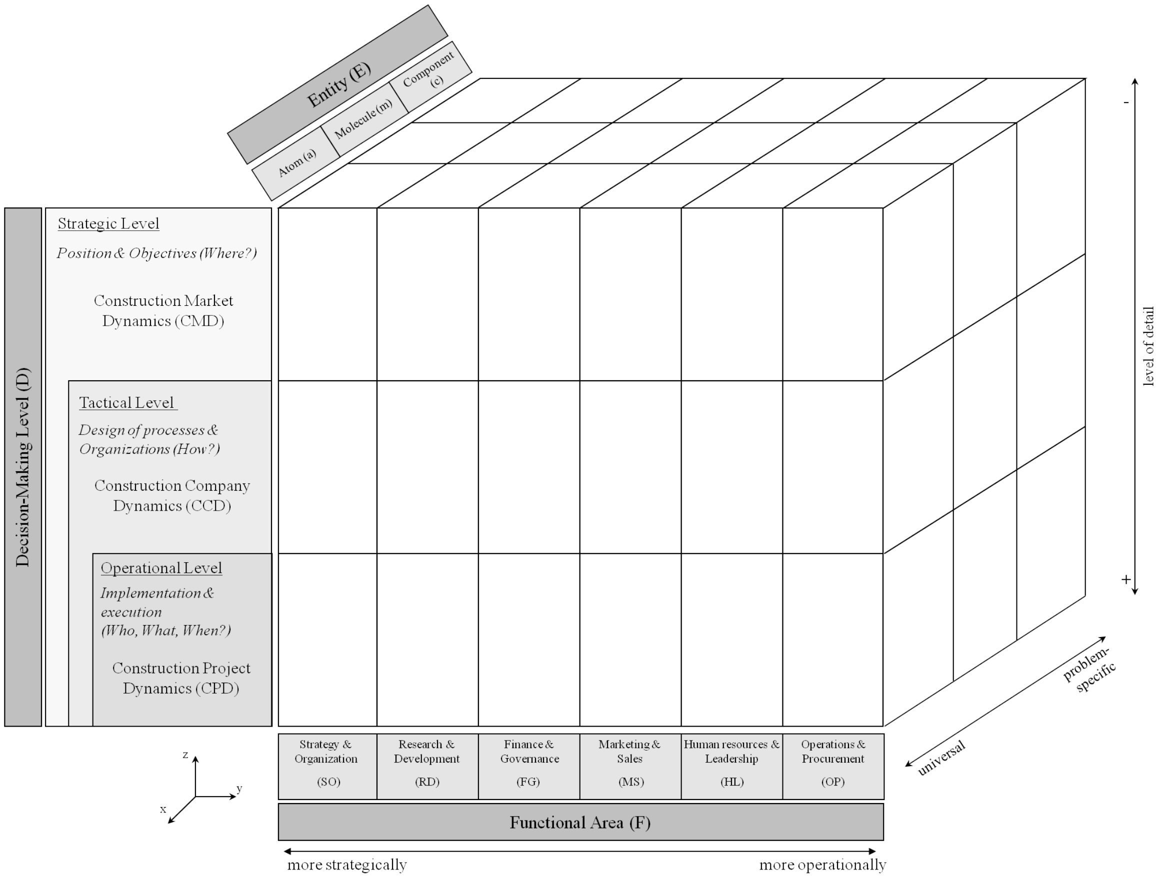


Figure 4.1: Structure of the CDL

- Determination of the optimal warehousing and quantity stored at minimal costs.
- Does warehousing pay off? If yes, which type and in which quantities?
- How much storage capacity is necessary for this?
- Which influence exert fluctuations on the bulk flow (choke points or similar)?
- How critical is price volatility during a construction project?
- In how far do workforce-specific parameters like experience and training-on-the-job influence the production?

4.2 System limits

Only surface construction is targeted in the model *construction project*. Furthermore, only the operations from the setup of the construction site to the completion of the building shell are considered in detail. These, in turn, are defined by the primary processes earthwork, reinforced concrete construction including formwork, reinforcements and concrete works, as well as brickwork. Resources like material, tools and personnel are included in the calculations. The remaining unconsidered tasks are seen as services contributed by subcontractors or third-parties.

4.3 Fundamental cause-effect relationships

First, the model *construction project* is conceptualized on the basis of the previously defined system limitations and then, in the following chapters, qualitatively modeled in detail using the top-down-method[4]. At this stage, the model construction project is built on fundamental reference figures[5] and their relationships to each other (figure 4.2). A first project definition is determined with the following input parameters: a) gross volume (GV) , b) gross floor space (GFS), c) free ground area (FGA), d) areas of the exterior and interior walls (AEW and AIW). Additionally, the required overall resources are calculated with the help of the materials needed by each of the trades. For this, ratios are taken from previously published technical literature[6]. Further input parameters are included: e) proportion of solids, f) proportion of formwork, g) proportion of reinforcements.

To determine the necessary amount of material to be excavated, the following parameters are considered: h) depth, i) additional excavation ratio. The parameter additional excavation ratio should give room for additional excavation work, which may be necessary depending on the depth and the resulting need to form berms. In the end, the output parameters of this model are quantities given for a) excavated earth, b) formwork, c) reinforced concrete, d) steel, e) brickwork (interior and exterior). Further parameters are relative auxiliary variables which may be useful in the later steps of the modeling process.

[4]cf.VDI 3633 (1996)

[5]The reference figures needed later for the simulation can be acquired from real projects or from sources in literature, e.g. the Baukosteninformationszentrum (2008)

[6]e.g. Spranz (2003)

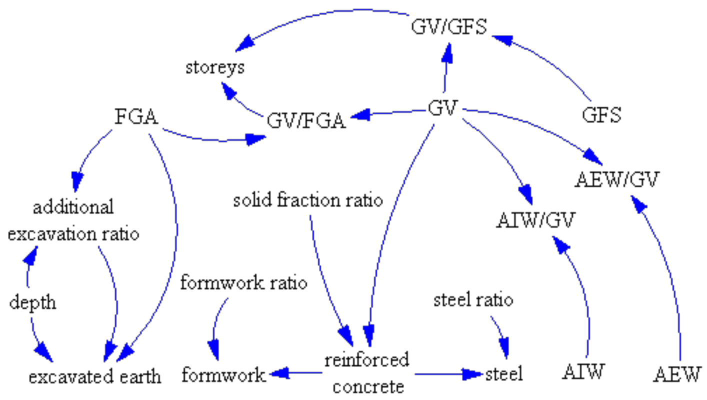


Figure 4.2: Fundamental project model

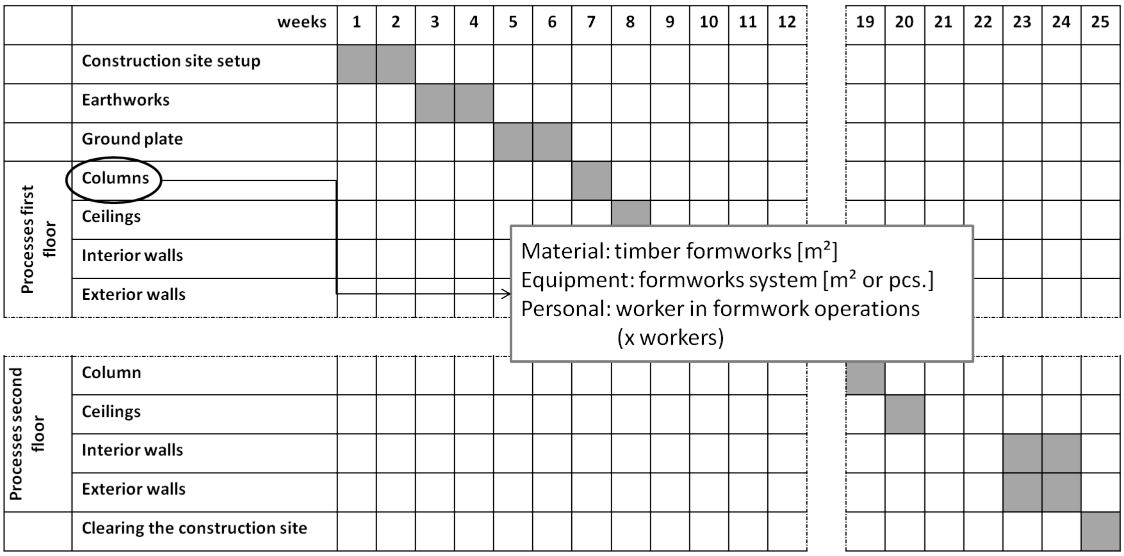


Figure 4.3: Rough operation chart of project model

4.4 Identification of the relevant system parameters

The model *construction project* will be additionally specified in the due course of development under inclusion of the SDL PO (p. 59) and in line with the processes and upcoming tasks. In due consideration of the usual and conventional planning of preparations and operating procedures in the construction industry, a hypothetical and rough draft of a generic construction project will be introduced in the following. In this, the first project definitions of the underlying model are filled with more details. To prepare the following modeling of the units, indispensable information like, e.g., processes, resources and characteristics, defined by the SDL notation, is located with the help of the SDL PO (figure 4.3).

At the beginning of the actual production, the setup of the construction site requires attention. This part of the modeling is relevant because the construction site setup can have significant influence on the general expenses of the construction in the area finance and governance (FG).

Table 4.1: Resources of construction site setup

process	Material	equipment	personnel
construction site setup	-	crane	crane operator
construction site setup	-	personnel container	workers
construction site setup	-	foreman container	foreman
construction site setup	-	construction management office	construction manager
construction site setup	-	sanitary facilities	all
construction site setup	-	first aid ward and equipment	all
construction site setup	-	office and meeting rooms	various
construction site setup	-	equipment storeroom	all
construction site setup	various	construction material storage	all
construction site setup	various	operating supplies	all
construction site setup	-	construction site workshop	various
construction site setup	-	laboratories	various

Table 4.2: Resources earthworks

process	material	equipment	personnel
excavation	ground	excavator	operator excavator
transport	ground	truck	truck driver

The choice of the individual elements of the construction site setup is based on Schach & Otto (2008) and is displayed in table 4.1.

After the setup of the construction site, the earthworks begin. These can usually be divided in the subsections of removal (excavation), hauling (transport) and disposal[7], whereas the first two of these will be in the main focus of interest. The excavated earth is expected to be unloaded and disposed of without any further costs at the end of the transport. The equipment and the personnel is assigned accordingly (table 4.2).

The monitored construction of the building shell is segmented in the two phases concrete/reinforced concrete construction (ground plate and processes ground floor to second floor) and brickwork (only processes ground floor to second floor). The included process groups of concrete/reinforced concrete construction are formwork[8], reinforcing and placing of concrete.[9] In addition, the storage of resources is already allowed in this phase of development (table 4.3).

Based on the relevant system parameters which were identified in this phase, the key variables in the sense of the AMCA are elaborated in the following.

[7] cf. Bauer (2007)

[8] In this process a distinction is necessary between timber formwork (used, among other areas, in bridge construction) and system formwork (used, among other areas, in general surface construction)

[9] cf. Bauer (2007)

Table 4.3: Resources building shell

process	material	equipment	personnel
formworks	timber	formworks system	worker in formwork operations
reinforcing	steel	-	worker in reinforcement operations
concrete placement	concrete	-	concrete worker
concrete pumping	concrete	concrete pump	operator of concrete pump
brickwork	bricks/ mortar	-	bricklayer
storage	various	various	warehouseman

4.5 Atoms

In general, each single identified resource presents an atom with multiple attributes and can be formally described according to the SDL notation (for details refer to p. 60) as shown in the following.

4.5.1 Materials

The atoms of the first three materials are listed exemplarily in the following; the remaining materials are described in a similar way.

excavated earth:

$$a_{MA,1} := a\left(CPD, p_{excavated\,earth}, F(p)\right) \in f(p)\;[u(p)] \tag{4.1}$$

p$_{excavated\,earth}$$(spec.\,weight\ solid, spec.\,weight\ loose, spec.\,costs, amount, ...)$;

F(p) $\in [FG, OP]$; f(p) $\in [stock, const, var]$;

u(p) $\in [m^3, to/m^3, to, Euro/m^3, m^3/t...]$, t = time unit

(timber) formworks:

$$a_{MA,2} := a\Big(CPD, p_{(timber)\,formworks}, F(p)\Big) \in f(p)\;[u(p)] \tag{4.2}$$

p$_{Formworks}$ $(weight, spec.\,costs, amount, ...)$;

F(p) $\in [FG, OP]$, f(p) $\in [stock, const, var]$;

u(p) $\in [m^2, to, Euro/t, €/m^2...]$, t = time unit

steel:

$$a_{MA,3} := a\left(CPD, p_{steel}, F(p)\right) \in f(p)\;[u(p)] \tag{4.3}$$

p$_{steel}$ $(weigjt, spec.\,costs, amount, ...)$;

F(p) $\in [FG, OP]$; f(p) $\in [stock, const, var]$;

u(p) $\in [to, Euro/to, to/t...]$, t = time unit

Depending on the material, atoms are available for the illustration of storage capacities as shown in the following.

4.5.2 Storage

storage:

$$a_{ST,x} := a\,(CPD, p_{storage}, F(p)) \in f(p)\;[u(p)] \tag{4.4}$$

x $\in [material\,code]$[10];

p$_{storage}$ $(volume, area, material, costs, ...)$;

F(p) $\in [FG, OP]$; f(p) $\in [stock, const, var]$;

u(p) $\in [m^3, m^2, €/m^3, Euro/m^2...]$

Apart from the storage capacities, according equipment resources have to be defined together with the materials.

4.5.3 Equipment

The atoms of the first three types of equipment are listed as examples. The rest of the equipment is described accordingly.

excavator:

$$a_{DE,1} := a\,(CPD, p_{excavator}, F(p)) \in f(p)\;[u(p)] \tag{4.5}$$

p$_{excavator}$ $(depreciation, interest, repair, fuel\,consumption, performance\,value, number, ...)$;

F(p) $\in [SO, FG, RD, OP]$; f(p) $\in [stock, const, var]$;

u(p) $\in \left[number, Euro, m^3, l/t, t/m^3, Euro/t, ...\right]$, t = time unit

truck:

$$a_{DE,2} := a\,(CPD, p_{truck}, F(p)) \in f(p)\;[u(p)] \tag{4.6}$$

p$_{truck}$ $(depreciation, interest, repair, fuel\,consumption, performance\,value, number, ...)$;

F(p) $\in [SO, FG, RD, OP]$; f(p) $\in [stock, const, var]$;

u(p) $\in \left[number, Euro, m^3, l/t, t/m^3, Euro/t, ...\right]$, t = time unit

concrete pump:

$$a_{DE,3} := a\,(CPD, p_{concrete\,pump}, F(p)) \in f(p)\;[u(p)] \tag{4.7}$$

p$_{concrete\,pump}$ $(depreciation, interest, repair, fuel\,consumption, performance\,value, number, ...)$;

F(p) $\in [SO, FG, RD, OP]$; f(p) $\in [stock, const, var]$;

u(p) $\in \left[number, Euro, l/t, t/m^3, Euro/t, ...\right]$, t = time unit

The containers which are necessary for the construction site setup are described in the following. These can serve as examples for the definition of further units.

personnel container:

$$a_{DE,5} := a\,(CPD, p_{personnel\,container}, F(p)) \in f(p)\;[u(p)] \tag{4.8}$$

[10] MA: 1 = soil, 2 = formwork, 3 = steel, 5 = brickwork (not storable 4 = concrete)

foreman container:

$$a_{DE,6} := a\,(CPD, p_{foreman\,container}, F(p)) \in f(p)\ [u(p)] \tag{4.9}$$

construction management office:

$$a_{DE,7} := a\,(CPD, p_{construction\,management\,office}, F(p)) \in f(p)\ [u(p)] \tag{4.10}$$

sanitary facilities:

$$a_{DE,8} := a\,(CPD, p_{sanitary\,facilities}, F(p)) \in f(p)\ [u(p)] \tag{4.11}$$

Generally true for the elements of the construction site setup:

p_i $(depreciation, interest, repair, power\ consumption, manageable\ employees, number, ...)$;

with i $\in [personnel\ container, foreman\ container, construction\ management\ office, ...]$;

F(p) $\in [SO, FG, RD, OP]$; f(p) $\in [stock, const, var]$;

u(p) $\in [number, Euro/Stk., to, Euro/to, Euro/t...]$, t = time unit

The system formworks must not be forgotten, it has to be defined as equipment as well.

(system-)formworks:

$$a_{DE,16} := a\left(CPD, p_{(system)\,formworks}, F(p)\right) \in f(p)\ [u(p)] \tag{4.12}$$

$p_{(system)\,formworks}$ $(weight, depreciation, interest, repair, spec.\ costs, amount, ...)$;

F(p) $\in [FG, OP]$, f(p) $\in [stock, const, var]$;

u(p) $\in \left[m^2, to, Euro/t, Euro/m^2...\right]$, t = time unit

To finalize the fundamental modeling phase, the required personnel resources have to be defined as well.

4.5.4 Personnel

The examples of an earth-moving plant (excavator) and an industrial employee (bricklayer) are used to demonstrate the definition of the currently needed units. The description of further units follows the same pattern

operator excavator:

$$a_{WO,1} := a\,(CPD, p_{operator\,excavator}, F(p)) \in f(p)\ [u(p)] \tag{4.13}$$

bricklayer:

$$a_{WO,7} := a\left(CPD, p_{bricklayer}, F(p)\right) \in f(p)\ [u(p)] \tag{4.14}$$

Generally true for the personnel:

$p_i(working\,time\,value, experience, motivation, spec.\,costs, number, ...)$

with i $\in$ $[operator\,excavator, truck\,driver, operator\,pump, worker\,in\,formworks, ...]$;

F(p) $\in [SO, FG, HL, OP]$; f(p) $\in [stock, const, var]$;

u(p) $\in [number, m^3/t, Euro/t, ...]$, t = time unit

The effect relationships between the individual atoms and their specific attributes are examined in more detail in the following. As a result, the previously defined atoms are combined and form molecules with their own system structure.

4.6 Molecules

Depending on the processes to be inspected, atoms are combined to form molecules. As the potential properties of atoms and, consequently, the resulting molecules are highly diverse, the following considerations are assigned to different functional areas. To set the structure of the molecules, a further discussion of the possible properties of the individual atoms is necessary. This specification is dependent on the purpose for which the molecule is to be developed.

4.6.1 Operations and procurement (OP)

4.6.1.1 Earthworks

According to Bauer (2007), earthworks can be subdivided in three main operations or procedural steps: removal, hauling, disposal. This means that the first activity is to loosen the soil and move it onto the means of transport. After the earth has been transported to the desired destination, it is unloaded, fitted and compacted. In the following, the previously defined atoms are used to devise two basic molecules, thereafter the latter being introduced in detail.

loosen:

$$m_{EA,1} := m\left(CPD, OP, a_{MA,1.1}, a_{DE,1.1}, a_{WO,1.1}\right) \in flow\ [m^3] \tag{4.15}$$

transport:

$$m_{EA,2} := m\left(CPD, OP, a_{MA,1.2}, a_{DE,2.1}, a_{WO,2.1}\right) \in flow\ [m^3] \tag{4.16}$$

For both molecules (figure 4.4 at p. 77) applies that a specific amount of material should be excavated and transported away. The process loosen is dependent on the amount of soil to be removed. The process transport can have the amount of earth to be removed as a basis, but in case the earth has been stored intermediately and is removed as a whole of in parts later on,

it appears reasonable to separately assign the amount of earth to be transported away to the process of hauling. Again it is true for both processes, that the soil to be loosened respectively be removed are additional parameters which have to be considered just like the performance values of the equipment employed for these tasks. Therefore, four more atoms need to be defined. Details are added to the previously defined units as shown in the following.
earth to excavate:

$$a_{MA,1.1} := a\,(CPD, amount\,to\,remove, OP) \in stock\;[m^3] \tag{4.17}$$

earth to transport:

$$a_{MA,1.2} := a\,(CPD, amount\,to\,transport, OP) \in stock\;[m^3] \tag{4.18}$$

performance value excavator:

$$a_{DE,1.1} := a\,(CPD, performance\,value\,excavator, OP) \in const\;[m^3/t] \tag{4.19}$$

performance value truck:

$$a_{DE,2.1} := a\,(CPD, performance\,value\,truck, OP) \in const\;[m^3/t] \tag{4.20}$$

with t = time unit
Furthermore, the staff-related units $a_{WO,1}$ and $a_{WO,2}$ need to be specified within the work molecules. In the due course of the earthworks, a time-dependent effect of experience gained by adjustment to the job may be necessary to consider.
adjustment to the job operator excavator:

$$a_{WO,1.1} := a\,(CPD, adjustment\,to\,the\,job\,factor\,excavator, OP) \in var\;[-] \tag{4.21}$$

adjustment to the job truck driver:

$$a_{WO,2.1} := a\,(CPD, adjustment\,to\,the\,job\,factor\,truck, OP) \in var\;[-] \tag{4.22}$$

Further staff-related properties are regarded in the section human resources and leadership (chapter 4.6.2 pp. 79).

4.6.1.2 Building shell

The fundamental units of the sub-process concreting (figure 4.5 at p. 78) are illustrated in the following, further units in the sub-processes formworks, reinforcing and brickworks can be developed in the same way. To begin, again a basic molecule is devised and then described in detail.

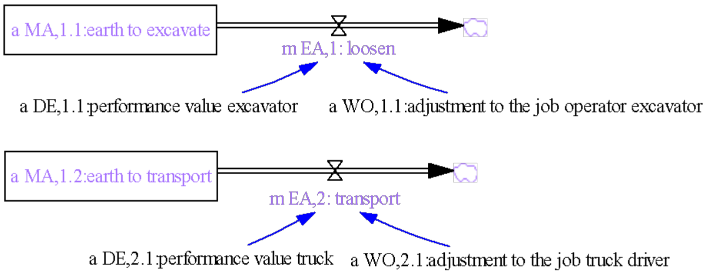


Figure 4.4: OP models for loosen and transport

concreting:

$$m_{SC,3} := m\left(CPD, OP, a_{MA,4.1}, a_{DE,3.1}, a_{WO,3.1}, , a_{WO,6.1}\right) \in flow\ [m^3] \tag{4.23}$$

Similar to earthworks, one type of material and one piece of equipment are considered here ($a_{MA,4}$ und $a_{DE,3}$). Hence, the properties have the following details:

amount of concrete to be poured:

$$a_{MA,4.1} := a\left(CPD, amount\,of\,concrete, OP\right) \in stock\ [m^3] \tag{4.24}$$

performance value concrete pump:

$$a_{DE,3.1} := a\left(CPD, performance\,value\,concrete\,pump, OP\right) \in const\ [m^3/t] \tag{4.25}$$

with t = time unit

A difference, however, is the involvement of two different groups of personnel. The inclusion of a concrete pump requires an operator ($a_{WO,3}$) on the one hand and a concrete worker ($a_{WO,6}$) on the other hand. Regardless of the fact that the concrete pump represents the central and foremost piece of equipment in this process, it appears reasonable to define the performance of the concrete worker as the maximum performance of the pump is primarily limited by the capabilities of the employee using it.[11]

performance concrete worker:

$$a_{WO,6.1} := a\left(CPD, performance\,value, OP\right) \in const\ [m^3/t] \tag{4.26}$$

with t = time unit

Similar to earthworks, in the due course of concreting a time-dependent process of gaining experience through adjustment to the task may be anticipated. This effect of adjustment to work is considered as follows:

[11] The modeler can decide himself or herself (during the design of the simulation) whether this aspect should exert any influence or not.

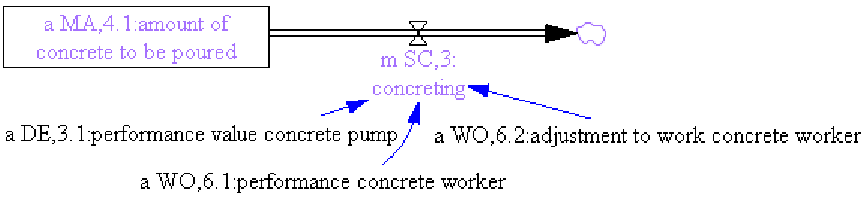


Figure 4.5: OP model concreting

adjustment to work concrete worker:

$$a_{WO,6.2} := a\left(CPD, adjustment\,to\,work\,factor\,concrete\,worker, OP\right) \in var\ [-] \tag{4.27}$$

Being a central support unit in the process of building shell construction, the crane is modeled as well. Two approaches are given as examples for the determination of the required number of cranes: Determination of crane quantity due to a) the ratio of employees per crane and b) performance of building shell construction. Taking into account the number of employees per crane follows the assumption that one crane (depending on the type of construction) can only support a limited number of workers on the construction site[12]. Thus, one more atom needs to be defined for the modeling of the crane.

workers per crane:

$$a_{DE,4.1} := a\left(CPD, workers\,per\,crane, OP\right) \in const\ [workers/crane] \tag{4.28}$$

The ratio of workers per crane results in the number of cranes I:

$$m_{DE,4.6} := m\left(CPD, OP, m_{WO,0}, a_{DE,4.1}\right) \in const\ [qty.] \tag{4.29}$$

with the sum of workers:[13]

$$\begin{aligned} m_{WO,0} \quad = \quad & \sum workers = m(CPD, OP, a_{WO,4.5}, a_{WO,5.5}, \\ & a_{WO,6.5}, a_{WO,7.5}, a_{WO,10.5}, a_{WO,11.5}) \in const\ [qty.] \end{aligned} \tag{4.30}$$

As the basic project model includes the gross volume (for details refer to p. 70), the number of cranes can alternatively be determined with the help of the building shell performance[14].

The building shell performance results in the number of cranes II:

[12]cf. Hoffmann, 2006

[13]It is the decision of the model designer whether the sum of the employees considers a supervisor respectively a crane operator or annual leave and the number of staff reported sick.

[14]cf. Hoffmann, 2006

$$m_{DE,4.7} := m\left(CPD, OP, a_{DE,4.11}, a_{DE,4.12}, a_{DE,4.13}\right) \in const\ [qty.] \tag{4.31}$$

with

building shell performance:

$$a_{DE,4.11} := a\left(CPD, gross\,volume, OP\right) \in const\ [m^3/t] \tag{4.32}$$

weight of construction material:

$$a_{DE,4.12} := a\left(CPD, construction\,material\,weight, OP\right) \in const\ [kN/m^3] \tag{4.33}$$

performance of crane:

$$a_{DE,4.13} := a\left(CPD, crane\,performance, OP\right) \in const\ [kN/t] \tag{4.34}$$

with t = time unit

Therefore, the following value is set for the calculation of the required number of cranes:

$$m_{DE,4.8} := max\begin{pmatrix} m_{DE,4.6} \\ m_{DE,4.7} \end{pmatrix} \in const\ [qty.] \tag{4.35}$$

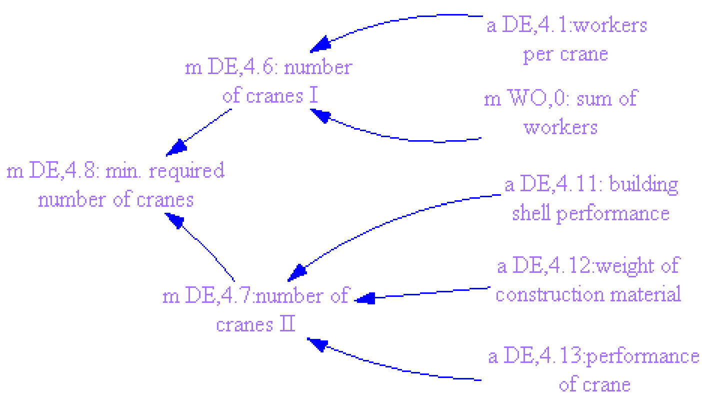


Figure 4.6: OP model number of cranes

4.6.2 Human resources and leadership (HL)

4.6.2.1 Earthworks

The personnel-related aspects in regard to the earthwork operations need to be elaborated in more detail in the previously defined units. For this aim, the following atoms are configured as examples.

Experience of excavator operator:

$$a_{WO,1.2} := a\,(CPD, experience\,factor\,excavator, HL) \in const, var\ [-] \tag{4.36}$$

Motivation of excavator operator:

$$a_{WO,1.3} := a\,(CPD, motivation\,factor\,excavator, HL) \in const, var\ [-] \tag{4.37}$$

4.6.2.2 Building shell

For the consideration of personnel-related aspects in the building shell process, the following units may be of interest, too (analog for the other trades):
Experience concrete worker:

$$a_{WO,6.3} := a\,(CPD, experience\,factor\,concrete\,worker, HL) \in const, var\ [-] \tag{4.38}$$

Motivation concrete worker:

$$a_{WO,6.4} := a\,(CPD, motivation\,factor\,concrete\,worker, HL) \in const, var\ [-] \tag{4.39}$$

Additionally, the number of employees per trade is especially important for the areas operations and procurement (OP) and finance and government (FG) (analog for the other groups of persons):
Number of concrete workers:

$$a_{WO,6.5} := a\,(CPD, number\,concrete\,workers, HL) \in const, var\ [qty.] \tag{4.40}$$

4.6.3 Finances and governance (FG)

The standard price contract is in the center of interest in the currently inspected operative area of the functional level finance and governance. This includes the separate costs of the following items of work: 1) labor costs, 2) costs of construction material and 3) equipment costs.[15]

4.6.3.1 Earthworks

Independently of the required performance, the accumulating costs are of paramount interest. To be able to calculate their values, further units are generated on the basis of the previously defined atoms and molecules. The properties of the deployed equipment and machinery have to be included, as the following exemplary development of further units for one piece of equipment demonstrates. Further equipment can be developed in the same pattern. Equipment costs are normally subdivided into the costs of inventory and maintenance on the one hand (contingency

[15] cf. Leimböck & Klaus (2007)

costs) and operating costs on the other hand.[16] Therefore, the molecule $m_{DE,1}$ (with the given example of an excavator) consists of the two molecules $m_{DE,1.1}$ und $m_{DE,1.4}$ which have to be specified.

equipment costs excavator:

$$m_{DE,1} := m\,(CPD, FG, m_{DE,1.1}, m_{DE,1.4}) \in const, var\ [Euro/t] \tag{4.41}$$

The contingency costs $m_{DE,1.1}$ consider elements of depreciation and interest rates as well as the repair costs[17] in the molecule $m_{DE,1.3}$. Furthermore, contingency costs include the reinstatement value of the equipment $a_{DE,1.2}$ and also the rates of depreciation and interest $a_{DE,1.3}$.

contingency costs excavator:

$$m_{DE,1.1} := m\,(CPD, FG, m_{DE,1.2}, m_{DE,1.3}) \in const\ [Euro/t] \tag{4.42}$$

The molecule $m_{DE,1.2}$ contains the calculation of the value for depreciation and interest in dependence on the mean reinstatement value:

reinstatement value excavator:

$$a_{DE,1.2} := a\,(CPD, reinstatement\,excavator, FG) \in const\ [Euro] \tag{4.43}$$

depriciation and interest rate excavator:

$$a_{DE,1.3} := a\,(CPD, depriciation\,and\,interest\,rate\,excavator, FG) \in const\ [\%/t] \tag{4.44}$$

depriciation and interest value excavator:

$$m_{DE,1.2} := m\,(CPD, FG, a_{DE,1.2}, a_{DE,1.3}) \in const\ [Euro/t] \tag{4.45}$$

with t = time unit;

Similarly, maintenance costs are calculated as percentage of the mean reinstatement value in the molecule $m_{DE,1.3}$:

repair rate excavator:

$$a_{DE,1.4} := a\,(CPD, repair\,rate\,excavator, FG) \in const\ [\%/t] \tag{4.46}$$

repair value excavator:

$$m_{DE,1.3} := m\,(CPD, FG, a_{DE,1.2}, a_{DE,1.4}) \in const\ [Euro/t] \tag{4.47}$$

[16] cf. Girmscheid & Motzko (2007)
[17] cf. Leimböck & Klaus (2007)

with t = time unit;

It has to be considered that the contingency costs are usually determined for a period of one month. Hence, the introduction of an auxiliary variable is necessary (factor 1 for simulation step), which adapts the result of molecule $m_{DE,1.1}$ according to the time increments used in the simulation (days, weeks, months, quarters).

$$a_{AUX,1} := a\,(CPD, factor\,1\,for\,simulation\,step, FG) \in const\ [Mo/t] \tag{4.48}$$

To specify the operational costs in relation to time, atoms are devised from the following parameters: a) engine power, b) fuel consumption, c) fuel costs and d) lubricant surcharge.

engine power excavator:

$$a_{DE,1.5} := a\,(CPD, engine\,power\,excavator, FG) \in const\ [Kw] \tag{4.49}$$

fuel consumption excavator:

$$a_{DE,1.6} := a\,(CPD, spec.\,fuel\,consumption\,excavator, FG) \in const\ [l/Kwh] \tag{4.50}$$

fuel costs excavator:

$$a_{DE,1.7} := a\,(CPD, fuel\,costs\,excavator, FG) \in const\ [Euro/l] \tag{4.51}$$

lubricant surcharge excavator:

$$a_{DE,1.8} := a\,(CPD, lubricant\,surcharge\,excavator, FG) \in const\ [\%] \tag{4.52}$$

Finally, the costs of the operating fluids are summarized in the following molecule.

costs of operating fluids excavator:

$$m_{DE,1.4} := m\,(CPD, FG, a_{DE,1.5}, a_{DE,1.6}, a_{DE,1.7}, a_{DE,1.8}) \in const\ [Euro/h] \tag{4.53}$$

Similarly to the contingency costs of the equipment, the costs of the operating fluids are usually calculated per operating hour. Therefore, it is necessary again to introduce a further auxiliary variable ($a_{AUX,2}$), which adapts the results of the molecule $m_{DE,1.4}$ according to the time increments used in the simulation (days, weeks, months, quarters).

$$a_{AUX,2} := a\,(CPD, factor\,2\,for\,simulation\,step, FG) \in const\ [h/t] \tag{4.54}$$

In case the costs of the excavator operator are supposed to be allocated to the equipment costs, the already introduced atom $a_{WO,1}$ has to be specified with the individual properties of the operator.

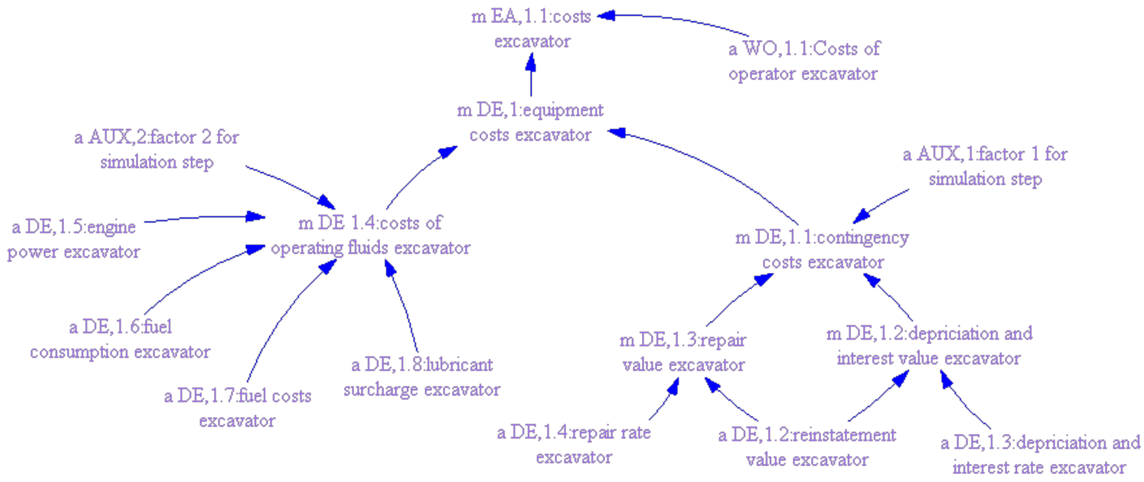


Figure 4.7: FG model of one item of construction equipment (example excavator)

costs of operator excavator:

$$a_{WO,1.1} := a\,(CPD, , spec.\,costs\,operator\,excavator, FG) \in const\ [Euro/t] \tag{4.55}$$

with t = time unit

Thus, the following molecule describes the overall costs of the equipment:

costs excavator:

$$m_{EA,1.1} := m\,(CPD, FG, m_{DE,1}, a_{WO,1.1}) \in const\ [Euro/t] \tag{4.56}$$

with t = time unit

An overview of the units developed in this context and their relationships is shown in figure 4.7. Based on the previous units, further construction equipment can be developed accordingly.[18]

Apart from the equipment costs, it has to be taken into account that the removed material causes costs itself. In case the excavated earth is to be disposed, the following applies:

spec. costs earth disposal:

$$a_{MA,1.3} := a\,(CPD, spec.\,costs\,earth\,disposal, FG) \in const\ [Euro/m^3] \tag{4.57}$$

costs earth disposal:

$$m_{EA,1.2} := m\,(CPD, FG, a_{MA,1.1}, a_{MA,1.3}) \in const\ [Euro/t] \tag{4.58}$$

with t = time unit

[18]The required data can be acquired from, e.g. Baugeräteliste (2007)

In case the excavated material is to be stored temporarily, storage costs need to be included in the calculation. As storage capacities are not necessarily equal to the amount of the excavated material ($a_{MA,1.1}$) (they may be larger or smaller), it is required to define the capacity of a storage on basis of the atom $a_{ST,1}$ in more detail.
capacity earth storage:

$$a_{ST,1.1} := a\,(CPD, capacity\,earth\,storage, OP) \in const\ [m^3] \tag{4.59}$$

Analog to the molecule $m_{EA,1.2}$, the costs for the earth storage are calculated in the following. However, the storage capacity is considered and not the excavated amount of earth.
spec. costs earth storage:

$$a_{MA,1.4} := a\,(CPD, spec.\,costs\,earth\,storage, FG) \in const\ [Euro/m^3] \tag{4.60}$$

costs earth storage:

$$m_{EA,1.3} := m\,(CPD, FG, a_{MA,1.4}, a_{ST,1.2}) \in const\ [Euro/t] \tag{4.61}$$

with t = time unit
As the ground removed in earthworks can normally be used again in other projects, there are possibly additional earnings to be considered. As it cannot be taken for granted that the material can be reused and sold for the same price at the point of time of removal, a specification of the re-usable amount of earth is necessary, similar to the earth storage. A further atom is specified on the basis of the previously defined atom $a_{MA,1}$.
reusable amount of earth:

$$a_{MA,1.5} := a\,(CPD, amount\,reusable\,earth, OP) \in stock\ [m^3] \tag{4.62}$$

Based on this, the specific earnings can be included to calculate the overall earnings in the area of reutilization.
spec. earnings earth:

$$a_{MA,1.6} := a\,(CPD, spec.\,earnings\,earth, FG) \in const\ [Euro/m^3] \tag{4.63}$$

earnings earth:

$$m_{EA,1.4} := m\,(CPD, FG, a_{MA,1.5}, a_{MA,1.6}) \in const\ [Euro/t] \tag{4.64}$$

with t = time unit
The above-mentioned units allow a diversity of combinations to illustrate disposal, storage of earth or its reutilization. A graphic overview of the units in this context is shown in figure 4.8.

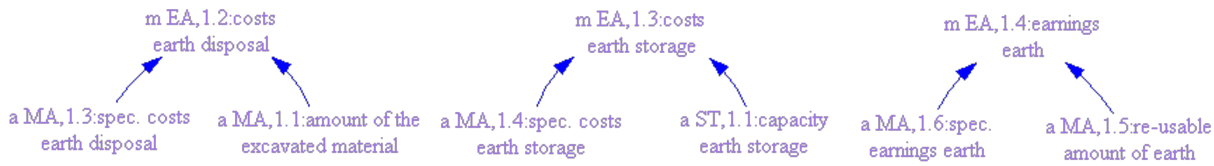


Figure 4.8: FG model for disposal, storage and reutilization of earth

A combination of the previously developed molecules can be used to define single components as to be seen in chapter 4.7 (p. 88 ff); these are the first mini-systems.

4.6.3.2 Building shell

Like in the area of operations and procurement (p. 75), the main interest is the costs of the concreting process again. The units developed in this context can be modeled for the other trades following the same procedure. Taking into account the previously devised units for the calculation of the equipment costs in the area of earthworks, the equipment costs are determined for the concrete pump involved in the concreting process. Opposed to that, the costs of material and personnel need to be differentiated much more than before. To specify the expenses for the material, the price of concrete and the quantity of it to be deployed are taken into account.

price of concrete:

$$a_{MA,4.2} := a\,(CPD, spec.\,costs\,concrete, FG) \in const\;[Euro/m^3] \tag{4.65}$$

concrete costs:

$$m_{MA,4.1} := m\,(CPD, FG, a_{MA,4.1}, a_{MA,4.2}) \in const\;[Euro/t] \tag{4.66}$$

with t = time unit

A possible and process-related concrete loss has to be considered and is included in an atom with a percentage factor of the overall quantity of concrete to be processed.

concrete loss:

$$a_{MA,4.3} := a\,(CPD, factor\,of\,concrete\,loss, FG) \in const\;[\%] \tag{4.67}$$

The atom $a_{MA,4.3}$ causes an increase of the needed quantity of concrete ($a_{MA,4.1}$), resulting in an increase of the construction material costs. Apart from the material costs, the personnel costs represent another part of the overall expenses. Therefore, the labor costs for this process are modeled in relation to the amount of concrete to be deployed $a_{MA,4.1}$, the performance value of the personnel $a_{WO,6.1}$, the number of the assigned employees $a_{WO,6.5}$ and their pay $a_{WO,6.3}$ (figure 4.5).

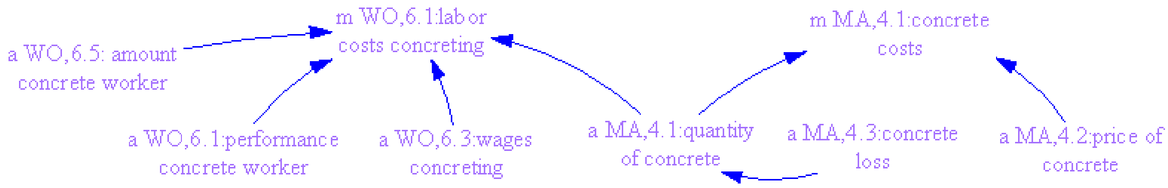


Figure 4.9: FG model concreting

labor costs concreting:

$$m_{WO,6.1} := m\left(CPD, FG, a_{MA,4.1}, a_{WO,6.1}, a_{WO,6.3}\right) \in const\ [Euro] \tag{4.68}$$

wages concreting:

$$a_{WO,6.3} := a\left(CPD, spec.\, wages\, concrete, FG\right) \in const\ [Euro/t] \tag{4.69}$$

with t = time unit

More basic values are needed to describe the construction site setup as part of the building shell process. Based on the previously defined atom $a_{DE,5}$ to $a_{DE,15}$ (refer to p. 74), the following additional units are necessary:

workers per container:

$$a_{DE,5.1} := a\left(CPD, workers/container, OP\right) \in const\ [workers/qty.] \tag{4.70}$$

foremen per container:

$$a_{DE,6.1} := a\left(CPD, foremen/container, OP\right) \in const\ [foreman/qty.] \tag{4.71}$$

construction manager per container:

$$\begin{aligned} a_{DE,7.1} &= a(CPD, construction, manager/container, OP) \\ &\in const\ [construction\, manager/qty.] \end{aligned} \tag{4.72}$$

persons per sanitary facility:

$$a_{DE,8.1} := a\left(CPD, Persons/container, OP\right) \in const\ [persons/qty.] \tag{4.73}$$

persons per first aid ward:

$$a_{DE,9.1} := a\left(CPD, persons/first\, aid\, ward, OP\right) \in const\ [persons/qty.] \tag{4.74}$$

Including the previously defined number of persons per trade ($a_{WO,4.5}$, $a_{WO,5.5}$, $a_{WO,6.5}$ and $a_{WO,7.5}$) respectively the supervisory personnel ($a_{WO,10.5}$ and $a_{WO,11.5}$), the number of required elements for the construction site setup can be specified with the following molecules:

number of worker containers:

$$m_{DE,5.1} := m\,(CPD, FG, a_{DE,5.1}, a_{WO,4.5}, a_{WO,5.5}, a_{WO,6.5}, a_{WO,7.5}) \in const\ [qty.] \tag{4.75}$$

number of foreman containers:

$$m_{DE,6.1} := m\,(CPD, FG, a_{DE,6.1}, a_{WO,10.5}) \in const\ [qty.] \tag{4.76}$$

number of construction manager containers::

$$m_{DE,7.1} := m\,(CPD, FG, a_{DE,7.1}, a_{WO,11.5}) \in const\ [qty.] \tag{4.77}$$

number of containers/sanitary facilities:[19]

$$\begin{aligned} m_{DE,8.1} : \;=\; & m(CPD, FG, a_{DE,8.1}, a_{WO,4.5}, a_{WO,5.5}, a_{WO,6.5}, \\ & a_{WO,7.5}, a_{WO,10.5}, a_{WO,11.5}) \in const\ [qty.] \end{aligned} \tag{4.78}$$

According to Poloczek (2013), the majority of construction businesses in the surface construction industry rents containers for social purposes, offices and storage facilities. Therefore, the specific and time-related costs per unit ($a_{DE,5.6}$) can be used to calculate the expenses for the above-mentioned elements as shown in the following example:[20]

spec. costs personnel containers:

$$a_{DE,5.6} := a\,(CPD, spec.\,costs\,personnel\,container, FG) \in const\ [Euro/t\,per\,qty.] \tag{4.79}$$

costs personnel container:

$$m_{DE,5.2} := m\,(CPD, FG, m_{DE,5.1}, a_{DE,5.6}) \in const\ [Euro/t] \tag{4.80}$$

with t = time unit

Alternatively, the costs for the construction site containers can be modeled similarly to the previously illustrated, more general approach for construction equipment. The relation between the above-mentioned units is shown by the example of four molecules in figure 4.10. However, on condition that there is or are more than one container of one type, this example follows the

[19] Number of required containers with first aid ward and equipment likewise ($m_{DE,9.1}$).
[20] Further elements of a construction site setup to be modeled accordingly.

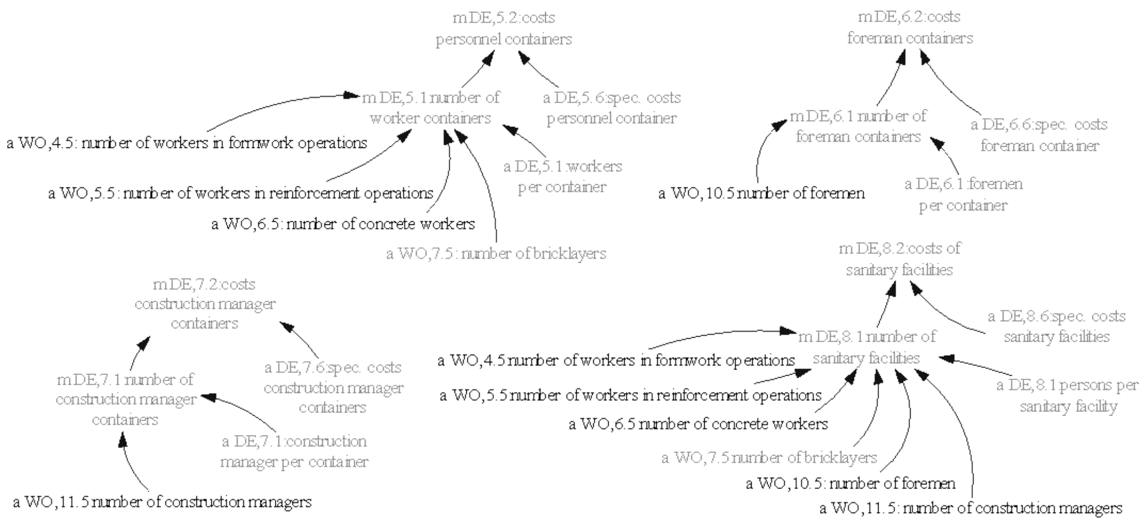


Figure 4.10: FG models construction containers

assumption that all containers of this one type are identical.[21]

4.7 Components

This phase of the modeling is characterized by the linking of molecules and atoms to form components which have their own internal problem-related processing logic. Building up on the already modeled units, these components depict a) the construction site setup, b) the earthworks and finally c) the process of the building shell construction.

4.7.1 Costs of construction site setup

The component *costs of construction site setup* ($c_{SF,1}$) is primarily composed of the two central parts a) container and b) crane.

$$\begin{aligned} c_{SF,1} : \; &= \; c(CPD, FG, m_{DE,4.5}, m_{DE,5.2}, m_{DE,6.2}, m_{DE,7.2}, \\ & \quad m_{DE,8.2}, m_{DE,4.5}, m_{DE,4.8}) \in const, var \; [Euro/t] \end{aligned} \tag{4.81}$$

with t = time unit

The above-mentioned components build up on the previously modeled units and are dependent on the employees of the construction site. Beyond this, the number of required industrial workers is also dependent on the amount of material to be deployed and used (this relationship will be considered in the subsequent generation of the project model, for details refer to p. 106 ff). Thus,

[21] Nevertheless, the open concept of the SDL approach makes different realizations possible on the basis of existing units, i.e. further specification can also allow different construction site containers per type.

the component construction site setup comprises units from the area operations and procurement on the one hand and from finances and leadership on the other hand. The further modeling is carried out on the assumption that all elements of the construction site setup (like containers or cranes) are identical in their categories if there is more than one of them. Based on the atoms defined in chapter 4.5, the separate elements of the construction site setup are primarily linked to the groups of persons which influence the number of elements. The sum of employees was already given on page 78 with the unit $m_{WO,0}$ and will be included in the subsequent procedure of the modeling. The following units are set as completely independent of the personnel:

- costs meeting rooms ($m_{DE,10.2}$)
- costs tools and hardware storage ($m_{DE,11.2}$)
- costs construction material storage ($m_{DE,12.2}$)
- costs operating supplies storage ($m_{DE,13.2}$)
- costs construction site workshops ($m_{DE,14.2}$)
- costs laboratories ($m_{DE,15.2}$)[22]

Further costs for the preparation and realization of a road transport infrastructure or other routes of transport, the construction site safety or the provision and disposal of media are incorporated as unit $a_{DE,16}$ and take the other costs of the construction site setup into account as one flat sum per simulation step. In regard to the modeling of the crane, its operation and standby displays similarities to the already introduced modeling of equipment, but fuel type and quantity is not based on the consumption of diesel, but on electricity. This aspect is going to play a role in chapter 5.1 on page 106 ff. Furthermore, the auxiliary unit $a_{AUX,3}$ is introduced during the determination of the required number of cranes in the component construction site setup. This auxiliary reflects the fact that not all workers of one construction site can access the support of the crane simultaneously[23].

$$a_{AUX,3} := a\left(CPD, parallelization\,factor, FG\right) \in const, var\ [-] \tag{4.82}$$

To illustrate the costs of the construction site setup, the above-mentioned considerations lead to the component $c_{SF,1}$, shown in figure 4.11.

[22] The modeler can decide whether and in which number the unit(s) should be represented in the model by choosing the appropriate quantity of units. If, e.g. no construction material storage is planned, the unit $a_{DE,12.1}$ can be set to zero (0) or can be removed entirely. However, if this quantity is dependent on further input parameters (e.g. the amount of building shell construction to be performed), the atom $a_{DE,12.1}$ can be expanded to the molecule $m_{DE,12.1}$, in which the unit quantity is specified by the other parameters.

[23] The unit can be set to values between one (1) and zero (0), whereas the value one means that all workers need to be considered in the calculation of the required crane quantity and, respectively, a value of 0.5 means that only half of the workers need to be considered. Finally, it is the model designer who can decide whether this factor plays a role at all and to which degree.

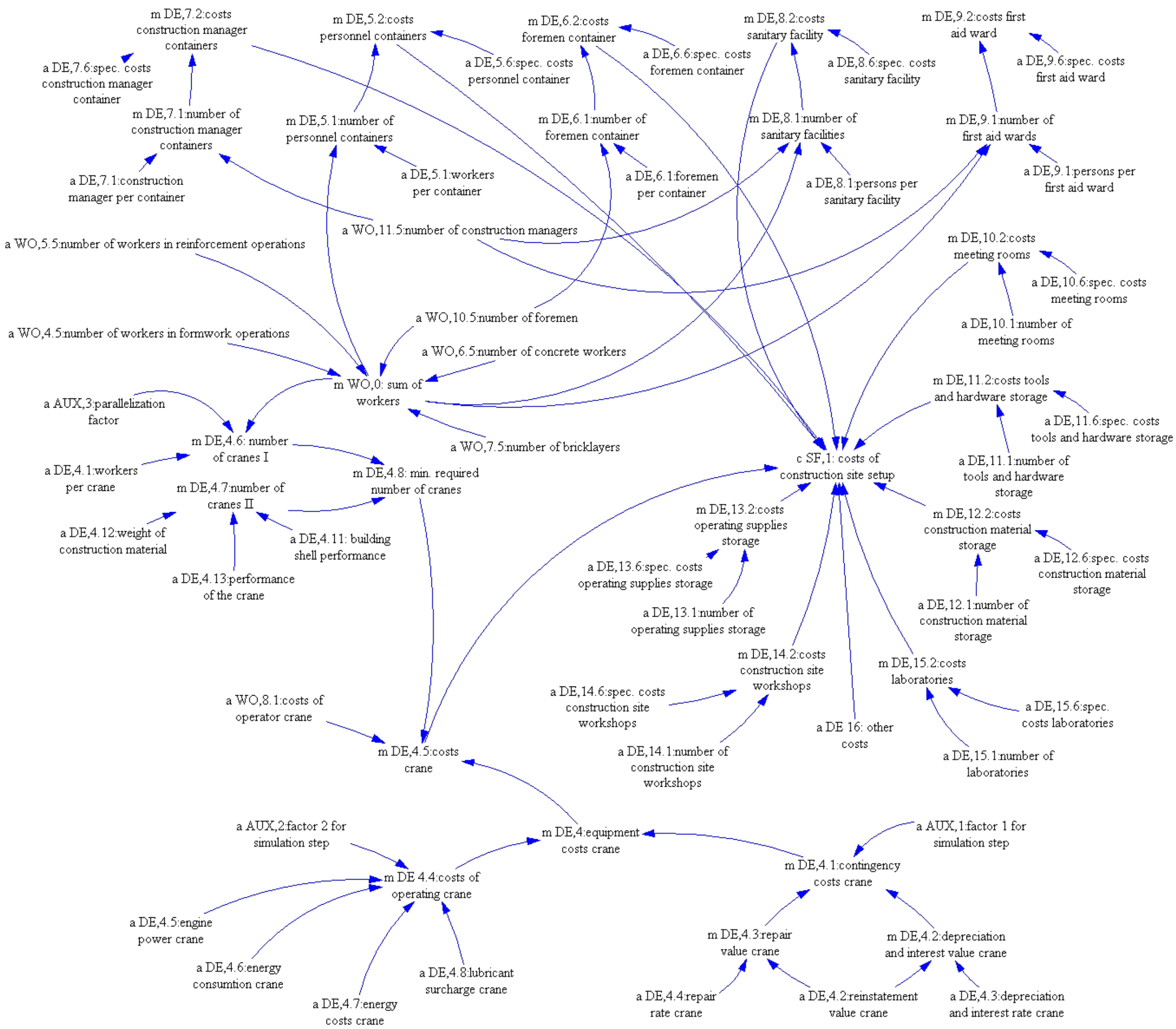


Figure 4.11: Components of construction site setup costs

4.7.2 Costs of earthworks

When modeling the costs of earthworks, it has to be determined whether a direct relationship exists between the removal of the earth, i.e. the primary piece of equipment in this context, the excavator or some other device with this purpose, and the process of transport realized with the help of the involved means of transport. If removal and means of transport form a logical chain, the required number of transport vehicles has to be established in dependence of the performance value of the removal device, e.g. the excavator. If, however, the loosened and removed earth is temporarily stored and potentially transported away at a later point of time, the number of needed means of transport cannot directly be derived from the performance of the removal equipment. In this case, the process of transport can usually be seen as independent of the loosening and excavation of the material. Hence, two components are introduced in the section of earthworks: a) *costs of earthworks without interim earth storage* and b) *costs of earthworks with interim earth storage*. Both units are based on the assumption that the excavating device can either directly load the material onto the transport vehicle or the storage can be filled directly from the excavator without the necessity to realize additional transport processes. Beyond this it is expected that several devices of one employed type, e.g. excavating devices or means of transport, always entail identical technical specifications.

As a consequence of the simulated time increments (hour, day, week, month etc.), it may be reasonable to consider the required time of the transport device. As the subsequent simulation may have time steps ranging from weeks to months, the separate consideration of the loading time as an independent unit does not appear sensible and is therefore included with the performance value of the removal device.[24]

As the atom $a_{MA,1.1}$ represents one level, it is required to fix the demanded amount of excavated earth in the component, thus allowing the reference of this value in the subsequent simulation. Hence, the required amount of earth to be excavated is included as a constant value as follows.

demanded amount of excavated earth:

$$a_{MA,1.0} := a\,(CPD, amount\,of\,excavated\,earth, OP) \in const\ [m^3] \tag{4.83}$$

Similarly to the example of brickworks on page 54, an end condition has to be established to indicate the completely achieved excavation amount. For this purpose the following auxiliary unit is used.[25].

$$a_{AUX,4} := a\,(CPD, excavation\,completed, OP) \in const\ [-] \tag{4.84}$$

[24] Depending on the aim of the simulation, it may be necessary to devise a model with smaller simulation steps. In such cases, the open architecture of CDL offers the possibility to complement existing units with further atoms and/or complete molecules to depict additional boundary conditions and relationships.

[25] The auxiliary unit $a_{AUX,4}$ can also play a facilitating role in the subsequent modeling of the functional area finance and governance, as it provides the basis for the process parameters schedule performance index (SPI), time estimate at completion (TEAC) and others (cf. Krause & Arora (2008)).

In the case that a part of the earth is to be used again, a differentiation between deposited earth and reusable earth ($a_{MA,1.5}$ on p. 84) has to be specified.

deposited amount of earth:

$$a_{MA,1.7} := a\,(CPD, deposited\,amount\,of\,earth, OP) \in stock\ [m^3] \tag{4.85}$$

The distribution of the demanded amount of excavated earth is realized with a relative value, which is depicted with the auxiliary unit $a_{AUX,5}$.

relative value[26]:

$$a_{AUX,5} := a\,(CPD, proportion\,disposal, OP) \in const\ [-] \tag{4.86}$$

The description of the two different groups of earth is based on the assumption, that the first layer of excavated earth is the reusable part and the earth to be disposed will be found in the later stages of the excavation process. To calculate the costs of the involved equipment in the sub-process loosen, the number of excavation devices planned for this task in the area operations and procurement is required.

$$a_{DE,1.9} := a\,(CPD, number\,excavators, OP) \in const, var\ [qty.] \tag{4.87}$$

As the necessary number of transport devices depends on the performance of the excavating equipment[27], the following molecule is devised to calculate this number in direct relation to the loosening process ($m_{EA,1}$), the performance value of the transport device ($a_{DE,2.1}$), the relative proportion of material to be transported (considered by $a_{AUX,5}$ in $a_{MA,1.5}$ and $a_{MA,1.7}$) and a potential adjustment to the job effect of the equipment operator ($a_{WO,2.1}$).

number of trucks:

$$m_{DE,2.5} := m\,(CPD, OP, m_{EA,1}, a_{DE,2.1}, a_{AUX,5}, a_{WO,2.1}) \in const, var\ [qty.] \tag{4.88}$$

The linking of these units to determine the equipment costs and the required quantity of devices for this process results in the overall equipment costs. The transport costs are based on the assumption that the employed means of transport for each route of transport or each destination are identical. Due to this, the number of necessary transport vehicles is added in the according molecules.[28]

costs of excavation:

[26] The value for $a_{MA,1.5}$ results out of $a_{MA,1.0} \cdot (1 - a_{AUX,5})$

[27] cf. Hoffmann (2006)

[28] Nevertheless, when using the units of the CDL, the model designer can decide himself or herself whether this simplification should be applied to the model in development. A classification of the equipment costs, e.g. according to the destination of transport, can be realized without any difficulties by repeated integration of the molecule $m_{EA,2.1}$ in combination with the corresponding number of transport devices.

$$m_{EA,1.5} := m\,(CPD, FG, m_{EA,1.1}, a_{DE,1.9}) \in stock\ [Euro] \tag{4.89}$$

costs of transport:

$$m_{EA,1.6} := m\left(CPD, FG, m_{EA,2.1}, \sum m_{DE,2.5}\right) \in stock\ [Euro] \tag{4.90}$$

Taking into account the molecules already introduced in chapter 4.6.3 on page 85, costs of earth disposal ($m_{EA,1.2}$) and additional earnings of earth reutilization ($m_{EA,1.4}$), the general costs for earthworks without interim earth storage are determined with the help of the following component (figure 4.12 [29]).

$$c_{EA,1} := c\,(CPD, FG, m_{EA,1.2}, m_{EA,1.4}, m_{EA,1.5}, m_{EA,1.6}) \in stock\ [Euro] \tag{4.91}$$

In contrast to component $c_{EA,1}$, the following component $c_{EA,2}$ integrates an interim storage of the excavated material. As already mentioned in the introduction of this chapter, the equipment used for the earth removal and the transport devices are not directly linked to each other. This means that the excavated material can be transported away at any point of time and the number of required transport devices ought to be viewed independently of the loosening process. For this, the modeling of $c_{EA,2}$ needs to differentiate three fundamental cases.

- case A: the quantity of available material in the storage is insufficient, i.e. the removal performance is not equivalent to the transport capacity of the vehicles and a transport standstill is the consequence.
- case B: the removal performance exceeds the transport capacity, i.e. an interim earth storage takes place.
- case C: the removal performance exceeds the transport capacity of the transport equipment, but at the same time it exceeds also the storage capacity, i.e. the removal process is halted.

Analog to the component $c_{EA,1}$, the time which is needed for the loading of the transport device with material from the storage is not explicitly represented in $c_{EA,2}$ (refer to p. 91). In the following, $c_{EA,2}$ is developed on the basis of $c_{EA,1}$. At the beginning, similarly to the required amount of excavation $a_{MA,1.0}$, the maximum capacity of the earth storage needs to be fixed in accordance to the unit $a_{ST,1.1}$ (refer to p. 84) and linked to the unit $m_{EA,1}$. The desired result is the halted excavation in case of a full storage. Furthermore, the previously defined unit $a_{MA,1.2}$ is substituted with the according storage capacity.

$$a_{ST,1.2} := a\,(CPD, capacity\,of\,used\,storage, OP) \in stock\ [m^3] \tag{4.92}$$

The independence of the processes excavation and transport is achieved by removing the rela-

[29] Note: the unit $a_{MA,1.2}$ should serve a) better understanding, b) as confirmation of plausibility ($a_{MA,1.2}$ has to be zero at all times, as nothing is stored) and c) for the facilitated preparation of the component earthworks including interim storage. The component $c_{EA,1}$ could also be modeled without $a_{MA,1.2}$.

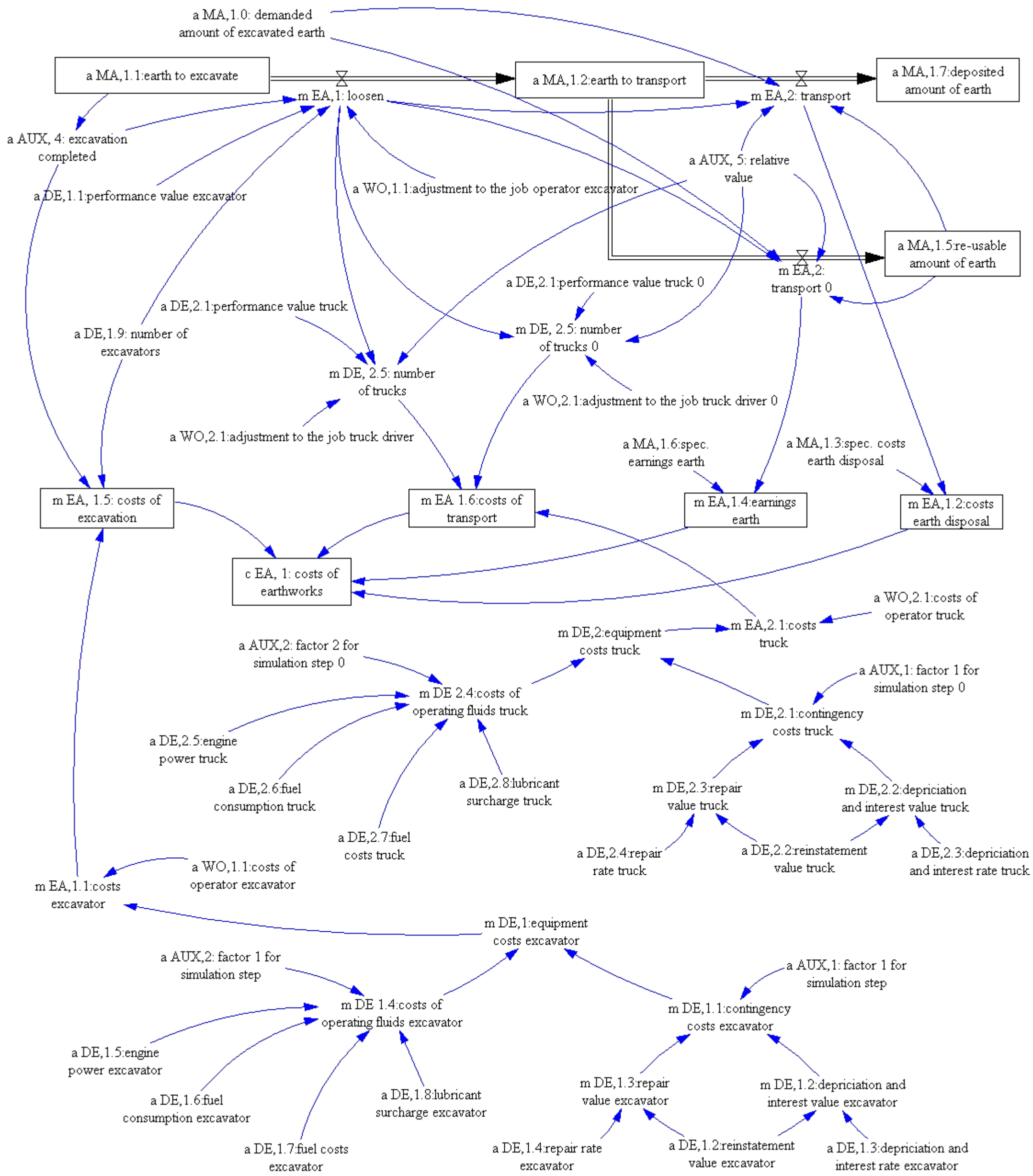


Figure 4.12: Component costs of earthworks excluding storage

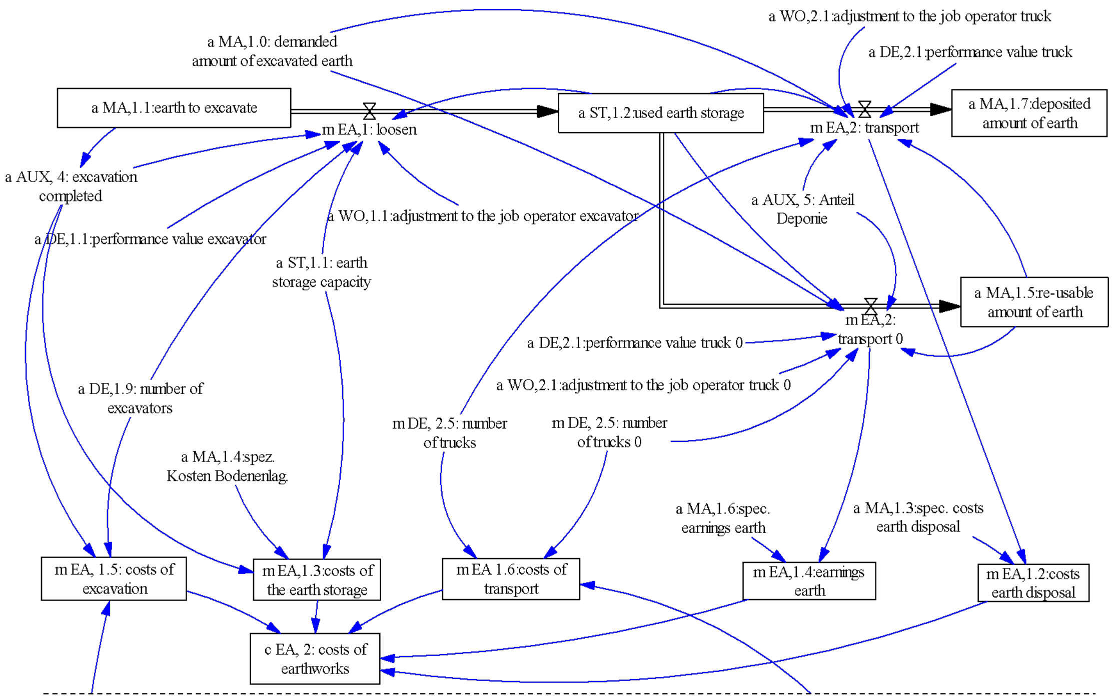


Figure 4.13: Component costs of earthworks including storage

tionships between $m_{EA,1}$ and the number of required transport devices ($a_{DE,2.5}$). With this new independence of the earth removal process, the performance values of the transport devices as well as the potentially applicable effects of adjustment to the job do not have to be considered anymore in the calculation of the required number of devices, but are directly included in the transport processes itself ($m_{EA,2}$). Finally, the costs of the earthworks are expanded with the molecule $m_{EA,1.3}$ to reflect the costs of the earth storage.

$$c_{EA,2} := c\,(CPD, FG, m_{EA,1.2}, m_{EA,1.3}, m_{EA,1.4}, m_{EA,1.5}, m_{EA,1.6}) \in stock\ [Euro] \qquad (4.93)$$

Figure 4.13 shows the component $c_{EA,2}$ with the changed units only; the units not shown here are analog to $c_{EA,1}$.

The combination of the components $c_{EA,1}$ and $c_{EA,2}$ can aid the development of further components, which could, e.g., illustrate the interim storage of the reusable earth (possibly top soil or surface soil) and the subsequent direct disposal of contaminated earth to a repository. This example shows the potential and flexibility of the CDL, with whose help a multitude of new units can be created on the basis of already existing ones.

4.7.3 Costs building shell

Based on the general project model (compare 4.3 on p. 70) and apart the already discussed processes, the component *costs building shell* ($c_{SC,5}$) incorporates the sub-processes formworks

($c_{SC,1}$)[30], reinforcing ($c_{SC,2}$), concreting ($c_{SC,3}$) and brickworks ($c_{SC,4}$). For this aim, an individual component will be modeled for each sub-process, all of which can finally be found in the component costs building shell.

$$c_{SC,5} := c(CPD, FG, c_{SF,1}, c_{SC,2}, c_{SC,3}, c_{SC,4}, \left\{ \begin{array}{c} c_{EA,1} \\ c_{EA,2} \end{array} \right\}, \left\{ \begin{array}{c} c_{SC,1.1} \\ c_{SC,1.2} \end{array} \right\}) \in stock\ [Euro] \tag{4.94}$$

4.7.3.1 Standard component

As a preparational step, a standard component is devised to serve as a basis for the modeling of the above-mentioned components. The aim of this development is, on the one hand, the illustration and research of the dependencies and effect-relationships within a production process in the construction context. On the other hand, the standard component should offer practical possibilities, e.g. to guarantee an uninterrupted production with optimized storage expenses through minimal storage capacities and minimized numbers of placed orders. To reach this aim, the component should generate options to influence a reduction or minimization of payments, so that frequencies of orders and the ordered quantities can be varied in such a fashion, that outgoing payments are distributed regularly within a given period of time. A more detailed examination of the cash flow[31] including the debits and credits within a production process is not implemented in this phase. In the end, the standard component is requested to be able to depict the following:

1. Illustration of a construction-specific production process including performance values, material losses etc.
2. Inclusion of influences exerted by work results of substandard quality and their remedy.
3. Consideration of personnel-related requirements like adjustment to the job, experience, motivation and overtime.
4. Illustration of limited storage capacities including potential material losses due to the storage itself (only applicable if a storage is planned for the according material).
5. Visualization of fundamental supply chains; especially consideration of delays caused by order placement, processing and delivery of material.
6. The storage should be used to capacity and the continuous production process guaranteed by constantly adjusted and monitored economic order quantities.
7. The ordered quantity should be adjustable even in accordance to the predicted production.

[30] As mentioned on p. 71, a distinction is necessary in $c_{SC,1}$ between timber formworks ($c_{SC,1.1}$) and system formworks ($c_{SC,1.2}$) which will be considered in the subsequent modeling process.

[31] This parameter of productivity shows the flow of financial resources in a set period (usually 12 months) as a result of working capital cycles and is therefore available for investments (cf. Krause & Arora (2008)).

8. The point in time of the last order placement should be free to define individually, so that a potentially available remaining quantity of material in the storage can be minimized.
9. A maximum of possibilities should be given to influence and examine the behavior of the component.
10. Illustration of the parameters respectively auxiliaries as, e.g., average storage time, actual production performance or prospective duration of production.
11. Open structure to allow expansion and integration of potentially required additional aspects in the further procedure of the development. This could, for example, include different risks and their influence.

Beyond these demands, the standard component is subject to the following conditions as well:

1. As the maximum period of time for the completion of the construction task is usually limited and set in the contract, the end of the process as set in the model should be seen as fixed.
2. The maximum storage capacity is limited, but can be reduced if necessary.
3. The storage (if existing for the according material) is completely stocked at the beginning of the process.
4. The frequency of order placement should be minimized in the sense of supply chain management[32].
5. The ordered amount is generally dependent on the fixed end of the process and the order frequency.
6. The stock of inventory, the production performance, potential delays as well as the already present material need to be considered when calculating the order amount.
7. Only one supplier exists for one material, i.e. there is no competition of different suppliers.
8. The supplier can always deliver the requested material at each point in time and in the ordered quantity and quality, independent of possible delays in order processing or delivery itself.
9. The availability of the material on the market is not limited.
10. The delivered material does not incur quantitative or qualitative losses or damage during the shipping procedure.
11. Quantitative material losses are only caused in the storage or during the handling at work.
12. The material taken from the storage is always of the expected quality. There is no loss of quality during the storage process.
13. Flaws in production and workmanship are only a consequence of experience, motivation or the overtime of the personnel.
14. Substandard performance of the production process itself is, apart from an insufficient speed of production, entirely impossible.

[32] cf. Krüger & Steven (2000)

15. Volatile acquisition prices of material neither have an impact on the order amount nor on the order frequency. Therefore, tactical order placement[33] is impossible.
16. The employer can always bring in requests and demand changes of the plan, resulting in necessary adaptations of the implementation and according quantities.[34]

Including the previously defined units, a production molecule serves as a fundamental basis and is successively complemented with further units in accordance to the simulation aim. To fulfill the previously listed requirements of the standard component, it is indispensable to develop further units which consider the aspects supply chain and flaws in workmanship. This results in the design of additional units, especially in the functional area operations and procurement (OP). To allow a clearly laid out overview, the nomenclature of SDL is omitted in figure 4.14 in the illustration of the different levels.

The standard component makes it already possible to thoroughly investigate the economic impact of production, storage, delivery etc. The required components for the sub-processes formworks ($c_{SC,1}$), reinforcing ($c_{SC,2}$), concreting ($c_{SC,3}$) and brickwork ($c_{SC,4}$) are developed out of the standard component in the following section.

4.7.3.2 Formworks

A distinction between timber formworks ($c_{SC,1.1}$) and system formworks ($c_{SC,1.2}$) is made in this component. Both need to be present on the construction site in sufficient quantity and at a specific point in time. Thus, in these two components of formworks the same constraints play a role as in the standard component, both in regard to orders and delivery. The component $c_{SC,1.1}$ does not require significant adaptations, as it is completely represented by the standard component. In contrast to this, the use of system formworks has to consider the aspect of reusability. Consequently, a further connection between production and storage has to be established in component $c_{SC,1.2}$, to picture the amount of returned formwork elements and the influence of their duration in the process. To integrate the wear and tear of formwork elements, an additional wear ratio needs to be integrated into the component. Lastly, the material expenses which are only generally characterized as costs of material in the standard component need to be specified in more detail in $c_{SC,1.2}$. Here, two possibilities are available. First, in case the formwork system has been modeled as its own component of equipment costs in the SDL, it can be linked here. Secondly, however, the formwork elements, armaments and shear walls are frequently rented in surface construction[35], so it is equally possible to include the rental costs per time unit. Figure 4.15 shows the component for the formwork processes with system elements which is derived from the standard component.

As no significant changes are necessary for the component $c_{SC,1.1}$ (timber formwork) in comparison to the standard component, an illustration can be omitted here.

[33] cf. Malkwitz & Karl (2013)
[34] More than 90% of the deviations in quantity result from changes on initiative of the employers (cf. Malkwitz et al. (2011)).
[35] cf. Poloczek (2013)

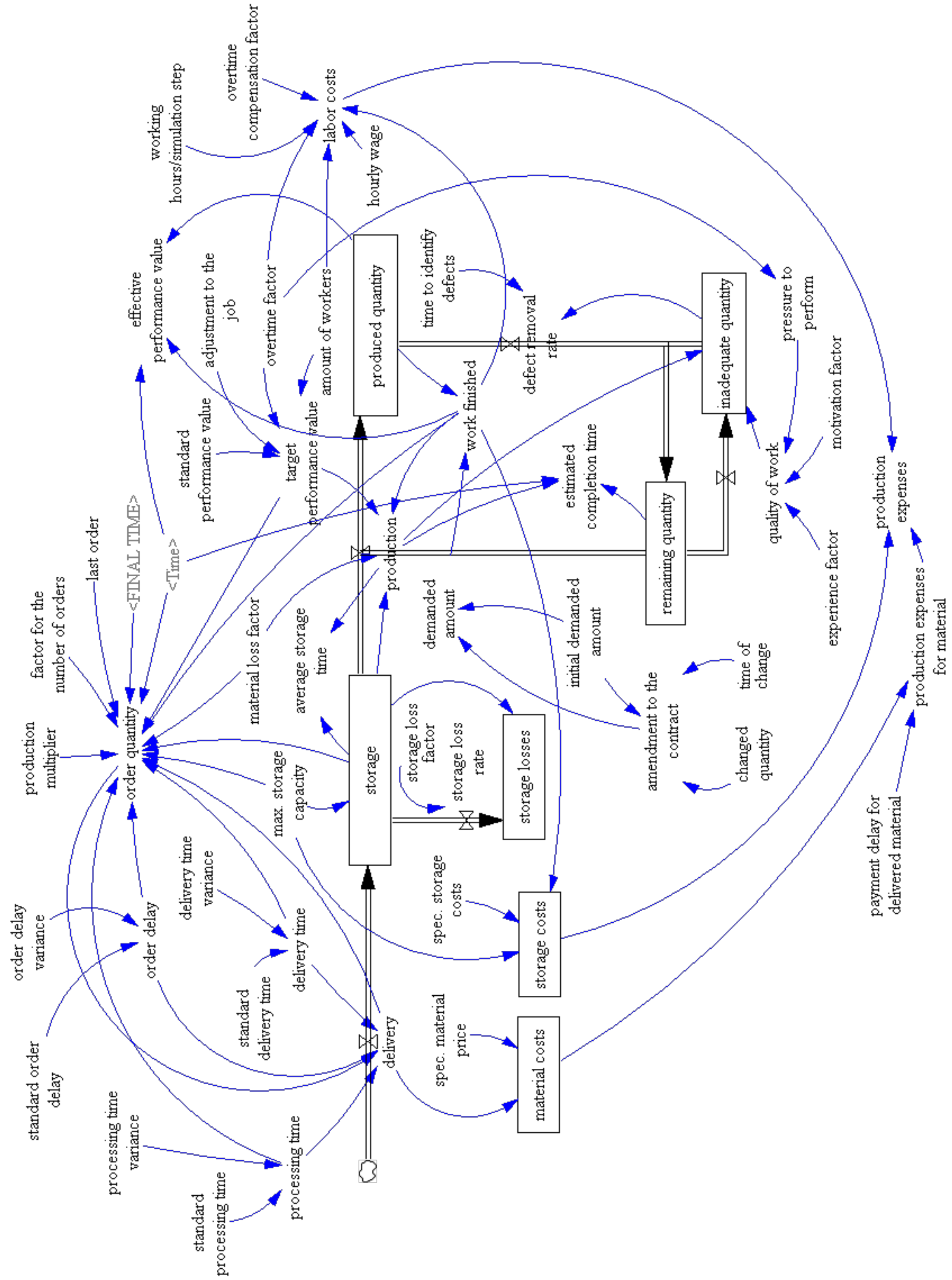


Figure 4.14: Standard component of a building shell process

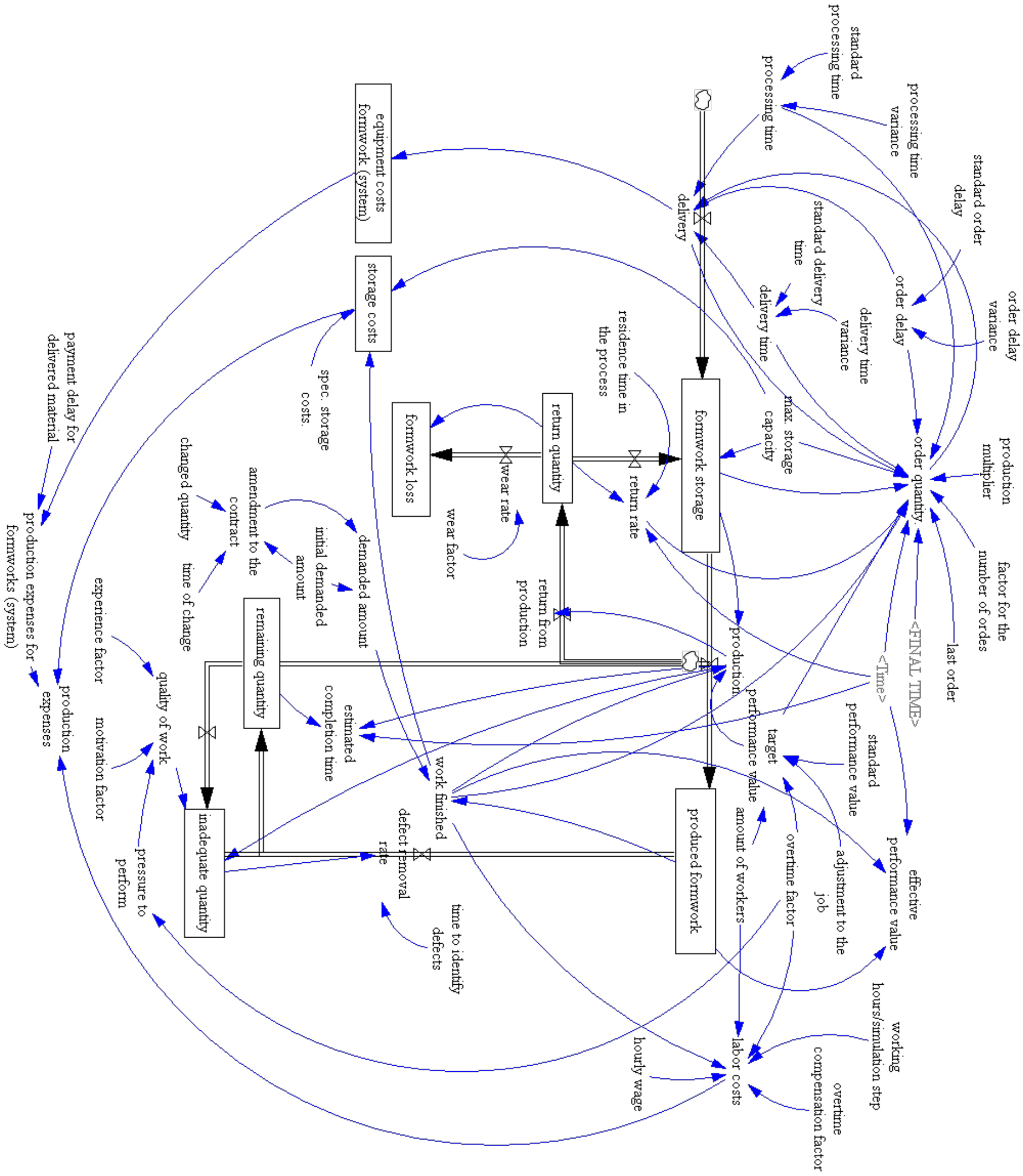


Figure 4.15: Component for formworks (system)

4.7.3.3 Reinforcing

In contrast to the formwork component $c_{SC,1.2}$, the reinforcing process can be derived from the standard component with less adaptations. Even here, the maximal available storage capacity is an important issue for the simulation. Again, the steel has to be available on the construction site in sufficient quantity and quality at the right point in time. Hence, the standard component represents the reinforcing component $c_{SC,2}$ completely and does not need to be adapted. An explicit illustration of this component can therefore be omitted.

4.7.3.4 Concreting

The component concreting ($c_{SC,3}$), however, does not allow storage of the conrete as it is usually delivered to the construction site on time. In general, two possibilities are available if a standard component has already been developed and is in use: a) irrelevant units are assigned the value zero if the system permits or b) the irrelevant units are removed completely from the component and the connections are adapted to fit the new system purpose[36]. Figure 4.16 shows the second alternative, in which irrelevant units and connections have been removed and other necessary units were integrated. One of the latter is the concreting cycle, which can be used to define at which intervals concreting should be carried out.

4.7.3.5 Brickwork

The component $c_{SC,4}$ displays similarities to the component $c_{SC,2}$. As a consequence, the standard component reflects this component entirely as well. Due to the reasons which apply to the components $c_{SC,1.1}$ und $c_{SC,2}$, an explicit illustration of this component is omitted here.

4.8 Project model

A qualitative project model concept, based on the previously developed units of the CDL, is introduced in the following (figure 4.17). This will prepare the ground for the following project simulations in chapter 5.1, starting page 106. The model depicts a three-story office building in reinforced steel construction for which the building shell is to be constructed. Due to the complexity respectively the multitude of required units, the graphic illustration of the overall model is realized with the USDML (for details refer to chapter 3.11, starting page 63) In contrast to other models, for example in pipeline construction, this type of illustration takes into account that the individual processes do not necessarily need to have start-end-relations (in the sense of network planning). This means that individual processes can potentially run in parallel or another

[36] Even if a standard component is employed, the consistency and reliability of the derived components has to be tested and confirmed in both cases.

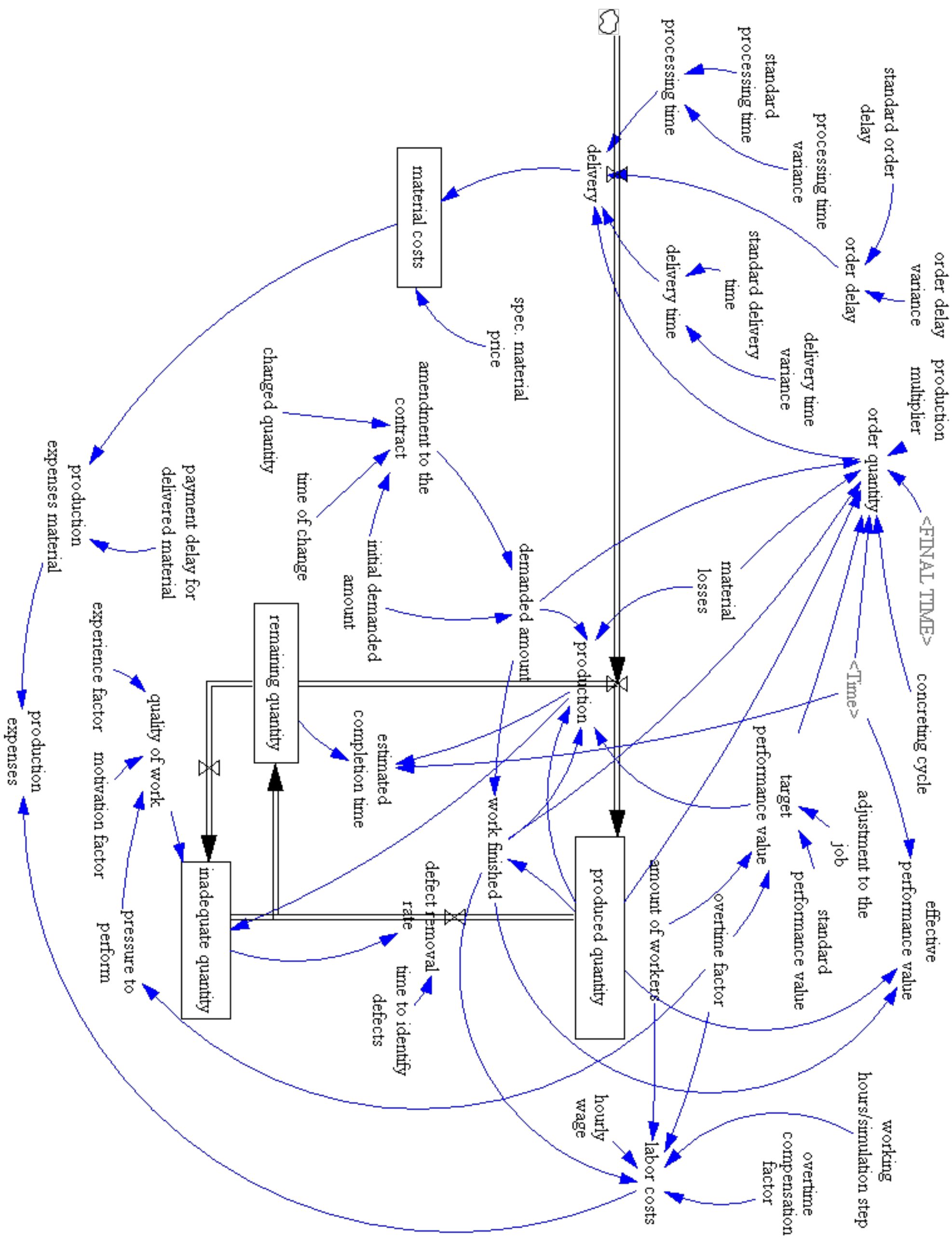


Figure 4.16: Component concreting

process can commence when a previous process has been concluded to a certain percentage of x only.[37] For this aim, the auxiliary unit $a_{AUX,6}$ is integrated.

Following the assumption that the represented object is composed of identical floors, i.e. the levels of the building are structurally the same, a query containing the auxiliary unit $a_{AUX,7}$ can be used to include a loop condition in the model. Due to this loop, the modeling processes for the generation of one floor only need to be modeled once and can be repeated with the help of the auxiliary unit $a_{AUX,7}$ as many times as requested in the context.

Both the purpose and the extent of the performance of the project model is determined by the general model purpose already defined on page 67, combined with the already realized demands and additional requirements from the definition of the standard component building shell (refer to p. 96).

Additionally, the model *construction project* respectively the simulation to arise out of it is supposed to independently determine a) the number of required pieces of equipment (excavators and trucks) and b) the number of required employees. The user merely has to define the available cycle times for the realization of the necessary tasks and processes.

As a consequence, the component earthworks $c_{EA,1}$ only needs the setting of the period of time for the given task in order to determine the required devices. The following parameters need to be added to the production components for the specification of the required number of workers: a) week/work cycle and b) working days/week.

Additionally, the following additional requirements and assumptions apply:

- As a matter of principle, the basic building data are always based on statistical data (Baukosteninformationszentrum (2008), section office buildings).
- The amount of materials calculated in the original project definition is evenly distributed on the individual floors of the building.
- If quantities increase or decrease, an immediate influence on the time duration of execution will be exerted, but not necessarily on the number of workers..
- The component *costs of construction site setup* ($c_{SF,1}$) inevitably has to be connected to the other, personnel-related production molecules available in the model to guarantee that the workers present on the construction site are also considered in the determination of the construction site setup. Further adjustment of $c_{SF,1}$ is not necessary.
- The originally and contracted amount of work to do is used for the calculation of the workforce.
- If learning curves are applied, these are valid during the entire time duration of the construction.
- Learning curves and learning ratios are viewed individually for each process (excavation, transport, formworks, reinforcement, concreting).

[37] An example taken from reality could be the beginning of reinforcing processes in one section of the construction site where the formworks have been completed already, or, alternatively, concreting processes in a section in which a part of the reinforcing work has been done already.

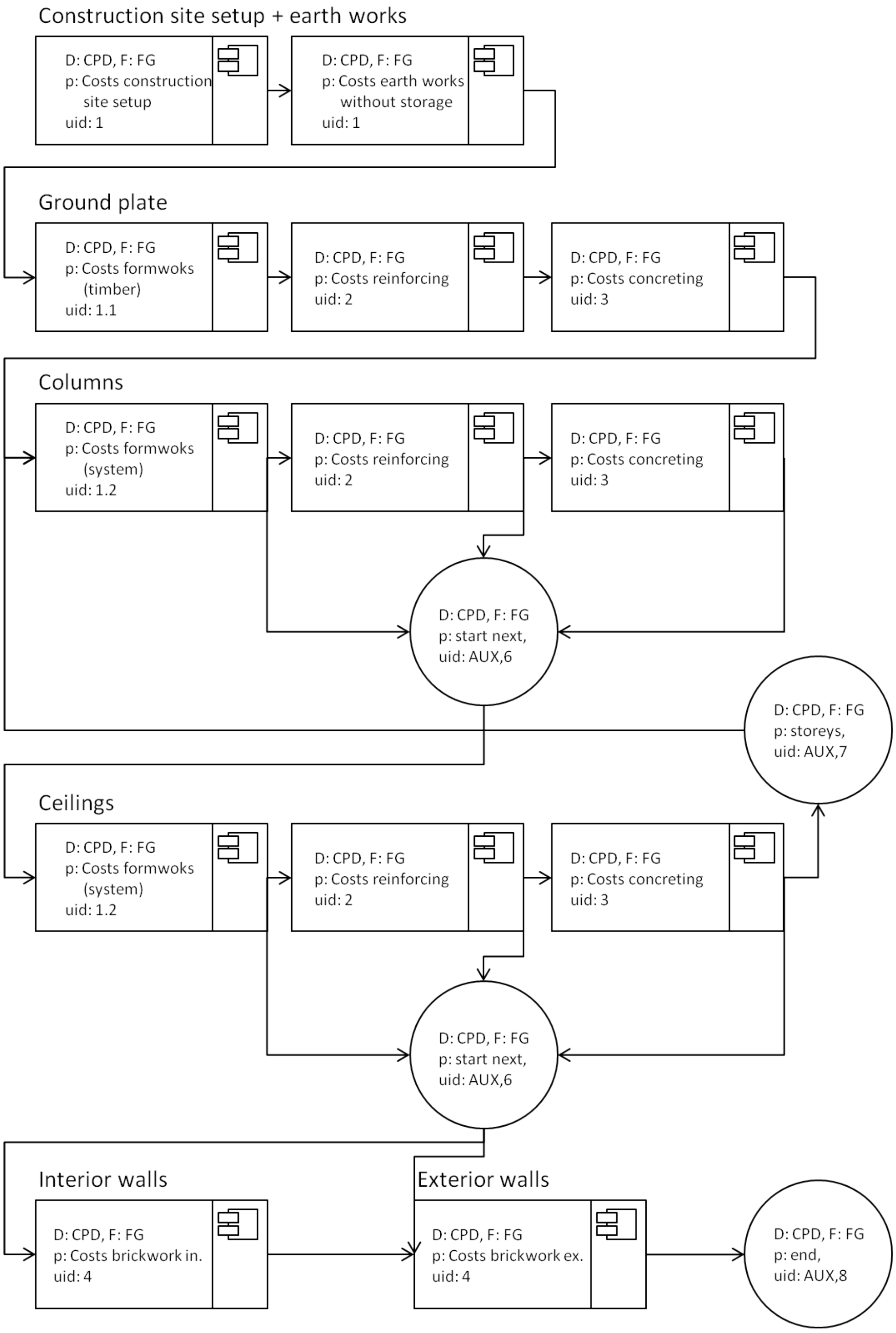


Figure 4.17: Project model (USDML illustration)

- Containers of the construction site setup are rented from external sources. Therefore, no further investigation of the construction site setup elements in the sense of equipment costs is carried out (for details refer to Baugeräteliste (2007), chapter X).
- Delivery of concrete for ground plate and ceilings includes pumping works from external sources. Concrete installation with concrete buckets.
- The ground plate as well as the columns available in the object are square.

In the end, the project model and the resulting simulation should be able to simulate an unlimited number of different types of buildings with up to 10 floors without further need to intervene in the system.[38]

[38] The amount of 10 floors should be sufficient for a first simulation model. More floors can be easily integrated with additional links.

5 Implementation of the developed model elements

The practical testing of the previously developed models in form of simulations is demonstrated in the following for the operative level, i.e. using the project model introduced in chapter 4.8 on page 101. The business game concept which is devised on the basis of CDL units is illustrated in chapter 5.2. Depending on the intended teaching and learning aims, a diversity of business game concepts can be realized with the help of the already developed CDL units or their subsequently generated models (chapter 4, p. 67 ff.).

5.1 Structure of the project simulation

Previously, the individual units were qualitatively viewed and registered. To prepare a quantitative examination and the subsequent analysis, the hitherto developed project model concept is implemented in Vensim as described in the following chapter. The simulation does not serve the primary aim to offer a complete, comprehensive and practicable method for the generation of cost-relevant data being as precise as possible. The main focus is rather to draft a realistic project model, which allows elucidating the relationships on the one hand and the influences on the other hand – from a qualitative or a relative and quantitative perspective. In addition to that, the simulation serves as a validation of the model and should help to determine realistic parameters which can be included as events in the business game.

As Vensim has already been used since the modeling phase, the contained project model needs to be equipped with corresponding mathematical equations[1] as well as realistic input data in the current simulation phase. The validation phase comprised both checks executed with a spreadsheet program or as manual calculations, aiming to verify the general validity of the model and also the system stability and integrity.[2] While designing a simulation using Vensim, different subdomains and partial models of the comprehensive model can be segmented in so-called "views" (this concept is similar to flags in spreadsheet applications). In the following chapter the developed central graphical user interface (GUI) is introduced. Additional views allow the input of project definitions as well as simulation constants. As examples, individual views are displayed (project definition, construction site setup and building shell process). The design of

[1] The project model consists of more than 750 differential equations.
[2] The quantitative database and the further requirements are available in the appendix 8.8, p.183 ff..

the simulation resulted in the *Construction Project Flight Simulator* (CPFS) of which the GUI is shown in figure 5.1 on 109.

The previously developed CDL units are assigned to 24 views in the CPFS, where the different parameters like, e.g., basic settings of the simulation, learning ratios, operating expenses and performance values can be adjusted in detail. Central views of the CPFS are introduced in brief summaries in the following.

5.1.1 Project definition

An upgrade of the introduced basic project model (refer to p. 70) appeared necessary and was implemented into the CPFS. The resulting project definition is shown in figure 5.2 on 110.

Main difference to the basic model is the extended degree of detail in regard to the materials required by the project, especially dependent on the dimensions of the project as a whole. Due to this, further units are to be included in correspondence to the previously described boundary conditions of the project model (refer to p.101). These units can represent specific dimensions of the ground plate, the ceilings or the columns, for example. To achieve a higher flexibility of the CPFS, the input of a prop grid is possible. Based on these additional inputs, all further required data is generated by the model, e.g. volume and areas for the formworks. According to the previously defined boundary conditions, the project model or the according simulation should be able to depict buildings of up to 10 storeys. Thus, the introduction of building floors as a definition is strictly necessary, too.

5.1.2 Construction site setup

The component *costs of construction site setup* ($c_{SF,1}$) requires a special adaptation when integrating it into the CPFS. As this component is dependent on units which, e.g., determine the amount of required personnel for the realization of specific processes, “shadow variables” are introduced (displayed with angle brackets in Vensim). These are variables which exist in one view already, but can be re-used in other views again. The resulting advantage is that central variables only need to be defined once. Hence, this approach makes it possible to change a central variable and automatically cause consequences in each view where it was used as well.

Regarding the view construction site setup, the number of employees per process can be specified in other views in more detail and serve as a basis for the calculation of the necessary construction site setup elements (figure 5.3). All further variables of the construction site setup can be adapted in this view according to the individual project specifications.

5.1.3 Building shell processes

As an example for all building shell processes, the ground plate from the CDL component $c_{SC,1.1}$ (timber formworks) is used to introduce the resulting view (figure 5.4). In this view, shadow variables are used to reflect, e.g. the termination of an operation (<excavation finished>), factors influencing the adjustment to the job (<learning curve formworks>), working hours per day (<working hours/day>) as well as the dimensions needed for the calculation of required material (<circumference of formworks for ground plate>). Further units which are only relevant for the shown process are introduced as normal variables, e.g. the parameter of weeks per working cycle. The experiments carried out with the help of CPFS are described in chapter 6.1 on page 125 ff.

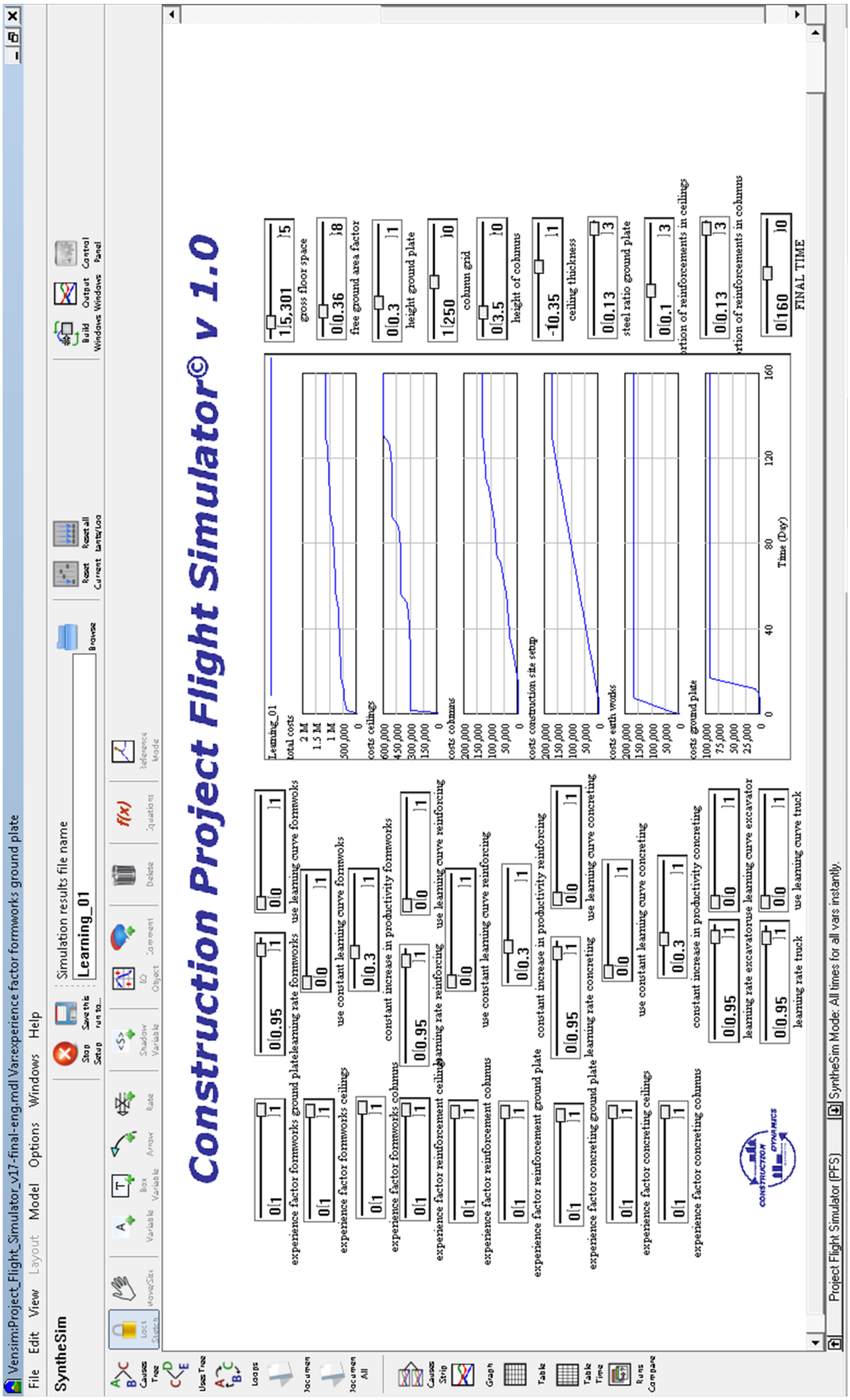


Figure 5.1: CPFS user interface in Vensim

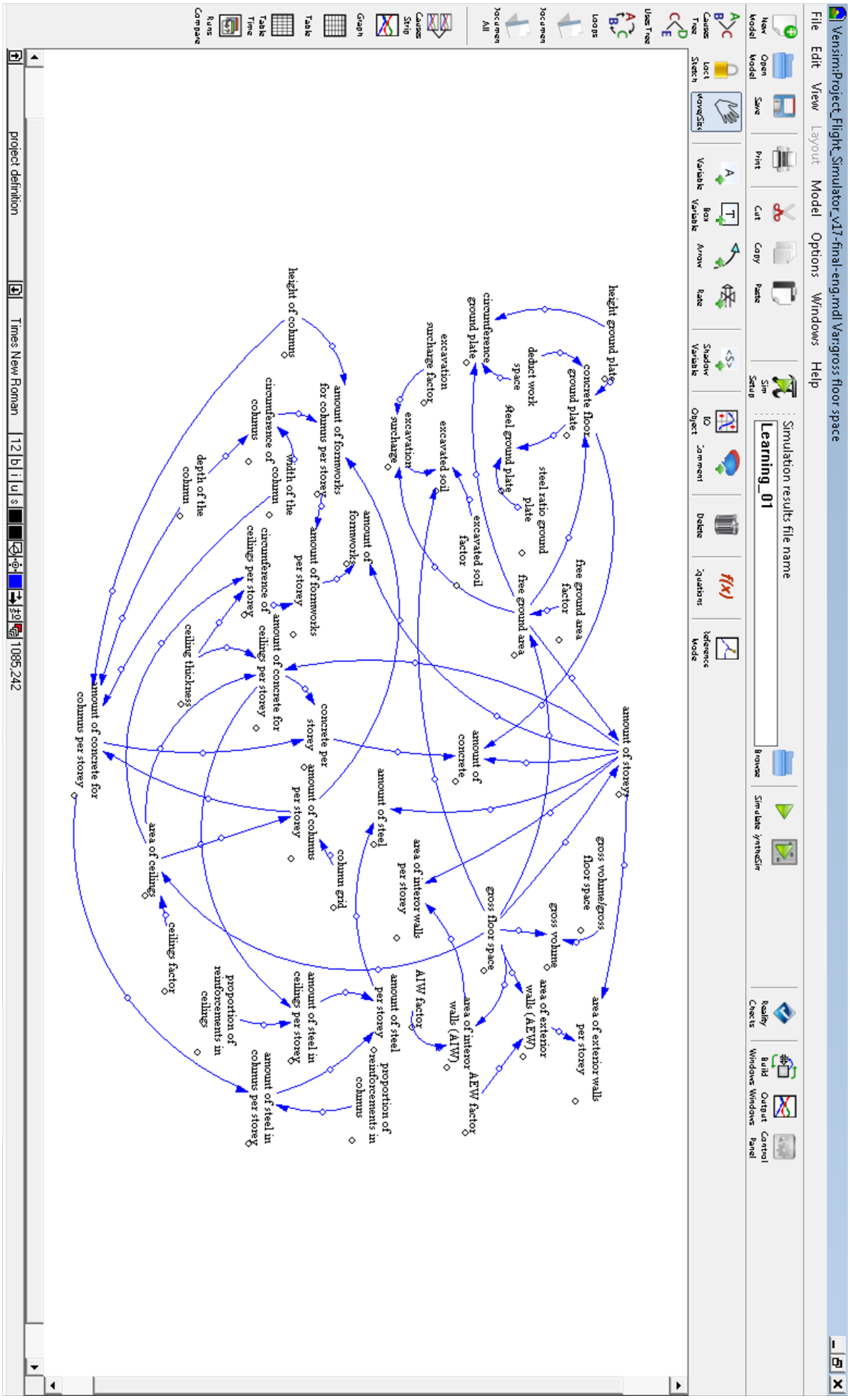


Figure 5.2: Project definition of the CPFS

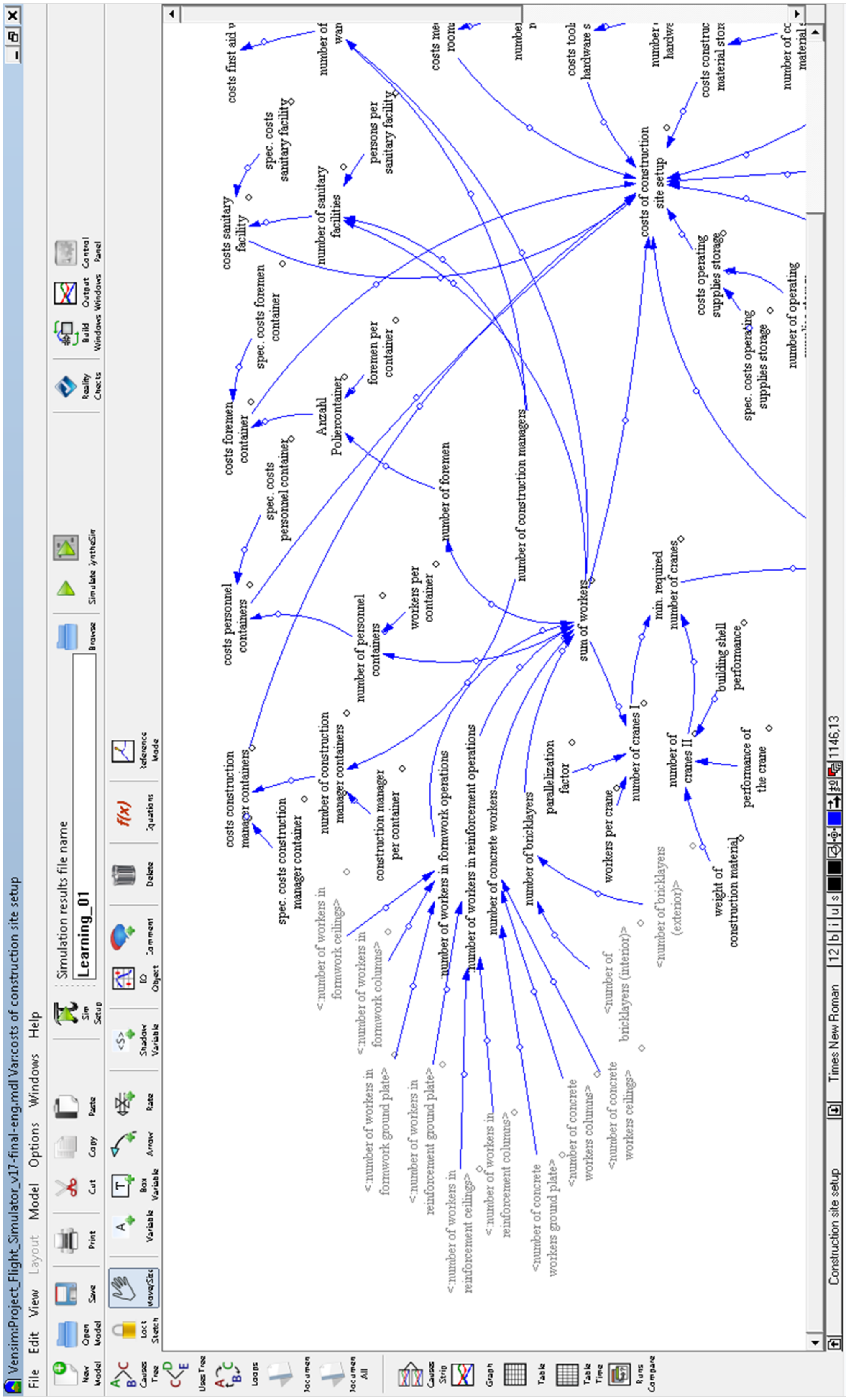


Figure 5.3: Construction site setup of the CPFS

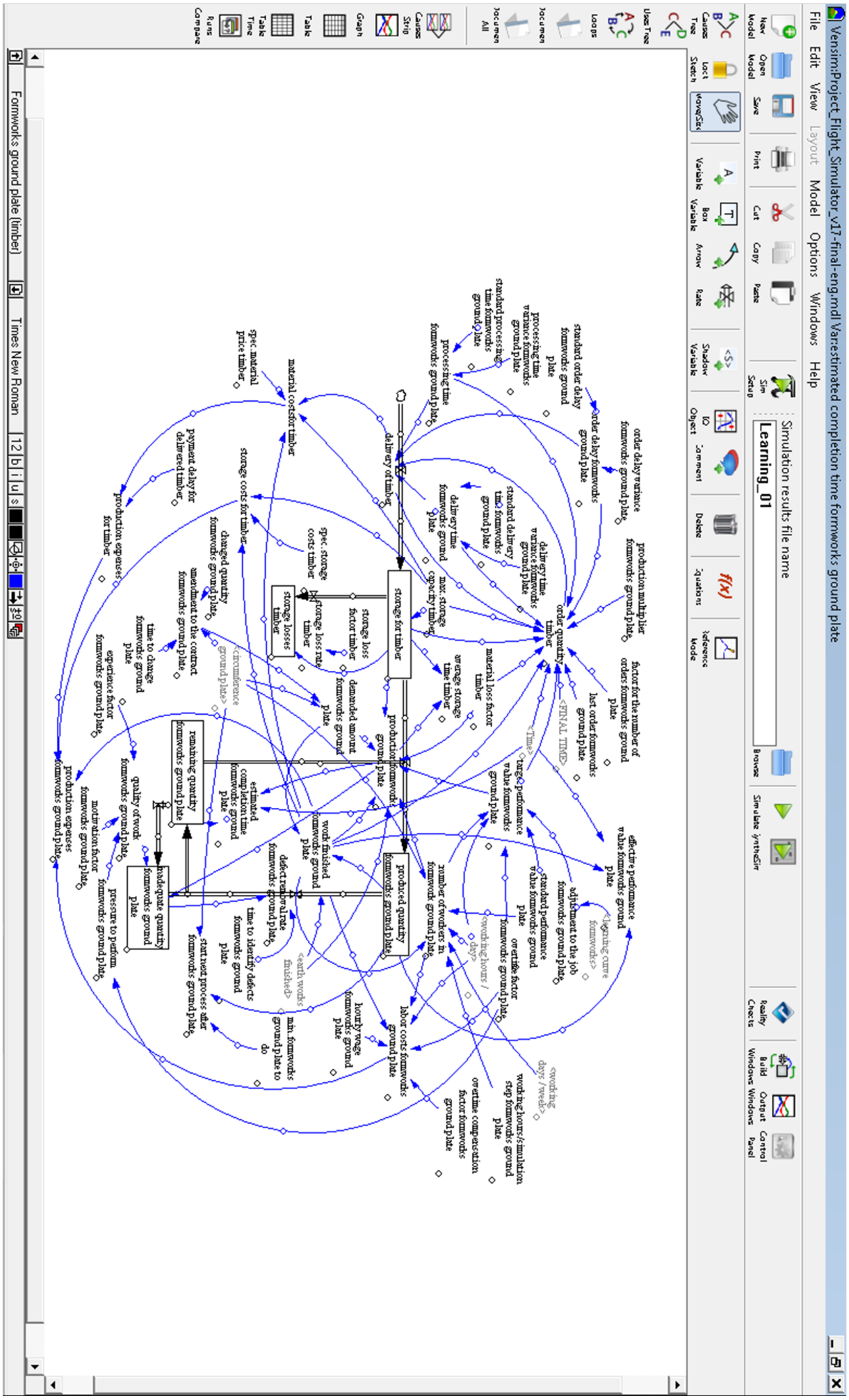


Figure 5.4: Formworks ground plate of the CPFS

5.2 Business game design

In line with the general motivation of this research project (refer to p. 9), the development approach of CDL-based business games is introduced in this chapter. This takes into account, that potentially very detailed units of the CDL may need to be subjects of didactic reduction if required by the general aim of the business game.

To limit the volume and the extent of this reduction which is necessary for teaching purposes, the demands on the educational game have to be identified. Considering all the currently led debates on competency acquisition in the academic education and further training, the demands on an educational game have to be derived from the competencies expected from construction engineers in the real world of work. For this reason it appears indispensably necessary to devise a frame for the development of competency-oriented educational games, on which the implementation of a CDL-based educational game can be based in the end. Here, a competency-oriented business game is defined as:

A competency-oriented business game is aligned in each phase to a valid and reliably developed, target group-oriented competency model. This model should motivate participants to develop specific capacities to act due to experience acquired in a realistic setting with conflicts and problems. The goal is to apply these specific capacities to act responsibly and successfully in a real and competitive context.[3]

In view of this, business games as a method for further training and education achieve high relevance in the context of the current discussions on competencies and their acquisition. However, within the current developments an appropriate basis is needed to further the establishment of the business game as a serious method on the one hand, and increase the quality of business game concepts in general on the other hand. Due to this, a formal development framework has been devised for the conceptualization of competency-oriented business games[4], which is practically implemented in this research project.

Core element of the development framework is the formulation of competency models, which are reflected in the demands on the business game.

5.2.1 Demands on the business game

With the help of a theoretically well-founded and empirically validated procedure for the development of domain-specific competency models[5], an empirical study was carried out in the construction industry[6] whose results are discussed in the following section in due brevity. The classification of the data allows the determination of specific competency profiles for different groups of addressees, which in turn can be taken as a basis for the subsequent configuration of a

[3] cf. Karl (2012)
[4] cf. ibid.
[5] for details refer to Karl (2012)
[6] KompBauDE: Competencies for the construction industry - A survey to determine current competency requirements for civil engineers, carried out by the author in the year 2010.

Table 5.1: Classification management level vs. occupation group

management level	occupation group
top (11)	managing director (9), authorized signatory (1), employee/staff section (1)
middle (17)	branch manager (4), personnel officer (6), human resources manager (1), head of the department (4), divisional head (1), functional department manager (1)
low (55)	superintendent construction (19), construction manager (17), team leader (1), project manager (14), employee (4)

Table 5.2: Composition of subjects

	management level				
work experience in years	low	middle	top	sum	proportion
0 < x < 2	1 (1,89%)	0 (0,00%)	0 (0,00%)	1	1,23%
2 < x < 5	4 (7,55%)	2 (11,76%)	1 (9,09%)	7	8,64%
5 < x < 15	20 (37,74%)	3 (17,65%)	1 (9,09%)	24	29,63%
x > 15	28 (52,83%)	12 (70,59%)	9 (81,82%)	49	60,49%
sum	53 (100,00%)	17 (100,00%)	11 (100,00%)	81	100,00%
proportion	65,43%	20,99%	13,58%		

business game (for example dependent on the management level, the work experience, the field of activity and many more). To define the demands on the business game, the test subjects are grouped in three management levels according to their fields of activity: a) top, b) middle, c) lower management[7]. Table 5.1 shows the relationships between the management level and the occupational groups of the test subjects. Here, the level of lower management represents the largest proportion, followed by middle and top management. There is evidence to support the claim that the data records acquired in this study appear to appropriately reflect the distribution in the real population.

Furthermore, the composition of the test subjects in regard to the management level and the work experience can be inspected in more detail (refer to table 5.2). Apparently, the subjects working in higher management levels are mostly also the test subjects with significant work experience, again a potential confirmation of the database validity.

General inspection of the gained data records reveals, that at least 15 main competencies could be covered by the business game method itself.

- structured thinking, interdisciplinary thinking, ability to work in a team, initiative (rank 1)

[7] cf. Becker (2005)

- analytical thinking, emotionality, awareness of interrelations, social skills, flexibility, personnel management, personal skills, decision-making ability (rank 2)
- creativity and innovative ability, capacity to work under pressure, management skills (rank 3)

Moreover, at least 12 specific competencies should be covered by the business game model.

- problem-solving skill in construction site management, practical orientation, general professional skills (rank 1)
- project communication management, operational competencies, negotiating skills, contractual competencies, economic competencies, entrepreneurial thinking, reliability, organizational capacity (rank 2)
- professional and discipline-specific English (rank 3)

Finally, the conclusive competence model was set as basis for the business game development. In this, all competencies rated as very important in all areas were considered as minimum requirements:

- problem-solving skills in construction site management
- project communication management
- operational competencies
- negotiating skills
- contractual competencies
- economic competencies

The intersection which was defined in this way presents the fundamental basis for the didactic concept of the business game and additionally serves as a configuration tool. The results of this study can be juxtaposed to the demands placed by the business game user on business games (p. 41), leading to the detection of significant analogies. Especially the requested possibility to depict the relationships between aspects of construction operations corresponds to the demanded competency of problem-solving skills in the field of construction site management. Equally apparent are the economic aspects which have to be integrated into the business game, they are analog to the demanded economic competencies. The same is true for the inclusion of contractual aspects and competencies. More similarities can be found in comparison to other studies. Poloczek (2013), for example, carried out an empirical study in which risk indicators were to be rated by German construction businesses. These are the top of the list with 43 indicators all in all: own project organization (91,0%), subject-specific competence and work experience of the personnel (89,6%), own coordination of the tasks (88,3%), communication among the involved parties of the project (88,1%), quality of the contract documentation (86,8%). Again, clear parallels can be found to the insights gained in this research project. Despite the different aims and heterogeneous populations in the above-mentioned empirical studies, the commonalities lead to the conclusion that the data records acquired in this research project as well as their results can be regarded as reliable.

Table 5.3: Teaching learning objectives in a business game

Competency	Teaching and learning objectives
problem-solving skills in construction site management	increasing awareness of project risks, experiencing consequences of project events
project communication management	generating, accumulating, disseminating and filing project information appropriately and in time, creation of an information and reporting system
operational competencies	learning and consolidation of calculation, understanding interrelations, experiencing consequences of miscalculations, planning material requirements and administering resources, both for individual projects and company-wide (personnel and device management)
negotiating skills	negotiations of workgroups with participants, organizing subcontractors, asserting interests of the corporation
contractual competencies	identification of "risky" construction contracts/ projects and awareness of consequences, enforcing of amendments, handling of warranty claims
economic competencies	taking decisions in planning, organisation and calculation of the corporation (accounting, cost calculation, controlling), professional settlement of the projects, profit and loss accounting, compiling a balance sheet for own company, devise and realize corporate strategies

The competency models serve as basis for a business game event which can be developed accordingly and potentially complemented with other sensible teaching and learning methods.[8] The six core competencies to be taken into account require specific teaching and learning objectives (table 5.3). Usually, the listed items demand more elaborated considerations in regard to the cognitive, activity-focused and affective learning objectives.

The course of events which was generally introduced for business games in the domain of construction business (refer to p. 16) can be substantiated by adding subject-specific elements both in the action area and in the reaction area (figure 5.5).

Considering the teaching and learning objectives, the domain-specific course of the business game allows the illustration of a project phase model (figure 5.6) which will be the basis for subsequent developments.

5.2.2 Integration of CDL elements

The core competencies and the derived specific teaching and learning objectives (table 5.3) have to be taken into account for the localization of the CDL units which are scheduled for integration into the business game. Central element is the project model developed in chapter 4.8 on p. 101 ff. in which the didactic targets of the business game are reduced or expanded. Regarding

[8]Such an integrative teaching and learning concept is introduced and discussed in Karl (2013).

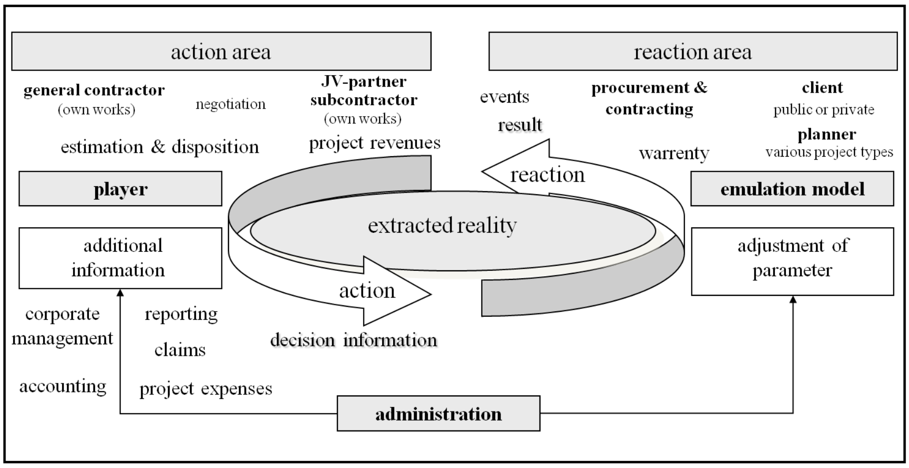


Figure 5.5: Domain-specific process of a construction-oriented business game

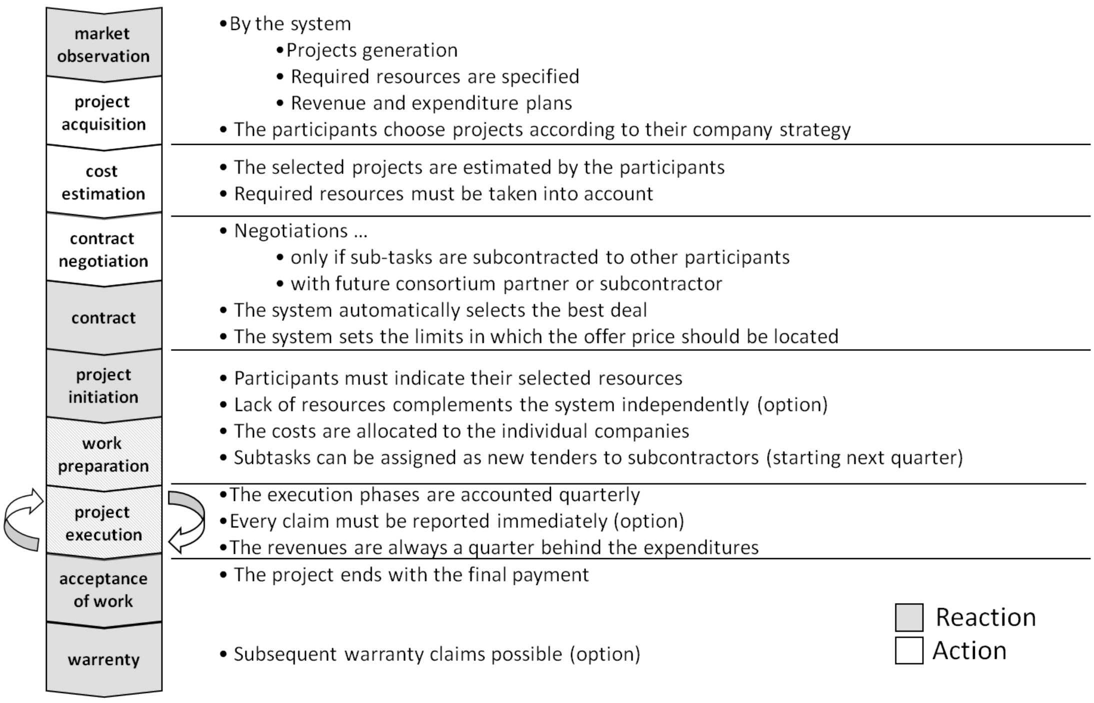


Figure 5.6: Project phase model of a construction-oriented business game

the teaching of the problem-solving skill in the field of construction site management, the units for the depicting of changes demanded by the contracting party are seen as indispensable for the concept of the business game. Furthermore, the potential dynamics caused by volatile prices of material in the project model are equally reasonable. A possibility to enable or disable the aforementioned volatile prices should exist in the business game model in dependence on the target group and the realized time progress. The project communication management, especially the appropriate generation of project information, is significantly influenced by the explicit integration of differentiated positions within the virtual corporation. This means that the participants or players, according to the allocated tasks of the business game, can gain different perspectives on the corporate data. Here, it is strictly necessary that the participants communicate within the corporation and exchange or share data respectively analyses which were already executed in their areas. The resource-bound CDL units play a crucial role in this process and need to be considered accordingly. Subdomains, e.g. the storage problem and the accompanying storage costs, are not explicitly included in the first development step. The order placement of goods is reduced in a comparable way, as it is simplified under the assumption that needed material is always available in desired and sufficient quantities in the market. The additional consideration of such units would be reasonable and necessary in an educational game, in which explicitly competencies in the procurement area have to be trained. Therefore it becomes apparent, how further units and modules can be integrated in an already existing educational game in order to realize diverse application possibilities with only one development project. This is, necessarily, dependent on the chosen target group and the desired teaching and learning objectives and progress. A further reduction of the project model details appears sensible in the training of competencies in construction operations. For this, no explicit differentiation of production processes illustrated in chronological sequence is represented in the business game model. Nevertheless, the units which are necessary for the representation of resources like workforce, equipment and material plus the associated costs are mandatory. Hence, although the project model integrated into the business game will calculate projects in detail, the degree of detail of the project information and the calculation tasks will be adapted according to the target group and intended teaching and learning aims.

The included resource units can help to take decisions, on the one hand, for the emulated projects, but on the other hand also assist planning and organization on company level. This has an influence on the economic competencies which are to be trained. Additionally, for example, taking the inventory of all company resources makes it possible to inspect the disposition of all current projects. Thus, participants can comprehend the effects of individual project decisions on, e.g., the business operating expenses of the company. Especially in this area, a return of insights, which were gained in the business game, to the CDL is to be expected, as effects of market developments on decisions taken in individual projects and therefore on company parameters can be imported into the CDL as input parameters or new units. The negotiating skill can be integrated into the business game by offering the possibility to delegate selected elements of project leadership in form of free negotiations to contractors (other participants). The data or insights acquired during the observation of negotiations in this context can be returned as further CDL units to continue the research of decision making. The training of contractual competencies can be implemented by assigning specific boundary conditions to the projects generated by the system. If, for instance, volatile prices of material are supposed to be enabled in the business game, the existence of a contractual automatic adjustment clause could exert influence on the risk assessment of the tendered project or even cause consequences for the price offer.

Beyond this, the inclusion of CDL units which depict sub-standard quality of workmanship can be reasonable to illustrate the effects of such performance during the project execution and (with a time delay) after the project completion in form of a warranty claim. Beyond the above-mentioned aspects, further boundary conditions which influence both company and local construction market are incorporated into the business game model. The system of the latter is described in general in the following chapter.

5.2.3 Setup of the business game model

On basis of the already acquired fundamentals, a system diagram is developed to show the different relevant systems, subsystems, elements as well as links and influences (figure 5.7). As previously demonstrated, the competencies to be trained include a dynamic combination of properties, skills and perspectives resp. opinions. Following the SDL structure, participants of the business game navigate in an action/reaction triangle, consisting of *market*, *product* and *company*. These three subsystems are allocated to the competencies which are indispensable for the areas of construction management, site management and corporate governance. Then, the teaching and learning objectives of the individual subsystems are derived from these. One main aim when designing a business game model is the possibility to recognize relationships and interactions within a local construction industry. The *market* is defined, among other factors, by demand and supply and the types of available tender offers. In regard to realism and acceptance, different product categories exist like residential housing, office buildings, industrial buildings, hospitals, cultural building structures and others. Each *product* (i.e. construction project) is dependent on its properties and these, in turn, on the local market (country x, country y etc.) in which it should be realized. Therefore, local market prices and their development for concrete, steel, labor costs etc., as well as local risks for the *market*, *project* or *company* and their resulting events play a substantial role in the business games and, with this, transfer an international character to the teaching and learning scenario.

In detail, the following requirements are demanded from the individual subsystem. The projects generated in the business game are implemented in the form of public, limited or private lump sum contracts. In the first development, it is assumed that the contracting entity in the local market generally has unlimited investment funds at its disposal and an unlimited number of different resources are available on the market, too. Planning services are not considered and rest with the contracting party. As a consequence, the entrepreneur neither has an influence on the method of construction nor on the employed material. However, the entrepreneur can accelerate

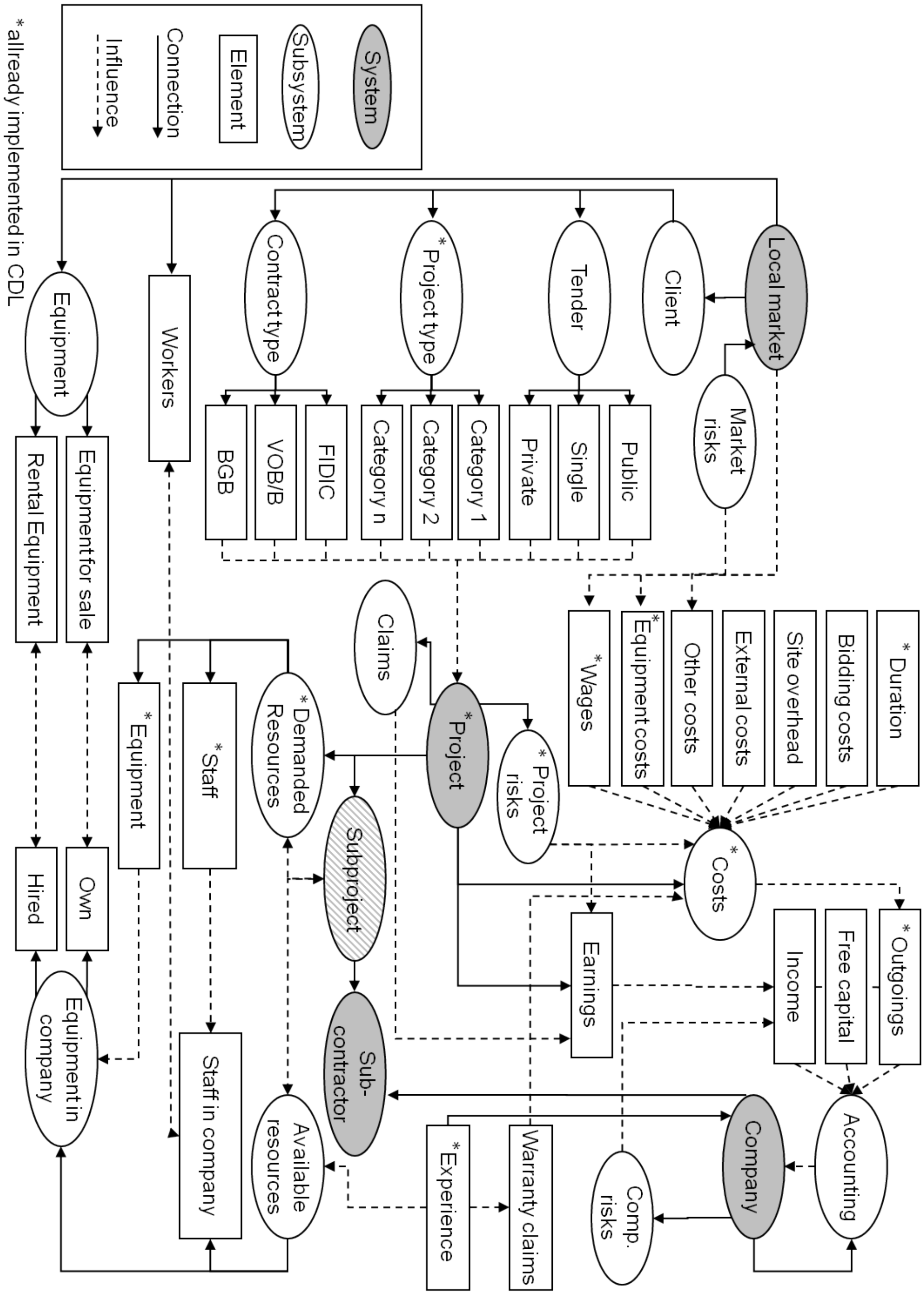


Figure 5.7: System diagram of the business game

or slow down projects by varying the personnel resources. This presumes that a) sufficient resources are available in the company or, respectively, b) further resources are available on the market. In addition to that, he accepts a project in its entirety, but can delegate parts of the project in form of sub-projects to contractors.

In the business game model, at first the previously developed CDL units are applied, e.g. resources tied to the project, the cost-specific elements equipment and labor costs, strictly defined plans of expenditure as well as the project duration. Added to this are new elements, which define parameters relevant for the project selection like, e.g., project-specific offering costs, dues for third-party services which cannot be influenced and revenue plans.

Beyond these elements, risk areas are defined for each sub-system. These areas can be assigned to the *market*, the *project* or the *company* itself and influence each business individually. Especially the ratios of increase or decrease in project costs which were acquired by simulating diverse scenarios are considered here to depict the effects of different project risks (the results of selected scenarios are introduced in chapter 6.1 on p.125 ff.).

The aspect of experience gained by the workforce needs to be included in the business game by considering the insights of the simulated scenarios as well. Only in this way it can be guaranteed that the business game based on the project model and all its various influencing factors appear realistic. The latter is required to increase acceptance of the model, the teaching success as well as the whole business game and make it possible to research the consequences of taken decisions both qualitatively and quantitatively.

The business games which were developed on the basis of the system diagram are introduced in appropriate brevity in the following. These games are, among other uses, offered in a required elective course of one semester in the master program "Construction Management and Infrastructure Systems" at the University of Duisburg-Essen.

5.2.4 Implementation of the business game

At the beginning, the course-relationship-method (CRM)[9] is applied to determine the previously gained knowledge as well as the already achieved learning of skills and make it available for potential consideration in the business game afterwards. For this, the viewing of the module descriptions, which define content, teaching and learning methods, examination requirements and the workload of the study module, is the first step. Result is a multitude of reasonable, subject-related and comprehensible links to previous knowledge of the participants.

The game management in the business games functions as an impartial administrator only, monitoring the compliance to the rules, setting parameters for the reaction area and delegate additional information to the players. Furthermore, the administrator is responsible for the generation of demand in the sector of construction projects and thus plays the role of the contracting parties. For the turn-based business games described in the next chapter, a minimum

[9] cf. Karl & Köster (2011)

of turns should always be adhered to, as otherwise the long-term effects of decisions could not be illustrated successfully. If consequences apply arising out of cyclical parameters like an economic boom, recession or stagnation, more turns are necessary to demonstrate their impact in the later gameplay. Due to this, according to Hoegsdal (1995), a business game should have at least four turns, for the demonstration of long-term developments preferably six to eight. Here it may be required or advisable to keep the players uninformed in regard to the exact number of turns to play. The desire to win often leads to the negligence of future prospects or consequences in the last turn of the game and eventually to the taking of decisions which achieve the highest immediate gain or profit only. This behavior can exert a negative impact on the pedagogical effectiveness of the whole business game seminar[10]. To avoid this, it has to be emphasized that the predominant aim is the learning and not the calculation of a winner[11]. Apart from that, it may be sensible to preconfigure several target variables for the participants to avoid an unwanted focus on one target value only. This is also closer to reality, as it is usually more advisable to reach a bundle of aims rather than one independent single goal.[12] To promote the skills of intercultural cooperation of the participants, the business games were intentionally designed with an international focus and completely realized in English, including the learning of subject-specific English as a by-product. Following this concept, two business games were developed: a) the board-based business game *Construction Giant* and b) the online business game *Chameleon*.

5.2.4.1 The board-based business game Construction Giant

Board-based business games are very suitable for the illustration of relationships without requiring a lot of previous knowledge in the context.[13] The simple imagery on the board helps the participants to gain access to the content quickly, facilitating the learning noticeably. Even more so, business game events with a shorter duration allow the participants to experience the gameplay together and more intensive at the board as well as reflect the gained insights within the group with little delay. The board-based business game Construction Giant grants control of an already existing construction company. This game involves the use of dice and has the goal to run a business successfully for as long as possible in a competitive situation. It is played on board which depicts a city map. To integrate an international dimension, separate play sets/editions offer extra material for different countries and with different properties and events, e.g. the Essen edition or the Athens edition. The minimum number of players per board is three, the maximum number six.

After an extensive testing period at the University of Duisburg-Essen, the board-based business game Construction Giant was successfully implemented in May 2011 for the first time within a master course with 25 participants at the department of Planning and Construction Management

[10]cf. Rohn (1964)
[11]cf. Siebecke (1995)
[12]cf. Orth (1999)
[13]cf. Blötz (2008)

of the National Technical University of Athens (NTUA).[14] In July 2011, this business game was officially introduced at the University of Duisburg-Essen as part of the bachelor program and realized with 40 participants for the first time. The first evaluation results can be found in Karl (2012).

5.2.4.2 The online business game Chameleon

Online business games are a mixture of computer-supported team games and remote business games with a competitive orientation.[15] The individual groups of players can work independently of each other and communicate via Email or use the chat function to stay in contact with their team members. During the online phases of the game, groups take their decisions and get the results back from the system. Between the game periods, sessions with compulsory on-site presence are used to refer to additional content (using different teaching and learning strategies) and are the opportunity to discuss the current progress in the game or the already applied strategies. In contrast to board-based business games, the online variant lends itself especially for events with a longer duration. This reinforces the individual experience of consequences arising out of cyclical parameters.

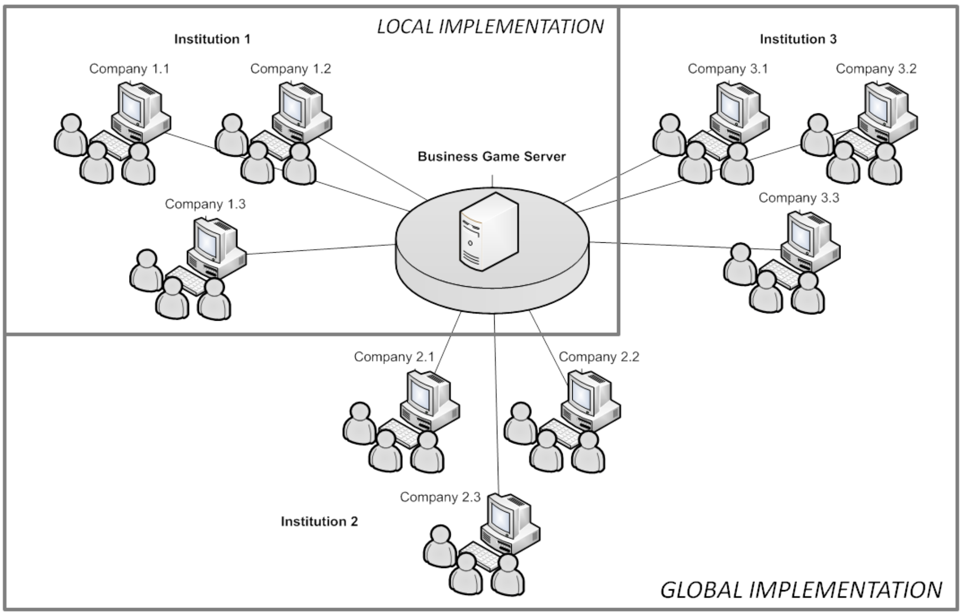


Figure 5.8: Local and global implementation

The positively evaluated business game Construction Giant was the basis for the development of the online-based educational game Chameleon[16]. To facilitate the development and guarantee a later implementation of further elements for the integration in a comprehensive online learning

[14] This was possible due to an Erasmus cooperation with the NTUA, initiated by the author in 2010.
[15] cf. Blötz (2008)
[16] With the successfully raised grant of the DAAD research program, the author managed to expand the up to this point developed online business game systematically and with special consideration of international dimensions.

environment, the content management system Drupal is used as a basis. It already contains fundamental functions like, e.g., user administration, communication and functions of system security.[17] The use of pre-configured systems can reduce development costs[18] and lead to a higher flexibility[19].

The business game Chameleon adopts the high affinity of students in regard to web 2.0 applications and social networks, utilizes it for the targeted internationalization and promotes the readiness of mobility. Due to this, the developed online business game can either be used locally or globally (figure 5.8).

In the global scenario, the participants of the game act in a virtual international market and need to comprehend both national and global relationships, question and consider them in their own decisions. The modular online business game (in English) offers a high degree of variation in regard to, among other factors, the target group (experienced or less experienced participants), the available time (short or long version, i.e. 2-3 days or up to one semester), the intended competency areas and the involved project countries.[20]

[17]The online business game was realized as an independent module for Drupal.

[18]The development costs of one educational game amount to approximately 40.000 Euro up to 150.000 Euro. This appears to be the main reason why this excellent teaching and learning method has not established itself on a larger scale, especially in academic education.

[19]cf. Moreno-Ger et al. (2009)

[20]The name *Chameleon* characterizes and represents the flexible structure of modules and models in this educational game.

6 Selected results of prototypical implementation

Based on the simulation devised in chapter 5.1 respectively the business game concept developed in chapter 5.2, the results of the implemented simulation experiments as well as of the carried out business game are introduced and discussed.

6.1 Results of simulation

The quantitative analyses executed with the following simulation studies serve the verification and validation of the simulation models on the one hand, but, on the other hand, the results should also offer indicators for the examination of specific situations and behaviors of the model and thereby potentially allow the derivation of decision dispositions. Especially the illustration of relationships and dependencies between the different elements should support the evaluation thereof and, even more so, the search for alternatives. Strong emphasis is placed on the overall costs and the duration of the project. A contractually fixed maximum duration for all processes of 160 days must not be exceeded.

Results of the simulation studies should be integrated into the execution of the business game, i.e. it should be possible to compare specific values of the simulation scenario either with the results of the business game implementation, and consider them within the mathematical model as single events. An estimated cost function, as shown in appendix 8.9 on p.186 ff., is assigned to each of the scenarios for the illustration of the costs development during the project. The functions can provide further assistance in other research projects or in other business games.

Without any doubt, the devised simulation can be used to create and examine a diversity of scenarios. This chapter introduces 8 selected scenarios, whose results are directly applicable in the context of business games.

In these scenarios, the system reactions on changes of the input values are explicitly fixed and are executed as deterministic simulations once only. The question settings for the individual deterministic scenarios are the following:

- Scenario S1 - Basic: Ideal construction operation, all further scenarios are compared to S1.
- Scenario S2 – Vocational adjustment: Which influence do familiarization effects have on the work? This scenario could answer the question if it is worth to consider vocational adjustment within the planning and execution of a construction project.

- Scenario S3 - Experience: Which influence can be measured in case of a less experienced workforce? This aspect could be important especially for projects with a high amount of subcontractors (like in global projects). In such cases it is necessary to know a) which performance can be assumed compared to the own work force and b) is it worth to invest in education for foreign work force and if so, which maximum investment should not be exceeded?
- Scenario S4 - Overtime: What is the influence of overtime? This scenario might give hints to decide until which limit mandated overtime can be seen as a common strategy to face delays within construction.
- Scenario S5 - Overtime (S4) & Vocational adjustment (S2): In how far does a combination of overtime and adjustment to the work result in the shortest possible period of time needed for the completion? Secondly, in how far can potentially negative effects of overtime be compensated by familiarization effects?
- Scenario S6 – Experience (S3) & Variation of time for quality management: Which influence does the quality of the construction management exert, especially in case of less experienced personnel? This scenario takes into account a similar problem like in S3 (e.g. global projects). To face the problem of poor quality as a result of less experienced work force, the management of the project might be a key factor.
- Scenario S7 – Overtime (S4) & Variation of time for quality management: Which influence does the quality of the construction management have in case of overtime ordered by it?
- Scenario S8 – Crisis management of a bad case scenario: How can a bad case scenario look like, and how does this change when it is influenced by familiarization effects (S2)?

6.1.1 Simulation experiments

Scenario S1: Basis

The basic scenario S1 represents the ideal construction process. All material (except concrete) needed for the first production cycle is present in full quantity at the beginning of the construction. Consequently, no placing of orders is necessary at the start. All employees have maximal experience and motivation, i.e. the work can be done with optimized quality and no revisions of previous processes have to be carried out. Furthermore, losses due to storage handling or wear and tear of the material are excluded. Theoretically possible increases of production due to familiarization to the job are not considered in S1 and no overtime is possible. Both the overall project costs and the overall duration for the regarded processes are basis for the comparison to other scenarios.

Scenario S2: Vocational adjustment

In S2, learning curves are defined for each work process (formworks, reinforcing, concreting) and serve as basis for the examination of effects which the work adjustment can exert on the overall costs and duration. The learning rate is set to 95% and develops individually for each process from the first activity and then continuously during the whole construction process. The maximal realizable increase of productivity is +30%. Results: costs -2,79%, time -8,40%.

Scenario S3: Experience

Scenario S3 focuses the influence of less experienced workers. In this case the work experience of the employees is assumed to be 10 % less than the given standard, resulting in a decrease of the same amount in the execution of assigned tasks. In contrast to S2, the reduction does not exert direct influence on the performance value, but mainly on the quality of the work results. Thus, the lower experience level leads to a faulty workmanship and then to the necessity of revision and corrective activities. Here, the time required for the detection of substandard work results is set to one day, i.e. potentially occurring defective results can be identified and corrected by the construction management on short notice. Result: costs +4,60%, time +10,00%.

Scenario S4: Overtime

Inspecting the scenario S3, the influence of mandated overtime on the overall project costs and on the overall completion time appears of central interest. To gain insights here, the available working hours per day are increased by 20 %. Assuming that the quality of work remains the same in spite of the mandated overtime, i.e. the overtime does not lead to substandard quality of workmanship, the scenario S4.1 displays the following result: costs -1,39%, time -10,69%. If the directive of overtime is linked to the quality of workmanship, i.e. the overtime has a detrimental effect on the quality of the work and thereby causes the need of revision and repair cycles, the result of scenario S4.2 is this: costs +2,88%, time -2,29%. Just as in scenario S3, S4.2 also expects the time required for the detection of substandard work results to be one day.

Scenario S5: Overtime (S4) & Vocational adjustment (S2)

Scenario 5.1 is supposed to represent a good case scenario, combining overtime (S4.1) and vocational adjustment (S2). This scenario, compared to the basic scenario S1, results in the following changes: costs -1,39% and time -11,45%. S5.2 poses the question in how far the negative influences of mandated overtime in scenario 4.2 can be balanced with the consideration of vocational adjustment effects. The results of scenario 5.2 in comparison to the basis scenario S1: costs +2,44%, time -3,05% and comparing scenario S5.2 to S4.2: costs -0,40%, time -0,78%.

Scenario S6: Experience (S3) & Variation of time for quality management

Both scenario S3 and S4 relied on the period of one day for the detection of substandard work results. It appears reasonable to elucidate the changes of overall costs and completion time if inexperienced personnel and a less attentive construction management work together. Consequently, scenario S6 examines the influence of the qualification of construction management especially in combination with less experienced construction site personnel. Here, the time required for the detection of substandard workmanship is set to two or three days.

S6.1 – time required/detection of substandard quality 2 days: costs +6,36%, time +12,21%

S6.2 – time required/detection of substandard quality 3 days: costs +9,07%, time +19,85%

Scenario S7: Overtime (S4) & Variation of time for quality management

Similarly to scenario S6, S7 enquires about the influence of qualified construction management on mandated overtime. Here, the time required for the detection of substandard workmanship is set to two or three days again.

S7.1 – time required/detection of substandard quality 2 days: costs +5,58%, time +6,87%

S7.2 – time required/detection of substandard quality 3 days: costs +7,84%, time +13,00%

Scenario S8 – Crisis management of a bad case scenario

Considering all the above-mentioned scenarios, an exemplary bad case scenario is constructed and attempted to be balanced with the help of vocational adjustment effects (S2). Scenario S3 is used as a basis and combined with an average time of two days needed for the detection of substandard workmanship. Additionally, the S8 scenario assumes a continuous material loss of 10% in the processing of concrete. This constellation leads to a massive exceeding of the contractually fixed maximum completion time. Integrating S2 can counteract this effect to a degree: costs +9,93%, time +16,03%.

6.1.2 Discussion of the simulation experiments

The contractually set completion time of 160 days is undercut by 18,12% in the basic scenario S1. This means that in further scenarios a potential time delay would be tolerable up to this percentage – independently of the incurred costs. Based on the basic scenario S1, the scenario S2 with the inclusion of vocational adjustment effects leads to a reduction of the overall project costs of nearly three precent and saved time of more than eight percent (table 6.1).

Table 6.1: Simulation results

Scenario	S1	S2	S3	S4.1	S4.2	S5.1	S5.2	S6.1	S6.2	S7.1	S7.2	S8
costs [%]	100	97.2	104.6	98.6	102.9	98.6	102.4	106.4	109.1	105.6	107.8	109.9
time [%]	100	91.6	110.0	89.3	97.7	88.6	97.0	112.2	119.9	106.9	113.0	116.0

It is questionable, however, in how far such effects of adjustment to the work can be initiated and operatively maintained for extended periods of time. Therefore, the result of S2 demonstrates the theoretical cost-saving potential of vocational adjustment effects, but further research is required in this field to certify how realistic these effects are. In contrast to S2, scenario S3 considers a reduced experience of the construction site personnel and its effect on the quality of realized workmanship. A reduction of 10% results in additional overall project costs of almost five percent and additional time requirements of 10%. The increase of costs as well as needed time fulfilled the expectations. The fact that the percentage of the additionally needed time precisely matched the percentage of reduced experience in this scenario is a coincidence which can be proven by variations with other reductions of experience. A mandated overtime of 20% leads to the reduction of overall costs of more than one percent in scenario S4.1. Especially apparent is the saved time in this scenario, at almost 11% a substantially higher value than in scenario 3 including the factor of work adjustment. Following the assumption that mandated overtime has a negative impact on the quality of work, scenario S4.2 displays an increase of the overall project costs of nearly three percent. Despite the necessary cycles of revision and repair, project duration shrank by more than two percent. This means that the influence on the quality of workmanship caused additional costs due to the cycles of revision and repair, but nevertheless the overtime still affected project duration in a positive manner. Especially in these scenarios, a valid determination of both increases and decreases in costs or required time is substantially difficult, as a reliable statement would need more detailed input data for the illustration of the relationship between overtime and work quality. The missing input data could be obtained from additional field studies. Despite that, the developed simulation model appears to depict the effects of the different scenarios correctly and can, therefore, demonstrate the relationships at least qualitatively. The scenario S5.1, originally seen as good case and supposed to show the advantages of combining overtime (S4.1) and adjustment to the work (S2), demonstrated a reduction of project costs indeed and a decrease of project time of almost 12% in comparison to the basic scenario S1. However, when compared to the overtime scenario S4.1, the inclusion of work adjustment effects has only marginal impact on the final values. The reason for this is the availability of the required material. While the materials and resources necessary for the implementation of the first production cycle are available in sufficient quantity at the start of the scenarios S1, S3 and S4.1, the situation which develops in S5.1 does not allow the crew to deploy their full performance potential. Although the increased frequency of order placement allows the execution of work processes, but the storage capacity limited to a specific value does not provide enough room for an increased stockpiling. This, in turn, leads to a production process which is not running smoothly and in the best way. Even though a theoretically higher production performance is available, this is only applicable up to a certain limit. Thus the expected advantages cannot be realized in scenario S5.1, because the production performance is constricted by the storage situation. The scenario S5.1 demonstrates that no more than 12% of time can be saved under the given circumstances. If the stockpiling is adapted accordingly, scenario S5.1 can realize a theoretical time saving of up to 41%. Scenario S5.2 shows that the negative effects of mandated overtime in scenario 4.2 can be countered marginally only with the inclusion of vocational adjustment effects. Compared to the basic scenario S1, S5.2 results in a cost increase of more than two percent. The overall project duration can be reduced by approximately three percent. In addition to that, the results derived from the S5 scenarios highlight the fact that due to diverse interdependencies and feedback effects within the system, a superposition of results from different scenarios (e.g. S4+S2) is not directly possible.

A relationship between less experienced construction site personnel and the quality of the management can be extracted from the results of scenario S6. This scenario offers the expected result: the necessity of closer quality monitoring in case of less experienced workers appears generally reasonable. This problem is even more relevant when integrating services provided by subcontractors, as – in contrast to employed staff members – the construction management (especially at the beginning of the project) normally has no valid reference points for the qualification of the external staff. If substandard and flawed workmanship is continually only detected and remedied after the second day, the overall project costs increase by more than six percent due to the reworking and repair. The project duration increases by more than 12%. In case the shortcomings and dissatisfactory work results are continually detected and repaired after the third day, the overall project costs increase by nine percent, the completion time increases by nearly 20% and nearly reaches the contractual maximum allowance of the project duration.

Similar, but less substantial consequences can be derived from the scenario S7, in which the time needed for the detection of flawed work results is inspected in combination with the reduced quality of work due to mandated overtime. In S7.1, the overall project costs rise by more than five percent. Even though S7.1 leads to an increased project duration of nearly seven percent, this value is still below the corresponding value from S6.1. Therefore, the reworking and repair cycles are less time-consuming in this constellation due to the mandated overtime. If the time needed for detection of substandard work results is increased to three days (S7.2), the overall costs increase by almost eight percent in comparison to S1. The overall project duration is still within the contractual limits with an increase by 13%.

The results of S6 and S7 clearly show the high relevance of quality management by the construction management. As quality and performance of the management depends on a diversity of factors, these results cannot be declared as final and comprehensive. Nevertheless, they hint at the impact and importance of late detection of flaws in workmanship. The bad case scenario depicted in S8, which is supposed to be balanced with the inclusion of the adjustment to work effect (S2), shows that the financial tolerance is nearly exceeded by 10%. The originally calculated completion time is exceeded by almost 16% and stays within the time limit set in the contract. If the material losses are increased or the detection period of substandard work result is longer than two days, the schedule of the project cannot be followed any more. In such a case, further parameters, e.g. personnel resources, would need to be adjusted accordingly. Even though the projects can be completed within the set time limit in the discussed scenarios and a (in German literature communicated) typical risk- and profit markup of between 1%-4%[1] is assumed, a significant loss occurred in some of the projects. While not each project of a corporation is completed negatively and therefore the more successful projects balance the less successful ventures, the previous scenarios suggest that the usual risk- and profit markups appear to be insufficient and need to be reconsidered[2].

6.2 Results of the business game

The evaluation of the business game covered and inspected a diversity of aspects. This chapter, however, covers only the results of the online business game in regard to the development of the company and the market as well as the decision-taking.

[1]cf. Künstner et al. (2002), Hoffmann (2006)
[2]one solution is suggested by Poloczek (2013)

6.2.1 Preparation of the business game

The preparation of the business game takes place on three levels: a) administration level, b) action level and c) reaction level (for details refer to figure 6.1 on p. 131). General preparations are carried out both on the action and the reaction level, e.g. the generation of projects (refer to chapter 6.2.1.2 on p.135 ff.) and companies (chapter 6.2.1.1 on p.133 ff.) as well as the allocation of participants to the individual companies. More extensive are the tasks on the administration level. Here the business game administrators (manager and trainer) as well as, if needed, superadmins are set up and activated. The business game is based on the development of market data, e.g. prices of material and resources or labor costs. These can either be described using fixed sets of data or individual mathematical functions. Furthermore, countries and the modules to be used in the business game need to be activated.

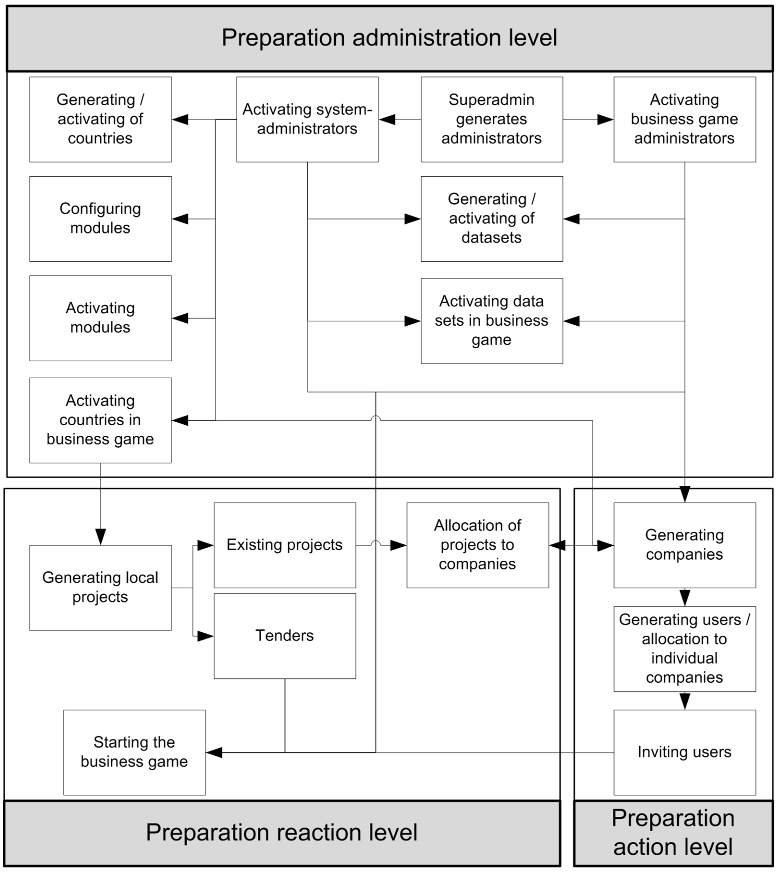


Figure 6.1: Activity diagram: preparation

In general, the different modules can be configured as follows: a) at the beginning of the business game event, b) individually within the course of the business game, c) automatic activation at a pre-defined point in time (quarter). Currently, 45 partly interdependent modules are integrated. The decision which module should be activated depends on the target group, the teaching and learning objectives and the temporal learning progress of the participants. The following modules are integrated in the discussed business game:

1. Module profile: changing of basic settings like account name, company name etc.
2. Module production costs: adjustment of details of the production costs.
3. Module tender: activation/deactivation of different types of tendering
4. Module ranking: different ranking lists can be accessed by the participants for the comparison with other companies and their performance
5. Module hire & fire: workers can be employed as new members of the company's labor force or laid off again
6. Module buy & sell: devices can be acquired or sold again
7. Module project events: influence of different project events
8. Module company events: influence of different events or incidents in the company
9. Module market events: impact of different market events

Further completely developed and tested modules of the business game are:

1. Module reject: projects can be rejected after successful acquisition (only reasonable at the beginning and in case of inexperienced participants).
2. Module adjust resources: resources can be changed individually in the projects
3. Module penalties: if projects are completed later than agreed on, e.g. due to changed resources, penalties are awarded.
4. Module headquarters: changing the home country of the company.
5. Module travelling costs: travelling expenses are often seen as parts of project costs (standard is the linear distance between project and company location)
6. Module company organization: activation/deactivation of this option to devise individual company hierarchy (the individual roles can be activated separately).
7. Module recruitment: participants can change employers and apply for positions in other companies or be headhunted.
8. Module tender history: participants can view all previous tender offers.
9. Module KPI: several KPI can be displayed (role-dependent).
10. Module messaging: business game players can communicate with each other.
11. Module decision comments: participants are given the possibility to comment on their own decisions. This serves as preparation for the debriefing.

Modules still in development:

1. Module merger & acquisition: possibility to merge or combine companies.
2. Module build new company: participants can found new companies with their capital.
3. Module rental equipment: offer to rent equipment and tools, even from competitors, instead of buying them.
4. Module experience workforce: the experience accumulated by the staff members during the project duration is recognized in the projects.

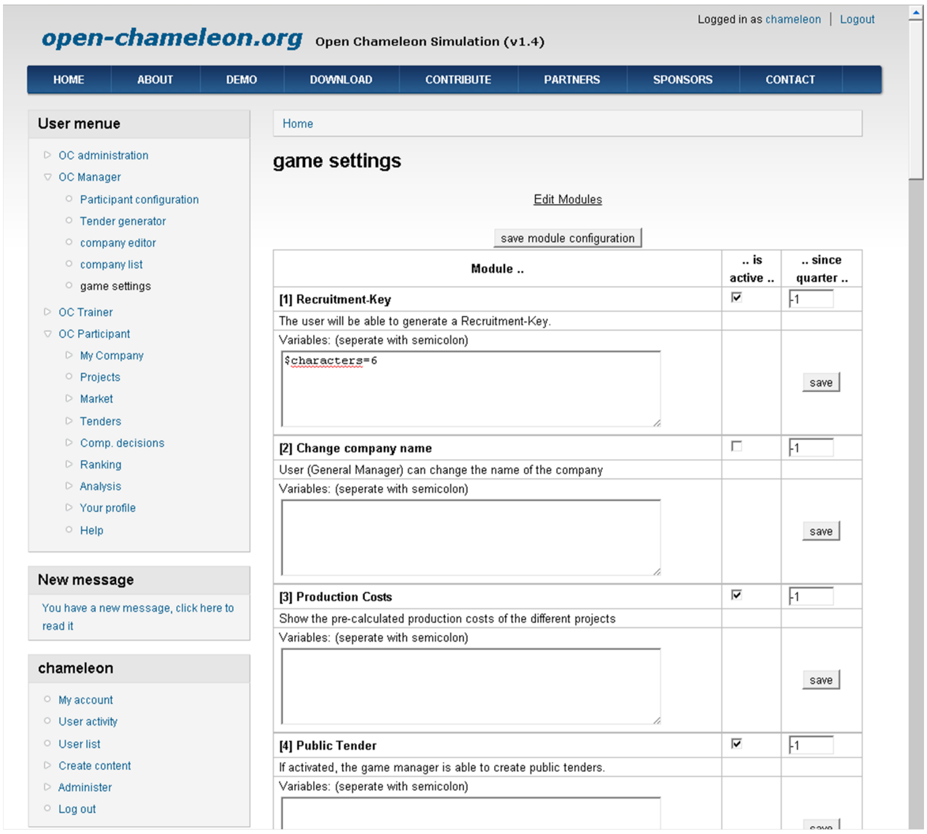


Figure 6.2: Module administration

5. Module personnel development: investments can be taken to increase performance and qualification of workers.
6. Module research and development: By investing in research and development, equipment costs can be reduced.
7. Module own projects: participants can initiate their own projects with their budget (assuming the role of contracting party).
8. Module cooperation: companies can work together in projects.

Figure 6.2 on p. 133 shows how the different modules can be administered in the online business game.

6.2.1.1 Companies

As the configuration of the companies represented in the business game is essential for the evaluation of the company's development and the decisions taken during the business game, it appears necessary to introduce the fundamental composition of the business game companies in detail as a start. Three possibilities can be distinguished:

a) Capital is placed at the participant's disposal to offer the chance of setting up and organizing their company ab initio.

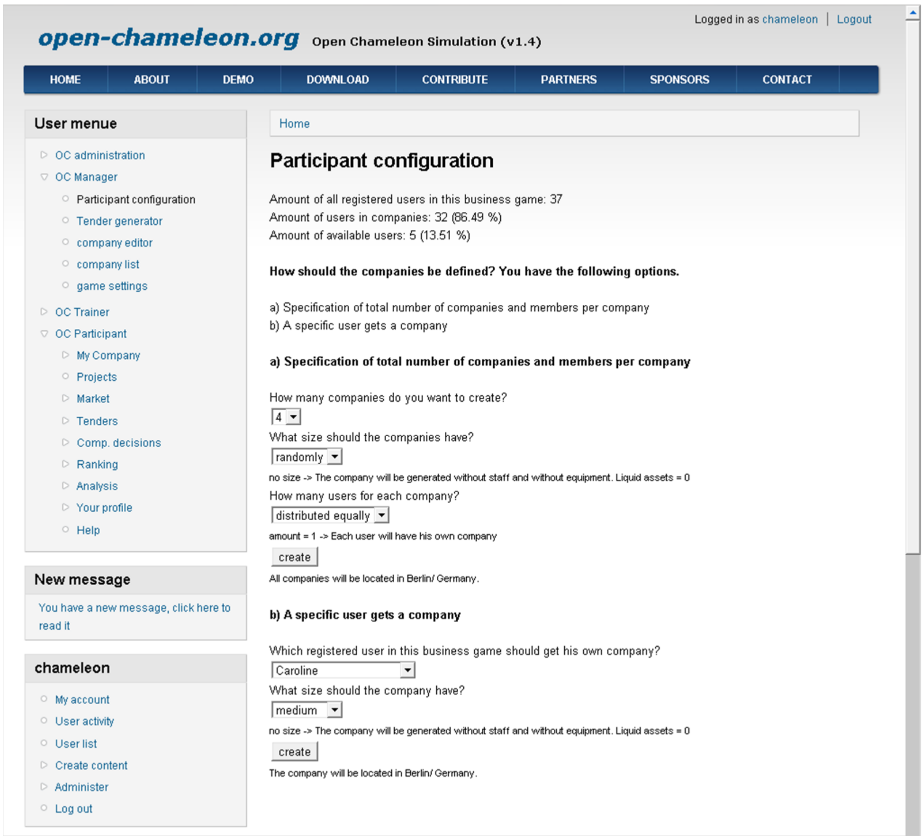


Figure 6.3: Generating companies

b) Generation of small, medium and large companies and a subsequent random allocation of these to the participants.

c) Generation of companies with identical size and allocation of them to the participants.

Within Chameleon, administrators can choose one of the above-mentioned alternatives from the beginning on. Nevertheless, it is equally possible to equip new participants with companies during the gameplay by using one of the above possibilities for its generation. Thus, a maximum of flexibility is given for the configuration of companies. In the business game sessions presented here, randomly created companies of different structures and sizes were configured and then randomly assigned to the participants. As already shown in the activity diagram of preparation (refer to figure 6.1), the business game manager carries out the allocation of companies and participants on the action level. This takes place in two ways:

a) Generation of a fixed number of companies with automatic and random allocation of the participants or

b) Generation of one company only with fixed allocation to one user (refer to figure 6.3 on p.134)

In a pilot study, 14 companies were generated (refer to table 6.2). Thereby, companies were created with a high quantity of equipment and/or personnel. In contrast, other companies had, compared to the market requirements, relatively few items of equipment and/or personnel. In

Table 6.2: company configuration

CompanyID	personnel	cranes	excavators	trucks	cash
115	100	14	10	10	6,838,428
116	30	30	40	30	4,045,652
117	30	10	5	10	2,392,633
118	120	5	15	21	8,098,312
119	30	30	30	30	3,829,751
210	100	30	40	30	8,329,652
211	40	10	8	11	3,100,810
212	65	25	40	35	6,277,383
214	30	30	30	50	2,500,584
215	85	10	12	19	7,823,892
216	35	10	7	12	2,794,810
217	35	5	10	15	2,804,627
218	60	40	30	30	4,426,312
322	85	30	40	30	7,411,652

both cases it was expected that participants reacted accordingly and appropriately to these factors during the gameplay. In chapter 6.2.4 on p.144 ff., selected business game companies are discussed to demonstrate whether the expected developments and decisions were also evaluated or considered by the participants.

6.2.1.2 Projects

The projects are constructed on the basis of the CDL model (refer to figure 5.2 on p. 110). The different project types draw on the Baukosteninformationszentrum (2008). This means that in one database per project type, parameters of at least one project type are stored and can be retrieved. The random variation of basic parameters (e.g. gross volume, proportion of building shell or steel construction and many more) can be employed to generate a diversity of different and realistic projects. The used Chameleon version considers three types of equipment and three types of materials in the projects. Additionally, the generated projects contain variables, e.g. costs of materials and resources, labor or operating supplies. Fixed costs of the construction site and general business expenses need to be added to the aforementioned, partly dependent on the activities of the individual company.

The project generator considers the currently valid wages, acquisition prices of material and the costs of operating fluids and supplies. If production costs are to be listed, they refer exclusively to the current point in time. However, the expenses during the gameplay of the business game are always determined with the currently valid prices, so a long-term observation of the market development can be expected of the participants.

Plans of income and expenditure are also generated automatically. The generation of projects in the online business game is shown exemplarily in figure 6.4 on p.136. The illustration of a

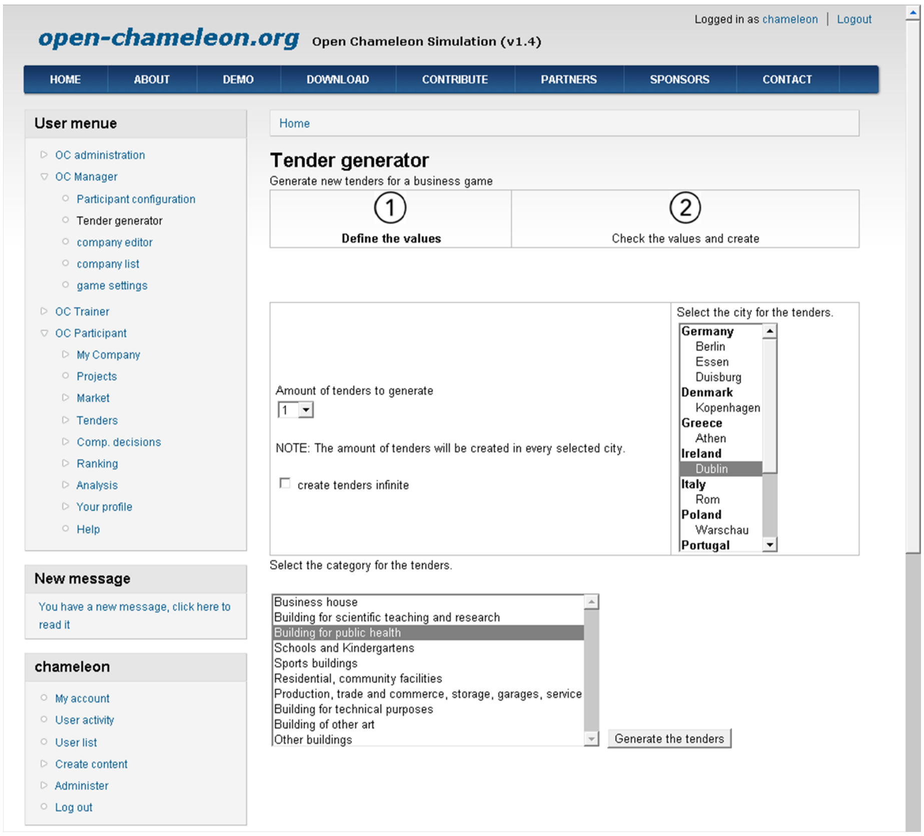


Figure 6.4: Generating projects

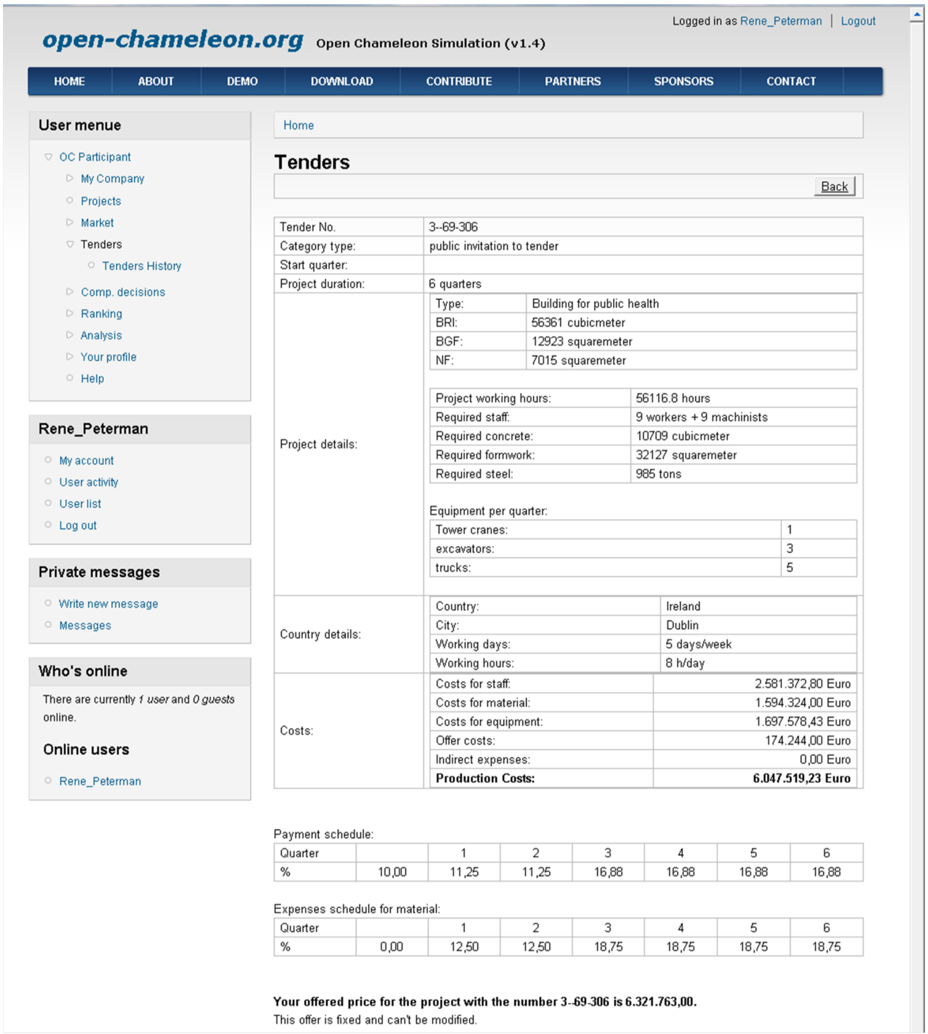


Figure 6.5: Example of a project

project from the perspective of a participant is shown in figure 6.5 on p.137.

6.2.1.3 Market

Apart from the configuration of companies and projects, the administrator also needs to define the market. In Chameleon, the administrator can a) set the level of demand at the beginning of the game event and for the whole duration of it or b) adjust the demand in each simulated quarter during the game, depending on the current developments in the gameplay. In both cases the participants are not informed about the current demand before the phase of tendering. The market was defined as follows: quarter 1 – high demand, quarter 2 – reduced demand, quarter 3 till end – fluctuating demand including volatile acquisition costs for material, increase of labor costs, project as well as company events[3]. Here it is necessary to mention that the integrated

[3]The additional or reduced costs caused by events are based on, among others, the calculated simulation results which can be found in chapter 6.1.

events are chosen to create a conflict (and thereby serve the desired learning purpose), but not to endanger the existence of the virtual company.

6.2.2 Implementation of the business game

The online business game event lasted five weeks in which nine quarters were played with 14 companies. To counter a potentially negative influence on the business game seminar, the participants were communicated a duration of at least 12 quarters at the beginning of the seminar (refer to p.122). The activities which had to be carried out in this time are schematically illustrated in figure 6.6 on p.138.

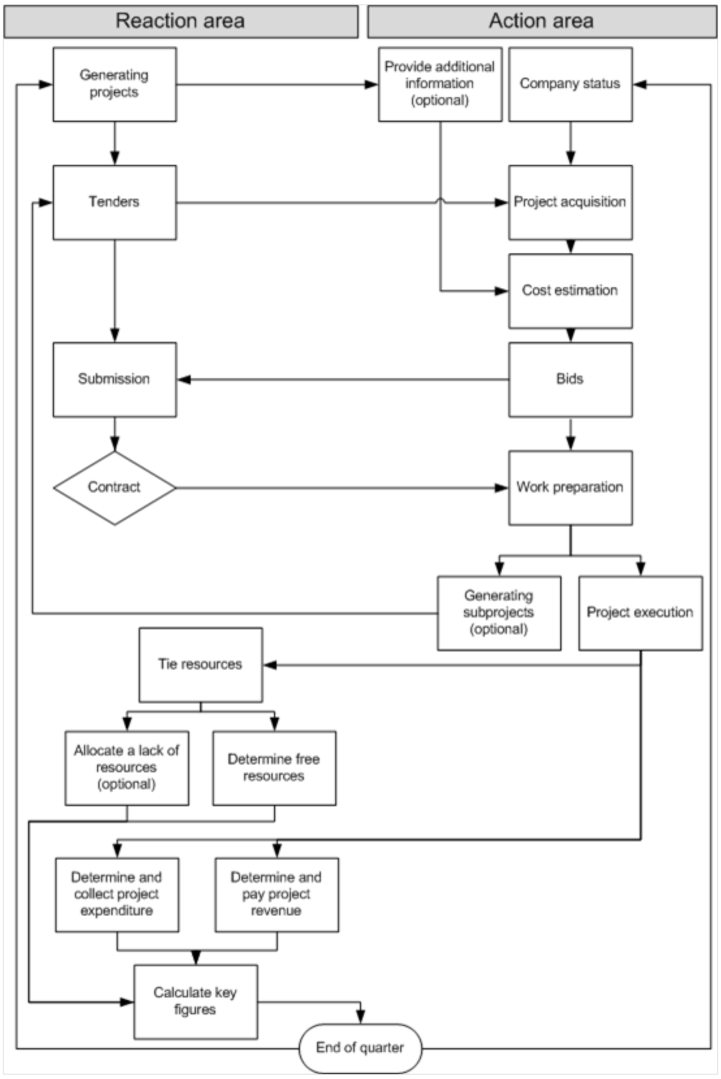
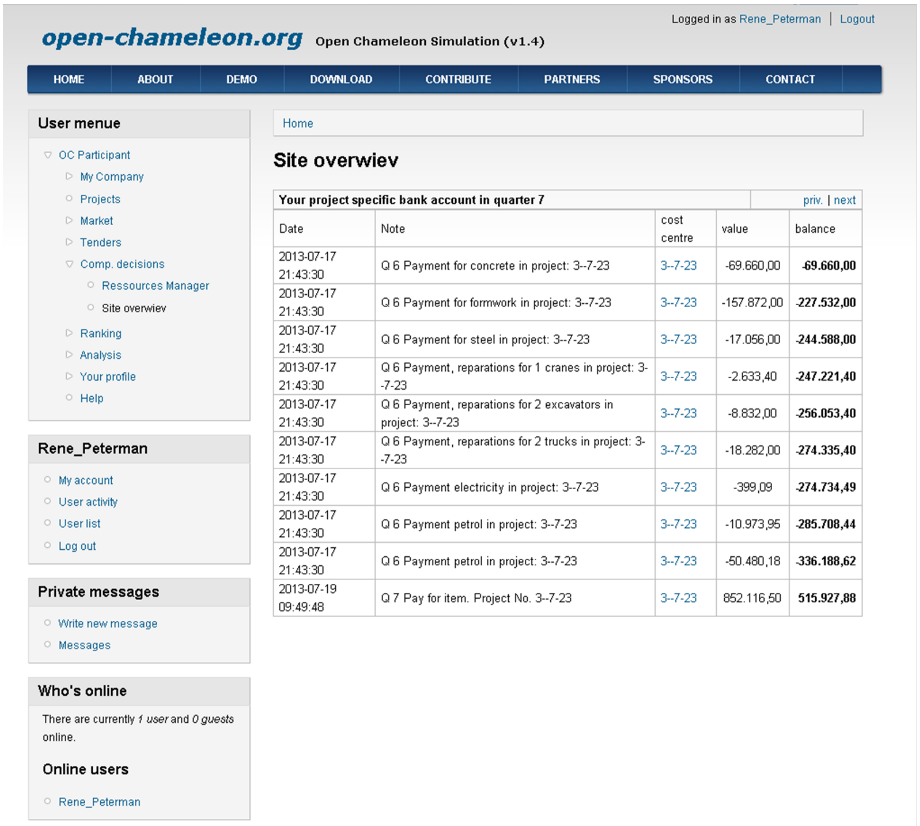


Figure 6.6: Activity diagram: implementation

In the reaction area, the business game supervisor generates projects and places information at the disposal of the participants. This created pool of orders is the basis for the project acquisition in the action area. After the processing of the projects, the offers need to be submitted in due



Date	Note	cost centre	value	balance
2013-07-17 21:43:30	Q 6 Payment for concrete in project: 3--7-23	3--7-23	-69.660,00	-69.660,00
2013-07-17 21:43:30	Q 6 Payment for formwork in project: 3--7-23	3--7-23	-157.872,00	-227.532,00
2013-07-17 21:43:30	Q 6 Payment for steel in project: 3--7-23	3--7-23	-17.056,00	-244.588,00
2013-07-17 21:43:30	Q 6 Payment, reparations for 1 cranes in project: 3--7-23	3--7-23	-2.633,40	-247.221,40
2013-07-17 21:43:30	Q 6 Payment, reparations for 2 excavators in project: 3--7-23	3--7-23	-8.832,00	-256.053,40
2013-07-17 21:43:30	Q 6 Payment, reparations for 2 trucks in project: 3--7-23	3--7-23	-18.282,00	-274.335,40
2013-07-17 21:43:30	Q 6 Payment electricity in project: 3--7-23	3--7-23	-399,09	-274.734,49
2013-07-17 21:43:30	Q 6 Payment petrol in project: 3--7-23	3--7-23	-10.973,95	-285.708,44
2013-07-17 21:43:30	Q 6 Payment petrol in project: 3--7-23	3--7-23	-50.480,18	-336.188,62
2013-07-19 09:49:48	Q 7 Pay for item. Project No. 3--7-23	3--7-23	852.116,50	515.927,88

Figure 6.7: Example of a bank account for a specific construction site

time. Each submission immediately causes the corresponding offer costs. After submission, the placing of the orders follows. For this, the system randomly selects and assesses submissions. Submissions which are too high or low can automatically be rejected (limits for this can be individually adjusted in the business games). Usually the most advantageous tenderer gets the acceptance. To prepare for the initialization of work, the companies need to take their decisions in due time and have to plan the employment of resources for their projects.

The resources are allocated by the system or, if necessary, missing quantities are complemented, incurring additional charges (according to the configuration). If resources exceed the current need, they are considered in the reaction area as well. Then, potential costs for the provision or standby availability are determined. Furthermore, the revenue and expenses generated in the projects are calculated. As each company uses an individual bank account, the revenue and the expenses or costs can be viewed from different role-dependent perspectives: a) company-wide, b) per cost center (e.g. general business expenses, costs of material etc), c) per construction site. These overviews can be displayed in form of summaries or for each quarter. Figure 6.7 on p.139 shows an exemplary overview of the debits and credits of a construction site for the quarter 7. All data generated in this phase are continually logged as company or project operating figures and are available as company status reports after the end of the quarter.

6.2.3 Results

The data records acquired in the business game activities are summarized according to different operating figures (table 6.3 to table 6.5). For each quarter, the following parameters are relevant: the number of tenders, the ratio of acceptance (number of accepted tenders/overall number of submitted tenders), the competition ratio (number of companies involved in this round/overall number of tenders), the number of successful bids and overall tendered submissions, the chosen margins in percent as well as a calculated mean ratio of successfully submitted offers (number of successful submissions/ overall number of submissions) per quarter or per company.

On general inspection, it becomes apparent that a multitude of tenders does not necessarily result in an increase of the mean ratio of successfully submitted offers in a quarter (Pearson's correlation coefficient: r = -0,02). Although it would have been expected that a high number of potential projects increases the average probability of an acceptance, the results show something else. The quota of successfully placed offers in the market is dependent on multiple factors, e.g. the general corporate strategy, the previous development and load factor of the company as well as the individual financial situation. Even in case of many tenders, companies operating at full capacity are not likely to place more offers (unless expansion is the principal aim). Beyond this, the success ratio of submissions is strongly influenced by the activities of the competitors. Do they tender for the same projects? What are their chosen margins? Are there possibly any projects several companies or no companies are tendering for? The latter is quite possible, as it is not transparent during the tender phase who places offers for which project. Such information is only accessible for the participants after the submission.

35 tenders were generated for the 14 companies in quarter 0. For this quarter, 83 offers were placed by 12 companies. 19 offers were accepted and the projects granted, i.e. no offers were placed for 16 of the projects. Due to the fact that companies do not submit offers for all projects if there is an ample availability of projects (e.g. to economize costs for offer placement), not all tenders could be granted. Consequently, the ratio of successful offers was only 26% in this quarter. If each company had tendered for two specific projects, the ratio of successful offers would have been 100%. In such an environment, corporation 214 would have been in the position to realize a margin of 46.4% (Assuming that the system assess this offer during the randomly generated inspection as acceptable and not overpriced within the submission phase). These relationships can be confirmed with the relatively high negative linear correlation between number of tenders and ratio of acceptance (r = -0,85). A slightly negative linear correlation can be identified in regard to the number of tenders in relation to competition ratio (r = -0,58). This means that a large number of tenders results in a reduced competition. This phenomenon was expected, as the generation of many tenders was supposed to lead to a relaxation of the competition. A slightly negative linear correlation can be detected on inspection of the competition ratio related to the mean ratio of successful offers: an increase of the competition (e.g. by reduction of the tender quantity or the increase of the companies participating in the competitive setting) leads to a decreased mean ratio of successful offers (r = -0,56). The overall assessment of the

Table 6.3: Evaluation of the business game (1/3)

quarter	tender (ratio of acceptance,competition ratio)		115	116	117	118	119
0	35	successful bids/sum bids		1/6	0/8	3/3	3/8
	(54%, 34%)	mean margin		3,1%/3,3%	- /8,9%	4,1%/4,1%	-4,2%/4,9%
		margin (max,min)		46,5%, -32,7%	35,7%, -38,1%	8,9%, 1,5%	39,3%, -44,0%
1	10	successful bids/sum bids	2/5		1/3		1/2
	(70%, 80%)	mean margin	-26,6%/4,0%		11,7%/-5,0%		-14,6%/-18,7%
		margin (max,min)	31,3%, -45,2%		11,7%, -14,9%		-14,6%, -22,9%
2	10	successful bids/sum bids		0/3	2/2	0/1	
	(100%, 70%)	mean margin		- /24,0%	6,1%/6,1%	- /28,1%	
		margin (max,min)		36,7%, 6,9%	8,3%, 4,0%	28,1%, 28,1%	
3	4	successful bids/sum bids	2/4	1/2	0/3		1/4
	(100%, 250%)	mean margin	-13,9%/4,0%	0,2%/0,6%	- /3,8		0,5%/0,5%
		margin (max,min)	44,7%, -19,7%	0,9%/, 0,2%	3,8%, 3,7%		0,5%, 0,5%
4	9	successful bids/sum bids		1/1	1/2		
	(100%, 88%)	mean margin		0,6%/0,6%	4,8%/5,3%		
		margin (max,min)		0,6%, 0,6%	5,8%, 4,8%		
5	7	successful bids/sum bids		0/2	0/3		
	(100%, 157%)	mean margin		- /10,5%	- /7,4%		
		margin (max,min)		14,3%/6,7%	10,1%, 5,5%		
6	12	successful bids/sum bids		2/3	1/3	1/1	
	(92%, 75%)	mean margin		8,5%/ 7,5%	2,1%/2,1%	0,5%/0,5%	
		margin (max,min)		14,1%, 2,9%	2,1%, 2,1%	0,5%, 0,5%	
7	11	successful bids/sum bids			2/2		
	(91%, 54%)	mean margin			3,2%/3,2%		
		margin (max,min)			3,5%, 2,9%		
8	6	successful bids/sum bids		3/3		1/1	
	(100%, 117%)	mean margin		3,8%/3,8%%		2,0%/2,0%	
		margin (max,min)		4,2%, 1,5%		2,0%, 2,0%	
9	11	successful bids/sum bids	5/5	1/1			
	(91%, 54%)	mean margin	-4,5%/-4,5%	10,1%/10,1%			
		margin (max,min)	-2,1%, -7,1%	10,1%, 10,1%			
	mean ratio of successfully submitted offers		63%	54%	40%	75%	38%

Table 6.4: Evaluation of the business game (2/3)

quarter	tender (ratio of acceptance,competition ratio)		210	211	212	214	215
0	35 (54%, 34%)	successful bids/sum bids	3/8	2/6	2/10	0/5	2/12
		mean margin	4,7%/17,8%	5,8%/14,0%	12,6%/19,8%	- /7,9%	22,2%/67,4%
		margin (max,min)	37,4%, 2,0%	41,6%, -23,3%	43,25%, 2,6%	46,4%, -37,1%	96,2%, 6,6%
1	10 (70%, 80%)	successful bids/sum bids		0/1			0/3
		mean margin		- / -17,6%			- /54,9%
		margin (max,min)		-17,6%, -17,6%			65,3%, 41,6%
2	10 (100%, 70%)	successful bids/sum bids				2/5	
		mean margin				27,7%/20,0%	
		margin (max,min)				27,8%, 0,5%	
3	4 (100%, 250%)	successful bids/sum bids	0/1		0/4	0/3	0/4
		mean margin	- /1,0%		-/ 5,0%	- /7,6%	- /41,3%
		margin (max,min)	1,0%, 1,0%		8,1%, 2,7%	8,7%, 7,1%	60,5%, 7,5%
4	9 (100%, 88%)	successful bids/sum bids		1/5	3/7	1/6	1/9
		mean margin		5,9%/10,1%	3,0%/5,9%	6,2%/6,52%	44,7%/42,9%
		margin (max,min)		27,5%, 4,0%	12,2%, 2,7%	7,4%, 5,7%	49,9%, 35,0%
5	7 (100%, 157%)	successful bids/sum bids	2/3	1/1	0/1	3/4	0/7
		mean margin	0%/0%	5,6%/5,6%	- / 16,7%	6,42%/6,57%	- / 49,8%
		margin (max,min)	0%, 0%	5,6%, 5,6%	16,7% , 16,7%	7,1%, 5,7%	68,1%, 39,9%
6	12 (92%, 75%)	successful bids/sum bids			2/9	1/3	0/9
		mean margin			20,0%/21,7%	8,3%/7,8%	- / 43,2%
		margin (max,min)			30,2%, 19,9%	8,3%, 7,5%	60,6%, 31,1%
7	11 (91%, 54%)	successful bids/sum bids			5/11	0/1	1/4
		mean margin			19,9%/22,0%	- / 6,5%	20,5%/25,1%
		margin (max,min)			26,4%/19,9%	6,5%, 6,5%	29,5%, 20,5%
8	6 (100%, 117%)	successful bids/sum bids			0/1	1/3	1/2
		mean margin			- /19,9%	6,7%/6,5%	21,0%/23,0%
		margin (max,min)			19,9%, 19,9%	6,7%, 6,4%	25,0%, 21,0%
9	11 (91%, 54%)	successful bids/sum bids	1/2		1/1	2/2	
		mean margin	4,8%/6,9%		43,1%/43,1%	9,3%/9,3%	
		margin (max,min)	9,1%, 4,8%		43,1%, 43,1%	12,0%, 6,5%	
	mean ratio of successfully submitted offers		39%	38%	29%	33%	13%

Table 6.5: Evaluation of the business game (3/3)

quarter	tender (ratio of acceptance,competition ratio)		216	217	218	322	mean ratio successfully offers
0	35 (54%, 34%)	successful bids/sum bids	0/5	2/5	1/7		26%
		mean margin	- /23,2%	-28,8%/-33,4%	2,2%/30,5%		
		margin (max,min)	46,0%, -40,4%	-21,5%, -41,4%	53,9, 2,2%		
1	10 (70%, 80%)	successful bids/sum bids	0/3		1/4	2/4	25%
		mean margin	- /14,1%		24,3%/ 23,5%	17,1%/35,1%	
		margin (max,min)	35,7%, -25,0%		37,1%, -3,5%	59,2%, -13,1%	
2	10 (100%, 70%)	successful bids/sum bids	3/4		2/4	1/4	41%
		mean margin	-0,2%/0,0%		10,2%/9,6%	38,7%/40,9%	
		margin (max,min)	1,8%, -1,1%		12,8%, 5,0%	45,4%, 34,4%	
3	4 (100%, 250%)	successful bids/sum bids	0/1		0/2		13%
		mean margin	- /0,9%		- /22,4%		
		margin (max,min)	0,9%, 0,9%		28,6%, 16,2%		
4	9 (100%, 88%)	successful bids/sum bids	1/3		0/3		34%
		mean margin	-0,4%/11,5%		- /26,6%		
		margin (max,min)	33,2%, -0,4%		39,9%, 18,2%		
5	7 (100%, 157%)	successful bids/sum bids	0/1	0/3	1/4	0/4	24%
		mean margin	- /14,9%	- / 13,9%	10,9%/10,5%	- / 41,31%	
		margin (max,min)	14,9%, 14,9%	14,3%, -13,5%	21,2%, -10,9%	62,8%, 30,0%	
6	12 (92%, 75%)	successful bids/sum bids	1/2		2/4	1/2	45%
		mean margin	0,0%/2,86%		1,7%/3,9%	42,1%/30,3%	
		margin (max,min)	5,7%, 0,0%		7,0%, 1,6%	42,1%, 18,6%	
7	11 (91%, 54%)	successful bids/sum bids	0/2		2/4		37%
		mean margin	- /18,0%		10,1%/29,2%		
		margin (max,min)	24,0%, 12,1%		90,9%, 2,4%		
8	6 (100%, 117%)	successful bids/sum bids		0/3		0/2	40%
		mean margin		- / 9,1%		- /40,8%	
		margin (max,min)		9,1%, 9,1%		54,7%, 26,8%	
9	11 (91%, 54%)	successful bids/sum bids			0/1		75%
		mean margin			- / 11,1%		
		margin (max,min)			11,1%, 11,1%		
	mean ratio of successfully submitted offers		20%	13%	24%	25%	36%

developments and relationships described here leads to the general conclusion that the span between the maximal and minimal selected surcharges decreases from quarter 1 to quarter 9 in many companies. As a result, it can be assumed that the possibilities of maximal or minimal limits were explored at the beginning of the event. In the following, three companies are selected to discuss the actions of individual companies in detail.

6.2.4 Discussion of selected companies

The three companies 115, 210 and 212 are viewed in the following discussion. All three companies differ both in their size and in their development. Some of the companies found themselves in direct competition when placing their bids for projects. The development of the company 115 (figure 6.8) is marked by significant losses.

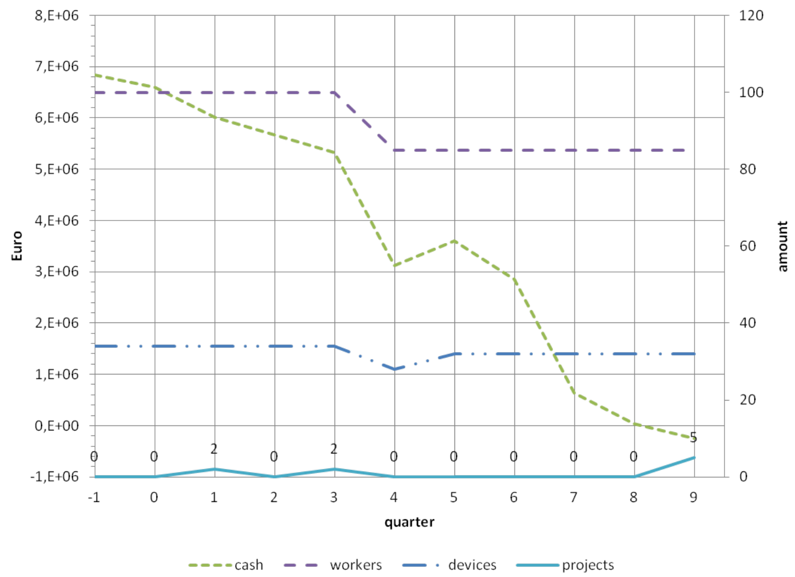


Figure 6.8: Development of company 115

At the start of the business game event, the participants announced their objective of high market shares. They attempted to reach this aim with the help of competitive and advantageous prices in the beginning of the game. Even though the company had a high ratio of successful bids of 63%, it should not be disregarded that at no point in time it managed to acquire a project with a sufficient margin. Margins of up to 44.7% were calculated in the third quarter, but could not be established in the market. The result is an insufficiently low number of projects for the available resources, confirmed by the participants in the debriefing. Additionally, no active acquisition took place in the quarters 4 to 8, even though the running costs of the company still had to be born. The reason for the inactivity could not be established in the debriefing, although the participants seemed to have developed a tendency to resign after the fourth quarter. Especially this passiveness, combined with the delayed layoff of personnel, was responsible for the failure of company 115. An early and adequate adaptation of the previous strategy was not implemented either. The development of company 115 demonstrates how unfavorable it is to operate with such small margins, even if it appears to be strategically important. However, the consideration of excessive margins in a period with only limited tenders (quarter 3) is an equally detrimental option. In how far the price policy of one single company can even influence the whole market is demonstrated by the other companies.

Company 210 (figure 6.9) is also characterized by a rather small number of acquired projects, but with positive margins. Considering the simulation results on p.126 ff., the potential occurrence of additional costs in one project could neutralize margins like the ones chosen by company 210. Albeit company 210 aimed at the utilization of its full capacity, success was not possible due to the limited number of projects. In contrast to 115, 210 used the possibility to sell unnecessary pieces of equipment rather early and thereby improved the liquidity. Interestingly enough, company 210 did not participate in the quarters 1, 6 and 7 (refer to 6.4 on p. 142).

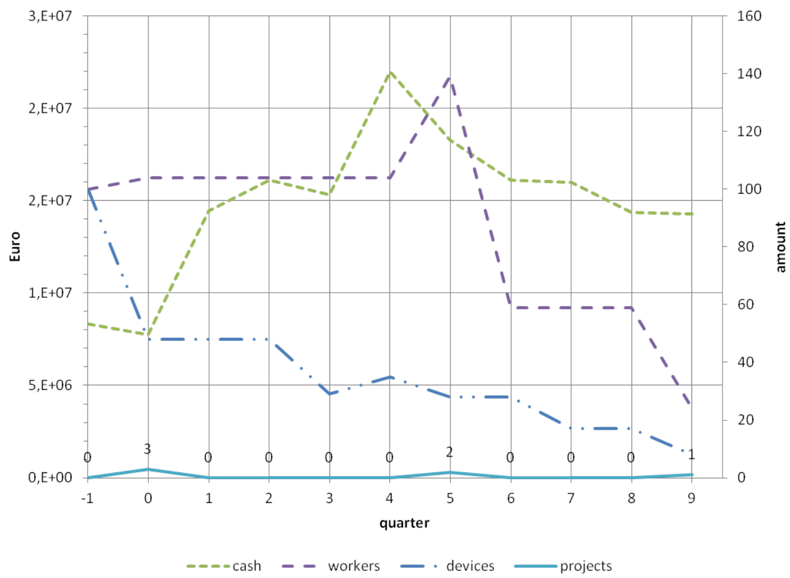


Figure 6.9: Development of company 210

Just in these round the ratios of awarded contracts was below 100% and so activities would have been sensible in this time. One reason which was voiced by the participants for the increasing inactivity was the negative market situation. This impression was mainly due to the fact that company 210 was underbid by company 115 in quarter 3 and thus did not manage to acquire project 98 (the only offered project). The margin calculated by company 210 was only 1%, but it was underbid by 115 with a margin of -8.1%. The consequence became obvious in quarter 5, in which 210 offered with a margin of 0% and was successful (probably also due to the fact that 115 did not participate in this round anymore). The little income and the massive personnel layoffs starting in quarter 5 placed additional burdens on the financial situation. All in all, company 210 relied more on its substance than on its own value creation.

In contrast to the two above-mentioned companies, company 212 (figure 6.10) displayed a favorable development. The fact that company 212, having been a small business at the beginning, managed to develop into a major corporation is especially remarkable. The participants' aim to stimulate growth of the company could be realized. Here it shows again, that a mean ratio of successful bids of 29% does not have to be an indicator for success (115: 63%, 210: 39%). An active participation in the market (in nearly every quarter bids were submitted) resulted in the successful acquisition of projects with partly very high margins.

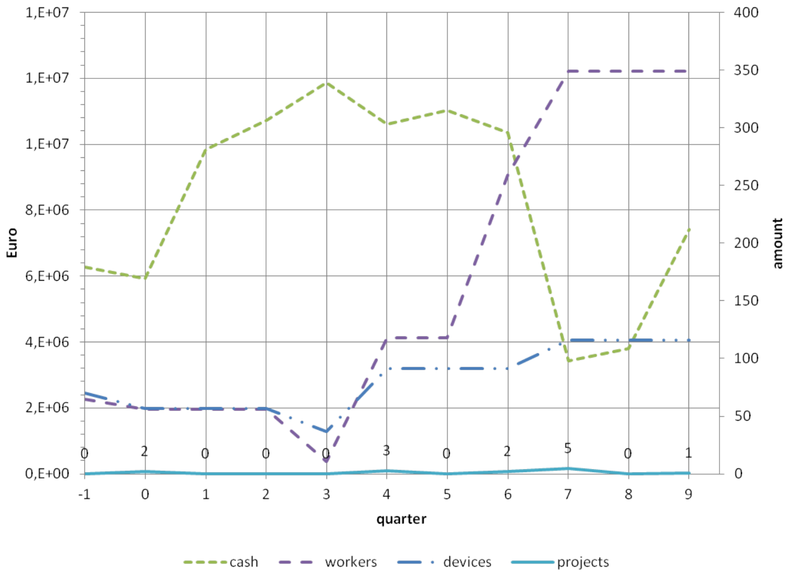


Figure 6.10: Development of company 212

These projects were intentionally characterized by intensive deployment of personnel and equipment with long-term duration. The only problematic aspects were the partly unfavorable plans for income and expenditure of single projects. These demanded significant payments in advance and relatively late incoming payments. Company 212 opposed company 115 in the projects 96 and 98 in quarter 3 as well. Company 212 offered with calculated margins of 4.6% and 4.8%. Company 115, however, offered with margins of -8.1% and -19.7%. In contrast to company 210, this event had no further influence on the decisions of the company and it could acquire projects with margins of up to 43.1% in the following quarters.

The results clearly show connections and influences of different types of company developments. The success of the individual business does not only dependent on one's own (even if appropriate) actions, but also on the activities of the other participants – no matter whether reasonable or nonsensical. It is just this fact which complicates the successful implementation of a strategy for some companies. Apparently, the following notions are primary factors of success: the precise and realistic definition of corporate objectives (e.g. a pure focusing on market shares without any regard to further parameters is not realistic), the retaining of one's own operating figures (internal focus), the continuous observation of the market and the constant market activity (external focus) as well as flexible reactions of the company management. In contrast, a passive and expectant attitude – possibly even combined with a high quantity of unused resources, few acquired projects and, lastly, insufficient margins – is to be seen as far from promising in the long term.

6.3 Expansion and optimization

To make the best use of the insights gained from the business game, it appears reasonable to develop both a basic setup of a company and a market model for the Vensim simulation. With these, it is possible to research the relationships identified in the business game (e.g. the system behavior in case of increasing competition or dropping demand). The integration of impulses, random fluctuation or reconfiguration of dependencies within the system allows the investigation of varying parameter constellations, but also different relations among themselves. Finally, the synergistic approach can be used to find answers to the following questions in the simulation or the business game itself: a) which are the relevant key parameters, b) where can time delays be expected to occur in the system, c) which relations exist between the entities and many more.

These newly generated entities can be integrated in the CDL respectively back into the business game to allow a more detailed scrutiny of the market and competition behavior influenced by the activities of the participants. Due to the open architecture of the CDL, it could be equally supportive to analyze already existing models (e.g. taken from Sterman (2004) or Bossel (2004)) and relate them to the knowledge gained here. Out of this, a substantial number of expansions could be expected within the CDL, especially on the tactical or strategic level.

Apart from that, the improvement both of the administration or participant area is another field for optimization. Thus, the development of unfinished modules should be continued and completed. The business game needs to be developed further in regard to its visualization in order to increase the acceptance and identification of the participants.

At the end of a business game event, some participants voiced their dissatisfaction and their impression of an unfair company configuration by the system. To counter this impression, the following procedure has proven itself in later business game events. Even though it is possible to generate and allocate different companies, it can be ensured that the total capital value of the companies is equal. This balance can be achieved in the business game by first setting the liquidity and then arranging the company resources accordingly. An identical amount of free capital is assigned to all participants. For the determination of this amount, it is reasonable to consider how long a company can operate and survive in the business game without any activity. For this, the contingency costs of the equipment and the labor costs are calculated and multiplied with the number of quarters the company should be able to exist without any activity. Income generated by sales of fixed capital is added to this value, i.e. selling pieces of equipment and machinery. If personnel was already included in the configuration, the costs for layoffs have to be added to the previously set capital. In case, however, the basic configuration did not include personnel yet, a further term can depict the costs of staff recruitment if necessary. Consequently, all participants would have the same financial assets if they chose to layoff all personnel and sell all equipment in the first quarter. Thus, equation 6.1 offers a general possibility to implement the above-mentioned configuration of the company.

$$\begin{aligned} Overall\ capital &= free\ capital + fixed\ capital + \\ & layoff\ costs + recruitment\ costs \end{aligned} \tag{6.1}$$

$$\begin{aligned} free\ capital &= (\sum_{i=1}^{3} amount\,of\,equipment_i \cdot specific\,contingency\,costs_i \\ &+ \sum_{j=1}^{2} amount\,of\,personnel_j \cdot specific\,labor\,costs_j) \cdot q \end{aligned} \tag{6.2}$$

$$fixed\ capital = \sum_{i=1}^{3} amount\,of\,equipment_i \cdot reinstatement\,value_i \tag{6.3}$$

$$layoff\ costs = \sum_{j=1}^{2} amount\,of\,personnel_j \cdot specific\,layoff\,costs_j \tag{6.4}$$

$$recruitment\ costs = \sum_{j=1}^{2} amount\,of\,personnel_j \cdot specific\,recruitment\,costs_j \tag{6.5}$$

with

i: type of equipment (crane, excavator, truck),

j: type of personnel (workers, operators (of equipment)),

q: quarter

7 Summary and outlook

The aim of this research project was the development and practical testing of a module-oriented modeling approach, which can be used both in the simulation of multi-causal and dynamic relationships on different levels of the construction industry and in educational games employed in academic and further education. Out of this primary aim, numerous research contributions emerged in the field of modeling, simulation and educational games (figure 7.1).

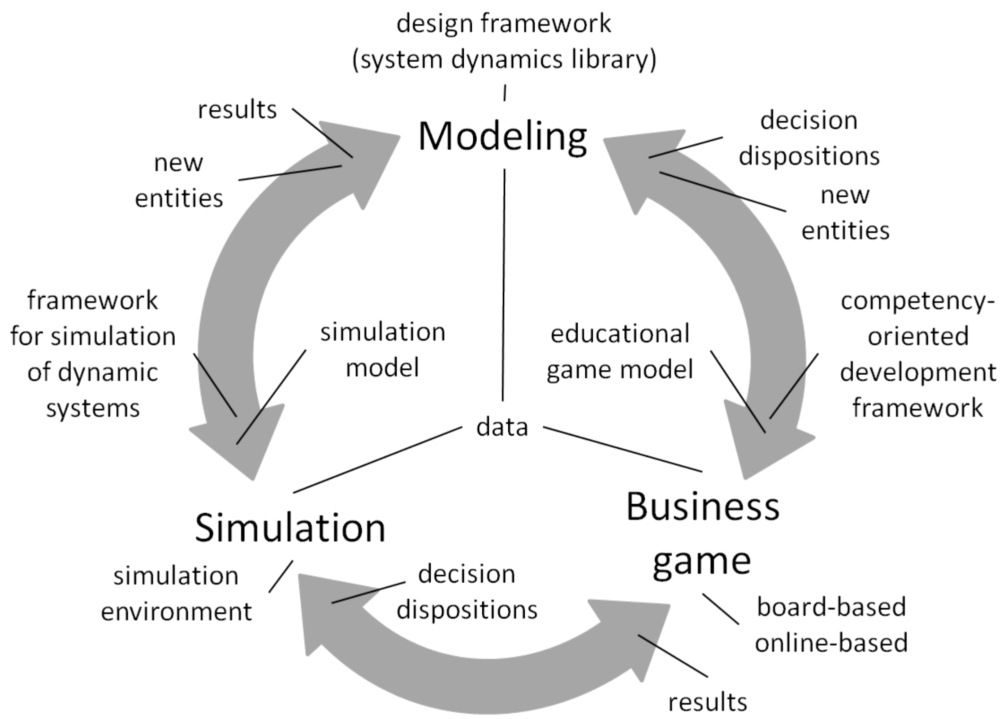


Figure 7.1: Overview and interrelations

7.1 Research contributions

Apart from the contributions illustrated in the following, two empirical studies aided in the determination of, on the one hand, the current status of the business game method in the German construction industry and, on the other hand, the current competency demands on construction engineers. Especially the procedure of devising competency models and the determined competency requirements can be helpful in many further areas of academic education for the conceptual design of teaching and learning scenarios. Therefore it is recommended to repeat the studies at regular intervals to allow the measurement of changes as well as potential future trends and tendencies in a longitudinal temporal section.

The successful conceptual design of a module-oriented development framework for domain-specific system-dynamic libraries (SDL approach) demonstrated that it is quite reasonable and possible to connect the development of simulations and business games. Thereby, knowledge synergies are created which enable the interdisciplinary development of business games and simulations in the sense of a synergistic knowledge absorption (SKA method). In the future, multidisciplinary R&D teams of scientists from different domains as well as practitioners have numerous possibilities to develop SDL units from varying perspectives. Compared to other fields, significantly less implementations of simulations or business games exist in the construction industry. Therefore, the approach introduced here can provide a valuable contribution to promote further developments. Additionally, an SDL allows to tap the potential of the business game method much more than before.

Beyond the formal procedure for the design of an SDL simulation, the first foundation of a domain-specific SDL (CDL) could be placed in the field of simulation. Apart from that, it was possible to demonstrate the practical implementation in the simulation program Vensim as well as the transferability of units from a simulation to educational games.

In the area of business games, the synergistic modeling approach and the connection of simulation and business game enable the application to explore and research human behavior – in addition to the classic use of a teaching and learning method.

When modeling human behavior, context is important.[1] The same is true for decisions which are a result of human behavior. Therefore describing the environment in which a person makes his or her decision plays a critical role in studying and understanding the decision-making process. Collecting context-related data can significantly help to draw a picture of the sphere in which different decisions were made. Hence, database-driven online decision games can play a vital role in the future. By applying this method, market and business developments as well as the most interesting variety of user decisions can be collected permanently.[2]

The analysis of this data will help to understand the decision making process in detail and the human behavior in general. In this context, the previously communicated and applied definition of educational games has to be expanded.

[1] cf. Luke (2004)

[2] If a business game is implemented as a Massively Multiplayer Online Game (MMOG), the continuous data recording and filing will lead to exorbitant amounts of data to be stored, possibly causing the classic relational database systems to be unable to manage the task. Here technologies with distributed processing of the data (for details refer to Big Data, White (2012)) should be considered to allow a reasonable data mining (cf. Fayyad et al. (1996))

On the one hand, an educational game represents a realistic, experience-based teaching and learning method which aims at the gaining of insights through the experiencing - mostly in teams - of conflict- and problem-based situations. On the other hand, on condition that the displayed excerpt of reality is sufficiently detailed, an educational game can equally be a research method, which - especially with the included time-lapse function - can achieve knowledge gains especially from the decisions and their resulting actions of the involved individuals and groups. As activities in such educational games can be systematically identified, analyzed and later reconstructed, these educational games can also be called *forensic decision games* (FDG).

7.2 Outlook and suggestions for future research activities

On the basis of the SDL approach respectively the domain-specific CDL developed in this research project, an open database is planned to be set up for the scientific community in the construction business.[3] This stock can successively be expanded by further developments from the scientific community and exchanged on the above-mentioned website. The internet platform functions as a type of shared modeling platform (SMP) and allows the collaborative development of units and complete models. Apart from the exchange and the continuous expansion of the library, the encouraged discourse in the community leads to a validation and thereby quality management of the CDL units. Primary prerequisite is, however, an open, fair and forgiving culture of development, which is based on the common goal to create sufficiently detailed and valid units and models.

In this context, CDL units can be of potential interest in the future if they examine the relationship between planning and the actual execution of the construction project. Regarding the current trends in the field of sustainable construction, the previously developed units can be expanded with additional attributes, which allocate in the individual sub-processes the CO_2 emissions, for example (e.g. dependent on the power of the device or on the carbon footprint of individual building materials). This would facilitate to estimate the costs and ecological burden of construction projects in advance.

Furthermore, CDL units, especially those serving the illustration of risks in different areas of the construction industry, could offer the basis for the development of special risk or danger models which can assist in the investigation of specific situations or behaviors and later the configuration of precaution and safety measures.

This could be, for instance, the elucidation of the risk situation of a company, the identification and evaluation of project risks or endangered operational procedures on various functional levels.

In addition to this described application, the SDL approach appears to be helpful in other areas of modeling and simulation.[4]

[3] The units and models developed in this research project are to be made available on www.constructiondynamics.org

[4] Apart from the domain-specific SDL, www.systemdynamicslibrary.org is supposed to serve as a further platform on which domain-independent SD libraries and their units can be published and exchanged.

As explicitly different levels and functional areas of a company are considered, an application in the research of organizational psychology would be possible, too. The SDL approach and the contained units could support the generation of hierarchically structured models through different levels and areas. Hence, interaction between the different levels (single individuals, teams or other functional units) could be interlaced and examined under consideration of further methods like the multi-level analysis (MLA)[5]. This means that SDL units and the resulting models can generally be examined with other simulation methods, too.

Combined with the business game method, units of CDL gain access to the previously developed business games or offer a basis for the design of further educational games. Therefore, the board-based business game Construction Giant is still subject of further development on the one hand and is used for the acquisition and analysis of decisions to gain insights on the other hand. The online game Chameleon is also scheduled to be developed successively. Emphasis should be given to the integration of those modules, which can depict a) different additional stakeholders (e.g. participants as contracting authorities) and b) adjacent markets (real estate market, energy market etc.).

A reasonable extension of the application is conceivable in the areas business start-up and entrepreneurship. Besides, the development of software agents for the support of a) decision-making of the participants and b) the trainer's analysis of the participants' decisions represents further potential to be used. The exploration of learning behavior displayed by participants, especially including mobile devices in the sense of a commuter learning approach (CLA)[6], constitutes another equally interesting research area with the help of the online educational game (figure 7.2).

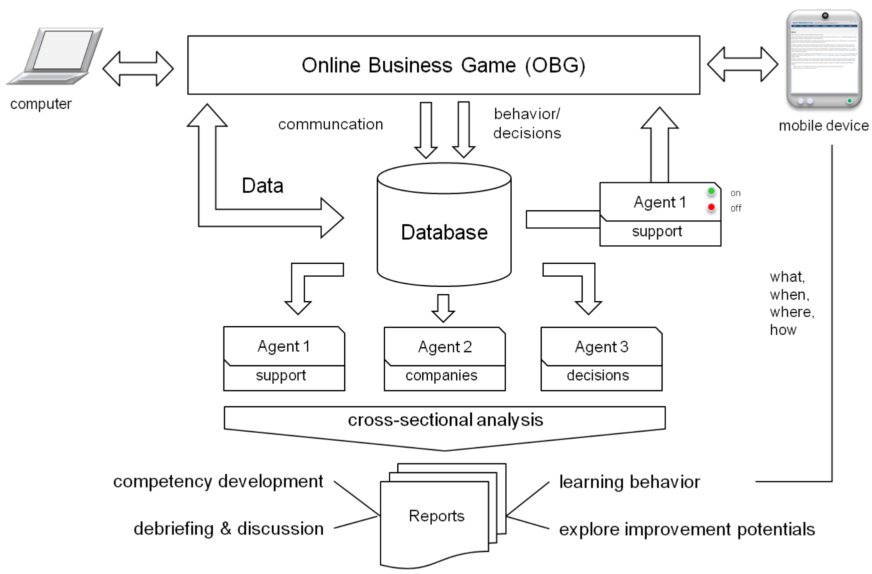


Figure 7.2: Concept of an agent-supported online educational game

[5] For details on MLA, refer to Ditton (1998), Raudenbush & Bryk (2002), Langer (2009), Hox (2010).
[6] cf. Karl (2013)

With the help of these module-oriented educational games, further remaining questions could be answered. These questions may include, among others, in how far different target groups achieve similar learning effects when exposed to different games[7] or the more generic questions, e.g. which influence can be exerted on learning in general by different target groups or even different educational games[8].

To promote both the development of online educational games in general and the implementation of business games especially in the academic context, a basic version of the Chameleon software, named *open chameleon*, is made publicly available on www.open-chameleon.org under the GNU GPL license.

Hence, *open chameleon* is possibly one of the first complex online educational games published under this license. The license offers the possibility of further development by the scientific community in the sense of swarm web development (SWD). Additionally, Chameleon aims to facilitate the organization of cooperative business game events across universities and political borders.

[7] cf. Wilson et al. (2008)
[8] cf. ibd.

8 Appendix

8.1 Background of simulations and business games in the USA

Table 8.1: Simulations and business games in the USA (1940 - 1953)

game/ event	year	background/ circumstances	association	source
Map Games / Map Exercises	1940	Map Games and map exercises have a long tradition at the Naval War College	Navy	McHugh & Fischer (1966)
First Navy Games	1945	ASWORG, machine-aided simulation	Navy	Perla (1990)
SAW	1948	Elaborate strategic military game	RAND	United States Army & STAG (1962)
COW (exercise)	1950	Game for international relations	RAND	United States Army & STAG (1962)
Map Exercises	1950	Basis for further developments in the Air Force (ABM)	RAND	United States Army & STAG (1962)
TIN SOLDIER	1950	Manually military game (George Washington University)	Army	Hausrath (1972)
LOGEX	1950	Logistical game with field experiment	Army	Hausrath (1972)
Founding "Advisory Board for Simulation"	1951	Air Force signs contract with University of Chicago	Air Force	Morganthaler (1961)
STRAW	1953	Military game in the curriculum of the Air Force Academy	Air Force	Paxson (1963)
STRAW	1953	Game for nuclear air war taking into account economic effects (resulting from SAW)	RAND	Paxson (1963)
Study on the air defense of North America	1953	First computer simulation in the history of Operations Research (OR)	Army	Hausrath (1972)
SYNTAC	1953	The first computer-aided game of the Army based on field experiments	Army	Hausrath (1972)
ATOMIC AIR-GROUND WAR GAME	1953	To demonstrate basic principles of tactical air operations (Developed in the Special Weapons School in Oberammergau/ Germany)	NATO	Hausrath (1972)

Table 8.2: Simulations and business games in the USA (1953 - 1957)

game/ event	year	background/ circumstances	association	source
Lockheed develops Management-Game	1953	Lockheed Missiles and Space Division develops a business and management game	Business Gaming	Burck (1964)
Project SIERRA (War Game)	1954	Manual military games considering economic and political aspects	RAND	United States Army & STAG (1962)
Combination of games and real maneuvers	1954	Potential hostile troop movements played by different groups of participants	Army	Brooks & Merriam (1956)
MONOPOLOGS	1954	RAND developed inventory management for all armed forces	RAND	Hausrath (1972)
School of Naval Warfare Strategic Game (War Game)	1955	Manual military game	Navy	McHugh & Fischer (1966)
Air Battle Model I (ABM)	1955	RAND Corporation develops first draft and conducted the first test of ABM	Air Force	Feldman (1964), Daniels (1961)
Development of war games for staff officers	1955	Cooperation with George Washington University	Army	United States Army & STAG (1962)
CARMONETTE I	1956	First digital computer game of the ORO as computer-aided Monte Carlo simulation (tanks against tanks)	Army	Adams & Forrester (1959), Adams & Forrester (1961)
AMA starts to develop business games	1956	AMA recruited RAND staff and involved the Naval War College	Business Gaming	Hausrath (1972)
Navy Electronic Warfare Simulator (NEWS)	1957	Machine-aided simulation	Navy	McHugh & Fischer (1966)
Air Battle Model I (ABM)	1957	Technical Operations Research Inc. completed the design	Air Force	Daniels (1961)
Air Battle Model I (ABM)	1957	From experimental design to working simulation (Project Office OMEGA)	Air Force	Feldman (1964)

Table 8.3: Simulations and business games in the USA (1957 - 1958)

game/ event	year	background/ circumstances	association	source
SAGE	1957	Automatic, computer-based national defense	Air Force	News (1957), Newsweek (1958), Fusca (1958), Aviation Week (1958), McMullen (1965), George E. Valley (1985), Edwards (1996), Hughes (1998)
TOP MANAGEMENT DECISION SIMULATION	1957	AMA in cooperation with IBM (IBM 650)	Business Gaming	McDonald & Ricciardi (1958)
BUSINESS MANAGEMENT GAME	1957	Andlinger (Mckinsey) developed a game without computer assistance	Business Gaming	Andlinger (1958)
CARNEGIE TECH MANAGEMENT GAME	1957	Faculty of Economics of the Carnegie Institute of Technology included an educational game in the curriculum	Business Gaming	Hausrath (1972)
UCLA EXECUTIVE DECISION GAME	1957	Graduate School of Business Administration of the University of California, Los Angeles developed their own decision game	Business Gaming	Hausrath (1972)
Naval Air Defense War Game	1958	Navy War Games Program / Digital simulation game	Navy	Musgrove (1965)
INDIGO I	1958	Developed by ORO to generate intelligence data	Army	Hausrath (1972)
FORT WIN	1958	Logistic game developed by the Army Management School	Army	Hausrath (1972)
LOGSIM-W	1958	Logistic game developed by ORO	Army	Hausrath (1972)
AMA-Game is popular	1958	Enthusiasm among 350 managers and 50 scientists	Business Gaming	McDonald & Ricciardi (1958)
General Electric develops simulation	1958	General Electric Simulation Laboratory develops simulation of operational tasks in production (IBM 704)	Business Gaming	Silk (1958)

Table 8.4: Simulations and business games in the USA (1959 - 1960)

game/ event	year	background/ circumstances	association	source
SWAP	1959	Military game in the curriculum of the Air Force Academy	Air Force	Paxson (1963)
SWAP	1959	Military game in the curriculum of the Air Force Academy	RAND	Paxson (1963)
FORT ROOT	1959	Logistic game developed by the Army Management School	Army	Hausrath (1972)
Amphibious Assault Trainer	1960	First military game of the Marine Corps.	Navy	McHugh & Fischer (1966)
Numerous computer-based war games	1960	Simulation of the effects of atomic first strikes	Air Force	Rosenberg (1983)
CARMONETTE II	1960	CARMONETTE I + infantry	Army	Brewer & Shubik (1979)
FORT SIMULATION	1960	Computer-aided logistic game developed by the Army Management School	Army	Hausrath (1972)
Breakthrough for business games	1960	Senior management executives of 95 corporations confirm the use of business games/ more than 2.000 management trainees of Boeing Airplane have participated in business games/ more than 3.600 staff members participated in the Minneapolis-Honeywell in-house training TOP BRASS GAME/ 250 executive managers participated in the PILLSBURY IN-HOUSE GAME/ several top management executives of the private economy participated in business games at the Army Management School (600 LOGSIM, 264 FORT SIMULATION)	Business Gaming	Hausrath (1972)

Table 8.5: Simulations and business games in the USA (1961 - 1970)

game/ event	year	background/ circumstances	association	source
FLIOP	1961	Determination of the optimal flight route by computer simulations	RAND	United States Army & STAG (1962)
STRAT	1961	Planning of a battle plan for the entire strategic forces based on FLIOP	RAND	United States Army & STAG (1962)
MUSTARD, QUICK COUNT	1961	Simulation for the calculation of civilian casualties and other consequences	RAND	United States Army & STAG (1962)
Breakthrough for business games	1961	15.000 mid- and high-level executives participated in the AMERICAN TELEGRAPH AND TELEPHONE COMPANY'S FINANCIAL MANAGEMENT GAME	Business Gaming	Hausrath (1972)
SAFE	1962	Military game in the curriculum of the Air Force Academy	Air Force	Paxson (1963)
MASTER BATTLE MODEL (TBM-63)	1963	Planning of joint operations (simulation of land, sea and air forces)	JCS	United States Army & STAG (1962)
RED PLANNING BOARD	1964	Game to emulate the Soviet side in the battle	JCS	Clyde Van Arsdall (1964)
CARMONETTE III	1966	CARMONETTE II + armed helicopters	Army	Brewer & Shubik (1979)
TACPIEL	1966	map-based military game for the Vietnam War, created from INDIGO I	Army	Hausrath (1972)
CARMONETTE IV	1970	CARMONETTE III + communication and night vision	Army	Brewer & Shubik (1979)

8.2 Advantages of business games

Table 8.6: Advantages of business games

Advantage	Fortmüller (2007)	Anderson & Lawton (2008)	Wilson et al. (2008)	Crookall & Thorngate (2009)	Chin et al. (2009)	Moreno-Ger et al. (2009)
stimulate discussion about learning (what and how)	S.69		S.238			S. 671
cognitive and affective learning is promoted			S.258		S.577	
awareness of consequences of own actions is increased					S.577	
examination of own individual attitudes		S.195				
change own attitudes in the long term					S.577	
imagination/ simulation of activities	S.69/S.78	S.194				
facilitate the presentation of difficult business activities		S.194				
promote decision-making		S.195				
(improve interaction between the participants		S.195				S. 670
promote social components	S.69					
think “outside the box“ or from a different perspective	S.69					
compile several arguments/ facts and conclude best result	S.78					
bridge between activity and own knowledge				S. 8		
fast accumulation of experience				S. 20		
participants can improve their awareness of developments			S.238			

8.3 Classification of business game models

Table 8.8: Classification of business game models

Classification	Properties
General	corporation as an overall system with its important subsystems, participants manage the corporation completely, requires basic knowledge only
Functional	participants manage one section of a corporation only, potential group of users is restricted due to required special knowledge
Universal	represents no real or existing markets, products or corporations (anonymous parameters), transfer of universally valid knowledge and skills
Specific	specific industrial sector, previous knowledge required, differentiation between real model and ideal model: ideal model - a non-specified corporation (empirical data sets), real model - a specific corporation (real operating figures)
Basic	only limited previous knowledge, only select aspects of reality, only variables of purchasing and sales are registered – whereas the achieved profit is the same as the success in the business simulation
Complex	higher number of variables and relations/connections between them, realism of more complex models very close to simulations techniques
Deterministic	the only decisive factor for the result is the entered management information, no consideration of random factors, result is mathematically unique
Stochastic	random elements are integrated into the calculation of results, higher degree of realism due to random deviations, causes need to be considered by the participants in their decision-making
Interactive	participants act in the same markets (buying market and/or sales market), decisions of the competitors have influence on the results of the player's own corporation
Isolated	decision of other participants are irrelevant for the own result, frequently used in functional models
Free	game manager takes over evaluation and debriefing player's decisions, game manager and his/her decisions seen as responsible for negative results by the players
Rigid	calculation of results follows non-ambiguous mathematical model, same validity for all participants, signifi-cantly higher acceptance
Dynamic	change of structure with time elapsed, participants need to consider changed parameters (advantageous for motivation of participants).
Static	no structural changes with time elapsed, set parameters remain constant, process of decision-making becomes routine
Manual	calculation of result information is implemented manually, applicable to easy models, independent of location, easily adaptable, calculation of results can be complicated and consume time, conflict between complexity and game dynamics
EDP-supported	high freedom from calculation errors, fast definition of results even in complex models, facilitates work of game management and participants alike, independent of location due to data transfer via the internet
Open	contact between participants legitimate and encouraged, goals only reachable in cooperation, acceptable compromises necessary for a successful game
Closed	contact to other participants prohibited, information about other teams of players remains unknown, practical implementation difficult

8.4 Presentation of current SD software

Table 8.9: Currently available SD-software 1/2 (alphabetical A-M)

name	license	freeware	last version	operating systems(s)	comment
AnyLogic	proprietary	no	2010	Macintosh, Linux & Windows	Supports SD, agent-based modeling and discrete events
Berkely Madonna	proprietary (free version with restrictions available)	no	2010	Macintosh & Windows	Differential equation solver with additional tools
Consideo	proprietary	no	2010	Macintosh, Linux & Windows	Combines different methods: SD, Concept Maps etc.
DYNAMO	proprietary (is no longer actively distributed)	no	1986	DOS/Windows	Only available from online retailers. Models are available through MIT.
Exposé 2.0	proprietary (Trial version available with restrictions)	no	2005(?)	Windows	Microsoft Excel add-in for creating CLD & SFD
Forio Simulations	proprietary (a free author account is available)	no	2012	platform-independent	Web-based, models and simulations can be made available online
Insight Maker	available for free use	no	2012	platform-independent	Web-based, models and simulations can be made available online
Mapsim	GNU/ LGPL	yes	2009	Windows & Linux	Simulation engine for SD contains .NET library and a GUI tool
MyStrategy	proprietary (5 months student version / product for educational institutions in development)	no	n.a.	Windows	Based on the Strategy Dynamics approach by Kim Warren (basis is SD), focus on SFD

Table 8.11: Currently available SD-software 2/2 (alphabetical N-Z)

name	license	freeware	last version	operating systems(s)	comment
NetLOGO 5.0.1	GPLv2	yes	2012	Macintosh & Windows	Multi-agent modeling environment for SD
OptiSim	Free for educational purposes	no	2010	platform-independent	Web-based SD software for teaching purposes
Powersim Studio	proprietary (free trial version available for 30 days)	no	2012	Windows	Supports SD and modeling of discrete events
Simile	proprietary	no	2011	Macintosh, Windows, Unix	Commercial SD software with object-based concept
Sphinx SD Tools 0.7b	Apache Lizenz, Version 2.0.	yes	2009	Windows	Modeling environment for SD simulation with export function for stand-alone applications.
Stella/ iThink	proprietary	No	2009	Macintosh & Windows	Primary for visualization of complex dynamic systems (CLD & SFD)
System Dynamics 1.3	GPL	yes	2009	Windows	graphical application for modeling, visualization and simulation of SD models
TRUE (Temporal Reasoning Universal Elaboration)	proprietary &30-day trial version (unlimited for educational institutions)	no	2011	Windows	SD + 3D Modeler (3D rendering with OpenGL graphics library) + animation
Vensim	proprietary, (free version for educational and personal use available)	no	2009	Macintosh & Windows	Software with many dynamic functions and export function for stand-alone applications

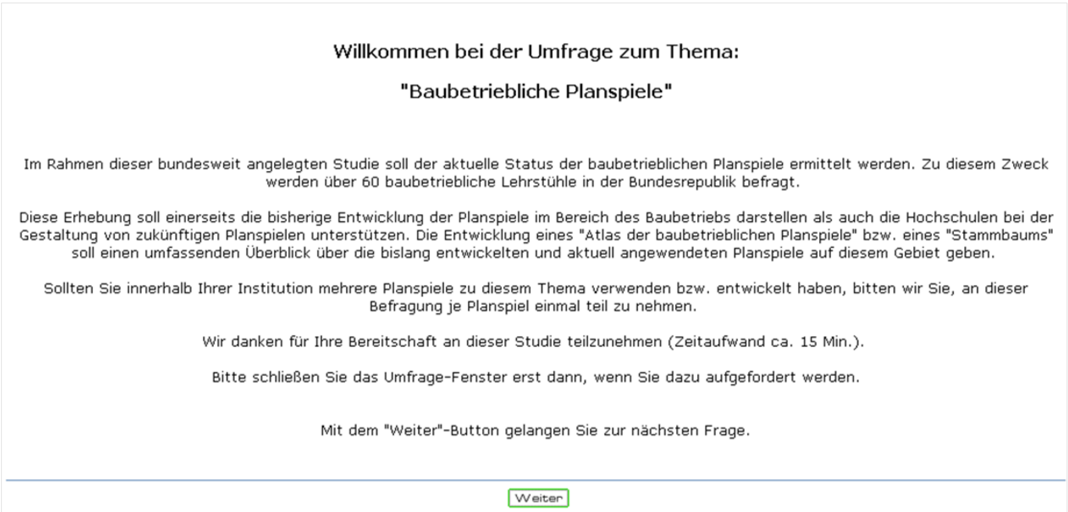
8.5 Competency catalog for PlanBauDE and KompBauDE

Table 8.13: Competency catalog

Methodological competencies	Subject-specific competencies	Social and communicativ competencies	Personal competencies	Activity- and implementation-related competencies
Analytical thinking (Erpenbeck & Heyse (2007))	Operational skills (Karl (2010))	Ability to work in a team (Erpenbeck & Heyse (2007))	Ability to work under pressure (Erpenbeck & Heyse (2007))	Awareness of global economic connections (Karl (2010))
Feeling for future developments (Erpenbeck & Heyse (2007))	Economic competencies (Galloway (2008), Karl (2010))	Project communication skills (Galloway (2008), Karl (2010))	Openness (Erpenbeck & Heyse (2007))	Decision making (Erpenbeck & Heyse (2007))
Interdisciplinary thinking (Ertl (2005), Erpenbeck & Heyse (2007),Karl (2010))	Problem-solving skills in construction site management (Karl (2010))	Negotiation skills (Karl (2010))	Willingness to perform (Erpenbeck & Heyse (2007))	Skills to avoid risks (Karl (2010))
Creativity and innovation (Erpenbeck & Heyse (2007))	Contractual competencies (Galloway (2008), Karl (2010))	Conflict resolution skills (Erpenbeck & Heyse (2007))	Readiness to assume risk (Erpenbeck & Heyse (2007))	Flexibility (Ertl (2005))
Structured thinking (Erpenbeck & Heyse (2007))	Professional and application-related English (Galloway (2008), Karl (2010))	Representative / Representational ability (Karl (2010))	Awareness of sustainability (Galloway (2008), Karl (2010))	Initiative (Erpenbeck & Heyse (2007))
Recognition of relationships and interactions (Erpenbeck & Heyse (2007))	Skills in project development (Galloway (2008), Karl (2010))	Skills in public relations (Galloway (2008))	Ethics Awareness (Galloway (2008))	Optimism (Erpenbeck & Heyse (2007))

8.6 Study PlanBauDE

8.6.1 Questionnaire of the study PlanBauDE



Willkommen bei der Umfrage zum Thema:

"Baubetriebliche Planspiele"

Im Rahmen dieser bundesweit angelegten Studie soll der aktuelle Status der baubetrieblichen Planspiele ermittelt werden. Zu diesem Zweck werden über 60 baubetriebliche Lehrstühle in der Bundesrepublik befragt.

Diese Erhebung soll einerseits die bisherige Entwicklung der Planspiele im Bereich des Baubetriebs darstellen als auch die Hochschulen bei der Gestaltung von zukünftigen Planspielen unterstützen. Die Entwicklung eines "Atlas der baubetrieblichen Planspiele" bzw. eines "Stammbaums" soll einen umfassenden Überblick über die bislang entwickelten und aktuell angewendeten Planspiele auf diesem Gebiet geben.

Sollten Sie innerhalb Ihrer Institution mehrere Planspiele zu diesem Thema verwenden bzw. entwickelt haben, bitten wir Sie, an dieser Befragung je Planspiel einmal teil zu nehmen.

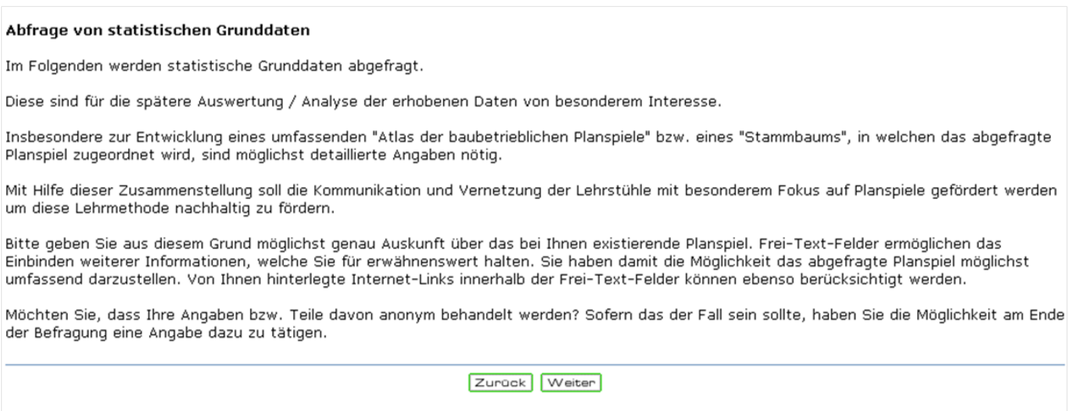
Wir danken für Ihre Bereitschaft an dieser Studie teilzunehmen (Zeitaufwand ca. 15 Min.).

Bitte schließen Sie das Umfrage-Fenster erst dann, wenn Sie dazu aufgefordert werden.

Mit dem "Weiter"-Button gelangen Sie zur nächsten Frage.

Weiter

Figure 8.1: PlanBauDE - Screenshot 1



Abfrage von statistischen Grunddaten

Im Folgenden werden statistische Grunddaten abgefragt.

Diese sind für die spätere Auswertung / Analyse der erhobenen Daten von besonderem Interesse.

Insbesondere zur Entwicklung eines umfassenden "Atlas der baubetrieblichen Planspiele" bzw. eines "Stammbaums", in welchen das abgefragte Planspiel zugeordnet wird, sind möglichst detaillierte Angaben nötig.

Mit Hilfe dieser Zusammenstellung soll die Kommunikation und Vernetzung der Lehrstühle mit besonderem Fokus auf Planspiele gefördert werden um diese Lehrmethode nachhaltig zu fördern.

Bitte geben Sie aus diesem Grund möglichst genau Auskunft über das bei Ihnen existierende Planspiel. Frei-Text-Felder ermöglichen das Einbinden weiterer Informationen, welche Sie für erwähnenswert halten. Sie haben damit die Möglichkeit das abgefragte Planspiel möglichst umfassend darzustellen. Von Ihnen hinterlegte Internet-Links innerhalb der Frei-Text-Felder können ebenso berücksichtigt werden.

Möchten Sie, dass Ihre Angaben bzw. Teile davon anonym behandelt werden? Sofern das der Fall sein sollte, haben Sie die Möglichkeit am Ende der Befragung eine Angabe dazu zu tätigen.

Zurück Weiter

Figure 8.2: PlanBauDE - Screenshot 2

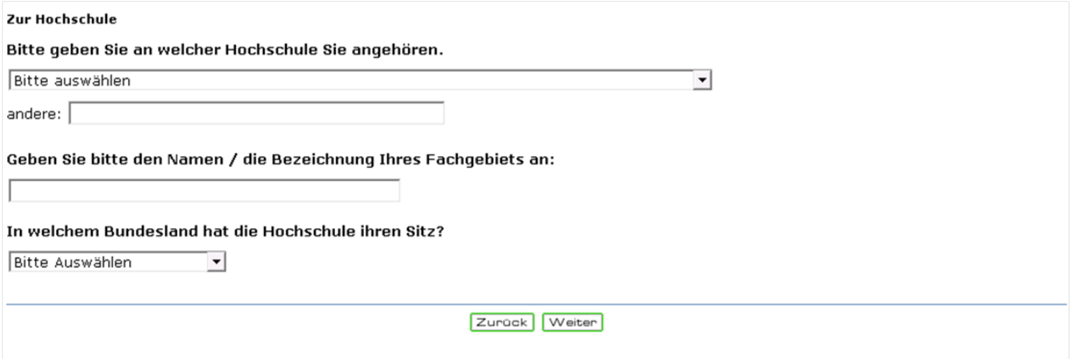


Figure 8.3: PlanBauDE - Screenshot 3

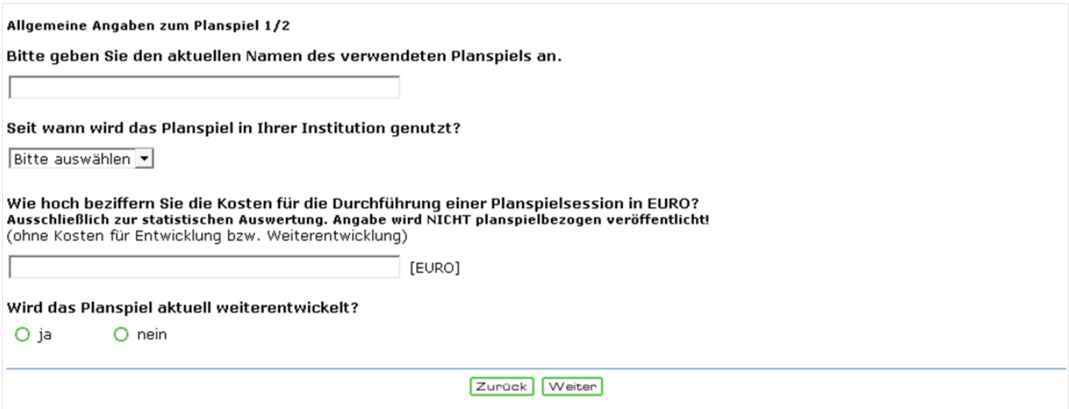


Figure 8.4: PlanBauDE - Screenshot 4

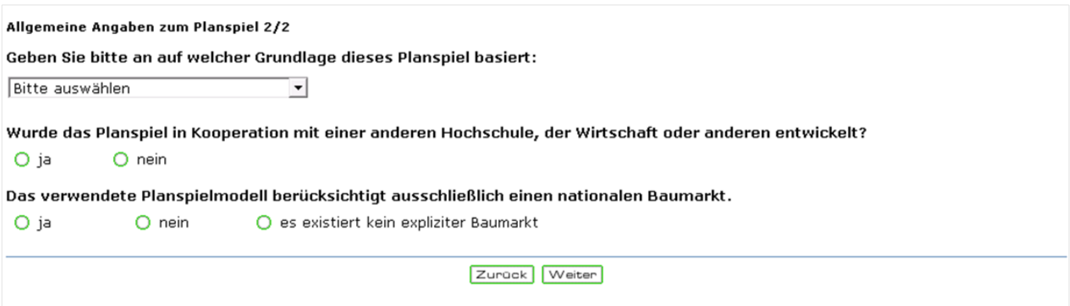
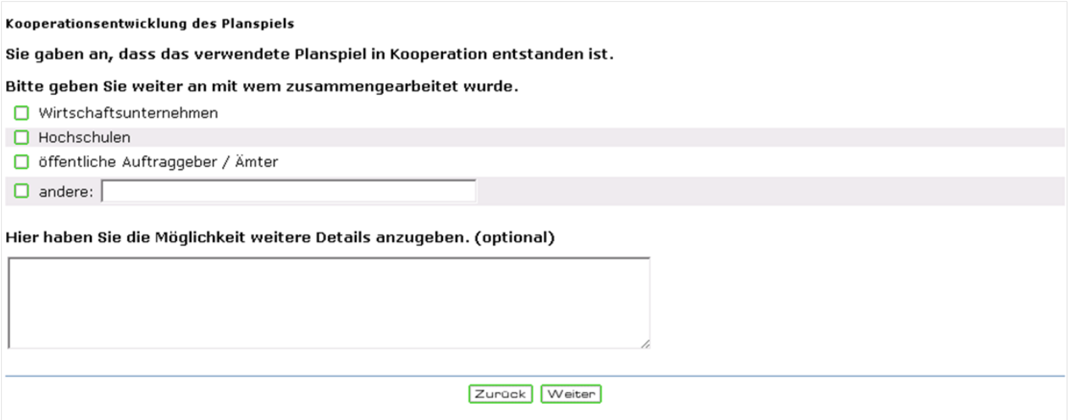


Figure 8.5: PlanBauDE - Screenshot 5


Kooperationsentwicklung des Planspiels

Sie gaben an, dass das verwendete Planspiel in Kooperation entstanden ist.

Bitte geben Sie weiter an mit wem zusammengearbeitet wurde.

- Wirtschaftsunternehmen
- Hochschulen
- öffentliche Auftraggeber / Ämter
- andere:

Hier haben Sie die Möglichkeit weitere Details anzugeben. (optional)

Zurück Weiter

Figure 8.6: PlanBauDE - Screenshot 6

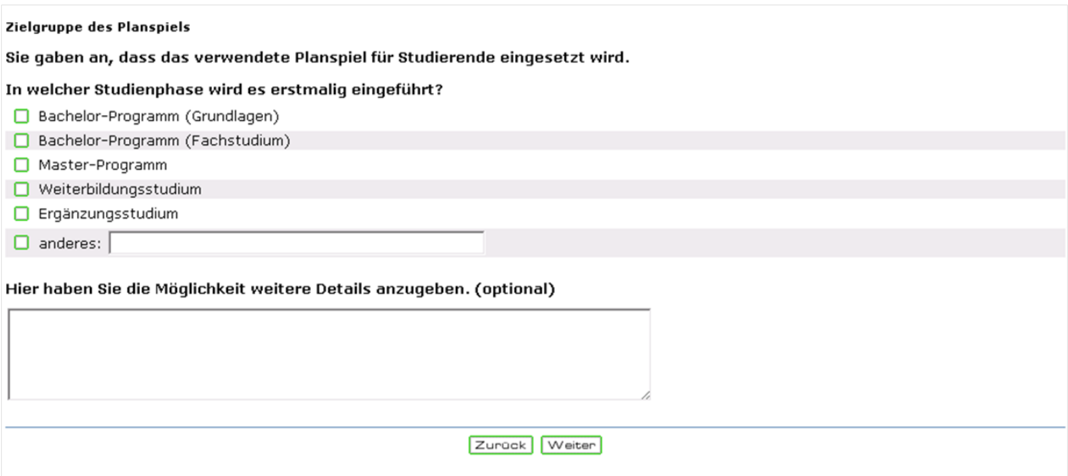

Zielgruppe des Planspiels

Für welche Zielgruppe wird das Planspiel eingesetzt?

	ausschließlich	überwiegend	teilweise	gar nicht
Schüler/innen				
Studierende				
Ingenieure/innen (Bauleiter/innen, Projektleiter/innen u.ä.)				
Managementpersonal (Geschäftsführer u.ä.)				
Existenzgründer/innen				
andere:				

Zurück Weiter

Figure 8.7: PlanBauDE - Screenshot 7


Zielgruppe des Planspiels

Sie gaben an, dass das verwendete Planspiel für Studierende eingesetzt wird.

In welcher Studienphase wird es erstmalig eingeführt?

- Bachelor-Programm (Grundlagen)
- Bachelor-Programm (Fachstudium)
- Master-Programm
- Weiterbildungsstudium
- Ergänzungsstudium
- anderes:

Hier haben Sie die Möglichkeit weitere Details anzugeben. (optional)

Zurück Weiter

Figure 8.8: PlanBauDE - Screenshot 8

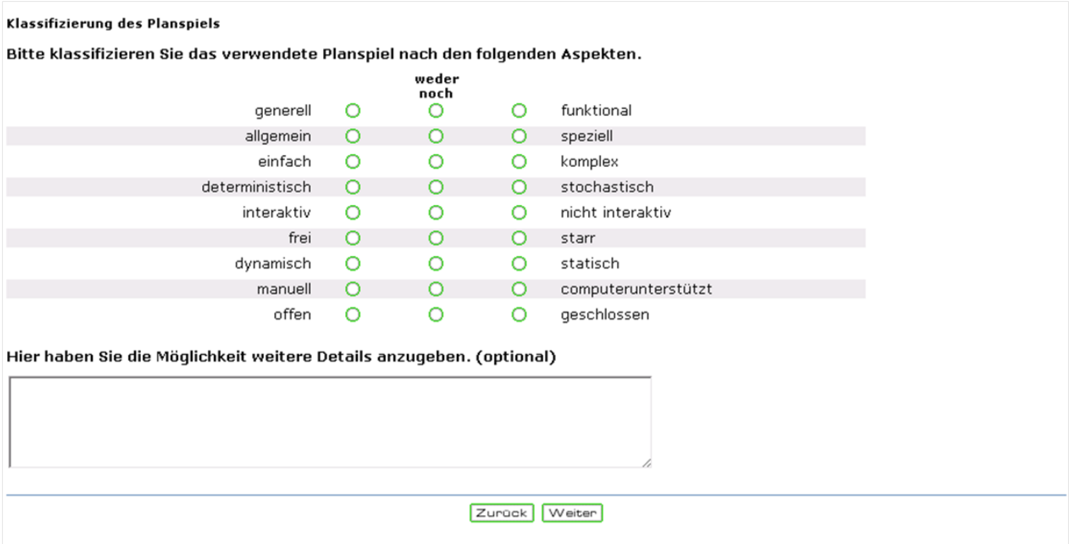


Figure 8.9: PlanBauDE - Screenshot 9

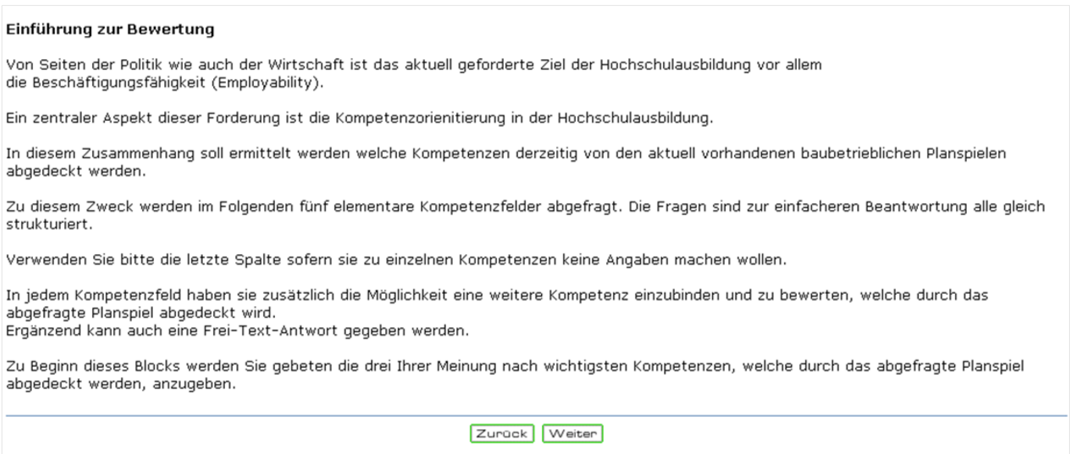
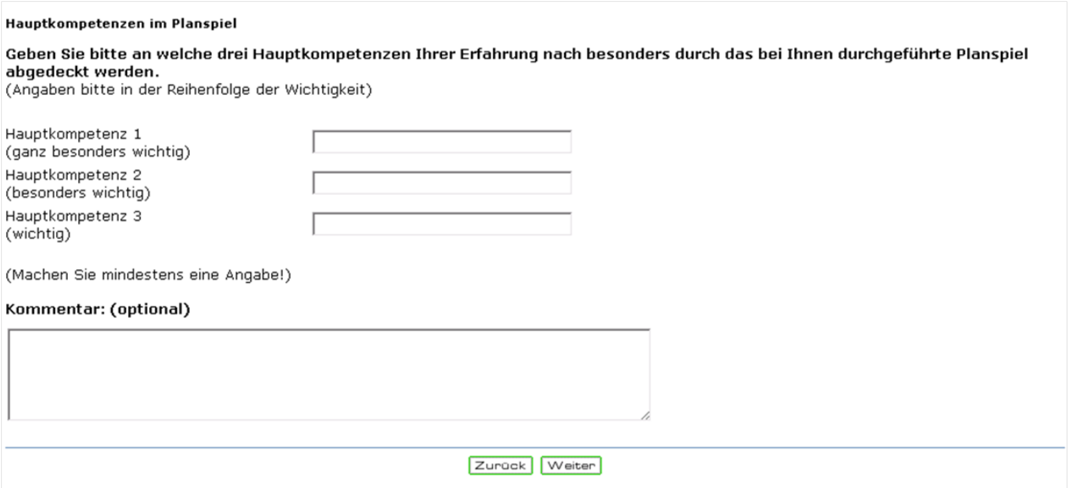


Figure 8.10: PlanBauDE - Screenshot 10



Hauptkompetenzen im Planspiel

Geben Sie bitte an welche drei Hauptkompetenzen Ihrer Erfahrung nach besonders durch das bei Ihnen durchgeführte Planspiel abgedeckt werden.
(Angaben bitte in der Reihenfolge der Wichtigkeit)

Hauptkompetenz 1
(ganz besonders wichtig)

Hauptkompetenz 2
(besonders wichtig)

Hauptkompetenz 3
(wichtig)

(Machen Sie mindestens eine Angabe!)

Kommentar: (optional)

Zurück Weiter

Figure 8.11: PlanBauDE - Screenshot 11

Kompetenzbewertung

Welche der folgenden Kompetenzen werden durch das bei Ihnen durchgeführte Planspiel besonders gefördert?

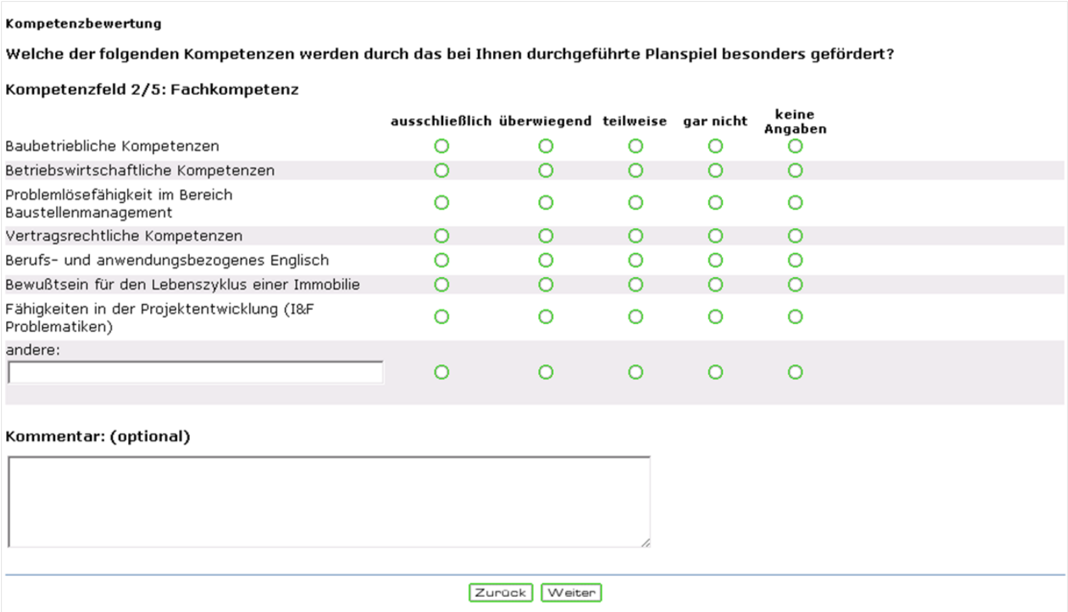
Kompetenzfeld 1/5: Methodenkompetenz

	ausschließlich	überwiegend	teilweise	gar nicht	keine Angaben
Analytisches Denken	○	○	○	○	○
Gefühl für künftige Entwicklungen	○	○	○	○	○
Interdisziplinäres Denken	○	○	○	○	○
Kreativität und Innovationsfähigkeit	○	○	○	○	○
Projektkommunikationsmanagement	○	○	○	○	○
Strukturiertes Denken	○	○	○	○	○
Zusammenhänge und Wechselwirkungen erkennen	○	○	○	○	○
andere:	○	○	○	○	○

Kommentar: (optional)

Zurück Weiter

Figure 8.12: PlanBauDE - Screenshot 12



Kompetenzbewertung

Welche der folgenden Kompetenzen werden durch das bei Ihnen durchgeführte Planspiel besonders gefördert?

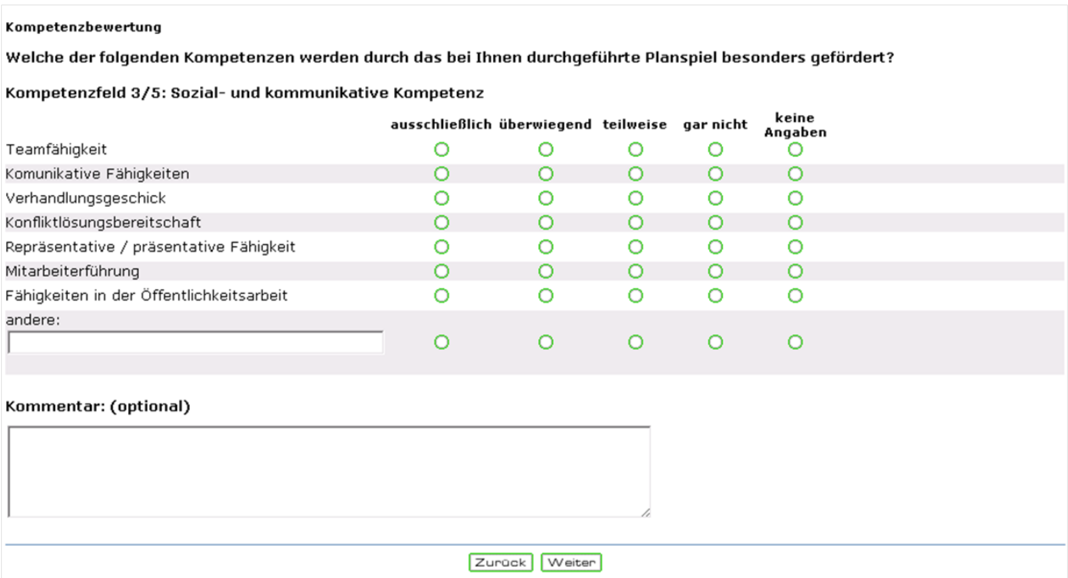
Kompetenzfeld 2/5: Fachkompetenz

	ausschließlich	überwiegend	teilweise	gar nicht	keine Angaben
Baubetriebliche Kompetenzen	○	○	○	○	○
Betriebswirtschaftliche Kompetenzen	○	○	○	○	○
Problemlösefähigkeit im Bereich Baustellenmanagement	○	○	○	○	○
Vertragsrechtliche Kompetenzen	○	○	○	○	○
Berufs- und anwendungsbezogenes Englisch	○	○	○	○	○
Bewußtsein für den Lebenszyklus einer Immobilie	○	○	○	○	○
Fähigkeiten in der Projektentwicklung (I&F Problematiken)	○	○	○	○	○
andere:	○	○	○	○	○

Kommentar: (optional)

Zurück Weiter

Figure 8.13: PlanBauDE - Screenshot 13



Kompetenzbewertung

Welche der folgenden Kompetenzen werden durch das bei Ihnen durchgeführte Planspiel besonders gefördert?

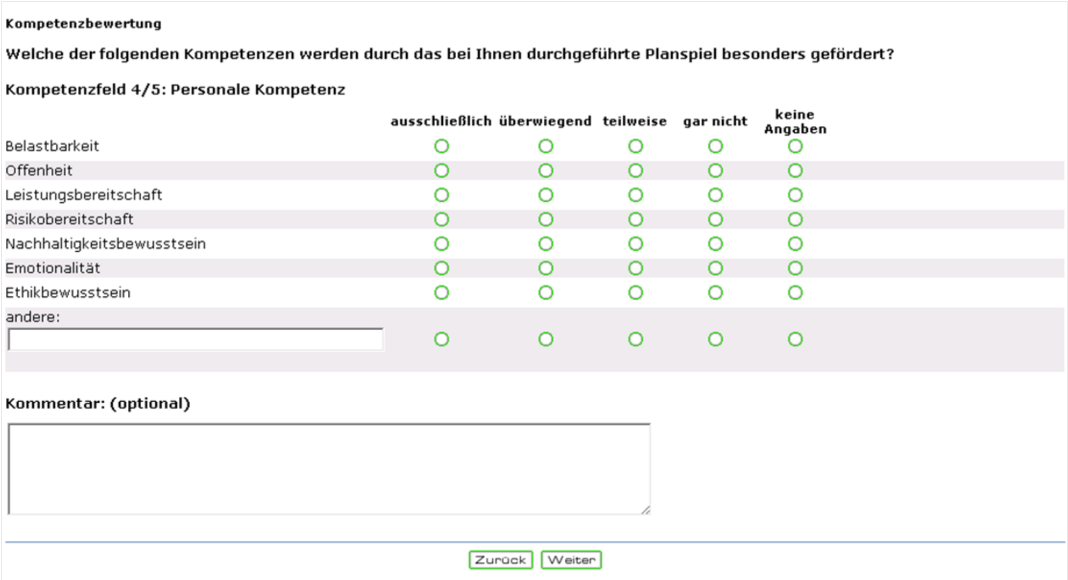
Kompetenzfeld 3/5: Sozial- und kommunikative Kompetenz

	ausschließlich	überwiegend	teilweise	gar nicht	keine Angaben
Teamfähigkeit	○	○	○	○	○
Komunikative Fähigkeiten	○	○	○	○	○
Verhandlungsgeschick	○	○	○	○	○
Konfliktlösungsbereitschaft	○	○	○	○	○
Repräsentative / präsentative Fähigkeit	○	○	○	○	○
Mitarbeiterführung	○	○	○	○	○
Fähigkeiten in der Öffentlichkeitsarbeit	○	○	○	○	○
andere:	○	○	○	○	○

Kommentar: (optional)

Zurück Weiter

Figure 8.14: PlanBauDE - Screenshot 14



Kompetenzbewertung

Welche der folgenden Kompetenzen werden durch das bei Ihnen durchgeführte Planspiel besonders gefördert?

Kompetenzfeld 4/5: Personale Kompetenz

	ausschließlich	überwiegend	teilweise	gar nicht	keine Angaben
Belastbarkeit	○	○	○	○	○
Offenheit	○	○	○	○	○
Leistungsbereitschaft	○	○	○	○	○
Risikobereitschaft	○	○	○	○	○
Nachhaltigkeitsbewusstsein	○	○	○	○	○
Emotionalität	○	○	○	○	○
Ethikbewusstsein	○	○	○	○	○
andere:	○	○	○	○	○

Kommentar: (optional)

Zurück Weiter

Figure 8.15: PlanBauDE - Screenshot 15

Kompetenzbewertung

Welche der folgenden Kompetenzen werden durch das bei Ihnen durchgeführte Planspiel besonders gefördert?

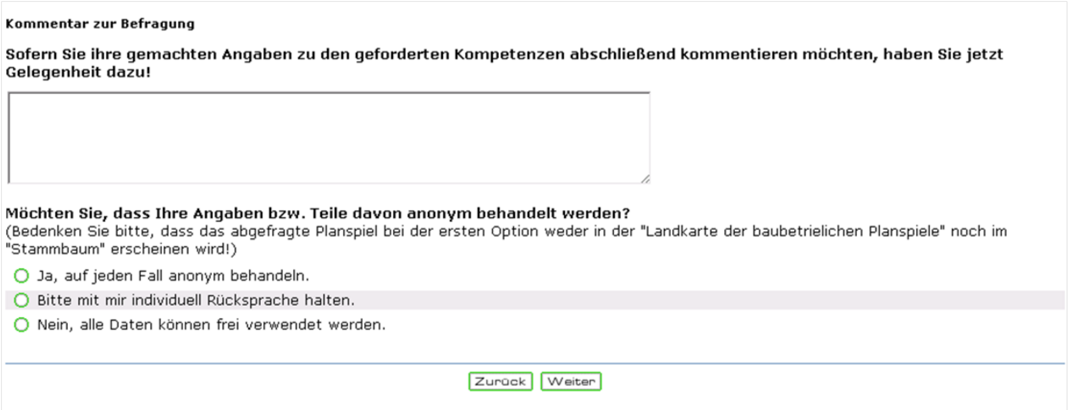
Kompetenzfeld 5/5: Aktivitäts- und umsetzungsbezogene Kompetenz

	ausschließlich	überwiegend	teilweise	gar nicht	keine Angaben
Bewußtsein für globalwirtschaftliche Zusammenhänge	○	○	○	○	○
Entscheidungsfähigkeit	○	○	○	○	○
Fähigkeiten zur Vermeidung von Risiken	○	○	○	○	○
Flexibilität	○	○	○	○	○
Initiative	○	○	○	○	○
Mobilität	○	○	○	○	○
Optimismus	○	○	○	○	○
andere:	○	○	○	○	○

Kommentar: (optional)

Zurück Weiter

Figure 8.16: PlanBauDE - Screenshot 16


Kommentar zur Befragung

Sofern Sie ihre gemachten Angaben zu den geforderten Kompetenzen abschließend kommentieren möchten, haben Sie jetzt Gelegenheit dazu!

Möchten Sie, dass Ihre Angaben bzw. Teile davon anonym behandelt werden?
(Bedenken Sie bitte, dass das abgefragte Planspiel bei der ersten Option weder in der "Landkarte der baubetrielichen Planspiele" noch im "Stammbaum" erscheinen wird!)

- Ja, auf jeden Fall anonym behandeln.
- Bitte mit mir individuell Rücksprache halten.
- Nein, alle Daten können frei verwendet werden.

Zurück Weiter

Figure 8.17: PlanBauDE - Screenshot 17

8.6.2 Queried institutions

Table 8.14: Queried institutions (1/2)

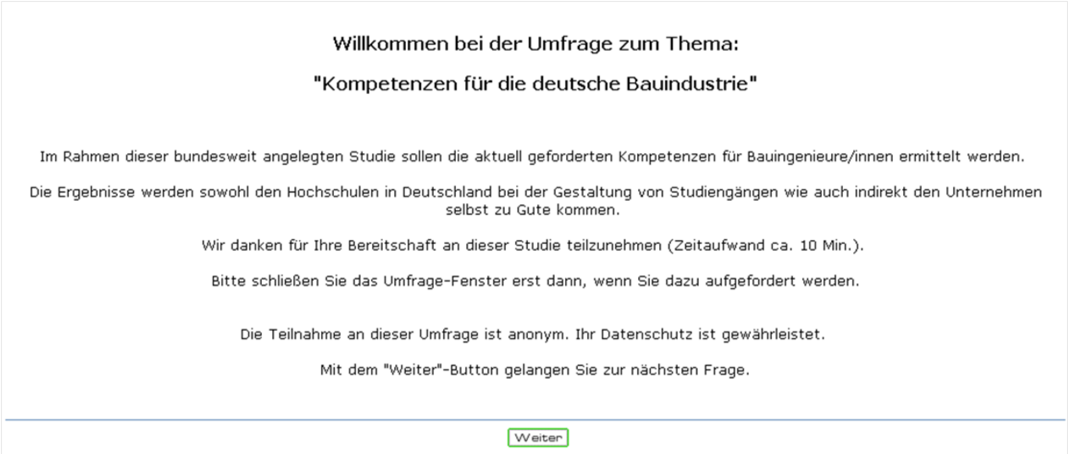
Bauhaus-Universität Weimar	Hochschule für angewandte Wissenschaften – Fachhochschule Coburg
Bergische Universität Wuppertal	Hochschule für angewandte Wissenschaften Fachhochschule Regensburg
Beuth Hochschule für Technik Berlin	Hochschule für angewandte Wissenschaften (FH) München
Brandenburgische Technische Universität Cottbus	Hochschule für angewandte Wissenschaften Würzburg - Schweinfurt
Fachhochschule Bielefeld – Campus Minden	Hochschule für Technik und Wirtschaft Dresden (FH)
Fachhochschule Erfurt - University of Applied Sciences	Hochschule für Technik, Wirtschaft und Kultur Leipzig
Fachhochschule Frankfurt am Main	Hochschule Karlsruhe – Technik und Wirtschaft
Fachhochschule für Technik und Wirtschaft Berlin	Hochschule Lausitz (FH)
Hochschule für Wirtschaft und Recht Berlin	Hochschule Magdeburg-Stendal (FH)
Fachhochschule Gießen – Friedberg	Hochschule Ostwestfalen-Lippe
Fachhochschule Kaiserslautern	Hochschule Wismar
Fachhochschule Köln	Hochschule Zittau/Görlitz
Fachhochschule Mainz - University of Applied Sciences	HTW – Hochschule für Technik und Wirtschaft des Saarlandes
Fachhochschule Münster	HTWG Konstanz
Fachhochschule Oldenburg/Ostfriesland/Wilhelmshaven	Leibniz Universität Hannover
Fachhochschule Osnabrück	Ruhruniversität Bochum

Table 8.15: Queried institutions (2/2)

Fachhochschule Potsdam	RWTH Aachen University
Fachhochschule Trier – Hochschule für Wirtschaft, Technik und Gestaltung – University of Applied Sciences	Technische Universität Braunschweig
Fachhochschule Wiesbaden	Technische Universität Darmstadt
FH Aachen	Technische Universität Dortmund
FH Koblenz	Technische Universität Dresden
FH Lübeck	Technische Universität Hamburg-Harburg
Georg-Simon-Ohm-Hochschule für angewandte Wissenschaften – Fachhochschule Nürnberg	Technische Universität Kaiserslautern
HafenCity Universität Hamburg	Technische Universität München
HAWK Hochschule für angewandte Wissenschaft und Kunst Fakultät Bauwesen Hildesheim	Universität der Bundeswehr München
Hochschule 21	Universität Duisburg-Essen
Hochschule Bochum	Universität Karlsruhe (TH)
Hochschule Bremen	Universität Kassel
Hochschule Darmstadt	Universität Siegen
Hochschule Deggendorf	Universität Stuttgart
Hochschule für angewandte Wissenschaften Fachhochschule Augsburg	Hochschule für Wirtschaft und Recht Berlin

8.7 Study KompBauDE

8.7.1 Questionnaire of the study KompBauDE



Willkommen bei der Umfrage zum Thema:

"Kompetenzen für die deutsche Bauindustrie"

Im Rahmen dieser bundesweit angelegten Studie sollen die aktuell geforderten Kompetenzen für Bauingenieure/innen ermittelt werden.

Die Ergebnisse werden sowohl den Hochschulen in Deutschland bei der Gestaltung von Studiengängen wie auch indirekt den Unternehmen selbst zu Gute kommen.

Wir danken für Ihre Bereitschaft an dieser Studie teilzunehmen (Zeitaufwand ca. 10 Min.).

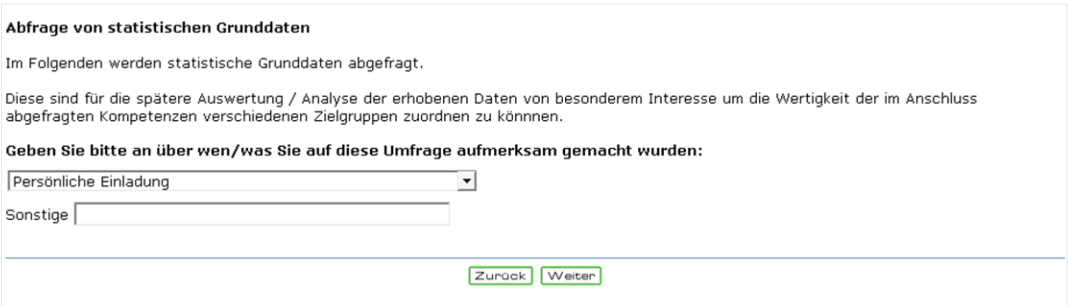
Bitte schließen Sie das Umfrage-Fenster erst dann, wenn Sie dazu aufgefordert werden.

Die Teilnahme an dieser Umfrage ist anonym. Ihr Datenschutz ist gewährleistet.

Mit dem "Weiter"-Button gelangen Sie zur nächsten Frage.

Weiter

Figure 8.18: KompBauDE - Screenshot 1



Abfrage von statistischen Grunddaten

Im Folgenden werden statistische Grunddaten abgefragt.

Diese sind für die spätere Auswertung / Analyse der erhobenen Daten von besonderem Interesse um die Wertigkeit der im Anschluss abgefragten Kompetenzen verschiedenen Zielgruppen zuordnen zu könnnen.

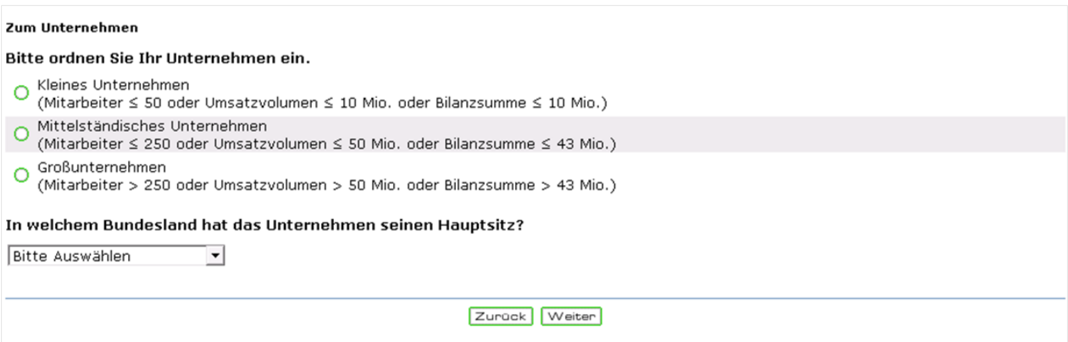
Geben Sie bitte an über wen/was Sie auf diese Umfrage aufmerksam gemacht wurden:

Persönliche Einladung

Sonstige

Zurück Weiter

Figure 8.19: KompBauDE - Screenshot 2



Zum Unternehmen

Bitte ordnen Sie Ihr Unternehmen ein.

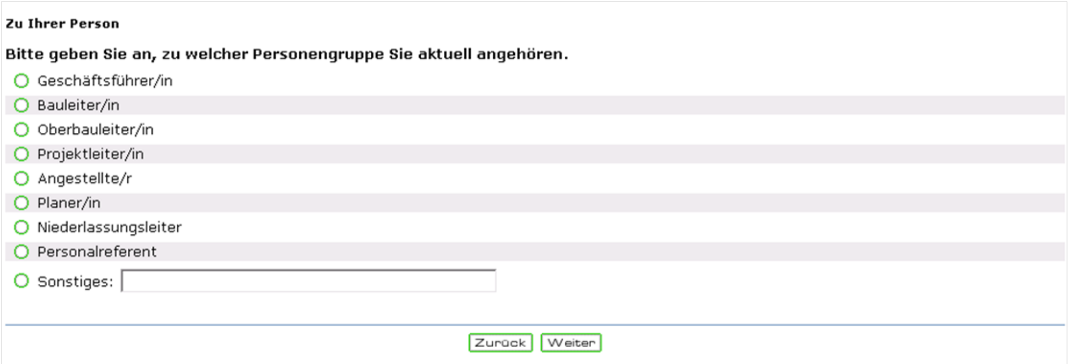
- Kleines Unternehmen (Mitarbeiter ≤ 50 oder Umsatzvolumen ≤ 10 Mio. oder Bilanzsumme ≤ 10 Mio.)
- Mittelständisches Unternehmen (Mitarbeiter ≤ 250 oder Umsatzvolumen ≤ 50 Mio. oder Bilanzsumme ≤ 43 Mio.)
- Großunternehmen (Mitarbeiter > 250 oder Umsatzvolumen > 50 Mio. oder Bilanzsumme > 43 Mio.)

In welchem Bundesland hat das Unternehmen seinen Hauptsitz?

Bitte Auswählen

Zurück Weiter

Figure 8.20: KompBauDE - Screenshot 3



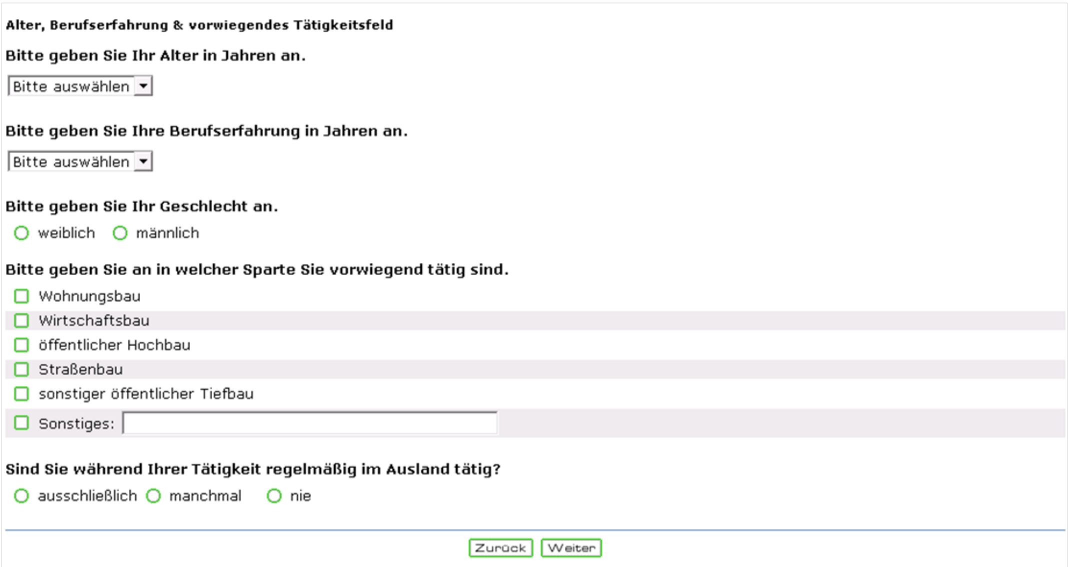
Zu Ihrer Person

Bitte geben Sie an, zu welcher Personengruppe Sie aktuell angehören.

- Geschäftsführer/in
- Bauleiter/in
- Oberbauleiter/in
- Projektleiter/in
- Angestellte/r
- Planer/in
- Niederlassungsleiter
- Personalreferent
- Sonstiges:

Zurück Weiter

Figure 8.21: KompBauDE - Screenshot 4



Alter, Berufserfahrung & vorwiegendes Tätigkeitsfeld

Bitte geben Sie Ihr Alter in Jahren an.

Bitte auswählen

Bitte geben Sie Ihre Berufserfahrung in Jahren an.

Bitte auswählen

Bitte geben Sie Ihr Geschlecht an.

weiblich männlich

Bitte geben Sie an in welcher Sparte Sie vorwiegend tätig sind.

- Wohnungsbau
- Wirtschaftsbau
- öffentlicher Hochbau
- Straßenbau
- sonstiger öffentlicher Tiefbau
- Sonstiges:

Sind Sie während Ihrer Tätigkeit regelmäßig im Ausland tätig?

ausschließlich manchmal nie

Zurück Weiter

Figure 8.22: KompBauDE - Screenshot 5

Ihrer Angabe nach sind Sie auch im Ausland tätig.
Geben Sie bitte an in welchen Ländern Sie tätig sind.

Hauptsächlich

Bitte auswählen

Oft

Bitte auswählen

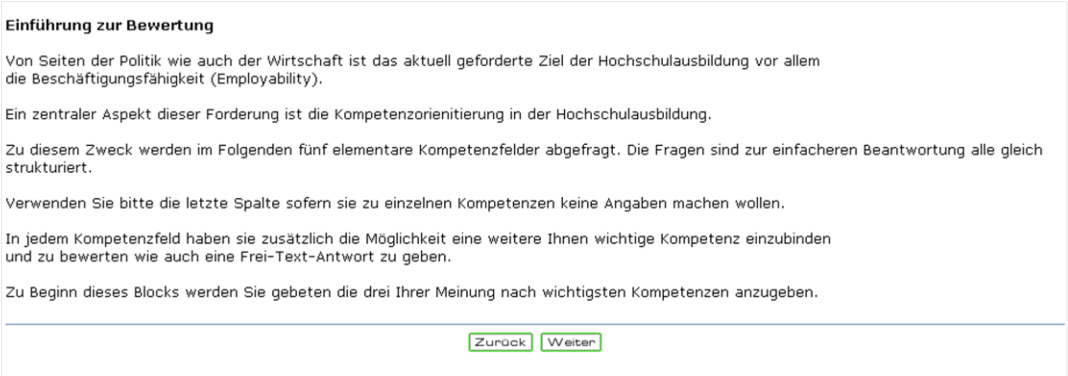
Manchmal

Bitte auswählen

(Es müssen nicht zwingend alle drei Felder ausgefüllt werden!)

Zurück Weiter

Figure 8.23: KompBauDE - Screenshot 6



Einführung zur Bewertung

Von Seiten der Politik wie auch der Wirtschaft ist das aktuell geforderte Ziel der Hochschulausbildung vor allem die Beschäftigungsfähigkeit (Employability).

Ein zentraler Aspekt dieser Forderung ist die Kompetenzorienitierung in der Hochschulausbildung.

Zu diesem Zweck werden im Folgenden fünf elementare Kompetenzfelder abgefragt. Die Fragen sind zur einfacheren Beantwortung alle gleich strukturiert.

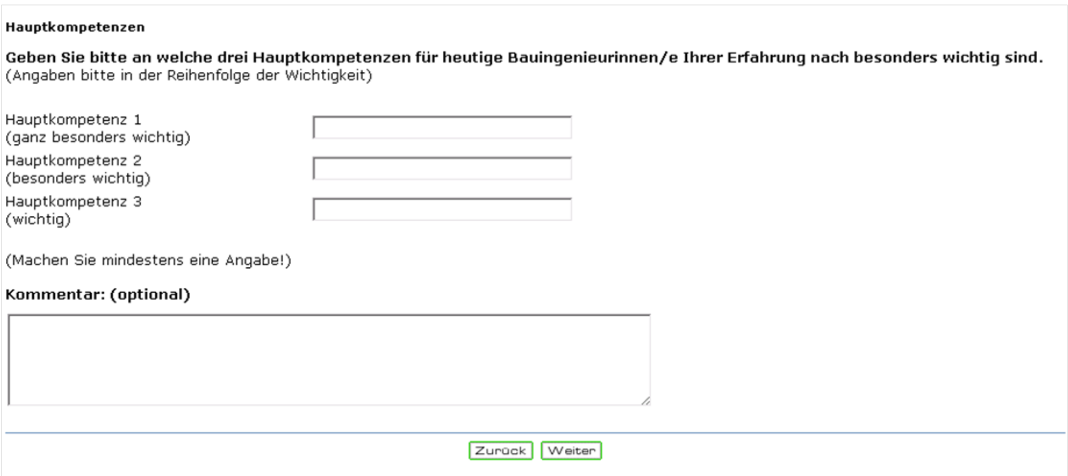
Verwenden Sie bitte die letzte Spalte sofern sie zu einzelnen Kompetenzen keine Angaben machen wollen.

In jedem Kompetenzfeld haben sie zusätzlich die Möglichkeit eine weitere Ihnen wichtige Kompetenz einzubinden und zu bewerten wie auch eine Frei-Text-Antwort zu geben.

Zu Beginn dieses Blocks werden Sie gebeten die drei Ihrer Meinung nach wichtigsten Kompetenzen anzugeben.

Zurück Weiter

Figure 8.24: KompBauDE - Screenshot 7



Hauptkompetenzen

Geben Sie bitte an welche drei Hauptkompetenzen für heutige Bauingenieurinnen/e Ihrer Erfahrung nach besonders wichtig sind.
(Angaben bitte in der Reihenfolge der Wichtigkeit)

Hauptkompetenz 1
(ganz besonders wichtig)

Hauptkompetenz 2
(besonders wichtig)

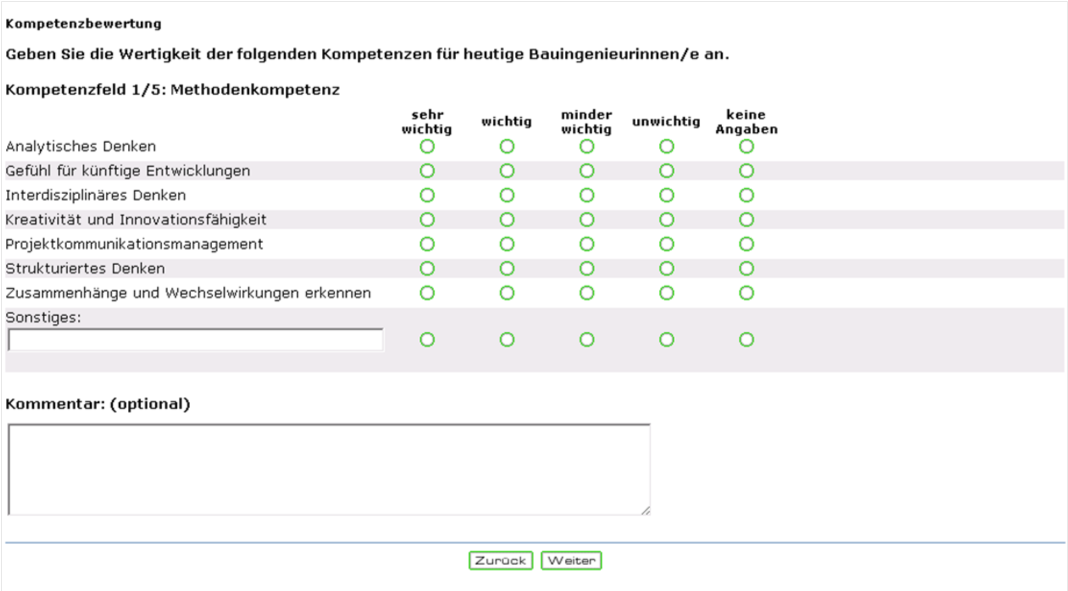
Hauptkompetenz 3
(wichtig)

(Machen Sie mindestens eine Angabe!)

Kommentar: (optional)

Zurück Weiter

Figure 8.25: KompBauDE - Screenshot 8



Kompetenzbewertung

Geben Sie die Wertigkeit der folgenden Kompetenzen für heutige Bauingenieurinnen/e an.

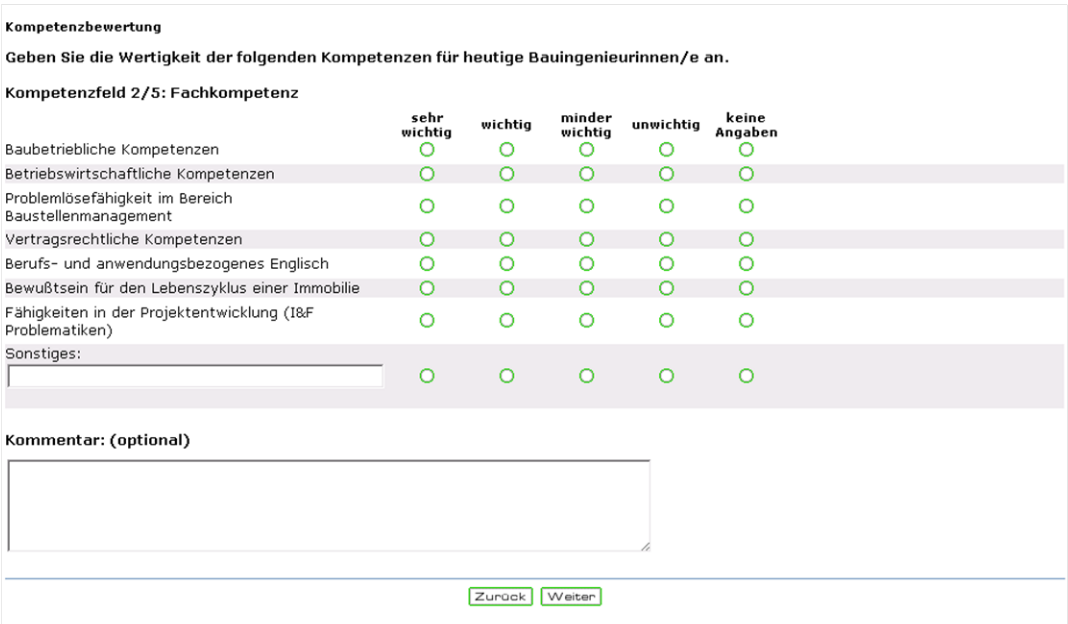
Kompetenzfeld 1/5: Methodenkompetenz

	sehr wichtig	wichtig	minder wichtig	unwichtig	keine Angaben
Analytisches Denken	○	○	○	○	○
Gefühl für künftige Entwicklungen	○	○	○	○	○
Interdisziplinäres Denken	○	○	○	○	○
Kreativität und Innovationsfähigkeit	○	○	○	○	○
Projektkommunikationsmanagement	○	○	○	○	○
Strukturiertes Denken	○	○	○	○	○
Zusammenhänge und Wechselwirkungen erkennen	○	○	○	○	○
Sonstiges:	○	○	○	○	○

Kommentar: (optional)

Zurück Weiter

Figure 8.26: KompBauDE - Screenshot 9



Kompetenzbewertung

Geben Sie die Wertigkeit der folgenden Kompetenzen für heutige Bauingenieurinnen/e an.

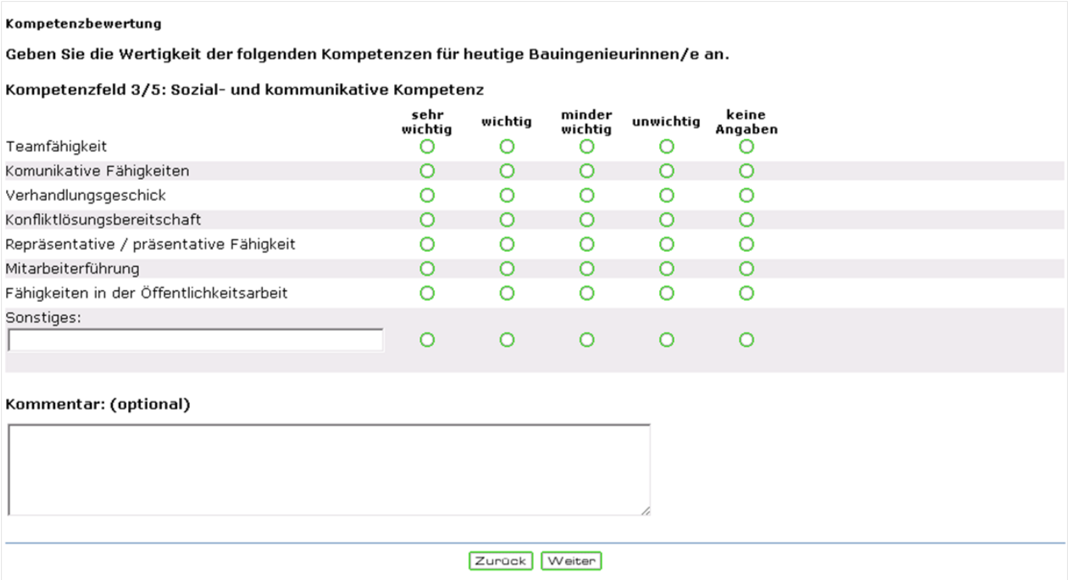
Kompetenzfeld 2/5: Fachkompetenz

	sehr wichtig	wichtig	minder wichtig	unwichtig	keine Angaben
Baubetriebliche Kompetenzen	○	○	○	○	○
Betriebswirtschaftliche Kompetenzen	○	○	○	○	○
Problemlösefähigkeit im Bereich Baustellenmanagement	○	○	○	○	○
Vertragsrechtliche Kompetenzen	○	○	○	○	○
Berufs- und anwendungsbezogenes Englisch	○	○	○	○	○
Bewußtsein für den Lebenszyklus einer Immobilie	○	○	○	○	○
Fähigkeiten in der Projektentwicklung (I&F Problematiken)	○	○	○	○	○
Sonstiges:	○	○	○	○	○

Kommentar: (optional)

Zurück Weiter

Figure 8.27: KompBauDE - Screenshot 10



Kompetenzbewertung

Geben Sie die Wertigkeit der folgenden Kompetenzen für heutige Bauingenieurinnen/e an.

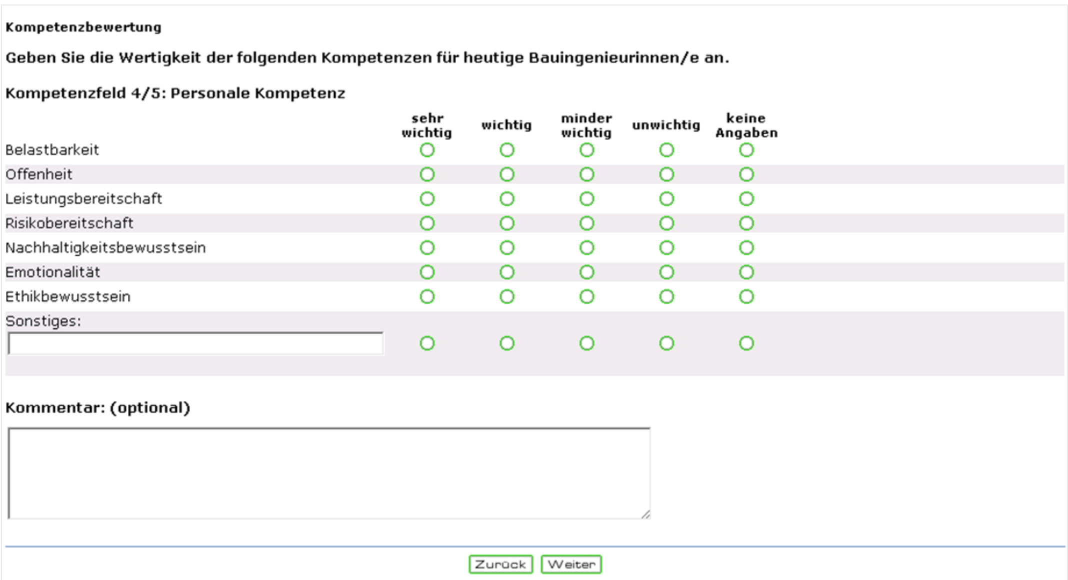
Kompetenzfeld 3/5: Sozial- und kommunikative Kompetenz

	sehr wichtig	wichtig	minder wichtig	unwichtig	keine Angaben
Teamfähigkeit					
Komunikative Fähigkeiten					
Verhandlungsgeschick					
Konfliktlösungsbereitschaft					
Repräsentative / präsentative Fähigkeit					
Mitarbeiterführung					
Fähigkeiten in der Öffentlichkeitsarbeit					
Sonstiges:					

Kommentar: (optional)

Zurück Weiter

Figure 8.28: KompBauDE - Screenshot 11



Kompetenzbewertung

Geben Sie die Wertigkeit der folgenden Kompetenzen für heutige Bauingenieurinnen/e an.

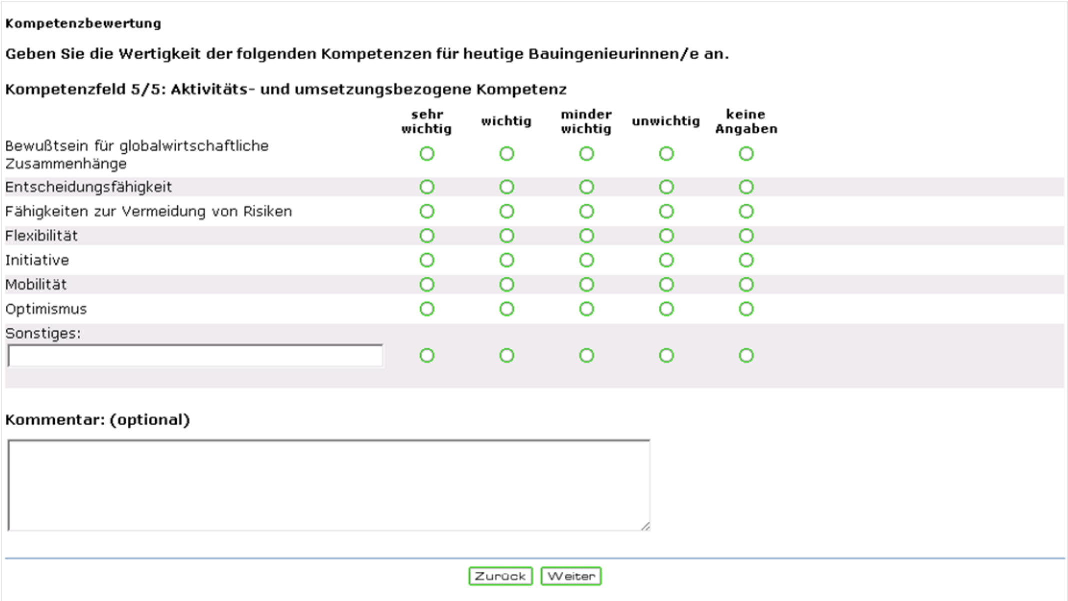
Kompetenzfeld 4/5: Personale Kompetenz

	sehr wichtig	wichtig	minder wichtig	unwichtig	keine Angaben
Belastbarkeit					
Offenheit					
Leistungsbereitschaft					
Risikobereitschaft					
Nachhaltigkeitsbewusstsein					
Emotionalität					
Ethikbewusstsein					
Sonstiges:					

Kommentar: (optional)

Zurück Weiter

Figure 8.29: KompBauDE - Screenshot 12


Kompetenzbewertung

Geben Sie die Wertigkeit der folgenden Kompetenzen für heutige Bauingenieurinnen/e an.

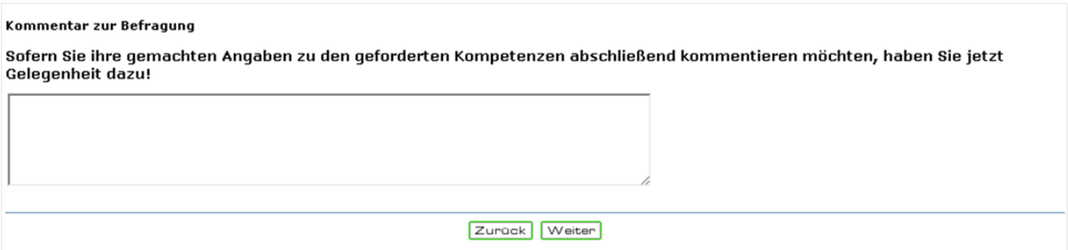
Kompetenzfeld 5/5: Aktivitäts- und umsetzungsbezogene Kompetenz

	sehr wichtig	wichtig	minder wichtig	unwichtig	keine Angaben
Bewußtsein für globalwirtschaftliche Zusammenhänge					
Entscheidungsfähigkeit					
Fähigkeiten zur Vermeidung von Risiken					
Flexibilität					
Initiative					
Mobilität					
Optimismus					
Sonstiges:					

Kommentar: (optional)

Zurück Weiter

Figure 8.30: KompBauDE - Screenshot 13


Kommentar zur Befragung

Sofern Sie ihre gemachten Angaben zu den geforderten Kompetenzen abschließend kommentieren möchten, haben Sie jetzt Gelegenheit dazu!

Zurück Weiter

Figure 8.31: KompBauDE - Screenshot 14

8.7.2 Queried companies

Table 8.16: Queried companies (> 50 Mio. Euro turnover) (1/2)

HOCHTIEF Aktiengesellschaft	KEMNA BAU Andreae GmbH. & Co. KG
Bilfinger Berger AG	Josef Rädlinger GmbH
STRABAG AG	Hülskens Holding GmbH & Co KG
Ed. Züblin AG	Wiebe Holding GmbH & Co. KG
Imtech Deutschland GmbH & Co. KG	Wilhelm Geiger GmbH & Co. KG
KAEFER Construction GmbH	GP Günter Papenburg AG
SAG GmbH	Bremer AG
GOLDBECK GmbH	SPITZKE AG
Bauer Aktiengesellschaft	Josef Möbius Bau-Aktiengesellschaft
EUROVIA GmbH	Christmann & Pfeifer GmbH & Co. KG
Lindner Holding KG	Stratebau GmbH
BELFOR Europe GmbH	Wayss & Freytag Ingenieurbau AG
Wolff & Müller GmbH & Co. KG	HASTRABAU-WEGENER GmbH & Co. KG
LEONHARD WEISS GmbH & Co. KG	SAM Stahlturm- und Apparatebau Magdeburg GmbH
Alpine Bau Deutschland AG	Wilhelm Faber GmbH
BAM Deutschland AG	Schreck-Mieves GmbH
Max Bögl Bauunternehmung GmbH & Co. KG	Wittfeld GmbH

Table 8.17: Queried companies (> 50 Mio. Euro turnover) (2/2)

Köster GmbH	Otto Wulff Bauunternehmung GmbH & Co. KG
VINCI Construction Deutschland GmbH	UMWELTTECHNIK und WASSERBAU GmbH
Heberger Bau AG	STRABAG Rail GmbH
KIRCHNER HOLDING GmbH	Hentschke Bau GmbH
MAX STREICHER GmbH & Co. KG	Georg Reisch GmbH & Co. KG
Axima Deutschland GmbH	Heitkamp Rail GmbH
Heitkamp BauHolding GmbH	SIAG Windenergietechnik GmbH
MATTHÄI Bauunternehmen GmbH & Co. KG	Gebr. von der Wettern GmbH
JOHANN BUNTE Bauunternehmung GmbH & Co. KG	Josef Hebel GmbH & Co. KG
Klebl GmbH	nesseler grünzig gruppe
ZAPF GmbH	Karl Groth Bau- und Beteiligungs-KG
AUG. PRIEN Bauunternehmung GmbH & Co. KG	Gottlob Rommel GmbH & Co. KG
Zechbau Holding GmbH	Gardemann Arbeitsbühnen GmbH
Baresel GmbH	Ebert GmbH
DB Bahnbau GmbH	HC Hagemann GmbH & Co. KG
Xaver Riebel Holding GmbH & Co. KG	August Heine Baugesellschaft AG
Weber GmbH & Co.	Tief- und Rohrleitungsbau Wähler

8.8 Quantitative data for the simulation experiments

- The simulation is based on an office building with the following boundary conditions:
  - Gross floor area 5.300 m^2
  - Three identical storeys
  - Reinforcement proportion: base plate and columns 0,13 to/m^3, ceilings 0,10 to/m^3
  - Base plate: d = 0,30 m
  - Square columns: h = 3,50 m, 0,25 m^2
  - Number of columns for each floor: 15
  - Ceilings: d = 0,35 m
- The following devices are represented:
  - Tower crane[1] with trolley jib, load torque 71 tm, radius 35 m, machine performance 31 kW
  - Truck[2], load capacity 10.2 to, bowl content 5.5 m^3, machine performance 230 kW, approximate performance 290 m^3/day
  - Excavator[3], shovel capacity 0.6 m^3, machine performance 60 kW, approximate performance 288 m^3/day
  - Timber girder system formwork for ceilings (unit price for simulation including ceiling joist formwork: 10.00 Euro/m^2)
  - System formwork for columns (unit price for simulatio: 30.00 Euro/m^2)
- soil disposal costs[4]:
  - Soil LAGA Z.2 (limited installation with defined technical safety measures): 20.00 Euro/m^3
  - Transport distance between construction site and nearest disposal site for LAGA Z.2: 60 km
- Performance factors for various processes[5]:
  - Formwork
    - Ground plate, conventional formwork: 0.15 h/m^2
    - Columns system formwork: 1.15h/m^2
    - Ceilings including ceiling joist, timber girder system formwork: 0.70 h/m^2
  - Reinforcement

[1] C.0.10.0071 cf. Baugeräteliste (2007)
[2] D.6.00.1023 cf. Baugeräteliste (2007)
[3] D.1.00.0060 cf. Baugeräteliste (2007)
[4] Source: anonymized expert interview
[5] Source: anonymized construction project (office building) in North Rhine-Westphalia/ Germany

    - ∗ Install reinforcing bars in columns: 21.00 h/to
    - ∗ Welded wire fabric in plate elements, cut and install: 17.00 h/to
  - Conreting
    - ∗ Reinforced foundation: 0.60 h/m^3
    - ∗ Columns, concreting with crane bucket: 1.30 h/m^3
    - ∗ Ceilings including ceiling joist: 0.70 h/m^3
- According to the federal collective agreement for the building industry[6]:
  - Weekly working hours 38 hours (December to March) and 41 h (April to November)
  - Overtime bonus of 25%
  - Employees as skilled workers (wage group 2)
  - Machinists as equipment operator or professional drivers (wage Group 3)
- Material prices[7]:
  - Concrete C35/45 F3 (columns): 140.00 Euro/m^3
  - Concrete C30/37 F3 (ceilings), including concrete pump: 145.00 Euro/m^3
  - Welded wire fabric BST 500 M(A), ductility class A, BSTG Q 188 A to BSTG Q 424 A, including surcharge for support baskets: 2,000 Euro/to
  - Steel bars IV 500 S, 8 mm to 28 mm: 1,200 Euro/to
  - Wooden formwork spruce/ pine, unplaned, waterproof: 6.00 Euro/m^2
- Market prices for operating supplies[8]:
  - Diesel: 1.36 Euro/l, electricity 0.36 Euro per kWh
- Rental rates for containers from currently freely accessible databases[9]:
  - Personal container (site manager, foreman, crew, sanitation, first aid, meeting room): 25.00 Euro/day
  - Material- and device-related containers (building materials magazine, devices magazine, operating supplies magazine): 10.00 Euro/day
  - Especially equipped container (laboratory, workshop): 50.00 Euro/day
  - Other costs as lump-sum per simulation step (electricity, water, telecommunications, etc.)

Furthermore, the following boundary conditions apply for the project simulation:

- Only the processes site preparation, earthworks, ground plate, columns and ceilings are considered.

[6] in German: Bundesrahmentarifvertrag für das Baugewerbe (BRTV)
[7] Concrete: Heidelberger Beton Donau-Naab GmbH & Co. KG, Steel: Ludwig Schierer GmbH, Timber: WIRBAU GmbH (data status 31st May 2013)
[8] data status 31st May 2013
[9] e.g. http://www.mietverbund.com

- Three employees are always the minimum number in a working group.
- The performance factors can be influenced by a learning curve with a learning rate of 95% and result in maximum productivity increase of +30%.
- Motivation and experience of the workforce contribute equally weighted on the quality of workmanship. Sinking motivation and/ or experience of the workforce, which leads to poor workmanship quality, leads in turn to a revision cycle.
- According to the collective agreement overtime with max. 20% of the working day can be realized.
- The overtime should influence the quality of workmanship.
- To represent the quality of the site management the time to detect poor workmanship can be varied between one and three days.
- A loss of material can be involved in all processes.
- Parallelization of processes is not included.
- Amendments by the contracting authority as well as storage losses are excluded.
- Orders are generally shipped out the next day. There are no further delays involved (e.g. by initiation and processing of the order).
- System formwork elements have no wear.
- All necessary storage space is available on the site surface. Therefore, costs by renting additional land for storage is excluded.
- All payments shall be made immediately without time delay.

8.9 Approximated cost functions

Resulting from the simulation, time-dependent cost curves are approximated as polynomials ($f : t \rightarrow at^n$ $n \in [5,6]$, $t \rightarrow [0, t_{max}]$, t = time in days). The coefficient of determination is 0.969 to 0.985. Using the following equations, a good approximation to the simulation data can be achieved in the range of $t = 0$ and t_{max}. To avoid that the function is unstable, the decimal places indicated are important to consider (especially in terms of high potency).

Scenario S1: Basis

$$y_{S1}(t) = 7,697166 \cdot 10^{-4}t^5 - 0,2794371t^4 + 37,23775t^3 - 2212,084t^2 + 61031,1t \tag{8.1}$$

$R^2 = 0,970,\ t_{max} = 131$

Scenario S2: Vocational adjustment

$$y_{S2}(t) = 1,17 \cdot 10^{-3}t^5 - 0,39t^4 + 47,7t^3 - 2600t^2 + 65600t \tag{8.2}$$

$R^2 = 0,974,\ t_{max} = 120$

Scenario S3: Experience

$$y_{S3}(t) = 5,099658 \cdot 10^{-4}t^5 - 0,201043t^4 + 29,09301t^3 - 1878,209t^2 + 56723,59t \tag{8.3}$$

$R^2 = 0,969,\ t_{max} = 144$

Scenario S4: Overtime

$$y_{S4.1}(t) = 0,0013t^5 - 0,4237t^4 + 50,684t^3 - 2699,1t^2 + 66631t \tag{8.4}$$

$R^2 = 0,975,\ t_{max} = 117$

$$y_{S4.2}(t) = 8,694 \cdot 10^{-4}t^5 - 0,3074t^4 + 39,87t^3 - 2303t^2 + 62080t \tag{8.5}$$

$R^2 = 0,973,\ t_{max} = 128$

Scenario S5: Overtime (S4) & Vocational adjustment (S2)

$$y_{S5.1}(t) = 1,301 \cdot 10^{-3}t^5 - 0,4199t^4 + 49,87t^3 - 2651t^2 + 66010t \tag{8.6}$$

$R^2 = 0,973,\ t_{max} = 116$

$$y_{S5.2}(t) = 8,993852 \cdot 10^{-4}t^5 - 0,3146805t^4 + 40,45985t^3 - 2322,295t^2 + 62341,95t \quad (8.7)$$

$R^2 = 0,973,\ t_{max} = 127$

Scenario S6: Experience (S3) & Variation of time for quality management

$$y_{S6.1}(t) = -6,4244 \cdot 10^{-6}t^6 + 3,2742 \cdot 10^{-3}t^5 - 0,64667t^4 + 62,052t^3 - 2959,9t^2 + 68669t \quad (8.8)$$

$R^2 = 0,982,\ t_{max} = 147$

$$y_{S6.2}(t) = -5,2442 \cdot 10^{-6}t^6 + 2,7667 \cdot 10^{-3}t^5 - 0,5654t^4 + 56,129t^3 - 2770,3t^2 + 66656t \quad (8.9)$$

$R^2 = 0,983,\ t_{max} = 157$

Scenario S7: Overtime (S4) & Variation of time for quality management

$$y_{S7.1}(t) = -9,6001 \cdot 10^{-6}t^6 + 4,5233 \cdot 10^{-3}t^5 - 0,82757t^4 + 73,814t^3 - 3288,8t^2 + 71756t \quad (8.10)$$

$R^2 = 0,983,\ t_{max} = 140$

$$y_{S7.2}(t) = -7,7242 \cdot 10^{-6}t^6 + 3,7929 \cdot 10^{-3}t^5 - 0,72253t^4 + 66,987t^3 - 3093,8t^2 + 69900t \quad (8.11)$$

$R^2 = 0,985,\ t_{max} = 148$

Scenario S8 – Crisis management of a bad case scenario

$$y_{S8}(t) = -5,555 \cdot 10^{-6}t^6 + 2,891 \cdot 10^{-3}t^5 - 0,5836t^4 + 57,35t^3 - 2809t^2 + 67100t \quad (8.12)$$

$R^2 = 0,981,\ t_{max} = 152$

8.10 Publications and other contributions associated with this work[10]

8.10.1 Book chapters

- C. K. Karl (2012). Integration of teaching/ learning methods in simulation games (published in German: Integration einer Lehr-/ Lernmethodenauswahl in Planspiele), in Schwägele, Sebastian; Zürn, Birgit; Trautwein, Friedrich (Ed.), Planspiele - Lernen im Methoden-Mix Integrative Lernkonzepte in der Diskussion, 95 - 112
- C. K. Karl (2011). Competency-oriented simulation games - A new approach for the design of simulation games in education and training (published in German: Kompetenzorientierte Planspiele – Ein neuer Ansatz zur Konzeption von Planspielen in der Aus- und Weiterbildung), in Kriz, Willy (Ed.), Planspiele in der Personalentwicklung, 23 - 58
- C. K. Karl (2010). Competency-oriented studies in the building and construction science (published in German: Kompetenzorientiertes Studium in den Bauwissenschaften) In Stahr, Ingeborg, Auferkorte-Michaelis, Nicole, Ladwig, Annette (eds), Hochschuldidaktik für die Lehrpraxis: Interaktion und Innovation für Studium und Lehre an der Hochschule, 1. Ed., Opladen & Farmington Hills, MI, Budrich UniPress Ltd., 211-229

8.10.2 Journal papers

- C. K. Karl (2011). Competency-based assessment model in construction sciences (published in German: Kompetenzorientierte Prüfungsmodelle in den Bauwissenschaften), Personal- und Organisationsentwicklung in Einrichtungen der Lehre und Forschung, (6), 67 - 72
- C. K. Karl (2010). Innovative teaching in construction sciences (published in German: Hochschuldidaktische Innovationen in den Bauwissenschaften), Personal- und Organisationsentwicklung in Einrichtungen der Lehre und Forschung, 5 (5), 2-5

8.10.3 Conference proceedings

- C. K. Karl (2014). Solving the Simulation Paradox - How Educational Games can support Research Efforts, Developments in Business Simulation & Experiential Exercises, Volume 41, (Best Paper Nominee)
- C. K. Karl (2013). Integrative Learning - Exploring Opportunities in Business Simulations, Developments in Business Simulation & Experiential Exercises, Volume 40, 48 - 57 (Best Paper Nominee)
- C. K. Karl (2012). Additional Benefit Through Competency-Oriented Business Simulations. Developments in Business Simulation & Experiential Exercises, Volume 39, 35 - 46

[10]Partly, the contents are cited, but not included in this work.

8.10.4 Presentations at Conferences, Invited Talks

- C. K. Karl (2013). Exploring Opportunities in Business Simulations. Presentation at the ABSEL 2013 conference in Oklahoma City, Oklahoma
- C. K. Karl (2012). CHAMELEON - The International Construction Management Simulation, (Presented in German with the same title), Presentation at the Workshop 2: Virtual mobility and diversity - approaches and projects, Erasmus Regional Conference, University of Duisburg-Essen, Essen
- C. K. Karl (2012). Additional Benefit Through Competency Models. Presentation at the ABSEL 2012 conference in San Diego, California
- C. K. Karl (2012). Competency oriented assesment - Impulse for the undergraduate training in the police service, (Presented in German: Kompetenzorientiertes Prüfen - Impuls für die Bachelor-Ausbildung im Polizeivollzugsdienst), 2. Praxisdialog Bachelorstudiengang Polizeivollzugsdienst, Fachhochschule für öffentliche Verwaltung NRW, Gelsenkirchen

8.10.5 Research projects

- Chameleon - The International Construction Management Simulation, Sponsor: German Academic Exchange Service (DAAD), Application processing, formal application & principal investigator, Duration: 2012 to 2013

8.11 Curriculum Vitae

Due to data privacy reasons, the CV is not included in the online version.

Due to data privacy reasons, the CV is not included in the online version.

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