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# Chapter Number

## Standards Framework for Intelligent Manufacturing Systems Supply Chain

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### 1. Introduction

The global market is striving to increase competitiveness among organizations and networks. Nowadays, management of supply chains does not only consider business processes in the traditional value chain, but also processes that penetrate networks of organisations. Indeed, the formation of cooperation and collaboration partnerships between several small organizations can be, in multiple cases, more efficient by comparison with big companies (Rudberg et al., 2002). This way, the research on supply chain management has turned from an intra-enterprise focus towards an inter-enterprise focus with companies looking for enhanced interoperability between computer systems and applications.

Supply chain networks are characterized by different structures such as, business processes and technological, organizational, topological, informational, and financial structures. All are interrelated but following their own dynamics. Thus, in order to ensure a high responsiveness level, the supply chain plans must be formed robustly and extremely quickly in relation to all the structures (Gupta & Maranas, 2003). In fact, with regards to supply chain in the advent of globalization, one of the difficulties enterprises are facing is the lack of interoperability of systems and software applications to manage and orchestrate the different structures involved (Farinha et al., 2007; Jardim-Goncalves et al. 2006a; Panetto et al., 2006). The increasing need for cooperation and collaboration together with the rapid advances in information and communication technology (ICT) have brought supply chain planning into the forefront of the business practices of most manufacturing and service organizations (Gupta & Maranas, 2003). Moreover, there has been a growing interest and research in e-business solutions to facilitate information sharing between organisations in the supply chain network.

However, despite enterprise networks and partnerships are desirable, the automation of processes still suffer some problems mainly in integrating Product Life Cycle (PLC) phases,

1 since manufacturers, distributors, designers, retailers, warehouses, often use proprietary  
2 solutions which are, typically, not interoperable with another (Jardim-Goncalves et al.,  
3 2007a). The exchange of information and documents between partners often cannot be  
4 executed automatically or in electronic format as desirable which creates inefficiencies and  
5 unexpected cost increase that might challenge the advantages of the network when not  
6 addressed (Brunnermeier & Martin, 1999). With this diffuse range of systems, industry has  
7 had its development of trading and supply partnerships restrained, e.g. inhibiting the  
8 shared fabrication of products. These barriers are real factors that stop innovation and  
9 development.

10 Therefore, standardization rapidly became an evident priority, and several dedicated  
11 reference models (e.g. ISO 10303, also known as STEP, the standard for the exchange of  
12 product model data) covering many industrial areas and related application activities, from  
13 design phase to production and commercialization, have been developed enabling  
14 industrial sectors to exchange information based on common models (Jardim-Goncalves et  
15 al., 2006a). STEP Application Protocols have been widely used in industrial environments, to  
16 support systems interoperability through the exchange of product data in manufacturing  
17 domains. Using them, designers and manufacturers will get a considerable advantage over  
18 those that don't (Agostinho et al., 2009). Sending and receiving e-commerce documents in  
19 standardised format may get easier access to new markets and facilitate the management of  
20 product data through PLC phases, reducing administration costs when handling quotations,  
21 orders, as well as the opportunity to have e-catalogues, product customization, user-centric  
22 design, etc. Nevertheless, alone, this kind of data representation standards does not solve  
23 semantic problems (Jardim-Goncalves et al. 2011; Sarraipa et al., 2009a). Moreover,  
24 industrial standards as STEP, often use technologies unfamiliar to most application  
25 developers or too expensive for SME-based industries which cannot spend large amounts of  
26 time and effort trying to implement standard recommendations and training the employees  
27 (Jardim-Goncalves et al., 2006b & 2007b).

28 Indeed, these kinds of organizations are much liable to use more user-friendly and  
29 supported technologies, such as Extensible Markup Language (XML) or Unified Modeling  
30 Language (UML). Their simplicity and the large availability of implementing tools make  
31 them popular and very well accepted. Therefore, a possible solution to facilitate the use of  
32 STEP and promote its adoption, would be to use standard-based platforms capable of  
33 applying rigorously defined transformation rules (i.e. morphisms) to STEP models, and  
34 supplying them to the industrial communities in different languages. This would allow  
35 reusing existing expertise and extending STEP capabilities in complementary application  
36 domains, like advanced modelling tools, knowledge management and the emergent  
37 semantic web technologies (Agostinho et al., 2007a).

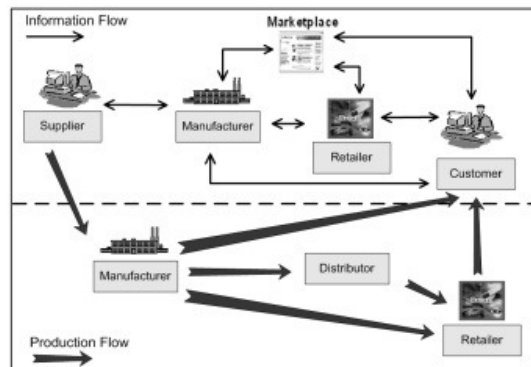
38 More recently, the development of ontologies is promising to provide companies with  
39 capabilities to solve semantic issues. Thus, each company is struggling to develop  
40 competencies at this ontological level, but inevitably different perspectives will lead to  
41 different final results, and achieving different ontologies in the same business domain is the  
42 reality. One possible solution is to have a common ontology for a specific domain that all the  
43 networked enterprises use in their business. Although, to force manufacturers or suppliers  
44 to adopt a specific ontology as reference is not an easy task, since each enterprise does not  
45 foresee any outcomes by changing their knowledge. An advantageous solution would be to  
46 let them to keep their terminology and classification in use, and adopt a reference ontology,

1 which will complement the data standard and become the organization knowledge front-  
 2 end, enabling inter-enterprises communications sharing the same terminology and  
 3 semantics (Sarraipa et al., 2009b).

4 Together with standards development, interoperability solutions have enabled a smooth  
 5 progress of supply chain systems to a next phase, where flexibility, intelligence and  
 6 reconfiguration should be reached. The 'intelligence' concept becomes more relevant  
 7 because of the need to maintain effective and efficient operations with minimum downtime  
 8 under conditions of uncertainty (Molina et al., 2005). Intelligence is taken to mean advanced  
 9 and efficient manufacturing technologies, management and procedures. Therefore, the  
 10 solution explored in this chapter to reach such intelligence is exploring the use of data  
 11 morphisms for standards integration and formal ontologies as a way of specifying content-  
 12 specific agreements for the sharing and reuse of knowledge among software entities  
 13 (Gruber, 1995).

## 14 2. Furniture sector problems and motivations for an intelligent supply chain

15 Based on the number of people it employs, the furniture industry is the largest manufacturing  
 16 sector in the world, involving mostly Small and Medium Enterprises (SMEs) (Gaston & Kozak,  
 17 2001; Roca de Togores & Agostinho, 2008). To keep its competitiveness, Europe needs to  
 18 accomplish rapidly the requirements in the digital global marketplace, and push promptly  
 19 SME-based industry to adopt seamless electronic business services in networked enterprise  
 20 environments using of modern ICT and standards among all agents involved in the furniture  
 21 product life cycle (Fan & Filos, 1999; Jardim-Goncalves et al., 2006a & 2008).  
 22



23  
 24 Fig. 1. Furniture supply chain flows (Jardim-Goncalves et al., 2007b)

25 The furniture supply chain is an end-to-end process required to procure, produce and  
 26 deliver furniture-related products and services to customers. During this process and, based  
 27 on the customer's order, raw materials, supplies and components are modified into finished  
 28 products and then distributed to the customers. Between the different players in the supply  
 29 chain, there are three main types of flow, namely production and information (represented  
 30 in Fig. 1) and financial. The first usually involves moving goods while the information flow  
 31 involves exchanging product data, electronic catalogues and orders, with the information  
 32 seamlessly exchanged between parties, giving the customer better choices, by offering them  
 33 a degree of power in customising their own particular product choices.

1 This way, the problem of data exchange to support the PLC phases of furniture product life  
2 cycle when doing business between manufacturers, retailers, suppliers, and customers is  
3 well understood (European Commission [EC], 2008a). In fact, the furniture community  
4 considers this problem as a major inhibitor of electronic businesses, and although identified  
5 as a problem for the furniture industry, there is a global concern in the SME-based industrial  
6 sectors.

7 Historically, companies have managed information flows in a number of ways, including  
8 telephone calls, letters, telex, faxes, and electronic data interchange (EDI) managed by a  
9 number of proprietary systems. More recently, the availability of reliable high-speed  
10 internet connections has become widespread and the cost of implementing technological  
11 solutions has dropped. Consequently, companies have begun to make better use of ICT to  
12 automate critical business communications. Indeed, furniture industry has become  
13 increasingly international, with retailers buying goods from manufacturers all over Europe.  
14 Similarly, manufacturers source raw materials from suppliers worldwide (Roca de Togores  
15 & Agostinho, 2008).

16 Product data standards (where they exist) differ across national boundaries, so the  
17 development of international product data standards extends business opportunities across  
18 the global supply chain. Many separate companies involved in the design, manufacture, sale  
19 and distribution of furniture, are requiring the sharing and exchange of huge volumes of  
20 information. For this reason, the *funStep* community ([www.funStep.org](http://www.funStep.org)) was setup in the  
21 late 90s with the support of European Commission, for implementing an European research  
22 strategy for better interoperability in organizations operating in networked environments.

23 The main objective of the *funStep*'s initiative is to research, develop and demonstrate in  
24 industrial environments, an open standards-based framework that supports the complete  
25 product life cycle in the furniture supply chain. This should be done adopting secure  
26 electronic services, and networked enterprise practices between other organizations,  
27 throughout agents, products, and services at 2 levels (Jardim-Goncalves et al., 2008):

- 28 • Interoperability among business user applications, and
- 29 • Interoperability among electronic commerce platforms.

30 The SMART-fm and INNOVAFUN<sup>1</sup> projects were two of the *funStep* driven projects that  
31 conducted to R&D initiatives pushing forward intelligent systems able to solve  
32 interoperability problems. SMART-fm objective was defined to improve effectiveness across  
33 the entire furniture manufacturing sector by adoption of a reference method of classification  
34 and intelligent information sharing. A major achievement of the project was to reach the  
35 enquiry stage for the STEP Application Protocol 236 standard submission, which was  
36 approved by unanimous consensus on that time. INNOVAFUN followed to bridge the gap  
37 between industry and research developments. It defined use-cases for the standard  
38 implementation and detailed a toolbox of intelligent services to enable SME's innovation. It  
39 also contributed for the identification of key open research questions, together with the  
40 findings and discussions in the international Enterprise Interoperability (EI) research  
41 community, that are guiding research nowadays (EC, 2008b & 2010; Jardim-Goncalves et al.,  
42 2010):

- 43 • Why is there so much effort wasted on the development of dedicated technical  
44 solutions for interoperability problems? How can this be reduced?

---

<sup>1</sup> SMART-fm IMS (IST-2001-52224) and INNOVAFUN (INNOVA-031139)

- 1 • How can we predict and guarantee the long-term knowledge and behaviour of
- 2 interoperability in engineering and manufacturing systems?
- 3 • How do we reduce complexity in EI and provide “Interoperability as a Service” (IaaS)?
- 4 Along these lines, can interoperability services be used as “plug-and-play” mechanisms
- 5 independently of the EI level for which they are designed (higher levels such as
- 6 business, or lower ones such as technical applications)?

### 7 **3. STEP paradigm and ISO 10303-AP236, the *funStep* Standard**

8 Standards play a crucial role in the definition of market conditions in many industrial  
9 sectors and not only in high-technology sectors. Their use is accelerating technological and  
10 organisational change and thus improving innovation processes. They play a major role in  
11 promoting innovative products and services, by providing stable references for the  
12 development of new innovative solutions and creating large scale markets. In addition, non-  
13 technological standards help shaping new organisational forms and business models and  
14 contribute to raising the quality of services and to the efficiency of business processes (Roca  
15 de Toghres & Agostinho, 2008).

16 The International Organization for Standardization (ISO) has been pushing forward the  
17 development of standards and models. Efforts like STEP have tried to deal with integration  
18 and interoperability issues, thus contributing to the reduction of transaction costs involved  
19 in the development and application of (new) technologies and of generating positive  
20 network externalities by reaching economies of scale. There is evidence to suggest that well  
21 implemented standards may contribute to the innovation process and therefore to economic  
22 growth (EC, 2008a). However, information must be neutral and unbiased in order to be  
23 credible.

24 STEP is a family of standards for the computer-interpretable representation of product  
25 information and for the exchange of product data under the manufacturing domain. It  
26 defines a framework which provides neutral mechanisms that are capable of describing  
27 products throughout their life cycle. From modelling, through data formats, to industrial  
28 data definition and conformance methodologies, STEP is widely used in Computer Aided  
29 Design (CAD) and Product Data Management (PDM) systems. It is nowadays adopted by  
30 major industrial companies in the world. Among them, are the automotive, aircraft,  
31 shipbuilding, furniture, building and construction, gas and oil industries, which use STEP  
32 for integration of manufacturing systems, some with significant savings (White et al. 2004).

33 STEP Application protocols (APs) are information models that capture the semantics of a  
34 specific industrial requirement and provide standardized structures, within which, data  
35 values can be understood by a computer implementation. This way, ISO 10303-236 (ISO  
36 TC184/SC4, 2006), also known as AP236 or the *funStep* standard, is the part of STEP that  
37 defines a formalized structure for catalogue and product data under industrial domains of  
38 the furniture sector. AP236 is focused on product definition of kitchen and domestic  
39 furniture, extensible to cover the whole furniture domain (e.g., bathroom, office, etc.). It is a  
40 foundation for data exchange in the furniture industry so that all the software involved in  
41 the design, manufacturing and sale of a product, understands the same vocabulary.

#### 42 **3.1 Modular design to enable reuse**

43 As illustrated in Fig.2 (left side), the AP236 standard is designed in order to optimize  
44 reutilization of existent standard models through modularization of components. Similar

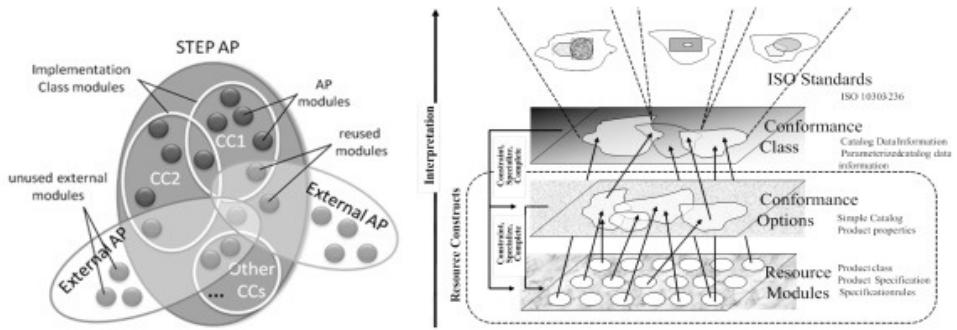


Fig. 2. Modular STEP AP and grouping into conformance options and classes

and common requirements have been identified from existent STEP APs, and subsets of these models (i.e. modules) were selected to be integrated as part of AP236 (Agostinho et al., 2009; Feeney, 2002; Jardim-Gonçalves et al., 2005). This characteristic enables a faster standard development process and guarantees a certain degree of cross-sectorial interoperability since some of the modules are the same. Product and interior designers, as other stakeholders, may now be part of multiple supply chains without greater concerns with interoperability issues since many other STEP industrial standards use some of the same resource models.

However, as illustrated on the right side of Fig.2 in addition to reutilization, modularization in AP236 also enables to define implementation/conformance classes (CCs) and options according to the stakeholder profiles. For example, in the furniture case, modules are grouped in six different implementation classes which allow different stakeholders to implement *funStep* at different levels of compliance namely<sup>2</sup> (Fig. 3):

- Simplified catalogue (CC1), which is still subdivided in 6 smaller conformance options to enable targeted implementations of micro enterprises (INNOVAFUN, 2008);
- Catalogue data and product geometry representation (CC2);
- Parameterized catalogue (CC3);
- Interior decoration project (CC4);
- Parameterized catalogue data and product geometry representation (CC5);
- Full AP236 that encompasses the others (CC6).

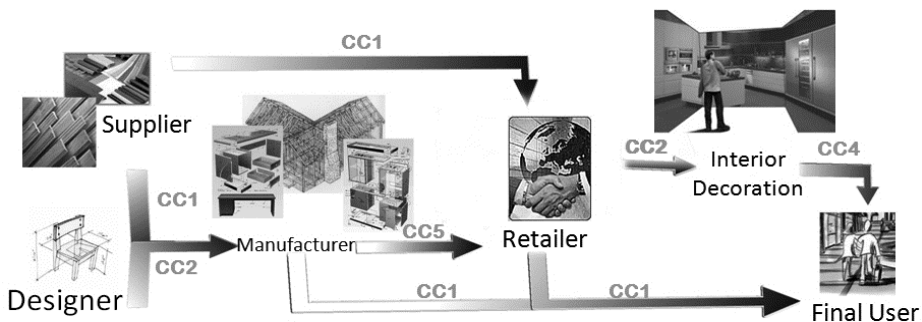


Fig. 3. *funStep* conformance classes needed in stakeholder relationships

<sup>2</sup> The enumerated names are simplified and do not correspond to the official AP236 CC names. Please refer to ISO TC184/SC4 (2006) for the formal designations.

### 3.2 Use case suite for the adoption and implementation of *funStep* standard

The ideal scenario in the communication between two different furniture stakeholders is that both of them are fully compliant with the *funStep* standard for product data. However, if that is not possible, the stakeholder receiving the information should have the same or higher level of compliance than the sender. Considering the number of CCs implemented: it is possible to define three different levels of *funStep* compliance (Agostinho et al., 2009):

- **Level 0**, the stakeholder has no part of the standard adopted and interoperability is never guaranteed;
- **Level 1**, for the stakeholders that have adopted some CC modules of AP236. Here, in a typical data exchange scenario, interoperability is only assured if the CCs implemented are the same, or if the receiver stakeholder implementations encloses the sender's CCs;
- **Level 2**, for the stakeholders that have adopted full AP236, i.e. CC6.

At present most of the furniture companies have not yet adopted any part of the *funStep* standard and will be on level 0 of compliance. Also, as analysed by Agostinho et al. (2009), many are in different maturity stages of ICT adoption which conditions the way they can adopt and implement *funStep*:

- Maturity stage **"Does not have an ICT Infrastructure"**. This is the case where no ICT equipment is used in the organization and all information is stored in paper format. In this case many design specifications are still being sent by fax to manufacturers;
- Maturity stage **"Has an ICT Infrastructure, but is not focused for information exchange"**. This is the case common to the majority of SMEs, where companies have computers, internet connection but have no specialized system to enable creative design, e-commerce or any kind of information management (e.g. ERP);
- Maturity stage **"Has an ICT Infrastructure for information exchange and management"**. This case reflects the situation of companies that have already invested in a system to enable e- business and PLC management. In this situation companies might already be adopting *funStep* (fully or partially), or may use proprietary formats not understandable by all, thus obstructing seamless interoperability.

Considering both the levels of *funStep* compliance and the ICT maturity in SME environments, the authors propose a methodology for the adoption and implementation of AP236 based on a set of 12 use cases which show the actions stakeholders should carry for a fast implementation of STEP standards, namely *funStep*. Table 1 guides the implementors on the order of UCs they should follow, to adopt certain parts of *funStep* and raise the level of compliance. This best practice methodology eliminates part of the complexity of implementing a STEP standard, i.e. where to start.

### 3.3 An e-marketplace implementing AP236 for the supply chain information flow

To better illustrate how the proposed use-case suite works, its best to follow an example: let's say that a furniture e-marketplace decides to implement the *funStep* standard to regulate his supply chain information flow as in Fig.1. Due to its business scope, the marketplace already uses an ICT system that enables to electronically receive furniture catalogues from different manufacturers, thus has an ICT Infrastructure for information exchange and management (highest ICT maturity level). However, it doesn't implement yet AP236 (level 0) and due to the heterogeneity of the information received, has trouble enlarging its business network.



ICT Maturity	Compliance	Steps (#, name)	Use-case #
Does not have an ICT Infrastructure	Level 0	1 Uptake basic ICT	UC-01
		2 Build data system based on <i>funStep</i>	UC-02
		3 Implement system interfaces	UC-03
		4 Populate data system	UC-04
		5 Test the level of <i>funStep</i> compliance	UC-05
Has an ICT Infrastructure, but is not focused for inform. exchange	Level 0	1 Build data system based on <i>funStep</i>	UC-02
		2 Implement system interfaces	UC-03
		3 Migrate internal data to <i>funStep</i> system	UC-06
		4 Test the level of <i>funStep</i> compliance	UC-05
Has an ICT Infrastructure for information exchange and management	Levels 0, and 1	1 Find requirements that the current system does not answer	UC-07
		2 Analyse how <i>funStep</i> could answer the requirements	UC-08
		3 Discover mapping from internal system to <i>funStep</i> (if starts from level 0)	UC-09
		4 Implement functionalities/ services to transform internal data in <i>funStep</i> data and vice-versa (if starts from level 0)	UC-10
		5 Implement new parts of <i>funStep</i> (if required)	UC-11
		6 Implement system interfaces for the new parts (if required)	UC-12
		7 Test the level of <i>funStep</i> compliance	UC-05

1 Table 1. Use-Case (UC) suite for the adoption of the *funStep* standards

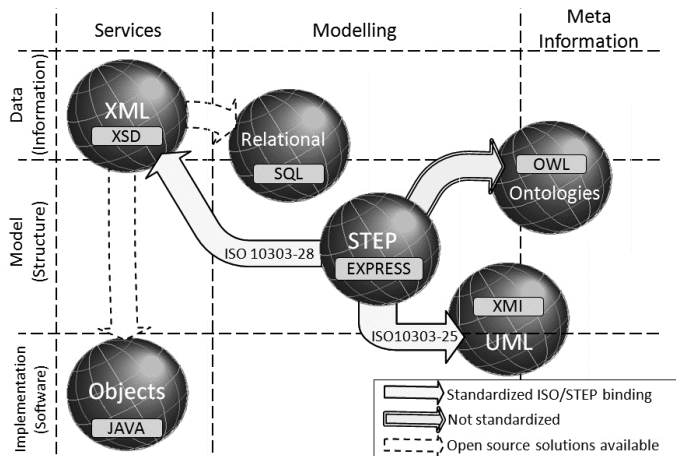
2 Clearly the e-marketplace is suffering from an interoperability problem, and according to  
3 Fig.2 would need the first conformance class (CC1) of the AP236 standard to be able to  
4 receive catalogue data from more manufacturers. However, if the marketplace, as a more  
5 technologically advanced form of retailer, already includes innovative product visualization  
6 functionalities and placement of furniture objects inside a room, would probably be  
7 interested in the implementation of CC2 and CC4 as well.

8 Following Table 1, the marketplace should start by finding and detailing the exact  
9 requirements that the current system does not answer (UC-07). Next, the second step relies  
10 on the profound analysis of the standard capabilities to see if and how it will solve the  
11 problem (UC-08), i.e. decide which conformance options and/or CCs to implement. The  
12 procedure continues with UC-09 defining morphisms from internal system functionalities  
13 and structures to the standard constructs, UC-10, UC-11 and UC-12 for the implementation  
14 of the morphisms and new functionalities if required, until it reaches UC-05 where it is  
15 foreseen that the organization will check if its implementation has been successful and  
16 obtains a compliance level certificate.

1 Due to space restrictions the full details of the use-case actions are not here detailed and can  
 2 be found on INNOVAFUN (2007).

### 3 4. Framework for the independency of STEP languages

4 STEP data has traditionally been exchanged using ISO10303-21 (Part 21) (ISO TC184/SC4,  
 5 2002), an ASCII character-based syntax. Although it's sufficient for the task, it lacks  
 6 extensibility, it's hard for humans to read, and it's interpretable only by systems supporting  
 7 STEP. This is one of the drawbacks STEP faces regarding its use and adoption by a wider  
 8 community, namely among SMEs. Another drawback is the fact that the STEP modelling  
 9 language (used in all their APs), EXPRESS (ISO10303-11) (ISO TC184/SC4, 2004), is  
 10 unfamiliar to most applications developers. Although it is a powerful language, it has been  
 11 relatively unknown in the world of generic software modelling tools and software engineers  
 12 (Subrahmanian et al. 2005). As opposed to other modelling technologies, such as UML or  
 13 XSD, few software systems support EXPRESS (Agostinho et al., 2006 & 2007a & 2007b).  
 14



15

16 Fig. 4. Integration of STEP with other technologies

17 In summary, the STEP standard, despite being very powerful regarding the representation  
 18 and the exchange of product data, is not very popular among the application developer's  
 19 community. Therefore, and because of the massive adoption and deployment of other  
 20 standard technologies, like XML and UML, the authors believe that the path to follow is to  
 21 define morphisms from STEP to these standard technologies, leveraging the cemented  
 22 knowledge gathered by STEP, with the popularity of the other standards (see Fig. 4). This  
 23 harmonization among complementary technologies would become a powerful tool for  
 24 lowering the barriers of STEP implementations and enable to widespread exchange and  
 25 share of digital data.

26 Several international research projects, like the Athena IP and the InterOP NoE<sup>3</sup>, in addition  
 27 to the *funStep* driven projects mentioned in section 2, have been supporting the development  
 28 and validation of similar solutions that apply innovative concepts such as the Model Driven

<sup>3</sup> ATHENA IP (IST-507849) and InterOP NoE (IST-508011)

1 Architectures (MDA), ontologies or Model Morphisms (MoMo) to solve real industrial  
 2 interoperability scenarios (Agostinho et al. 2007a; Franconi, 2004; INTEROP, 2005; Jardim-  
 3 Goncalves et al.,2007b; Kalfoglou & Schorlemmer, 2003; Lubell et al., 2004; Sarraipa et al.,  
 4 2010).

#### 5 **4.1 Model Morphisms (MoMo)**

6 Morphism is an abstract concept drawn from mathematics for describing a structure-  
 7 preserving map between two structures. It can be a function linking two objects or  
 8 aggregations of objects in set theory; the relation between domain and co-domain in  
 9 category theory; or the transformation operator between two vector spaces, in linear algebra  
 10 (INTEROP, 2005). Recently, this concept as been gaining momentum applied to computer  
 11 science, namely to systems interoperability where it specifies the relations (mapping,  
 12 merging, transformation, etc) between two or more information model specifications (let  $M$   
 13 be the set of all models). In this context, a MoMo describes a model operation.  
 14

MoMo	Formalization	Classification
Mapping: $\theta(A, B)$	$\forall A, B \in M: \theta(A, B) \subseteq Sub(A) \times Sub(B)$	Non-altering
Transformation: $\tau: A \times \theta \rightarrow B$	$\forall A, B \in M: \text{if } \exists \theta(A, B) \text{ then } \tau(A, \theta) = B$	Model altering
Merging: $\lambda: A \times B \times \theta \rightarrow C$	$\forall A, B, C \in M:$ $\text{if } (\exists \theta(A, C) \wedge \exists \theta(B, C)) \text{ then } \lambda(A, B, \theta) = C$ $\text{and } C \subseteq A \cup B$	Model altering

15 Table 2. Types of MoMo

16 INTEROP (2005) was the catalyst for the MoMo research applied to interoperability  
 17 domains identifying two core classes of MoMo, i.e., non-altering and model altering  
 18 morphisms. Since then the authors have been formalizing interoperability operations  
 19 accordingly and classifying them within the morphism types specified in Table 2 (Agostinho  
 20 et al., 2007a & 2011):

- 21 • In the non-altering morphisms, given two models (source model  $A$  and target model  $B$ ),  
 22 a mapping relationship is created relating each element of the source with a  
 23 correspondent element in the target, leaving both models intact.
- 24 • In model altering morphisms, the source model is transformed using a function that  
 25 applies a mapping to the source model and outputs the target model. Other relations,  
 26 such as the merge operation, can also be classified as model altering morphisms since it  
 27 is a transformation with two input models.

28 The integration of technologies envisaged in Fig. 4 targets model altering morphisms, namely  
 29 transformations where the source model  $A$  is translated into a different modelling language  
 30 in the target model  $B$ , thus accomplishing the harmonization of STEP with other more  
 31 popular and less expensive technologies.

##### 32 **4.1.1 EXPRESS to XSD transformation**

33 This function translates an EXPRESS schema to XML Schema (XSD) format according to the  
 34 standardized mapping rules defined by Part 28 of STEP (ISO10303-28) (ISO TC184/SC4,  
 35 2007). Adopting the mathematical notation to define the morphism, let:

- 1 a.  $MEXP$  be the set of all models described by the EXPRESS language,  $MEXP \subseteq M$ ;
- 2 b.  $MXSD$  be the set of all XML models described in XSD,  $MXSD \subseteq M$ ;
- 3 c.  $\theta(MEXP, MXSD)$  the mapping defined ISO10303-28;
- 4 EXP2XSD is a transformation  $\tau: A \times \theta \rightarrow B$ , where  $\forall A \in MEXP, \exists B \in MXSD: \tau(A, \theta) = B$ . Its
- 5 implementation is detailed in section 4.2.

#### 6 **4.1.2 EXPRESS to XMI transformation**

7 This function translates an EXPRESS schema to XMI format of the Unified Modeling  
8 Language (UML) according to the standardized mapping rules defined by Part 25 of STEP  
9 (ISO10303-25) (ISO TC184/SC4, 2005). Adopting the mathematical notation to define the  
10 morphism, let:

- 11 a.  $MEXP$  be the set of all models described by the EXPRESS language,  $MEXP \subseteq M$ ;
- 12 b.  $MXMI$  be the set of all UML models described in XMI,  $MXMI \subseteq M$ ;
- 13 c.  $\theta(MEXP, MXMI)$  the mapping defined ISO10303-25;
- 14 EXP2XMI is a transformation  $\tau: A \times \theta \rightarrow B$ , where  $\forall A \in MEXP, \exists B \in MXMI: \tau(A, \theta) = B$ . Its
- 15 implementation is detailed in section 4.2.

#### 16 **4.1.3 EXPRESS to OWL transformation**

17 This function translates an EXPRESS schema to OWL format according to a set of  
18 customized mapping rules defined by the authors (Agostinho et al., 2007b). Adopting the  
19 mathematical notation to define the morphism, let:

- 20 a.  $MEXP$  be the set of all models described by the EXPRESS language,  $MEXP \subseteq M$ ;
- 21 b.  $MOWL$  be the set of all OWL models,  $MOWL \subseteq M$ ;
- 22 c.  $\theta(MEXP, MOWL)$  the mapping defined by Agostinho et al. (2007b);
- 23 EXP2OWL is a transformation  $\tau: A \times \theta \rightarrow B$ , where  $\forall A \in MEXP, \exists B \in MOWL: \tau(A, \theta) = B$ . Its
- 24 implementation is detailed in section 4.2.

#### 25 **4.1.4 XSD to RDB and XSD to JAVA transformations**

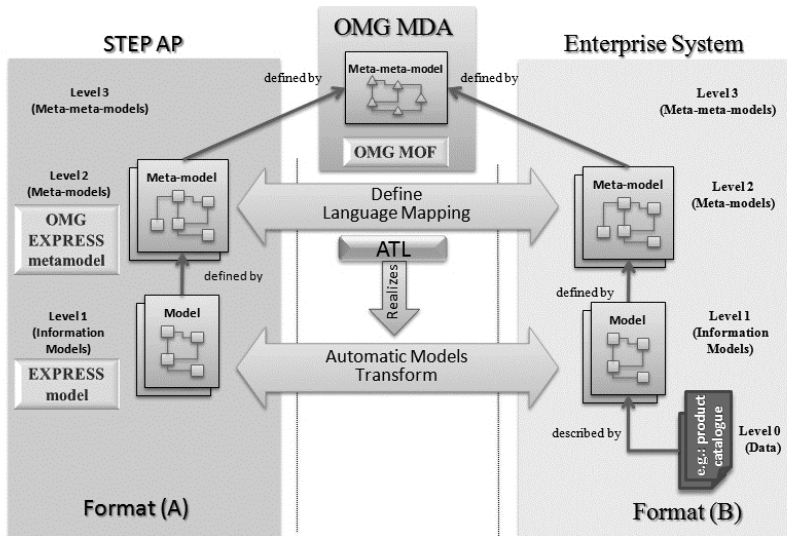
26 As in the previous 3, these functions are also transformations, however, the input model is  
27 an XML Schema (XSD) and the outputs are in the form of relational database SQL scripts or  
28 object-oriented classes. These morphisms complete the framework of Fig 4 using mappings  
29 realized by open source solutions available that can be parameterized to produce the  
30 desired results, and enable developers to have access to STEP standards even at an  
31 implementable format. The formalization follows the same logic as before.

#### 32 **4.2 MDA-based transformations for STEP models**

33 To accomplish the above EXPRESS-based morphisms, a *funStep* research prototype, i.e. the  
34 UniSTEP-toolbox, as been developed applying the principles of the OMG MDA  
35 methodology<sup>4</sup>. MDA recommends handling of information at different meta-levels for  
36 integration purposes (Frankel, 2003; Jardim-Goncalves et al., 2006c). At that level, the effort  
37 to define valid transformation morphisms from the EXPRESS modelling language to others  
38 is heavily reduced since there is more information available about both the operand model  
39 languages (input and output). Hence, for the UniSTEP development, the OMG EXPRESS  
40 metamodel (Object Management Group [OMG], 2009) as been used specifying all the  
41 possible variations that a STEP data model can have.

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<sup>4</sup> OMG Model Drivel Architectures (MDA). [www.omg.org/mda/](http://www.omg.org/mda/)



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Fig. 5. MDA-based architecture for transformation of STEP models

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The proposal to implement the transformation morphisms relies on a four level architecture that structures the relationships between meta-meta-models, meta-models, information models and data (see Fig. 5). The left-hand side of the figure represents the source STEP model, using the EXPRESS language as the information modelling language, whereas the right-hand side represents the organization's internal models. Using a common meta-meta-model, such as the OMG MOF<sup>5</sup> it is possible to define the mappings among the meta-models at the level 2 of the MDA, which are the specifications of the modelling languages. With this, the transformation from any EXPRESS model to the desired format B at the Level 1 can be realized, enabling the organization to implement with their preferred technologies, the parts of the AP it requires for a data exchange with other organizations (level 0), as explained in section 3.

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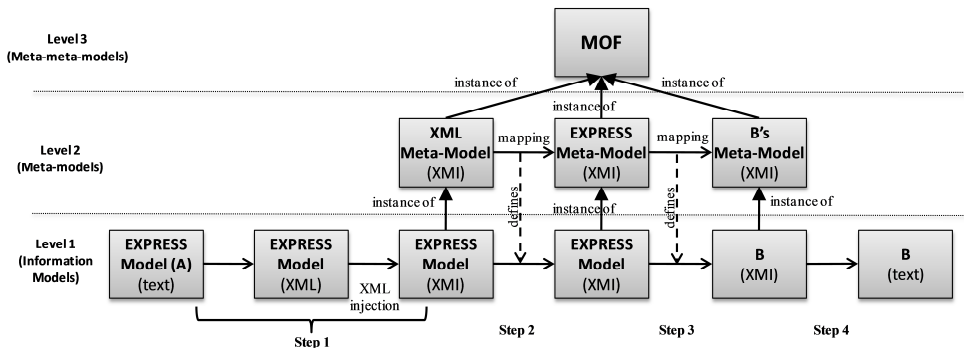
26

Given the context of MDA and MOF based meta-models transformation languages, the Atlas Transformation Language (ATL) is currently the largest user-base and has the most extensive available information such as reference guides, tutorials, programmers' forum, etc. It is the most used language to implement MDA based tools (Jouault & Kurtev, 2007), having a specific Development Toolkit plug-in available in open source from the GMT Eclipse Modelling Project (EMP)<sup>6</sup>. Since the ATL can be applied to OMG meta-models (Grangel et al., 2008; Wimmer & Seidl, 2009), automatic model transformations at the information model level are attained if the mapping of level 2 is written in ATL.

Consequently, using the proposed architecture, the language mapping procedure is a manual process, but the language transformations are always automatic and repeatable. Considering that the number of languages used for information modelling is not so high, it is an acceptable cost since each map is done only once for each language, independently of the number of the times it is used / executed.

<sup>5</sup> OMG Meta Object Facility (MOF). [www.omg.org/mof/](http://www.omg.org/mof/)

<sup>6</sup> <http://www.eclipse.org/modeling/>



1

2 Fig. 6. ATL execution steps

3 Although ATL transformation input models can be represented in plain text like EXPRESS,  
 4 it is preferable to use previously validated serialized XMI and EXPRESS meta-model (OMG,  
 5 2009) conforming models. Yet to achieve this, a number of steps have to be followed (Fig 6):

6 Step 0. **(prerequisite)** - All mappings from EXPRESS meta-model (format A) to the format  
 7 B meta-model need to be properly described in ATL;

8 Step 1. **(from plain text to XML tagged file)** - Eurostep EXPRESS Parser (EEP)<sup>7</sup> is a  
 9 command line parser which allows EXPRESS models (level 1) in text format to be  
 10 validated against the published STEP standard, and can export an XML form of the  
 11 validated models. The use of XML simplifies the process of representing the input  
 12 models as instances of the EXPRESS meta-model, since XML can be natively injected by  
 13 the ATL modelling tools, creating a valid XMI serialised instance;

14 Step 2. **(EXPRESS meta-model injection)** - the XML representation of the model has to be  
 15 injected to the EXPRESS meta-model conforming model, and to accomplish that a  
 16 transformation from the XML representation of the model must be executed, i.e. from  
 17 the tags generated by the EEP to the ones used in the EXPRESS meta-model. This step  
 18 can use specific ATL;

19 Step 3. **(transformation)** - After a successful EXPRESS injection, an instance of the  
 20 EXPRESS meta-model, XMI serialized, is obtained. Using the EXPRESS mapping  
 21 previously defined it is possible to execute the ATL rules automatically;

22 Step 4. **(deserialize)** -The result of step 3 provides a serialized XMI output according to B's  
 23 meta-model. Therefore, in order to implement the STEP standard using language B, a  
 24 model to text transformation must be written (ATL can also be used).

25 The number of steps might cause the impression of great complexity. However, that is not  
 26 the case and those have only been here included to guide readers in their implementations.  
 27 Also, in the future probably the steps will reduced to the fundamental step 3, with the  
 28 further development of ATL frameworks.

## 29 5. Semantic enrichment of standard-based product data

30 Data can exist in multiple ways, independently of being usable or not. In the raw format, it  
 31 does not have meaning in and of itself. However, information is data that has been given

<sup>7</sup> <http://www.eurostep.com/global/solutions/download-software.aspx>

1 meaning by way of relational connection to a context (Breiter & Light, 2004). Still, in  
2 information, this "meaning" can be useful for some, but not necessarily to all. It embodies  
3 the understanding of a relationship of some sort, possibly cause and effect, thus, people  
4 might "memorize" information (as less-aspiring students often do). Nevertheless, they  
5 would still be unable to understand it since they require a cognitive and analytical ability,  
6 i.e. knowledge (Bellinger et al., 2004).

7 Nonaka et al. (2001) define two kinds of knowledge: 1) Tacit, that people carry in their  
8 minds, which provides context for people, places, ideas, and experiences; 2) and Explicit,  
9 that has been or can be articulated, codified, and stored in certain media such as a STEP  
10 standard. In an ideal semantic based interoperability framework, both should be addressed  
11 and processable to achieve more advanced stages of knowledge, such as understanding and  
12 wisdom (Bellinger et al., 2004; Jardim-Goncalves et al., 2009a or 2009b; Syed & Shah, 2006).  
13 Since the explicit form has been handled by the industrial product data standards, the major  
14 research challenge nowadays is to gather the tacit knowledge domain stakeholders hold, in  
15 interpretable knowledge bases, thus transforming it to explicit knowledge stored in a  
16 structured organized way (Boudjlida & Panetto, 2008). For reaching that purpose, literature  
17 suggests the usage of knowledge representation technologies such as dictionaries (domain,  
18 technical and natural language), glossaries, taxonomies, thesaurus and also ontologies, to  
19 build sustainable knowledge bases.

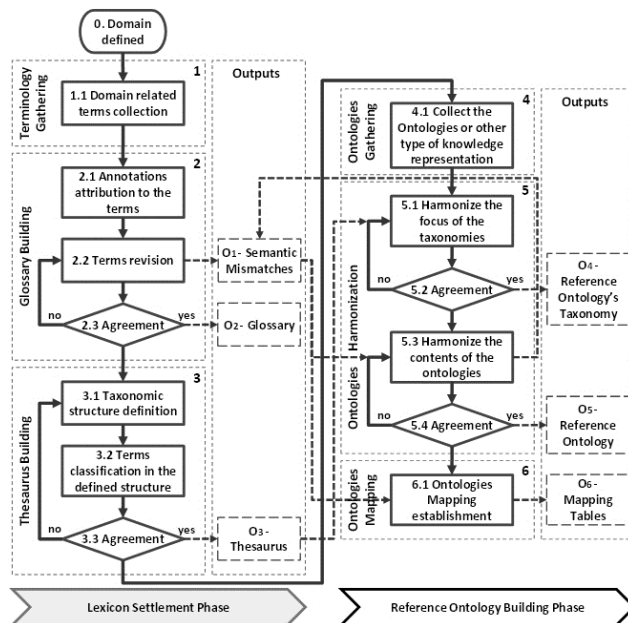
20 In the furniture industry, explicit knowledge is handled by the AP236 standard. However,  
21 as explained above, the use of the AP236 or any other STEP Application Protocol alone does  
22 not solve all the interoperability problems. Each supply chain stakeholder can have its own  
23 nomenclature and associated meaning for their business products. Therefore the  
24 information exchanged, in spite of sharing the same structure, still may not be understood  
25 by all business partners (Sarraipa et al., 2009a). Semantics interoperability is of major  
26 importance, and as such it is still to be solved, thus the authors, under the *funStep* initiative,  
27 are proposing the semantic enrichment of the furniture product data as a solution. The main  
28 objective is to organize the knowledge associated to the furniture products in order to  
29 enable a full understandable business messages and supply chain data exchange.

### 30 **5.1 Reference ontology for interoperability within enterprise networks**

31 An ontology produces a common language for sharing and reusing knowledge about  
32 phenomena in a particular domain. It is an agreed specification of how to describe all the  
33 concepts, (objects, people, processes, relationships, transactions, etc), of a particular domain  
34 of interest. Indeed, by defining concepts and relationships used to describe and represent an  
35 area of knowledge it provides a common understanding of the same, that before may have  
36 had different views and interpretations from the different practioners (Berners-Lee &  
37 Fischetti, 1999; Guarino & Oberle, 2009; Gruber, 1995). Following very simple modelling  
38 principles, it uses classes, properties and relationships to define a hierarchical view of the  
39 world (designated by taxonomy). An ontology is engineered by members of a domain  
40 which try to represent a reality as a set of agreed upon terms and logically-founded  
41 constraints on their use (Mika, 2005).

42 The development of ontologies has lately been widely adopted by companies. However, if  
43 all were to develop one of their own, all semantic issues would remain. This way, as a  
44 standard is needed to harmonize different information models existing in a supply chain, a  
45 reference ontology is needed to harmonize semantics. This reference ontology will be the

1 knowledge front-end, enabling inter-enterprises terminology sharing (Jardim-Goncalves et  
 2 al., 2009a or 2009b). Its building process is long and involves gathering human knowledge  
 3 from many organizations.  
 4



5

6 Fig. 7. MENTOR methodology (Sarraiapa et al., 2010)

7 In this context, the development of an enterprise reference ontology can follow the  
 8 MENTOR methodology (Fig 7). MENTOR - Methodology for Enterprise Reference  
 9 Ontology Development, is a collaborative methodology developed for helping a group of  
 10 people, or enterprises, sharing their knowledge with the other in the network, and provides  
 11 several steps as semantic comparisons, basic lexicon establishment, ontology mappings and  
 12 some other operations to build a domain's reference ontology. It aims to combine the  
 13 knowledge described by different formalisms in a semantic interoperable way (Sarraiapa et  
 14 al., 2010).

15 The Lexicon Settlement, or Phase 1, represents the knowledge acquisition by getting a  
 16 collection of terms and related definitions from all participants. This phase is divided into  
 17 three steps: Terminology Gathering, Glossary Building, and Thesaurus Building. The first  
 18 step is a very simple one, and represents the knowledge gathering from all participants in  
 19 the collaborative network in a form of a list of terms. In the Glossary Building step, a  
 20 glossary is built after a series of discussions about the terms that every participant  
 21 contributed to the network on the previous step. These discussions are followed by a voting  
 22 process, with all participants deciding which corresponding terms and definitions compose  
 23 the glossary. Beyond the glossary, the semantic mismatches record is another output that  
 24 results from this step. Finally, the last step of this phase is composed by a cycle where the  
 25 knowledge engineers define a taxonomic structure with the glossary terms. If there is an  
 26 agreement in both structure and classified terms, the thesaurus is defined. If not, the cycle

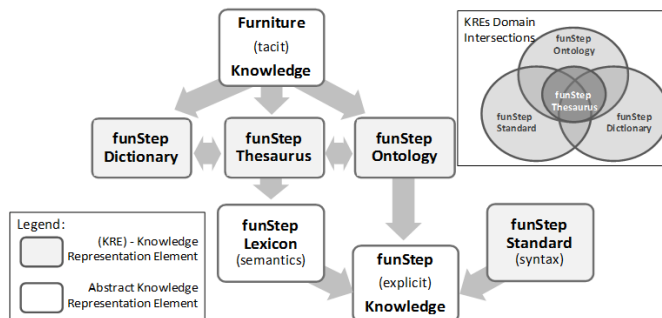


1 starts again for another iteration. In this first phase, it could be valuable to have a multi-  
 2 language dictionary for situations where a common language is not shared by all  
 3 participants.

4 The Reference Ontology Building, or Phase 2, is the phase where the reference ontology is  
 5 built, and the semantic mappings between participant's ontologies and the reference  
 6 ontology are established. This phase, just like the first phase, is divided into three steps:  
 7 Ontologies Gathering, Ontologies Harmonization, and Ontologies mapping. The first step  
 8 comprehends the acquisition of ontologies in the defined domain. In Ontologies  
 9 Harmonization step, it is needed to proceed for taxonomic harmonization and contents  
 10 harmonization. First, a discussion and voting process about the reference ontology structure  
 11 takes place where the common classes are defined by unanimity. This process of discussing  
 12 and voting is then repeated for the contents harmonization. The final step of this phase, the  
 13 Ontology Mapping, attempts to relate the vocabulary of two ontologies that share the same  
 14 domain. In this case, the idea is to establish mappings between each participant's ontology  
 15 and the reference ontology defined on the previous step (Sarraipa et al., 2010).

## 16 5.2 The *funStep* knowledge representation elements

17 As evidenced in Jardim-Goncalves et al. (2010) *funStep* endeavours to gather the tacit  
 18 knowledge that furniture supply chain stakeholders hold into machine interpretable  
 19 knowledge bases. For reaching that objective, the authors are proposing to integrate the  
 20 *funStep* standard (AP236) with the reference *funStep* Lexicon, which embodies the reference  
 21 concepts and semantics, and with a *funStep* reference ontology, which embraces product  
 22 classification to its related properties. This leads to the knowledge architecture definition  
 23 where the integrated knowledge is composed by four Knowledge Representation Elements  
 24 (KREs): the *funStep* Ontology; the *funStep* Thesaurus; the *funStep* Dictionary, and the *funStep*  
 25 AP236 (Fig 8).  
 26



27 Fig. 8. *funStep* knowledge architecture (Sarraipa et al., 2009a)  
 28

29 For a good explicit knowledge representation, it is needed to have significant input from the  
 30 tacit source (i.e., domain experts). Thus, such characteristic requires a knowledge  
 31 architecture enabling the management of the evolution between the KREs:

- 32 • The evolution of the first three KREs leads to the *funStep* Lexicon establishment which is  
 33 an abstract KRE because that it is composed by thesaurus contents;
- 34 • On the other hand, the *funStep* explicit knowledge KRE is another abstract KRE since it  
 35 is composed by the addition of the *funStep* Lexicon with the ontology and the standard

1           itself. The *funStep* explicit knowledge represents all the furniture machine interpretable  
2           knowledge where the *funStep* dictionary and the thesaurus are supporting KREs to the  
3           *funStep* Lexicon establishment and maintenance.

#### 4           **5.2.1 funStep dictionary**

5           A domain dictionary has been found to be one of the most useful tools for a domain  
6           analysis. The use of a dictionary reduces miscommunication by providing users an easy  
7           access to information about terms and abbreviations that are completely new to them. The  
8           *funStep* dictionary supports a multilingual collection of terms, thus enabling a correct  
9           coordination between international partners. Also, the terms are associated to other related  
10          terms.

#### 11          **5.2.2 funStep ontology**

12          The *funStep* ontology is being developed thanks to some of the *funStep*-driven research  
13          projects such as SMART-fm. It started by being a set of reference data for furniture product  
14          classification in electronic commerce, but nowadays, it is being evolved according to the  
15          MENTOR methodology and gifted with functionalities such as semantic comparisons, basic  
16          lexicon establishment, harmonization among other ontologies, etc.

#### 17          **5.2.3 funStep thesaurus**

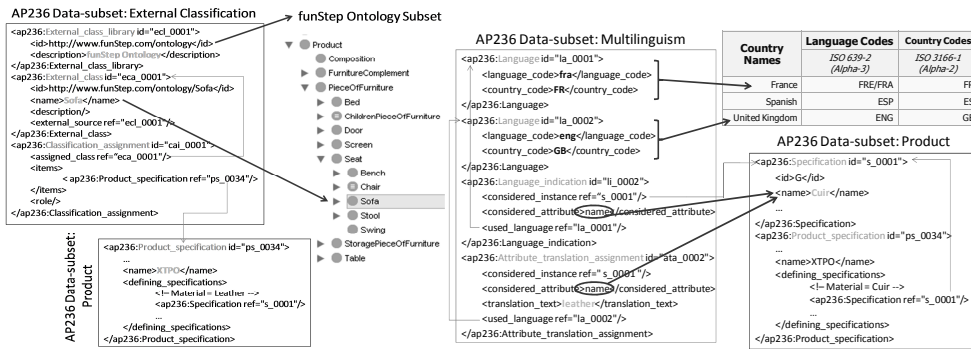
18          The basic lexicon establishment is reached by the development of a thesaurus on the  
19          domain. It is composed by a set of domain reference terms and concepts, clustered on the  
20          basis of their similarity, and organized by means of semantic relationships (e.g.,  
21          equivalence, subsumption, generalization, disjunction) to enable a better retrieval process of  
22          semantically related terms (Missikoff et al. 2004). A thesaurus can serve as a controlled  
23          vocabulary where terms are constrained to its domain-specific meanings, avoiding the  
24          problem of ambiguity (Gatlin, 2005). The *funStep* thesaurus envisages a multi-national scope  
25          of vocabulary, where terms with the same meaning coexist in multiple languages. Therefore,  
26          the thesaurus can be seen as a collection of parts of the dictionary, ontology and AP236 as  
27          illustrated on the top right part of Fig 8.

#### 28          **5.2.4 Semantic modules of the funStep AP236 standard**

29          As described earlier in this chapter (section 3.1) the AP236 standard has been developed  
30          following a modular approach to optimize reutilization and harmonization with the other  
31          STEP application protocols. In fact, some of these common structures are the modules that  
32          enable a direct link with knowledge representation elements to semantically enrich standard  
33          data. The set of modules of *funStep* standard (conformance options) that enable product  
34          classification and multilinguism are examples of relevance for semantic enrichment.

#### 35          External Classification

36          Each company in a supply chain has its own product nomenclature and structure. This is  
37          easily verified not only in the way catalogues are arranged, but also in the different  
38          designations companies use for the same concept. However, for an improved business,  
39          networks of organizations may define, or use shared reference ontologies or thesaurus,  
40          instead of legacy taxonomies. In this case, when exchanging product information, they  
41          should classify their products using that reference nomenclature. AP236 provides a  
42          mechanism for that, i.e. the external classification conformance option.



1

2 Fig. 9. AP236 semantic link examples

3 External classification enables a direct link between the context and the classes of products.  
 4 Nevertheless, the mentioned link uses meanings that are expressed in libraries physically  
 5 described in remote locations. The left side of Fig 9 illustrates how external classification  
 6 works: the product manufacturer links with the *funStep* reference ontology, using the AP236  
 7 entities: “external\_class” and “external\_class\_library”, to identify the externally defined  
 8 concepts, and “classification\_assignment” to establish the link with the product in the  
 9 catalogue.

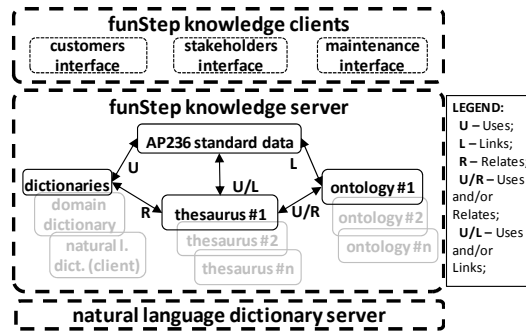
10 Multilingualism

11 For a better internationalization of the market, companies must be able to send their  
 12 products and associated information in several languages, especially in the language the  
 13 receiver company speaks. The multilingualism conformance option of AP236 addresses such  
 14 need, so that any organization could receive data in their native language independently of  
 15 where it was introduced or manufactured.  
 16 Multilingualism allows the translation of the attributes of AP236 entities in any number of  
 17 languages. In the right side of Fig 9, it is possible to notice that the AP236 entity “language” is  
 18 used to indicate the reference language. The entity “language\_indication” points to the attribute  
 19 that one wants to translate, and the “attribute\_translation\_assignment” specifies the translation  
 20 itself. In the example, it is the value of the attribute “name” that is being translated from the  
 21 French “cuir” to the English “leather”.

### 22 5.3 The *funStep* knowledge framework

23 Semantics is the study of language units meaning and their combinations. Therefore,  
 24 semantic enrichment is the act or process of adding specific meaning elements to some  
 25 knowledge representation structure in a domain, to help on the information clarification.  
 26 This way, the *funStep* standard semantic enrichment is characterized as being performed at  
 27 two basic levels: Terminological annotation, by using the terms identified in the Lexicon  
 28 (Thesaurus); and semantic annotation, by using concepts and expressions drawn from the  
 29 reference ontology.

30 Both levels are conducted through a knowledge framework as illustrated on Fig 10, which is  
 31 based on the KREs identified before. It is built up on web services technology enabling  
 32 interoperable open services over the internet between the *funStep* knowledge client systems  
 33 and the *funStep* knowledge server. This architecture is composed by three parts:



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2 Fig. 10. *funStep* knowledge framework

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- The *natural language dictionary (NLD) server* that complements the domain dictionary in the translation procedure of natural language information used within the AP236 multilingual data. For instance, let's imagine a request for quotation for a special request of a 2,5 meters long bed, sent by the e-marketplace of section 3.3 to a Portuguese manufacturer. He would need to translate something like "Bed 1452 with a length of 2,5m" and would use the domain dictionary for the translation of "bed" and possibly "length", but the rest needs to be handled by a NLD.
  - The *funStep knowledge server* which is composed by the four *funStep* KREs described in the previous section, whose relationships enable the semantic enrichment of the standards data;
  - The *funStep knowledge clients* that can be administrators, customers, or stakeholders. The role of the first is mainly related to KRE's evolution and maintenance, while the second are provided with functionalities that go beyond simple product search, namely enabling software developers with skills to develop enhanced intelligent products search engines based on knowledge reasoning. Finally, stakeholder interfaces are related to standard semantic enrichment itself.

## 19 6. Conclusions

20 To solve interoperability problems in the furniture supply chain, consisting mostly of SMEs  
 21 with heterogeneous needs, *funStep* has created an ISO standard which defines a formal  
 22 structure for catalogue and product data under industrial domains of the furniture sector.

23 Due to the modularization properties of STEP it is possible to establish direct cross-sectorial  
 24 links with other ISO standards. Among them are the automotive, aircraft, ship-building,  
 25 building & construction and other relevant sectors to the furniture segment, e.g. many  
 26 furniture manufacturers and designers act as suppliers sub-contracted by other sectors, like  
 27 automotive (refurbishment), ship-building (luxury Yates) or building & construction (wood-  
 28 made houses).

29 However, the main benefit of adopting the ISO *funStep* standard is the increased efficiency  
 30 that results from sharing data between different ICT systems seamlessly bringing additional  
 31 benefits without the need for re-enter information. Thus, there is a reduction of human  
 32 errors and end-to-end transaction time (lead-time). Using standard compliant systems  
 33 means that, component or products suppliers can provide full technical information about  
 34 their products to the retailer or e-marketplace, who in turn, can publish catalogues, operate

1 e-commerce systems, manage stock control systems or supply data to interior designers in  
2 an interoperable manner, all without the need to enter any data more than once. Customer  
3 orders placed with retailers can be communicated back up the supply chain immediately,  
4 enabling components, materials and manufacturing resources to be allocated at the earliest  
5 opportunity. Furthermore, it enables to combine catalogue data from several sources in a  
6 single retail management system by importing component specifications from multiple  
7 suppliers to a furniture design or manufacturing system.

8 Nevertheless, due to the complexity associated with the implementation of standards,  
9 especially STEP standards, the SMEs require a push. Mechanisms to facilitate and accelerate  
10 the adoption task and simultaneously minimizing the costs are required and are proposed  
11 in this chapter. Indeed, an example of which steps an e-marketplace should take to  
12 implement AP236 and become rapidly integrated with more manufactures has been  
13 demonstrated and used successfully during the INNOVAFUN project. Also, due to being an  
14 unfamiliar technology and lacking support from open or free solutions, in that situation the  
15 company decided to go for a XML-based implementation instead of using the native STEP  
16 formats.

17 Information and communications technology combined with the use of open-standards can  
18 be a very powerful tool to improve enterprise competitiveness via a wider adoption of STEP  
19 APs. However, with so many different modelling and implementation standards being  
20 used, interoperability problems arises when the chosen product model is described using  
21 one particular technology (e.g. EXPRESS) and is required to be integrated with systems that  
22 use totally different technologies (e.g. XML). Being ISO10303 STEP acknowledged, by most  
23 of the major industrial companies in the world within different sectors, as one of the most  
24 important family of standards for exchange of product data under the manufacturing  
25 domain, it would be expected to be broadly used. However, that is not so, especially on  
26 SME-based environments because the technology is unfamiliar to most application  
27 developers.

28 Based on that requirement, MDA technology can be used to enable automation of model  
29 morphisms, and therefore, translation at the information model and data levels (level 1 and  
30 0 of MDA). The first translation (level 1) is used exclusively to obtain language  
31 independency, providing a neutral ground for implementations and to define the necessary  
32 mappings to enable supply chain systems interoperability (level 0), which is realized by the  
33 real link between two enterprises. The proposed MDA-based architecture enables gradual  
34 and sustained system interoperability, since allows incremental AP236 implementations  
35 (using the conformance options and classes) without the need to rewrite the full system  
36 from scratch. Once the mappings are defined, the standard modelling language is no longer  
37 an issue, and the same MDA principle can be applied to the actual data to be exchanged, i.e.  
38 if its internal system already has the capabilities implemented but they are not integrated  
39 with the standard, only additional mappings need to be defined to transform internal data  
40 into AP236 format. The results presented in this part of the work have been applied and  
41 validated in several European/International industrial research projects such as IMS  
42 SMART-fm, Athena-IP, and InterOp NoE.

43 Finally, apart from being a technical issue, interoperability challenges also appear in the  
44 enterprises at organizational and semantic level, underlying the need for patterns and  
45 solutions that support the seamless cooperation among ICT systems, information and  
46 knowledge, organizational structures and people (Tursi, et al 2009, Jardim-Goncalves et al.,  
47 2009; Jardim-Goncalves & Grilo, 2009a & 2009b). Indeed, Schrage (1990), emphasizes that the

1 issue in collaboration “*isn’t communication or teamwork, it’s the creation of value*”. By this  
2 definition, it is possible to conclude that he was looking at collaboration from a perspective  
3 of people and not systems. Therefore, if instead of just looking at the software systems  
4 perspective, one could generalize to the everyday’s experience, it is possible to conclude the  
5 even though people have different cultural backgrounds or education, they can  
6 communicate (at least at basic level) if they speak the same language. The authors use this  
7 premise and apply it to the systems inter-enterprise level proposing a knowledge  
8 framework for semantic enrichment of supply chain data. The proposed *funStep* knowledge  
9 framework provides enterprise and manufacturing systems a semantically seamless  
10 communication with other stakeholders up and down the supply chain.

11 The authors, under the *funStep* initiative which is continuing the activities begun by the IMS  
12 SMART-fm project, propose the semantic enrichment of standardized product data as a  
13 solution for making interoperable intelligent manufacturing systems a reality. They  
14 endeavour to gather the tacit knowledge that furniture domain stakeholder’s hold into  
15 machine interpretable knowledge bases, which should be stored in a structured organized  
16 way, where syntax and lexical semantics are integrated as explicit knowledge. This allows  
17 enterprises to keep their internal terminologies and classification systems, and still remain  
18 interoperable with their business partners, through the usage of knowledge mapping  
19 procedures. Together, the domain dictionary, the thesaurus, the reference ontology and the  
20 AP236 standard itself act as explicit knowledge repository and reference lexicon for the  
21 application domain.

22 In the past, the *funStep* framework was able to deliver two levels of product data exchange  
23 interoperability compliance: (level 1) - *not funStep compliant* – where the messages exchanged  
24 are following any kind of format other than the AP236 standard; (level 2) - *funStep compliant*  
25 – where, the exchanged messages were compliant with the AP236 standard. From the  
26 research results presented in this chapter, the *funStep* Knowledge framework is extended  
27 adding semantics compliance to it, i.e. (level 3) - *funStep knowledge compliant*. With level 3  
28 compliance, systems communications would be syntactically compliant with the AP236  
29 standard and as well semantically compliant with the reference *funStep* knowledge.

30 Besides what has been here detailed, *funStep* provides a permanent support to the furniture  
31 supply chain with a set of services available to the end user in the form of: a) Software Services;  
32 b) Training Services; c) Validation Services and d) Consultancy Services (INNOVAFUN, 2008).  
33 The services have the objective of assisting on the *funStep* standard comprehension,  
34 implementation process, and also on development and design of new business practices on  
35 SMEs. They offer new opportunities for innovation and content management, while also  
36 achieving lower costs and more rapid deployment

## 37 **6.1 Future work**

38 Manufacturing and retailing systems are becoming more and more complex and dynamic.  
39 They need to be constantly adapting to new market and customer requirements who  
40 demand a faster and better quality service. Even standards need to be adjusted from time to  
41 time. This behaviour is reflected in a constant fluctuation and evolution of business  
42 networks and system models, which makes interoperability difficult to maintain.

43 The open research questions raised in the introduction are not completely answered, and  
44 despite of the importance of enterprise interoperability (EI) in the global economy, there is  
45 not yet an established scientific base for EI. Due to this fact, situations such as loss of  
46 interoperability have a great impact on the enterprise turnover. Indeed, it is of paramount

1 importance to identify an EI science base that embodies lessons learnt from the  
2 neighbouring domains such as complexity or services science. The aim in the future is to  
3 formalise interoperability problems and solutions such as the ones here discussed,  
4 ultimately guaranteeing reusability and repeatability.

5 The authors intend to address this non-linear problem in future research involving  
6 feedback, monitoring and prognosis mechanisms as part of the business network solutions.  
7 With these, they intend to include dynamism in the morphisms maintenance among  
8 systems, thus allowing automatic readjustments in the information flows without the need  
9 to reprogram the full systems. In this line, the ENSEMBLE FP7 project  
10 (<http://www.ensemble-csa.eu>) is already providing the framework to validate such results  
11 and considerations, working within the Future Internet Enterprise Systems (FIInES)  
12 community to develop and implement a systematic approach to the establishment of EI as a  
13 science.

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