ON FOUNDATIONS OF CONSTRUCTION PROCESS MODELING

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ABSTRACT

The goal of the paper is to evaluate current efforts towards modeling of construction processes in the context of process modeling state-of-the-art. We try to answer to the question: What should be required from models of construction? At the outset, developments in the general area of process modeling are reviewed. The important concepts of modeling power and decision power of a modeling approach are discussed. It is concluded that there is no consensus on the basic constructs needed for process modeling.

It is argued that for reaching sufficient modeling power, construction process models should be focused on construction specific issues, they should have the necessary breadth across various processes of a project, and they should have the depth of various basic constructs. A number of current modeling efforts are discussed on basis of these and other relevant criteria.

It is concluded that there are several research issues unsolved, hindering progress in construction process modeling. We should beware of quick solutions, that exceed present theoretical understanding.

1. INTRODUCTION

It is obvious that processes are important in construction. Many processes have to be designed anew in each project, in addition to being planned (scheduled). For designing, planning, controlling and improving processes in construction, we have to model and represent them in various ways. Conventionally, this has been carried out through descriptions of various kinds: written, diagrammical, graphical, tabular, etc. (Laufer & al. 1994). Process descriptions may be found in project specific plans, company manuals, industry standards, and technical guidelines.

Recently, interest in more rigorous modeling of construction processes has rapidly developed in two different application areas: construction computing and construction process improvement and redesign. Beyond that, there have been requests for more sophisticated conceptual foundations of construction in general.

Thus, modeling methods and tools are being developed by several groups, with differing agendas. Evidently, the requirements to modeling also differ. However,

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not rarely a modeling tool developed for one application area (say construction computing) is adopted as a solution for the other application area (process improvement and redesign).

Accordingly, it is of primary importance to clarify the generic requirements to be set to models of construction processes: we need criteria by means of which we can compare different modeling approaches and tools, and analyze their applicability in a specific use situation.

In this paper, we evaluate current efforts towards modeling of construction processes in the context of process modeling state-of-the art. We try to answer to the question: What should be required from models of construction?

2 DEVELOPMENTS IN PROCESS MODELING METHODOLOGY

2.1 General considerations

There are following generic needs for process models (Curtis & al. 1992):

1. Facilitate **human understanding and communication**: It is required that a group be able to share a common representational format.
2. Support **process improvement**: A basis for defining and analyzing processes is required.
3. Support **process management**: A defined process, against which actual process behaviors can be compared is required.
4. Support **automated execution**: A computational basis for controlling behavior and communication within an automated environment is needed.

Methodology for **process management** models exists since long. Most such models are scheduling oriented (like Critical Path Method).

In the last two decades, development of process modeling methodology has primarily been motivated by needs of **automated execution**, especially information technology implementation. The emphasis has been on the description of information flows in view of their partial or complete computerization, and conceptual modeling of process related information, aiming at computer integration or automated code generation.

However, in the 90'ies, also the objective of manipulating the processes themselves, through redesign, has prompted methodological development. In **process improvement** and redesign, modeling is aimed at better understanding of the process, locating improvement potential in the process, and standardizing the realization of a redesigned or improved process.

Maturation of commercial process description and modeling software is a recent development, reflecting, at least partially, growing interest in modelling for **understanding**.

2.2 Models and modeling

The notion of **model** is defined and used in a myriad of ways. Let us just refer to one current definition: "Models are useful abstractions of reality that filter out irrelevant detail and represent only information essential to the task" (Petrie 1992).

Analysis of the notion of **modeling** discloses one reason for the many meanings of 'model'. It is instructive to conceive modeling as a process with several steps (Kochikar & Narendran 1994). In totality, a typical modeling process may be described as follows. First, through abstraction, all system features germane to the issue at hand are identified. As the result, we have a conceptual framework, consisting of concepts and their relations. Next, this conceptual framework is represented as a mathematical structure, which is converted into software. As the last step, the implemented model is used for learning about the system and this knowledge is applied for actual decisions.

Thus, during the modeling process, actually several models, but on different layers[ii], are prepared. In practice, often only a part of the modeling process is used. For example, for many purposes, say in preparation of classification systems, only the conceptual framework is used. Instead of the computer, other representational media may be used, like graphical notation.

Modeling is a very common activity: behind any process related computer application, there is a model of the respective real system. Such models are often implicit, but can be derived from applications by reverse engineering (Enterprise... 1992, p. 20).

Often, a specific **modeling approach** is used in the modeling process. A modeling approach typically provides concepts, mathematical structures, representational notations and suitable computer software, which may greatly help in the modeling process. However, in general, a modeling approach constraints the way modeling is carried out.

For analyzing modeling approaches, the distinction presented by Kochikar and Narendran (1994) is instructive. They distinguish between modeling power and decision power of a modeling approach.

[ii] In (Enterprise... 1992, p. 17), three senses of 'model' are distinguished: Model-A - the abstraction; Model-B - the type (of representation); and Model-I - the instance. They represent the semantic, syntactic and pragmatic view to 'model'.

The **modeling power** is given by the universe of system features that a modeling approach can represent. The **decision power** is defined as the amenability to analysis of a model developed using a given approach. These concepts may be further detailed into operational criteria (Table 1). Of course, the concepts of theoretical validity and methodological sophistication correspond roughly to modeling power and decision power.

Table 1. Criteria related to modeling power and decision power of modeling approaches (Kochikar and Narendran 1994)..

Modeling Power	*Decision Power*
• Sufficient number of system features represented • Ability to represent different levels of abstraction • Hierarchical modeling • Model verifiability • Ability to represent system evolution	• Efficacy on computational considerations • Quality of results • Interactivity of tools • Data requirements • Ease of understanding and use (including graphical representation)

Generally, there is a trade-off between modeling power and decision power: the more complicated model, the more difficult it is to handle and analyze. However, decision power is to some extent secondary in comparison to modeling power. This is because shortcomings of modeling power cannot be compensated through enhanced decision power. However, shortcomings of decision power, caused by an emphasis on modeling power, can be compensated by hard work, in the short run, and methodological development, in the long run. Also, in case the model is primarily for understanding, modeling power is the paramount feature.

Of course, models (rather than modeling approaches) can also be evaluated with the notions of modeling and decision power. However, the corresponding criteria have to be interpreted against the purpose of the model.

2.3 Process

The notion of **process** lacks a commonly agreed definition. A typical definition is as follows:

- "A set of partially ordered steps intended to reach a goal" (Humphrey & Feiler 1992; referred in Curtis & al. 1992)

There are four common perspectives to processes (Curtis & al. 1992):

- **Functional** represents what process elements are being performed, and what flows connect these elements.

- **Behavioral** represents when process elements are performed, and how they are performed through feedback loops, iteration, decision making conditions, etc.
- **Organizational** represents where and by whom process elements are performed.
- **Informational** represents the informational entities produced or manipulated by the process.

Which are the generic constructs that can be used in process models? The **functional** view is to think that processes consist of **activities**, that together realize the purported goal (Curtis & al. 1992). In addition, such auxiliary concepts as artifact (product of an activity) can be used for process representation.

In **behavioral** perspective, processes may consist of precedence relations or information and material flows (time explicitly represented).

In **organizational** perspective, processes may consist of agents (performing activities) and roles(set of activities assigned to an agent). Also, the process may be viewed as composed of a supplier-customer pair.

In **informational** perspective, processes consist of data, objects, documents, etc.

In principle, these perspectives, when combined, produce a complete model of a process. However, in practice, the functional perspective to processes often dominates: activity is seen as the basic construct[iii]. However, this process concept responds only to the question: How to achieve the result?

The answer to this question is sufficient for realizing the process; however, it does not exhaust all improvement potential. There are two other relevant questions, that generally should be tackled: How not to consume unnecessary resources? How to ensure that the result corresponds to requirements? For the sake of these questions, contributions from behavioral and organizational perspectives are needed.

In behavioral perspective, **flow process** concepts focus on what happens to material and information in timeline. There are four generic activities: Processing, moving, waiting and inspection. Of these, only processing is strictly viewing needed for achieving the intended result. Thus, the focus is on elimination of (unnecessary) moving, waiting and inspection activities. The roots of this approach are in JIT efforts and in logistical modeling.

In organizational perspective's **customer-supplier process** concept the process is composed of a supplier-customer pair, where the customer requirements are transformed into a product (or service) that provides value to the customer. Here,

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[iii] For a more extensive argumentation, see (Koskela 1992, Koskela & Sharpe 1994).

the focus is on ensuring that this transformation of requirements into value is as perfect as possible.

Because most modeling efforts, directly or indirectly, aim at improvement of the system modeled, it is important that all improvement sources are explicitly considered. This is the reason why these three conceptual approaches (activity, flow, customer-supplier) are, in the opinion of the author, primary ones, and should be used concurrently in any major modeling effort.

2.4 Some current approaches to process modeling

There are a number of currently popular approaches to process modeling. For the purposes of subsequent discussion, we briefly review two methods, related to functional and informational modeling.

In **functional modeling** of processes, the IDEF0 tools are becoming de facto standards[iv]. IDEF0 provides a structured representation of the functions, information, and objects that are interrelated in the system analyzed (Kusiak & al. 1994). However, time is not explicitly modeled, and thus sequences of activities can not be represented orderly[v].

The modeling power of IDEF0 is somewhat restricted (for a comprehensive, empirically based analysis, see Busby & Williams 1993). Regarding decision power, its graphical output and understandability (at least for those fluent in IDEF0) are merits. However, IDEF0 is not based on a mathematical formalism, and thus mathematical techniques are difficult to apply (Kusiak & al. 1994).

In **informational** perspective, conceptual modeling is a recent, important method. It consists of defining concepts in a problem solving domain (de Gelder & Lucardie 1995). It is a general method, rather than geared solely to process modeling. Conceptual modeling is nowadays seen as an important or even the main activity in the development of knowledge based and database systems. Thus, in conceptual modeling, existing terms are defined in a mode suitable for computer representation: "... a conceptual modeler doesn't need to construct the meaning. The meaning is already existing in peoples' mind or written text" (de Gelder & Lucardie 1995).

Thus, the emphasis in conceptual modeling is in ensuring decision power, through the application of effective database and KBS formalisms. Conceptual modeling

[iv] For an analysis of other functional methods, see (Kartam & al. 1994).

[v] There exists also IDEF3, which is specifically focused on process modeling; however, it is little known.

is not oriented towards justification of terms, concepts, etc. themselves, e.g. modeling power[vi].

3 WHAT SHOULD BE REQUIRED FROM A GENERAL MODEL OF CONSTRUCTION?

Consider that we have an ideal general model of construction (process), which, in different versions and layers, could be used, as such or as a basis, for understanding and education, improvement, planning, management, and automation (including standardized data transfer).

Of course, we presume that this model would provide sufficient modeling power and decision power.

3.1 Modeling power

Regarding modeling power, the generic criteria, mentioned earlier, like different levels of abstraction, hierarchical modeling, ability to represent system evolution, etc. apply here. Beyond that, it is required that the conceptual structures have sufficient focus, breadth and depth.

Construction focus

It is required that the issues caused by construction peculiarities, like site work, temporary organization, and one-of-a-kindness can be explicitly tackled. Site work provides here a good example. On site, the work teams, along with their machines, move from point to point, and it is thus important to be able model this flow in time and space. The temporary organizational structure, for its part, would suggest that multiple views to the model should be provided.

Breadth

The model should be comprehensive: it should cover the widely differing processes and their interaction in any construction project. Firstly, there are two primary processes (transformations generating value to the end customer): (1) from requirements into design solution, and (2) from materials and other resources into facility. In other industries, these two transformations are typically tackled in separate efforts: product development modeling, factory modeling.

Secondly, there are supporting processes for these primary processes, like design management, production planning and control.

[vi] In the methodology of science, **conceptualization** (the preparation of a conceptual framework for the domain researched) is a well known activity. In contrast to conceptual modeling, conceptualization deals mainly with modeling power.

Thirdly, there are different process types, which all should be tackled: (1) informational processes, (2) material processes, and (3) (mobile and stationary) work processes.

Depth

The model should include all important basic constructs. As an example, it should be possible to view processes simultaneously as conversions, flows, and customer-supplier pairs.

3.2 Decision power

Of course, good decision power is required from the ideal model[vii]. Thus, all the generic criteria of decision power (mentioned above) apply. From experience, we know that such criteria as easiness of use, understandability and moderate input data requirements will have priority.

4 CURRENT CONSTRUCTION PROCESS MODELING

On basis of the requirements discussed above, current modeling approaches or model classes are characterized, and their strengths and weaknesses are commented. An overview on evaluation is given in Table 2. The purpose of this exercise is to show that an evaluation is possible, rather than to present definitive judgements.

4.1 Current industry practice

Current industry practice in managing processes (project management, cost management) is based on models, even if they often are implicit. Although it at first sight seems hopeless to characterize the fragmented and multifaceted industry practice, it is factually possible to discern some common modeling traits.

First, there is no total model, but various submodels in use, leading to suboptimization. Thus, the breadth of modeling is poor. Secondly, almost exclusively processes are conceived as activities only, indicating poor depth.

Decision power varies from good to poor: many independent applications have been formulated with just decision power in mind. However, often there are overwhelming data requirements, due to the need of specifically preparing the input data in non-integrated environment.

[vii] Or, strictly speaking, compatibility with modeling approaches providing good decision power

4.2 Critical path method models

Even if critical path method models can be seen, at least partly, as current industrial practice, they have held such a prominent place in academic construction thinking that they deserve a separate analysis. In fact, judging by popular text books in construction management and engineering, CPM has been forwarded as the main model of construction.

Regarding modeling power, the cardinal problem of traditional CPM models is poor focus: they do not support the analysis of spatial work flows on site[viii], as critics have since long argued (Peer 1974, Birrell 1980).

In contrary, the decision power of CPM models is good, only eroded by often overwhelming data requirements in repetitive construction, due actually to the mentioned limitation (Russell & Wong 1993).

Obviously, CPM methods have been popular for decision power, and unpopular for lack of modeling power.

4.3 Construction process models

There are many general descriptions of the total construction process, prepared with different notations. The most ambitious of these are using the IDEF0 methodology, like in (Sanvido 1990, Zhong & al. 1994).

The objectives of these efforts (in relation to which modeling and decision power will be evaluated) include the following (Sanvido 1990):

- understanding: various project participants can understand which factors influence different tasks, and how their activities relate to the project as a whole
- improvement: current project management procedures can be analyzed for improvement
- management: for example, for defining task boundaries and responsibilities in contracts
- automation: basis for designing a facility information system.

The modeling power of these models is both enhanced and restricted by the description methodology used: IDEF0. It provides such excellent features as hierarchical modeling and graphical output. However, because temporal aspects are not modeled, parallel and iterative features of work flows can not be explicitly

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[viii] Recent research (Russell & Wong 1993) shows that it is possible to define a generalized method that overcomes this problem. There is also commercial software that supports this generalized method, but it is still little known.

represented. Thus, even if their depth is modest, these models usually have good breadth. In totality, the modeling power of these models is on medium level.

The decision power of these models is judged to be poor. The model of a whole construction process becomes complicated and is not easy to understand and use (Sanvido 1992). The lack of mathematical tractability is another major problem.

4.4 Conceptual core models of construction

Recently, a number of high level models of construction processes have been defined, which would serve as unifying reference models for more detailed models used for standardizing information exchange (Froese 1995):

- IRMA (Information Reference Model for AEC)
- Building Project Model
- ICON
- General Reference Model for Life Cycle Facility Management
- ATLAS.

Even if the models vary in different dimensions, they share a number of properties, by means of which they can be evaluated collectively.

The idea of such core models has been conceived as generalization of product modeling efforts. Thus, the formulation of these models has primarily consisted of conceptual modeling, and the interrelations of process and product concepts have received a prominent attention.

From the point of view of processes, the modeling power of these models is poor. Even if their breadth usually is sufficient, the depth is problematic. The basic construct in all models is activity; they are solely functionally oriented. This is a serious drawback in such foundational models. There seems not to be systematic construction focus in these models, due to their generation process, focusing on conceptual modeling rather than on conceptualization.

These models "are used to provide a consistent approach among the detailed models and to directly support information exchange between different discipline areas" (Froese 1995). Thus their decision power is made up by their compatibility with powerful modeling methods, to be used downstream. Some models have been conceived as augmentations of corresponding product models, while for some models, requirements analysis, focusing on data transfer between different as-is (rather than ought-be) applications, has been done. It is concluded that their decision power is from poor to medium.

However, models should be evaluated in relation to their purpose: if it is narrowly to facilitate data transfer between existing application, a core model, even with low modeling and decision power, might excellently serve its purpose. If the purpose is to provide foundational guidelines for future detailed models, high modeling and decision power should be explicitly pursued.

Table 2. Evaluation of construction models and modeling approaches: overview.

Type of modeling	*Modeling power*	*Decision power*
Current industry practice	Poor	Poor to good
CPM models	Poor	Medium to good
Construction process models	Medium	Poor
Conceptual core models of construction	Poor	Poor to medium

5 CONCLUSIONS

Construction modeling is not a mature field. There are several research issues unsolved, hindering progress. A part of these issues stem from the generic process modeling area. There is no agreement on the basic conceptual constructs needed for describing processes. Another part stem from the shortcomings of theoretical understanding of construction. This is illustrated by the fact that there is no agreement on which processes a construction project is made up from.

Our modeling efforts need to have more modeling power and more decision power. To achieve this, research in appropriate conceptualizations of construction and more sophisticated modeling approaches is needed. In application oriented efforts, like standardization of construction process models, we should beware of "naive push for quick solutions" (Eastman 1993).

When using existing modeling approaches, we should be sensitive to shortcomings of the respective approach. Experience shows that modeling approaches, when popular, easily guide our thinking and focus our attention in ways never intended by the originators of that approach.

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