A New Method for Enhanced Information Content in Product Model

László Horváth

***Abstract*—** This paper introduces a new method in order to establish a better communication between engineers and modeling procedures during lifecycle management of product information in computer based engineering systems. The proposed method is intended as one of the initial attempts for resolution of an inherent conflict in product modeling. This conflict is between information content based thinking of engineer and information based processing in classical product modeling systems. The author applies a new sector of product model that describes information content for engineering activities. This sector controls engineering object data in the second sector for classical product model entities. In this manner, the new modeling can be interconnected with existing modeling in industrially applied engineering systems. Information content is stored in interconnected levels of the product model for human intent, meaning of concepts, engineering objectives, contexts, and decisions. This paper explains basic concepts, refers to research in the related topics, introduces role of humans and human-computer interactions in the proposed modeling, and details information content based product modeling. Following this, it emphasizes difficulties of decisions in case of high number of dependencies amongst engineering objects in large product models and proposes a new method for change management in those models. Implementation of the proposed product modeling methods can be realized in industrial professional modeling systems by using of their functionality for open architecture.

***Keywords*—** Product modeling, Lifecycle management of product information, Information content based product model, Design intent, Product changes, Affect zone of modified engineering object.

I. Introduction

Recent challenges in product related engineering such as shortened innovation cycle and demand for high number of variants of durable and highly engineered products stimulates the development in simulation and decision assistance of products. Engineering activities are being concentrated in extensive model based software systems at most of the competitive industries. These systems have been developed from conventional CAD/CAE/CAM systems by their extension to the entire lifecycle of products. Numerous significant engineering software providers offer complete product lifecycle management (PLM) systems.

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Despite advanced features of PLM systems, several drawbacks of modeling in CAD/CAE/CAM systems have been transferred to PLM systems. The presently prevailing modeling is based on processing of input data into increasing number of interrelated engineering object descriptions. There is a serious conflict between the information content based thinking of engineers and the information based processing in classical product modeling procedures Relating of different engineering objects is done by the definition of increasing number of unstructured dependencies. When one of the attributes of a modeled product object is changed during an engineering activity, it is practically impossible to reveal all possible allowed and not allowed consequences of this change. This is a serious problem in the industrial practice of PLM systems. The above drawbacks make establishment of effective assistance of engineering decisions impossible. Considering the above outlined situation, the author recognized that major improvements are needed in modeling for PLM systems, in the following two areas..

- Information content based communication between human and information based modeling procedure.
- Structured processing of huge number of relationships in large product model in order to assist coordinated decision making on engineering objects.

The purpose of this paper is to introduce concepts and methods by the author towards the above improvements in PLM systems.

According to the engineering object definition by the author, it can be any object in product, production, and other product related areas that is included in a product model structure and that product model includes its description or citation. This generalized definition assures unlimited modeling in PLM systems.

In the concept and method by the author, a new sector of product model describes information content for engineering activities. Engineer should not enter engineering object data as input any more. Instead, the new information content based sector calculates engineering object data in a second sector of product model for classical product model entities. In the proposal by the author, interconnected information content and data oriented sectors serve harmonic cooperation between human and computer. In the information content based sector of the product model, interconnected levels are defined for human intent, meaning of concepts, engineering objectives, contexts, and decisions. Implementation of the proposed product model can be realized in industrial professional modeling systems by using of their functionality for open architecture.

This paper explains basic concepts, refers to research in the related topics, introduces role of humans and human-computer interactions in the proposed modeling, and details information content based product modeling. Following this, it emphasizes difficulties of decisions in case of high number of dependencies amongst engineering objects, in large product models and proposes a new method for change management in those models.

II. Background and Basic Concept

Computer-integrated engineering (CIE) is a new style of engineering where engineering activities are supported by computer system for lifecycle of products. Engineers, who join to this system at a remote computer, feel system resources as they are available in their own workstation. Concept of CIE is implemented in product lifecycle management (PLM) systems that can include software for any possible product related engineering activity. Database in a PLM system can represent any information that may be necessary for these activities.

While development of integrated description of product structures and other related objects is a success story, integration of results of knowledge based and intelligent computing in product modeling is still one of the main problem areas in CIE. The author of this paper recognized data level communication between human and modeling procedures as the primary cause of this situation in present product modeling. Data level does not allow communication on the level of decision process. Communication is done on the level of results of decisions. This communication is not suitable for the transfer of intelligent information and does not able to support integration of human thinking in modeling and model. Moreover, existing knowledge based and intelligent computing procedures are hard to integrate in product modeling because they are too closed and they can not accept demands from product modeling.

In order to draw a definite line at the start of the proposed modeling, the author of this paper introduced the term classical product model (CPM) for the present information based product model. CPM describes data interactions between engineers and computer procedures, history of product model development, attributes of elements and structures of products, and production and other related processes. CPM is theoretically well grounded, fully organized, unambiguous, and consistent. It represents engineering objects with a set of attributes, and defines logical and quantitative relationships between them.

The author of this paper proposed his information content based product model in order to fill the gap between engineer and information based modeling procedure. Representing content oriented virtual engineering, it is placed in the structure of PLM system. The extended PLM functionality is shown in Fig. 1 together with company functions closely related to PLM. CIE is supported by product data management (PLM) for the coordination of different modeling systems and engineering processes. All communications are coordinated by collaborative functionality of the PLM system.

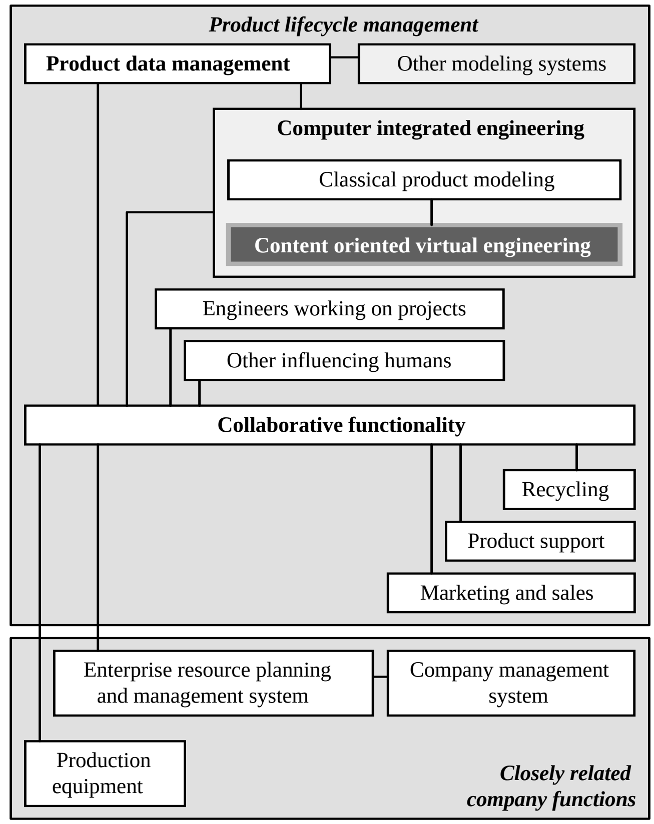

Fig. 1 The proposed modeling in PLM system

Information content of a product model acts as an interactive media to transfer content information from humans to data based computer, facilitating effective communication between engineers and information based modeling procedures. Information content ensures clear picture about actual situation at decision-making on engineering objects for engineers and it is suitable for explanation and evaluation.

Humans use content of their mind during interactions with modeling procedures (Fig.2). In case of development of a CPM, information content is created in human mind in order to human control over creation of modeled engineering objects by joint answering the questions why and how. Information content can be included in product model by appropriate transfer of human mind into product model. According to concept by the author, information content based product definition is aimed to include reasonable and suitable amount of content of human mind in product model. When this concept is realized in product modeling, content based product definition can answer questions why and how for any engineering object, its attributes, parameters, and relationships.

The author proposed a new multilevel structure of data oriented product model as it is shown in Fig. 3. Identification of an engineering object points to its application mainly for the purpose of specification of essential design information. Detailed description of an engineering object by its attributes is preceded by definition of its associative connections (AC) to other engineering objects. An AC carries information about its function such as engineering calculation, placing, or DOFs. Engineering objects are described in the usual way. Representations, for example topology and geometry of a shape are mapped to attributes.

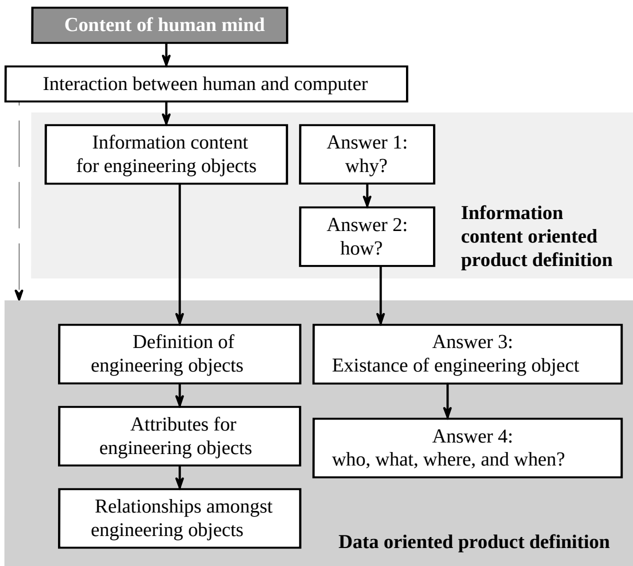

Fig 2. Data and information content

The proposed multilevel structure for the information content oriented sector of product model is shown in Fig. 4. Engineering activities are initiated by the definition of human intent and are aimed at making decisions on product model objects (Fig. 4). Making, revising, and reproduction of interrelated decisions on engineering objects need information about meanings of concepts and contexts of the decided items, as well as about engineering objectives.

Extension by information content based product model required the definition of the following new entities in product model.

- Product objects behavior and situation for its definition [11].
- Multiple human intent filtered knowledge for embedding, integration, or linkage [8], [9].
- Change affect zone (CAZ).
- Change chain (CHC).
- Structure of associative connections in a purposeful form of graph.
- Adaptive action to carry modification information [10].

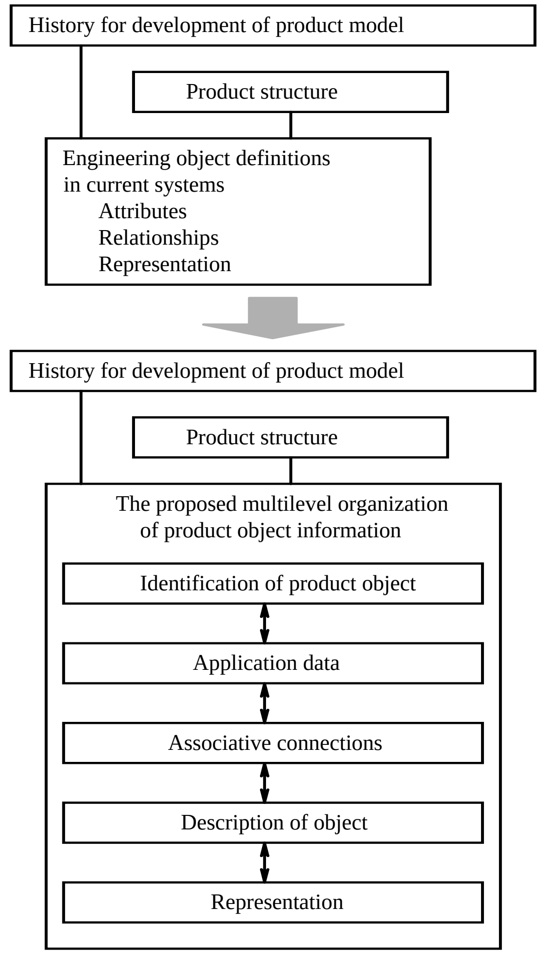

Fig. 3. Multilevel structure of data oriented product model sector

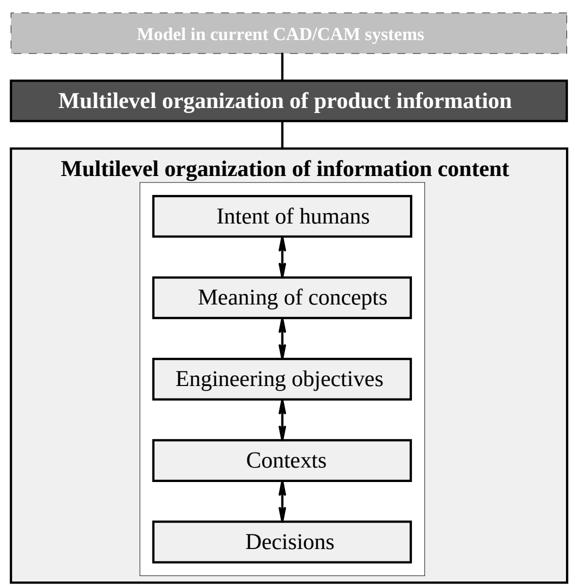

Fig. 4. Multilevel organization of information content based sector

III. Related Research

In order to placing the reported research in the related research activities, several relevant results are cited below from researches in human activities and product model creation (Fig 5). Issues in the cited works include information modeling, extraction of views from product information, form feature recognition, knowledge capitalization, definition of associative features, and multi-disciplinary character of work of engineers.

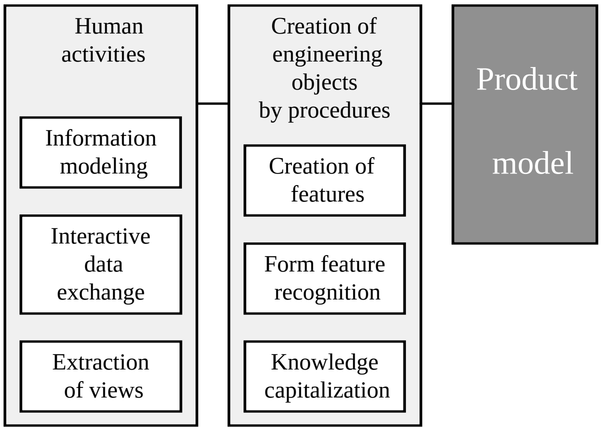

Fig. 5. Essential issues in present industrial modeling

In the area of information modeling, IDEF1-based process-oriented information modeling methodology is proposed in [1]. The IDEF0 process model is integrated with the enhanced IDEF1 information model. The result is easy identification and analysis of information requirements through the corresponding process models. Recently, methods are applied for the extraction of subsets of application-specific product data, from large and very complex product models, in the form of views. An integrated design framework is shown in [2] where the product model used by the process planner is extracted from the global product model by filtering.

Well-engineered and styled shapes of mechanical parts are constructed in the course of a sequence of shape modifications by form features. When a shape is generated by a different modeling system or its modification information is unavailable, sequence of shape modification can be reconstructed only by feature recognition. In [3], graph and hint based methods, convex hull decomposition, and volume decomposition-recomposition techniques are introduced for this purpose.

Numerous recent works show the actuality of research in knowledge based product models. The authors of [4] propose tools and models for knowledge capitalization. An approach to definition and mapping of knowledge, based on the point of view of an expert in manufacturing is discussed.

Research in associative connections in product models generally focuses onto partial problems and cannot provide general solution. Paper [5] presents associative assembly design feature as a new type of features. This new feature allows associations between parts that have not been defined geometrically, between geometric entities defining interfaces between parts, and between part geometry and intermediate geometry used to define a part. Extension to traditional assembly feature properties allows complete product architectures to be defined using features. Despite process orientation in product data management (PDM) systems, support of flow of product information is weak in current engineering systems. In paper [6], interfacing knowledge-oriented tools and CAD applications is identified as a technical gap for intelligent product development. The authors of [6] consider definition of associative features in the form of self-contained and well-defined design objects as essential for high-level reasoning and the execution of decisions.

Characteristics of products require multidisciplinary work at their modeling. Multidisciplinary activities are done with participation by high number of areas of expertise. Paper [7] emphasizes very multi-disciplinary character of work in an early stage of aircraft design. Large variety of specialized tools must be compatible. Otherwise, interface problems are the consequence.

The author of this paper participated in several projects in product modeling. The ones that he consider as preliminaries of the work that introduces in this paper are in the following (Fig. 6). In order to establish an enhanced human-computer interaction (HCI), human intent were analyzed then modeled [8]. Corporate knowledge was defined, filtered, and accepted according to human intent in [9]. Method for associative engineering object definition and product behavior analysis driven management of product changes were published in [10]. As complex model object, comprising closely connected product and other related objects, concept of integrated model object (IMO) was introduced in [11]. Relevant problem solving techniques available at model-based engineering were surveyed in [12].

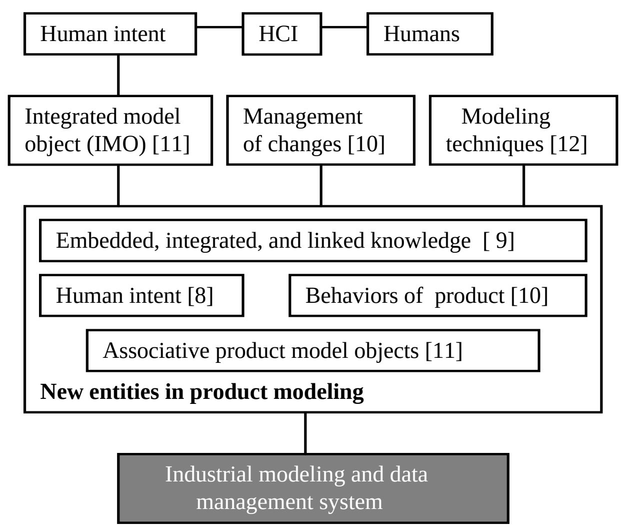

Fig. 6. Results of pervious research

IV. Human-Computer Interactions

In order to include information content in product model, a restricted modeling of the human thinking process just for the purpose of information content based modeling was developed by the author of this paper. Relationship between this model of human thinking process and the product modeling environment is summarized in Fig. 7. In the scope of an actual thinking process, human develops a solution in the course of interdependent decisions on relevant engineering objects. Solution in this context is a result of engineering work that is not practical to divide because of inside close connections. Result of the human thinking process is communicated with model creation procedures for the relevant engineering objects in CPM. These procedures generate new or modified sets of data for the engineering objects.

Human thinking process for a solution is divided into its elements and partial decision points are defined. Human utilizes problem solving methods and procedures, and defines and accepts knowledge at each element of the thinking process. Interdependencies with other humans are realized through received and defined constraints. In the proposed modeling, constraint is defined as human intent. Human also receives decisions from higher level of hierarchy, in the form of constraints. Constraint may have accepted, rejected, argued, or applied status. In case of status applied, the constraint is previously decided and the responsibility is held by the decision-maker. Decisions from higher level of hierarchy may be argued according to the valid measures in an engineering environment.

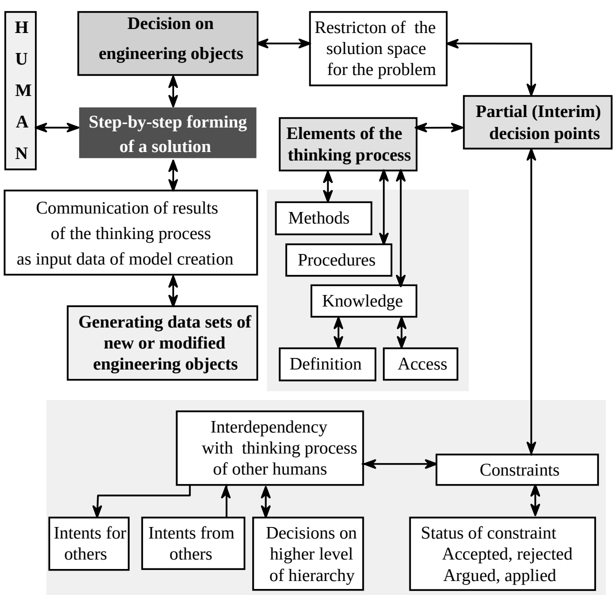

Fig. 7 Human thinking process in engineering

Actually, intent record describes human effort for a value-adding activity and it can be considered as an intelligent history of model construction that is completed by a simplified description of human thinking process. Definition of human intent for information content based product model includes information about authorization, characteristics of the intent, simplified thinking process, and the content itself (Fig. 8). Human communicates with intent definition through authorization and access information. Characteristics of intent are purpose, type, and status of the intent and status of the human. Fig 8 shows representative sets as examples for a possible choice of application oriented characteristics. Intent definition carries decisive information content from authorized human. Authorization is coordinated for engineering projects and intent definitions. Motivation of the communicated intent informs us about why the thinking process is initiated. Type of intent refers to its purpose. Besides definition of attributes for engineering objects, intent may serve a strategy, a counter-proposal, an application of an engineering object, etc. Status of intent informs about its strength. It varies from the strong standard to the weak maybe. Status of human informs about the strength of the human who defined the intent at a relevant decision. Roles of humans in projects within a group work organization are listed in the choice of status of human.

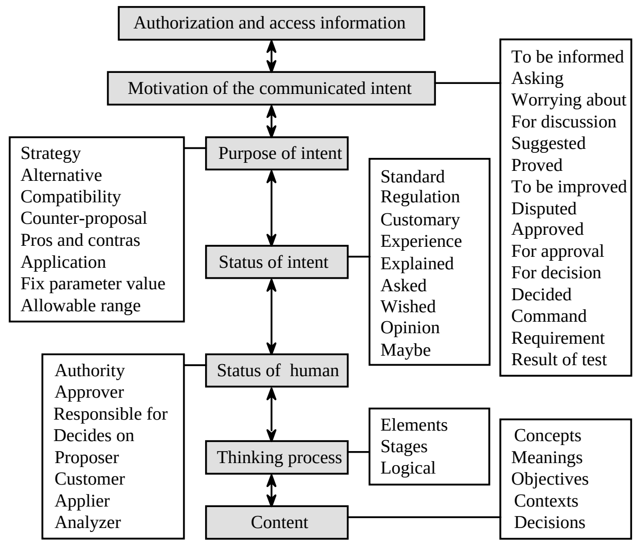

Fig. 8 Composition of intent definition with examples

V. Information Content Based Model

In this sector of the paper, first communication between humans “A” and “B” is compared in the course of product definition process, for the case of classical information based and information content based modeling methods. Following this, content of the levels in data and information content based sectors of the product model is explained.

Process of product definition for classical product model is outlined in Fig 9. Human is in interaction with procedures that generate data structures for the classical product model (CPM). Human communicates result of thinking process for the definition of engineering objects with model creation procedures. Procedures generate and relate data sets for model entities representing engineering objects. Attributes of engineering objects are defined. Engineer controls model creation process by data communication to decide on attributes of new engineering objects and on revision of earlier defined model objects. Because information content is not available in the product model, outside - of - model collaborative communication between engineers fills the gap. Although this communication may be enhanced by advanced annotation, it is only an auxiliary communication instead of communication of information content.

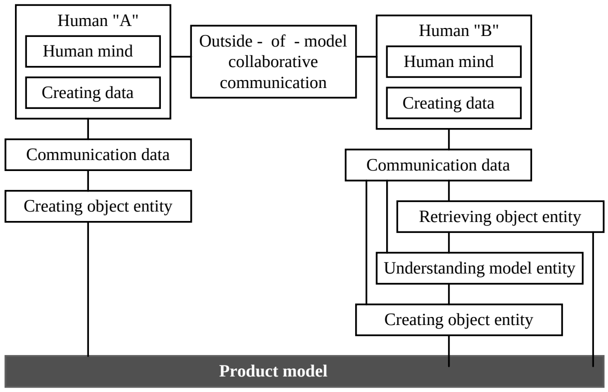

Fig. 9 Schema of the classical information based product modeling

In case of information content based modeling (Fig. 10) human "A" defines an intent. At the same time, this human may be allowed to define information content for the other four levels of the information content based sector of product model as direct intervention. Anyway, the normal route leads through the five levels of content definition. Control of data of engineering objects is encountered as execution of result of decisions.

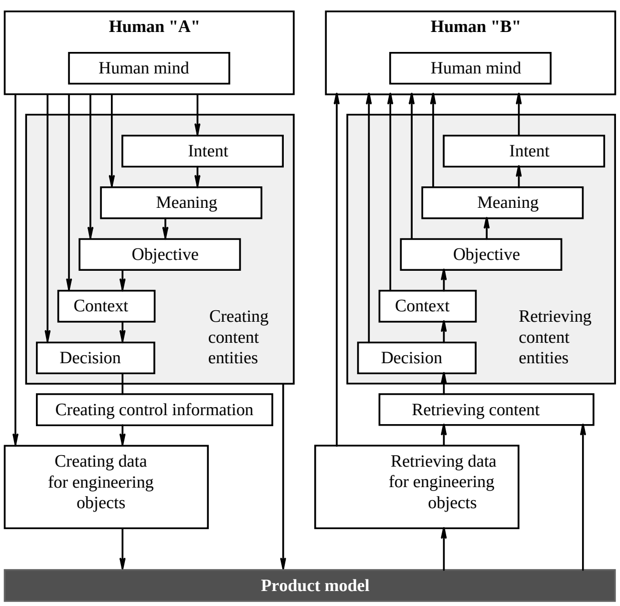

Fig. 10 Content based communication of humans

When direct intervention is necessary in the information based product model, human can control the input of data generation directly. The problem is that in case of omitting certain even all levels in the information content based sector of product model, the chain of content information is interrupted. Human "B" retrieves and applies information content together with model data.

Function of levels in the data based sector of the product model is as follows.

- *Level of identifications.* It includes access information that blocks unauthorized control to engineering objects.
- *Level of application data.* It connects engineering objects to their application in product, production, product support, marketing, and at company level.
- *Level of associative connections*. Engineering objects, their attributes, and representations are related.
- *Level of descriptions.* This level includes definition of engineering objects by their attributes.
- *Level of representations*. Representations are applied for shape and other engineering objects.

Levels of the information content based sector of product can be characterized briefly as follows.

- *Level of intent of humans.* Includes intent definitions by responsible and other influencing humans.
- *Level of meaning of concepts*. Meaning carries information about background of a concept.
- *Level of engineering objectives*. Objectives are described for the behaviors of engineering objects at certain situations.
- *Level of contexts*. Contextual connections are defined amongst engineering objects. At their application, target engineering objects are defined in context of other engineering objects.
- *Level of decisions.* Control of data of engineering objects uses information content from this level.

VI. Analysis of Effects of Changes

Interactive tracking of associative connection chains in product models is time consuming and it is a main source of errors and mistakes. In case of large product models with high complexity, this activity requires robust computer assistance otherwise it is impossible to do. Product models in current PLM systems have no information for the structure of associative connections that would be appropriate for effective assistance of tracking. In order to avoid this situation, responsible engineers often instruct other engineers to handle associative objects only within certain units of products

As an introduction to the concept for tracking by the author, Fig. 11 outlines role and place of associative connections in a product model. Essential groups of elements for construction of a product model and their basic associative connections are shown. Elementary product entities are applied as construction elements of parts and are connected by their parameters. Components of products are associative with elementary entities, other components, entities for their analysis, and manufacturing processes. This concept is suitable for both current product modeling and the modeling extension by the author.

The author proposed methods for organized description of dependencies of engineering objects (Fig. 12). They are description of dependency structure, definition of affect zone for engineering object parameters, and modeling of information content of associative connections. Dependency structure is represented as a graph where nodes are for engineering objects represented by the actual parameter or parameter set, and arcs are for associative definitions. Change affect zone (CAZ) of an engineering object parameter is defined as a restricted search space in the graph for consequences of change of that engineering object parameter. Information content may include any things about origin and intent of an associative definition that is needed by any engineering activity during the lifecycle of a product. Information content depends on task, humans, and environment. Unstructured relationships are placed in a graph as they are defined at product development (Fig. 12/a). The proposed methods facilitate recognizing and mapping of change affect zone (CAZ) of a modeled object and change chains (CHC) in the graph (Fig. 12/b). Consequences of changes are propagated along CHCs.

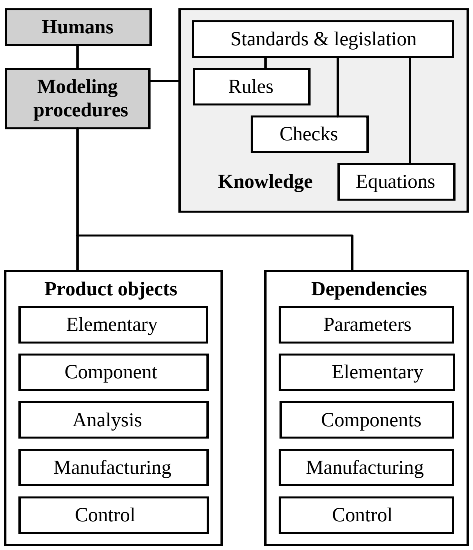

Fig. 11. Essential dependencies in product model

A node in the structure of associative connections is an intersection of different change chains (CHC) at an associative connection (Fig. 13). In other words, an associative connection may receive different change attempts in different change chains. A parameter of an engineering object may be modified by several associative connections and it can receive different change attempts. Status of a change attempt in a change chain may be "under revision", "under discussion", "argued", "decided"

In Fig. 13, dependency *DEAB* is active between EO_A and EO_B. *DEAB* is defined between parameters P_A and P_B of the EO_A and EO_B, respectively. Route of two *CHC*s, CHC_x and CHC_y pass through the dependency *DEAB*. *CHC*s are emerged by an attempt to modify the target engineering object EO_x.

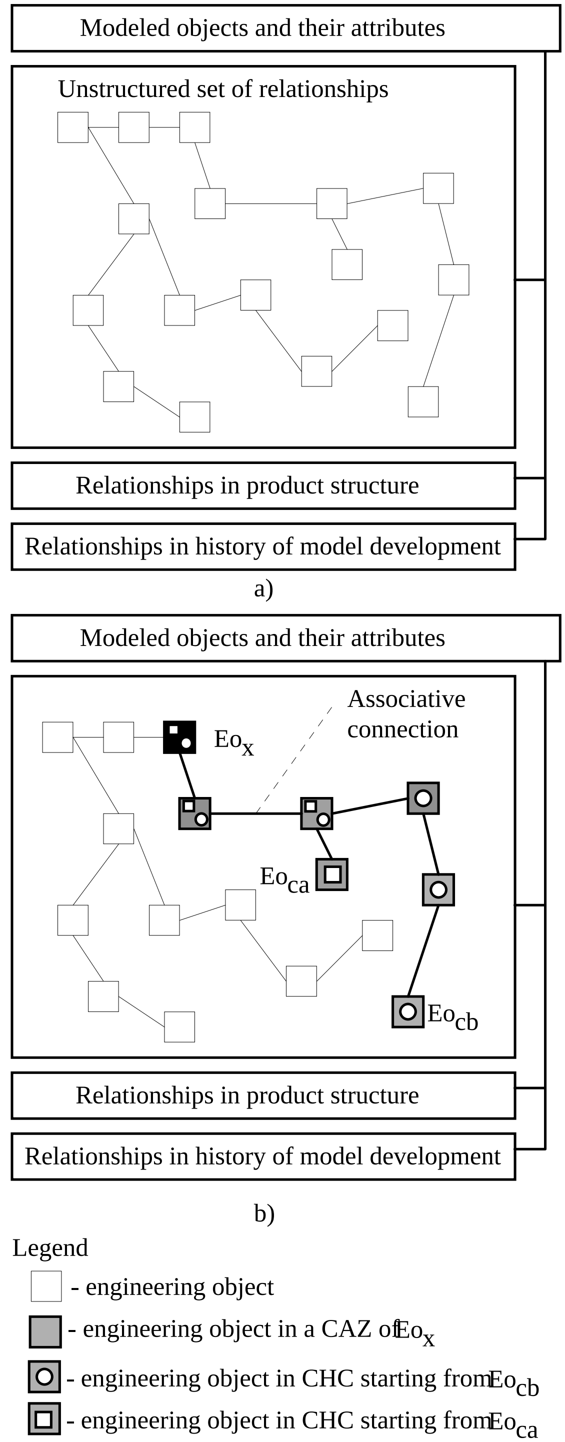

Fig. 12. Extended approach to product modeling

VII. Implementation and Future Plans

Objective of the reported research was development of information content based product modeling methods that have a great chance for implementation in industrial PLM systems. PLM systems include extensive modeling software tool sets (Fig. 14). Related functional units of PLM systems are for management of product data from different modeling systems, for interoperability to enable data exchange with non-integrated modeling systems, as well as for group work and Internet portal communication. Modeling procedures, model data structures, and the graphic user interface can be accessed from programs in the information content extension, developed by using of tools that are available in PLM systems. Access is available through standard application programming interface (API).

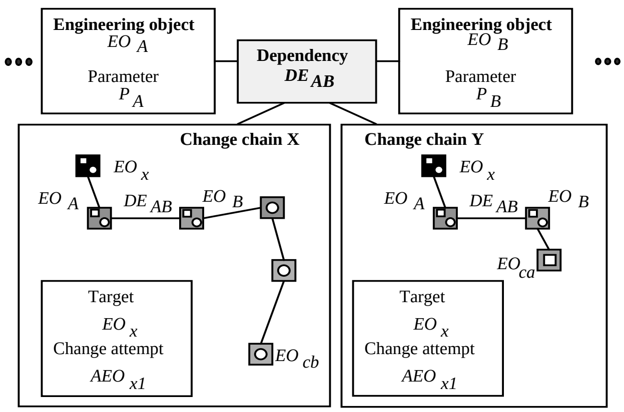

Fig. 13. Arc in the dependency graph

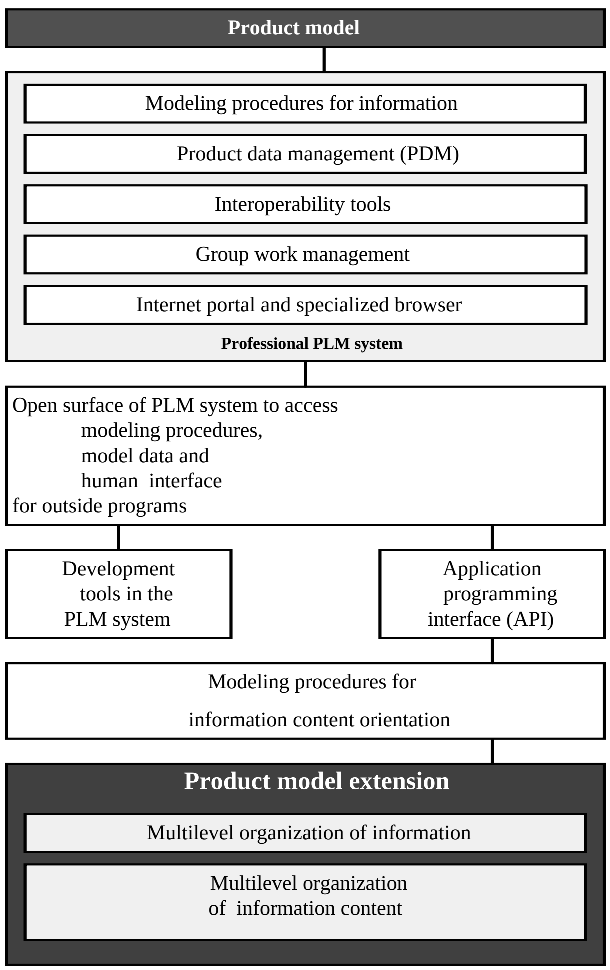

Fig. 14. Implementation in PLM systems

Laboratory of Intelligent Engineering Systems (LIES) of the Institute of Intelligent Engineering Systems, John von Neumann Faculty of Informatics, Budapest Tech. has been equipped with leading industrial PLM, intelligent computing, and mathematics software, among others for the purpose of experiments with information content oriented modeling.

Future research in information content modeling will concentrate on better understanding and definition of information content based model entities and their interconnections with data based model entities. Emphasis will be on the critical issue of coexistence and relationships of content and data oriented model entities.

VIII. Conclusion

This paper reported a work to seek solution for some critical problems in current industrial product modeling at information content based communication between humans and data based modeling procedures and structured processing of huge number of relationships in large product models. The question was that what concepts and methods could lead to the solution. The answer was given by analysis of human-computer interactions, information content based product model, and effects of changes of engineering objects. The conclusions of these analyses resulted development of models and modeling methods in human intent controlled definition of engineering object data, in new multilevel information content based sector of product model, and in traceable structural description of large amount of dependencies in product model, respectively.

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