Control of design and manufacturing processes based on information content

Lutters, D.; Kals, H.J.J.
University of Twente, Laboratory of Production and Design Engineering
P.O. Box 217, 7500 AE Enschede, The Netherlands
d.lutters@wb.utwente.nl

Abstract: In analysing design and manufacturing tasks and their mutual interactions, it appears that the underlying information of these tasks is of the utmost importance. If this information is managed in a formalised, structured way, it can serve as a basis for the control of the design and manufacturing processes. The ontological description that is used for this purpose is elaborated upon. Significant in this respect, is the introduction of expedient differentiations in distinct aspects of the ontology.
Based on the overall ontology, it is indicated how an ontological description of the information content can be applied to govern design and manufacturing processes.
Keywords: concurrent engineering, information structuring, ontology.

1. INTRODUCTION

In Concurrent Engineering, emphasis is put on a simultaneous execution of shared tasks by separate departments, and, more important, on the control of co-operative decision making [Sohlenius, 1992]. Therefore, it is important to understand the need for interaction and communication between the diverse disciplines. As a matter of fact, the possibility of communication is based on both the availability and the accessibility of coherent information. Instead of merely exchanging data, it is preferred to have access to meaningful representations of the existing information, reflecting the current state of affairs [Kals & Lutters, 1998]. This is emphasised in recognising that the main input and output of most design and engineering processes is information. Consequently, the vast majority of all manufacturing processes can be considered to consist of sheer information processing.

2. INFORMATION MANAGEMENT

In recognising the fact that each of the departments in a company makes myriad decisions in order to generate required information, it is obvious that the reasoning behind all these decisions can hardly be transferred together with the information. Consequently, the need for feedback and interdepartmental communication increases, which may lead to extremely complex and uncontrollable flows of information between departments.

H. Kals et al. (eds.), *Integration of Process Knowledge into Design Support Systems*

However, providing that information generated by the separate departments is attached to an overall and widely accessible model, this situation may change considerably. In this case, instead of 'pushing' information from one department to another, departments can 'pull' the information they require and are given access to. Hence, the focus can be on the information in support of the control of the manufacturing processes, and for this reason, the course of the manufacturing processes may be guided by the use of, and the need for information. It is clear that the types of objects the information is concerned with can vary considerably. Despite this variation, for the way the information is structured and attached to an overall model, it is unimportant whether information bears reference to e.g. a product, a machine or its operator. Still, it is important to distinguish between different types of objects, as their different significance for the manufacturing processes is apparent.

Each type of object can be attached to an overall model, a so-called information structure. In concordance with the engineering processes recognised in the reference model [Lutters et al., 1997], three of these information structures are discerned (see figure 1):

- product information structure;
- order information structure;
- resource information structure.

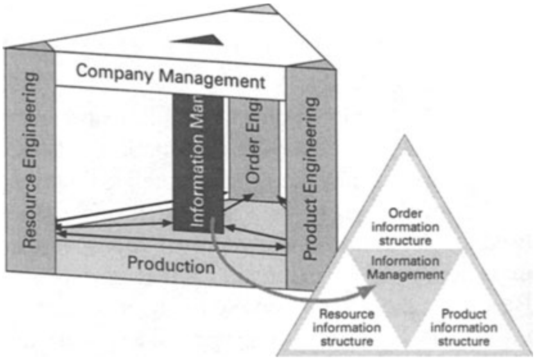

Figure 1*; The manufacturing engineering reference model and the Information Structures*

Because the structures evolve independently, whereas the ways of their mutual interactions remain the same, the entire range of manufacturing environments can be addressed: from engineer-to-order to mass production. The different behaviour of the information structures in different environments implies that each of the structures has its own life cycle. In aiming for the integration of processes, the life cycles must be oriented on the information contained in the information structures, instead of on the processes concerned with this information. In elaborating this concept for the product information structure, the product life cycle is oriented upon the product instead of on the design and manufacturing processes.
Therefore, in this definition, the product life cycle is the span of time in which it is possible to refer to either a product type or to one physical instantiation of a product variant. The life cycle ranges from initial perception until final recycling/disposal. The information that describes the product life cycle, i.e. establishes the change of the product information structure over time, can be used to denote the design history and even the entire manufacturing history of a product.
In this way, Information Management as part of the reference model, comprises of an integrated collection of tasks that can be used as a basis to initiate, accompany, control and evaluate all the manufacturing processes in a structured and transparent way. These tasks are based on the information contained in the three information structures (figure 1).

3. STRUCTURING OF INFORMATION CONTENT

The information that constitutes the basis for the design and manufacturing processes must be established in a structured, transparent manner. Based on the Product Information Structure (PRIS), the structuring of the information will be discussed.

The goal of the product information structure is the management of all the relevant information of a product type. In this context, the perception of relevant information can be outlined as anything that is a consideration or a result of a manufacturing decision. Such a decision can bear reference to any stage of a product's life cycle. Moreover, such a decision can be concerned with elements of different aspect systems of the product, it can address e.g. function, geometry or quality, to mention just a few. However, all manufacturing decisions can be associated with a certain part of the product information structure [Lutters et al., 1998].

3.1 Elements and relations

It is generally accepted that a product information structure reflects a product by means of the elements and relationships it consists of [Tichem & Storm, 1996]. Furthermore, additional information can be related to either elements or relationships between the elements, addressing the various processes in the manufacturing cycle. Two important aspects come forward in adopting this model. Firstly, there is no exclusive reference to geometric entities. An element can also be part of any other aspect system, e.g. a function or a piece of control software. Consequently, the transition from one aspect system to another can be represented in a more natural way. This leads for example to an easier representation of the translation from function to geometry during the design stage. Secondly, no explicit hierarchy exists in this model. Usually this hierarchy is assumed in using a part-of relation. However, in this model, the part-of relation has the same status as any other relation between elements.

3.2 Aspect systems and domains

As mentioned in the above, elements are part of a certain aspect system representing the product. Generally, it is assumed that the number of aspect systems required for the definition of a product is limited. The most obvious aspect system is of course the physical product definition. Most of the research concerned with product structures is based on merely this model, which often leads to artificial solutions.

Contrary to this, the framework for the product information structure presented here discerns a number of separate aspect systems, referred to as domains. The actual number of domains required to fully specify a certain product type is not always known on beforehand. This may become obvious, as the representation of e.g. a car makes other demands on the product information structure than e.g. a simple component. However, a number of domains that are generally applicable as templates are discerned:

- objective domain;
- physical product definition domain;
- control domain.

The *objective domain* comprises of the information that delineates the specifications and requirements of the product (e.g. functional structure, conceptual design). The *physical product definition domain* is used to establish the physical elements of the product, together with the attributes that further specify these elements (e.g. bill of materials, process plans). All the information describing the adaptable behaviour of the product is contained in the *control domain* (e.g. software). The domains themselves are rather independent; e.g. one and the same function can be realised by several (combinations) of geometric elements. Or, the demeanour of a computer changes with a different operating system (software), though the geometry remains the same.

3.3 Views and filters

Whereas the domains are sovereign and deal with different aspect systems of a product, a resource or an order, also different interpretations of one domain are possible. For example, a process planner has a different idea about a certain product geometry than an industrial designer. In other words, they are both concerned with the geometry, but with a different goal and in a different manner. For this purpose, a view on a certain domain is introduced. A view furnishes a focussed, partial representation and specification of the information in a certain domain of an information structure.

In formalising the example of the designer and the process planner, they are both concerned with the same elements and relations, however, the attributes are different. Furthermore, there can be elements that differ in different views. For example, the multiple views problem on form features comes forward here. For a designer, a group of faces can make up a design feature, whereas the process planner wants to discern manufacturing features (see figure 2). Different views on the same domain are mutually dependent, because the core structure (object) is present in all views. Besides, a hierarchical ordering can exist between the views. It is obvious that if the core model changes, all views have to be updated as well. On the other hand, elements, relations or attributes in one specific view can change, from which updates in selected other views are initiated.

In an information structure, the user can focus on a selected portion of the entire amount of information by applying a filter to the information content.

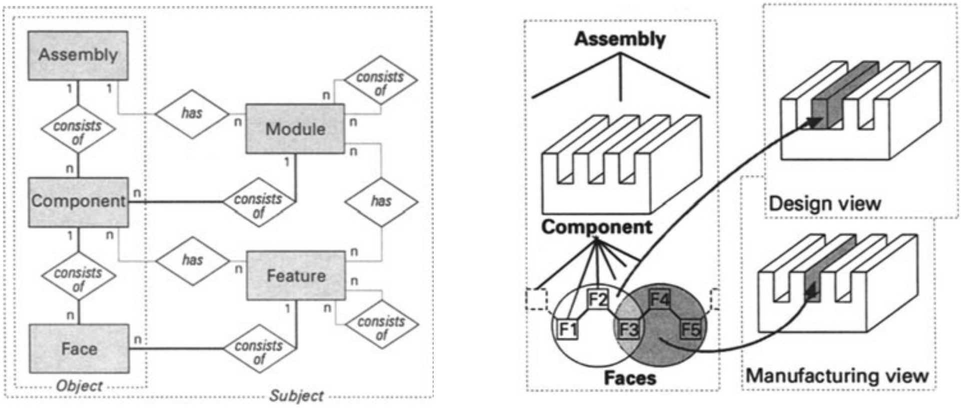

***Figure 2;** Objective and subjective interpretation of information in different views*

From a management point of view, the use of domains, views and filters is extremely useful in defining tasks, co-ordinating processes and keeping abreast with the current state of affairs. Furthermore, information can selectively be made available, be secured or transferred discriminatingly. In other words, a framework for a product information structure as described in the above is a firm foundation for the control of design and engineering processes in a company. [Lutters et al., 1998] An overall sketch of the framework for a product information structure is shown in figure 3.

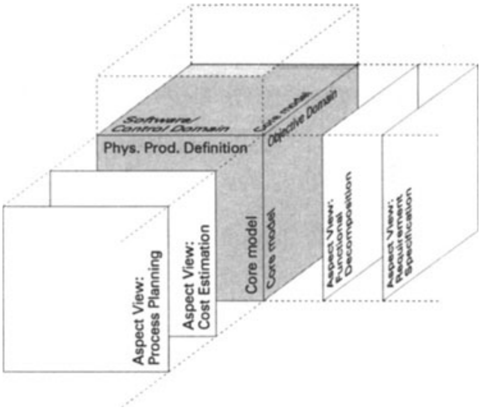

Figure 3*; Basic representation of the Product Information Structure (PRIS)*

4. FORMALISATION OF INFORMATION CONTENT

Structuring of information mainly addresses the organisation of objective and subjective interpretations of information in domains and views. Formalisation of the information content focusses on the elements and relations that constitute these domains and views. In other words, the structure in figure 3 represents the backbone for the information contained in the views as shown in figure 2. As mentioned before, the information in the structure can be assumed to consist of elements and mutual relations. Consequently, the fundamental structure that can be used as a building block in information structures can be represented by the (conceptual) graph shown in figure 4. The graph in figure 2 can clearly be constructed from this building block.

Arbitrary concatenations of instantiated building blocks lead to meaningless structures. Therefore, it is obvious that information structures must be constructed in accordance with a certain blueprint or skeleton. This implies the existence of a definite, inherent context characterisation, in which certain elements must, can -or can not- exist and must, can -or can not- be related to certain other elements. In fact, this characterisation is a description of the structure at a higher level of aggregation and can be indicated by the term ontology.

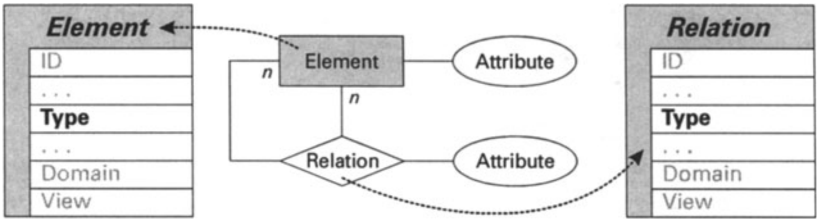

Figure 4*; The fundamental building block and its constituents*

4.1 Ontology

In the Concise Oxford Dictionary, the lexeme ontology is depicted as:

> **ontology** /ɒn'tɒlədʒi/ *n.* the branch of metaphysics dealing with the nature of being

At first sight, this is a rather philosophical explanation. In effect, it is very suitable in the context of information structures. This is best recognised by means of an example. If a certain product is said to consist of two parts, it will immediately be recognised for being an assembly. Therefore, the product type will be 'assembly'. In other words, every element in a structure is of a certain type; this type can be employed to specify its nature and genius. The same yields true for the relations between elements: the assembly is said to *consist of* parts and perhaps *have* a certain 'weight'. Here the strength of ontological descriptions comes forward: if this 'assembly' *has* 'weight', any other assembly can likewise be assigned a 'weight'. From collecting typological definitions of elements and relations, the blueprint or skeleton mentioned above emerges.

If the elements and relations are established by means of a record-like data structure (as shown on both sides of the graph in figure 4) the 'type' fields obviously take an important position. It is the apposite way to link an instantiated element or relation to its formal context. Two other fields in the data structure that bear importance in this respect are the 'domain' and 'view' fields. Whereas the 'type' field positions elements and relations in proportion to each other, the 'domain' and 'view' fields locate the elements and relations with respect to their position in the entire information structure. In effect, two different, but complementary, types of ontologies can be distinguished here. The 'type' field is a

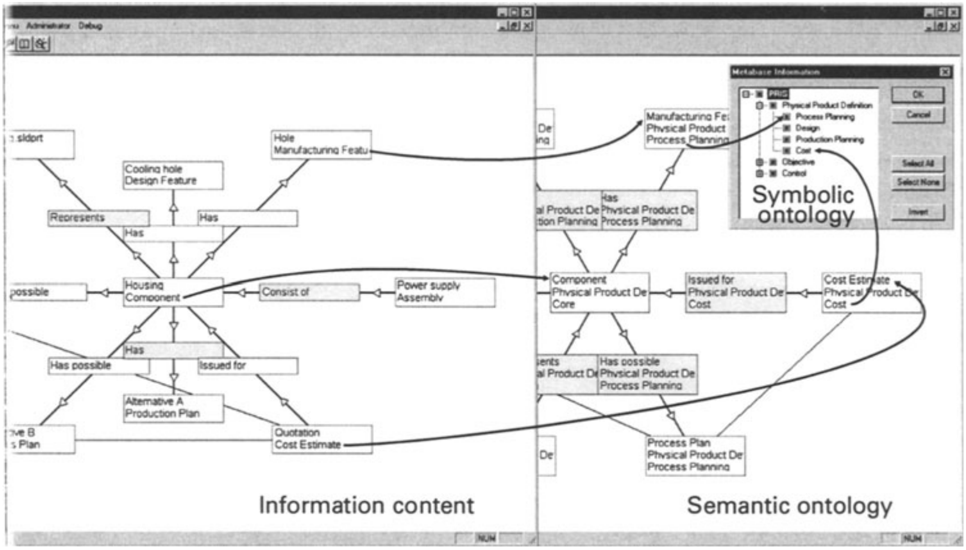

Figure 5; Information content, semantic ontology and symbolic ontology (screen dumps obtained from prototype implementation) representation of the semantic ontology, whereas the 'domain' and 'view' fields reflect the symbolic ontology. In summary (see also figure 5):

- Semantic ontology: definition of elements and relations between these elements;
- Symbolic ontology: definition of the structure the semantic ontology adheres to.

Both ontologies additionally share a very important characteristic: all 'types', being either elements, relations, domains or views, have to be detailed in the ontological representation as soon as an instantiation arises. This implies that the ontology must constitute a 'convex-hull' of the information content of an information structure.

Here the fundamental difference between two ways of obtaining ontologies comes forward. Traditionally, the formal representation of an ontology is often based on a theoretical analysis of a certain specialism. Often, the ontology is completed by additional theoretical means to cover for exceptions. Subsequently, the obtained ontology is imposed on resembling situations. In general, this way of obtaining an ontology can be seen as an a priori, deductive approach, which can be logically independent from experience. This method presumptively approximates the actual situation from the theoretical abstraction. Therefore, this way of defining an ontology can become very inflexible, and the realisation of alternative solutions can become extremely difficult.

More elaborate ways of obtaining ontologies (e.g. [Slattery, 1997][Schlenoff et al., 1998]) construct the way in which the ontology can be related to the instantiated information. However, still a discrepancy between this instantiated information and its abstract description can exist, as the description is enforced externally. It would therefore be advantageous, if the description logically emerges from the information content.

In the current research, the context of the ontology is as important as the ontology itself. This explains the introduction of, and the value assigned to, the symbolic ontology.
Both the symbolic and the semantic ontology are created using similar building blocks as used for the definition of the instantiated structure itself (see also figure 5). Therefore, the semantic ontology can ensue from the evolution of the information content. If a new type of element is introduced, it is immediately incorporated in the ontology, by once defining its demeanour in the structure and its possible or required relations to other types of elements. Consequently, this approach is very flexible, and it can easily adjust to changing circumstances, as the ontology evolves together with the evolution of the product itself.
Once a certain basis is realised, this basis can be applied to other products. For the larger part, this can be done without problems (e.g. an 'assembly' always *consists of* 'components'). In other cases, there can always be anticipation for shifting relevance of ontological content, because it is based on the actual information content.
In comparison to the method described in the above, the proposed approach can be considered to be an a posteriori, inductive method to continuous evolution of the information context and its ontological description. Obviously, this assumptively obtained ontology offers more flexibility compared to the deductive ontology.

5. CONTROL OF DESIGN AND MANUFACTURING PROCESSES

In the previous section, a formal description of a stationary information structure was introduced. Here, the ontology specifies the static characterisation of the elements and relations in an information structure. Ergo, no incentive for a change in the state of the information structure can emerge from the ontology proposed in section 4.

However, in the first sections of this publication, the possibility of controlling design and manufacturing processes based on the information content was introduced. Logically, a description of the stationary information content is inadequate for this purpose.

Accordingly, a subdivision of the semantic ontology is made here:

- Static ontology: describes the stationary dependency of elements and relations;
- Dynamic ontology: describes the process-related dependency of information entities.

The dynamic part of the ontology establishes the information requirement of design and manufacturing processes in terms of their required inputs. In fact, the dynamic ontology adds additional relations between elements of the information structure.

For example, the static part of the ontology defines that a 'component' *has* a 'process plan' and *has* a 'production plan'. Then, the dynamic part of the ontology can add the relation that a 'production plan' *presupposes* a 'process plan'. That is, it is immediately clear that a production plan can not be generated if no process plan exists for this component.

This dependency can be noted as: production plan (process plan).

In general:

- if b is required information to obtain/establish a, notation is: a(b).
- if a(b) and a(c), then a(b,c)
- if a(b) or a(c), then a(b|c)
- if a(b) and b(c), then a(b(c)).

Applying this notation, enables the 'calculation' of information dependencies. Moreover, in recognising the fact that the filling-in of any element is realised by performing a certain process, the same calculation can be applied to define inter-dependencies of design and manufacturing processes.

Consequently, if the required input for a certain process is defined in terms of information requirements, so-called process-chains of information evolution emerge.

At first sight, these chains show considerable similarity with e.g. scenarios or other prescriptions of process paths. However, these scenarios establish rigid, predefined sequences of processes. Therefore, these scenarios always need to be executed step by step, disregarding the actual goal of the applied processes.

The difference with using a dynamic information ontology is that here, a process is considered to be a means to achieve an evolution of the information content. This evolution is defined for every process, which allows for a modular approach towards the arrangement of processes. This substantially increases the flexibility. Moreover, because the execution of processes depends on the actual information requirement, the entire control of design

and manufacturing processes can be expressed in terms of information requirements, and therefore in terms of the dynamic ontology.
For example, if a FEM-analysis is part of a scenario, it has to be performed for every component the scenario is applied to. In the proposed approach, the need for a strength analysis (being an information requirement) of a certain component initiates the FEM-analysis or any other process performing strength analyses. Via the information requirements of the FEM-analysis, the necessary input can be obtained by subsequent initiation of apposite processes.

6. APPLICATION OF ONTOLOGICAL REPRESENTATION

The approach described in the above has been tested in three quite different situations: a prototype implementation and two case studies.
The prototype implementation is based on a realisation of Information Management as discussed in the first sections of this publication. Both the static and the dynamic ontology are part of the background against which the actualisation of the information structures is performed (see also figure 5). All tasks related to the construction, evaluation and evolution of information are performed by the Information Management kernel. All applications based on this kernel can access this functionality by means of a straightforward API (application programming interface). This API not only addresses the basic functionality, it allows for the handling of process chains as well.

Based on the notation introduced in section 5, the kernel can calculate all possible subsequent process steps based on the current information content. In other words, if the dynamic ontology defines production plan (process plan), and for a certain component the process plan is available, Information Management will recommend generating a production plan next. The other way around, if the user tries to start a certain process A, Information Management indicates all possible process chains in order to achieve the required information to start process A. After selection of such a process chain, this chain can be processed more or less automatic.

An excellent opportunity to acquire experience with Information Management and ontologies is to implement the principles in manufacturing environments. In two case studies, performed in two large Dutch companies, the application of selected parts of Information Management is studied.
The first case study aims at the definition of a Product Information Structure (PRIS, see figure 1) in the company. To this end, the information requirements of the manufacturing processes have been surveyed in order to obtain the basics for a static ontology. Immediately, the structured handling of documents, information, processes and their mutual relations offered an improved overview of the information content of the manufacturing processes.

The second case study focusses on the analysis and improvement of both interdepartmental cooperation and information exchange. Both a static and a dynamic ontology enable the autonomous formulation and maintenance of checklists, aiming at e.g. the support of design reviews. Several advances have already been realised, especially regarding collaborative design and the integration of e.g. process planning and documentation in the early design stages.

7. CONCLUDING REMARKS

In manufacturing systems, the role of both information and its management should not be underestimated. Especially the availability and requirement of information and the coordination of processes strongly cohere. An Information Management platform enables a high level of process integration and a better view of the design and manufacturing processes.
The structured, formal representation of the information content, by means of an ontology, offers good opportunities for the government of design and manufacturing processes. Especially the distinctions in types of ontologies (semantic/symbolic and static/dynamic) contribute to this.
Further research will address application of the ontology in more, and more detailed, practical situations; both in industry and as the basis for application development.

8. REFERENCES

[Kals & Lutters, 1998] Kals, H.J.J.; Lutters, D.; "The role of Information management in intelligent manufacturing" (inv. keynote); In: *Proc. of the CIRP Int. Conf. on Intelligent Computation in Manufacturing Engineering: ICME'98*; Capri.

[Lutters et al., 1997] Lutters, D.; Streppel, A.H.; Kals, H.J.J.; "Product information structure as the basis for the control of design and engineering processes"; In: *Proc. of the 29th CIRP Int. Conf. on Manufacturing Systems*; pp. 167-166; Osaka.

[Lutters et al., 1998] Lutters, D.; Brinke, E. ten; Streppel, A.H.; Kals, H.J.J.; "Computer Aided Process Planning for Sheet Metal based on Information Management"; In: *Proc. of the 6th Int. Conf. on Sheet Metal: SheMet'98*, Vol 2., pp. 159-170; Enschede.

[Schlenoff et al., 1998] Schlenoff, C.; Ivester, R.; Knutilla, A.; "A Robust Ontology for Manufacturing Systems Integration"; In: *Proc. of the 2nd Int. Conf. on Engineering Design and Automation*; August 9-12; Maui.

[Slattery, 1997] Slattery, N.J.; "A Study of Ontology and Its Uses in Information Technology Systems"; In: *Proc. of the 1997 Mitre Software Engineering & Economics Conference*; April 2-3; McLean.

[Sohlenius, 1992] Sohlenius, G.; 1992; "Concurrent Engineering"; In: *Annals of the CIRP*; Vol. 41, No. 2; pp.645-655

[Tichem & Storm, 1996] Tichem, M.; Storm, T.; "Issues in product structuring"; In: *Proc. of the 2nd WDK workshop on Product Structuring*, pp. 1-14; Delft