# Óbuda University

Thesis Booklet

Information content models of objects for communication between engineers

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# I. Background of the Research

At the modern ages of the industrial revolution, the traditional design will be upgraded to the smart design to enter a “smart era". Computer-based simulation is becoming an invaluable asset in the design of complex products. Classical Product Model (CPM) [1] relies upon the highly integrated physical level model of the product. This integration does not support multidisciplinary product engineering because capability cannot provide the demanded unified modeling mechanism for different engineering areas [2]. In product design, multidisciplinary engineering becomes the need of every product. Engineering design is increasingly becoming a collaborative set of tasks among multidisciplinary, distributed design teams [3]. Requirement Functional Logical Physical (RFLP) structure is a complex modeling methodology from the systems engineering and supports the Model Based Systems Engineering (MBSE) process [4]. Currently, a multidisciplinary product assembly is done in the specification tree of the RFLP structure. Behaviors are included in Functional level and Logical level elements of RFLP structure in the context of content on the level of engineering objectives [5]. There is three essential product behavior represented in the RFLP structure namely dynamic logical behavior, global dynamic behavior and discrete behavior as explained in the paper [6]. Discrete behavior is evaluated and represented in Functional and Logical level elements of the RFLP structure. Dynamic behavior analysis [7] is the area of investigation in the Product Lifecycle Management (PLM) structure [8] system. Here, the Behavioral modeling approach is used for the analysis of the dynamic behavior of a product.

To derive an intelligent product in the PLM system, the Product model handing procedures are controlled indirectly by the Information Content (IC) structure sector [9] [10]. This sector is placed between human and information based product models to enhance the HCI at product development [11] [12] and derive an intelligent product as per the Industry 4.0 [13]. It is applied at the contextual definition of objectives and decisions rather than application as a direct engineering object relationship. For Multidisciplinary product modeling, IC controls the RFLP level by the Multilevel Abstraction based Self-Adaptive Definition (MAAD) structure [14] [15] [16]. While the ability to share product knowledge has increased, it is still inadequate for developing complex products by distributed design teams [17]. There are numerous problems with the current multidisciplinary product model such as structure is formal so that the causes and characteristics of connections are hard to reveal at the development or revision of an existing structure [1], critical for the effective assistance of decision making in the Behavioral modeling of a Multidisciplinary product and management of high number of changes of modeled Engineering Objects (EOs) and representation of background of modeled information in the multidisciplinary product model [10]. As there are multiple disciplines of EOs present in the model, there is an unstructured relationship that exists between them [18]. Hence, a fully integrated product model is required as a virtual prototype for the lifecycle of the multidisciplinary product [19] [14].

Hence, there is a need for a novel approach required for the Behavioral modeling, Behaviors representation, Structured processing of interrelated Engineering Objects (EOs) and a Simplified representation of the complex multidisciplinary product to take coordinated decisions during the modeling [20]. Therefore, this work focuses on the above mentioned research problems and proposes innovative concepts in the Information Content (IC) to drive the RFLP structure product model considering the Product Lifecycle Management (PLM) systems. The author makes the research to resolve the challenging issues in the multidisciplinary product modeling like behavior representation, behavior evaluation, correlated decision between the multiple disciplines and simplified Human Computer Interaction (HCI) for behavioral modeling.

# II. Directions and Goals of the Research

The research work started with the structured organization of the engineering objects in the multidisciplinary product model by introducing the concepts of Community zone and Community diagram [Y1] in the Representation layer of Information Content (IC). The Community zones categorized the multidisciplinary product model based on the discipline involved during the product modeling and Community diagram is the visualization of the Community zone depends on the zone type and discipline. Then, the Process plane [Y2] is proposed in the Engineering objective layer, Contexts layer and Decisions layer of Information Content (IC) to classify the process involved during the multidisciplinary product modeling.

Then, the concepts of Info-Chunk entities [Y3] are proposed in the Functional level and Logical level of the RFLP structure for behavioral modeling of a multidisciplinary product model. Here, Functional Layer Info-Chunk (LiCF) is the high-level entity and retrieves the information from the Functional layer. The Sub-Function Info-Chunk (SFiC) is the low-level entity retrieve the information from the LiCF. Similarly, Logical Layer Info-Chunk (LiCL) is the high-level entity and retrieves the information from the Logical layer of the RFLP structure. Component Info-Chunk (CiC) retrieves the information from the Logical component and placed in the LiCL. The entities of the RFLP structure are mapped with the IC to handle the product behaviors of the multidisciplinary product model. This is done by classifying the IC based on the Engineering discipline and System behavior. In other words, Conceptual models categorized the IC into Discipline content and Behavior content. Behavioral modeling of a multidisciplinary product is done by the contents, which controls the Info-Chunk entities. Hence, it can be an integrated model and can be realized in industrial professional modeling systems by using their functionality for open architecture. For Behaviors representation of a Multidisciplinary product, Info-Chunk entities are converted into the Info-Chunk objects, which are based on the Object-Oriented Principle (OOP) [Y4] concepts. Here, Behavior Info-Chunk (BiC) objects and Context Info-Chunk (CxiC) objects are proposed in the Behaviors level and Contexts level of the Multilevel Abstraction based Self-Adaptive Definition (MAAD) structure to model the behaviors of the multidisciplinary product. The Info-Chunk objects are used to store the behaviors related data of the multidisciplinary product and exchange the information with SFiC, LiCF, CiC, LiCL objects of the RFLP structure.

For the practical approach of the Behavioral representations, An Application Programming Interface (API) called "InfoChunkLib" is proposed in the IC by using Info-Chunk objects for the web application and a content web server to store and represent the modeled behaviors information of the IC web Application. The API is coded by using the Java programming language with the JavaFX software platform. The IC web application is coded by using the programming language Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), Java Server Pages (JSP). The Content web server is Apache based. The backend is coded by using the Java Servlets and the database used is PostgreSQL. Therefore, the proposed model is flexible enough to integrate with the existing modeling in industrially applied engineering systems. Then, an active knowledge model of a multidisciplinary product is proposed for behavioral modeling. Here, various scenarios are proposed to handle the multidisciplinary product application of the PLM system through the IC application [Y5]. Therefore, this model can establish better communication between engineers and modeling procedures during the lifecycle management of product information in computer-based engineering systems.

Then, the author enhances the scope of the research by proposing the Info-Chunk entities driven RFLP structure for multidisciplinary Cyber Physical System (CPS) and Requirement Functional Logical (RFL) blocks by using fuzzy logic concepts. Here, the discrete behavior of a multidisciplinary product in the real environment is monitored by using Fuzzy logic [Y6]. In this case, the behavior of a product system is monitored by the conceptual model of the IC. Here, Info-Chunk concepts are proposed in the Active Information Content (AIC) and extended Engineering Model System (EMS) [Y7] for the behavioral modeling of the multidisciplinary CPS. Using the Fuzzy logic, Mamdani Fuzzy Inference System (FIS) is used to monitor the behaviors of a multidisciplinary product whereas Adaptive Neuro FIS is used to monitor and improves the behaviors of a multidisciplinary product in the real environment.

# III. Methods of the Research

The Community zone, Process plane, Info-Chunk entities, and Info-Chunk objects are proposed for a better understanding of complex multidisciplinary product models to take correlated decisions. Then, the *InfoChunkLib* API is proposed based on the Info-Chunk objects. It is coded by using the Java programming language and the JavaFX software platform is used as Graphical User Interface (GUI) for the behavior representation of the multidisciplinary product. Then, the *InfoChunkLib* API is imported in the Information Content (IC) Application for the behavior representation of the multidisciplinary product. Further, the Content server is proposed to store and represent the information of the IC Application. The server is based on the Apache Web server. The IC application is a web application. The front end is coded by using programming languages like Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), Java Server Pages (JSP) and Java Server Pages Standard Tag Library (JSTL). The backend is coded by using the Java Servlets and the PostgreSQL database is used to store the modeled behaviors and zone information of a multidisciplinary product model. Then, the concept of Fuzzy logic is proposed in multidisciplinary product modeling. Here, the MATLAB toolbox, Fuzzy Logic toolbox (Mamdani FIS and Sugeno FIS) is used to validate the concepts.

# IV. New Scientific Results

In this section, *obtained results* are divided into the sub-sections and their detailed descriptions are as follow:

## V.1. Community Diagram and Process Plane in the Information Content

***Thesis 1.1:*** *I have introduced the concepts of Community zone and Community diagram [Y1] in the Information Content (IC) for the structured organization of the multidisciplinary product model. The structure of a multidisciplinary product model is formal so that the causes and characteristics of connections are hard to reveal at the development or revision of an existing structure [1] and management of the high number of changes of modeled engineering objects and representation of background of modeled information in product models [9]. Therefore, a Community zone is defined as the area in a multidisciplinary product where an engineering discipline can conceptualize their work by performing various tasks on the Engineering Objects (EOs). Hence, a complex ISO 10303 standardized STEP product model is divided into various Community zones depending on the engineering discipline. Inside the zones, EO is categorized as Single zone EO and Multiple zone EO. Finally, a Community zone is demonstrated by the Community diagram in the IC. It is the visualization of a community zone in terms of Single zone EO and Multiple zone EO. Therefore, an engineer can evaluate the multidisciplinary product model relevant to its discipline.*

**Thesis 1.2:** *I have introduced the Process plane [Y2] in the Information Content (IC) to organize the process activities for effective decision making during the multidisciplinary product modeling. As mentioned in the paper [10], there are critical issues occur for the effective assistance of decision making in product modeling. Therefore, the Process plane categorizes the Analysis process, Contextual process and Optimization process in the IC. The Analysis process is the set of activities applied for analyzing a multidisciplinary product model. Based on the analysis, the Contextual process stores the information about the process involved in the context of EOs in a multidisciplinary product model. The optimization process is the set of activities to optimize the set of analyzed data. It can be local optima or global optima. Here, Decision is related with the best possible output from the optimized data according to the specification of modeled product. This plane* *provides an effective decision methodology for representing the behaviors of the multidisciplinary product.*

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***Selected publications linked to the Thesis 1***

Relevant own publications about this thesis group: [Y1], [Y2].

# V.2. Info-Chunk driven Information Content for the Multidisciplinary Product Modeling

**Thesis 2.1*:*** *I have introduced entities called Info-Chunk [Y3] in the Functional and Logical layer of the Requirement Functional Logical Physical (RFLP) structure for the behavioral modeling of the multidisciplinary product. In the paper [38], Behavior based models with intelligent content were emphasized, where feature models for specification and knowledge representations were conceptualized. It is based on the classical product modeling and has limited knowledge to simulate the behavior of the modeled objects. Whereas, this research work proposes the behavior models for the multidisciplinary product with Behavior content and Discipline content based on the Info-Chunk Entities. They can simulate the behavior of the modeled objects based on the information stored on the Functional and Logical layer of the RFLP structure. The conceptual models are used to guide the engineer for the simplified representation of the multidisciplinary product to take the correlating decisions.*

**Thesis 2.2:** *I have introduced the Info-Chunk objects [Y4] in the Behaviors and Contexts layer of the Multilevel Abstraction based Self Adaptive Definition (MAAD) structure for behavior representation of the multidisciplinary product. In the paper [45], the average behavior of the input-output signals of the switched reluctance generator has been reproduced required for system level analysis of the aircraft power distribution system. Considering it as a base, this research work proposes the representation of the behavior of a multidisciplinary product, which is based on the analysis, contextual connection, and optimization activities. The rules and logic are defined as per the Process plane of the Information Content.*

**Thesis 2.3:** *I have introduced the Info-Chunk entities concepts in the extended Engineering Model System (EMS) and Info-Chunk objects concepts in the Active Information Content (AIC) for the behavior representation of the multidisciplinary Cyber Physical System (CPS) [Y7]. As mentioned in the paper [66], there is a need for a definition of model entities, object parameters, and contextual connections with the demand of implementation in the multidisciplinary system based industrial model by* *using configuration, structuring, object definition and programming capabilities for CPS systems [31]. Therefore, this research work focus on Information Content based EMS and AIC. Here, communication between the Information Content proposed LiC entities and CPS entities is explained first. Based on the experienced situations, values of Info-Chunk can be changed so that the system can be operated accurately according to the situation. Also, communication between AIC, Info-Chunk objects and cyber units is done through dynamic and state logic behavior. As compare to the existing methodologies, the proposed entities and objects are a novel approach for the contextual connections between the EMS, AIC and multidisciplinary CPS. The author made an effort to represent behaviors efficiently in CPS modeling through Info- Chunk entities and objects.*

***Selected publications linked to the Thesis 2***

Relevant own publications about this thesis group: [Y3], [Y4], [Y7].

# V.3. Relationship between Info-Chunk and Virtual World

**Thesis 3.1:** *I have introduced the InfoChunkLib Application Programming Interface (API) [Y4], IC web application [Y9] and Content web server [Y10] for the representation of the behaviors of the multidisciplinary product. It is the practical approach to represent the community zone information and extracted modeled behavior data of a multidisciplinary product. As compared to the research work [45], where average behaviors of a product model have been implemented in a virtual test bench and its response by the real system, this research work focuses on the representation of the behaviors of a multidisciplinary product through the graphs. The proposed concepts can be used for collaborative engineering in terms of handling the multidisciplinary product indirectly by the Information Content. The Apache HTTP Server hosts the IC web application with a PostgreSQL database that is used to store the modeled behavior data from the process plane of the IC. The API is code by using the Java language as a JavaFX application. It is imported to the IC application and generates the graphs related to the behaviors of the multidisciplinary product. The author makes an effort to visualize the outcome of the research work through the web technologies*

**Thesis 3.2:** *I have introduced a practical approach to the Behavior modeling of a multidisciplinary product model using the Information Content (IC) and Intelligent Property (IP) [Y5]. In the paper [38], Feature definition in case of agent based active model is outlined. In this research work, Info-Chunk objects are used for the active models as it stores the detailed information of the modeled behaviors data from the* *functional and logical layer of the Requirement Functional Logical Physical (RFLP) structure based on the disciplines. Further, the active knowledge based model is used in the Information Content (IC) for the behavior modeling of a multidisciplinary product and can be accessed and updated remotely by the cloud. The proposed method can be considered as an extension of collaborative engineering in terms of the product design to take the collaborative actions by the various engineering disciplines. For the flexibility of the IC, there are various scenarios considered for interaction between the IC application and the multidisciplinary product application.*

***Selected publications linked to the Thesis 3***

Relevant own publications about this thesis group: [Y4], [Y5], [Y9], [Y10].

# V.4. Behavior Evaluation of the Multidisciplinary Product using Fuzzy Logic

**Thesis 4:** *I have introduced Requirement, Functional and Logical Blocks in the Requirement Functional Logical Physical (RFLP) structure for discrete behavior evaluation of a multidisciplinary product by using the fuzzy logic [Y6]. Indeed, the application of the fuzzy set theory is applied to the evaluation performance system [70]. In terms of product modeling, the Fuzzy logic strategy was used for solving multidisciplinary design optimization problems [71]. In this research work, the system discrete behaviors evaluation of the multidisciplinary product is done by using fuzzy logic. The discrete system behaviors of the multidisciplinary product are analyzed by the Matlab toolbox, Mamdani FIS, and Adaptive Neuro FIS. Adaptive Neuro FIS can be considered a good approach for critical systems as feedback is obtained from the real time physical modeled product while Mamdani's FIS can be considered as a good approach for a general system where some functions are more important than others and define the system behavior. The proposed blocks based on the fuzzy logic can be used in the development of intelligent systems for decision making during the behavioral modeling. It could be applicable in the initial phase of the product modeling to check the feasibility as accuracy is the drawback. As, fuzzy logic is not the best approach for analyzing all types of behavior in a product system, but it is a promising approach in the area of product modeling.*

***Selected publications linked to the Thesis 4***

Relevant own publications about this thesis group: [Y6].

# V. Possible Application & Implementation Issues

The proposed concepts of Community zones, Community diagram, Process plane, Info-Chunk entities, Info-Chunk objects, Discipline-based content, Behavior-based content and InfoChunkLib API in the Information Content (IC) for the Multidisciplinary product modeling could be implemented in the form of the Web application. It is important to note that the behaviors representation and behavioral modeling of the multidisciplinary product proposed in this research work are on the conceptual level. The author proposed the practical approach based on the white papers of the RFLP structure of Engineering systems, CATIA V6 [72] and 3DEXPERIENCE [4]. These systems are using the Modelica [57] component in the Logical level of the RFLP structure. The Modelica component is coded by using the Modelica programming language. There is a possibility to code IC based web applications with similar principles. Therefore, there could be some implementation issues. There could be various scenarios to the handle the multidisciplinary product model through the IC based web application like Multidisciplinary product application and Engineering software is on the local machine and

IC application is on the web server, Multidisciplinary product application and engineering software is on the one web server and IC application is on the other web server, Multidisciplinary product application and IC application are on the same server, IC application is accessible through an interface from the multidisciplinary product application. Further, the IP level and Process plane of IP are not defined yet. The behavior representation for IP is the topic of future work. In the case of CPS modeling, the definition of objects and code an API of CPS modeling based on the in the library of Modelica is the topic of future work.

During the Ph.D. studies, the author works on the Internet technologies and Machine learning as well. He proposes an algorithm for future internet considering the Product Lifecycle Management (PLM) [Z1], Predicting the future using Web Knowledge [Z2] and Gender Prediction of European Schools Principal Using Machine Learning [Z3].

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