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THE COMPLEMENTARY USE OF THE PARAMETER-BASED DESIGN STRUCTURE MATRIX AND THE IFC PROCESS MODELS FOR INTEGRATION IN THE CONSTRUCTION INDUSTRY

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1 INTRODUCTION

Building design is a collaborative process by its nature. It involves several participants with diverse disciplinary backgrounds, viewpoints and working methods. It has long been recognized that shared product and process models are essential for supporting building design processes efficiently (Björk, 1994; Tolman, 1999). Despite the various tracks of research in this field, product and process integration and distributed cooperation in design teams have remained to be a main problem in the construction industry.

The development of the Industry Foundation Classes (IFC) has been the largest scale effort to standardize the representation of Architecture, Engineering, and Construction (AEC) knowledge. IFCs are developed by an international non-profit organization named BuildingSMART (formerly known as IAI) (BuildingSMART, 2010). The IFC specification targets at a common view of building data that can be shared by the AEC community and software development professionals. This common view is known as the IFC object model, defined using a top-down approach. By starting with a very general view of the industry, an overall model of a building is defined suitable for software applications. The IFC specification involves both process modelling (usage scenarios and process diagrams) and product modelling (classes, attributes, relationships and interfaces) components.

Being a widely accepted standardization effort, IFC development shapes the future of building information modelling. The IFC explicitly model a variety of project information, however, it was observed that most of the existing IFC implementations primarily support modelling and exchange of building product information. In fact, relatively little research effort has been devoted to process modelling compared to product modelling in the construction industry. As a result, process modelling components of the IFC schema have not been fully analyzed and exploited yet (Halfawy and Froese, 2005). In order to alleviate this problem, this paper focuses on the methods of process modelling for IFC and discusses that the high-level activity-based IFC process models fail to represent the complex and iterative collaborative building design processes. In order to augment top-down process modelling, the complementary bottom-up use of the parameter-based Design Structure Matrix (DSM) method was suggested and demonstrated through an example from elevator design.

2 PROCESS MODELLING FOR IFC DEVELOPMENT: IDEF0 AND BPMN

IDEF0 has been the most popular process modelling tool in the construction industry, since it was declared as the preferred notation for the creation of graphical process models for Industry Foundation Classes (IFC) specification in 1999. The standardization body recently began recommending Business Process Modelling Notation (BPMN) instead of IDEF0 for the IFC development (BuildingSMART, 2009). However, it seems that IDEF0 continued to be favoured, largely due to the fact that the industry gained familiarity with it in due course. Studies on IDEF0-based AEC process models include but are not limited to Sanvido and Norton (1994), Karhu (2000), and Rezgui et al. (2002).

The U.S. Air Force Standard IDEF was developed from SADT (Structured Analysis and Design Technique) for process modelling in computer-integrated manufacturing and concurrent engineering (US NIST, 1993). The IDEF model consists of hierarchically decomposed diagrams, along with text for each of the diagrams. The two basic components of the IDEF0 diagram are a box and arrows. Boxes represent processes, while the arrows represent different interfaces such as input, output, control, and mechanism. Inputs are the data or objects that are transformed by process into output. Controls are conditions required to produce correct output and mechanisms are the means used to conduct a process.

BPMN is a relatively new activity-network based modelling tool which is currently maintained by the Object Management Group (OMG, 2010). BPMN consists of activities, events, gateways, and data objects. Activities can be shown in different swimlanes that are used to distinguish the actors. Events represent the points in time at which something important happens. A BPMN model contains also gateways standing for the decision points as well as connecting and data objects. Generic IDEF0 and BPMN diagrams of a process are shown in Fig. 1.

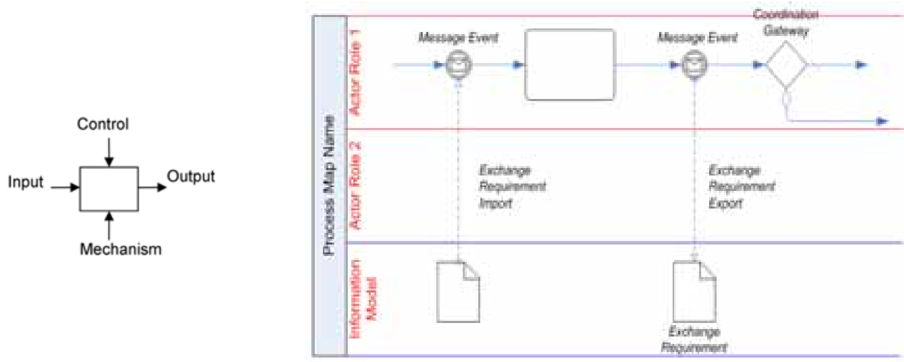

Figure 1. Generic IDEF0 (left) and BPMN (right) diagrams of an activity

As a modelling language, IDEF0 has the advantages of being a well-tested and established language which can be generated by a variety of computer graphics tools. BPMN is very new for the construction industry and related work is scarce; but, it enables comprehensive modelling and has the potential to be the standard for business process modelling worldwide. However, it was observed that both IDEF0 and BPMN suffer from several weaknesses which hinder their standalone efficiency in today's complicated collaborative building design activities:

1. Activity-network based process modelling techniques like IDEF0 and BPMN are only well structured when the activities constitute the focus. Information controls and mechanisms are connected to each process step but there is no way of analysing the total information structure processed in the system.
2. Although IDEF0 and BPMN may be capable of showing iterations in processes, they do not indicate how to minimize them.
3. The techniques give weak support for modelling parallel sub-processes. Therefore, iterations between levels are difficult to analyse with them.
4. Similar to other graph-based representations, IDEF0 and BPMN suffer from size limitations. They tend to grow rapidly for a large number of tasks and visual inspection of the information structure becomes very intricate and misleading.
5. These methods mainly capture document-producing activities in the process. They are not suitable for modelling informal communication among the design team.

Collaborative building design is characterized by its iterative nature and highly interdependent decision-making processes of design participants (Pektas and Pultar, 2006). In IFC process modelling, the modelling process starts at a high-level definition and it is decomposed as needed. In this approach, there is no way of going backward i.e. using the information flows as building blocks and integrating the model in a bottom-up manner. Therefore, the accuracy of deliverable flows is always questionable. Moreover, many important information flows between the participants of the design process are not documented in the construction industry (Austin et al., 1994). Since the IFC process models take only the document producing activities into the consideration; comprehensiveness of such models would also be limited for most of the cases.

In sum, it seems that the IFC process models of collaborative building design processes tend to be highly abstract representations which are not often suitable for further analysis and implementation in collaborative design systems. Eastman (2006) also supported this argument and claimed that more structurally integrated process modelling methods should be sought for in the construction industry. Within this perspective, the present paper suggests the combinational use of the parameter-based DSM and the high-level IFC process models in order to alleviate the deficiencies of the latter. The details of the parameter-based DSM method are discussed in the following section.

3 THE PARAMETER-BASED DESIGN STRUCTURE MATRIX METHOD

In a parameter-based DSM, marks in a single row represent the parameter decisions whose output is required for the parameter decision corresponding to that row. Similarly, reading down a specific column reveals which parameter decision receives information from the parameter decision corresponding to that column. Through an operation called partitioning, the system elements are re-ordered in order to minimize the iteration cycles. The parameter-based DSM is a low-level, compact and analytical technique that can be used as a bottom-up system analysis and process modelling tool. The method was previously applied in automobile design (Black et al., 1990; Dong, 1999), aerospace engineering design (Mascoli, 1999), software development (Rogers and Salas, 1999) and suspended ceiling design (Pektas and Pultar, 2006).

4 AN INTEGRATION EXAMPLE FROM THE ELEVATOR DESIGN PROCESS

The use of the DSM method for process integration was first suggested by Browning (2002). However, to the best of the author’s knowledge, this study is the first to integrate domain-specific activity-based process models by the help of the parameter-based DSMs. The following example illustrates this functionality. The data was collected in collaboration with a major elevator design company in Turkey. The example was extracted from the large models for convenience. Two activities of the elevator design process and the deliverables (parameter decisions) for each activity are defined in the figure below. The diagram shows that there is a coupling between activities 1 and 2. However, the structure of this cycle, namely which parameter decisions are dependent on each other, is not clear (Fig. 2).

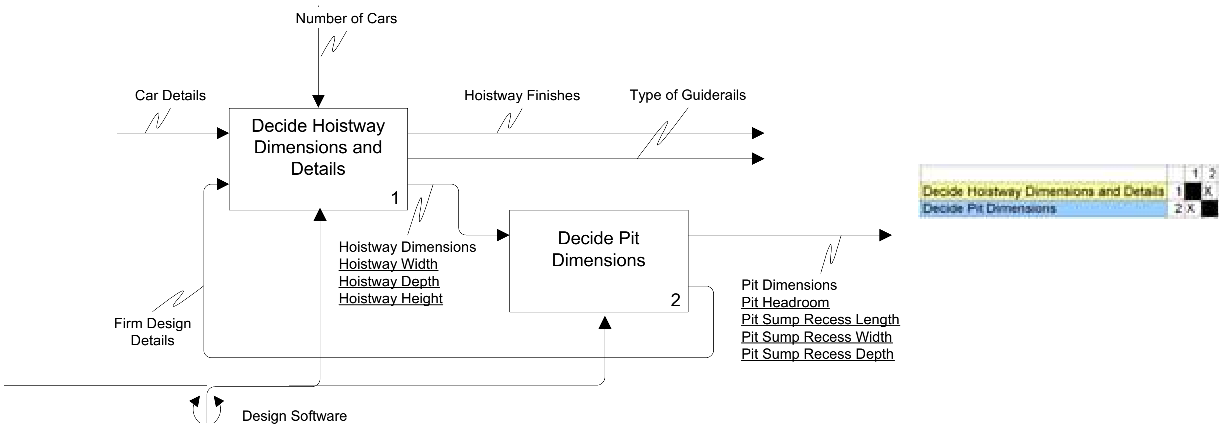

Figure 2. Two coupled activities of elevator design process: IDEF0 model (left) and activity-based DSM (right)

The representation of the same relationships in an activity-based DSM (Fig. 2) does not lend itself to further analysis either. Fortunately, the Parameter-based DSM shows the information flows (dependencies) between the parameter decision points in two activities and works as a detailed process map (Fig. 3). When the DSM is partitioned, the optimum sequence of the decisions is obtained and the iteration is removed from the process (Fig. 3). In this way, the integrated process model is based on accurate information flows rather than overviewed activities (Fig. 4).

		1	2	3	4	5	6	7	8	9
Hoistway Width	1									
Hoistway Depth	2									
Hoistway Height	3	X	X				X			
Hoistway Finishes	4	X	X							
Type of Guiderails	5			X						
Pit Headroom	6									
Pit Sump Recess Length	7		X							
Pit Sump Recess Width	8	X								
Pit Sump Recess Depth	9									

		1	2	4	6	3	5	7	8	9
Hoistway Width	1									
Hoistway Depth	2									
Hoistway Finishes	4	X	X							
Pit Headroom	6									
Hoistway Height	3	X	X		X					
Type of Guiderails	5					X				
Pit Sump Recess Length	7		X							
Pit Sump Recess Width	8	X								
Pit Sump Recess Depth	9									

Figure 3. Two coupled activities of the elevator design process: the initial parameter-based DSM (left) and the partitioned DSM (right)

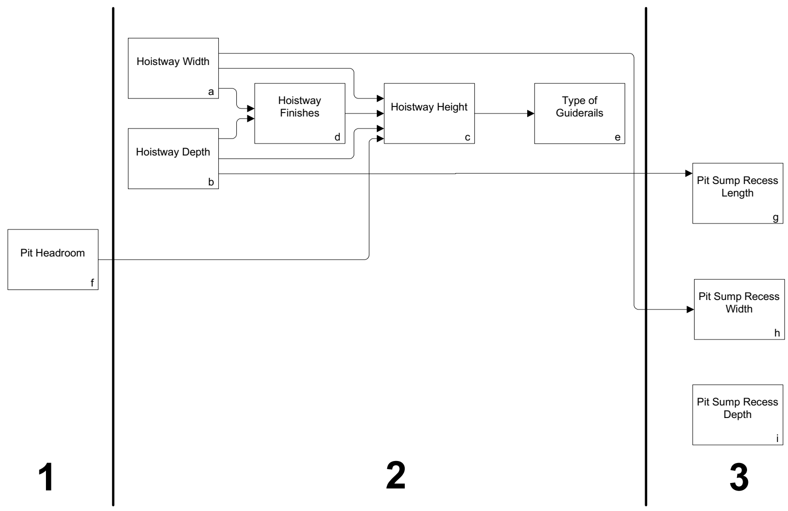

Figure 4. The integrated process

Of course, total elimination of iteration between two activities may not be possible for most of the design processes. Still the author believes that this example well illustrates how the complementary use of the parameter-based DSM with activity network-based models could provide better insights into the process structure.

5 CONCLUSION

The findings of this study supported the hypothesis that IFC process modelling and the parameter-based DSM could be used complementarily in modelling collaborative building design processes. In the case study, IDEF0 models provided an overview of the process and guided the development of detailed parameter-based DSMs which provided valuable insights into the process structure, optimum sequence of parameter decisions, iterative cycles and concurrency in the process.

The participants were not familiar with both types of the modelling before the experiment and they reported that IDEF0 models had been easier to use compared to parameter-based DSMs for the higher levels of the process, as the models detailed the opposite had been true. This finding paralleled that of Keller et al. (2006) who conducted experimental surveys to compare design structure matrices and node-link diagrams and concluded that the appropriateness of a particular representation depends highly on the nature of the task in question. In Keller et al.'s study (2006), node-link diagrams were found to be more suitable for small and sparse graphs, while design structure matrices were more useful for dense and iterative activities. Early phases of collaborative building design processes were known to be characterized by dense and iterative information flows among the design participants (Pektas and Pultar, 2006). In our case study, such stages of the elevator design process were found to be the most advantageous for the complementary use of the methods. The IDEF0 models indicated large iteration cycles in early design and the parameter-based DSM provided further insights into the iterated processes and facilitated for process integration.

A challenge of the parameter-based DSM approach observed in the case study was the large number of parameters related to the design processes. Capturing and managing all parameter decisions in a process may not be always necessary. In order to increase the efficiency of the models, a selection should be made depending on the purpose of the parameter deployment. Activity-based models can be useful in this choice, because they represent feedback loops in the process and the critical activities can be identified visually. Then, the parameter-based DSMs can focus on the critical activities.

Another observation made during the case study was the lack of process monitoring documentation in the construction industry as expected after Austin et al. (1994). Unlike other large industries, such as automotive and aerospace, construction industry is fragmented into small organizations. The interviews revealed that small design companies participated in the study did not have enough resources to be allocated for monitoring their processes. However, the participants responded very positively to the study, because it made them think from a systems point of view.

This study showed that the complementary use of IFC process modelling and the parameter-based DSM deserves further attention. The proposed methodology provides insights into the process structure, identifies problem areas in processes and enables process re-engineering. These functionalities are especially important to support the implementation of collaborative design support systems, since such systems need explicit definition of structure and semantics of design information. We hope that our work will facilitate for further researches in this respect.

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The Complementary Use of the Parameter-Based Design Structure Matrix and the IFC Process Models for Integration in the Construction Industry

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MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Outline

- The problem of collaboration in building design
- Industry Foundation Classes (IFC)
- The deficiencies of the existing tools
- A three-level scheme for building design process modelling
- The parameter-based DSM as a process integration tool
- Conclusions

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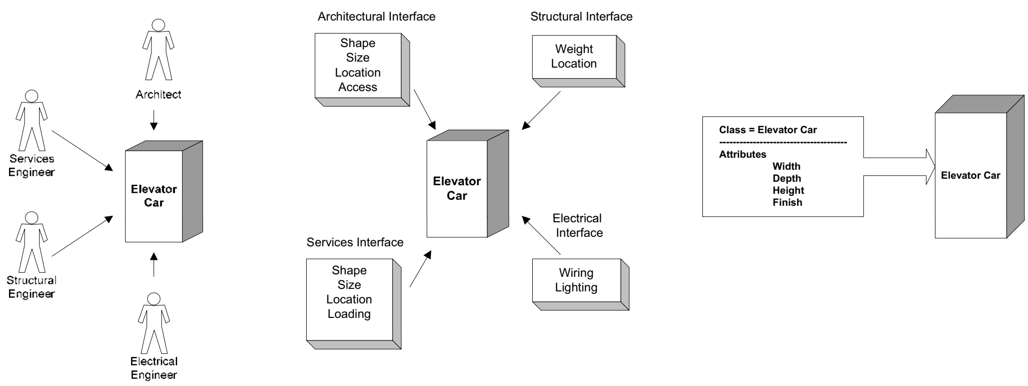
The problem of collaboration in building design

- Design management is a relatively ignored subject compared to production management in the construction industry.

- Although there is an intense flow of information in building design processes, there is a lack of research to better understand and manipulate these flows.

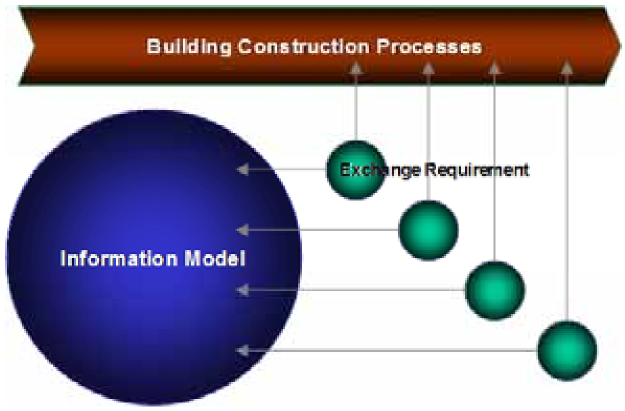
Industry Foundation Classes (IFC)



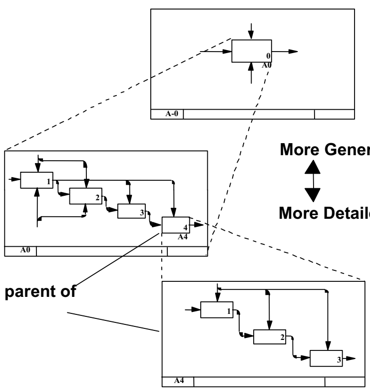
buildingSMART

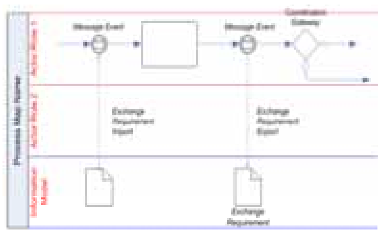
http://www.buildingsmart.com/

Information Delivery Manual (IDM)



Process modelling for IFCs





IDEF0

BPMN

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The deficiencies of the existing tools

- In order to integrate a group of activities the flow deliverables among them must be well-defined.
- In the existing IFC tools, the accuracy of deliverable flows is always questionable since there is no way of integrating the model in a bottom-up manner.

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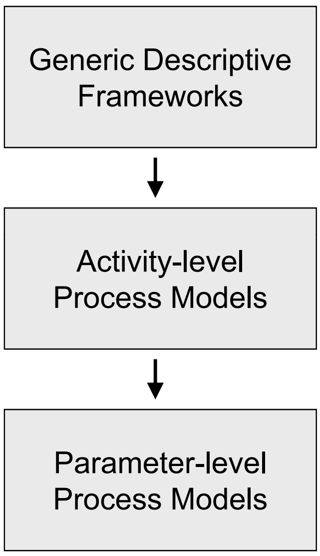
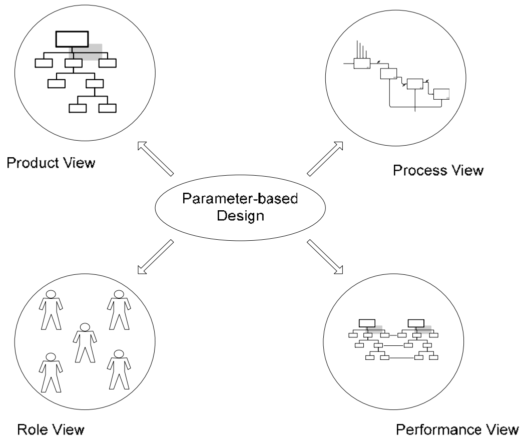
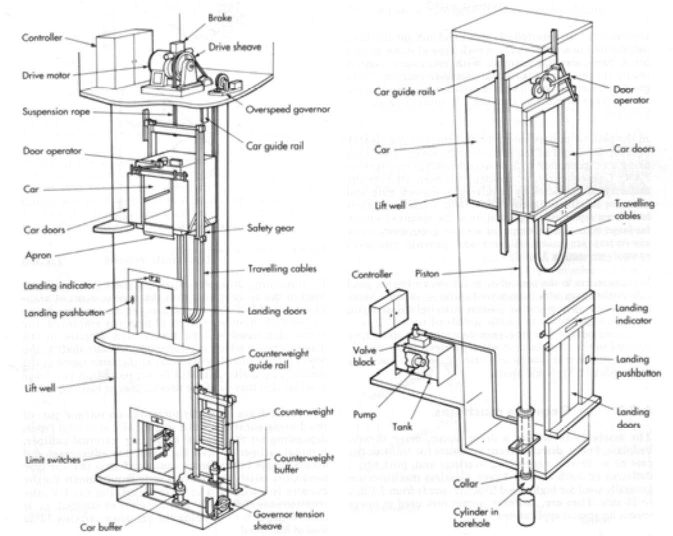
A three-level scheme for building design process modelling

Modeling Level	Tools
Process	High level process definitions (RIBA Plan of Work, GDCP, Design theory models)
Activity	Process diagrams based on tasks (IDEF0, CPM, UML activity diagrams, Activity-based DSM)
Parameter	Parameter-based DSM

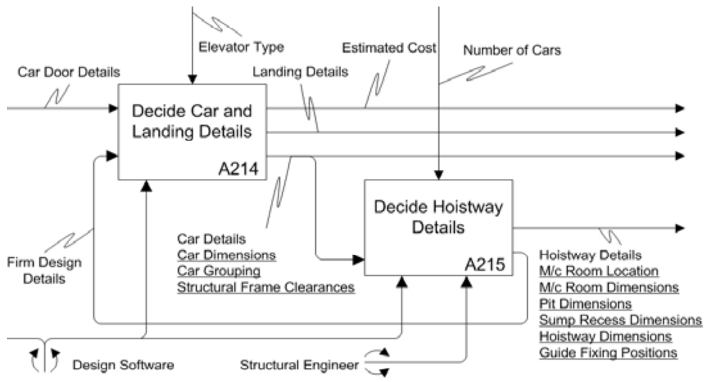




Elevator design problem



The parameter-based DSM as a process integration tool



		1	2
Decide Car and Landing Details	1	1	X
Decide Hoistway Details	2	X	2

The parameter-based DSM as a process integration tool

		1	2	3	4	5	6	7	8	9
Car Dimensions	1	1							X	
Car Grouping	2	X	2							
Structural Frame Clearances	3			3						
Machine Room Location	4				4					
Machine Room Dimensions	5	X	X			5				
Pit Dimensions	6	X					6		X	
Sump Recess Dimensions	7	X						7	X	
Hoistway Dimensions	8	X	X	X					8	
Guide Fixing Positions	9	X							X	9

		3	4	1	2	8	5	6	7	9
Structural Frame Clearances	3	3								
Machine Room Location	4		4							
Car Dimensions	1			1		X				
Car Grouping	2			X	2					
Hoistway Dimensions	8	X		X	X	8				
Machine Room Dimensions	5			X	X		5			
Pit Dimensions	6			X		X		6		
Sump Recess Dimensions	7			X		X			7	
Guide Fixing Positions	9			X		X				9

Applications in the construction industry

- The method was applied in analyzing suspended ceiling and elevator design processes in real life context.
- The findings of these studies supported the hypothesis that IFC process modelling and the parameter-based DSM could be used complementarily in modelling the collaborative building design processes.

When should the parameter-based DSM be applied?

- Highly coupled activities
- Activities which require intensive information exchange among different design professionals
- Critical activities which tend to cause delays

The complementary use of the IFC process models and the parameter-based DSM

- Better understanding of the processes
- Minimized iteration
- Bottom-up process modelling
- Support for computerised parametric design tools

as a result…

More integrated processes.