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Generic Axiomatic Requirement Management Model (GARM-M) – Accelerated Target Oriented Handling of Total Service Contracts

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ABSTRACT

Nowadays clients are demanding more and more the quick realisation of their construction projects ("time to market") to be early on the market in order to generate revenues early. As such fast track planning and realisation processes are absolutely crucial for the success of construction management companies. Therefore, the ETH Zurich develops an optimized generic axiomatic requirement management model (GARM-M) in collaboration with a major European construction firm.

The aim is to accelerate the fundamental planning process and avoid recurring and non-productive planning processes by identifying interactive interdependencies and their feedback. The generic axiomatic requirement management process model is being developed in several sequential steps. With the input of the state of practice and the definition of requirement categories as well as the extent of details required, the interactive relation model for the process optimisation will be developed to generate a high level of benefit for both the client and the contractor.

KEYWORDS

Requirement Management, Construction Management, Planning Management, Process Optimisation

1 INTRODUCTION

Following a target-based and risk-oriented preparation of their investment decisions, construction industry clients expect, above all, a rapid completion of their construction projects ("time to market"). This is particularly true in the case of total service contractor or system provider forms of project delivery. Comprehensive decision information right from the early stages of a project coupled with a high degree of parallelization of the associated processes is crucial to implement this accelerated planning and completion. A systematic, generic approach is needed to identify the interactive interdependencies and to plan the activities in line with their interdependencies and to build accordingly (Girmscheid, 2007). The aim is to

- accelerate the planning and construction processes through as high a degree of parallelization as possible, and
- avoid repetitions of activities as a result of an insufficient predecessor.

This ensures that planning and construction activities can be performed cost efficiently and in parallel ("simultaneous engineering"), thus avoiding activities that do not add value. Experience of projects (Girmscheid, 1996) has shown, however, that plans undergo ten or more changes before construction can begin – especially on fast track projects – or, in some cases, expensive changes become necessary after actual execution. This is caused by the fact that the works are to be performed once the structure has been built and their impacts on the structure are planned too late. Technical facility planners, e.g., often only estimate the possible cable and duct routes and dimensions when drawing up the formwork and execution design. During the final technical facility or utilization planning, comprehensive changes then arise that not only cause technical problems but also delays and cost increases. This also applies to user requirements, which are often clarified at too late a stage. If they have not been fully defined, the planning must include a corresponding degree of flexibility, if at all possible. Nowadays, requirement management plays a central role on all projects, but especially on projects put out by a functional output oriented tender. Although DIN 18205 (DIN, 1996) provides an initial approach to structuring optimized requirement planning using a well structured question framework, it lacks any weighting or prioritization of the requirements, together with a time reference framework for the individual project phases. Equally, it does not address the process of requirement planning and the interaction among user requirements.

A goal-oriented structuring of planning and execution activities requires innovative, interactive and integrated planning processes in order to generate high levels of benefit for both the client and the contractor (Fig. 1).

Benefit	Benefit to the client	Benefit to the contractor
Phase		
Planning	<ul style="list-style-type: none"> - Optimization of project costs, schedule and quality - Limit uncertainties from an early stage - Contractor assumes planning and construction risks 	<ul style="list-style-type: none"> - New fields of business (income) - Involvement in decisions from an early stage - Optimal deployment of competencies for acquiring contracts
Execution	<ul style="list-style-type: none"> - Minimization of construction time - Reduction of follow-on risks/ construction costs - Reduction of utilization costs (from early life cycle analysis) 	<ul style="list-style-type: none"> - Optimization of parallel planning and production processes - Optimal use of the procurement market
Goal	→ Rapid completion in line with objectives	→ Improved profit

Figure 1 Benefit generated for the client and contractor

2 STATE OF RESEARCH

The state of research in regard to fast track projects is given in Girmscheid (1996) and Girmscheid and Hartmann (1999). Taylor and Moore (1980), Albano (1992) as well as Melvin and Suh (2002) developed concepts for the simulation of axiomatic design structures as input for the PERT- and GERT-Planning (Moore and Clayton, 1976). But in practise a generic axiomatic planning tool is required to prepare all important decisions in the different project developing phases in time and robustly.

The ETH Zurich is developing with a major European construction firm a generic axiomatic requirement management model (GARM-Model). This consists of:

- empirical exploration of generic requirements for the different important decisions from the concept up to the execution phase with all interaction,
- a qualitative axiomatic, mathematically structured interaction model to functionalise the above generic requirements into variables to plan decisions and the design.

Each major decision or the design of a specific construction element can now be expressed by independent variables of the client's functional requirements and design parameters as well as planning or execution process parameters in the different project phases.

These variables will be interrelated in the generic axiomatic requirement management model with regard to content and time dependency for the anticipated decision or design task. Doing this will enable scheduling, planning and execution in a fast target oriented way without unnecessary repetitions.

3 RESEARCH METHODOLOGY

A "generic axiomatic requirement management model" (GARM-M) is being developed to design an interoperative interaction model among the generic spheres (Fig. 2) of a construction project to systematically define the client's goals and the functional, design and process requirements in terms of content and temporal interdependency. The "deductive-analytic" GARM-Model is embedded in a cybernetic system theoretical reference framework and validated using realizability test.

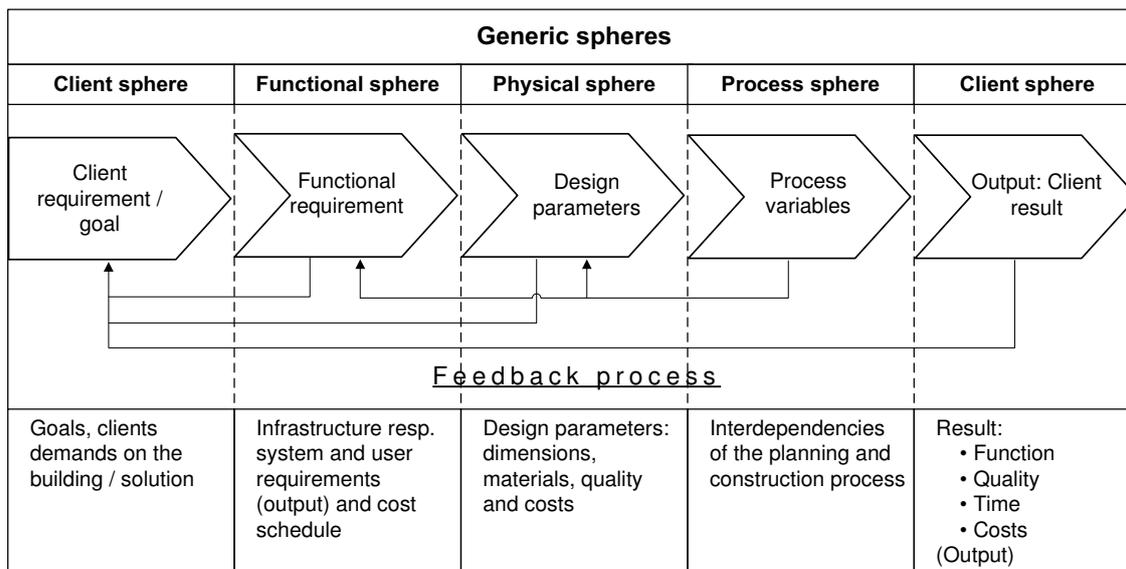


Figure 2 Generic spheres and interaction processes

In the first phase of the research project the generic requirements to make the proper sound and robust decision for building projects will be explored by qualitative, half-structured interviews with leading construction manager (CM). In the second phase the generic axiomatic requirement management model (GARM-M) will be developed. The explored generic requirements will be implemented as variables in the mathematically structured axiomatic requirements management model to express the content and temporal dependency of major decisions and the design.

The axiomatic planning theory (Albano, 1992) and hierarchical structure of the project systems (Fig. 3) and the generic spheres (Fig. 2) are used as system structure to formulate mathematically the interactive process interdependencies. The GARM-Model will result in the development of

1. the decision and design parameters for any functional requirement of the client, and
2. the process interdependencies of the design with regard to functional requirements, design parameters and the temporal dependencies of planning and execution.

4 GARM-MODEL

4.1 Functional axiomatic interrelationships among the generic phases

Besides the requirements in the different generic phases (Fig. 2) the project system structure with the cybernetic information aggregation (Fig. 3) is the underlying structure of the mathematical presentation of GARM-Model. To comply with function requirement F_j the design parameters E_i must adhere to:

$$E_i = (D_{i1}, D_{i2}, \dots, D_{in_D}) \cdot (F_1, F_2, \dots, F_j, \dots, F_{n_D})^T \quad \text{resp.} \\ (\underline{E}_i) = (\underline{D}_{ij}) \cdot (\underline{F}_j) \quad (1)$$

E_i = design parameter i ; F_j = function requirement j ; D_{ij} = content interdependency coefficient of design parameter i to function requirement j .

The vector of design parameters

$$(\underline{E}_i) = (E_1, E_2, \dots, E_i, \dots, E_n)^T$$

have to clearly and sufficiently describe the function requirement F_j . By the same token, the planning and construction processes must be coordinated in such a way as to ensure that the requisite process findings from the interactive upstream and lateral activities, resp. the requisite design parameters with minimum knowledge resp. minimum result are available for each planning and construction activity.

$$(\underline{P}_k) = (\underline{B}_{kl} \mid \underline{C}_{ki}) \cdot \begin{pmatrix} \underline{P}_l \\ \underline{E}_i \end{pmatrix} \quad (2)$$

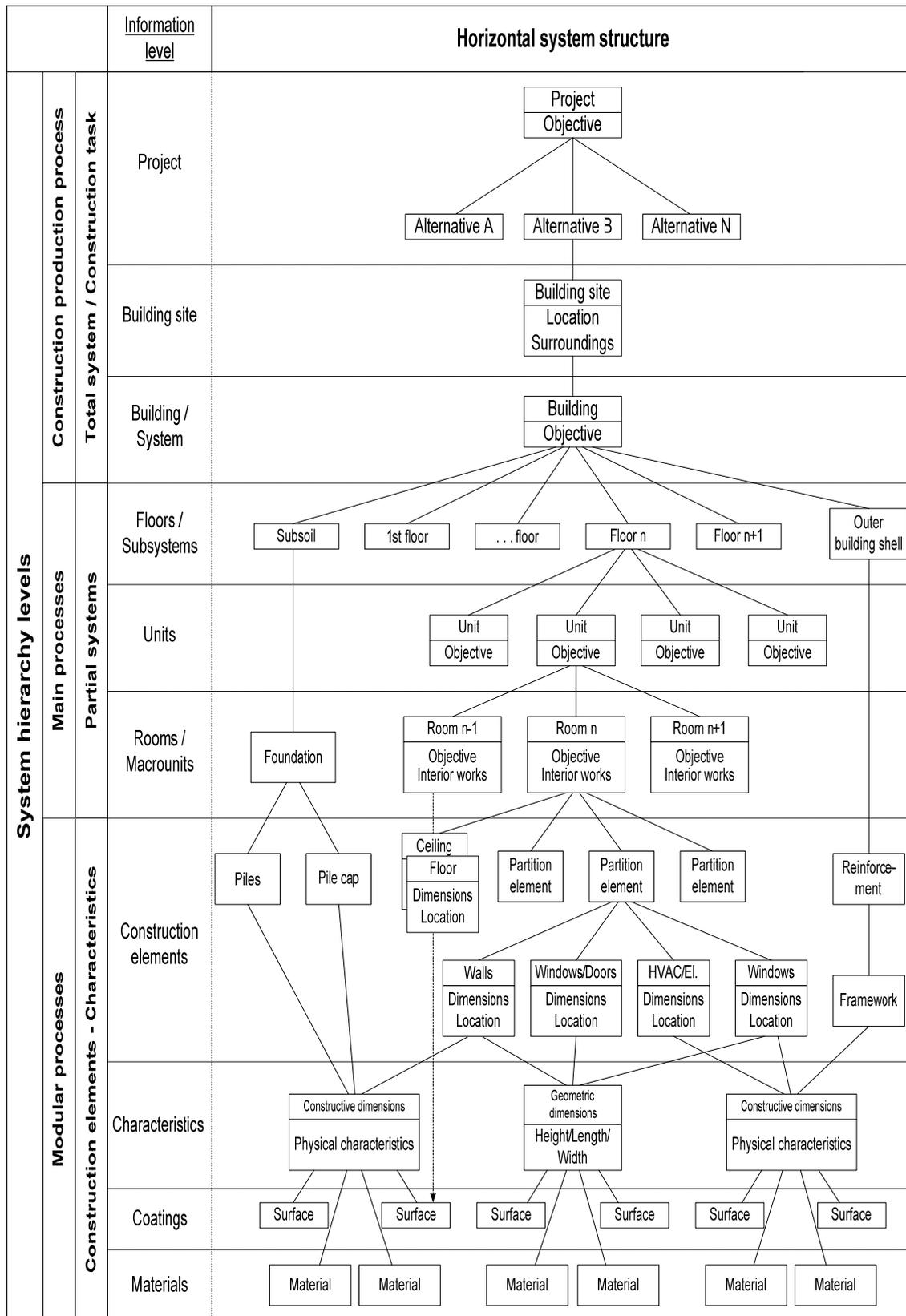


Figure 3 System structure of projects and the cybernetic aggregation of information

B_{kl} = time interdependency coefficient of process step k to process step l; C_{ki} = time interdependency coefficient of process step k to design parameter i; E_i = design parameter i; P_k/P_l = process step (planning and construction activities) k respective l. The interdependency coefficients A_{ij} and B_{kl} and C_{ki} range between:

$$\{B_{kl}; C_{ki}; D_{ij}\} = [0; +1]$$

This means:

$$\{B_{kl}\}; \{C_{ki}\}; \{D_{ij}\} = 0 \quad \text{no interdependency}$$

$$\{B_{kl}\}; \{C_{ki}\}; \{D_{ij}\} = 1 \quad \text{fully dependent on the upstream activity}$$

$$\{B_{kl}\}; \{C_{ki}\}; \{D_{ij}\} = \{x \mid 0 \leq x \leq 1\} \quad \text{partially dependent on the upstream activity}$$

There are also cases of reverse interdependency, in which case:

$$\{B_{kl}\}; \{C_{ki}\}; \{D_{ij}\} = \{x \mid -1 \leq x \leq 0\} \quad \text{applies.}$$

The interdependency coefficients indicate the approximate work load of the upstream resp. parallel action resp. hierarchy levels, but not the actual information content. This should be kept in lists relating to the interdependency coefficient.

Axiomatic planning theory aims to identify the goal-oriented overlap of as many project activities as possible in order to parallelize the planning and construction process and optimize the value creation process. Means of accelerating downstream activities depend to a major degree on the sensitivity of the upstream activities. Downstream activities, e.g., can be parallelized with upstream activities if the information from upstream can be rapidly identified for downstream before the upstream works have been completed.

4.2 Interdependent information density with regard to parallel processes

The simultaneous strategy must incorporate all interdependent relationships and cybernetic information development progress in order to avoid possible errors. Figure 4 shows the possible basic

- upstream information developments, and
- downstream information requirements.

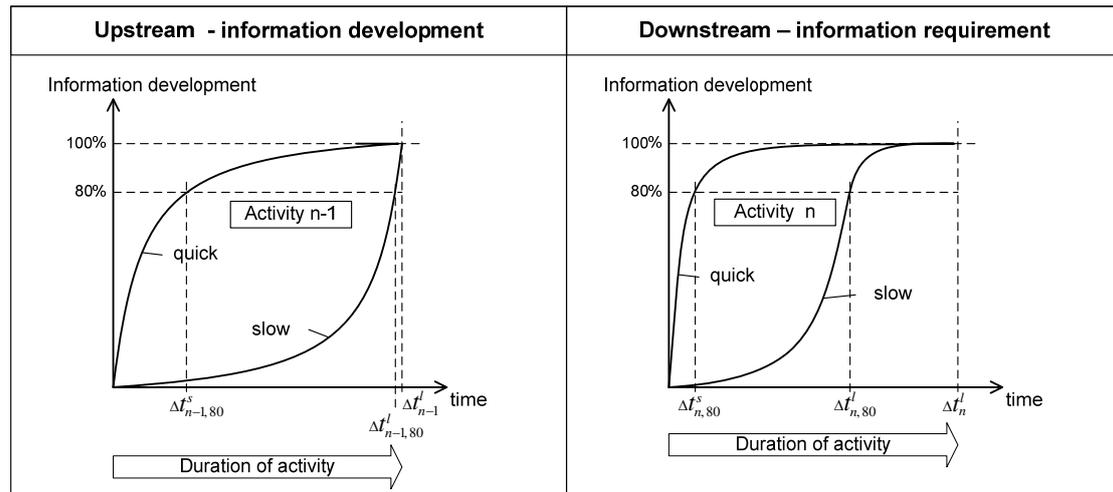


Figure 4 Information development and requirement

Fig. 4 shows the information interdependency of upstream and downstream activities that develop slowly resp. quickly. It shows, for example, the extent to which activities can be time-overlapped when, e.g., 80% of the upstream information from activity $A_{K_{n-1}}$ must be available for downstream activity A_{K_n} . In addition, it clearly shows whether downstream activity A_{K_n} needs the upstream information very quickly or whether this can be provided at a very late point in time (slowly).

The time interdependency coefficients can be determined with the help of the temporal process interdependencies $B_{n-1,n}$ relative to the design data of predecessor $n-1$ as follows:

$$B_{n-1,n} = \frac{\Delta\Delta t_{n-1,n}}{\Delta t_{n-1}} \quad [-] \quad (3)$$

$B_{n-1,n}$ = temporal process interdependency coefficient of design activity n to the design result of activity $n-1$; $\Delta\Delta t_{n-1,n} : \{R^-; R_0^+\}$ temporal parallelization of activities $n-1$ and n ; Δt_{n-1} = action time of activity $n-1$; $t_{a,n}$ = start of activity n ; $t_{a,n-1}$ = start of activity $n-1$; $t_{e,n}$ = end of activity n ; $t_{e,n-1}$ = end of activity $n-1$.

This can be used to create an upstream-downstream information dependency matrix with the four main overlap cases of the upstream-downstream interrelationships.

4.3 Example for parallelizing planning and construction activities

Schedules for implementing construction planning must incorporate the interactions among the execution activities for building sections (Fig. 3) and part processes i (Fig. 5) of the production process as well as the order process for equipment and materials.

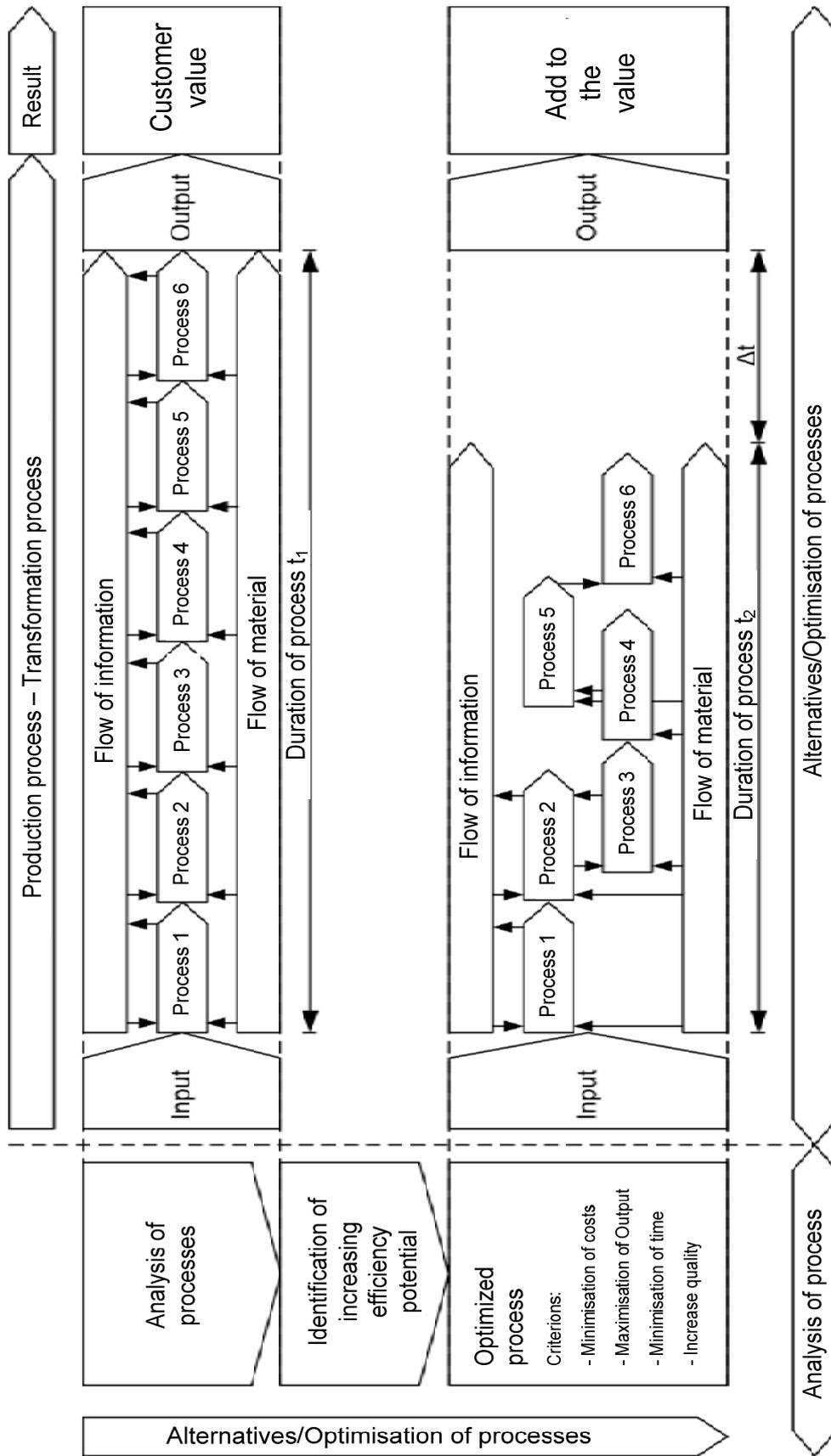


Figure 5 Analysis of production process and process optimisation

The aim must be to supply construction execution with valid and approved plans at any time and to parallelize the construction and planning processes, e.g., for a fast track construction project (Girmscheid, 1996).

Fig. 5 shows a high degree of interaction and simultaneous parallelization. This requires to stipulate and to incorporate the generic findings of best practise interdepending in regard to the system dimensions

- generic phase structure – top down (Fig. 2)
- construction sequence – bottom up (Fig. 3)
- process structure – content (Fig. 5)

in a content and temporal dependent relation. Fig. 6 shows the GARM-Model for the execution planning with their dependency of the execution process, and in dependency of design parameters and of the results of the approved design.

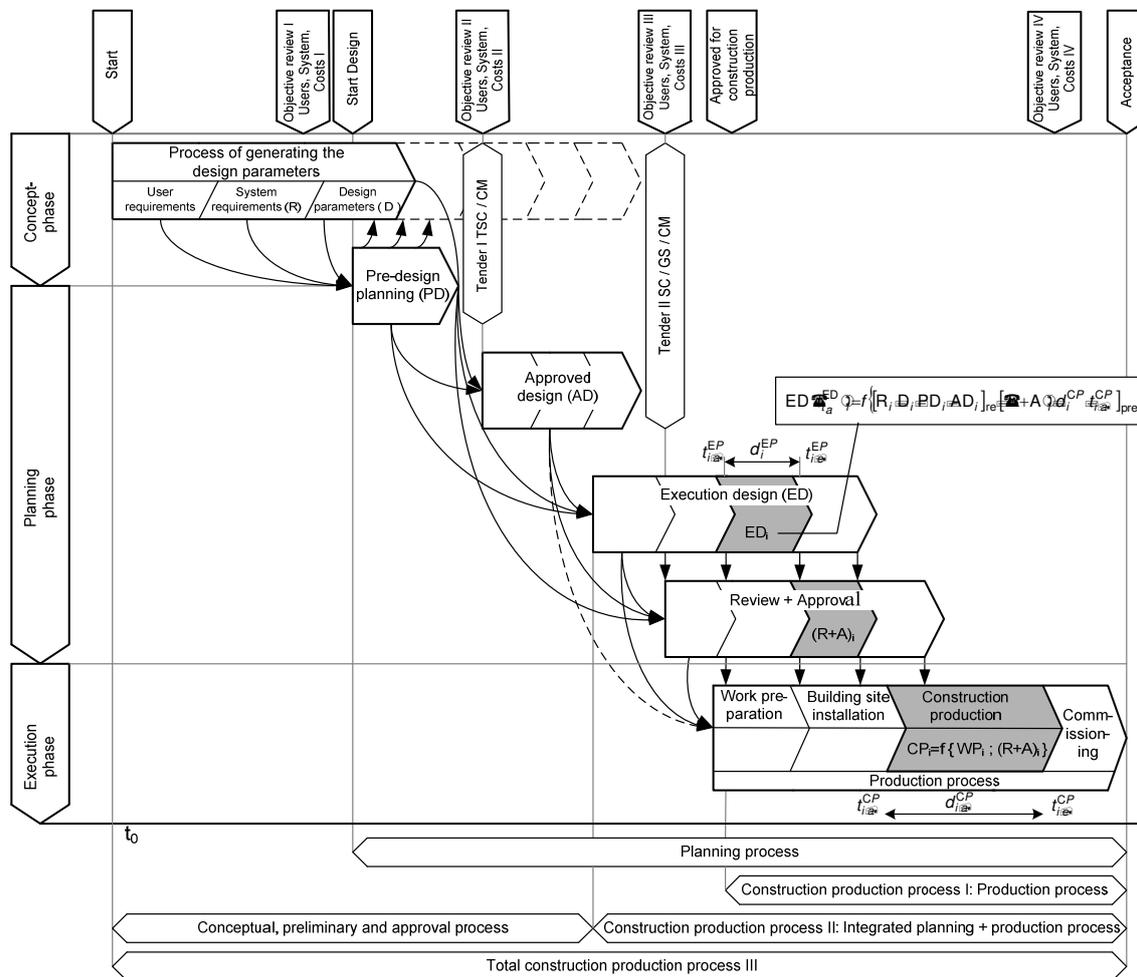


Figure 6 Generic axiomatic planning interrelationships – to the construction process in terms of time, to the system requirements, design parameters, preliminary and approval planning in terms of time and content

A generic axiomatic approach such as this allows identification of the interdependencies, particularly for complex projects, which can be used as the basis for conducting the deterministic or probabilistic scheduling and resource planning. According to equation (2), the planning process interrelationships are as follows:

$$\left(P_{\text{component } x} \right) = \left(B_{kl} \mid C_{ki} \right) \left(\frac{P_{\text{component } x}}{E_i} \right)$$

(B_{kl}) = time component interdependency coefficient matrix of process steps k to process steps l of building section x ; (C_{ki}) = time interdependency coefficient matrix of process steps k to design parameters i of building section x ; (E_i) = vector of design parameter i ; $(P_{\text{component } x})$ = vector of process steps (planning and construction activities) k for building section x . The planning processes are content dependent on both the results of upstream planning processes and on design parameters. These dependencies are shown in matrices (B_{kl}) and (C_{ki}) . The vector $(P_{\text{component } x})$ sorts the processes by starting time, i.e. sequential numbering in reverse order relative to the starting relationships.

As a result, matrix $(B_{k,l})$, which shows the interdependencies among the individual processes, always has the lower triangular shape. The value of one is always on the diagonal (dependency of a process step on itself); all interdependency coefficients above the diagonal are zero.

If an interdependency were to exist between a process step and the result of a process step that would not begin until later, which would result in an entry not equalling zero above the diagonal in the interdependency coefficient matrix (B_{kl}) , the process steps would need to be re-sorted and the numbering changed since a smooth process flow would otherwise not be possible. The content interdependency of the design parameters, which should be known at the time of submitting a bid, and the functional requirements result from the equation (1).

Since these interdependencies relate, e.g., to the period before the concept phase, i.e. prior to execution, they are only shown here in content form, without any time component. Nevertheless, the temporal interdependency could be shown in line with the planning process interrelationships. In the case of fast track projects the principle applies that the planning must be coordinated to the construction workflow in advance, taking all auditing and approval periods into account.

Down times during construction production caused by planning omissions or errors are extremely cost intensive in terms of both workforce and equipment. Added to which, the need for amendments caused by inadequate design parameters or insufficient interactive planning information has to be avoided. It is crucial that this is taken into account during planning.

4.4 Model as a basis for scheduling methods

The generic axiomatic planning relationships can be converted into a schedule using the Critical Path Method, CPM (O'Brian and Plotnick, 1999) resp. in combination with "Program Evaluation and Review Technique", PERT (Neumann, 1990) or, since recently, with "Graphical Evaluation and Review Technique", GERT (Moore and Clayton, 1976).

In addition to specifying the probabilistic duration of an activity in line with the PERT method, the GERT method (Moore and Clayton, 1976) also incorporates time-relevant risk activities arising from the risk analysis. As such, construction flow simulation using the GERT method, which is not addressed in any more detail here, offers a realistic basis for risk-based scheduling that takes the risk management findings into account (Girmscheid and Busch, 2003).

5 CONCLUSIONS

A generic axiomatic approach provides requirement management with a mathematical relationship link between the process-dictating spheres and the probabilistic scheduling, workflow and resource planning. As such, requirement management can be systematically formalized across projects. This cross-project formalization requires project type-specific research in order to make the new innovative project delivery forms, which largely pursue an integrated approach (CM, TSC, GSC, life cycle providers), even more efficient. This saves time and money and allows property developers to clarify their requirements more clearly.

Nowadays, requirement management is a central task of all project delivery forms that aims to quickly and securely define the property developer's objectives, thus providing clear information at an early stage in terms of the anticipated costs and the interactive time framework in which outstanding issues have to be clarified among the partners.

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