Integrating Product Knowledge with Modular Product Structures in PLM

M.P. Giddaluru, J. Gao, and R. Bhatti,

***Abstract*— The changes in world economy are changing very fast and the company knowledge assets and processes are becoming primary source of organization which is intellectual property that need securely stored and maintained. Challenges that companies are facing today such as need to reduce time-to-market, the development and manufacture costs, or to manage complex products with advancing technology. Due to recent global financial crisis price competition in the market has led companies to fight with competitors for limited orders. The external pressure on delivery time has increased, which again has put internal pressure on bringing down development time, which leads for collaborative work environments. Modularisation of product structures will facilitate in collaborating design activities between a diversity of disciplines in global companies, which again involves supporting computer based tools for enhancing interaction, communication and design management. Product Lifecycle Management (PLM) serves as particularly useful tool for product data and knowledge management. The deployment of a PLM tool has been seen as an important facilitator for achieving success with the modular design strategy. One of the biggest challenges in implementing new techniques is how to handle existing knowledge and / or information. This paper describes how modular product structure can be implemented in PLM and connects relevant product knowledge at different levels when the product is generated in the process of new product development. This will enable to trace the information across products to compare existing information and reuse for future products.**

***Index Terms*—Product Lifecycle Management (PLM), Modular Architecture, Product Data and Knowledge Management.**

I. Introduction

THE inability to collaborate effectively across product development teams is mainly due to lack of integration of product development and manufacturing systems which prevents companies from effectively innovating new products or even releasing the product to market quickly. Collaboration requires the integration of information and processes. Integration also prevents big challenges, as companies must align the overall IT landscape to enable innovation.

Some of the challenges in collaborative design methods are [1]

- Difficult to integrate the development over several departments, which may total thousands of employees.
- Difficult to recognise and manage modules and interfaces because of product data scattered in both CAD systems and other architecture descriptions.
- Difficult for designers to find and re-use existing modules.

The management of product development processes faces more challenges than ever before, because it significantly concerns product data (PD) sharing, process controlling, cost reduction, and inter organizational cooperation in the international market [2]. PLM is considered as a strategic business approach that applies a consistent set of business solutions to support the collaborative creation, management, use, and dissemination of product information across the extended enterprise [3].

CAD and CAE tools traditionally rely on integrated data management platforms to directly and easily manage interaction and support concurrent engineering by multiple people within a design and engineering discipline. A known PLM challenge has emerged with use of these tools that are not well integrated with enterprise Product Data management (PDM), Enterprise Resource Planning (ERP) and Customer Resource Management (CRM) systems.

Many global companies are grown their business locally for the many years. From the last two decades, there seems to be general transformation from independent projects for developing the products to developing product families. Modular architecture based product development has been developed for many years, to address this changing way of developing products, which focuses on the design of product ranges instead of individual products. This can be done by reuse of knowledge, components, processes and utilization of economics of scale in many activities that are necessary to provide products to customers.

Providing the right information to designers about the product or assembly including the required function, customer requirement, any spatial limitations, and methods that have been applied successfully in the past, will increase the scope of innovation. The main focus of this research is to attain the traceability of product information so that designers that can

M. P. Giddaluru is with the Greenwich University Maritime, Gillingham, Chatham ME4 4TB, Central Ave, Gillingham, Chatham ME4 (e-mail: gm85@greenwich.ac.uk).
J. Gao, is with the Greenwich University Maritime, Gillingham, Chatham ME4 4TB, Central Ave, Gillingham, Chatham ME4 (e-mail: author@lamar.colostate.edu).
R. Bhatti is with the Greenwich University Maritime, Gillingham, Chatham ME4 4TB, Central Ave, Gillingham, Chatham ME4 (e-mail: author@nrim.go.jp).

make decisions on how previous designs may satisfy similar specifications of new products, which enables the use of the existing product knowledge and reduces the time to market.

II. Theoretical work

A product development process is a sequence of steps or activities, which an enterprise employs to conceive, design, and commercialize a product. The generic product development process consists of six phases [4]. During this process, large amount of product data or information is generated. A product data is defined to be all product related data including drawings, digital documents, CAD files, product structure, Bill of Material and so on. The challenge is to ensure all data is shared among personal who need this information as and when required, so that all participants spend time on designing the new products rather spending time in searching for information [5]. Providing the right persons the right information in the right formats at the right times by capturing, generating, associating, structuring and maintaining information in an efficient way according to enterprise business practice is very challenging [6]. Around 20% of the designer's time is spent on searching for and absorbing information. This figure is even higher for technical specialists. Furthermore, around 40% of all design information requirements are met by personal stores, despite the fact that more appropriate information may be available from other sources. The type of information used changes during the design process [7]. Many Knowledge-Based Engineering (KBE) tools provide knowledge relating to geometry that can otherwise be reused through the formalisation of associations between product parameters. However, there is a wealth of non-engineering knowledge elements that is a wealth of non-geometric knowledge elements that could be reused but maybe missing from KBE systems.

In the engineering and manufacturing industries Product Data Management and Product Lifecycle Management (PDM/PLM) have become one of the most important investments because the management of high quality product data is a core capability that boosts new product development process. The product development processes are quite different from the typical business operations and manufacturing processes in managing information quality of product development. Due to the complex nature of new product development process, firms need to pay extra managerial effort to acquire relevant information quality [2]. Because the involved parties for a particular product development project may be scattered over different locations and have a rather limited understanding of how the relevant PD was processed and the information quality was achieved, firms need to provide valuable information for the involved parties to improve confidence and avoid misunderstanding of product development [8]. Thus, trying to analyze, evaluate, test, experiment, demonstrate, verify, and validate are important activities of product development to create valuable and high-quality product development [9]. Companies often use a PLM tool for management of CAD files, documents, and drawings, but they do not take advantage of the full potential of the PLM system to support the development activities of modular product designs. [1].

The most common use for PDM/PLM is used for managing design data, possibly CAD and manufacturing data of products and their variations, which represents a Computer-Aided technologies (CAx) oriented view of PLM [10]. A Closed Loop Lifecycle Management (CL2M) was proposed by Matsokis and Kiritsis [11] attempting to extend PLM to the usage, refurbishing, disposal and other life cycle phases that product instances go through. The objective of CL2M is to be able to continually improve design, manufacturing, use and end-of-life.

Modularisation of product structures, appropriately applied, can serve as a means to provide the variety needed from a customer point of view and at the same time reuse sub-solutions across different products to improve time-to-market and maintain predictable product quality [12]. The efficiency of information reuse in product design relies on the definition and management of equivalence information between various product data and structure representations [13]. The most prominent idea behind PLM systems, or the top-down perspective on new product development, is that companies can create more value by integrating data from multiple systems in order to obtain synergies of all available product-related data and to eliminate redundant data existing in different system environments. However, many manufacturing companies deploy PLM systems in an ineffective way, merely for documenting and managing product data as CAD files, product related documents, and drawings. The result is that firms might find themselves far from the expected operational or strategic outcomes from PLM tools [11–14] then they expected.

By use of a modular product architecture economies of scale can be achieved by the repetition effect in order to reduce unit costs and to increase the quality [14]. The expected savings of a modular product architecture are about 20% cost saving in development, logistics and production and up to 30% time saving in time to market [15]. Especially for the ramp-up and fast reaction to market requirements a modular base is needed to realize competitive advantages. However, most companies lack a systematic approach to developing modular product architecture, instead they use the existing products as basis and adapt them for new products. This leads to more effort in the process of product development, both in time and cost.

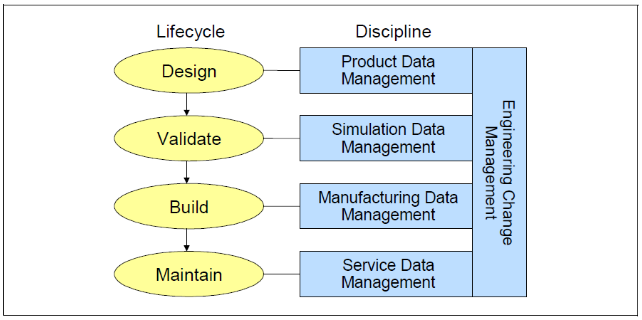

Fig. 1. PLM disciplines with product life cycle management

PLM has the capability to implement modular product architecture and also not only storing the design data but also manage simulation, manufacturing, service and change management data. Fig. 1 shows how the four data management disciplines correspond to each phase of the product life cycle, while the Engineering Change Management discipline spans all phases. [16].

A case study has been conducted with a global manufacturing company to understand the basic issues in new production development in relation to product knowledge management maintenance. The company is in the process of implanting PLM system (PTC Windchill). This paper presents an approach using modular product structure in PLM and organizing the product knowledge within PLM connected to respective data. One of the biggest challenges to implement new technique is how to handle the existing knowledge. To narrow down the scope of this paper it deals mainly with the product knowledge; how the product knowledge is systematically created, leverage, sharing and reuse. A tool has been proposed to arrange the legacy data in the form of product modular structure and migrate to PLM system.

III. Case Study

The sponsoring company is a global manufacturing company producing engines (gas, diesel), power generation, turbos, filtration, emission controls, switch gears and other related products. The company locations are spread across the globe in all disciplines of life cycle design, validation, manufacture, distribution, service and commissioning. This paper covers the study of one product family i.e. Power Generation taken voices few sites that are involved in product development process. A detailed survey was conducted in three different forms: face-to-face interviews, telephonic interviews and online survey for those who were unable to make for the first two. Two of the survey results are shared below which are relevant to this paper.

Q1: How often do you think you need to use existing product information or knowledge in new product development process?

Result: almost 75% people responded that they often needed to use the existing product information or knowledge. Twenty three percent said they used some times. This gives an indication that more than 75% will need existing product information in developing new products.

Q2: How easily can you find existing product information for your job?

Results: Fifty six percent replied that it is hard to very hard to find the existing product information or knowledge, 14% said that they are neutral; either they can find information or they will redesign if they cannot find. This leads to duplicating the work.

The results from interviews and survey shows there is gap or need to have robust product knowledge management methodology to achieve good traceability for reuse for the existing knowledge. Since the company has grown locally in different locations there has been a trend in the use of local processes in generating and storing the information in different systems. To move from a local to a global company, they need to harmonize the process and systems. A detailed study of generator product family is conducted to understand the product structure. The company has very good modular product structure on paper, but the data is not organized in the system as per the structure. In the following section a framework has been proposed to integrate product knowledge to the modular product structure.

IV. Modular Product Structure

Modular products consist of detachable modules, which can be manufactured, assembled, and serviced separately. Some of the modules may be reusable, recyclable or re-manufacturable depending on product requirements. Thus, modular design can provide benefits to many aspects of the product life cycle [17]. Product modularity is primarily seen as a product-structuring concept, in which the product system is decomposed into

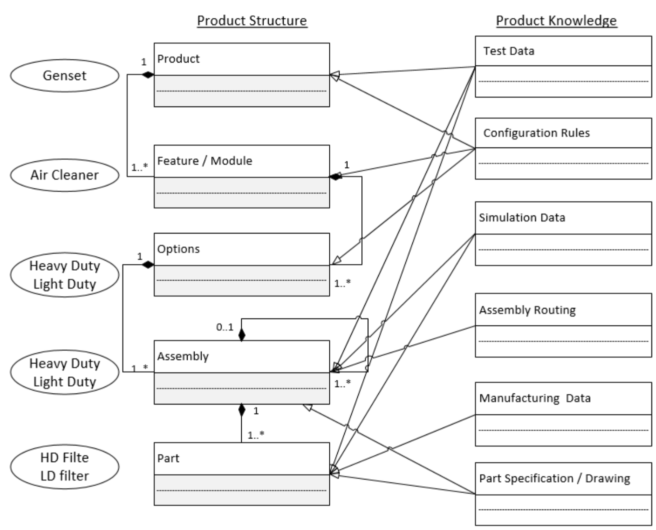

Fig. 2. Modular product structure class diagram with product knowledge relationships

smaller more manageable chunks (modules) in order to better manage design and manufacturing complexity. The common way this is done is by the decomposition of the product down to component level and then grouping of the components to form modules. Modularity is a concept and process of clustering the independent components into logical units that are relatively independent of each other in functions [18].

Modular design methods that have been focused on include function-based [19] [20], manufacturing or assembly [21], and mass customization [22]. Ulrich and Tung [23] gave a summary of different types of modularity and their advantages and disadvantages.

Modularity allows the designer to control the degree to which changes in product maintenance and service processes affect the product design. By promoting interchangeability, modularity also gives designers more flexibility, with decreased cycle time to meet these changing processes. The flexibility that modularity offers is increasingly important as uncertainty in service requirements (due to new diagnostic and repair technology and ever changing warranty agreements) increase. This flexibility allows some design decisions to be delayed because they have a lower impact on the total product. Controlling the impact of changes and being flexible to respond to changes are the benefits of modularity. A flexible product can more readily adapt to a late influx of service technology or a late change in service strategy.

Fig. 2 shows an example of modular product structure of the sponsoring company; Genset product is discussed below. Genset is a power-generating machine consisting of approximately 22 modules depending upon the configurations. The multilevel structure consists of features, options (variants), assemblies, sub-assemblies and parts. This structure is initially generated from engineering function called engineering BOM (E-BOM) and then modified or re-structured in different stages thru its life cycle; for example manufacturing BOM (M-BOM), configuration BOM (C-BOM), service BOM (S-BOM) and others.

Fig 3. Courtesy Cummins Power Generation (http://power.cummins.com/sites/default/files/literature/brochures/APSB-5795-EN.pdf)

In the example shown in Fig. 3, is a Genset product family; in the PLM terminology this is called End-Item. The products can be configurable product, pre-configured and engineered to ordered products. Products at level 1 item consist of one or more features. Features or modules at level 2 items are defined as sub-functions and are part of overall product performance. Air-Cleaner is a module within Genset that represents a sub-system in handling the air intake to the engine. Similar to this feature there are 22 other sub-systems in the Genset product family, for simplicity only one feature is shown in the above example. Each feature may have one or more options or variations. Air-Cleaner feature has 2 or 3 options depending upon the operating conditions of the product; heavy duty, medium duty and light duty. If the product is operated in open condition and high-polluted environment the customer will select heavy duty and if the product is running in closed environment or the product is enclosed then it can be selected as a light duty option. Each option will consist of having an assembly or part designed, in this case there will be different assemblies for heavy, medium and light duty as each has got specific requirements to meet. The assemblies at level 4 items in the structure consist of E-BOM. At this level we should be able to see the parts or sub-parts either manufactured in-house or purchased from suppliers or a combination of both. In the Air-Cleaner feature, the air-filter is the main part that distinguishes between the options. There are many more levels (10) under parts, but which are not discussed in this paper.

Due to the use of many systems and processes in PD process data, knowledge exists in many different systems or places. Some additional knowledge is available only from engineers, workers or maintenance experts. The first question is how to capture and extract relevant data and knowledge from different available sources so that this information can be connected to design data modules, which can be traced back when needed in decision-making process for future products. As mentioned earlier companies who implemented PLM are using mainly CAD data management or part data management. Very few are taken advantage of the full potential of the PLM capabilities. PLM supports product structures with many levels of BOM, so this paper proposes to design the product structures in PLM systems where CAD data and part data reside in the same system. Then make a direct or indirect relation to the product information as mentioned in modular product structure section like simulation, manufacturing, service, test data. Most new versions of PLM systems have got capability of storing or managing many different types of objects (files), for examples simulation data in the form of reports either PPT or PDF or MS Docs.

In the example shown in Fig. 2 there is direct co-relation between product information/knowledge to the product modular structure. One of the many advantages with this methodology is traceability of information from the connected part or CAD geometry. A sample scenario is run for this methodology, as per engineering standard requirements and a theoretical simulation needs to be undertaken for the Air-Cleaner module. This can be done at assembly level where 3 simulations need to done, or one simulation for worst-case condition. Depending upon which method is used the output would be connected to that level, if the simulation is done at module level the information is connected to feature or module level and if it is done at assembly level it is connected to assembly. Knowledge can be in any forms, simulation models, failures and suggestions, reports of final results. This will enable engineers to search for all similar simulation

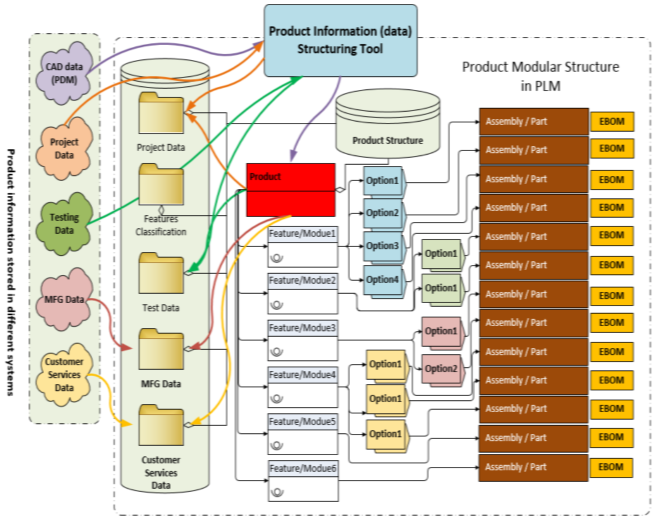

Fig. 4. Modular product structure class diagram with product knowledge relationships

information across all products to make decisions in development of new products. Since PLM systems have a very robust revision control methodology, it allows comparing the changes done on each revision with the same item or comparing can also be done with similar part from other products. This will reduce the time in searching the information and comparing the same with other products.

V. Methodology Implementation

Current Out-Of-The-Box PLM systems do not provide any mechanism to create a modular product structure. One of the biggest challenges in implementing any new technology is how to deal with existing data. All PLM systems provide tools for data migration, but they are mainly focused on migrating data as it is from the legacy systems, do not have much flexibility in making changes or configuring the data for re-organizing. This is mainly because the tools are developed for general purpose not specific to any product types, which leads to either using custom tools or to adopt to the default system processes. There is a trend in recent years that companies are not in preference of doing customization. There are advantages and disadvantages of doing so; over customization will increase the cost of maintaining the system while there are any upgrades. Data translation and migration from one system to other system is increasingly difficult based on the volume of data, quality and complexity. Automation of data translation and validations at each step helps to achieve higher ROI. Detailed planning, analysis, selection and prioritization of the data are some of key parameters for successful data migration. It is important to try to establish the value of the data that is considered for conversion and the scope of that effort [24].

A global product structure with knowledge data integration was proposed by Giddaluru [25] and is shown is Fig. 4. To demonstrate the methodology a tool has been designed using Visual Basic for Applications (VBA) within Excel. It is an integration of Microsoft's event-driven programming language Visual Basic with Microsoft Office applications such as Microsoft Excel, Microsoft Word, Microsoft PowerPoint and more. By running Visual Basic IDE within the Microsoft Office applications, we can build customized solutions and programs to enhance the capabilities of those applications. The tool has been named 'Integrated Product Modular Structure'. A sample data of few products is collected from the sponsoring company. The well-defined product structure of this product type is studied and incorporated into the tool. The design will also allow for future scalability to any product structure; this may include different product types as well.

The tool has the ability to create new products , features and options. Once the required features and options are created, a product structure can be created by selecting required level 2 and 3 features and options, respectively. The example data shown in Fig. 5 is from sponcering company product strucuture data. The main function of this tool is to create a product with modular product structure including features and options making a meta data connections in the background. The three left boxes are used to create new products, features and options.

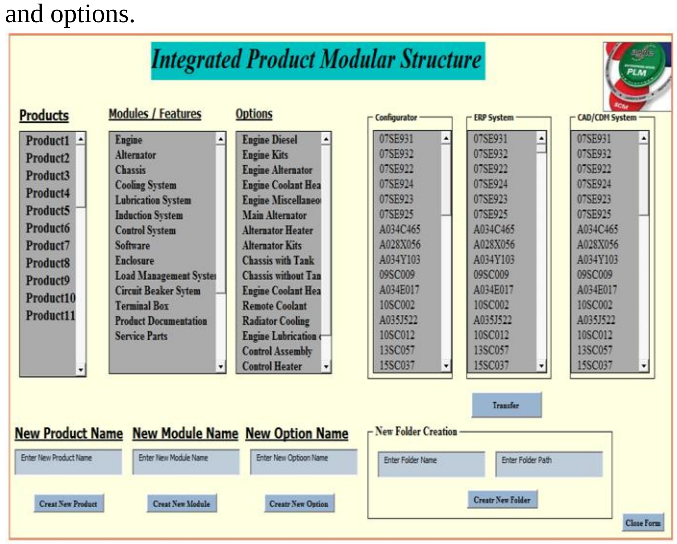

Fig. 5. Integrated Product Modular structure interface tool

The product data is collected from three different systems; product data management (PDM), enterprise resource planning (ERP) and product configurator. Most of the global companies use ERP systems for their operations and order management. These systems will have product strucuture in some format if not flat BOM that is used to product the product. Another system where BOM is structured is Configurator. A configurator can have over loaded BOM of the product, in which rules are created to drive the configurable product. This is also referred to as CBOM. The CAD data which is the starting point of the product development process is maintained in many locations, but mainly on CAD data management system or product data managment. Data from all these systems are imported to this tool. Boxes on Right side shows the data from three systems, Frame 'New Folder Creation' is used to create the folder structure for storing different forms of product data.

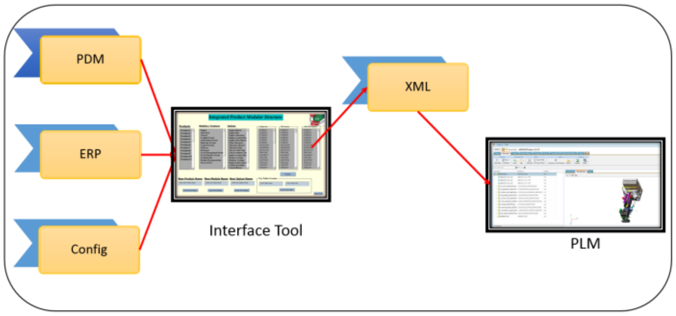

Fig. 6. Data transfer mechanism process model from legacy systems to PLM with modular structure

The meta data from the three systems is fed to the interface tool, where the modular structure can be created by selecting the data points. The process of getting the legacy data from existing systems to PLM is done in three main stept: importing the meta data from existing systems to interface tool, converting this data to modular product structure, exporting the meta data to XLM and finally from importing from XML to PLM. Fig. 6 shows the pictorial representation of this process. The PLM sytem offers multiple methods for automation. The current study is undretaken on Windchill PLM system, which has the scripting langauge called Info Engine that works directly on the implemented data model. Other PLM systems are likely to have similar langaugaes.

VI. Conclusion

Manufacturing enterprises have evolved for many years and there is a large amount of product information already in existance in the industries. Implementing a modular product structure in PLM has been proposed based on the case study undertaken in a global company. The proposed methodology gives anopputunity to migrate the raw data into structure format which will enable manageability, integrity, consistency, security, and traceability of product data in the whole lifecycle of the product. It helps in sharing and comparing the similar product data dynamically in the product evolution chain. The mapping process of product data between CAD, PLM and ERP systems is a feasible approach that gives seamless flow of information between them. This can be achieved with the modular product structure methodology. Future work of this project is the development of an application with the concept of the proposed tool for the migration of legacy data to the modular product structure.

VII. References

[1] H. P. L. Bruun, "PLM system support for modular product development," Computers in Industry, pp. 97–111, 2015.
[2] S. Li, et al., "Investigation on auditing principles and rules for PDM/PLM system implementation," Computers in Industry, Vol. 64, PP. 741–753, 2013.
[3] F. Belkadi, "Knowledge based and PLM facilities for sustainability perspective in manufacturing: A global approach," Procedia CIRP, vol. 29 pp. 203 – 208, 2015.
[4] K. T. Ulrich, Product Design and Development. New York: McGraw-Hill, 2008.
[5] C. Chi-lan, "A Function Analysis Model Based on Granular Computing and Practical Example in Product Data Management," Physics Procedia, vol. 24, pp. 1140-1146.
[6] Q. Nia, P. K. D. V. Yarlagaddaa, "A configuration-based flexible reporting method for enterprise information systems," Computers in Industry, vol. 58, pp. 416–427, 2007.
[7] D. Baxter, J. Gao, et al, "An engineering design knowledge reuse methodology using process modelling". Springer-Verlag London Limited, pp. 37-48, 2007.
[8] T.R. Browning, J.J. Deyst, S.D. Eppinger, D.E. Whitney, "Adding value in product development by creating information and reducing risk," IEEE Transactions on Engineering Management, vol. 49, pp. 443-458, 2002.
[9] D. Reinertsen, "Testing: annoyance or opportunity," Electronic Design, vol. 46, 1998.
[10] K. Fr¨amling et al., "Sustainable PLM through Intelligent Products," Engineering Applications of Artificial Intelligence, vol. 26 pp. 789–799, 2013.
[11] A. Matsokis, D. Kiritsis, "Towards sustainable product lifecycle management information systems using ontology – based solutions," Proceedings of the IMS2020 Summer School on Sustainable Manufacturing, pp. 26–28, May 2010.
[12] M.H. Meyer, A.P. Lehnerd, "The Power of Product Platforms Building Value and Cost Leadership," The Free Press, New York, NY, pp. 267, 1997.
[13] A. Brie`re-Co^te´, L. Rivest, A. Desrochers, "Adaptive generic product structure modelling for design reuse in engineer-to-order products," Computers in Industry, vol. 61 (1), pp. 53–65, 2010.
[14] G. Schuh1, S. Rudolf1, T. Vogels, "Development of modular product architectures," 2nd International Conference on Ramp-Up Management (ICRM), Procedia CIRP Vol. 20, pp. 120 – 125, 2014.
[15] K. Koppenhagen, "Systematische Ableitung Modularer Produktarchitekturen," PPS Management, 7/2002.
[16] R. Credle, M. Bader, K. Birkler, M. Harris, M. Holt, Y. Hyakuna, "SOA Approach to Enterprise Integration for Product Lifecycle Management," International Business Machines Corporation, 1st ed., pp. 14-15, 2008.
[17] P. Gu, S. Sosale, "Product modularization for life cycle engineering," Robotics and Computer Integrated Manufacturing, vol. 15, pp. 387- 401, 1999.
[18] S. Yua, Q. Yanga, J. Taoa, X. Tiana, F. Yinb, "Product modular design incorporating life cycle issues - Group Genetic Algorithm (GGA) based method," Journal of Cleaner Production, vol. 19 , pp. 1016-1032, 2011.
[19] C. K. Huang, "Modularity in design of products and systems," IEEE Trans. Syst. Man Cybern. Syst. Hum., Part A 28 (1), pp. 66-77, 1998.
[20] V. B. Krenga, T. P. Leeb, "Modular product design with grouping genetic algorithm—a case study," Computers & Industrial Engineering vol. 46, pp. 443–460, 2004.
[21] A. K. Bryan, "Co-Evolution of product Families and assembly systems," CIRP Ann-Manuf. Techn, vol. 56 (1), pp. 41-44, 2007.
[22] J. G. Mikkola, "Managing modularity of product architecture: toward an integrated theory," IEEE T. Eng. Manage, vol. 50 (2), pp. 204-218, 2003.
[23] K. T. Ulrich, "Fundamentals of Product Modularity," American Society of Mechanical Engineers, Design Engineering Division (Publication) DE, vol. 3973-80, 1991.
[24] K. Murthy, "Best Practices for CAD Data Migration," https://www.hcltech.com/.../Best_practices_for_CAD_Data_Migration_v01_2.pd, 2011.
[25] M. P. Giddaluru, J. Gao, R. Bhatti, "Incorporating Modular Structure principles for global product development knowledge management in PLM system implementation," Proceedings of the 13th International Conference on Manufacturing Research (ICMR2015), pp.123-123, 2015.