Challenges in supporting product design and manufacturing in a networked economy: A PLM perspective

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Abstract

In this paper, we provide an overview of the changing design and manufacturing landscape in the 21st century that has come about because of the arrival of Information Technology (IT), a new disruptive technology, and the changing global conditions. Based on this overview and a review of the current state of IT for Product Lifecycle Management (PLM) support in the design and manufacturing sector, we identify the areas of need for standards. A review of areas covered by standards leads us to the development of an initial typology of standards and a potential path for bringing convergence of these standards in support of PLM. We make a case throughout the paper that given the nature of the task we need to aspire to create open standards with wide participation.

Keywords: Product lifecycle, interoperability, data exchange, standards, product design, ontology.

1. Introduction

There has been a significant shift in the design and manufacturing of products since the post-World War II industrial setting that created a large number of vertically integrated industries. The modern global economic structures that have evolved in the last two decades have changed several aspects of the product design and realization processes. Gone are the days of pure mass production, where economy of scale was the primary driving force in the creation and structuring of product design and manufacturing organizations. The aerospace and automobile industries now see themselves as system integrators; their role is not to manufacture all of the underlying parts and components but to purchase them from a global marketplace. In this new context, managing variety and providing mass customization have become the driving forces in design and manufacturing organizations. The most visible form of this approach is the rise of the modular designs that are starting to dominate the strategies of product development [1]. Platform based designs, common architectures with substitutability, and plug and play capabilities are increasingly becoming the norm [2]. These are responses to the changing

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economic and technological landscapes as well as to the variety demanded by a global customer base [3]. While the movement towards modularity has been successful in the electronic consumer product and micro-computer industries, there are significant limits to modularity in the domain of complex electro-mechanical systems [4]. In this larger context, what it means to create products and manage the intellectual property of networked firms are the questions underlying the movement towards Product Lifecycle Management (PLM). PLM is a strategic approach to creating and managing a company's product-related intellectual capital, from its initial conception to retirement. As information technology (IT) undertaking, supporting PLM entails the modeling, capturing, exchanging and using information and data in all PLM decision making processes.

In this paper we explore trends in product design and manufacturing and their implications for the management of product development, the development of standards and the preservation of competitive advantage for the manufacturing sector in the US. The changing landscape of the design and manufacturing sector in the 21st century is described in section 2. Section 3 reviews the current state of IT use in design and manufacturing. Section 4 provides an overview of IT support for PLM in the networked economy. Section 5 reviews the state of commercial tools supporting PLM. Section 6 provides results of a preliminary study of where standards are needed for supporting PLM and a brief comparison of US and overseas industries. Section 7 presents a typology of current standards and their convergence for PLM support. Finally, Section 8 concludes with a summary and recommendations.

2. Design and manufacturing in the 20th and 21st centuries

Twentieth century manufacturing was heralded by the introduction by Henry Ford of mass production that moved from custom made expensive automobile for the few to the standardized automobile for all [5]. This model of the manufacturing enterprise dominated the last century with its ability to create mass produced objects affordable by a large number of customers. The underlying model of design and production was based on standardization within a firm, allowing for independent manufacturing of several components that merged on the assembly line to create the product. Variants of this model of design and production were exported and established in other countries, leading to the first models of globalization of firms [6]. This phase of globalization relied on a single-location based, vertically integrated production lines exploiting economies of scale. These models of globalization were often based on providing the same product irrespective of the needs and social preferences of the customer base.

In the last two decades of the last century, there was a significant shift emerging in the manufacturing industry. This is driven by the disruptive technology of computers and the emergence of a worldwide transportation and telecommunication infrastructure. The transportation infrastructure aided by innovations such as the commercial jet plane and the giant container ships led to the easy movement of people and goods, while the communication infrastructure led to the movement of information and knowledge in an unprecedented manner. The authors of the book “Death of Distance,” points out that we are in the third phase of the revolution in technology that in succession changed the transportation first of goods, then of people, and now of ideas and information [7].

The implications of the above changes have been profound. First, the location of production was distributed across the globe to leverage the competitive advantage of different countries as the costs of transportation, codification and distribution of knowledge and transactions decreased, aided by the diffusion of new technologies. The world moved from manufacturing everything needed to produce a product within a country, using raw material from all over the world, to the assembly of components and subsystems produced around the world, based on the competitive advantage of closeness to raw materials or low-cost labor. Meanwhile, as the non-industrialized world's aspirations started matching those of the industrialized world, the demands for products and services have expanded to these countries. The age of global demand for customized products had arrived. The response addressing these phenomena has often been termed mass customization. The increase in demand for technological products and mass customization worldwide has further accelerated the globalization of industries in the form of outsourcing and off-shoring.

Before this socio-technical change took place, the social landscape that defined the vertically integrated economy of the US was one of lifetime employment and preservation of the intellectual capital of the firm in its people. Increasingly, the demographics of US and other industrialized countries and the slack in the engineering and science skill base in these countries are being compensated by the increasing skill base in erstwhile developing countries, available at lower costs. Thus, the emergent globalization has brought with it profound changes in the economies of both the industrialized and the developing world.

This change did not happen overnight. It was triggered by critical innovations in computing and communications technology. While productivity improvements due to IT have been questioned by some economists, management scientists and others have argued that productivity in US has been fueled by technology [8].

In this paper, we put forth the hypothesis that large improvements in productivity from IT will come only when the networked economy engendered by technology allows for the realization of positive network externalities[6] to their fullest extent. Part of the reason for not being able to exploit the positive network externalities comes from the lack of full interoperability and the difficulty of adoption of these technologies by small and medium enterprises (SMEs) [9; 10]. The SMEs (45 % of the US economy) form the bulk of the supplier base to the larger system integrators in the automobile and aerospace industries. The cost of interoperability barriers of the IT systems used in engineering and manufacturing in the US auto industry, estimated to be of the order of $1 billion per year, is an indication of the industry's inability to exploit IT to realize its full benefits [11]. It is

[6] Economists call failures in the behavior of an economic structure or a market negative externalities and the benefits positive externalities. The term positive network externalities is used when the benefits accrue due to the presence of the economic network. We will use the term positive network externalities to identify benefits due to a network structure.

in this context that information exchange standards will be critical and will determine what role IT will play in the design and manufacturing area.

3. Current state of IT use in product design and manufacturing

Computing in the design of products was first observed in the work of a Westinghouse engineer in the early 1960's who wrote a program to design a motor analytically [12]. The initial use of computers for drafting has morphed into Computer Aided Design (CAD), centered on the spatial definition (geometry) of the product. CAD is frequently augmented by physical model-based functional analyses for kinematics, structural strength, fluid flow, etc., collectively designated Computer Aided Engineering (CAE)[7]. The developments in CAD were paralleled by developments in Computer Aided Manufacturing (CAM), for planning and monitoring manufacturing operations and for creating programs for numerically controlled (NC) tools from the CAD geometry. In the last twenty years technological changes arising out of faster and cheaper computer hardware and better connectivity have created the possibilities of large scale interaction and real time collaboration in design and manufacturing, leading to applications in manufacturing resource planning (MRP), enterprise resource planning (ERP) and product data management (PDM). However, the dream of full seamless interoperation across and within organizations implied by the "death of distance" is yet to be realized.

Debate will continue over what aspects of IT and how much of IT have helped the manufacturing industry. There is empirical evidence that IT has enhanced globalization, allowing the exploitation of global resources and globalized manufacturing, which in turn have provided improvements in productivity at the level of the national economies [8].

A lesson from history

As an industry moves from its birth through its early stages, it creates a surge of initial productivity and then plateaus before a second of level of significant productivity improvement takes place [13]. This pattern has been observed in the evolution of the dynamo and the electric power network; parallels can be seen in the development of information and communications technologies. The second level of productivity takes place when the innovation becomes part of the fabric of the organizations and disappears into the background as a technology, accompanied by changes in work and organizational structures [13]. In a recent interview Professor Brian Arthur of the Santa Fe Institute points out that IT is profoundly changing industrial organizations [14]. Prof. Arthur claims that technologies, especially information technologies, are the backbone of cognitive and communication processes of organizations and the economy, just as the railroads provided the backbone of physical transport and communication processes at the turn of the last century. If history is a guide, IT as a means for communication, along with the ubiquity of computing power for use in mental skill automation similar to the dynamo for physical skill automation, will lead to the next boom in productivity.

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[7] In the electronics industry, functional and spatial design, analysis and simulation are collectively called CAD

In the emerging model of product development and lifecycle management, the importance of information and IT enabling the provision of customer satisfaction and agility in the marketplace with new innovations is critical to the survival of today's firm. Innovations arise from a continuous improvement of processes in what has been termed operational innovations [15]. Further, the tendency to modularize products will increase the variety in products to satisfy different customer needs. This change implies that the economics of substitution will play a major role in the development of product platforms and product architectures [2]. In a networked enterprise, not all innovations are localized within a company; the nodes in the design and manufacturing network that are innovative are more directly involved and have a more direct impact on a automobile manufacturers' (system integrators) product development activity [16].

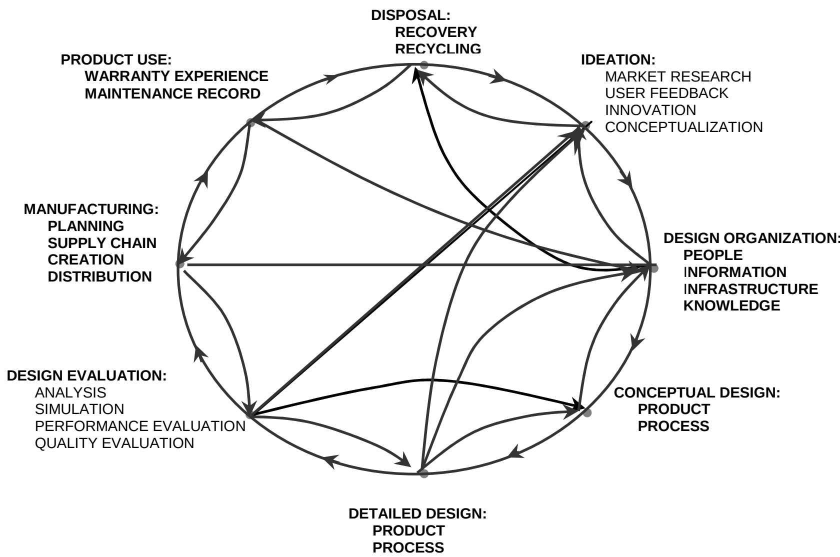

Figure 1: Epicycles in product lifecycle development (adapted from [17])

Interoperability

Today' s networked organizations are still only partially integrated islands of information and tend to have a static view of the use of information, rather than viewing PLM as a holistic real-time control system that is continually adjusting and improving the underlying business and operational processes [18].

The new view of product lifecycle is best illustrated through the metaphor of epicycles in the product lifecycle, illustrated in Figure 1. The nodes on the periphery stand for the major stages in the lifecycle: conceptualization; organization of resources; design; analysis, simulation and verification; manufacturing and distribution; in-use performance and customer feedback; and eventually disposition. The wide clockwise links on the periphery stand for the "normal" information flows from stage to stage, while the links on the inside stand for the feedback information that creates the various epicycles or sub-loops of reappraisal, redesign and product improvement or evolution. The feedback loops shown in the figure are only suggestive to convey the idea of interdependence among the stages and are not comprehensive.

A breakdown in any of the feedback links in the epicycles will lead to inefficient use of knowledge affecting both the efficiency of operation and the quality of the product. Stewart has made the claim that only 20% of a firm's knowledge is effectively used by today's organizations, providing further evidence that these epicycles are indeed broken [19]. Hence the conceptualization of product development presented in Figure 1 provides credence to the analogy of today's product lifecycle management systems to a real-time control system. This recognition has resulted in proposals for maturity models for interoperability to asses and evaluate an organization's ability to provide an interoperable environment [20; 21].

The importance of interoperability for PLM has been recognized by a number of institutions including the US DOD, the European Ministries of Defense and, more recently, by the vendor and end-user community [21; 22]. There are two further factors at work: first, globalization has spread the need for mass customization of products and services to different markets; and second, global environmental concerns have led to the heightened consideration of the servicing and disposal of products as integral parts of the product development lifecycle. It has been observed that the cost of servicing and evolving a product is higher than the initial development cost.

A further push for addressing interoperability arises from the importance that economics of substitution will play in the continuous upgrade of complex systems in response to changing technology. This can also be observed in the modular open systems approach advocated by the DOD Joint Task Force for future DOD acquisitions [23]. In all of these recommendations and efforts the ability to integrate legacy systems as well future technological innovations to interoperate seamlessly is the primary objective. The cornerstone in achieving this objective requires near decomposability of system, as was observed by Herbert Simon in his essay on "The Architecture of Complexity" [24]. We argue that open standards and clear specification of interfaces provide complementary means for achieving full interoperability.

4. Product lifecycle management and the networked economy

Product lifecycle management (PLM) has come to signify what some call the 21st century paradigm for product development. In this concept of PLM, the management of a product from inception to disposal is the strategic initiative that will define 21st century product development [25]. These claims have been made primarily because of the emergence of the networked firm and the networked economy, in contrast to the market- or hierarchy-based model of organizations that used a transactions cost model as the cornerstone for the choice of organizational structure [26; 27].

In the world of networked organization, relationships between the different nodes in the network are not of the same quality or character. This is due to the inability to arrive at complete modularity or decomposability because of various physical and organizational limitations. For example, four levels of supplier interaction have been identified in the Japanese automobile industry: partner; mature; child; and contractual [28]. This model of supplier relationship is also frequently found in the US and UK automobile industries [29]. The more standardized the parts are, the more applicable is the transaction cost market mechanism for procuring the parts. However, for higher levels of supplier interaction, traditional transaction cost models are not sufficient to explain the outsourcing of designs by the parent company. It appears that at these levels the technical capabilities of the supplier and the innovations internal to the supplier are the key factors, rather than pure transaction costs [29].

The above characterization of performance and interaction in a networked industry shows that several levels of information and knowledge exchange among the participants in the network are needed and that all such levels need to be standardized.

5. Product lifecycle management support architecture and the current status of commercial tools

PLM entails the management of product design, manufacturing and service knowledge that goes beyond the interaction of suppliers with the system integrator. PLM reaches into the sales, customer service and product disposal activities that participate in the larger network. For example, a firm that is involved in the disposal of the product requires information on the material composition and assembly for optimizing its recovery of materials. Without a comprehensive information base providing the information required by the different partners in the entire lifecycle, overall efficiencies that can in principle be achieved in the network cannot be realized. It is in this sense that the system integrator such as an automobile manufacturer will also serve as an information provider to the nodes in the product lifecycle network.

The IT industry that supplies product knowledge management and engineering support systems to the design and manufacturing industry is currently vertically integrated. The industry extensively uses proprietary standards. Vertically integrated support systems do not provide for opportunity of full diffusion of new innovations across the entire community of users. The IT industry, in particular the sector that supports PLM systems, must go through the same kinds of processes that were described above for design and manufacturing organizations in order to become mature and ubiquitous.

Various architectures for PLM support have been suggested [30; 31]. In all these architectures, the two major support functions are: (1) the support of information exchange among the enterprise nodes introduced in Figure 1; and (2) the support for data, information and knowledge integration within the nodes. A study by AMR identifying the provision of PLM support by a representative set of major vendors shows that the availability is partial and incomplete [30]. The study covers several areas beyond the collaborative design. Some vendors cover several areas, while there are areas that are poorly covered or not covered at all by any vendor. Relying on a single vendor to cover all areas of PLM support would not provide the kind of innovation needed by PLM customers. Without standards, it is infeasible for a new vendor to introduce an innovative technology for interoperability across functional needs. The data suggests that there is lack of facilities for interoperability across tools and the barriers to entry for software developers that could provide a plug and play approach to PLM support. Currently only a few IT companies with vertically integrated tool sets are able to provide facilities that are even partially integrated.

This state of support makes it difficult for a number of SMEs to enter the information age. A project undertaken by the CMU Software Engineering Institute and NIST on the use of Advanced Engineering Environments (AEE)[8] by small manufacturing enterprises (SMEs) with commercial off the shelf (COTS) tools identified the benefits that SMEs could derive, as well as the potential barriers to their adoption, such as interoperability and training expenses [9].

The above studies and data on coverage and interoperability that is feasible with commercial tools point to the problem of not having appropriate standards. Without the right standards the SMEs may need several tools to service different customers or use services that are external to the organizations to be able to translate the information formats needed by the SMEs' customers [32].

Today's standards, particularly in the area of CAD, have produced direct improvement in productivity, especially in the manufacturing arena, by reducing transaction costs and even more so by increasing the richness of interactions between supplier and customer [11; 33; 34]. The real cost of the lack of interoperability is difficult to measure and is often buried in day to day operations of individuals needing the information or needing to transmit the information.

In a previous section, we made the case that the time has come for a systematic approach to exploit the positive externalities that are emerging with the rise of the network economy. These positive externalities cannot be achieved without providing interoperability within industrial sectors to address the costs of interactions that go beyond pure transaction costs. Any new regime of interoperability will have to accommodate meaningful and semantically rich interactions required to support the full range of levels of interaction that has been observed in networked industries.

6. Areas of need for standards

To understand the needs of interoperability and gain a better insight into the current practices we got the data from Dr. Gahl Berkooz[9]. The data provided an insight into the use of tools and standards and the level of richness of the standards used by the five companies characterized in Table 1.

The data showed that in all these companies, while for the geometry-based representation of products the use of COTS is dominant, the use spreadsheets or custom applications

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[8] Advance Engineering Environments is a concept similar to PLM support systems put forth by NASA. The report is based on the adoption of support systems for supporting the technical tasks of CAD, CAE and CAM.

[9] Dr. Berkooz was the director of the PLM program at D.H. Brown and Company prior to the engagement with NIST and was an independent consultant at the time of this engagement.

prevails in the representation of non-geometric information such as functional requirements.

Company no.	Business and location	2003 revenues
1	US Auto OEM	> $50B
2	European Auto OEM	$10B - $50B range
3	US Tier One Supplier	$10B - $50B range
4	US Aerospace OEM	$10B - $50B range
5	Electronics Manufacturing Services	$5B - $10B range

Table 1: Characterization of companies studied

The data support the earlier observations that: (a) clearly defined syntactic information exchange at the low end of the parts procurement process is well supported by COTS; while (b) high complexity, large volume exchanges are not well supported. In terms of the supplier network interactions categorized earlier, the nodes that have been termed contractual and child relationships are supported but not the mature and partner level interactions. The second major observation is that the companies reviewed often have informal and ad hoc information models for defining product requirements, functional decompositions and behaviors of the product components. Table 2 provides responses from the five companies studied on their perception of the financial impacts of standards in various aspects of the product lifecycle. The industry participants did not indicate an insignificant impact in any of the aspects.

7. Towards a typology of standards and their convergence for PLM

To achieve a PLM support system we need to move from product data exchange to product information exchange and eventually to product knowledge exchange. In the near future e-marketplaces will exchange design product and process knowledge over the web, and to do this we need both syntactic and semantic interoperability of various systems. With this overall objective, we have identified the following typology of standards that are relevant to PLM support.

Information aspect	Impact			
	Insignificant	Somewhat significant	Significant	Very significant
Product requirements, functions and behavior (non geometrical)		5	1,2	3,4
Geometric representation of product (CAD)				1,2,3,4,5
Bill of material (BOM)		4		1,2,3,5
Manufacturing process		4	1,2,3	5
Build order information / order management		4		1,2,3,5
Change management				1,2,3,4,5

Table 2: Expected financial impact of new standards (Numbers denote the companies considered for the study)

Standards for architectural frameworks

In order to achieve the objective of full interoperability, it is imperative that the different types of standards described below are reconciled and made convergent. In terms of integrating the types of standards described below, we will have to take into consideration the architectural frameworks for creating integrated PLM support system perspectives. Several integration frameworks standards have been proposed, such as the Zachman Framework [35] and the Department of Defense Framework (DoDAF) [23].

Content standards

Standards such as STEP are directed toward a particular type of content. In the case of STEP the content is the product structure, geometry and part-related information.

Information models for function, assembly and behavior are critical in the conceptual development of a product and its evaluation. The NIST work on a core product model and its extension to an assembly model may serve as organizing principles for standards that may emerge in this area [36-40]. A similar effort is the ESPRIT funded project MOKA (Methodology and tools Oriented to Knowledge-based engineering applications) [41]. The MOKA modeling language is based on UML and is designed to represent engineering design knowledge at a user level for deployment in Knowledge Based Engineering (KBE) applications.

A NIST focus area is the standardization of the representation of manufacturing processes, called the Process Specification Language (PSL) [42]. Like product data, process data is used throughout the lifecycle of a product. This effort uses first order logic and OWL-like representations for its modeling.

SysML is an effort directed towards the specific domain of Systems Engineering. SysML is derived from the basic UML to cover the requirements, structure, behavior, parametrics, and the relation of structure to behavior (allocation) [43]. SysML reuses a subset of UML 2.0 diagrams and augments them with some new diagrams and modeling constructs appropriate for systems modeling.

Information modeling standards

The prime examples of information modeling standards are Express, RDF, UML and OWL. Industry consortia, standard organizations, and software vendors have come out with various standards such as ebXML, BizTalk, cXML, CML (Chemical markup language), Bioinformatics Sequence Markup Language (BSML), MathML, MatML, etc., which primarily define XML vocabularies in specific domains.

Ontology standards

Semantically rich modeling languages, based on different forms of logic, have been developed through the W3C consortium and other bodies. These include standards such as KIF, DAML, OIL, OWL and RDF that support reasoning over the information representing a content domain. All of these efforts are directed towards building formal ontologies that are expected to aid the process of semantic interoperability.

The term ontology has been used for a number of years by the AI and knowledge representation communities, but is now commonly used by a much wider community including the object modeling and XML communities. Gruber defines ontology as a specification of a conceptualization [44]. Sowa defines ontology as a catalog of the types of things that are assumed to exist in a domain of interest from the perspective of a person who uses a language for the purpose of talking about the domain [45]. Ontology can also be defined as the study of concepts and their relationships. The objectives of efforts to develop shared foundational ontologies are based on their potential to use them as the basis for interoperation among trading partners in electronic markets. An ontology based approach for achieving interoperability is expected to have potential of enabling interoperability at the level of technical and business semantics. To quote Berners-Lee, "The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation." [46]. DARPA has funded a program called the DARPA Agent Markup Language (DAML) [47]. The goal of DAML effort is to develop a language and tools to facilitate the concept of the semantic web.

Information exchange standards

Examples of information exchange standards are EDI, XML, SOAP and other specialized standards for exchange of data and information. Specialized versions of these standards are: STEPml, a library of XML specifications based on the content models from the STEP standard [48]; the Product Data Markup Language (PDML) being developed as part of the Product Data Interoperability (PDI) project under the sponsorship of the Joint Electronic Commerce Program Office (JEPCO[10])[49]; PLMXML, a set of XML schemas serving as a transport protocol; and BPML (Business Process Modeling Language), a meta-language for the modeling of business processes.

Visualization standards

Designers have been creating 3D artifacts with CAD applications for more than 25 years, creating a large library of data with a vast potential for reuse. One estimate suggest that for every 3D CAD user in design, engineering, or manufacturing, there are thirty potential users of data in marketing, product documentation, sales, support, customer service, and beyond. Through the 3D Industry Forum (3DIF), Intel is working with other companies to develop a standard file format to support the efficient reuse of 3D data [50]. The Universal 3D (U3D) specification is intended to simplify the transformation of complex 3D data into a format that can be streamed, compressed and viewed on affordable, nonproprietary software/hardware platforms while providing a high quality 3D visualization.

[10] JECPO has been re-named the Defense Electronic Business Program Office.

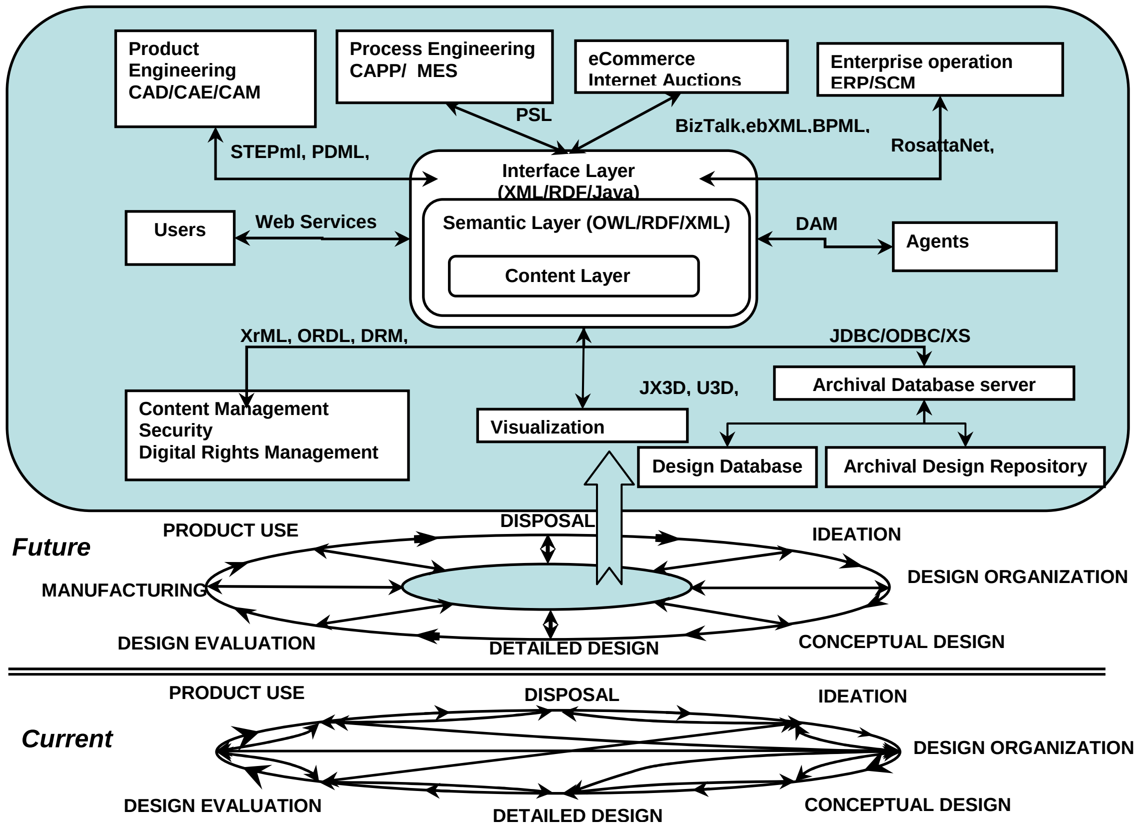

Figure 2: The relationship between product lifecycle, standards and their support

Access and Exchange Rights Standards

The earlier types of standards focused on what is to be represented, how it is to be represented and how it is to be exchanged. What is missing is how much of the information needs to exchanged and with whom. This is important from the point of view of information overload, intellectual property rights, and security. DRM (Digital Rights Management) refers to technologies that have been specifically developed for managing digital rights. The XrML - eXtensible rights Markup Language - provides a universal method for specifying rights and issuing conditions associated with the use and protection of content. Various organizations such as the NIST Information Technology Laboratory and the World Intellectual Property Organization (WIPO) are establishing international standards in this area [51].

How do they all fit together?

While there has been a rich set of standardization activities deriving from different needs and perspectives in the creation of standards for information, it is not clear how all of these standards will play a role in the development of a PLM system support for a networked organization. Figure 2 provides a vision of how all of the above standards potentially fit together for PLM support, without any detailed architectural suggestions. The architectural framework standards and information modeling standards are not identifiable in this figure; the various contents standards for the business processes illustrated in the top row of the figure address the contents layer shown; while the information exchange standards, visualization standards and access standards are identified in the figure. The picture is by no means complete; it only serves to illustrate the functional roles played by the different standards. However, their integration remains an open question. Clearly the task of integrating the entire set of standards is beyond the capabilities of a single vendor to any given industry.

We believe we are at the threshold of exploiting the efforts of a large number of researchers, practitioners, users and students to continuously integrate their work into the larger vision of full PLM support for particular industries. However, the current disparate standards with differing assumptions and purposes are not easily reconciled; neither can they be solved by single entities. The extraction of positive network externalities in the networked manufacturing economy can only be achieved by the free flow of ideas and the exchange of knowledge in a public or semi-public space to create new innovations in the new knowledge economy [52]. We will be left with no choice but to develop a pragmatic mechanism for supporting the development of standards in an open environment where the participation of all parties concerned will become critical.

The convergence of standards can only take place in an open environment given the complexity of the task ahead. This realization can be seen in the publications of information technology vendors such as IBM, end users such as DOD and engineering consultants making a case for open standards for the information base required to support the underlying IT infrastructure to accommodate legacy and changing technologies [20; 22; 53; 54]. To encourage this process, the Manufacturing Interoperability Program of the Manufacturing Engineering Laboratory of NIST is focusing on achieving convergence among these types of standards. However, more open and wide industrial participation that include vendors, end-users and other interested parties including DOD and NIST will have to be created to address this challenge. Beyond the convergence of the types of standards referred to in this paper, other aspects such as traceability, validation, verification and other audit functions will have to considered in the support system for PLM [55].

8. Conclusions

In this paper, we provided an overview of the changing design and manufacturing landscape in the 21st century that has come about because of the prevalence of IT, a new disruptive technology, and the changing global conditions. Based on this overview and a review of the current state of IT for PLM support in the design and manufacturing sector, assisted by a preliminary study of some industries, we identify the areas of need for standards, the development of an initial typology of standards and a potential path for bringing convergence of these standards in support of PLM. We make a case throughout the paper that given the nature of the task we need to aspire to create open standards with wide participation. It is always said that markets are the best determinants of standards and, if history is a guide, even market forces lead to co-operation among competitors to work towards open standards. Publications in the popular press lead us to believe that IT vendors are ready for a move towards open standards. In this context, institutions such as

NIST play an important role, and act as a neutral party in the standards debates and implementations.

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