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To cite this version:

Ricardo Goncalves, Hervé Panetto, Maria-José Nunez, Adolfo Steiger-Garcao. SMART-fm:Setting Interoperability in SME-based Industrial Environments. Advanced Manufacturing – An ICT and Systems perspective, Taylor & Francis, pp.51-63, 2007, ISBN: 9780415429122, 10.1201/9781439828328.ch5 . hal-00094261

HAL Id: hal-00094261

https://hal.science/hal-00094261v1

Submitted on 28 Feb 2011

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SMART-fm: setting interoperability in SME-based industrial environments

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Abstract

PLM (Product Lifecycle Management) is a set of capabilities that enable an enterprise to manage its products and services throughout the business lifecycle. A major trend in the present global market is the increasing need for cooperation among enterprises, which organizations can increase flexibility and reduce operational costs by focusing on its core competencies. However, enterprise applications need to be interoperable in order to achieve seamless interaction across organizations, leading to the need for adoption of data standards. This contribution to the chapter proposes a framework to support PLM, enhancing the interoperability in networked environments, and assisting the integration of reference models described following dissimilar methodologies. This framework assists in the automatic mapping between ISO10303 STEP, UML and XML models. The proposed work results from research developed and validated in the scope of the IMS SMART-fm project (www.smart-fm.funstep.org, www.ims.org), involving partners from USA, Europe, Canada and Australia, using emerging approaches for modelling and technology.

Keywords

Product Lifecycle Management (PLM), Open Integration, Standards, Information Technology, Interoperability

1 Introduction

According to Wikipedia, Product Lifecycle Management (PLM) is a term used for the process of managing the entire life cycle of a product from its conception, through design and manufacture to service and disposal. PLM tackles a set of capabilities that enable an enterprise to effectively and efficiently innovate and manage its products and related services throughout the entire business lifecycle.

Many software solutions have been developed to organize and integrate the different phases of a product's lifecycle. PLM should not be seen as a single software product but a collection of software tools and working methods, integrated together to address either single stages of the lifecycle, to connect different tasks, or to manage the whole process. Indeed, nowadays the enterprises have information technology that could fulfil their requirements in each operational phase and with external partners, e.g., suppliers. For instance, in industrial environment, many applications are available to support operating their Product Lifecycle stages. However, organizations typically acquire them aiming to solve focused needs, without an overall view of the global enterprise's system integration. Even when enterprise models are interoperable, very often difficulties arise with respect to data semantics when information has to be exchanged, thought common semantic models are not in place [1].

In order to gain revenues and reduce redundancies, all the activities performed along the manufacturing process must be coordinated and efficiently managed [2]. For realizing such coordination, manufacturing has to become evermore an integrated manufacturing process, enabling the communication between all methods, tools and environments dispersed along the manufacturing process itself [3,4,5].

PLM paradigm aims to integrate all activities disposed along the product lifecycle line in order to improve coordination and cooperation among them [6,7,8]. However, the existing PLM suites can not be really connected and, therefore, the adoption of the PLM paradigm is typically reduced to one IT choice, which becomes a sort of "trust" choice: after taken it, the enterprise is "obligated" to life with it and by it.

In this scenario, seamless data exchange between internal and external production agents plays a key role, where an initial product data model must be instantiated during the early design and tooling phases, being updated along the product lifecycle. To have this data flow accurate, data models and processes need to be interoperable [9]. However, this situation has been identified difficult to achieve, because typically there are many different software applications in use, each one adopting its own data structure and semantics. Additionally, when developing a product each participant team normally has its specific method of work and self-containing language, which does not result in a flawless interaction with others [10,11,12,13].

To help attain enterprise and systems interoperability, several dedicated reference models covering many industrial areas and related application activities, from design phase to production and commercialization, have been developed. Most of these have, however, been developed using divergent methodologies, and without the concern of being interoperable among themselves (standard to standard) [14].

New modeling methodologies have taken place in the market, which have recognized importance. Among them there is the Unified Modeling Language (UML), which has distinguished itself in industrial environments, allowing the specification, visualization, and documentation of reference models [15]. Additionally, Extensible Markup Language (XML) has also become prominent in the last years, playing an increasingly important role in the exchange of a wide variety of data. XML is open and freely available from the World Wide Web Consortium (W3C) having the support of the world's leading technology companies. These languages present the advantage of being widely supported and having a large variety of tools, which help in the design and management of such models [16,17].

Nevertheless, in order to support interoperability in heterogeneous networked manufacturing environments, it would be valuable to adopt recognized standard models for Product Data Exchange, like the ISO10303 STEP Application Protocols [18]. If these STEP standards can be harmonized with UML and XML, the users can benefit from the advantages of all of these technologies.

1.1 Industrial and research motivations

Based on the number of people it employs, the furniture industry is the largest manufacturing sector in the world. Most of the companies in the furniture manufacturing and related sectors are Small and Medium Enterprises (SMEs). To keep its competitiveness, Europe needs to accomplish rapidly the new requirements in the e-global marketplace, and push promptly SME-based industry to adopt PLM services and extended enterprise practices. In order to maintain and increase the competitiveness of these companies in the advent of the emerging digital economy and smart organizations, the use of modern information technologies and standards among all agents involved in the furniture Product Lifecycle Management has to be considered.

The problem of data exchange to support the manufacturing phase of the furniture product lifecycle when doing business between manufacturers, retailers, providers, and customers is well understood. The furniture community considers nowadays this problem as a major inhibitor for e-commerce, IT suppport and smart enterprises (see FSIG: http//www.funStep.org) and, although identified as a problem for the furniture industry, there is a global concern in the SME-based industrial sectors.

The large number of proprietary systems operating in the furniture industrial sector (as weel as in other sectors) makes this problem bigger and more difficult to solve. Thus, this industrial

community is eager to have an International Standard for product lifecycle information support in which software providers can have confidence on its worldwide adoption. Support from the international research community to create such a standard is being looked for support, too.

The main objective of the IMS SMART-fm project is to research, develop and demonstrate in industrial environments, an open standards-based framework that supports the management of the complete product lifecycle in the furniture manufacturing industry. It will establish new concepts, methodologies and technology frameworks supporting all phases of the furniture product lifecycle.

SMART-fm brings together manufacturers, retailers, suppliers, designers, and industrial trade associations from the furniture sector as well as research & development centres, academic institutions, software vendors, and consultants. It is a forum for research and development in the state of the art, publishing roadmaps and guidelines that assist industry's short-term planning and implementation, and identifying needs for continued research and development. Although focused on the furniture industry, due to its open and general characteristic, SMART-fm will concern to enable the reuse of its results and deliverables to other industrial environments based on SMEs.

One of the principal SMART-fm motivations is to create and support an interdisciplinary network of actors involved in the study of smart manufacturing having as a basis the FSIG - funStep Interest Group (http://www.funStep.org). FSIG is a worldwide interest group whose main objective is to follow and support the development of an International Standard for furniture product and interior design data exchange. FSIG has now more than 600 members from industry (75%) and research/academia (25%), from 21 countries, and used by SMART-fm as a source of requirements, a forum for industrial review, and a privileged medium for the dissemination and acquisition of the project results.

Communication between the different stakeholders is at the core of developing any valuable business. ICT, which is part of the communication process in the information flow for PLM, is becoming a higher priority as businesses seek to reduce costs, improve design time, and manage production and inventory systems. Information is seamlessly exchanged between parties, giving the customer better choices, by offering them a degree of power in managing and customising their own particular product choices. This drastically reduces the wait-time, from the time the customer orders a particular product until it's received.

SMART-fm is focused on interoperability issues to assist in PLM, aiming to fill the communication gap between the product lifecycle phases using ICT. It has been identified that SME´s in the furniture sector need new ways of working for better integration, as well as, encouragement to work in cooperation. Instead of proprietary solutions, the use of standards, with the help of the funStep services, will enable the sector to work faster, giving SME´s the ability to be more efficient and cost-effective.

Standardisation is one of the main aims of the SMART fm. Standards for data representation like ISO 10303 (STEP), ISO 13584 (PLIB), OMG/UML and the Extensible Markup Language (XML) are used. SMART-fm combines proven methods and standards for data specification with the XML language to demonstrate how furniture product lifecycle information can be exchanged and shared as well as inside any enterprise between common applications and between networked enterprises in an e-commerce environment using low-cost, scaleable software tools. Nevertheless, specification of e-business services and XML documents for furniture industry is a key issue to be standardised in order to contribute to the open interoperable platforms operating in this industry.

Recent developments in ISO TC184/SC4 have created an environment in which data exchange capabilities based on STEP application protocols can be created in a modular fashion, reusing components of existing validated standards and, therefore reducing the time and cost to develop, implement, and deploy standards-based solutions [19].

2 Technological background and interoperability in Product Data Exchange

2.1 STEP models and technologies

The International Organization for Standardization (ISO) has been pushing forward the development of standards and models to foster the exchange of information related to goods and services [20]. Efforts like ISO10303 STEP – Standard for the Exchange of Product model data – have tried to deal with the issues of integration and interoperability problem.

STEP represents the standard for the computer-interpretable representation of product information and for the exchange of product data. It aims to provide a neutral mechanism capable of describing products throughout their lifecycle. Nowadays, STEP has been recognized as appropriate to help in the integration of manufacturing systems in industries such as automotive, aircraft, shipbuilding, furniture, building and construction, gas and oil [18].

Widely used in Computer Aided Design (CAD) and Product Data Management (PDM) systems, STEP is today adopted by some of the major industrial companies in the world in the automotive, aircraft, shipbuilding, furniture, building and construction, gas and oil industries. All of the above industries are using it to help in the integration of their manufacturing systems and applications. Recent studies show that the use of STEP technology, whether in-house or between organizations, could generate savings of about $1 billion per year in U.S. automotive, aerospace, and shipbuilding industries. The same result could be forseen also in Europe. Through these numbers, STEP has proven its value to some sectors of the world industry [21,22].

EXPRESS is the STEP modelling language. It combines ideas from the entity- relationship family of modelling languages with object modelling concepts. It provides general and powerful mechanisms for representation of inheritance among the entities constituting the conceptual model, and it also encloses a full procedural language used to specify constraints on populations of instances.

The extent of standards required to support all the detailed characteristics of systems in the product lifecycle, may lead to highly complete models i.e., Application Protocols (APs). These are described in STEP using the EXPRESS language and represent reference models for a specific industrial scope of application, providing the basic mechanisms to reflect interoperability for complex engineering product models. STEP APs provide the basic mechanisms for interoperability between product data models. However, STEP translators have typically been implemented only in a selected number of systems, due to their complexity and specialized data exchange format.

Conversely, XML has been widely used to interface many different systems, due to its standardized format, easier understanding by common users and wide availability of supporting tools. Due to the knowledge embedded in the models developed using the STEP methodology, it would be relevant to reuse all those models and implement them using a more popular representation. This way, a convenient solution would be to continue using the EXPRESS language for APs definition, and then translating them, e.g. to the XML Schema Definition (XSD) format.

In order to represent an EXPRESS schema in equivalent XML Schema definition, the emerging Part 28 of the STEP standard specifies the mapping of XSD type definitions and element declarations that are dependent on the EXPRESS schema. Part 28 also specifies the rules for encoding conforming data in XML to match the XML Schema and certain configuration directives [23].

2.2 UML methodology

Unified Modeling Language (UML) is a language for specifying, visualizing, constructing, and documenting software system components. UML has become more popular than other modelling

languages, mainly because it is a general purpose “language”, with broad application and a large variety of tools that assist in working with the models. Just like STEP, not only the structural part of the model is represented in UML, but the behavioural. The last, is represented through constraints using OCL (Object Constraint Language), the UML constraint language [15].

Also, the OMG (Object Management Group) has developed a neutral language with the intention of providing a common mechanism for interchange of UML models using XML representation, the XMI (XML Metadata Interchange) [18]. XMI has been adopted by most of the popular tools for data modelling, and bindings for the main modelling languages, such as UML and EXPRESS, have also been defined for it. In this last case, STEP is developing mapping specifications described by Part 25 of STEP, "Implementation methods: EXPRESS to OMG XMI binding" [25].

2.3 The XML paradigm

The Extensible Markup Language (XML) was developed under the auspices of the World Wide Web Consortium (W3C) [24]. It is considered to be a simple, very flexible text format derived from SGML (ISO8879). Originally designed to meet the challenges of large-scale electronic publishing, XML has been playing an increasingly important role in the exchange of a wide variety of data, in particular, for Web applications [26].

XML can be used in a wide variety of platforms and interpreted with a wide variety of tools. XML Schema Definitions (XSDs) provide the mechanisms for defining the structure, content and part of the semantics of XML documents, and it is through them that XML allows representation of data models. However, the current XSD specification does not yet support restrictions to the model, like UML does with the OCL, or like EXPRESS does with the rules.

Compared with EXPRESS, the availability of XML tools, resources, and related technologies have made the use of XML more practical, cost effective, and widespread. Furthermore, web-services using the XML technology are extending these capabilities in order to provide a common, technology-independent infrastructure for remote implementation of open services.

2.4 PD/MSE and EE integration initiatives

A reference framework for PLM has been developed addressing the PD/MSE (Product Development and Manufacturing System Engineering) and the Enterprise Engineering (EE) fields [27]. PD/MSE integration efforts include three main directions of investigation and development: integrated, collaborative environment for supporting the PD/MSE activities (A-I); international consensus among users concerning enterprise engineering and integration based on modelling technology (A-II) and creation of a reference standard for enabling product data representation (A-III) (Figure 1).

Within the EE area, the efforts in setting up a common data format for connecting different company processes can be divided in two groups. The first one (B-I) is strongly supported by international (European and world-wide) offices for standardisation, which are the leading actor in Enterprise Modelling and Integration (ISO TC184/SC5, CEN TC310/WG1), System Life Cycle Processes (ISO/IEC 15288) and Enterprise Control-System Integration (IEC 62264 series of standards).

The second group of relevant works (B-II) is done by non-profit organizations like OAG (Open Applications Group), developing TOGAF (The Open Group Architectural Framework) and Object Management Group (OMG) elaborating the Object Management Architecture (OMA) to develop integration for object-oriented applications.

In the PD/MSE area, the efforts spent during the last decade setting standard modelling methodologies (e.g. IFAC-IFIP Task Force GERAM, GRAI Integrated Methodology) are converging within a single project proposal for creating a Unified Enterprise Modelling Language (UEML) [28,43] for describing and designing an enterprise system, composed by

manufacturing, business and others processes. Something similar is presented within the developing of ebXML language, which aims to identify a standard data format for managing an electronic market and IMS (Intelligent Manufacturing System) community [29].

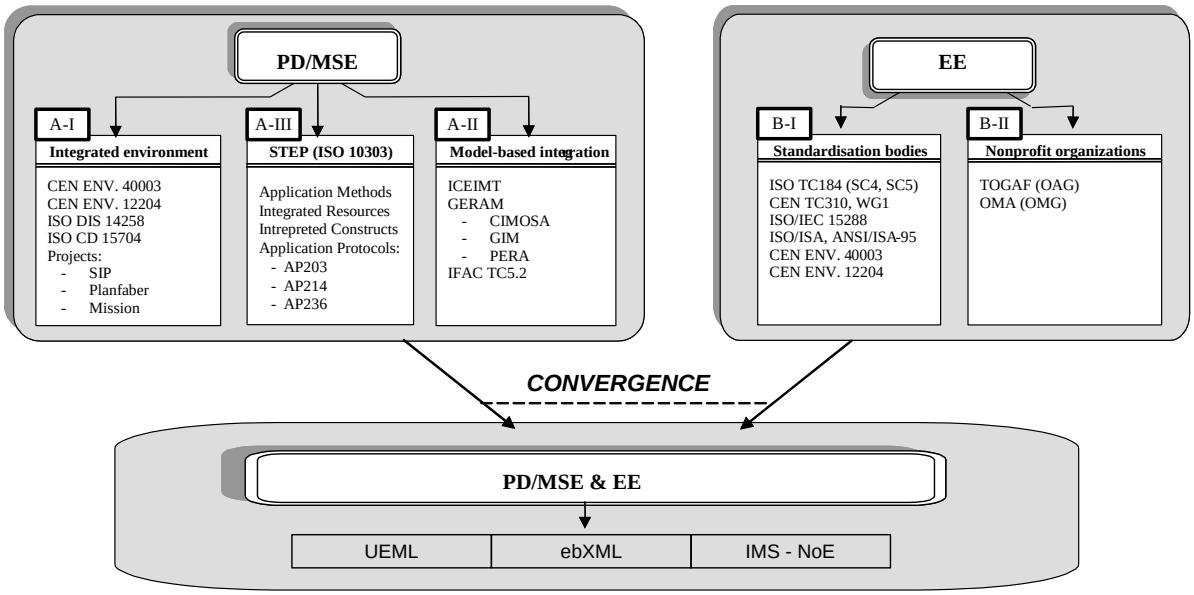


Figure 1: PD/MSE and EE integration initiatives

The main features of all these efforts resulted that all the works are done by many different international projects and close collaboration between science and industry. The most successfully efforts were accepted by some standardisation groups (at European and International level), and the most of the projects are supported by International organizations such as IFAC, IFIP, etc. [30]. As well, there is a close relation between integration activities and standardization processes, like vendors of the PLM market participate in many activities. For example some vendors (IBM, i2, SAP, PeopleSoft) are already providing their integration features according to the first OAG specifications. As well, all the most important vendors within PDM area are using STEP standard to guarantee the most open interoperability to their customers. For instance, IEC 62264 standards are starting to be used as the basis for many control and MES (Manufacturing Execution System) vendors (such as Honeywell, Rockwell, Sequencia, Invensys-Baan, Siemens and Fisher-Rosemount). Moreover, some vendors (EDS-Tecnomatix) are collaborating to propose their PLM-XML standard integration, deriving their XML parser specifications according to SGML-ISO8879 strategy.

PLM aims to integrate three main enterprise *streams* (Figure 2):

- The stream of the PD&MSE activities, composed by such activities as product/process/factory design, distributed along the life cycle of the generic product;
- The stream of the Production Planning and Control (PP&C) activities, such production planning, scheduling and control.
- Between these two main streams, it exists an intermediate stream (Enterprise Management and Engineering), composed by such activities that are mutually connected with MSE and PP&C streams, as Marketing, Procurement, Distribution, and etc.

Several tools and environments, such as CAx and PDM in PD/MSE stream, MRP and APS in Production Management, ERP and CRM in the Enterprise Management and Engineering, power each stream.

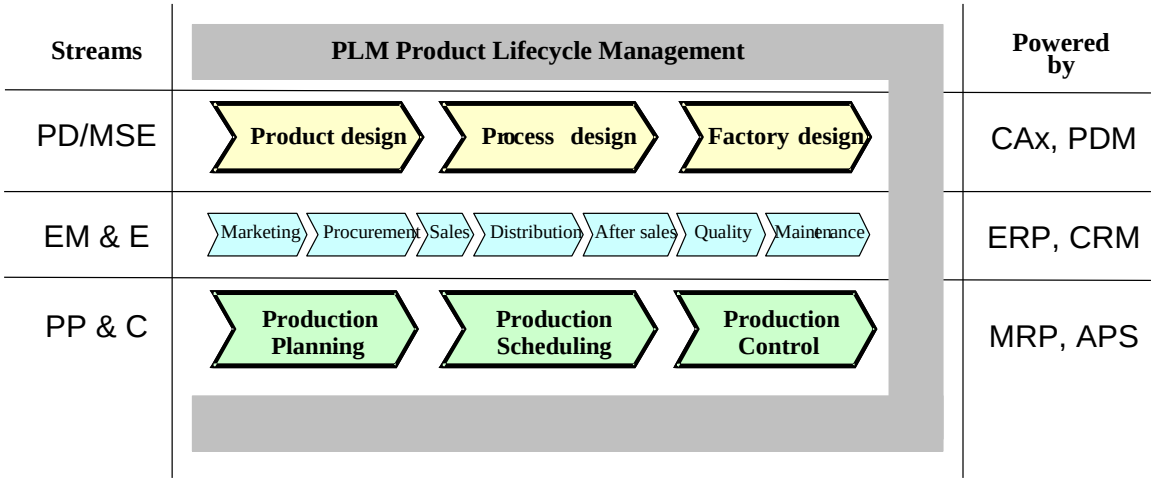


Figure 2: Streams enabled within PLM

3 The SMART-fm framework

Developed under the scope of SMART-fm, the ISO10303-236 (STEP AP236) [31] standard is a foundation for data exchange in the furniture industry, so that all the software involved in designing, manufacturing, and selling a product understands the same vocabulary. Through the usage of this AP, seamless communication can be established among the several stakeholders of the furniture industry.

However, the acceptance of STEP technologies has been facing difficulties when applied to sectors primarily composed by SME's, such as the furniture sector. The main problem is that this technology is unfamiliar to most application developers, and SME's don't have the budget that larger companies do to hire or educate specialized personnel.

Moreover, STEP data (i.e., an instance population of an EXPRESS schema) is typically exchanged using an ASCII character-based syntax defined in ISO 10303-21 (also known as Part 21 of STEP). As well, the STEP Part 21 syntax, although adequate for the task at hand, lacks extensibility, is hard for humans to read, and is computer-interpretable only by software supporting STEP. ISO, predicting this situation, is developing standards for representation of EXPRESS schemas and data in XML and UML, which are technologies that are more popular and have better tool support.

For data exchange based on these models, the standard's recommendations should be followed, such as STEP's Neutral Format described in Part 21, or XML described in Part 28 of this standard. However, acting as explicit specifications of a set of concepts and relations between models, it seems relevant that the information contained at the meta-level is also addressed.

For the representation of data corresponding to an EXPRESS schema, the STEP Part 28 specifies the mapping of type definitions and element declarations to XML Schemas (XSD), the rules for encoding conforming data in XML, and also certain configuration directives. STEP Part 25 has similar purposes. It specifies a mapping of EXPRESS constructs into the UML Interchange Metamodel conforming to the XMI standard [32,33,34].

AP236-XML is a standard-based framework developed by SMART-fm to assist in the integration of data models described following dissimilar methodologies, through a standardized meta-model harmonization (Figure 3). In the framework used, Application Protocol models at the meta-data level are mapped from STEP, to UML and then to XML.

Using the directives defined in STEP part 25 (phase 1 of Figure 3) the model is mapped to XMI, which has been accepted as the UML standard for meta-model representation. Having the model represented in UML, another mapping must be made (phase 2) to reach XML. The combination of both phases results in an XML representation of the AP model through XML Schemas. These

are equivalent as if the transformation was performed directly from EXPRESS using the Part 28 recommendations. This way, an XML neutral data format compliant with the XML Schemas will be understood by every stakeholder using the same standard AP model.

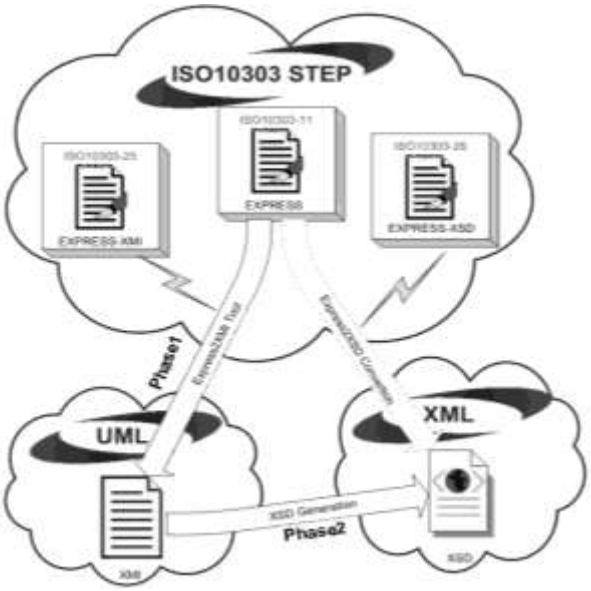


Figure 3 - Framework for mapping between STEP, UML and XML

When employing standards for meta-model representation associated to automatic code generators, the traditional effort required for the development of the translators can be significantly reduced. Thus, to help in the construction of the AP236-XML framework, automatic code generators are used. As a part of the framework, UNINOVA developed the STEP25 tool that translates an EXPRESS-based model to XMI, following the emerging STEP Part 25 directives. This tool implements and proves the concept of EXPRESS to XMI binding and, reporting to Figure 3, it also maps the STEP reference models to UML. The mapping from XMI to XSD is automatically generated following a methodology based in the STEP Part 28 mapping specifications. The tool that enables to complete this last phase has been also developed.

However, the use of facilitators can be even more powerful. Due to the capabilities associated to UML, especially after establishing the dynamic component of the model, it is possible to automatically deploy applications that conform to the specifications addressed in the model, using the functionalities available in popular UML tools [35].

The SMART-fm framework includes the following set of tools:

- "STEP to UML" - STEP25 tool that translates an EXPRESS-based model to XMI, following the emerging STEP Part 25 directives;
- "STEP to XML" – UNISTEP28 tool, translating STEP model and data to XML according to Part 28 of STEP;
- "XML to RDBMS" –XSD2RDB is the result of the integration of the Apache Torque (*http://db.apache.org/torque/*) database resource generator with an XSD Part 28 compliant parser;
- "XML to OO" – the OO generator is the result of the integration of JAXB, *(http://java.sun.com/xml/jaxb/)* with a .NET extension;

After performing the first phase of the transformation sequence, the model is translated to XMI, UML and XSD formats. Figure 4 illustrates an example of this translation results. Since STEP

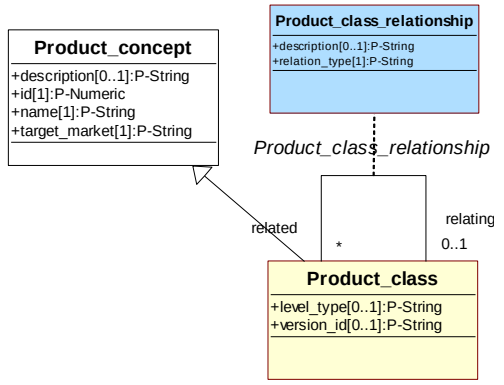
Part 25 still doesn't define how to map the constraint mechanisms of EXPRESS, further processing on the mapping should be defined by SMART-fm thought it is desired to include these mechanisms in the transformation, e.g., "Product_Class" can only exist if the inherited attribute "target_market" is not assigned.

```
ENTITY Product_concept;
        id : STRING;
name : STRING;
        description : OPTIONAL STRING;
        target_market : OPTIONAL Market;
UNIQUE
        UR1: id;
END_ENTITY;

ENTITY Product_class
  SUBTYPE OF (Product_concept);
        version_id : OPTIONAL STRING;
        level_type : OPTIONAL STRING;
WHERE
WR1: NOT EXISTS
(SELF\Product_concept.target_market);
END_ENTITY;

ENTITY Product_class_relationship;
        description : OPTIONAL STRING;
        relating : Product_class;
        related : Product_class;
        relation_type : STRING;
END_ENTITY;
```

ISO 10303-11 EXPRESS Schema

```
<xsd:element name="Product_class"
type="Product_class"
substitutionGroup="Product_concept"
nillable="true"/>
<xsd:complexType name="Product_class">
  <xsd:complexContent>
    <xsd:extension base="Product_concept">
      <xsd:all>
        <xsd:element name="version_id"
type="xsd:normalizedString"minOccurs="0">
        </xsd:element>
        <xsd:element name="level_type"
type="xsd:normalizedString" minOccurs="0">
        </xsd:element>
      </xsd:all>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
```

XSD Schema



UML Schema

Figure 4 – Model and Metamodel harmonization, between EXPRESS, XSD and UML

3.1 The industrial demonstrators

The implemented SMART-fm demonstrators cover the furniture's PLM, starting with designers creating a new furniture catalogue [36]. Manufacturers publish such AP236 based catalogues in business portals, and automatically manufacture the requested products as soon as orders arrive through the Internet, either from customers or retailers. The manufacturer has as its central point ERP (Enterprise Resource Planning) system that accepts requests according to the AP236 data representation and, later on, forwards those requests to production. The CNC (Computer Numerical Control) machines through computer programs that understand AP236 are responsible for automatic control, motion, tools and parts necessary to produce furniture objects.

The demonstrators show a scenario of complete manufacturing process integration in PLM. Manufacturers observe interoperability and integration, starting with item requests at ERP Level, passing through CAD systems and ending with CNC production machinery. The SMART-fm framework can be used with any kind of STEP Application Protocols. However, it has only been tested in the area of product data exchange between manufacturers, distributors, suppliers, e-Marketplaces, and retailers, with information exchanged in XML format according to the AP236 model specification and Part 28 recommendations. The XML information that circulate among the several stakeholders must be compliant with the AP236 model, so that every stakeholder

understands the data received. In order to achieve this, it is the XML data validated against an XML Schema (XSD) that reflects the model.

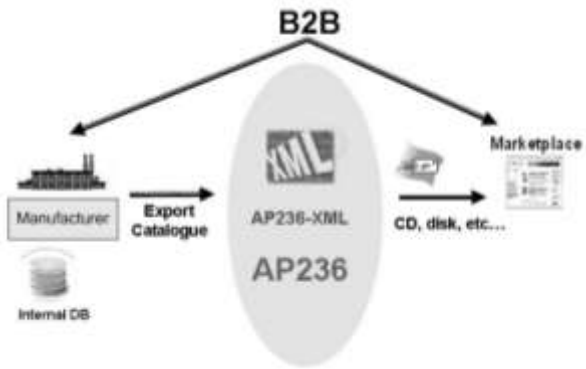


Figure 5 - AP236-XML Catalogue Exchange Scenario

The product catalogue exchange scenario illustrated by Figure 5 is one of the demonstrated PLM's scenarios that use the platform:

1. A furniture manufacturer has all data stored in an internal database, which has been used for years with good results. For this reason, the manufacturer does not want to change the way it works internally, but wants to publish its catalogues in an international marketplace, in order to expand its business;
2. Using AP236 would facilitate the execution of this task, so the manufacturer must map the catalogue to AP236 format;
3. The Manufacturer exports the AP236 catalogue to XML and sends it to the marketplace by CD, mail, etc;
4. The marketplace receives and understands the catalogue because it is compliant to AP236;
5. The catalogue is uploaded into the marketplace system;
6. Visitors of the marketplace can select some products from the specified manufacturer, configure them, and send an order directly to the manufacturer;
7. The manufacturer receives the order and imports the Purchase Order file to its ERP-system to proceed with the business.

The platform proves itself important for points 2 and 3 of the described scenario, because it provides the means to create an alternative storing system (e.g. database) where the manufacturer can map only the data he wants to use in the transaction. From that database, services exist to export data to AP236-XML format directly. In point 4, the marketplace can use a conformance checker service to determine if the data is AP236 valid. If it is valid, automatic generated OO interfaces can be used to read the information from the XML files, thus saving time in processing the data received.

Until now, the platform has only been validated among the SMART-fm partners. The comments received state that it is a very valuable work, reducing considerably the implementation time of the AP236 standard. The platform is publicly available through standard web-based services published, providing a global open interface to access to the SMART-fm framework.

4 CONCLUSIONS

More than 95% of the companies working for the furniture industry are small sized ones. Based on the number of people it employs, this industry is the largest manufacturing sector in the world, and in Europe in particular. To keep its competitiveness, Europe needs to accomplish

rapidly the new requirements for the furniture industrial sector in the e-global marketplace, and pushes manufacturers and their trade partners to promptly adopt PLM electronic services and extended enterprise practices, in the advent of intelligent agents, products and web-based services. The adoption of standard-based methods, models and tools to support interoperability between agents and applications is a key issue to achieve this objective.

The work developed by the IMS SMART-fm project contributes with a standard-based framework for PLM, to support data model integration and interoperability between applications through meta-model harmonization (STEP, UML and XML). It resulted in a framework that enables the reuse and integration of knowledge and data described under heterogeneous methodologies, providing the mechanisms for a normalized framework, for dynamic collaborative business processes through and within the product life cycles stages. The IMS SMART-fm project has been the test-bed for assessment of this proposal. The results achieved clearly contribute to the revised European strategy i2010 [37].

In order to show results to industry (SMEs and large companies), the SMART-fm partners developed 8 PLM scenarios of demonstration, based on real industrial cases identifying the needs of the industry. A common understanding is that this integrated demonstrator is becoming a referential platform for PLM in advanced interoperability for SMEs.

These scenarios presented some solutions as examples on how to solve the PLM problems for interoperability, in this case between a manufacturer and an e-marketplace on catalogues and product information by exchanging XML files (being compliant with AP236 format) and order information. To solve the interoperability problems between a manufacturer and a retailer on catalogues, a catalogue was exchange by using an AP236-compliant database. It was also shown how manufacturers, architects and interior decoration companies could exchange 3D data through AP236-compliant XML files. Another group of scenarios showed how complex furniture can be configured by customers, including the use of 3D modelling. Now, the targeted user is mainly the retailer. Other groups of scenarios were developed to show solutions regarding e-marketplaces interoperability. Also, SMART-fm enables users to browse and place orders across multiple marketplaces in a seamless manner. The technology proposed for this is web services (including UDDI registries) in combination with AP236-compliant XML.

Major results achieved by SMART-fm are within the standard-based platform to support data model integration and interoperability between applications, through meta-model harmonization, normalized services, and standard data representation. This proposal enables the reuse and integration of knowledge and data described under heterogeneous methodologies, providing the mechanisms for a normalized framework to enhance PLM.

The validation performed in the scope of the SMART-fm piloting scenarios, has providing understanding on the requirements of each stakeholder and how they could be addressed by the platform. Its usage has resulted in a considerable reduction of the AP236 standard implementation time. Nevertheless, the validation process also demonstrated that each technology binding may result in the loss of some expressiveness. This happens especially on the behavioural (knowledge) parts of the model, because neither STEP Part 25 nor Part 28 recommendations deal with this kind of information.

A major challenge to face in future research is to contribute with enhanced proposals to cover this gap. Further processing on each transformation is required, and some complementary technologies specifically designed for knowledge representation can be used:

- Schematron, a language for making assertions about patterns in XML documents, is used along with XSD [38];
- UML Object Constraint Language (OCL);
- And PL/SQL, a trigger and procedural language, to specify rules and assure accuracy in RDBMS.

Also, the platform's framework has to consider integrating the work from the emerging Semantic Web technologies. Ontology Web Language (OWL) and Resource Description Framework (RDF) provide interesting new possibilities for the exploitation of STEP application protocols on the Web [39,40]. The W3C Semantic Web standards are based on work in the fields of ontology and logic languages providing means for moving beyond typical data exchange scenarios [41,42]. Thus, challenging possibilities include integrated product knowledge bases distributed on the Internet, and usage of technologies developed in the area of the Semantic Web such as reasoning, advanced visualization, and comparison.

Acknowledgement

The authors would like to thank all the organizations supporting the international projects that resulted in the development of the platform presented in this paper. Namely, the European Commission that is funding the IMS SMART-fm project; SMART-fm partners that somehow contributed for the presentation of this work; CEN/ISSS and ISO TC184/SC4 for the effort in developing industrial standards and binding guidelines. The SMART-fm inter-regional consortium includes companies from 4 IMS regions: USA, Europe, Switzerland and Australia. Also Brazil, although not an IMS region, is part of the consortium joining the European region and Canada is studying its participation. The Network is co-ordinated in Europe by the Portuguese Research and Development Institute: UNINOVA (Technical co-ordination) and by the Spanish RTD Association of furniture manufacturers: AIDIMA (Administrative and Inter Regional Co-ordination).

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