

# **Integrative Factory Design by Efficient Interaction Models**

Achim Kampker, Alexander Meckelnborg, Peter Burggräf, Tobias Welter

Laboratory for Machine Tools and Production Engineering (WZL)

at RWTH Aachen University, Germany

Steinbachstrasse 19, 52074 Aachen, Germany

E-Mail: A.Kampker@wzl.rwth-aachen.de - Phone : +49 (0) 241 - 80 - 27406

POMS 23rd Annual Conference

Chicago, Illinois, U.S.A.

April 20 to April 23, 2012

## **ABSTRACT**

Factory design projects comprehending the planning of the production system and the industrial building face continuously increasing complexity. Common factory design approaches cannot cope with the rising coordination costs among the planning participants and disciplines. Therefore, efficient interaction models for an integrative factory design will be presented in this paper.

## **1. Introduction**

Factory design projects that include the planning of the production system and the industrial building are characterized by a growing complexity (Figure 1). This can be reasoned by two aspects:

- Growing complexity within technical disciplines leads to a higher specialization of the planning participants and

- Requirement of a shorter planning duration results in a higher interdisciplinarity within the planning team



**Figure 1: Increasing specialization and interdisciplinarity in factory design projects [1]**

*Growing complexity within technical disciplines – the example of growing energy efficiency requirements*

Studies of DEUTSCHE POST [2] AT KEARNEY [3] show that in B2B- and B2C-markets, the importance of the CO<sub>2</sub>-footprint for the production of products gets more important for the purchase decision or the selection of suppliers. In addition to customer demands, requirements regarding the energy efficiency of factories are getting stricter by the legislature. E.g. in Germany the Energy Conservation Act requires builders to fulfill standards. In the amendment of 2009, the permissible primary energy consumption was further reduced by approximately 30% compared to the edition of 2007. Fields of action are factory buildings including building services, production processes and the machinery or equipment. In each of these fields of action, the scope of duties increases requiring more specialists.

*Requirement of a shorter planning duration*

Within the last decades, the number of product variants increased significantly and product lifecycles were reduced considerably [4]. With an increasing number of product variants and a shorter lifecycle, time-to-market has to be reduced resulting in a shorter duration for product development as well as for factory design. WESTKÄMPER stated that the accepted planning

duration for factories had to decrease by 75% between 1995 and 2005 [5]. A shortened planning duration can be achieved by increasing planning efficiency and by parallelizing planning tasks. Parallelization has significant effects on the planning duration. However, planning tasks which are depending on each other have to be executed at the same time. This increases the number of involved planners working on the project simultaneously. Information exchange between planning participants has to happen more frequently and in smaller units. Therefore, specialists from different disciplines are required to work together and to coordinate their work in an interdisciplinary factory design team.

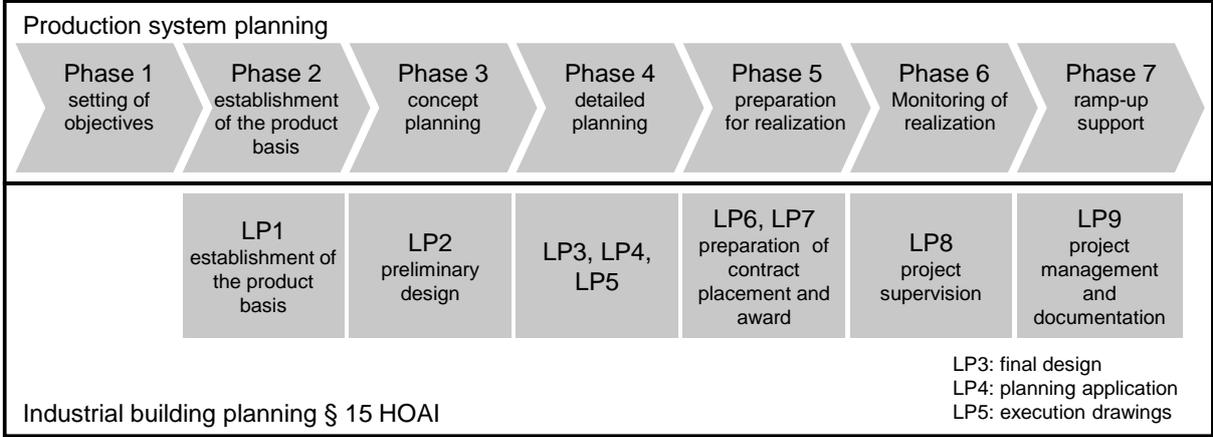
Furthermore, complex factory design projects are exposed to a high turbulence and dynamic given by the surrounding of the projects. Planning criteria, e.g. production quantity forecasts, are subject to changes during the whole planning process and cannot be fixed at the beginning of the project. Moreover, at the beginning of the project, it is not always clear what criteria are affecting the project [6]. This causes frequent re-planning by iterating previous planning tasks. Thereby, new turbulences are created as iteration of planning tasks effects other planning tasks and results. At the same time, factory design projects are exposed to a high cost pressure as they need to be terminated successfully with the lowest planning effort possible.

## **2. Challenges in interdisciplinary complex factory design projects**

### ***2.1. Problems of the current planning approach***

In literature, procedures for planning the production system [7, 8, 9] and for industrial building planning [10, 11, 12] are described as a linear process consisting of multiple consecutive and discrete phases. The German guideline VDI 5200 defines seven phases for production system planning beginning with the setting of objectives and terminating with ramp-up support [13]. In order to integrate the industrial building planning process, the

VDI 5200 assigns the performance phases defined by article 15 of the German HOAI (Official Scale of Fees for Services of Architects and Engineers) to the before mentioned seven phases of production system planning (Figure 2).



**Figure 2: Assignment of performance phases according to HOAI, article 15, to the production system planning phases [12]**

Aside from the assignment of phases shown in Figure 2, no further interfaces have been defined between both disciplines. In practice, the work within one phase takes several months and it is run through without a description what information has to be exchanged between which planning participants at what point in time. In a system without dynamic changes of the planning criteria, experienced planners could compensate lacking interfaces.

Due to the high dynamics in factory design projects, planning criteria are changing continuously. As a result, earlier planning phases must be iterated to adjust the planning results. These impact in turn other results having to be adjusted again. Thus, transparency on the impact of a planning criteria change is missing in particular in complex factory design projects.

The lack of transparency in the interfaces between the planners of the two disciplines shall be equalized through a hierarchical organizational project structure. The VDI 5200 describes the kind of cooperation between the two disciplines as follows: "The services of other technical planners and consultants involved in construction will not be covered since in this case the

architect with his responsibility of coordinating and integrating these services is the central instance" [13].

Accordingly, all information is exchanged in practice between the project manager of production system planning and the architect coordinating the information flow and the work tasks in their respective disciplines. Therefore, all information exchanged has to flow in series through a bottleneck between the two project managers as shown in Figure 3. Subsequently, information has to be redistributed to the corresponding planners. Such an organizational structure works only up to a certain degree of complexity of factory design projects, as the project coordinator has to compensate for the lack of interfaces with his experience.



**Figure 3: Example for an organizational structure in factory design projects [12]**

However, this degree of complexity is frequently exceeded in today's and future factory design projects. The lack of transparency in the interfaces between the planners and in the organization of information flow leads in particular in the dynamic environment of factory design projects to

- Idle time in the planning process,
- No value adding planning due to lack of information and
- A high level of coordination effort between the parties involved in planning.

Based on the overall project, this results in

- Delays in the planning process,
- Lack of quality in the planning results and thus
- Exceeding project costs,

which - according to DREIER - can be attributed to 53% to the planning area [14].

## 2.2. Increasing coordination costs in factory design projects

In factory design projects, coordination costs occur for organizing and controlling the planners, the planning tasks and the information flows. In detail, coordination costs are composed of initiation, information, negotiation, adaptation and control costs. These arise due to

- The high number of planners,
- The lack of transparency in the planning procedure within the own and other disciplines,
- The spatial separation of the planning team,
- The different mentalities and educational backgrounds,
- The different target systems of the different planning disciplines and
- Different data formats and structures.

With increasing interdisciplinarity and specialization, the previously mentioned points and thus the intensity of coordination are growing above average (Figure 4) [15].

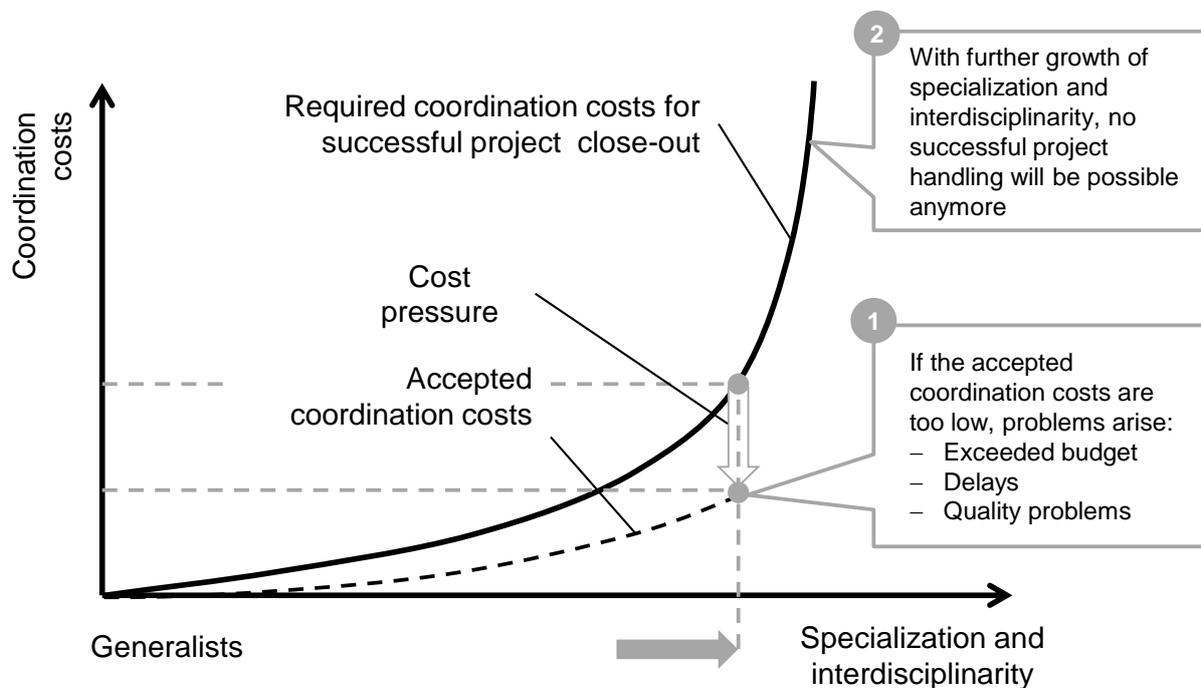
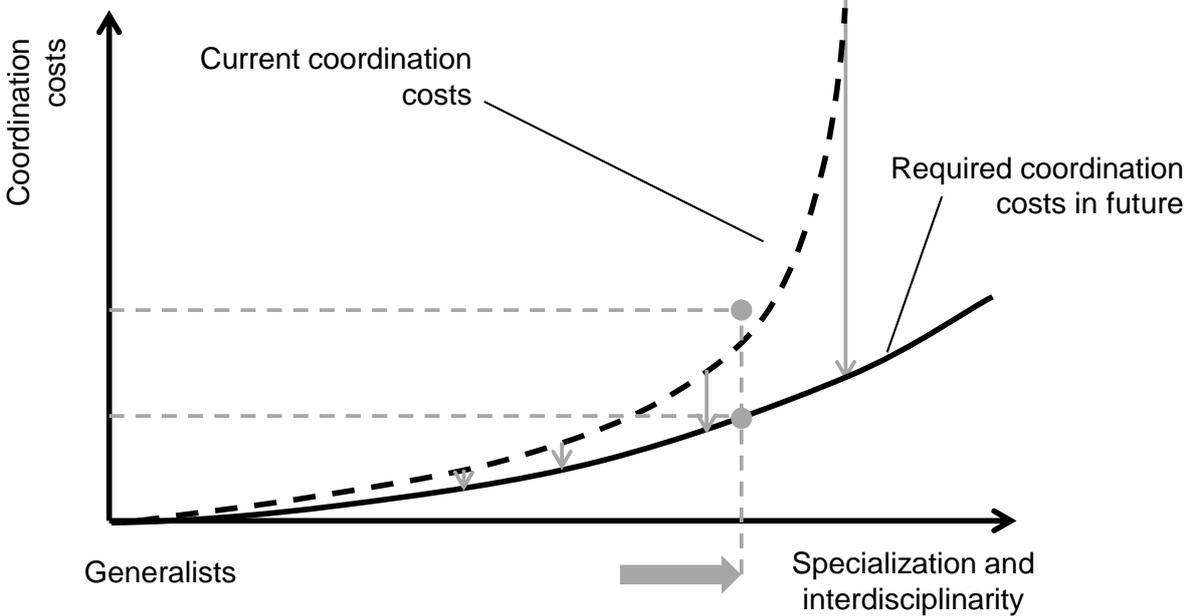


Figure 4: Coordination costs with increasing specialization and interdisciplinarity [16]

The curve of the necessary coordination costs in Figure 4 shows those coordination costs necessary to finish the project successfully – i.e. within the scheduled time, budget and quality. Due to the high cost and time pressures bearing down on factory planning projects, the accepted level of coordination costs is lower than necessary in many projects. This results in problems that cause increased costs, delayed completion or quality defects.

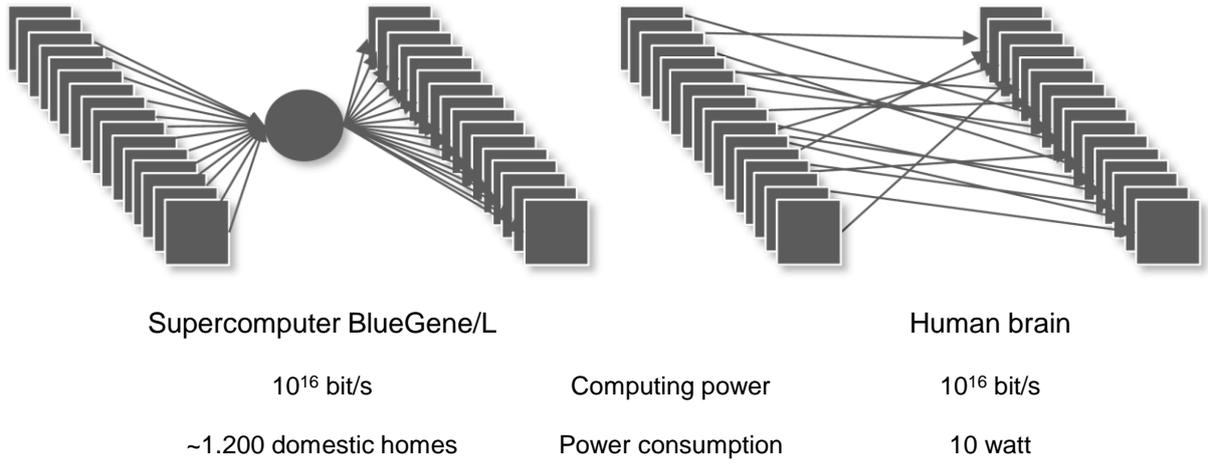
Therefore, the following question needs to be asked: How can coordination costs be reduced in interdisciplinary factory design projects? Since coordination costs have to be reduced significantly, a paradigm shift is required (Figure 5).



**Figure 5: Requirement to lower coordination costs in interdisciplinary factory design projects**

The necessary paradigm shift can be illustrated by an example shown in Figure 6. A human brain is compared with the Supercomputer BlueGene/L, which is at the Lawrence Livermore Laboratory in California. Both reach a computing capacity of ca.  $10^{16}$  bit/s. However, the human brain needs only 10 watts of power while in comparison, the supercomputer consumes as much energy as 1200 average U.S. households [17]. Therefore, it can be deduced that the human brain works more efficiently which can be explained by its structure and functioning. While the supercomputer has a central node where all information has to flow through

serially, the information flow in the human brain is decentralized in a network architecture. This means that information flows in parallel, connections are designed redundantly and can be replaced in the event of an outage of one connection. If the central node in the supercomputer is broken, the information flow is interrupted.



**Figure 6: Comparison between a supercomputer and a human brain [17]**

Based on the considerations in chapter 1, on the need for a paradigm shift and on the analogy consideration between supercomputer and brain, the following hypothesis is derived: The coordination costs in complex factory design projects can be reduced by efficient interaction models.

**2.3. Requirements to efficient interaction models**

Based on a weak point analysis of the current planning process, eight requirements to efficient interaction models were defined. This work was conducted within the research project funded by the German state of North Rhine-Westphalia "DIB - Services in the industrial building design and construction process".

1. Create transparency

The project coordinator should understand all planning processes and information flows in the planning project. This includes the planning of the production system and the industrial building.

2. Create understanding

Planning participants should understand those planning processes and information flows that are relevant to them. This includes not only the processes in their immediate periphery, but also the processes to which they deliver their results and on which they build up their planning results.

3. Filter information

Planning participants shall only receive the information they require and that have an impact on their planning task.

4. Synchronize information flow

Planning participants shall have the right information at the right time.

5. Reduce loss of information

All information should arrive without losses and without media disruptions.

6. Reduce transformation efforts

All information should be able to process without transformation effort.

7. Synchronize maturity levels

Planning participants will generate the required level of maturity of their planning task at the correct point in time. This will enable a higher level of parallelization in the planning procedure.

8. Integrate changes with little effort

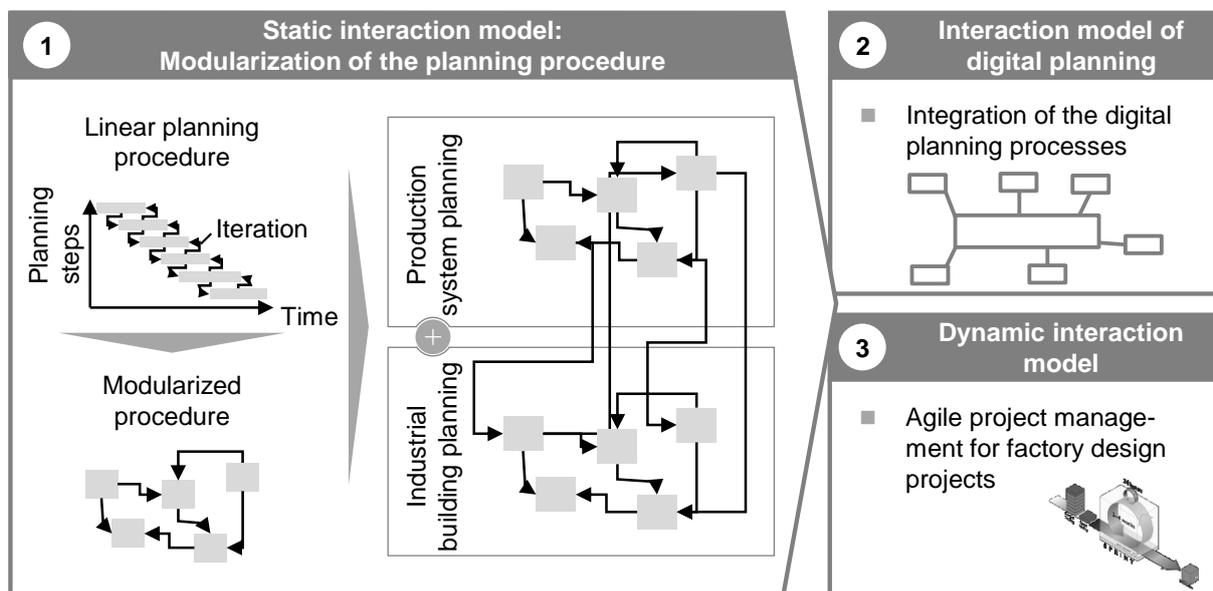
It should be possible to integrate changes of planning criteria with little effort.

### 3. Efficient interaction models in factory design

From the eight requirements derived in section 2.3, three fields of action can be derived:

1. Construction of a static interaction model (requirements 1, 2, 8)
2. Construction of an interaction model of the Digital Planning (Requirements 5, 6)
3. Construction of a dynamic interaction model (Requirements 3, 4, 5, 7, 8)

The three areas are embedded in a regulatory framework for the solution concept as shown in Figure 7.



**Figure 7: Proposed regulatory framework for the solution concept**

Consequently, the first step is the development of a static interaction model that depicts the informational relationships between the tasks of production system and industrial building planning. Based on the static interaction model, an interaction model of digital planning and a dynamic interaction model will be developed.

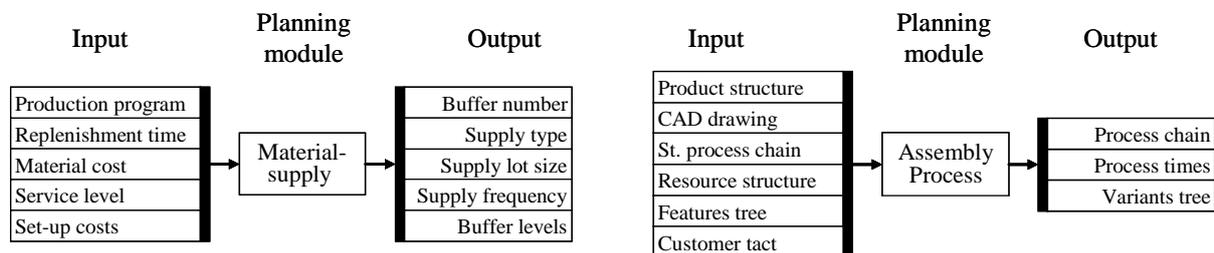
#### 3.1. Static interaction model

The static interaction model consists of two descriptive and one explanatory model. The two descriptive models describe the planning processes for the production system and for the

industrial building as well as the information flows. To build up the explanatory model, the informational relationships between the two disciplines are identified.

### 3.1.1. Condition based planning for production systems

Condition based planning for production systems is a modular parallel planning approach that can be reconfigured according to the specific needs of the project and the company. The modular design allows the standardization of the content (methods, tools, etc.) within a planning module. These modules encapsulate the planning content (Figure 8) on the basis of an object-oriented approach known from software development [18]. It has been developed at WZL at RWTH Aachen University within the cluster of excellence “Integrative Production Technology for High Wage Countries” funded by the German Research Foundation (DFG) as part of the Excellence Initiative and has already been described in detail in several publications [19, 20].



**Figure 8: Exemplary planning modules**

Dependencies between modules are defined by interfaces and occur when a module builds up on the results of another module. This is the basis for the individual configuration of the modules to a specific planning procedure (Figure 9) that can be reconfigured according to the changes in the environment (e.g. changes in quantity forecasts) [19].

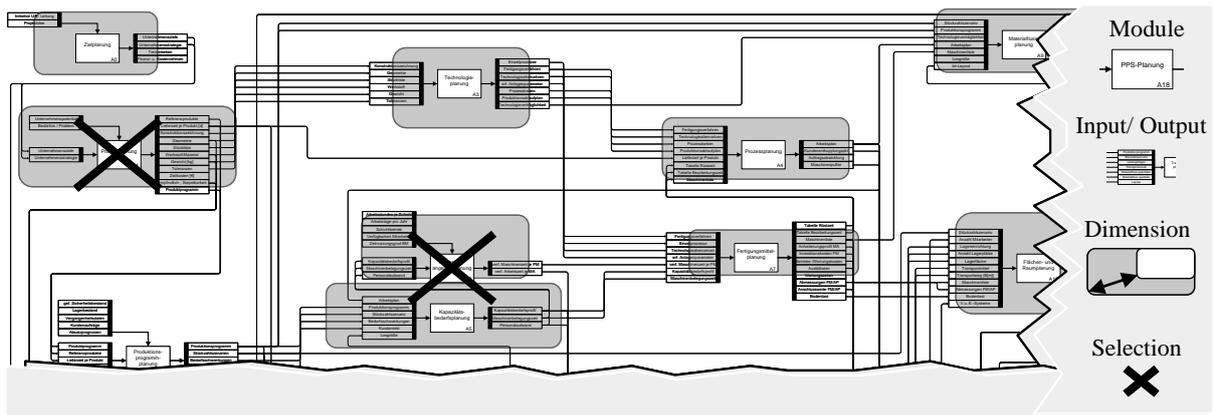


Figure 9: Cross-linked and configured planning modules [19]

### 3.1.2. Condition based planning for industrial buildings

In condition based planning for industrial buildings, the planning content of industrial building planning is encapsulated in 25 planning modules. Necessary input and output information as well as required tools and methods are determined for each module (Figure 10). Input and output information of the planning modules are cross-linked according to the information flow in the planning process. This work has also been conducted in the research project "DIB - Services in the industrial building design and construction process" and was described in further detail in [21].

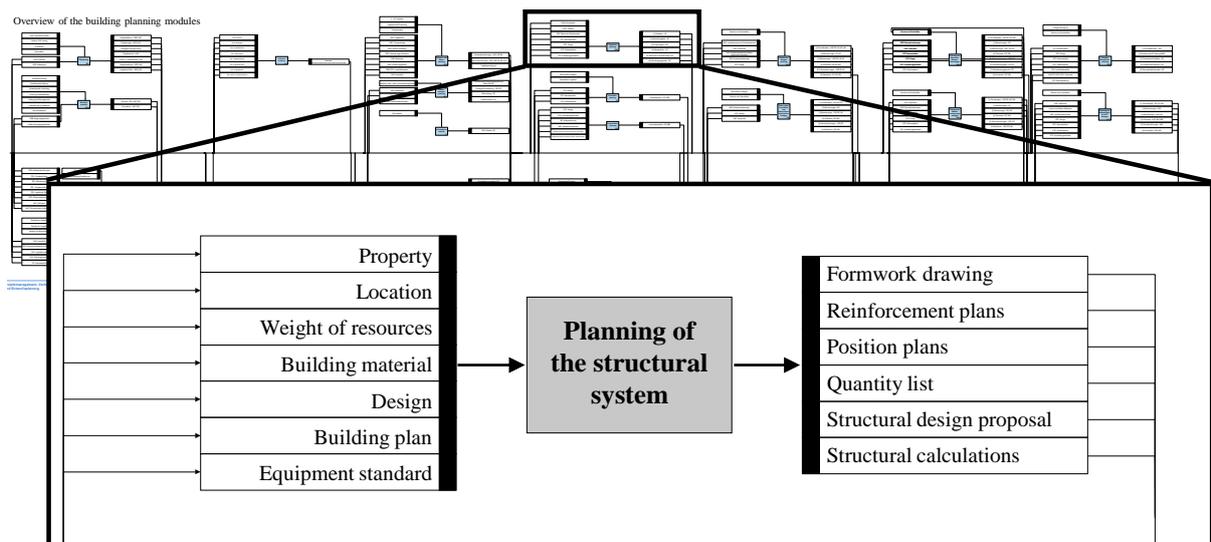
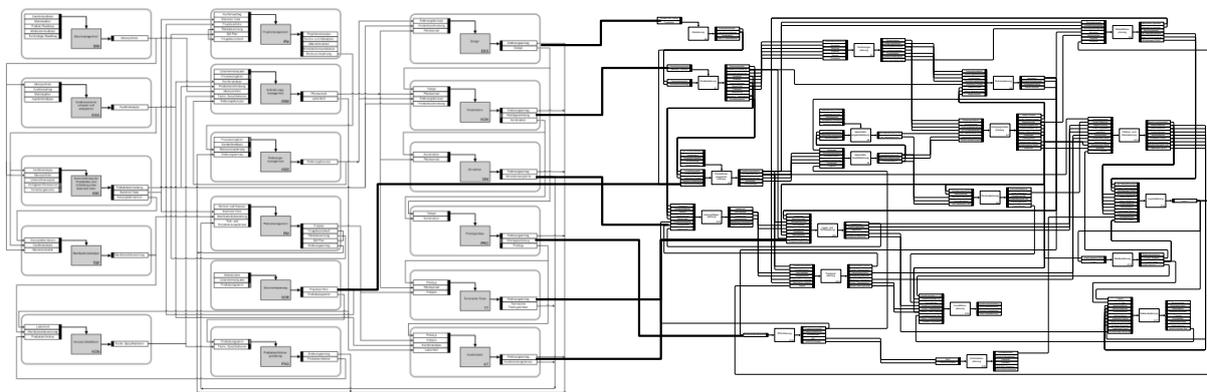


Figure 10: Planning modules of condition based planning for industrial planning [21]

### ***3.1.3. Informational linking of production system and industrial building planning***

After modularization of the planning processes for the production system and the industrial building, the informational interfaces between the two disciplines are defined in a next step (Figure 11). There to, all information is examined resulting of a module and being a planning basis for processing a module of the other discipline. E.g. required floor space would result from the planning module “layout planning” and be necessary to conduct the “architectural planning” of the industrial building.



**Figure 11: Informational linkage of production system and industrial building planning**

The result is a static interaction model creating transparency on all planning tasks and processes as well as all information flows required. Impacts of changes in planning criteria can thus be traced directly and affected planning tasks can be iterated. Another advantage is the ability to carry out an integrative configuration of factory design projects including the construction of the industrial building and the planning of the production system.

### ***3.2. Interaction model of digital planning***

The interaction model of digital planning ensures the integration of digital tools of production system and industrial building planning. The aim is to prevent information losses and to reduce transformation effort. Therefore, digital planning tools suiting the requirements of the planning task in terms of complexity have been defined for each planning module. For example, the solution space is still very large in a very early project stage. Therefore, simple

planning tools (e.g. MS Powerpoint or MS Visio-based) can be used for designing true to scale 2D-blocklayouts. In a later planning phase, when the solution space is smaller and the planning gets more detailed, more sophisticated software tools can be applied for layout design (e.g. 3D-layout design tools). The use of planning tools with an appropriate level of complexity helps focussing on value adding planning tasks. However, it is necessary to ensure re-usage of planning results in a later project stage.

For cross-linking commercially available and/ or proprietarily developed software tools, a concept has been developed enabling the transfer of results between different planning tools without data losses and few transformation effort. For this, each digital planning tool has a program-specific developed converter that links the tool to a common data management system (backbone) serving for all data exchange. The system has been developed within the research project “VFF – Virtual Factory Framework” that was funded by the European Union and has been described in more detail in several publications [22].

### ***3.3. Dynamic interaction model***

The static interaction model provides transparency regarding the planning tasks and the necessary flow of information between the planning modules. However, there is no information about the temporal dimension. Therefore, the planner does not know at what point in time he has to deliver which information in what level of maturity. Especially in the dynamic environment of factory planning projects, planning fundamentals change so frequently that a continuous adaptation of the project plan cannot be ensured on information level. At the same time, the project leader of complex factory planning projects is not able to coordinate all information flows between the planners due to the cognitive limitation of human beings. A shift from traditional system-oriented project management systems is required. Therefore, a dynamic interaction model has been designed referencing on elements from agile software development (e.g. Scrum, Extreme Programming) [23, 24]. The target is

to develop an agile project management system for integrative factory design projects that organizes the exchange of information within a planning project in an efficient, dynamic and flexible way. By this, the dynamic interaction model reduces idle time of planners in the planning process. It also enables the reduction of planning errors caused by a lack of information and the reduction of the coordination effort of planning participants.

The necessity and the basic principle of an agile project management system for complex factory design projects has been derived in the first phase of the cluster of excellence “Integrative Production Technology for High Wage Countries” and is going to be detailed within the second funding period.

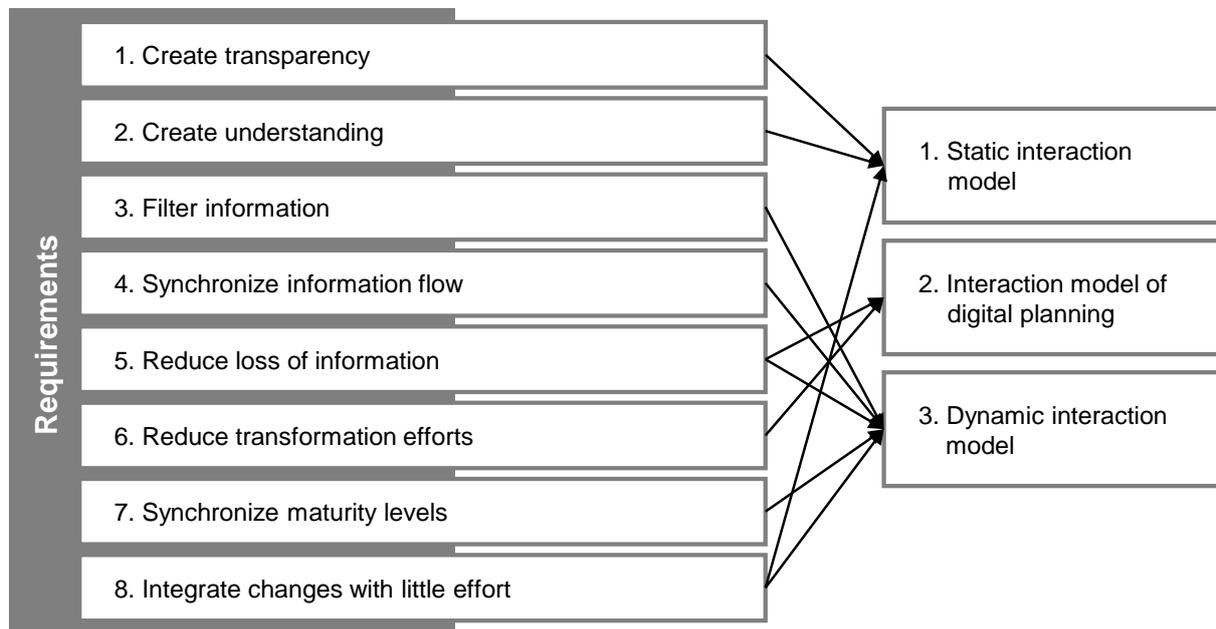
### ***3.4. Interim conclusion***

The eight requirements to efficient interaction models outlined in chapter 2.3 can be fulfilled in accordance to Figure 12 by the three presented interaction models. The static interaction model modularizes the planning process and defines informational links between input and output information of the planning modules. Therefore, the static interaction model creates transparency for the project coordinator and understanding for all planning participants. As the static interaction model shows all interactions between planning modules, impacts of changes are visualized and hence transparent. Condition based factory planning permits an easy adaptation of the planning procedure what allows the integration of changes with little effort.

The interaction model of digital planning connects the software tools used during the planning process. As it links software tools with different degrees of complexity and from different disciplines, the loss of information and the effort to transform planning results are reduced.

The dynamic interaction model ensures that the planners exchange the right information at the right maturity level at the right point in time. Therefore, the information gets automatically

filtered, the information flow and maturity levels are synchronized, losses of information are reduced and changes can be integrated in the existing planning results with little effort.



**Figure 12: Fulfillment of the requirements by the outlined interaction models**

## 4. Summary

The complexity in factory design projects is growing due to an increasing specialization and interdisciplinarity within the planning team. A rising complexity causes an above average growth of the coordination costs within a project. If a certain level of complexity is exceeded coordination costs rise too high and a successful project conclusion is not possible anymore. Therefore, coordination costs need to be lowered significantly by efficient interaction models. The static interaction model modularizes the planning process, defines input and output data required to carry out the planning tasks within the modules and interconnects the planning modules. This increases transparency and enables a flexible configuration of the planning process. The interaction model of digital planning links software tools with different degrees of complexity and reduces data losses as well as transformation effort. The third model is the dynamic interaction model that builds up on agile software development methods in order to exchange the right information between the planners in the correct level of maturity at the

right point in time. The development of the models will be detailed in future research work and applied in an industry case.

Acknowledgement: The new approach of CBFP is being investigated by the Laboratory of Machine Tools and Production Engineering (WZL) within two publicly funded research and development projects (German Research Foundation, DFG): the "Cluster of Excellence - Integrative Production Technology for High Wage Countries" and the Graduiertenkolleg 1491/1 (University graduate training programme) "Interdisciplinary Ramp-Up". The building design and construction process is studied in the publicly funded research and development project (State of North Rhine-Westphalia, NRW.BANK Ziel2): "Services in the industrial building design and construction process".

- 
- [1] Wiendahl H-P, Reichardt J, Nyhuis P (2009) Handbuch Fabrikplanung. Konzept, Gestaltung und Umsetzung wandlungsfähiger Produktionsstätten. Hanser, München.
- [2] Deutsche Post AG (2010) Delivering Tomorrow. Zukunftstrend Nachhaltige Logistik. 1<sup>st</sup> Ed. Deutsche Post AG, Bonn.
- [3] AT Kearney (2011) Carbon Disclosure Project. Supply Chain Report 2011. Migrating to a low carbon economy through leadership and collaboration. Carbon Disclosure Project.
- [4] Schuh G. (2005) Produktkomplexität managen. Strategien. Methoden. Tools. Hanser, München.
- [5] Westkämper E, v. Briel R, März L (1997) Planung in dynamischen Produktionssystemen - Wandlungsfähigkeit als Wettbewerbsvorteil. ZWF 92/12:639-642.
- [6] Schuh G, Franzkoch B; Burggräf P; Nöcker J; Wesch-Potente C (2009) Configurable planning processes for factory planning. wt Werkstattstechnik online 99/4:193-198.
- [7] Aggteleky B (1987) Fabrikplanung - Werksentwicklung und Betriebsrationalisierung, Bd 1 - Grundlagen, Zielplanung, Vorarbeiten. Hanser, München.
- [8] Tompkins J A et al. (2010) Facilities Planning. Wiley, Hoboken.

- 
- [9] Kettner H, Schmidt J, Grein H R (1984) Leitfaden der systematischen Fabrikplanung. Hanser, München.
- [10] NA (2007) AIA document B101-2007.
- [11] NA (2007) RIBA Outline Plan of work. <http://www.architecture.com/Files/RIBAProfessionalServices/Practice/OutlinePlanofWork%28revised%29.pdf>. Accessed January 21, 2012.
- [12] NA (2009) HOAI - the official scale of fees for services by architects and engineers. [http://www.hoai.de/online/HOAI\\_2009/HOAI\\_2009.php](http://www.hoai.de/online/HOAI_2009/HOAI_2009.php). Accessed January 21, 2012.
- [13] NA (2011) VDI 5200: Factory Planning - Planning procedures.
- [14] Dreier F (2001) Nachtragsmanagement für gestörte Bauabläufe aus baubetrieblicher Sicht. Diss. Cottbus.
- [15] Ahlers G. M. (2006) Organisation der integrierten Kommunikation. Entwicklung eines prozessorientierten Organisationsansatzes. Gabler, Wiesbaden.
- [16] Emery F.E. (1969) Systems thinking: selected readings. Penguin, New York.
- [17] Markert B., Fraenzle S., Tieben C. (2009) Information und Informationsverarbeitung. Teil 2: Das Internet und die Pflege emotionaler Intelligenz. Umweltwissenschaften und Schadstoff-Forschung 21/5: 483-486.
- [18] Schuh G, Bergholz M (2003) Collaborative Production on the Basis of Object Oriented Software Engineering Principles. Annals of the CIRP 52/1:393-396.
- [19] Schuh G, Kampker A, Wesch-Potente C (2011) Condition based factory planning. Production Engineering 5/1:89-94.
- [20] Schuh G. et al. (2012) Virtual Production Systems. In: Brecher C. (Ed.) Integrative Production Technology for High-Wage Countries. Springer, Heidelberg.
- [21] Schuh G. et al. (2011) Condition based planning for processes, resources and industrial buildings. In: Correa E. (Ed.) Proceedings of the 22nd Annual Conference of the

---

Production and Operations Management Society, POMS 22nd Annual Conference Reno-Operations Management: The Enabling Link.”, Nevada, U.S.A., April 29 to May 2, 2011.

[22] Sacco M. et al. (2011) Virtual Factory Manager. In: Shumaker, R. (Ed.) Virtual and Mixed Reality. Systems and applications. Lecture Notes in Computer Science 6774/2011: 397-406.

[23] Schwaber K., Beedle M. (2001) Agile software development with scrum. Prentice Hall, Upper Saddle River, NJ.

[24] Beck K. (2000) Extreme Programming Explained. Embrace Change. Addison Wesley, Reading, MA.