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Continuous Operational Interoperability

Nicolas Figay

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Nicolas Figay. Continuous Operational Interoperability. Computer Science [cs]. Université Claude Bernard Lyon 1; LIRIS UMR 5205 CNRS/INSA de Lyon/Université Claude Bernard Lyon 1/Université Lumière Lyon 2/École Centrale de Lyon, 2021. tel-04413469v2

HAL Id: tel-04413469

<https://hal.science/tel-04413469v2>

Submitted on 11 Feb 2024

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N°d'ordre NNT : 034 2021

HABILITATION A DIRIGER DES RECHERCHES

DE L'UNIVERSITÉ DE LYON

opérée au sein de

l'Université Claude Bernard Lyon 1

Ecole Doctorale N° 512

Informatique et Mathématiques

Discipline : Informatique

Soutenue publiquement/à huis clos le 12/07/2021, par :

Nicolas Figay

Continuous Operational Interoperability

Interopérabilité Opérationnelle Continue

Devant le jury composé de :

Biennier, Frédérique, Professeur des Universités, INSA de Lyon, Présidente
Ait Ameer, Yamine, Professeur des Universités, L'INP-ENSEEIH, Toulouse, Rapporteur
Charoy, François, Professeur des Universités, Université de Lorraine, Rapporteur
Koukam, Abderrafiaa, Professeur des Universités, Université de Technologie de Belfort-Montbéliard, Rapporteur
Drira, Khalil, Directeur de Recherche, CNRS Toulouse, Examineur
Goncalves, Ricardo, Professeur des Universités, NOVA University of Lisbon, Examineur
Exposito, Ernesto, Professeur des Universités, Université de Pau et des Pays de l'Adour, Examineur
Ghodous, Parisa, Professeur des Universités, Université Claude Bernard Lyon 1, Examinatrice

Acknowledgement

First of all, I would like to thank the members of my jury. I address my warmest thanks to Pr Yamine Ait Aneur, Pr François Charoy and Pr Abderrafiaa Koukam for accepting to be reviewer of this brief and for their insightful and constructive comments.

I warmly thank Frédérique Biennier for having accepted to chair my jury.

I also express my gratitude Pr Parisa Ghodous, Pr Ernesto Exposito and Pr Ricardo Gonçalves for having agreed to participate in my jury.

I would like to express my thanks to Parisa Ghodous who many years ago suggested that I make a thesis. She not only supervised it, but also allowed me to co-supervise Malik Khalfallah's one, making it possible for me to pretend to have this Authorization to Drive Research. Our collaboration for publications has always been fruitful and an actual pleasure.

With great sincerity, I thank David Tchhoffa I met during the SIP project, and who always encouraged me and pushed me for writing research articles, in particular after the closure of the research department of Airbus. I also thank Ernesto Exposito, who made the collaboration between LAAS and EADS a success during the IMAGINE project.

I don't forget those who trusted me and relied on me for my expertise, giving me opportunities for further personal development, exciting and challenging projects, fruitful collaborations and better visibility: Jean-Yves Delaunay, Jean Brangé, Frédéric Féru, Yves Baudier, Jean-Yves Mondon, Amaury Soubeyran, Frédéric Darré, Pierre Duchier, Sophie Herail, Thomas Vosgien, Lyes Kermad, El Mouloudi Dafaoui, Kevin Letutour, Véronique Dubillot, Pierre Faure ...

Obviously, I will not forget to recall here the great pleasure experienced in working alongside the students, applicants or PhD, and for the continuous feedback they gave me about their career evolution and successes: Malik Khalfalah, Emna Moones, Jonas Martin, Sebastien Guermonprez, Ludovic Duchemin, Sophie Gatoux, Raphaël Lang, Flora Robin ... I wish them all the best for the future.

To all other members of the research, standardization or industrial project teams I participated in, as well as the other members of the organizations that I come into contact with daily, here is the sign of my gratitude and my friendship.

I also would like to give huge thanks to the passionate and brilliant people who have been producing incredible open standards or open source free software relying on open standards over the years. I learnt so much from them, and they have always been a source of inspiration. I'm thinking in particular of Phil Beauvoir & Jean-Baptiste Sarrodie (Archi for Open Group's ArchiMate), Sasa Bojanic (Shark and JaWe - workflow editor and engine based on Wfmc standards), Brian Chan (Liferay Horizontal portal),

I just can't forget to mention some important influencers (at least for me) such as Guy Doumeingts (Gray Methodology author, and a major contributor to Enterprise Application Interoperability through IDEAS and, Interop), Hervé Panetto (Holons for systems synchronisation and interoperability), Tim Berner Lee (Semantic Web), Jean-Jacques Urban-Gallindo (PSA PLM), Laurent Gouzenes (KM3), Christophe Longépé (Controlled Urbanisation of Information Systems), Gerben Wierda (Mastering ArchiMate), Ed Barkmeyer (NIST expert), Joel de Rosnay ("Le macroscope"), Isaak Asimov (Robots and Foundation cycles), Frank Herbert (Dune) and so many others.

Finally, a special thought will go to Françoise, Romain and Charlotte to whom I dedicate this memoir as well as to all my family.

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Résumé du mémoire d'HDR « Interopérabilité Opérationnelle Continue »

J'effectue depuis de nombreuses années (depuis 1997) des activités relatives à l'interopérabilité des applications techniques d'entreprise en lien avec la mise en œuvre des standards d'échange, de partage et de pérennité des données décrivant le produit et les processus associés. Ces activités se sont faites en étroite collaboration avec le monde académique, le monde industriel et le monde de la normalisation. Cela m'a permis de développer un profil d'expert reconnu internationalement (Expert Airbus, Expert International à l'ISO), y compris dans le monde de la recherche avec la réalisation d'une thèse sur le sujet défendu en 2009 à l'Université C.B. Lyon 1 sous la direction de Pr. Parisa Ghodous.

Depuis, j'ai encadré des travaux de thèses, toujours avec l'étroite collaboration entre mon entreprise et mes partenaires académiques. J'ai également contribué à l'état de l'art au travers de diverses publications scientifiques sur la thématique liée à mon expertise. Obtenir l'habilitation à encadrer la recherche s'inscrit tant dans mon projet de recherche que dans mon projet professionnel au sein d'Airbus.

En termes de recherche, l'ambition est de continuer à faire progresser l'état de l'art tout en transmettant le savoir acquis durant ces 20 dernières années à de jeunes chercheurs.

Au sein d'Airbus, l'objectif est de faire évoluer le cadre d'interopérabilité développé pour répondre, en s'appuyant sur l'état de l'art et les meilleures pratiques industrielles, aux défis liés à la digitalisation que les membres de l'industrie aéronautique, spatiale et défense doit relever pour rester compétitifs.

Mon principal thème de recherche est l'établissement de l'interopérabilité opérationnelle continue, et ce à un coût acceptable, requise pour le Product Life cycle Management¹.

Mes travaux de recherche ont visé à définir une approche innovante pour soutenir, préparer et construire une interopérabilité opérationnelle continue entre les applications, et ce à un coût acceptable, dans un environnement commercial et technique en constante évolution. Les applications sont distribuées au sein des entreprises et à l'extérieur des entreprises, c'est-à-dire au sein des chaînes d'approvisionnement d'écosystèmes numériques d'entreprises collaborant autour de produits donnés incluant des filières multiples. L'interopérabilité souhaitée doit se construire tant au niveau de l'organisation des entreprises et de leurs processus, qui s'appuient sur ces applications, que sur les technologies permettant de réaliser ces applications et de les connecter. Les données sont distribuées entre divers systèmes interconnectés et en reconfiguration permanente. Enfin, la sémantique des données doit être préservée en dépit des multiples transformations qu'elles subissent pour pouvoir être manipulées et traitées par des produits logiciels extrêmement hétérogènes et en constante évolution.

¹ « Une approche stratégique qui applique un ensemble cohérent de solutions pour soutenir la création, la gestion, la diffusion et l'utilisation collaboratives des informations de définition de produit dans toute l'entreprise étendue, et s'étendant du concept de produit à la fin de vie - intégrant les personnes, les processus, les systèmes métier et les informations. » ([CIMDATA glossary](#))

Adresser cette thématique de recherche m'a amené à:

- Soutenir une thèse de doctorat et obtenir le titre de docteur en informatique
- Co-encadrer 4 doctorants et 5 masters
- Publier 9 articles dans des revues internationales, 18 chapitres d'ouvrage et 25 communications dans des conférences du premier plan.
- Monter et réaliser de nombreuses études de recherche au sein du réseau de recherche et technologies du Groupe, environ 60 sur 20 ans
- Lancer, piloter ou contribuer à 15 projets de recherche européens ou français
- Evaluer et caractériser une centaine de technologies et standards censés permettre de construire l'interopérabilité, ainsi que des modèles et des cadres d'interopérabilité
- Publier 67 articles de vulgarisation sur LinkedIn depuis 2016, qui ont cumulé 200 000 vues et permis la constitution d'un réseau d'environ 10 000 suiveurs.
- Etre invités à plus de 30 conférences nationales et internationales pour présenter mes travaux
- Etre reconnu comme expert international dans les organismes de standardisation depuis 1997
- Etre reconnu comme expert au sein d'Airbus depuis 2004
- Etre invité à présenter les résultats de mes travaux à une trentaine de conférences
- Dispenser environ 2500 heures de cours depuis 2002 à des étudiants de master niveau M2

D'après l'état de l'art et de la pratique, l'interopérabilité est une thématique de recherche importante (mentionnée par 2157 projets européens) qui s'applique à de très nombreux domaines. La définition de l'interopérabilité dépend du domaine et des systèmes considérés donc il est nécessaire de clairement définir l'interopérabilité visée dans le contexte du PLM et de préciser le système d'intérêt.

En outre, les besoins d'interopérabilité ont donné lieu au développement de nombreux modèles, plateformes et standards avec les cadres associés. Néanmoins ces derniers, considérés séparément, ne répondent pas de manière exhaustive aux besoins relatifs à la préparation et à la construction d'une interopérabilité continue à un coût acceptable pour le PLM, notamment du fait de nombreux problèmes identifiés qui ont pu être collectés et évalués sur le long terme au travers de retours d'expérience de projet tant opérationnels que de standardisation et de recherche sur le sujet.

Pouvoir adresser l'ensemble de ces problèmes de manière consistante a guidé la définition de activités de recherche que j'ai pilotées, et de définir les problématiques pour lesquelles il a été possible de proposer des approches innovantes contribuant à l'état de l'art.

Mes quatre principales contributions à l'état de l'art sont :

1. La fédération des cadres et solutions d'interopérabilité. Il s'agit d'une approche innovante pour utiliser conjointement les cadres et les solutions d'interopérabilité existantes, qu'il s'agisse de modèles de référence, de plateformes, de solutions ou de standards. Ces cadres et solutions ont chacun leur propre cycle de vie, et sont développées mais surtout gouvernées de manière indépendante et par des acteurs différents. Ceci impose d'adopter une approche permettant de fédérer ces cadres pour sélectionner des ensembles consistants de standards et de solutions les implémentant, couvrant de manière globale l'ensemble des besoins, afin de pouvoir préparer, en lien avec la gouvernance, et construire, en lien avec l'architecture du système considéré, l'interopérabilité opérationnelle. Les

solutions retenues sont en particulier celles identifiées par la communauté de recherche sur l'interopérabilité des applications d'entreprises : la modélisation d'entreprise, l'ingénierie par les modèles, les plateformes d'exécution de modèles orientées services et les ontologies. L'évolution continue des environnements métiers et des technologies de l'information et de la communication implique de gérer en configuration l'ensemble des solutions à utiliser et de s'appuyer sur une architecture modulaire, composite et reconfigurable du système à considérer. Du fait des contraintes PLM, notamment liées à la rétention des informations sur des périodes excédant la durée de vie des pratiques métiers et des solutions utilisées qui deviennent obsolètes très rapidement, l'approche doit de plus permettre la rénovation et l'extension continue et à un rythme soutenu des systèmes considérés. Ici encore, l'interopérabilité doit être maintenue à coût acceptable tout en adressant les risques associés à ces évolutions. Cette approche a été développée et utilisée de manière continue, en s'appuyant sur une plateforme collaborative expérimentale, la cPlatform, qui a connu des itérations successives selon un processus défini par cette même approche. Ceci a permis d'évaluer, de valider et de démontrer l'approche, ce qui a donné lieu à la publication de plusieurs articles scientifiques, au développement de nombreux démonstrateurs et à l'implication tant de thésards que d'étudiants M2 en apprentissage.

2. **La préservation sémantique.** Il s'agit d'une approche permettant de préserver la sémantique des données lorsque l'on met en œuvre tant les processus PLM s'appuyant sur les normes d'interopérabilité PLM que les processus d'ingénierie par les modèles des composants applicatifs d'une plateforme PLM collaborative. Elle est motivée par le constat que toute transformation de données visant à changer de langage amène forcément une perte de données, du fait de l'absence d'une équivalence 1 à 1 de toutes les constructions des langages utilisés. L'approche proposée s'appuie sur le concept de l'hypermodèle, qui est un ensemble de représentations d'une même chose avec des langages et pour des usages différents. Ce concept a été étendu pour supporter l'interopérabilité PLM au travers de l'approche de fédération des cadres et standards d'interopérabilité, et afin de pouvoir générer automatiquement des composants des plateformes de collaboration à partir des standards. Une première proposition, issue de ma thèse, a adressé les multiples représentations de graphes sémantiques, sans prendre en compte les représentations modulaires avec des langages de descriptions composites. Les limitations des graphes sémantiques ont été identifiées pour l'échange de telles représentations. Ceci a donné lieu à une seconde proposition innovante pour modéliser des représentations s'appuyant sur la sémantique d'un langage métier au-dessus des langages de modélisation supportant la modularisation et les modèles composites. Cette approche devrait permettre de coupler l'usage des technologies du Web sémantique permettant de publier des ontologies sur le Web avec l'usage des modèles produits par l'ingénierie système par les modèles. Ces travaux ont donné lieu à plusieurs publications scientifiques, au développement de plusieurs démonstrateurs et à de multiples cas d'usage permettant de valider l'approche.
3. **La modélisation de la mise en réseau dynamique des entreprises collaborant pour les produits manufacturés.** Il s'agit d'une approche répondant aux limitations des standards de modélisation d'entreprise pour adresser la problématique visant à préparer et à construire l'interopérabilité opérationnelle et continue pour le PLM. En effet, ces langages sont en général assez limités en ce qui concerne la représentation d'un produit dans un contexte PLM. Une telle modélisation est nécessaire et pertinente pour planifier, qualifier et surveiller les capacités des membres d'un réseau dynamique industriel à collaborer en utilisant les standards PLM avec des participants, personnes ou applications, qualifiés. Une approche innovante a été proposée pour supporter ces besoins au sein d'un écosystème numérique mature en termes d'interopérabilité, utilisant des hubs PLM collaboratifs. Pour

les processus collaboratifs mis à disposition pour exécution au travers du hub, les capacités requises par chaque type de participants considéré dans ces processus, ou rôle, sont décrites. Chaque partenaire souhaitant jouer un rôle dans tel ou tel processus développe ses capacités pour pouvoir jouer ce rôle. Il devient ainsi un participant potentiel qualifié, et il publie cette information au sein du hub. Une collaboration ne peut être mise en œuvre selon un processus collaboratif basé sur l'usage des normes PLM que lorsque que l'on peut trouver des participants pour jouer chaque rôle défini par le processus. Le modèle de processus de collaboration devient ainsi un contrat de collaboration, et le hub de collaboration un médiateur. L'approche a donné lieu à une expérimentation au-dessus de la cPlatform. Pour cela, trois composants de la cPlatform ont été étendus par l'implémentation des fonctionnalités requises pour mettre en œuvre cette approche. Elle a donné lieu à plusieurs articles de recherche. La capacité à coupler les processus des partenaires au travers du processus de collaboration a donné lieu à une thèse que j'ai co-encadrée, sur l'interopérabilité des processus.

4. **Banc d'essai pour l'interopérabilité PLM.** L'approche innovante proposée vise à répondre à des limitations identifiées concernant la capacité des membres d'un écosystème numérique collaborant au travers d'un hub PLM à évaluer les standards PLM à mettre en œuvre d'une part, et à spécifier et tester les implémentations de ces standards par les produits logiciels réalisant leurs applications d'autre part. Une approche innovante a été proposée qui consiste à faire de la plateforme collaborative un banc de test d'interopérabilité. Dans la phase d'évaluation des normes et d'expérimentation, la plateforme peut être générée automatiquement par une usine logicielle, s'appuyant sur une librairie de composants qui s'enrichit au fur et à mesure. Cette évaluation donne lieu à la création de jeux de données de tests, et de procédures de test qui pourront être rejoué dans la phase de test. Dans la phase de test des solutions applicatives des partenaires implémentant ces normes, la plateforme permet de rejouer les scénarios de test et réaliser tant des tests unitaires par application, que d'intégration pour toutes les applications à impliquer dans une collaboration. Enfin, dans une logique d'intégration continue, la plateforme peut être utilisée pour surveiller le déroulement des collaborations et identifier des dysfonctionnements demandant des actions correctives. L'approche proposée a donné lieu à des publications scientifiques, et a pu être appliquée sur une dizaine de cas concrets, démontrant sa pertinence, tant pour l'évaluation de normes et de leurs implémentations avec plusieurs types de technologie que pour l'évaluation de la mise en œuvre d'une norme dans un contexte industriel. Enfin, elle a donné lieu à une collaboration pour la réalisation d'une thèse avec la mise en œuvre des normes d'intégration entre l'entreprise et l'usine.

Toutes ces contributions à l'état de l'art adressent la même problématique: adresser conjointement l'ensemble des freins identifiés qui empêchent d'obtenir l'interopérabilité opérationnelle continue requise pour le PLM. Néanmoins tous les freins ne sont pas adressés, et tant les pratiques que les technologies émergentes amènent de nouveaux problèmes nécessitant de faire progresser l'état de l'art et la transformation numérique. Trois perspectives à court terme concernent l'interopérabilité PLM en relation avec le Cloud, l'Intelligence Artificielle (IA) et les produits connectés autonomes.

1. **PLM collaboratif au-dessus de cloud distribués et hétérogènes:** les tendances actuelles concernant le Cloud entraînent l'utilisation de plus en plus fréquente de containers orchestrés pour des solutions élastiques à bases de micro services. Cela amène une nouvelle complexité, tant en termes de technologies que de gouvernance. Quels sont les standards requis, existants ou à développer, à fédérer avec ceux déjà identifiés pour maintenir

l'interopérabilité PLM dans les écosystèmes numériques? Un aspect particulier est lié à l'impact de la virtualisation sur la capacité à préparer et à construire l'interopérabilité.

2. **PLM collaboratif et technologies de l'IA:** les tendances actuelles concernant l'intelligence artificielle, qu'il s'agisse de bases de connaissances avec moteurs de règles ou d'apprentissage en profondeur, posent la question de la publication ou de la mise à disposition des données décrivant les produits et les processus associés vers ce type de solutions. Comment préserver la sémantique et le contexte d'interprétation des données en question pour les intégrer dans une chaîne de collaboration maîtrisée? Un aspect particulier est lié à la capacité de produire des représentations multiples de règles métier échangeables entre les plateformes technologiques, de telles sortes que les informations produites par les systèmes d'IA soient consistantes avec les données sources en provenance des plateformes PLM.
3. **Banc d'essai PLM étendu pour des produits connectés autonomes avec jumeaux numériques:** les tendances actuelles concernant les « makers», en lien avec l'extension de l'open source au matériel et aux processus de fabrication additifs, créent une situation nouvelle sans précédent : des produits complets s'appuyant sur des technologies innovantes sont mis à disposition sur étagère, avec les modèles de conception et les processus de fabrication permettant de les construire rapidement avec des coûts très bas, comme prototypes parfaits des nouveaux produits devant communiquer ou interagir avec leurs environnements. Tout en étant représentatifs de la nouvelle complexité à appréhender pour ces types de produits, ils ne sont pas soumis aux contraintes rencontrées pour les autres produits industriels concernant l'accès aux données, qui sont en général confidentielles ou difficiles d'accès. Ils sont par conséquent des composants de choix pour constituer de nouveaux types de banc d'essai pour l'interopérabilité PLM à établir pour des produits connectés autonomes et des jumeaux numériques. Les modèles de conceptions des produits peuvent être réutilisés pour dériver des jumeaux numériques de ces produits, pour leur surveillance, leur paramétrage ou leur contrôle à distance dans les divers contextes reflétés par une plateforme collaborative PLM bâtie selon les principes de l'approche fédérative.

Ces sujets sont propres à faire surgir de nouveaux problèmes d'interopérabilité dont la résolution se fera dans le cadre de l'approche globale définie avec la Fédération des cadres et solutions d'interopérabilité, permettant d'intégrer les activités de recherche dans des cycles d'innovation raccourcis et adaptés au nouveau contexte résultant de l'évolution des technologies de l'information et de la communication.

Le manuscrit est structuré en sept chapitres.

- Le premier chapitre décrit mes activités liées à la recherche et à l'enseignement.
- Le second chapitre introduit le sujet de l'interopérabilité PLM basé sur les standards PLM.
- Le troisième chapitre décrit ma contribution relative à la Fédération des cadres d'interopérabilité.
- Le quatrième chapitre décrit ma contribution relative à la Préservation Sémantique.
- Le cinquième chapitre décrit ma contribution relative à la mise en réseau dynamique.
- Le sixième chapitre décrit ma contribution relative au banc de test pour l'interopérabilité.
- Le septième chapitre conclut et présente les perspectives de nouvelles contributions à la thématique de l'interopérabilité opérationnelle continue pour le PLM.

Introduction

For many years (since 1997) I have been carrying out activities relating to the interoperability of business technical applications in connection with the implementation of standards for the exchange, sharing and sustainability of data describing the product and the associated processes. These activities were carried out in close collaboration with the academic world, the industrial world and the world of standardization. This allowed me to develop an internationally recognized expert profile (Airbus Expert, International Expert at ISO), including in the world of research with the completion of a thesis on the subject defended in 2009 at the CB Lyon 1 University under the supervision of Pr. Parisa Ghodous. Since then, I have supervised thesis work, always with the close collaboration between my company and my academic partners. I have also contributed to the state of the art through various scientific publications on the theme related to my expertise. Obtaining authorization to supervise research is part of both my research project and my professional project within Airbus. In terms of research, the ambition is to continue to advance the state of the art while passing on the knowledge acquired over the past 20 years to young researchers. Within Airbus, the objective is to develop the interoperability framework developed to respond, based on the state of the art and best industrial practices, to the challenges linked to digitization that the members of the Aeronautics, Space and Defense industry must step up to remain competitive.

My main research topic is establishing the continuous operational interoperability, at an acceptable cost, required for Product Life Cycle Management (PLM).

My research has aimed to define an innovative approach to support, prepare and build continuous operational interoperability between applications, at an acceptable price in a constantly evolving commercial and technical environment. The applications are distributed within companies and outside companies that is to say within the supply chains of digital ecosystems of companies collaborating around given products including multiple sectors. The desired interoperability must be built both at the level of the organization of companies and their processes, which are based on these applications, and on the technologies enabling these applications to be produced and connected. The data is distributed among various interconnected systems and in permanent reconfiguration. Finally, the semantics of data must be preserved despite the multiple transformations they undergo in order to be able to be manipulated and processed by extremely heterogeneous and constantly evolving software products

Addressing this theme has been performed through various research projects and led me to defend a doctoral thesis, to supervise PhD and students' work, to teach and to publish. It led to be recognized within the industrial, standardization and academic world.

According to the state of the art and the practice, interoperability is an important research topic (mentioned by 2157 European projects) which applies to very many fields. The definition of interoperability depends on the domain and the systems considered, so it is necessary to clearly define the intended interoperability in the context of PLM and to specify the system of interest.

In addition, interoperability needs have given rise to the development of many models, platforms and standards with associated frameworks. However, the latter, considered

separately, do not exhaustively meet the needs relating to the preparation and construction of continuous interoperability at an acceptable cost for the PLM, in particular due to the many problems identified that could be collected and evaluated over the long term through feedback from the project, both operational and standardization and research on the subject.

Being able to address all of these problems in a consistent manner guided the definition of my research activities, and to define the problems for which I was able to propose innovative approaches contributing to the state of the art.

My four main contributions to the state of the art are:

1. **The federation of interoperability frameworks and solutions.** It is an innovative approach to jointly use existing interoperability frameworks and solutions, whether they are reference models, platforms, solutions or standards. These frameworks and solutions each have their own life cycle, and are developed but above all governed independently and by different actors. This requires adopting an approach making it possible to federate these frameworks in order to select consistent sets of standards and solutions implementing them, covering all the needs in a global manner, in order to be able to prepare, in connection with governance, and build, in link with the architecture of the considered system, operational interoperability. The solutions selected are in particular those identified by the research community on the interoperability of business applications: enterprise modelling, model based engineering, service-oriented model execution platforms and ontologies. The continuous evolution of business environments and information and communication technologies involves managing all the solutions to be used in configuration and relying on a modular, composite and reconfigurable architecture of the system to be considered. It is due to PLM constraints particularly related to the retention of information over periods exceeding the lifespan of the business practices and the used solution components - which become obsolete very quickly. The approach must also allow continuous renovation, upgrade and extension of the considered collaborative systems, with a sustained pace. Here again, interoperability must be maintained at an acceptable cost while addressing the risks associated with these changes. This approach has been developed and used on an ongoing basis, relying on an experimental collaborative platform that has undergone successive iterations according to a process defined by this same approach. This made it possible to evaluate, validate and demonstrate the approach, which resulted in the publication of several scientific articles, the development of numerous demonstrators and the involvement of both PhD students and M2 students in apprenticeship.
2. **Semantic preservation.** This is an approach to preserve the semantics of data when implementing both PLM processes based on PLM interoperability standards and Model Based Engineering processes of the applicative components of a collaborative PLM platform (Software Factory). It is motivated by the observation that any data transformation aiming to change language inevitably leads to a loss of data, due to the absence of a 1 to 1 equivalence of all the constructions of the used languages. The proposed approach is based on the concept of the hypermodel, which is a set of representations of the same thing with different languages and for different uses. This concept has been extended to support PLM interoperability through the federation approach of interoperability frameworks and standards. In this approach, automated generation of the components of collaboration platforms from the elected standards is to be supported. A first proposal, resulting from my thesis, addressed the multiple representations of semantic graphs, without taking into account the modular representations with composite description languages. The limitations of semantic graphs

have been identified for the exchange of such representations. This gave rise to a second innovative proposal to model representations based on the semantics of a business language on top of modelling languages supporting modularization and composite models. This approach should make it possible to couple the use of knowledge base relying on ontology, semantic web and linked data technologies, with the use of models produced by Model Based System Engineering. This work has given rise to several scientific publications, the development of several demonstrators and multiple use cases to validate the approach.

3. **Modeling of the dynamic networking of companies collaborating for manufactured products.** This is an approach that meets the limitations of standardized enterprise modelling languages to address the issue of preparing and building operational and continuous interoperability for PLM. Indeed, these languages are generally quite limited when it comes to the representation of a product in a PLM context. Such modelling is necessary and relevant to plan, qualify and monitor the capabilities of members of a dynamic industrial network to collaborate using PLM standards with qualified participants, people or applications. An innovative approach has been proposed to support these needs within a mature digital ecosystem in terms of interoperability, using collaborative PLM hubs. For the collaborative processes made available for execution through a hub, the capacities required by each type of participant considered in these processes, i.e. role, are described. Each partner wishing to play a role in a particular process develops the capacities to be able to play this role. He thus becomes a qualified potential participant, and he publishes this information within the hub. Collaboration can only be implemented in a collaborative process based on the use of PLM standards when participants can be found to play each role defined by the process. The collaboration process model thus becomes a collaboration contract, and the collaboration hub a mediator. The approach gave rise to an experiment above the cPlatform. For this, three components of the cPlatform have been extended by implementing the functionalities required to implement this approach. It has given rise to several research articles. The ability to couple partner processes through the collaboration process gave rise to a thesis that I co-supervised, on the interoperability of processes.
4. **PLM interoperability test bench.** The proposed innovative approach aims to respond to the identified limitations concerning the ability of members of a digital ecosystem collaborating through a PLM hub to assess the PLM standards to be implemented on the one hand, and to specify and test the implementations of these standards by software products carrying out their applications on the other hand. An innovative approach has been proposed which consists of making the collaborative platform an interoperability test bed. In the standards assessment and experimentation phase, the platform can be generated automatically by a software factory, relying on a library of components that is enriched over time. This evaluation gives rise to the creation of test data sets, and test procedures that can be replayed in the test phase. In the test phase of the application solutions of partners implementing these standards, the platform makes it possible to replay the test scenarios and perform both unit tests per application, and integration for all the applications to be involved in collaboration. Finally, in logic of continuous integration, the platform can be used to monitor the progress of collaborations and identify dysfunctions requiring corrective actions, including improvement or extensions of the standards. The proposed approach has given rise to scientific publications, and has been applied to around ten concrete cases, demonstrating its relevance, both for the evaluation of standards and their implementations with several types of technology and for the evaluation of the implementation of a standard in an industrial context. Finally, it gave

rise to collaboration for the completion of a thesis for the implementation of integration standards between the company and the factory.

All of these state-of-the-art contributions address the same issue: jointly addressing all of the identified brakes that prevent obtaining the continuous operational interoperability required for PLM. However, all the brakes are not addressed, and both practices and emerging technologies bring new problems that require advancing the state of the art and supporting digital transformation. Three short-term perspectives concern PLM interoperability in relation to the Cloud, Artificial Intelligence (AI) and autonomous connected products.

These subjects are likely to give rise to new interoperability problems, the resolution of which will be done relying on the global approach defined with the Federation of interoperability frameworks and solutions, making it possible to integrate research activities into shortened cycles for innovation, for a better adaptation to the new context resulting from the evolution of information and communication technologies.

The manuscript is structured into seven chapters.

- The first chapter describes my activities related to research and teaching.
- The second chapter introduces the subject of PLM interoperability based on PLM standards.
- The third chapter describes my contribution relating to the Federation of Interoperability Frameworks.
- The fourth chapter describes my contribution relating to Semantic Preservation.
- The fifth chapter describes my contribution to dynamic networking.
- The sixth chapter describes my contribution relating to the test bench for interoperability.
- The seventh chapter concludes and presents the perspectives of new contributions to the theme of continuous operational interoperability for PLM.

Chapter 1 - Activity Report

1.1 - Curriculum Vitae

First Name: Nicolas

Family Name: Figay

Birth date and place: 17/09/1965 at Paris

Nationality: French

Actual Professional situation

Title: Researcher- Interoperability for PLM Expert, System-Architect

Employer: AIRBUS

Since: 1st of September 1991

Diploma

2009: PHD in Computer Science (Doctorat en informatique) entitled « Technical Enterprise application interoperability» at University Claude Bernard - Lyon I, 27/11/2009.

- Jury members: Dr Shaw Feng, Pr. Ricardo Jardim-Goncalvez, Pr. Yvon Gardan, Dr Jean-Yves Mondon (Industry expert)
- Supervisor : Pr. Parisa GHODOUS
- Reporters: Pr. Aris M. Ouksel, Pr. Yamine Aït-Ameur.
- Defence the 27-11-2009 at University Lyon 1, within the frame of "École Doctorale d'Informatique et Mathématiques (Lyon)" , in partnership with LIRIS laboratory (Laboratoire d'Informatique en Image et Systèmes d'information - Lyon, Rhône)

1991: E.I.S.T.I. Engineer diploma (Ecole Internationale Sciences du Traitement de l'Information – CERGY- France), specialization « mathematics for decision”

Previous Professional situations

Since 2019: System Architect at Airbus Defence & Space within Engineering Department

Missions:

- Leading the System Engineering Governance Group which defines the requirements for Enterprise Architecture Framework Definition & Airbus Company architecture modelling.
- Supporting Programs as System Architect, disseminating and applying Model Based System Engineering practices, contributing to PLM strategic standardization as an expert.

2018-2019: Advanced Engineering Domain Architect at Airbus Defence & Space within the Information System Department

Mission: Production of Architecture Dossiers for Engineering Domain solutions in alignment with Enterprise Information System governance, Digitalization strategy and Operations.

Results and realization: Successful deployment and shared Return on experience for cross-enterprise collaborative cloud on Azure

1997-2018: Research Engineer at Airbus Group Innovations within the department dedicated to system engineering and PLM data engineering

Mission: supporting Airbus Group and his industrial programs

- for Process & Product data exchange, sharing and long term archiving needs
- By making the link between research community and industry

Drivers: Manufacturing 4.0, Concurrent Engineering aiming at reducing the time to market, efficient and secured eBusiness collaboration within the extended enterprise, Model Driven Engineering with multi-disciplinary simulation, certification and traceability constraints for Airbus Group's products, Software obsolescence

Results and realizations:

1. Contribution to Airbus Group PLM harmonization since 2004
 - Airbus Group representative/French international expert for ISO 10303 (STEP)
 - Participation as expert to PLM strategic standardization groups since 2004
 - Contribution to several standards development, implementation and usage projects for PLM (e.g. AP242 : « Managed model based 3D engineering » and AP239 : « Product Life Cycle Support »)
 - Orientation of research via contribution to several research roadmap, being Airbus Internal or related to international or national research framework programs
2. European/national research projects and research studies for Airbus Group divisions (Civil Aircraft, Helicopters, Defence and space: proposal writing, management, technical and scientific coordination/contribution)
Some figures : 13 research projects since 1997, more than 29 scientific publications since 2004)

1991-1997 Project manager and software solution development at **Aerospatiale**, Centre des Technologies de l'information, Suresnes

Mission: analysis, design and realization of applications within various domains

Some realizations:

- Analytic accounting of Aerospatiale
- Statistical Analysis of deformation of melded items of an aircraft
- Applications for headquarter applications related to human HR, Training & Payment

1.2 - Professional and Research activities

My research activities concern resolving Interoperability of Technical Enterprise applications based on Open Standards. I present below these activities in chronological order.

1.2.1 - Before 1997

I was initially an Engineer in the area of Sciences of Data Processing, with specialization in Mathematics for Decision. I spent 6 years as a Project Manager in the Information and Communication Technologies department at Aerospatiale. It gave me the opportunity to perform all the activities related to application development: capture and analysis of users' needs, design, development, deployment, support and evolution/migration - and to use and master a wide set of technologies and methods.

1.2.2 - From 1997 to 2018

From 1997, as researcher at Airbus Group Innovations, I carried out various research activities related to the usage of open standards as interoperability enablers for Product Data Exchange, Sharing & Long Term Archiving, Concurrent Engineering within the Supply Chain, Cross Life Cycle Interoperability for Product Life Cycle Management, or Virtual Manufacturing within a Dynamic Manufacturing Network. It took advantage of emerging information technologies supporting engineering practices.

In this department, I had also to carry out activities for contributing properly to the innovation process within the Airbus Group, relying on different Instruments (Europe or France funded research projects, internal studies, Research & Technology Groups) and resources, including research projects partners' ones but also interns, CIFRE master thesis I had to supervise and internal teams.

These activities consisted in:

1. Internal research studies for the Business Units of the Airbus Group within the frame of Research Technology Group related to Interoperability and PLM - for short term topics and support for dissemination and exploitation of the results
2. Contribution to responses to call for proposal, and participation to several research projects, as project leader or as participant, to many European or National research projects - for longer term research
3. Establishment of relations and coordination of these research activities with :
 1. Standardisation activities as International Standardisation expert through AFNOR CP IDMI - Ingénierie des Données et des Modèles pour l'Industrie - and ISO SC4 TC184: Industrial Data
 2. Internal strategic initiatives related to eBusiness and to PLM harmonization within the Group as Airbus Expert
4. Continuous survey concerning the state of the art and the state of the practice in my domain, being emerging technologies, practices or standards, and including various domains contributing to the establishment of continuous operational interoperability preparation and building.
5. Networking in the academic, standardization and industrial worlds, with establishment of long term collaboration contributing to achieve the long term vision of sustainable interoperability
6. Dissemination of the results of the research projects through communication, expertise and teaching activities inside and outside Airbus, in collaboration with some schools and universities.
7. Participation to Standardization Strategic Groups related to Product Lifecycle Management within Airbus and its Digital Business Ecosystem
8. Participation for establishment of the practices for PLM standards Implementor forums (through the Standard Interoperability PLM project)
9. Participation to the modernization of the considered standard architectural framework
10. Participation to and support of some standardization projects (e.g. ISO 10303 Application Protocol 242 - Managed model based 3D engineering)

If I gained Airbus internal recognition for the Standards Based PLM Interoperability through an Expert nomination in 2006, I also managed the recognition in the academic area by preparing a PHD thesis related to « Interoperability of Technical Enterprise Applications » which was successfully defended in 2009, in front of an International Jury. It allowed me to

contribute both to the state of the art (scientific contribution) and to the state of the practice with actual impacts on standardization or within my company.

1.2.3 - From 2018 to 2021

Due to the closure of the Research Centre, announced in 2016 and to the reorganization of research in the Group, I found other positions within the Group, first as an Enterprise Architect supporting Engineering Activities and then as a System Architect for systems to be delivered to the client.

I however continued to play my expert role: I contributed to model based practices by pointing out the need to consider model exchange and sharing. This was a different way to disseminate, to apply and to evaluate the results of my research activities, within an operational environment.

In addition, playing this role has allowed me to consider the impacts on interoperability of new trends such as agile practices at scale or DevSecOps (Integration of development and operations in a secured environment) approaches.

During this period, my continuous survey of the State of the Art and of the State of the Practice didn't stop, and encompassed new trends for anticipating new needs to be covered and new research challenges in terms of interoperability: distributed heterogeneous clouds, graph technologies, agile at scale relying on model based approaches, Internet of Everything with their applications to virtual manufacturing, digital twins, digital threats or autonomous & connected cyber-physical systems.

I also maintained my connection with the academic world by contributing to the writing of research articles:

- P00: « Alignment of the Product Lifecycle Management Federated Interoperability Framework with Internet of Things and Virtual Manufacturing » was recently submitted and accepted at “Computers in Industry” (P00). It was derived from an ICIST 2017 conference paper.
- P40: « Semantic Interoperability: Why and How to deal with Instantiable and Constrained Relations with OWL DL » is another article in preparation for the Journal of Web Semantics.

However, being not anymore within a research department but within an operational department, the time dedicated to research is currently reduced compared to my previous position at the Research Centre for producing research articles.

I consequently found another way for promoting and disseminating the results of my past and current research activities, but also for establishing closer links between research, standardisation and industry, by relying respectively on a social enterprise network and on research networks, respectively LinkedIn and ResearchGate/GoogleScholar. It is completed by a knowledge portal I put in place and used since my thesis for promoting the results of Interoperability Research Projects I contributed to and the PLM standardisation activities from development to governance I was involved in.

Since March 2016, many LinkedIn articles have been published (67 articles in June 2021) aiming at the vulgarization of my research results, with a continuously growing number of followers (9 790 in June 2021). The articles are promoting, informing, explaining and popularizing the PLM Interoperability topic, and the underlying enabling technologies and

practices relying on their combined usage. It includes cloud technologies, agile at scale, ontology, enterprise modelling, distributed software interoperability framework or model based engineering relying on consistent sets of relevant open standards. About 200 000 views were reached in June 2021, with a distribution indicating the most popular topics. Interoperability for PLM and standards appear as confidential topics, despite their importance when dealing with Digital Continuity, Secured Collaboration, Model Based System Engineering or Virtual Manufacturing. Cross references are provided with standardization and research activities outputs, in order to reinforce links between what has been produced through the industrial, standardization or academic activities.

In 2021, my expert position should be reinforced with more activities consisting in driving research. It is what motivates me to apply for Ability to Conduct Research.

1.3 - Teaching activities derived from research activity

Teaching activities were mainly undertaken within the context of Airbus Innovation Works, as a way for contributing to the dissemination of the research results but also for:

- 1) Finding students which can apply for internship inside my company
- 2) Preparing continuously up to date material for internal dissemination derived from the training preparation, i.e. various reports such as state of the art, state of the practice, awareness reports, etc. It was done in collaboration with Engineer schools with apprentices, or with university partners.
- 3) Involving students in the development of demonstrators or of proof of concept, assessing some identified interoperability enablers and various Standardized Enterprise Information System building blocks.

The concerned identified enablers were enterprise architecture/modelling for controlled urbanism, ontology, model driven approach and service oriented platforms. The concerned solution building blocks were enterprise workflow systems, enterprise portal, enterprise service bus and related technologies (middleware, Enterprise Java, etc.). The subjects I teach have been aligned with the evolution of my research topics and of the industrial trends I had to deal with, making the training activities contributing to the research activities, and the reverse.

The following table provides the number of training hours and practical experimentation given on these topics.

* Addressed Academic degree: M2 for master 2, M1 for Master 1

**schools and universities:

- **ITIN** (Institut De Formation En Informatique), Rue du Pas Saint Christophe 95800 Cergy which became ITESCIA
- **ITESCIA**, l'école de l'i-management (<https://www.itescia.fr/>)
- Institut Informatique Avancée (**IIA**) Laval (<https://www.ccifformation53.fr/>)
- University **Lyon 1** (<https://www.univ-lyon1.fr/>), Computer science department
- Ecole des **Ponts** Paritech (<https://www.ecoledesponts.fr/>)
- **CBAM** College of Business Administration for Managers 226Bis Dien Bien Phu St., Dist. 3, Ho Chi Minh City, Vietnam

When relevant and available, I also added in the table the concerned cursus defined by the schools:

*** Cursus (Optional): **ISI** for Information System eng(I)neering, **GLA/GM** for Software Architects, **ILM/GIC** for knowledge management.

Usually the training was made for the second year of master (M2) level, but some years, introduction of the topics (e.g. UML) were made during the first year (M1).

Precise (D)escriptions of sessions came progressively and are indicated when existing, in addition to the training (S)upport. Link to description of work to be performed during directed (P)ractices are indicated when available.

Name		School	Designation	Training	Practical	Total
Year 2002-2003				8	0	8
XML	M2	ITIN	XML Technologies- Usage and comparison to other similar and complementary technologies S	8	0	8
Year 2003 2004				48	16	64
Interoperability	M2	ITIN	Interoperability S	8	0	8
Product Data Management			Product Data Management S	8	0	8
XML			XML Technologies- Usage and comparison to other similar and complementary technologies S	8	0	8
EJB			Enterprise Java Beans S	8	0	8
Workflow			Workflow et Wfmc S S P	8	8	16
CORBA			CORBA D S	8	8	16
Year 2004- 2005				148	28	176
XML	M2	ITIN ISI	XML Technologies- Usage and comparison to other similar and complementary technologies S	8	0	8
PDM			GDT et Windchill S	8	0	8
HMI		ITIN GIC	Cours IHM-MDA S	8	0	8
HMI		ITIN GLA	Cours IHM-MDA S	8	0	8
OMG MDA EJB		ITIN ISI	CORBA-EJB-MDA S S S	12	12	24
Workflow			Workflow et Wfmc S P	8	8	16
Interoperability			Interoperability of Enterprise Applications applied to Industrial Sharing S	8	0	8
CORBA			CORBA D S	8	8	16
PLM		CBAM	Product Lifecycle Management	40	0	40
Interoperability		CBAM	Interoperability	40	0	40
Year 2005-2006				68	28	96
CORBA	M2	ITIN ISI	CORBA D S P P	8	8	16
OMG MDA EJB			OMG MDA EJB S S	12	12	24
Workflow			Workflow et Wfmc S	8	8	16
Ontology			Ontology S	8	0	8
Ontology		ITIN GM	Ontology S	8	0	8

Ontology		ITIN GIC	Ontology S	8	0	8
IHM MDA		ITIN GIC	IHM MDA S	8	0	8
Semantic Cartography		ITIN GIC	La cartographie sémantique: Introduction, approche et outils actuels S	8	0	8
Year 2006-2007				60	44	104
OMG MDA EJB	M2	ITIN ISI	OMG MDA EJB S	12	12	24
CORBA			CORBA S	8	8	16
PDM			GDT et Windchill S	8	0	8
Workflow			Workflow et Wfmc S , P	8	8	16
PDM	M2	ITIN ILM	GDT et Windchill S	8	0	8
IHM MDA	M2	ITIN GLA	IHM MDA D S	8	8	16
IHM	M2	ITIN GM	IHM S	8	8	16
Year 2007-2008				132	52	184
Interoperability	M2	ITIN ISI	Interoperability S	8	0	8
Ontology			Ontology D S	12	4	16
PDM			GDT et Windchill S	8	0	8
IHM MDA		ITIN GLA	IHM MDA D S	8	8	16
Ontology			Ontology D S	12	4	16
Semantic Cartography		ITIN ILM	La cartographie sémantique: Introduction, approche et outils actuels S	8	0	8
Ontology			Ontology D S	8	8	16
Open Source			Open Source and interoperability D S	8	8	16
Open Source		IIA	Open Source and interoperability D S	8	8	16
EAI			Interopérabilité/EAI D S	8	0	8
PDM			GDT et Windchill S	8	0	8
IHM MDA			IHM MDA D S	8	8	16
Interoperability			Interopérabilité S	8	0	8
Ontology			Ontology D S	12	4	16
Interoperability		Ponts	Enterprise Application Interoperability D S	8	0	8
Year 2008-2009				132	16	148
Interoperability	M2	Ponts	Enterprise Application Interoperability D S	8	0	8
Interoperability		ITIN ISI	Enterprise Application Interoperability	8	0	8
Ontology			Ontology	8	8	16
MDA		ITIN GLA	MDA D S	8	8	16
Ontology			Ontology	16	0	16
MDA		IIA	MDA D S	16	0	16
MDA IHM			MDA IHM D S	16	0	16
Ontology			Ontology	8	0	8
UML	M1	ITIN MSI	UML	16	0	16
Interoperability	M2	ITIN MSI	Interoperability	20	0	20

Interoperability		Lyon 1	Interoperability of Technical Enterprise Applications S - Including OpenDevFactory related training material S	8	0	8
Year 2009-2010				140	140	280
Workflow	M2	IIA	IIA Laval 2009-2010 D S	20	20	40
Ontology			IIA Laval 2009-2010 D S	20	20	40
Workflow		ITIN	ITIN 2009-2010 D S	20	20	40
Interoperability			Interopérabilité D S	20	20	40
Middleware			ITIN 2009-2010 D S	20	20	40
Ontology			2 times Ontology D D S	40	40	80
Year 2010-2011				188	180	368
Workflow	M2	IIA	Workflow tutorial D S	20	20	40
HMI & MDA			HMI & MDA D	20	20	40
Ontology			Ontology S	20	20	40
Controlled Urbanism		ITESCIA	Control Urbanism D S	20	20	40
HMI & MDA			HMI & MDA D S	20	20	40
Modeling			Modeling D S	20	20	40
Interoperability			Interoperability D S	20	20	40
Middleware			Middleware D S	20	20	40
Ontology			Ontology D S	20	20	40
Interoperability		Lyon 1	Interoperability S	8	0	8
Year 2011-2012				60	60	120
HMI & MDA	M2	ITESCIA	HMI & MDA D S	20	20	40
Distributed Architecture			Distributed Architecture D S	20	20	40
Ontology			Ontology D S	20	20	40
Year 2012-2013				124	124	248
Controlled Urbanism	M2	IIA	Urbanisation D S	20	20	40
Advanced UML			UML avancé D S	20	20	40
Workflow			Workflow D S	20	20	40
Controlled Urbanism		ITESCIA	Urbanisation D S	20	20	40
HMI & MDA			IHM & MDA D S	20	20	40
Interoperability			Interopérabilité D S	20	20	40
Interoperability		Lyon 1	Interoperability S	4	4	8
Year 2013-2014				144	144	288
Workflow	M2	IIA	Workflow D S	20	20	40
Controlled Urbanism			Urbanisation D S	20	20	40
HMI & MDA			IHM & MDA D S	20	20	40

Modeling			Modélisation D S	20	20	40
Controlled Urbanism	M2	ITESCIA	Urbanisation D S	20	20	40
Advanced UML	M2		UML Avancé D S	20	20	40
UML	M1		UML D S	20	20	40
Interoperability	M2	Lyon 1	Interopérabilité S	4	4	8
Year 2014-2015				144	144	288
Controlled Urbanism	M2	IIA	Controlled urbanisation and big data D S	20	20	40
Workflow	M2	ITESCIA	Workflow D S	20	20	40
Workflow			Workflow D S	20	20	40
Controlled Urbanism			Controlled urbanisation and big data D S	20	20	40
HMI & MDA			IHM & MDA D S	40	40	80
Modeling	M1		Modélisation D S	20	20	40
Interoperability	M2	Lyon 1	Interopérabilité S	4	4	8
Year 2015-2016				84	84	168
Advanced UML	M2	IIA	UML Avancé D S	20	20	40
Workflow		ITESCIA	Workflow D S	20	20	40
Controlled Urbanism		ITESCIA	Controlled Urbanism D S	20	20	40
Advanced UML		ITESCIA	UML Avancé D S	20	20	40
Interoperability		Lyon 1	Interopérabilité S	4	4	8
Year 2016-2017				4	4	8
Interoperability	M2	Lyon 1	Interopérabilité S	4	4	8
Year 2017-2018				4	4	8
Interoperability	M2	Lyon 1	Interopérabilité S	4	4	8
Year 2018-2019				4	4	8
Interoperability	M2	Lyon 1	Interopérabilité S	4	4	8
Year 2019-2020				4	4	8
Interoperability	M2	Lyon 1	Interopérabilité S	4	4	8
2020-2021				8	0	8
Interoperability	M2	Lyon 1	Interopérabilité S	8	0	8
All years				1424	1076	2500

Table 1 : Training activities

Tutorials

In addition, some training with associated training supports (documents or videos) were delivered within the frame of research projects:

- ATHENA: Contribution to Curriculum of the Interoperability Training Service by producing the Training for the Aerospace Industry training and associated support-2006

- IMAGINE: Contribution to produced training, reflected at the following address: <http://www.eads-iw.net/web/Imagine/training> . It was done through the production of the “IMAGINE Platform in the Aerospace and Defence domain training “with associated support on the pointed web page, but also derived videos on Youtube.
- IMAGINE: Producing The IMAGINE in Aeronautics training with associated support (TMT1)
- SIP: several trainings have been produced for training the members of the projects and the people involved in Standards Implementor forum or Standards usage in enterprises.

A dedicated web site, part of the collaborative platform I’ve been maintaining since my thesis, contains the training (D)escriptions and the training (S)upports referenced in the previous table at <http://www.eads-iw.net/web/training>

My public contribution to the research projects I participated to are also available through dedicated public web sites hosted on the same platform:

- <http://www.eads-iw.net/web/Imagine>
- <http://www.eads-iw.net/web/crescendo>
- <http://www.eads-iw.net/web/standards-interoperability-plm> which gives in particular access to the following subway map for PLM interoperability. Each station allows access to a web site or a video.

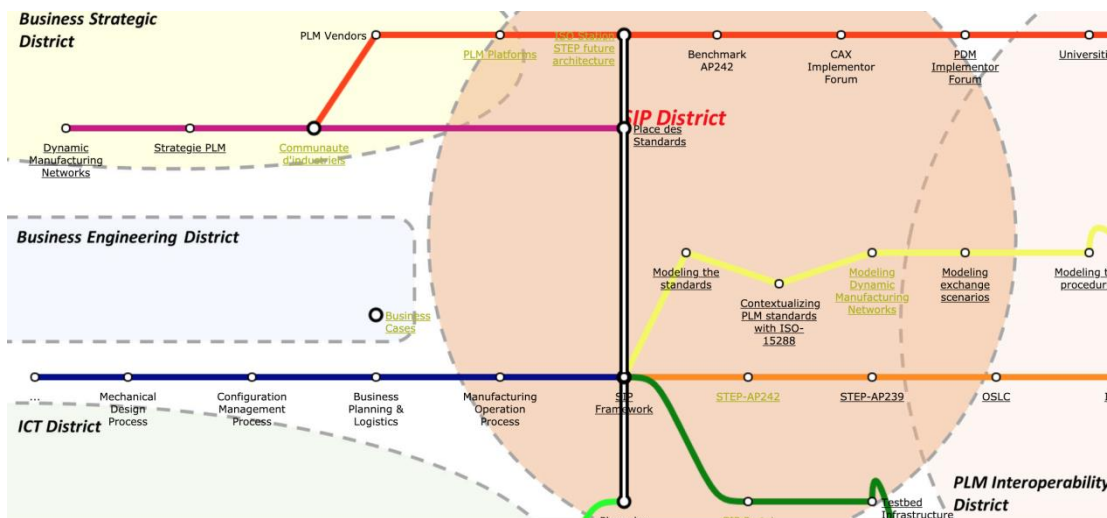


Figure 1 : Subway Map for PLM Interoperability for navigating SIP results

To some extent, the published content on the collaborative platform and on social platforms can be considered as a way to share knowledge, with a larger audience, but with similar objectives: to allow the people to know and to learn more about interoperability. The content constitutes support material for training. The publishing platform itself is an illustration of the usage of the promoted enabling technologies and of the application of my research results for developing interoperability of Enterprise Applications, in particular in terms of open knowledge sharing.

Vulgarisation and knowledge transfer

Several media have been used for promoting my research activities and results, with content which can be used as material for knowledge transfer, training support and vulgarisation:

YouTube online tutorials

- **Imagine tutorials**
 - [TCT1 Using the IMAGINE Platform](#)
 - Imagine Platform in the Aeronautic Domain Tutorial [Part 1](#), [Part 2](#), [Part 3](#) and [Part 4](#)
- **MOOC at University Lyon 1**
 - [Cloud et Internet des objets à AIRBUS](#) - 16th of July 2015
- **Knowledge base with Archi or Protégé**
 - [Graph Technologies Knowledge Base with Archi or with Protege](#)
- **Dynamic Manufacturing explanation and illustration**
 - [Qu'est qu'un DMN?](#), [What a DMN is](#), [DMN modelling with factories using ArchiMate 3, Archi and Graphico](#)
- **Future at SystemX - SIP presentations**
 - [Future@SystemX 20140306 SIP Presentation](#)
 - [SIP@Future2016IRTSytemX](#)
- **Practical usage of Proxmox**

It highlights the role of a virtualisation solution for machines and networks (SIP related)

[Proxmox 4.2 - creation of a bridge using PVE](#), [Proxmox V4.2 - appliance update and upload](#), [Proxmox V4 .2- creation of two networks vNIC vmbr0 and vmbr1](#), [Proxmox 4.2 - Debian KVM Install from Debian 8.5 netinst on a VMware on OSX](#), [Proxmox 4 - Creation of LXC Container Debian 8.4](#), [Proxmox 4.2 - Container creation and installation of Ansible](#), [Proxmox 4.2 - Vagrant installation on LXC and snapshot mechanism](#), [Proxmox 4.2 Installation on OSX with VMware Fusion](#), [Proxmox 4.2 usage in the Standards Interoperability PLM Project](#)
- **Practical usage of Liferay**

It highlights usage of a generic Horizontal Enterprise Portal for digital collaboration and knowledge sharing relying on application and organization virtualisation (SIP related)

[How to Liferay - sharing resources between communities](#), [Liferay How to - store a document](#), [Liferay How to - Dynamic views](#), [Liferay How to - Querying Portal Content](#), [How to Liferay - portal vs eroom](#), [Liferay How to: controlled access to portal resources](#), [Liferay How to - Add application on a page](#), [Liferay How To - Publish content across multiple communities](#), [Liferay How to- Publish content on several pages](#), [Liferay how to - Publish a content on a page](#) , [Comment créer un contenu Web](#)
- **You tube videos - ISO TC184 SC4 Industrial Day for Digital threads and Digital twins**
 - [MBE Mfg Process Implementing the digital thread using the digital twins 1st Part](#)
 - [MBE Mfg Process Implementing the digital thread using the digital twins 2nd Part](#)
 - [MBE Mfg Process Implementing the digital thread using the digital twins 3rd Part](#)
- **YouTube videos pointed by the SIP Subway map**

[Full infrastructure of the SIP Test Bed](#), [Stratégie PLM](#), [Standard modelling with SIP - first example with ISA95](#), [STEP Future Architecture](#), [Business cases integrated](#), [Modeling a scenario: dekenz case](#), [modéliser DMN](#), [procedure tests](#), [place des outils](#), [Place des standards](#), [PDM IIF](#), [OSLC analysis performed within the frame of SIP](#), [ARAS AP242](#), [SIP framework integrated](#)

LinkedIn articles

N°	Year	Title	Views	Likes	Publication Date
A01	2020	What are the high added value usages of jArchi, the scripting solution integrated with Archi?	374	20	2020-11-15
A02	2020	The emerging landscape of reactive: do you know what it is really about?	377	11	2020-10-28
A03	2019	Current trends and challenges for Complex Systems Design & Management	1390	40	2019-12-02
A04	2019	Does it make sense using ArchiMate with XMind?	818	23	2019-12-01
A05	2019	The emerging landscape for distributed knowledge, ontology semantic web, knowledge base, graph based technologies and standards	19030	322	2019-11-22
A06	2019	ArchiMate Interoperability: is Open Exchange Format schemas really suited for Interoperability?	758	11	2019-11-01
A07	2019	ArchiMate Interoperability: from models to linked data using semantic web technologies?	636	17	2019-10-20
A08	2019	When Enterprise Architecture and MBSE meet in an Agile Context(part 2)	1624	32	2019-09-06
A09	2019	Product Life cycle Management (PLM): a neutral Product Data Management (PDM) Service model to reuse by Enterprise Architects in ArchiMate?	1062	37	2019-06-18
A10	2019	When Enterprise Architecture and MBSE meet in an Agile Context (part 1)	3724	100	2019-04-15
A11	2019	ArchiMate Interoperability: potential issues illustrated with practical cases with Archi, EA, Modelio, jArchi, PlantUML	4661	56	2019-04-04
A12	2019	What are the different types of architects considered for Enterprise Architecture?	3564	99	2019-03-01
A13	2019	Dealing with continuously changing environment fly using ArchiMate?	1932	41	2019-02-19
A14	2019	What should we expect from Software Architects?	2234	62	2019-02-14
A15	2019	Back to the CIMDATA's PLM Definition: do you need PLM for the new digitalization challenges?	633	35	2019-02-09
A16	2018	The emerging research challenges for PLM effective digital collaboration	1463	27	2018-11-02
A17	2018	Agile: from Drawing to MBSE/Enterprise Models with SPEM?	11330	165	2018-09-28
A18	2018	What Digital Experience Platforms bring to Enterprise Navigation Systems	1353	13	2018-03-03
A19	2018	Dynamic Semantic Cartography: what is the li with multidimensional descriptive statistics? (English versions)	725	11	2018-01-18
A20	2018	Cartographie sémantique dynamique: quel lien avec les statistiques descriptives multidimensionnelles? (Version Française)	274	3	2018-01-10
A21	2017	All the Enterprise Models are false!	463	15	2017-12-23
A22	2017	Semantic Cartography with ArchiMate: a first step for Enterprise Navigation Systems	4688	140	2017-12-15
A23	2017	Is it possible to take advantage of LinkedIn?	415	16	2017-11-01
A24	2017	ISO STEP: you can exchange descriptions of products with their geometries between heterogeneous CAD tools!	310	15	2017-09-18
A25	2017	How to have successful posts and articles on LinkedIn for technical topics?	383	8	2017-09-09
A26	2017	Linked Enterprises: about deriving a Web Ontology from the ArchiMate language?	4388	97	2017-09-09
A27	2017	Assessing LinkedIn articles impact: what can we learn concerning data analytics?	283	7	2017-08-07
A28	2017	Why the choice of ArchiMate for supporting PLM Interoperability?	1025	41	2017-08-07
A29	2017	What will be the future Smart Manufacturing Reference Model?	802	54	2017-07-24
A30	2017	Enterprise Architecture: from Drawing to Enterprise Navigation Systems with ArchiMate	4790	170	2017-07-21
A31	2017	Do you know what Upper Ontologies are and the value it brings?	1253	28	2017-07-10
A32	2017	Equivalent IDEF0 and SysML models	2499	50	2017-05-30
A33	2017	UML2: InstanceSpecification and InstanceSpecification Link	333	15	2017-03-27
A34	2017	Usage of SysML InstanceSpecificationLink and IntanceSpecification	253	18	2017-03-20
A35	2017	Dynamic Manufacturing Network modelling with factories using ArchiMate 3, Archi and	735	39	2017-03-03

		coArchi			
A36	2017	LinkedIn ranking services and other suppressed!	272	16	2017-02-17
A37	2017	When deep learning meets semantic technologies	281	7	2017-02-16
A38	2017	I-PLM 2017 le 20 Avril prochain: quand l'industrie rencontre les collectivités locales	124	4	2017-02-11
A39	2017	When ArchiMate 3.0 meets Production	779	28	2017-02-10
A40	2017	When eGovernment meets ArchiMate: the European Interoperability Reference Architecture	488	24	2017-02-02
A41	2017	Federating Ontology, System Engineering - LEGOs to the rescue	1734	59	2017-02-03
A42	2017	PLM Interoperability: when ArchiMate meets ISA-95 manufacturing standard	2664	59	2017-01-28
A43	2017	What System Engineers and ontologists can learn from Frankenstein	598	20	2017-01-27
A44	2017	Ontology, Big Data and System Engineering: Platypuses to the rescue	1755	54	2017-01-24
A45	2017	Sharing about PLM Interoperability: Platypuses will care	153	8	2017-01-20
A46	2017	Enterprise and PLM Interoperability: how was used the ATHENA Interoperability Framework	442	12	2017-01-10
A47	2017	When ArchiMate meets PLM for Aircraft OEM like Airbus	1361	63	2017-01-07
A48	2017	PLM Interoperability STEP AP209 for Multidisciplinary Analysis and Design	194	10	2017-02-02
A49	2017	PLM Interoperability - STEP AP 242 - Managed Model Based 3D Engineering	437	14	2017-02-02
A50	2017	Do you know why PLM open standards and Research should not be disconnected?	147	15	2017-01-02
A51	2016	When ArchiMate meets Cloud	2154	33	2016-12-25
A52	2016	About 10 years ago: the Digital Business Ecosystem initiative	795	8	2016-12-13
A53	2016	Some advanced visualisation techniques for embracing complexity of Dynamic Networks of networks - May 2020 updated	6108	179	2016-12-10
A54	2016	Ontology promises and limitations for System Engineering on top of Big Linked Data	4293	151	2016-12-08
A55	2016	PLM Interoperability: the ASD SSC Radar chart	500	11	2016-12-07
A56	2016	When ArchiMate meets complex systems of systems: solving ArchiMate limitations ... without changing ArchiMate	2185	33	2016-12-04
A57	2016	When ArchiMate meets UML: how to conciliate Enterprise Architects and Software Applications Designers	2687	45	2016-12-02
A59	2016	Interopérabilité PLM pour la continuité numérique- vers les plateformes d'expérimentation et les bancs de test	78	0	2016-11-24
A60	2016	PLM Interoperability: make up your mind concerning SysML Parametric Diagrams with Papyrus	612	14	2016-11-24
A61	2016	Blockchains for PLM and Manufacturing context	1300	62	2016-11-12
A62	2016	Usage of Proxmox V4.2 in order setting up PLM Interoperability TestBed	169	0	2016-11-03
A63	2016	Advanced usage of ArchiMate for Dynamic Manufacturing Living Lab	1458	31	2016-11-01
A64	2016	Project management and ArchiMate viewpoints	1166	26	2016-10-30
A65	2016	The potential of ArchiMate viewpoints from usual EA modeling to PLM	2156	43	2016-10-27
A66	2016	Industry 4.0/Smart Manufacturing recommendations for ISO strategy	1034	74	2016-10-17
A67	2016	Virtual Manufacturing: Implementing the digital thread using the digital twins!	225	4	2016-10-10
A68	2016	Standards & Interoperability PLM (Product Life cycle Management)	445	10	2016-03-23
Total number of views			119376		

Table 2 : LinkedIn articles

Observable reactive notebook articles/tutorials

- [Timelines of LinkedIn articles](#)
- [Experimenting Functions changing cells content](#)
- [Experimenting the JavaScript InfoVis Toolkit Integrating a carousel](#)

- [Experimenting the JavaScript InfoVis Toolkit Feeding Data Automatically](#)
- [Experimenting the JavaScript InfoVis Toolkit Notebook cells as variables](#)
- [Experimenting the JavaScript InfoVis Toolkit Changing variable sizing the TM](#)
- [Experimenting the JavaScript InfoVis Toolkit Several vizs in one notebook](#)
- [Playing with PlantUML in Observable](#)
- [Working with Three.js in Observable!](#)
- [vis.js network can be used with observable](#)
- [My first experience with Observable](#)
- [Advanced visualisation techniques for embracing complexity of Dynamic Networks of Networks](#)

Prototypes/Platforms/Demonstrators/Metamodels for proof of concepts and research demonstrators

- Windchill Platform with automated configurator for business configuration and demonstrator switch
- ArchiMagine components
 - [JaWine](#): Extension of standard based workflow modelling for qualification of the participants within a Dynamic Manufacturing Network
 - [SharKine](#): Extension of standard based workflow engine for dynamic aided reallocation of activities within a Dynamic Manufacturing Network according to the available qualified members of a Dynamic Manufacturing Network
 - [ArchiMagine](#) model publisher: generator of portal enabled enterprise model in ArchiMate describing a Dynamic Manufacturing Network
 - [cPlatform](#): collaborative platform associated to Federation of Interoperability framework for PLM
- [ArchiMate Language and Models interactive viewers](#) based on advanced interactive visualization technologies (force constrained graphs), as component of an Enterprise Navigation System
- STEP Mapper: prototype for deriving consistently ontology and models as input for model driven generated platforms and standard quality checking
- Archi scripts with jArchi: set of scripts for demonstrating publication of enterprise models within various
- « Creation of Transversal Folder Structure" script
 - « PlantUML ArchiMate export » script (advanced visualization)
 - « Generating ArchiMate Allowed Relations tables from jArchi » script
- [Derived OWL representation from ArchiMate](#) associated with paper in preparation and assessment of graph related technologies
- [Derived UML2 representation from ArchiMate](#) associated with paper on flat models
- Future STEP architecture demonstration on top of Magic Draw with SysML and OCL2
- IDEF0 to SysML demonstrator
- Platform generator from Business standards to Enterprise server relying on AndroMDA demonstrator
- S.U.S.I.E: System of Urbanisation of enterpriSe Information systEm, a proof of concept and training subject for generating Enterprise Modeling Platform relying on model based approach on top of Standardized Application Server.
- Collaborative Networked collaboration and experimentation platform, based on [Liferay](#), with effective use since 2009:

- Hosting private and public content for standardization or research projects such as AP242, AP239, MosseC, TDP Message, ASD SSG, Crescendo, IMAGINE, SIP, ArchiMagine, ATHENA, as a living lab for digital collaboration implying multiple organizations and taking advantage of some of the components of the cPlatform
- Quality Checker: solution checking quality of exchange product models within the scope of a standard based collaboration
- TestBed Generator: model based generator of testing environment for multi enterprise collaboration

1.4 - Research activities

The main research theme I've been addressing is the Interoperability of Enterprise Applications when following a Product Life Cycle approach.

My research aims at defining a new approach for supporting, preparing and building an operational continuous interoperability between applications at an acceptable price within an always changing business and technical environments. The applications are distributed within the enterprise and outside the enterprise, i.e. within the supply chains of a Digital Business Ecosystem.

1.5 - Research projects

This section mainly describes the research projects I contributed to in terms of launching and realization, in order to contribute to the thematic I've been addressing.

European and National funded research projects have been some of the instruments I used for my research activities. It was combined with Airbus Group internal studies for the different business units of the Group, in order to efficiently support the innovation process. It allowed to identify emerging scientific challenges and research opportunities in close relationship with the state of the practices (reflected by industry open standards) and with the state of the art (related to the academic world, the Research Communities Roadmaps and the Research Technology Roadmaps inside the Airbus Group).

For each projects are provided the names (short and long), the grant agreement, the funding program, the overall budget, the addressed topic, the web site when still available, the start date, the end date, the duration, the partners, the description, my role in the project, the deliverables I contributed to with my role, the concerned standards and the outcome related to my research activity.

1.5.1 International Projects

These projects were launched in the frame of responses to successive calls launched by the European Commission research programs. Such projects enable the collaboration between many partners in Europe, and are quite suited for the research on interoperability. Launching, managing or participating to these projects responded to a defined strategy for contributing to my research problematic, in alignment with the quick exploitation of the results in operation and a shorten innovation process. I had the opportunity to play multiple roles, from defining the business cases to contributing to the state of the art and to the definition of the solutions. The more important projects related to my research are **RISESTEP** , SAVE, IDEAS, ATHENA and IMAGINE.

RISESTEP Grant agreement: 20459	Enterprise Wide Standard Access to STEP Distributed Databases	Funded under FP4 ESPRIT
Overall budget € 5 996 000	Topic: Information Technology for Product & Process Data Modelling Web site: https://cordis.europa.eu/project/id/20459	Start: 1996-01-01 End: 1998-03-31 Duration: 26 months
Partners: Aerospatale (Coordinator), BMW, Matradatavision, ProSTEP, Rover, Volvo My role: Project Leader		
<p>Description: Issued from the AIT pilot phase and as such strongly user-driven, the RISESTEP project aimed at and succeeded in developing a middle-ware environment. It was based on the ISO STEP standard for data exchange and storage aspects, and on the OMG CORBA standard for the distribution aspects.</p> <p>My Role: I was the project leader for the last year of the project and I led the project to its successful end.</p> <p>Outcome: Demonstration of the feasibility of sharing digital mock up units between heterogeneous applications distributed between partners relying on the combination of the STEP and CORBA standards. Identification of the need of a higher level interface standard which led to the launch of the SAVE project.</p> <p>RISESTEP made me discover a new domain, the Product Data Exchange, Sharing and Long term archiving, and underlying standard technologies such as ISO STEP and CORBA. It was the starting point of the development of my research career and of the development of my expertise in the Interoperability for Product Life Cycle Management area.</p> <p>Concerned standards (referenced in table 10): [AP203], [CORBA]</p>		

SAVE Grant agreement: BRPR980760	STEP in a Virtual Enterprise	Funded under FP4 BRITE/EURAM 3
	Topic New methodologies for product design and manufacture Web site: https://cordis.europa.eu/project/id/BRPR980760	Start: 1998-09-01 End: 2000-12-31 Duration: 26M
Partners: BAE Systems (Coordinator), Airframe Engineering, Dassault Aviation, Dassault Systèmes, EADS, PTC, ProSTEP My role: EADS business scenarios and use cases definition responsible		
<p>Description: Objectives and content The SAVE project aims to enhance the competitiveness of European Industry through the use of standards in support of the Engineering Supply Chain. It will show how data and information can be delivered to the right place at the right time in the right format and with the right CAD-CAM tools and applications being made available at lower cost for SME members of the supply chain.</p> <p>A working prototype will be delivered that will show how a supplier can gain remote access to the lead contractor CAD- CAM/Product Data Model/Enterprise Resource Planning systems to pull the latest data and information relating to a particular task he has been asked to carry out. The technical objectives of the project are: To develop a Virtual Enterprise Data Model - This will take and extend existing information modelling standards (STEP AP 203,AP214, AP232) to create a central model which represents the different contractual relationships and business protocols which govern engineering information exchange in a Virtual Enterprise.</p> <p>To develop tools to support a mapping methodology which will allow members of a Virtual Enterprise to translate their own, proprietary models and ways of working into the Virtual Enterprise Data Model. To implement a Virtual Enterprise Framework based on standards (CORBA, AIT Reference Model, AIT Implementation Platform) which will enable companies at whatever level from prime contractors to 2nd tier suppliers (and beyond), to, at low cost, rapidly join, participate in, and leave a Virtual Enterprise, exchanging and sharing information and applications with high degrees of integrity. The use of Java Applications and remote access to high cost tools through Intranet/Internet technology will be a key element of reaching this goal.</p> <p>Expected benefits from the project are: A 10% reduction in the number of requests for change created during the design and manufacture of complex components and assemblies by the supply chain. A 10% improvement in lead-time towards the creation of the first component or assembly. A time improvement in the selection of strategic suppliers and the implementation of a data exchange strategy. A reduction in the need for face to face meetings arising from queries over data misinterpretation. Reduction in waste material from manufacture of incorrect specifications.</p> <p>A significant reduction in the average cost incurred by an SME when joining a new extended enterprise as a member of its supply chain.</p> <p>My role: I participated in the project by providing EADS business scenarios and use cases. I also participated in the specifications and in the assessment of their realisations.</p> <p>Outcome: I developed my knowledge related to the concerned standards and technologies. I also had the opportunity to identify an important issue: the adopted approach, which implied the efforts</p>		

of 10 partners during 3 years, only allowed having a demonstration on 14 objects. It was clearly insufficient for preparing interoperability at an acceptable cost. The project contributed to the PDM Enablers specifications, which I assessed later on through the implementation made available by software provider partners involved in the project. It was not responding to the expected quality criteria for usage in operation. Performed analysis allowed to identify why, and motivated to address the topic of Enterprise Application Interoperability.

Concerned standards (referenced in publication tables): [AP203] ,[AP214], [AP232], [CORBA], [PDM Enablers]

IDEAS Grant agreement IST-2001-37368	Interoperability Development for Enterprise Application and Software	Funded under FP5 IST
	Topic: Strategic roadmaps for applied research Web sites: https://cordis.europa.eu/project/id/IST-2001-37368 http://interop-vlab.eu/ideas/	Start 2002-06-01 End: 2003-05-31 Duration: 11M

Partners: Université de Bordeaux I, AIDIMA, BAAN, CRF, Computas, EADS CCR, GRAISOFT, Gruppo Formula, IC Focus, INTRACOM, SAP, UNINOVA
My role: Contributor to the establishment of the vision, state of the art, requirements and taxonomy

Description: The objectives of IDEAS project was to create and to manage a Working Group to elaborate a strategic roadmap in the domain of enterprise application and software interoperability for the next ten years and to propose to European Commission a structure and an organisation to support the implementation of this roadmap in the sixth Framework Program (FP6). For each of the technology areas of the interoperability study: architecture, modelling and ontology, the Working Group will provide a State of the Art and User requirements. IDEAS Working Groups provided a "vision" and scenarios on how the European Industry will face the challenges of interoperability. The Technology Roadmaps for the interoperability was extracted from the gap analysis between the state of the art and the vision. Then, management tools to pilot roadmaps implementation was defined, based on the tools proposed by European Commission for FP6.
My Role: Contributor to the submission and to the writing of the Description of Work, bringing the experience and scientific issues identified from the RISESTEP and SAVE projects, plus business needs of Aerospatiale. I also participated in the project and contributed to the elaboration of the vision and to the roadmap delivered by IDEAS, which led to many European Research Projects related to Interoperability of Enterprise Applications, in particular the Network of Excellence (NoE) Interop.

The IDEAS deliverables, with my assigned role (Responsible ® and Contributors ©) are the following:

- D 1.1: State of the Art (intro)©
- D 1.1: Part A. Enterprise Modelling State of the Art©
- D 1.1: Part B. Ontology State of the Art©
- D 1.2: User requirements©
- D 2.3: Goals and challenges of the industry for the 21st century©
- D 2.4: The vision for 2010©
- D 3.4/ D 3.5/ D 3.6: Gap analysis, required activities, roadmaps©
- D 4.1: The action plan for future research activity©
- D 4.2: Project management plan for large projects and networks©
- D 5.2: The interoperability terminology and taxonomy©
- D 6.2: Report on dissemination©
- D 7.2: Management and progress report©

Concerned standards (referenced in table 10): [AP214], [CORBA], [MDA], [OWL], [XML], [UML]

Outcome: The produced roadmap was realized through several successive Framework Programs (FP6,FP7) and is at the origin of the Network of Excellence Interop which is still active in 2021

VIP-ROAM Grant agreement IST-2001-37605	Virtual Product creation RoadMap	Funded under EC FP5 IST
Overall Budget: € 300 738	Topic: Strategic roadmaps for applied research Web site: https://cordis.europa.eu/project/id/IST-2001-37605	Start: 2002-07-01 End: 2003-06-15 Duration: 18M

Partners: Fraunhofer (Coordinator), CRF, EADS CCR, Siemens
My role: Contributor to the requirements, vision elaboration and to the development of the roadmap

Description: To succeed in the global competition European industry has to improve its product creation processes by applying information society technologies. Focussing on this aim ViP-RoaM develops a vision on Virtual Product Creation technologies and methodologies and defines a strategic roadmap for RTD activities for the next 5-10 years. This ensures a precise and synergetic use of RTD resources. The development of the roadmap is based on a comprehensive collection and integration of information gathered from industrial key players and research organisations. Business implementation paths and integrating scenarios will be derived to enable European industry to set up and follow a strategy for future product creation procedures based on innovative technologies and to be competitive in international markets. This project aims at defining a Virtual Product Creation strategy that enables European industry to improve their product creation processes and consequently to be successful in international markets. The proposers gather their strategic knowledge to emerge a vision on the progression of Virtual Product Creation technologies and methodologies for European manufacturing industry. Starting from this vision a strategic roadmap will be set up that describes necessary RTD activities for the coming 5 to 10 years along with a concerted RTD implementation path. This will be based on the contribution of identified key players in Europe, and reconciled with industrial needs by discussion with potential industrial stakeholders about essential innovations in central areas in manufacturing and IT solution providing industry.

The work performed within the project is divided into the following domains:

Requirements and vision elaboration:
Development of a roadmap

My Role: Contributor to the submission and to the writing of the Description of Work, bringing the experience and scientific issues identified from the RISESTEP and SAVE projects, plus business needs of Aerospatiale

I also participated in the project and contributed to the elaboration of the vision and to the development of the roadmap, providing the viewpoint of the aerospace industry.

ATHENA Grant Agreement IST 507849	Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and their Application	Funded under EC FP6
Overall Budget € 26 207 361	Topic: Networked business and governments Web sites: https://cordis.europa.eu/project/id/507849 http://interop-vlab.eu/athena/	Start 2004-02-01 End: 2007-03-31 Duration: 38M
Partners: SAP (Coordinator),AIDIMA, AIAG, AVA, CAS, CRF, CNDR, DFKI, EADS France, University of Belgrade, Fraunhofer, FESI, FORMULA, IBM UK, IEAA, INTRACOM, ITREC, SIEMENS, SINTEF, SMC, Trous Technologies, TXT, Uninova, University Saint Gallen, University Bordeaux I		
My role: Contributor to the Call response and to the definition of the Description of work, Responsible of the Dynamic Requirements Definition methodology, contributor to the Interoperability Framework, member of the technology watchdog group		
Description: Increasing collaboration among enterprises during the entire product life cycle is a global trend; Organizations are transforming themselves into "networked organizations". To achieve this, enterprise systems and applications need to be interoperable in order to achieve seamless business interaction across organizational boundaries. Currently, enterprises face many difficulties related to lack of interoperability. Interoperability, defined as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged", needs to be addressed in respect of all layers of an enterprise (including ICT Systems, Knowledge, Business and Semantics). It needs to be tackled using a holistic perspective, a multi-disciplinary approach, and by bringing together the best research teams, industry expertise and ICT suppliers. ATHENA aims to be the most comprehensive and systematic European research initiative in IT to remove barriers to interoperability, to transfer and apply the research results in industrial sectors, and to foster a new- networked business culture. Building on its vision statement "By 2010, enterprises will be able to seamlessly interoperate with others", ATHENA aims to enable interoperability by providing a comprehensive Interoperability Framework. In ATHENA, Research and Development will be executed in synergy and collaboration with Community Building: research will be guided by business requirements defined by a broad range of industrial sectors and integrated into Piloting and Training. ATHENA will be a source of technical inventions for interoperability. It will also lead to prototypes, technical specifications, guidelines and best practices that form a common European repository of knowledge.		
My Role: Contributor to the project submission, and to the writing of the Description of Work Scientific manager of the "Dynamic Requirement Management" B4 sub project EADS assessment responsible for the assessment of the ATHENA solution		
I was involved within the program as Aeronautic, Space and Defence sector representative, in order to formalize interoperability issues related to collaborative product development within the extended enterprise, to orient research effort to respond to industrial needs and objectives, to contribute to innovative solutions development by providing expertise related to PLM standards and Product Data Sharing, Exchange and long term retention, to assess solutions provided by partners and finally to disseminate the solutions of interest within the EADS business units through		

Research Technology Groups or Business Units oriented research studies.

I produced business scenarios (PDM coupling, Product Data Sharing within the Virtual Enterprise, and Integration of Technical Information Systems), with definition of as-is situation and expected to-be situation. I led the establishment of a Dynamic Requirement Definition Process for the whole ATHENA program, which allowed defining and consolidating between different industrial partners about 100 interoperability requirements, proposing several classifications to support efficiently the ATHENA program process.

Based on expected results from the different research projects, I also proposed a to-be business scenario, called Networked Collaborative Product Development Scenario, aiming to take advantage of more important results and to provide the context of elaboration of pilots aiming to assess the proposed solutions. The four elaborated pilots were dealing with "Semantic Mediation", "Cross Organizational Business Process", "Model generated workplaces" and "Integrative scenario: establishment of a Networked Product Development Organisation and Infrastructure".

I implemented an alternative solution to the DRDS planned in D B4.4, , based on Protégé, as the budget was consumed before implementing the services for mapping requirements to solutions for supporting B4.6

I assessed with the support of Flora Robin the ATHENA Solutions, in parallel with on the shelves free open solutions.

Cross Organisational Business Process for change and configuration management
Semantic Mediation on PDM metadata with from ATHENA A*, ATHOS, ARES... and from the outside EXPRESS-X and XSL-T

Inference on Ontologies in OWL - Protégé, SWOOP, Fact++, SWRL, SPARQL

OWL Semantic Graph

Model Transformation for Product Data Exchange. ATHENA solutions were not possible to assess due to integration issues, so solution from the outside used were AndroMDA, ModelInaction and Eclipse GMF

PLM Service Oriented Execution Platform with from ATHENA Johnson and Nehemiah, and from the outside Axis, Application Servers based on EJB2 and EJB3, XPDI PLM services server of reference, WEB application (STRUTS, JSF, Tomcat)

The ATHENA Interoperability Framework was also globally assessed, as well as the adopted approach, and led to the launching of my thesis in order to solve the various identified issues in RISESTEP, SAVE, IDEAS and ATHENA (cf. table 11)

I contributed to the ATHENA Interoperability Framework (AIF) and to the production of the the following list of deliverables indicating my assigned role (Responsible ® ,Contributors ©):

D.B4.1 Dynamic Requirement Definition Principle ® ©

D.B4.2 Global processes of reference ©

D.B4.3 Scenarios mapped with Interoperability issues ©

D.B4.4 Dynamic Requirement Definition System ©

D B4.4.1 Starting business scenarios ® ©

D.B4.4.2 Formalize and structured scenarios ©

D.B4.5.1 To-Be Scenario Analysis Process, Method and Templates ® ©

D.B4.6.1 ATHENA Mapping Approach Definition between Requirements and Interoperability Issues ©

D 4.6.2 ATHENA Mapping Approach Validation Report ©

D.B5.1.1 Term of Reference for the Technology Testing Network ©
 D.B5.3.1 Users Guide to Athena Prototyping Services ©
 D.B5.4/5 Test cases and Post-test evaluation ©
 D.B6.2 Curriculum of the Interoperability Training Service ©
 D.B6.3.1 Training and education material and activities ©
 D.C2.5 User Group Watchdog Report to the Technology Council ® ©
 D.C1.1 ATHENA Key Results ©
 D.C1.2 Project Reports ©
 D.C1.3 Interoperability Roadmap update ©
 D.C1.4 Yearly detailed implementation plan ©
 D.C3.1.1 Exploitation Handbook ©
 D.C3.2.1 Athena Exploitation Workshop ©
 D.C3.3.1 Joint and Individual Exploitation Plans ©
 D.A4.1 Requirements for Interoperability Framework, product-based and process-based Interoperability Infrastructures, Interoperability Life-cycle Services ©
 D.A4.2 Specification of Interoperability Framework and Profiles, Guidelines and Best Practices ©
 D.A4.6 Validation of research results – product-based and process-based interoperability infrastructures, Interoperability life-cycle Services

Related publications (referenced in publication tables 2 to 8): P30, 031, P32

Main outcomes:

First valuable result to point out is related to "Cross-Organisational Business Process", applied to interconnection of internal private change management workflow processes through a transversal public change management process.

Second valuable result is related to assessment of emerging technologies for the Semantic Mediation, in particular Semantic WEB technologies that seem very accurate to allow flexible sharing of heterogeneous PLM resources between the systems used by the members of a networked organization. Since ATHENA, I continuously followed-up and assessed those technologies in order to identify when the required level of maturity will be reached to support industrial processes.

Third valuable result is related to automated generation of collaborative workplaces from organisational models and business models on top of standardised Service Oriented Execution Platform, using a Model Driven approach based on OMG standards. It should allow to drastically fasten establishment of a collaboration enabled by a workspace connecting legacy eBusiness Platforms of partners (e.g. applications supporting PLM approach), with low cost. It is particularly important for short and episodic collaborations with numerous external partners or subcontractors having their own specific methods, processes and applications (addressed issue being "How to avoid digital break within the network of enterprises working on a given Product, all along the lifecycle of the product?")

The ATHENA Interoperability Framework was the starting point of the Federated Interoperability Framework, which was initiated during my thesis. The set of assessed free platform components was the starting point for the cPlatform, as no components coming from the ATHENA partners were reusable.

Related Publications (referenced in tables 3 to 8): P30, P31, P32, P36

Concerned standards (referenced in table 10): [AP214], [CORBA], [MDA], [OWL], [XML], [UML], [WSRP], {JRS 168}, [JSR 186]

IMAGINE Grant agreement 285132	Innovative End-to-end Management of Dynamic Manufacturing Networks	Funded under FP7-2011-NMP- ICT-FoF
Overall budget € 11 392 598	Topic: Virtual Factories and enterprises Web site: https://cordis.europa.eu/project/id/285132	Start: 2011-09-01 End 2014-12-03 Duration: 39M
<p>Partners: INTRACOM (Coordinator), SAS, Fraunhofer, Software AG, AIDIMA, Airbus Group SAS, CNRS (LAAS), NTUA, PANEPISTIMIO PATRON, SANTER REPLY SPA, CRF, UNINOVA, LOGO and University of Warwick...</p> <p>My role: Contributor to the Call response and to the definition of the Description of work, Responsible of the Aeronautics and Space Living Lab, contribution to the end-to-end DMN Management methodology, responsible of the Aeronautic and Defence requirements</p>		
<p>Description: IMAGINE is a Research & Development project, funded by the European Commission under the “Virtual Factories and Enterprises” theme of the 7th Framework Programme (FoF-ICT-2011.7.3, Grant Agreement No: 285132). The project targets the development and delivery of a novel comprehensive methodology and the respective platform for effective end-to-end management of dynamic manufacturing networks in an innovative plug and produce approach, and aims at supporting the emergence of a powerful new production model, based on community, collaboration, self-organisation and openness rather than on hierarchy and centralized control.</p> <p>My Role: I contributed to the Novel Approach to DMN Management by elaborating on the case studies associated with the Living Labs for Aerospace, by pointing out the Technology/Regulations. Standards used in Manufacturing for Aerospace, by participating to the definition of the Methodology for end-to-end DMN management, and by identifying the Business drivers, environment, benefits and risks for aerospace.</p> <p>I contributed to the Technology Foundation and Architecture Specification, provided use Cases of the IMAGINE platform related to the virtual product (and not to the physical one like the other industrial partners), and to the definition of the Architecture of IMAGINE Platform.</p> <p>With LAAS, I was in charge of the Living Lab Demonstrations for Aerospace and Defence Industry.</p> <p>I then contributed to the Technical Evaluation, to the Evaluation of the end-to-end DMN management approach and to the Quantitative Impact Assessment and Business Case. Being not industry driven, the solution providers didn't consider the needs expressed by EADS, and the Living Lab was consequently relying on a new extended version of the cPlatform, enriched by DMN components I specified, in order to adapt the DMN to support virtual product development. I then developed some dedicated demonstrator components with the support of Malik Khalfallah: SharkIne and JaWine. The living lab was extended by the Autonomic Service Bus defined and developed by LAAS.</p> <p>I contributed to the Stakeholders Engagement and Dissemination activities, to the online Presence (http://www.eads-iw.net/web/ imagine), to the production of dissemination material and to training activities across Europe (cf. training section). I also made the link with Standardization, promoting the IMAGINE approach and relying on a set of elected relevant standards to be considered for</p>		

through life cycle PLM interoperability including production systems.

I was responsible ® and contributed © to the following deliverables:

[D1.1.1 Compendium on virtual manufacturing management](#) ©

D1.2 - Methodology for end-to-end DMN management ©

D 2.1 – Use Cases of the IMAGINE Platform ©

D 4.1 – Living Lab in Aerospace and Defence domain Report ®

D.6.5 - IMAGINE Training Material ©

Research Outcome: Aerospace virtual lab co-developed with LAAS, and derived from the cPlatform V2, which led to the cPlatform v3 used and extended in SIP. Results of IMAGINE were an input for the SIP project.

Related publications (referenced in publication tables 2 to 8): P24, P14, P19, P29

Trainings and training supports: D6.5, plus online training supports mentioned on the training section

Related Supervision: Malik Khalfallah Phd (direct), Kamoun Aymen (indirect) and Code Diop (indirect)

Concerned standards (referenced in table 10): [AP242], [ISA 95], [SCOR], [SCORM], [ArchiMate]

CRESCENDO Grant agreement 234344	Collaborative & Robust Engineering using Simulation Capability Enabling Next Design Optimisation	Funded under FP7-Transport
Overall Budget M€ 55	Topic: Integrated approach to full virtuality in design and product development within the extended enterprise Web site: https://cordis.europa.eu/project/id/234344	Start: 01/05/2009 End: 30/04/2013 Duration: 36M

Airbus (Coordinator) + 59 organisations from 13 different countries
My role: contribution to the Model store definition and to the standards to be used

Description: Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation” (CRESCENDO) is an EU co-founded R&T project with a 55 M€ budget, launched in May 2009. The project is led by Airbus and brings together 59 organisations from 13 different countries, including major aeronautics industry companies, service and IT solution providers, research centres and academic institutions. The ambition of the consortium is to make a step change in the way that Modeling and Simulation activities are carried out, by multi-disciplinary teams working as part of a collaborative enterprise, in order to develop new aeronautical products in a more cost and time efficient manner.

My role: contributor to the Work Package 5.2 “BDA Model Store Capabilities”, BDA standing for Behavioural Digital Aircraft. I contributed to the identification of the relevant open standards to consider, but also to the design of a new standard for the support of distributed simulation, MOSSEC.

Research Outcome: Enrichment of the cPlatform by considering the secured collaboration constraints (cf. <http://www.eads-iw.net/web/crescendo/welcome>), addressing the interoperability

brake related to secured collaboration: most of the time, defined interoperability approaches are not addressing the security, considering it is out of scope. It prevents industrialization of the results.

Concerned standards (referenced in table 10): [AP233], [WSRP], [JSR 168], [JSR 286], [STEP TAS], [AP209]

TOICA Grant Agreement 604981	Thermal Overall Integrated Conception of Aircraft	EC FP7
Budget: 26.5M€	Topic: Integrated thermal analysis and design for aircraft Web site: https://cordis.europa.eu/project/id/604981 https://www.toica-fp7.eu/	Start: 2013-09-01 End: 2016-08-31 Duration: 36 M
Partners : Airbus (Coordinator) + 31 partners,8 countries My Role: Contribution to Interoperability related work package, Liaison with SIP		
Description: Thermal behaviour of aircraft has recently become a crucial subject due to many factors: the increasing number of complex systems required by modern, more electric, commercial aircraft, the introduction of hotter engines with higher by-pass ratios, the increased use of composite material in aircraft structures, and the confinement of highly dissipative equipment and systems in smaller areas to gain space for passengers and cargo. New advanced techniques to manage aircraft thermal behaviour at the very early stages of development are essential to take the right configuration decisions while meeting market demands. To work efficiently on emerging innovative solutions, it is essential to perform thermal management at the global aircraft level.		
Research Outcome: contributed to the MOSSEC standard development and assessment		
Concerned standards (referenced in table 10): [MOSSEC], [AP233]		

1.5.2 - National Projects

Acronym: SIP	Name: Standard Interoperability PLM	Type: IRT-SystemX Project
Budget: 3,6 M€	Start:2016-01-01 End: 2016-12-31	web site https://www.irt-systemx.fr/projets/sip
Industrial Partners: Airbus Group Innovations, Boost Conseil, CIMPA, Datakit, OVH, SOFYNE, Dassault Academic partners: CNRS, Université Lyon 1 (LIRIS), University Paris 8 (LISMMA)		
My role: Writer of the proposal and of the Description of Work, Project Leader, Writer of all the Deliverable reports		
Objectives: Create a methodology and a test platform to accelerate the implementation of standards and PLM interoperability, based on open-source / COTS approach allowing to prototype and validate processes interoperability at a controlled cost. Challenge: facilitate operations on the entire subcontracting chain thanks to a homogenization of model standards and management tools the life of the product cycle.		
Deliverable reports <ul style="list-style-type: none"> • Reference Framework: L0.1 SIP Referential Framework, L0.2 SIP Knowledge Base • State of the Art and state of the practice:L1.1.SIP SoA and SoP synthesis, L1.2 SIP Base de connaissance • Industrial cases: L2.1 SIP Configuration management, L2.2 SIP System Engineering, L2.3 SIP Simulation, L2.4 SIP Manufacturing, L2.5 SIP Support, L2.6 SIP DataPack AP242 • Testbed evaluation and prototyping: L3.1 SIP Test bed specifications, L3.2.1 SIP Developed components, L3.2.2 SIP Integration of components, L3.3 SIP Test data sets, L3.4 SIP test bed usage guide, L3.5:SIP Test bed evaluation REX, L3.6 SIP REX DataPack AP242 • Interoperability Solutions: L4.1. SIP REX and justification of choices made, L4.2 SIP Recommended practices and usage roadmap • External Liaisons and Participations: L5.1 SIP Professional association, L5.2.SIP_standardization_organization, L5.3 SIP International equivalent, L5.4 SIP Solution providers, L5.5 SIP Education • Dissemination and exploitation: L6.1.SIP Study association creation, L6.2.1.SIP specification of business cases and publication, L6.2.2.SIP White book PLM Interoperability L6.3.1 SIP Preliminary study future collaboration mode, L6.3.2 SIP proposal for SIP Platform at IRT , L6.4.1 SIP Training scenarios , L6.4.2 SIP training packages L6.4.3 SIP Training platform integration 		
Publications (referenced in publication tables 3 to 8): P01,P02, P03, P04, P07, P08, P10, P12, P13, P14, P15, P16, P17, P18, P19,P20, P21, P22, P29, P34, P36, P38		
Articles (referenced in table 2): A57		
Related indirect supervision: Emna Moones		
Outcome: the cPlatform v4, update of the FIF for unleashing testability brakes,some identified future research topics		
Concerned standards (referenced in table 10): [AP242], [MOF], [MDA], [UML2], [SysML], [IDEF0], [XML], [SCHEMATRON], [XML Schema], [OWL], [ArchiMate], [OSLC], [STEP], [XMI].		

SEINE	Standards pour l'Entreprise Innovante Numérique Etendue	AFNET
Budget: N/A	Start: 2007 End: 2009	Web site https://afnet.fr/dotank/sps/seine/
Industrial partners: AFNET, EADS, THALES, Dassault Aviation, SAFRAN Role: Production of EADS use case		
<p>Description: The objective of S.E.I.N.E. is to accelerate the digitization of the Aérospatiale & Defense supply chain, and of partner industrial sectors, through the implementation of open and interoperable solutions.</p> <ol style="list-style-type: none"> 1- By accelerating the deployment of digital working methods, up to n-tier suppliers, in the field of logistics, through private supplier portals or collaborative mutualism platforms, to facilitate SMEs' access to these technologies. 2- by making the same effort (standardization, operational platforms) in the area of PLM (Product Lifecycle Management), which covers the activities of design, industrialization and support of the product life cycle. The objective of the S.E.I.N.E. is to concretely demonstrate the operational effectiveness of innovative digital uses in companies, to accelerate their diffusion in the industrial fabric, and to promote the mastery of complex systems, which is at the heart of competitiveness and innovation. <p>The major industrialists in the A&D sector (Airbus, Dassault Aviation EADS, Safran, Thales, etc.) actively participated in the project, particularly in the phases of expression of needs, specifications, pilots and acceptance, as common objective of accelerating the digitization of the Aerospace and Defense (A&D) supply chain and sectors of the same industrial ecosystem, with comparable businesses and sharing the same suppliers.</p> <p>My Role: production of EADS use cases, Interoperability for PLM standards expert</p> <p>Outcomes:</p> <ul style="list-style-type: none"> • Business cases and motivation for IMAGINE and SIP, with identification of interoperability brakes to be unleashed • Origin of BoostAerospace • Involvement in the EADS PLM harmonization project as Standard expert <p>Concerned standards (referenced in table 10): [AP214], [AP233]</p>		

OpenDevFactory	Pôle Systematic	
Usine Logicielle		
Budget: N/A	Start: 2006-02-21 End: 2009-01-31	Web site N/A
Industrial partners: THALES, CEA, EADS		
My role: Responsible for the EADS business scenario “System Engineering factory for virtual enterprise and PLM”, definition of a pilot for evaluation of the platform defined by the project		
<p>Description: The Software Factory macro-project brought together the 3 OpenDevFactory, Inflexion and Modrival projects. The Software Factory aims to create a platform for integrating software engineering tools to support the engineering of complex systems in an IDM (Model-Driven Engineering) approach. The focus is on real-time on-board systems. OpenDevFactory is an open modelling platform for model engineering. Inflexion is a flexible execution infrastructure based on components and connectors, oriented towards distribution, reconfiguration and fault tolerance. Modrival is a model-driven validation system.</p> <p>The objective of the OpenDevFactory project was to develop and validate model-driven engineering (IDM - Ingénierie Dirigée par les Modèles) technology and tooling for embedded systems, with concurrent multi-point of view engineering (performance, reliability, etc.) and multi-domains (IT, electronics, mechanics, etc.), integration and migration (including management of obsolescence of IDM tools, urbanization of the technical information system and multi-formalism semantic correspondence in the domain real time), independence from execution platforms, automatic test generation, static verification of behavioural properties, hardware architecture simulation and component-based execution platforms.</p> <p>My role: responsible for the EADS business scenario “System Engineering factory for virtual enterprise and PLM”, with the definition of a pilot for evaluation of the platform defined by the project, based on Eclipse and Open Standards and the integration of the developed components to this platform. Finally, I assessed the results and delivered demonstrations</p> <ul style="list-style-type: none"> • Interconnection of Procube Designer, tool allowing to formalize methodology by mean of SPEM, and Microsoft Project, a tool allowing to deal with project management, applied to a SLM collaboration • Generation of BPEL from Procube Designer, tool allowing to formalize methodology by mean of SPEM - it means that some workflow can be generated relying on BPEL • AndroMDA profiles creation on Papyrus UML • UML2 model transformation in UML2 profile • Transformation chain XPDL XML Schema => XPDL UML 2 Model => XPDL UML2 profile • Usage of enterprise modelling framework (COMET) on top of open source modelling environment and open standards <p>Responsible ® and Principal contributor © to the following deliverables:</p> <p>D1.2.5: Specification of the EADS CCR demonstrator ® ©</p> <p>D1.3: EADS Innovation Works Evaluation ® ©</p> <p>Outcome</p> <ul style="list-style-type: none"> • Assessment of the Eclipse platform for Model Driven Approach, with derived practices and planning formalized with OMG’s SPEM and the Eclipse Project Framework from Workflow models formalized with Wfmc standardized language (XML Process Description 		

Language).

- Definition of components as part of the cPlatform and associated model factory.
- The performed work contributed to my thesis
- Integration of the results and of the demonstration within my training supports

Concerned standards: [AP214], [MDA], [OWL], [SPEM], [XPDL], [RM]

1.6 - Scientific influence

The scientific influence is first reflected by the contribution to the state of the art, validated through the acceptance of research papers by Journal publishers, and related to the principal original contributions I brought.

The scientific influence is also reflected by the invitation for presenting my work by different event and conference organisers.

1.6.1 - Membership of research related committee

- Member of the IJPLM Editorial board in 2005 cf. [IJPLM Leaflet](#)
- Member of Program Committee of IEEE ICWS 2021
- Member of the Scientific board of the ATLAS Project

1.6.2 - Contributor to Research Roadmaps

- VIP-ROAM
- IDEAS
- Airbus Innovation Works

1.6.3 - Contribution as Expert on Interoperability to International Standardization

- ISO TC184 SC4 - Manufacturing Data
- ASD Strategic Standardization
- Airbus Group Strategic Standardization Committee
- ProSTEP

1.6.4 - Contribution as Expert on Interoperability to National Standardization and Industrial organization or projects

- AFNOR: Association Française de NORMalisation, commission IDMI
- BNAE: Bureau de Normalisation de l'Aéronautique et de l'Espace
- AIF: Alliance Industrie du Futur - Participation groupe de travaux sur RAMI 4.0
- AFNET: L'Association Française de référence du numérique dans les filières industrielles
- GIFAS: member of the PLM task Force
- AFIS: Association Française de l'Ingénierie Système
- [ATLAS](#) - Project on Digital standards and norms of Industrial Sectors

1.6.5 - Invitation for presenting my work

The performed research work allowed me to be invited for presenting my work at:

- [Complex Systems Design & Management \(CSD&M 2019\) conference](#) as a guest for promoting the event, through the LinkedIn article "[Current trends and challenges for Complex Systems Design & Management](#)", the 2nd of December 2019
- iPLM 2014 Workshop « Interoperability & PLM » - "PLM interoperability: towards Dynamic Manufacturing Network and manufacturing standards test bed"
- iPLM 2015 Workshop "Vers des plateformes pédagogiques Interopérabilité et PLM" - "[L'orientation académique de la plateforme SIP](#)"
- iPLM 2016 Workshop « Interopérabilité & PLM : Interopérabilité PLM et Ingénierie - Système : Un nouveau défi » - "[Building a secured collaboration for PLM and System Engineering with standard as network protocols](#)"
- iPLM 2017 - "Systèmes d'Information, Interopérabilité-PLM et Collectivités locales : La Réutilisation des approches numériques de l'industrie aux services des collectivités locales"
- PLM'16 <https://www.plm-conference.org/docs/2016.pdf>
- AFNET Standardization day 2016: "[Presentation of Standard Interoperability PLM](#)", Paris, July 2016
- AFNET Standardization day 2017: "[Standards for Virtual Manufacturing and Factory of the future: Position and status of ISA 95](#)", Paris, 19-20/04/2017
- AFNET Standardization day 2017: "STEP Architecture update : integration of the STEP standards in the state of the art Model Based IS development frameworks"
- Icosyl'2018: "[Enterprise Architecture for MBSE and Virtual Manufacturing digital continuity based on open standards](#)" - presentation I made at
- GIFAS - PLM TF Steering Committee - 2007-06-28 "[OSLC Open Services For Lifecycle Collaboration](#)"
- [PI PLMx CHICAGO 2018](#): "PLM Infrastructure and Interoperability - Emerging Research Challenges for Effective Collaboration", 5th of November 2018, Chicago. Related LinkedIn article : "[The emerging research challenges for PLM effective digital collaboration](#)", 2nd of November 2018
- "[Standards for virtual manufacturing and factory of the future position and status of ISA95](#)", presentation I made at
- ISO SC4 TC184 65th workshop: "[Linking standards for Dynamic Manufacturing Standards](#)", 5th of September 2016
- Workshop Interoperability and PLM "[Towards dynamic manufacturing network and manufacturing standards test bed](#)", presentation made at - the 18th of February, 2016
- ISO SC4 TSC184 Workshop: "[SIP presentation to Implementation Forum](#)", the 8th of May, 2014
- ISO SC4 TC184 Industry day 2013: "[Standards and Research relationships](#)", 5th of June 2013 at Paris
- ISO SC4 TC184 Industry Day: "[Which digital exchange of tomorrow for increasing global competitiveness and market share? Aeronautic, Space & Defense industrial and research approach - The new standard ISO 10303 STEP AP 242](#)", Belfort meeting the 5th of November
- [Ontology Summit 2009](#) Panel Session - "Toward Ontology-based Standards - A Synthesis" - Chaired by Dr [Steve Ray](#) and with as panellists Mr. [Howard Mason](#), Professor [Michael Gruninger](#), Mr. [David Connelly](#), Dr [Katherine Goodier](#), Mr. [David Leal](#) and myself, where I presented "[STEP APs Formalization Suggestions](#)" [Audio archive of the session](#) are available!

- 16th International Conference on 3D Web Technologies: “[Conception assistée par ordinateur, Gestion des données, et besoins en validation 3D: 3D visualisation needs for CAD and PDM](#)”, presentation by Jean Brangé and Nicolas Figay made at, 21st of June 2011
- [PDT Europe 2015](#) - The perfect storm for PLM - the product innovation platform - “[Achieving sustainable interoperability despite Emerging Technology](#)”, 27-10-2015

1.7 - Supervision

1.7.1 - PHD thesis

Supervision

1. Malik Khalfallah PhD, “A formal framework for Process Interoperability in Dynamic Collaboration Environments”. The thesis was co-directed with Pr Parisa Shariat Ghodous and Dr Mahmoud Barhamgi. It was run through a CIFRE convention involving EADS and LIRIS, and connected to the contribution to the IMAGINE and to the SIP research projects. The collaboration led to 13 scientific publications. My supervision rate was 60%

Contribution to the following PHD through collaboration in research projects

1. **Emna Moones**, for “**Proposition d'une approche méthodologique d'interopérabilité multi-niveaux dans un environnement de PLM collaboratif.**” (Proposal of a methodological approach of multi-level interoperability in a collaborative PLM environment.”), **supervised by Pr. Abderrahman El Mhamedi** - Paris 8. The thesis contributed to the extension of the Federated Interoperability Framework to manufacturing relying on the ISA 95 standard (Enterprise-Control System Integration) within the context of the SIP project.
2. **Kamoun Aymen**, for “**Adaptation of access control software architectures in collaborative ubiquitous environments**”, **supervised by Pr. Said Tazi and Pr Khalil Drira**, Toulouse 1. The thesis occurred within the context of collaboration between the LAAS and EADS within the frame of the IMAGINE project, and contributed to the establishment of the infrastructure layer of the experimental platform aiming at studying PLM interoperability within a Dynamic Manufacturing Network, which I designed in collaboration with Pr Ernesto Exposito, on the basis of the FIF principles.
3. **Diop Code** for “**An autonomic service bus for service-based distributed systems**” **supervised by Pr. Ernesto Exposito**, Toulouse 1. The thesis occurred within the context of collaboration between the LAAS and EADS within the frame of the IMAGINE project, and contributed to the establishment of the infrastructure layer of the experimental platform aiming at studying PLM interoperability within a Dynamic Manufacturing Network, which I designed in collaboration with Pr Ernesto Exposito, on the basis of the FIF principles.

1.7.2 - Supervision of school enterprise internships

1. Supervision of **Olivier Demarez** in enterprise during his DESS IRS (**Master**) internship at Université de Versailles Saint-Quentin-En-Yvelines from October 2002 to September 2003. It consisted in proposing **an applicative exchange control system for PDM Enablers**.
2. Supervision of **David Hassoun** internship for DESS (**Master**) « Logiciels Fondamentaux» at University Denis Diderot Paris VII from April to September 2003. It concerned **the study of the implementation of PDM Enablers by PTC for Windhill, after the SAVE project**.
3. Supervision in enterprise for an internship for DESS (**Master**), after a Master at ITIN with participation in a school project I drove: **Jonas Martin** (2003-2004). Jonas attended my training sessions related to controlled urbanism at ITIN before working with me. He worked on a controlled urbanism demonstration platform generated using model based generation (Système d'Urbanisation du Système d'Information d'Entreprise - **Urbanization System of Enterprise Information System**), and he drove ITIN Maser students on the evolution of the platform.
4. Supervision in enterprise for internship, preceded by a Master at ITIN with participation in a school project I drove, Ludovic **Duchemin** (2004 to 2005). Like Jonas, Ludovic attended my training sessions related to controlled urbanism before working with me. He continued the work on the controlled urbanism demonstration platform generated using model based generation (Système d'Urbanisation du Système d'Information d'Entreprise - **Urbanization System of Enterprise Information System**), and also drove ITIN M2 students on the evolution of the platform.
5. Supervision of 6 months internship **Sophie Gatoux - ArchiMagine ArchiMate publisher prototype** April 2013-September 2013 Ecole Centrale Lille for a **Master Organisation Modelling and Management**

1.8 - List of publications

1.8.1 - International peer-reviewed journals

N°	Title	Details	
P00	Alignment of the Product Lifecycle Management Federated Interoperability Framework with Internet of Things and Virtual Manufacturing	Accepted the 10th of April 2021 David Tchoffa, Nicolas Figay, Parisa Ghodous A. El Mhamedi Hervé Panetto (2021), Alignment of the Product Lifecycle Management Federated Interoperability Framework with Internet of Things and Virtual Manufacturing ,Computer in Industry	SJR Q1 Impact Factor: 3.954 (2019)
P01	Dynamic Manufacturing Network - from flat Semantic Graphs to Composite Models	David Tchoffa, Nicolas Figay, Parisa Ghodous, Ernesto Expósito, Kouami Seli Apedome & Abderrahaman El Mhamedi (2019). « Dynamic manufacturing network – from flat semantic graphs to composite models ». International Journal of Production Research, vol. 57, n°20, pp. 6569-6578. doi : 10.1080/00207543.2019.1570375. HAL : hal-02433065	SJR Q1 Impact Factor 4.577 (2019)
P02	Towards a Formal Framework for Product Level Agreements	Malik Khalfallah, Nicolas Figay, Mahmoud Barhamgi, Parisa Ghodous: Towards a formal framework for product level agreements. International Journal of Business Process Integration and Management 8(1): 31-52 doi: 10.1504/IJBPIIM.2017.082759. HAL : hal-01636852 (2017)	Impact Factor 0,45
P03	Digital Factory System for Dynamic Manufacturing Network supporting Networked Collaborative Product Development	D. Tchoffa, N. Figay, P. Ghodous, E. Exposito, Lyes Kermad, Thomas Vosgien, A. El Mhamedi, Digital factory system for dynamic manufacturing network supporting networked collaborative product development, Data & Knowledge Engineering, Volume 105,2016,Pages 130-154,ISSN 0169-023X, https://doi.org/10.1016/j.datak.2016.02.004 . (https://www.sciencedirect.com/science/article/pii/S0169023X16300040)	SJR Q1 Impact Factor: 1.476 i
P04	A cloud-based Platform to Ensure Interoperability in Aerospace Industry	M. Khalfallah, NFI Figay, C Ferreira Da Silva, P Ghodous, « A cloud-based platform to ensure interoperability in aerospace industry », Journal of Intelligent Manufacturing, vol. 27 pp. 119-129, Springer US, ISSN 1572-8145. 2016.	SJR Q1 Impact factor 1,731
P05	Interoperability Framework for Dynamic Manufacturing	Nicolas Figay, Parisa Ghodous, Malik Khalfallah, Mahmoud Barhamgi. Interoperability framework for dynamic manufacturing networks. Computers in Industry, Elsevier, 2012, 8, 63, pp.749-755. (hal-01353096)	SJR Q1 Impact Factor 1,937,
P06	Enabling interoperability of STEP Application Protocols at meta-data and knowledge level	Nicolas Figay, Ricardo Jardim-Gonçalves, Adolfo Steiger-Garção. Enabling interoperability of STEP Application Protocols at meta-data and knowledge level. International Journal of Technology Management, Inderscience, 2006, 4, 36, pp.402-421. (10.1504/IJTM.2006.010275). (hal-01511467)	Rang Q2
P07	Pragmatic PLM Process Interoperability for Aeronautic, Space and Defence DMN	Nicolas Figay, Parisa Ghodous, Samer Abdul Ghafour, Catarina Ferreira da Silva, Ernesto Expósito. Pragmatic PLM process interoperability for aeronautic, space and defence DMN. <i>Journal of Aerospace Operations</i> , IOS Press, 2015, Concurrent Engineering, 3 (3,4), pp.147-166. (10.3233/AOP-150050). (hal-01267419)	
P08	Standards Compliant Platform for Product Design in Dynamic Environment	Malik Khalfallah, Nicolas Figay, Mahmoud Barhamgi, Parisa Ghodous. Standards Compliant Platform for Product Design in Dynamic Environments. International Journal of Services Computing, STCC, 2014, pp.44-57. (hal-01301127)	

Table 3 : [LinkedIn](#) articles

1.8.2 - International peer-reviewed conferences and published proceedings

N°	Title	Details	
P09	Alignment of the PLM Federated Interoperability Framework with IoT and Virtual Manufacturing	David Tchoffa, Nicolas Figay, Danioko Fadaba, Abderrahman El Mhamedi. Alignment of the PLM federated interoperability framework with IoT and virtual manufacturing . 7th International Conference on Information Society and Technology, ICIST2017, Mar 2017, Kopaonik, Serbia. (hal-01506813)	
P10	Interoperability Improvement in a Collaborative Dynamic Manufacturing Network	Emna Moones, El Dafaoui, El Abderrahman, Nicolas Figay, Ali Koudri. Interoperability Improvement in a Collaborative Dynamic Manufacturing Network. 13th IFIP International Conference on Product Lifecycle Management (PLM), Jul 2016, Columbia, SC, United States. pp.286-295, (10.1007/978-3-319-54660-5_26). (hal-01699735)	
P11	An Application Domain-Based Taxonomy for IoT Sensors	Vitor Rozsa, Marta Deniszczwicz, Moisés Dutra, Parisa Ghodous, Catarina Ferreira da Silva, et al.. An Application Domain-Based Taxonomy for IoT Sensors. 23rd ISPE International Conference on Transdisciplinary Engineering: Crossing Boundaries, Oct 2016, Curitiba, Brazil. ff10.3233/978-1-61499-703-0-249ff. fhal-01581127f	
P12	Generating Executable Workflows from solution plans	M. Khalfallah, N. Figay, M. Barhamgi and P. Ghodous, "Generating Executable Workflows from Solution Plans," <i>2015 IEEE International Conference on Web Services</i> , New York, NY, 2015, pp. 535-542, doi: 10.1109/ICWS.2015.77.	
P13	Simulation Data Management and Reuse: Toward a Verification and Validation Approach	Anais Ottino, Thomas Vosgien, Julien Duigou, Nicolas Figay, Pascal Lardeur, et al.. Simulation Data Management and Reuse: Toward a Verification and Validation Approach. <i>12th IFIP International Conference on Product Lifecycle Management (PLM)</i> , Oct 2015, Doha, Qatar. pp.476-484, (10.1007/978-3-319-33111-9_43). (hal-01377473)	
P14	Model Based Enterprise Modeling for testing PLM Interoperability in Dynamic Manufacturing Network	Nicolas Figay, Parisa Ghodous, Bezhad Shariat, Ernesto Expósito, David Tchoffa, et al.. Model Based Enterprise Modeling for Testing PLM Interoperability in Dynamic Manufacturing Network. <i>6th International IFIP Working Conference on Enterprise Interoperability (IWEI)</i> , May 2015, Nîmes, France. pp.141-153, (10.1007/978-3-662-47157-9_13). (hal-01438398)	
P15	PLM standards modelling for enterprise interoperability: A manufacturing case study between ERP and MES information exchange business scenario based on ISA 95 standard	Emna Moones, Thomas Vosgien, Lyes Kermad, El Dafaoui, Abderrahman El Mhamedi, et al.. PLM Standards Modelling for Enterprise Interoperability: A Manufacturing Case Study for ERP and MES Systems Integration Based on ISA-95. 6th International IFIP Working Conference on Enterprise Interoperability (IWEI), May 2015, Nîmes, France. pp.157-170, ff10.1007/978-3-662-47157-9_14ff. fhal01438399f	
P16	Patterns for Monitoring Parallel Processes	M. Khalfallah, N. Figay, M. Barhamgi and P. Ghodous, "Patterns for Monitoring Parallel Processes," <i>2014 IEEE International Conference on Services Computing</i> , Anchorage, AK, 2014, pp. 9-16, doi: 10.1109/SCC.2014.11.	Rang A
P17	Model Driven Conformance Testing for Standardized Services	M. Khalfallah, N. Figay, M. Barhamgi and P. Ghodous, "Model Driven Conformance Testing for Standardized Services," <i>2014 IEEE International Conference on Services Computing</i> , Anchorage, AK, 2014, pp. 400-407, doi: 10.1109/SCC.2014.60.	Rang A
P18	Towards an extended interoperability systemic approach for dynamic manufacturing networks: role and assessment of PLM standards	Emna Moones Nicolas Figay Thomas Vosgien Lyes Kermad François Steph an Abderrahman El Mhamedi, El Mouloudi Dafaoui, (2015) Towards an Extended Interoperability Systemic Approach for Dynamic Manufacturing Networks: Role and Assessment of PLM Standards. In: Boulanger F., Krob D., Morel G., Roussel JC. (eds) <i>Complex Systems Design & Management</i> . Springer, Cham. https://doi.org/10.1007/978-3-319-11617-4_5	

P19	An Architecture for a Centralized mediation In Dynamic Networks	Malik Khalfallah, Mahmoud Barhamgi, Nicolas Figay, Parisa Ghodous. An Architecture for a Centralized Mediation in Dynamic Manufacturing Networks.. <i>IEEE International Conference on Web Services, ICWS, 2014</i> , Jul 2014, Anchorage, United States. pp.720--721, <10.1109/ICWS.2014.114>. <hal-01477969>	Rang A
P20	Interoperability of Simulation Applications for Dynamic Network Enterprises Based on Cloud Computing Aeronautic Applications	Anais Ottino, Parisa Ghodous, Hamid Ladjal, Behzad Shariat, Nicolas Figay: Interoperability of Simulation Applications for Dynamic Network Enterprises Based on Cloud Computing - Aeronautics Application. ISPE CE 2014: 597-606	
P21	Towards Combining Declarative Specification with On-the-fly mediation	M. Khalfallah, N. Figay, M. Barhamgi, C. F. Da Silva and P. Ghodous, "Towards Combining Declarative Specification with On-the-Fly Mediation," <i>2013 IEEE International Conference on Services Computing</i> , Santa Clara, CA, 2013, pp. 691-698, doi: 10.1109/SCC.2013.18.	Rang A
P22	Controlling the Evolution of Product-based Collaboration Contracts	M. Khalfallah, N. Figay, M. Barhamgi and P. Ghodous, "Controlling the Evolution of Product-Based Collaboration Contracts," <i>2013 IEEE International Conference on Services Computing</i> , Santa Clara, CA, 2013, pp. 713-720, doi: 10.1109/SCC.2013.86.	Rang A
P23	Cross-Organizational Business Processes Modeling Using Design-by-Contract Approach	Malik Khalfallah, Nicolas Figay, Parisa Ghodous, Catarina Ferreira da Silva. Cross-organizational Business Processes Modeling Using Design-by-Contract Approach. 5th International Working Conference on Enterprise Interoperability (IWEI), Mar 2013, Enschede, Netherlands. pp.77-90, ff10.1007/978-3-642-36796-0_8ff. fhal-01339152f	
P24	Product-Based Business Processes Interoperability	Malik Khalfallah, Mahmoud Barhamgi, Nicolas Figay, Parisa Ghodous. Product-Based Business Processes Interoperability. <i>Symposium On Applied Computing</i> , Mar 2013, Coimbra, Portugal. pp.1472-1473. <hal-01339153>	Rang B
P25	A Novel Approach to Ensure Interoperability Based on a Cloud Infrastructure	Malik Khalfallah, Mahmoud Barhamgi, Nicolas Figay, Parisa Ghodous. A Novel Approach to Ensure Interoperability Based on a Cloud Infrastructure. 19th ISPE International Conference on Concurrent Engineering – CE2012, Sep 2012, Trier, Germany. pp.1143-1154, <10.1007/978-1-4471-4426-7_96>. <hal-01353010>	Rang B
P26	Innovative interoperability framework for enterprise applications within virtual enterprises	Nicolas Figay and Parisa Ghodous. 2009. Innovative interoperability framework for enterprise applications within virtual enterprises. In Proceedings of the International Conference on Management of Emergent Digital Ecosystems (MEDES '09). Association for Computing Machinery, New York, NY, USA, Article 49, 325–331. DOI: https://doi.org/10.1145/1643823.1643884	
P27	Extended Hypermodel for Interoperability within the Virtual Enterprise	N. Figay and P. Ghodous, "Extended Hypermodel for Interoperability within the Virtual Enterprise," 2009 Fifth International Conference on Signal Image Technology and Internet Based Systems, Marrakesh, 2009, pp. 393-400, doi:10.1109/SITIS.2009.68	
P28	FLOSS as Enterprise Applications Interoperability Enabler	N. Figay and P. Ghodous, "FLOSS as Enterprise Application Interoperability Enabler," 2009 Fifth International Conference on Signal Image Technology and Internet Based Systems, Marrakech, Morocco, 2009, pp. 435-442, doi: 10.1109/SITIS.2009.74.	
P29	Dynamic Manufacturing Network, PLM Hub and Business standards testbed	Figay N., Tchoffa D., Ghodous P., Exposito E., El Mhamedi A. (2014) Dynamic Manufacturing Network, PLM Hub and Business Standards Testbed. In: Mertins K., Bénaben F., Poler R., Bourrières JP. (eds) Enterprise Interoperability VI. Proceedings of the I-ESA Conferences, vol 7. Springer, Cham. https://doi.org/10.1007/978-3-319-04948-9_38	

P30	Collaborative Product Development: EADS Pilot Based on ATHENA	Figay N., Ghodous P. (2008) Collaborative Product Development: EADS Pilot Based on ATHENA. In: Mertins K., Ruggaber R., Popplewell K., Xu X. (eds) Enterprise Interoperability III. Springer, London. https://doi.org/10.1007/978-1-84800-221-0_33	
P31	The ATHENA Interoperability Framework	Berre A.J. et al. (2007) The ATHENA Interoperability Framework. In: Gonçalves R.J., Müller J.P., Mertins K., Zelm M. (eds) Enterprise Interoperability II. Springer, London. https://doi.org/10.1007/978-1-84628-858-6_62	
P32	Collaborative Product Development: EADS Pilot Based on ATHENA Results	Figay N., Ghodous P. (2008) Collaborative Product Development: EADS Pilot Based on ATHENA. In: Mertins K., Ruggaber R., Popplewell K., Xu X. (eds) Enterprise Interoperability III. Springer, London. https://doi.org/10.1007/978-1-84800-221-0_33	

Table 4 : International peer-reviewed conferences

N°	Title	Details
P34	Gestion et réutilisation des données de simulation : vers une approche de vérification et validation des modèles	A.Ottino, J.Le Duigou,T.Vosgien, N.Figay, P.Lardeur, B.Eysnard CFM15 22 ème Congrès Français de Mécanique 24-28/08/2015

Table 5: published proceedings French conference

1.8.3 - National peer-reviewed journal

N°	Title	Details
P33	Utilisation innovante de l'implémentation du concept « Tout-Partie » pour assurer l'interopérabilité requise pour la gestion du cycle de vie des produits" (Innovative usage of "Whole-Parts" concept implementation for PLM interoperability)	Nicolas Figay, Parisa Ghodous & David Tchoffa (2017). « Utilisation innovante de l'implémentation du concept « Tout-Partie » pour assurer l'interopérabilité requise pour la gestion du cycle de vie des produits ». Génie Logiciel GL & IS, n° 117, pp. 22-33. HAL: hal-01505854.

Table 6: National peer-reviewed journals

1.8.4 - Book Chapter

N°	Title	Details
P36	Resolving Interoperability in Concurrent Engineering	Nicolas Figay, Catarina Ferreira Da Silva, Parisa Ghodous & Ricardo Jardim-Goncalves. « Resolving Interoperability in Concurrent Engineering ». Concurrent Engineering in the 21st Century, Springer International Publishing, pp. 133-163. doi : 10.1007/978-3-319-13776-6_6, 2015.

Table 7: Book Chapters

1.8.5 - White Paper

N°	Title	Details
P35	White Paper Blockchain: Myth or Reality	Contribution as reviewer. Editor and coordinator: Rodrigues Germany. Publication Editor: Jean Pierre Thual - Systematic Paris Region, ISBN: 978-2-9549444-4-9

Table 8: White papers

Chapter 2 - Introduction to Interoperability

2.1-The Business Context

Preparing and building continuous operational interoperability for digital continuity in the Manufacturing Domain has been important during the last 20 years, due to the rise of Information and Communication technologies, in particular the Internet. The Internet has been continuously changing the life of the citizens and the way of working or doing business. It is true in particular within the manufacturing industry with successive innovative transformations.

The successive transformations were related to:

- Computer Aided Design and Manufacturing with virtualization of product and progressive replacement of physical mock-ups by Digital Mock-ups and Behavioural Digital Products
- Virtualization of the organizations, with the evolution from standalone autonomous enterprises to networked enterprises constituting digital business ecosystems
- Development of digital marketplaces with eBusiness applications offering new distribution and support channels relying on applications
- Progressive adoption of Product Lifecycle Management (PLM) Approach and Model Based System Engineering
- Virtual Collaborative working environment for people working inside but also outside their enterprise facilities, being for homework or nomadic work
- Gradual abandonment of in-house software for Commercial of the Shelves with a deployment model evolving from on premises solutions to heterogeneous hybrid multi clouds solutions.
- Cyber Physical Systems connected to organizational systems through the emerging protocols developed for the Internet of Everything. It prepared the ground for Smart Environments, being for production with Virtual Manufacturing (VM), for Maintenance, Repair & Operations (MRO) or for smart exploitation or usage environments (e.g. Smart cities for Autonomous transportation systems). It creates opportunities for Digital Twins, which are digital representations of physical product instances reflecting their state during various phases of the lifecycle of the product. These representations are closely related to the digital representations used for defining the product during the design phase. In order to ensure related data (i.e. those describing the product, the product instances and the associated processes) homogeneity, consistency and simple universal access, the concept of Digital Threads has been developed, for virtual manufacturing [1] or for the global value chain [2].
- The Circular Economy, which aims at avoiding the waste of not inexhaustible resources related to human activities and leading to their rarefaction and to the destruction of the natural ecosystem. It will be done by supporting the recycling of products that will consequently have several lives, through localized services closer to users. New regulations will also probably emerge.

All along this continuous transformation, combining 1) virtualization of the product, 2) virtualization of the enterprise, 3) virtualization of the applications and 4) multi-disciplines collaboration implying distributed or nomad workers, ensuring the required **continuous operational interoperability** for the successive generations of enterprise technical applications has remained a constant problem.

In the manufacturing domain, interoperability is necessary, in order to ensure

- 1) Efficient global configuration management
- 2) Coherency of product information/data distributed between the different Product Data Management systems of the partners involved in collaboration
- 3) Efficient product data exchange, sharing and long term retention in order to support engineering and collaboration processes. The processes concerned by product lifecycle management strategy are exploitation, maintenance and support processes, but also change and configuration management, and finally traceability for legal aspects.
- 4) Seamless collaboration of actors despite the fact they belong to different organizations or communities
- 5) Smooth transition without any disruption on operations and with continuous evolution and upgrade of legacy systems.

Several PLM interoperability challenges are to be considered:

1. **Person to Person collaboration:** for two engineers belong to different organisation, one being the Original Equipment Manufacturer (OEM) and the other being the equipment provider, they have to collaborate despite the fact their respective enterprise have different objectives, process and applications, realized with heterogeneous and sometimes incompatible software and hardware products and technologies. Hence non interoperability may occur due to interoperability barriers at business, applicative and technology layers, as illustrated by the Figure 2.

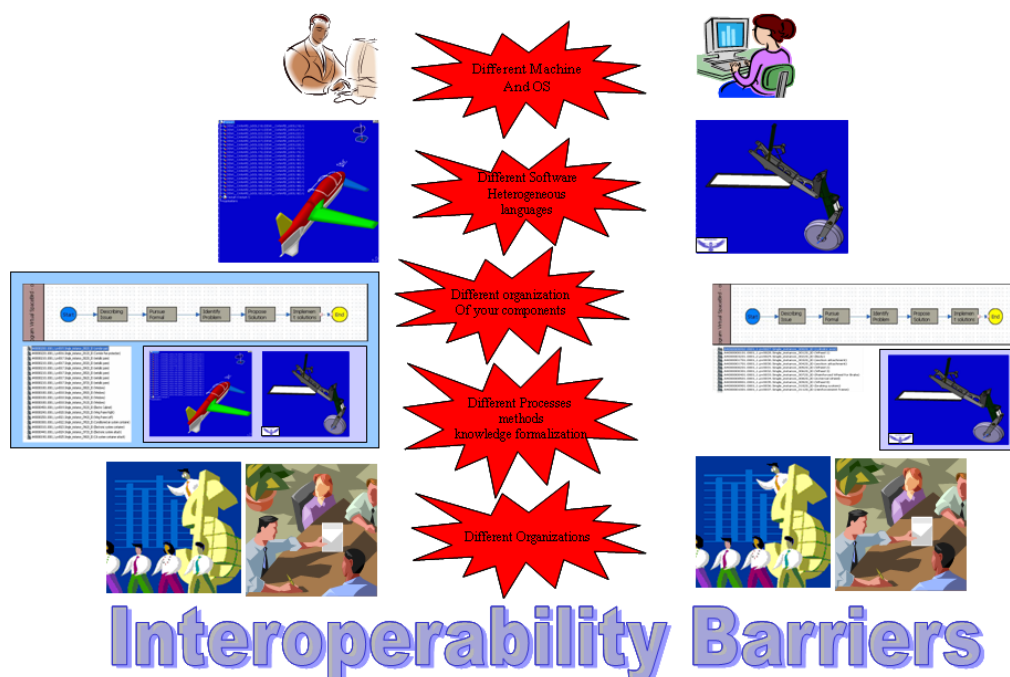


Figure 2 Challenge for collaboration between two engineers in their respective organisations

2. **Enterprise to Enterprises collaboration:** one enterprise having to collaborate with the outside can master the internal working environment, but have to interface it with the working environment of many other enterprises or organisations, which are willing to impose their way of working to the other, being by imposing their extended enterprise processes or exchange protocols. This is illustrated by Figure 3.

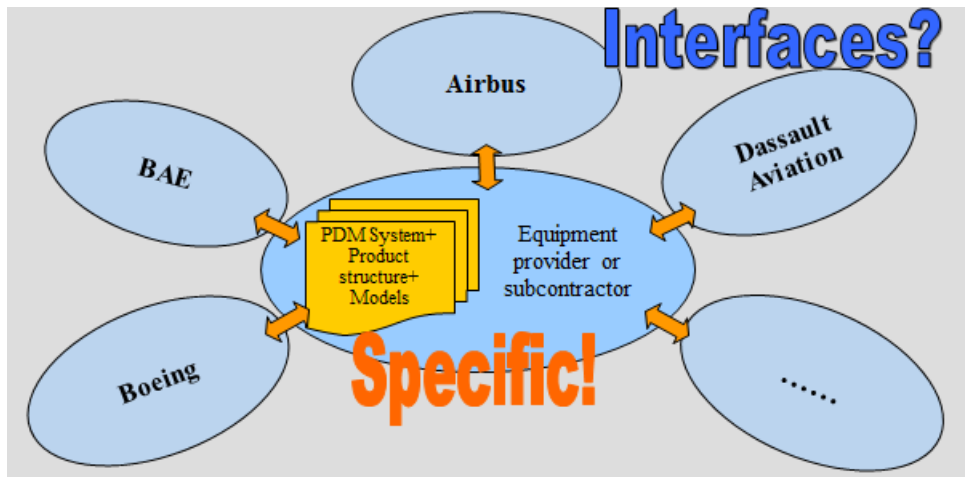


Figure 3: challenge related to interfacing internal specific information system with the different clients

3. **Collaboration within a the scale of a global supply chain:** for a given product, an Original Equipment Manufacturer has to collaborate with many subcontractors, which are themselves working with many subcontractors, and so on. Product data are to be exchanged and shared seamlessly with a complex network of organisation, for the different phases of the lifecycle of the product, as illustrated in Figure 4. In some cases, more than 80% of the value chain is out of the Original Equipment Manufacturer (OEM).

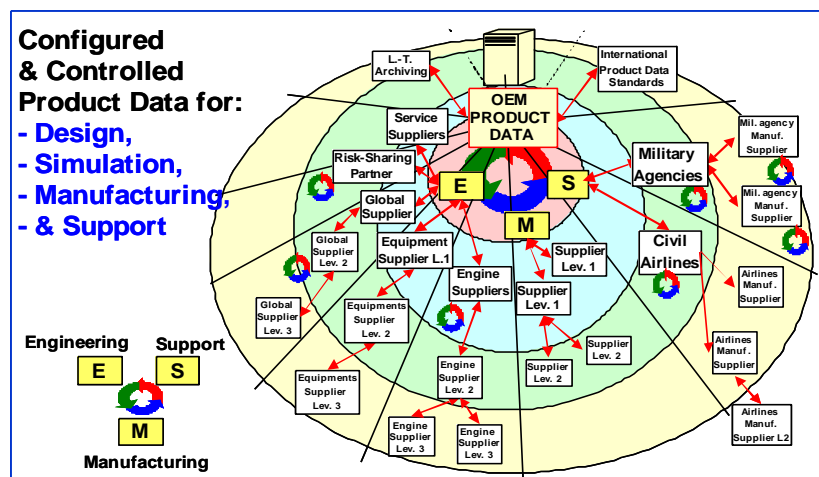


Figure 4: challenge for exchange configured & control product data in the whole supply chain

- **Combined complexity of products and of their environments:** because the complexity of the products and of their environments, more and more disciplines are to be involved all along the lifecycle of the product, each having their own domain of knowledge and digital representations of the product which is specific to the concerned disciplines and used software products. It becomes even worse when

aiming at using digital twins, and when the product is part a complex system of systems which have to communicate and interact. Many Original Equipment Manufacturers and Organisations have to be involved being for the product of system interest or for the supporting systems as illustrated by Figure 5 for a satellite. We have to deal with a complex product with complex design and production environments. Both products and support systems have to be served by a complex information system. The digital continuity is to be ensured between the various considered systems, i.e. the ability to exchange data between people and machines seamlessly, for any collaboration or interaction to be enacted.

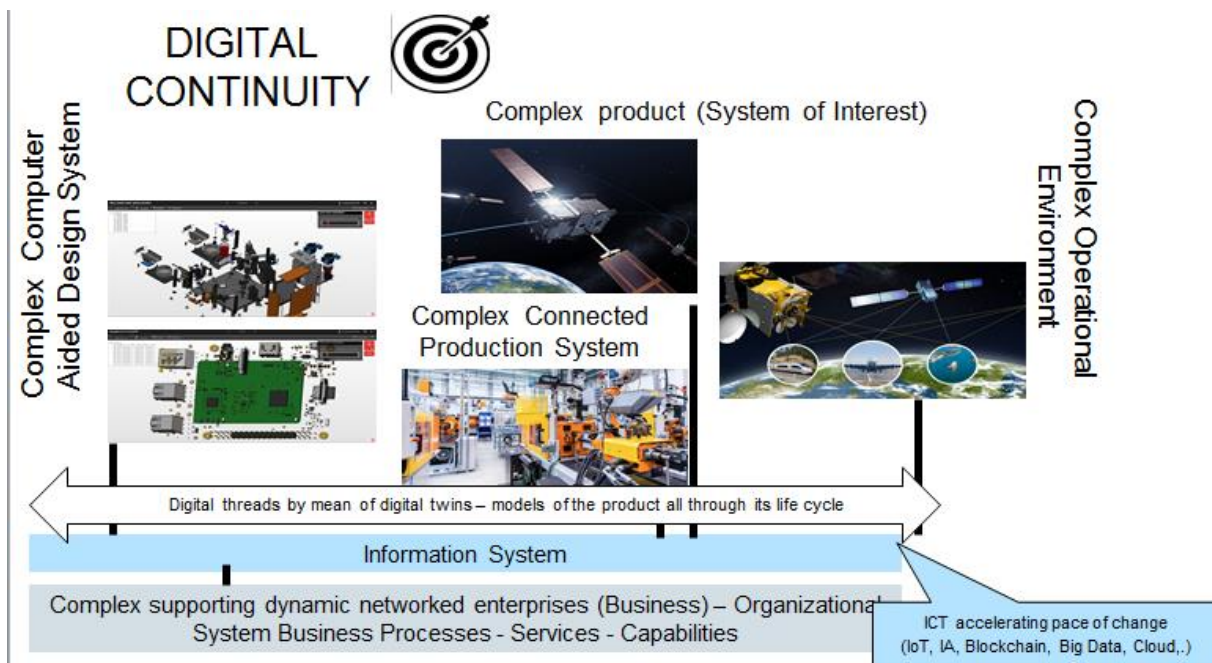


Figure 5: challenge of the digital continuity for complex system of systems.

For supporting all these challenges and despite the barriers, the interconnection of the applications the organisations are working with must be ensured at a reasonable cost, in order to share and exchange digital information through accurate services. The interconnected systems should support agile task flows and the enactment of structured but flexible workflow models within a nomadic environment.

2.2 - Definitions of Interoperability

Resolving such challenges have been motivating various standardization and research initiatives along the 30 past years, relying on successive interoperability technological frameworks and extending the types of interoperability to be considered. It is probably the reason why providing a single and universally accepted suitable definition of interoperability is challenging.

According to [3] sixty-four types of interoperability are mentioned in research papers as part of their survey and thirty-four definitions of interoperability were identified from 1977 to 2008 within the Department Of Defense documents. It demonstrates the richness of the interoperability field, but also the complexity of the topic. Considering the study, it appears that interoperability definitions are context and considered systems dependent. As an example, the following definition repeated under convenience and often rephrased, mentions "units" and "forces":

Interoperability is “The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together”.

Concerning the information system field, many definitions mentioning “information exchange”, “communication”, “software” or “networks” have been also proposed:

Interoperability is:

(a) Ability of information systems to communicate with each other and exchange information.

(b) Conditions, achieved in varying levels, when information systems and/or their components can exchange information directly and satisfactorily among them.

(c) The ability to operate software and exchange information in an heterogeneous network (i.e., one large network made up of several different local area networks).

(d) Systems or programs capable of exchanging information and operating together effectively.

Considering a more recent definition in literature related to an emerging innovative technology such as cloud [4]:

In the context of cloud computing, interoperability should be viewed as the capability of public cloud services, private cloud services, and other diverse systems within the enterprise to understand each other’s application and service interfaces, configuration, forms of authentication and authorization, data formats, etc. in order to work with each other.

As stated by [5], “We may never have any agreement on a precise definition due to differing expectations that are constantly changing. New capabilities and functions continue to offer new opportunities for interactions between systems.”

This is the reason why it is important to provide a precise definition related to the considered interacting systems and to the expectations defined by the research context, i.e. in our case the interoperability for Product Lifecycle Management (PLM).

The considered PLM definition is the one provided by [CIMDATA]. What is expected here is:

“to put in place a strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, and spanning from product concept to end of life—integrating people, processes, business systems, and information.”

PLM is not a piece, or pieces, of technology. It’s a business approach for managing the complete set of product and associated processes definition information— considering its creation, management through its life, dissemination and usage throughout the lifecycle of the product. For a PLM approach, processes are as important as, or more important than data, considering both “how a business works and what is being created.”

[CIMDATA] points out that PLM requires 1) Universal, secure, managed access and use of product and associated processes definition information 2) Maintaining the integrity of that product definition and related information throughout the life of the product or plant 3) Managing and maintaining business processes used to create, manage, disseminate, share, and

use the information. Indeed, while information includes all media (electronic and hardcopy), PLM is primarily about managing the digital representation of that information.

It means that interoperability is to be established between applications supporting the PLM processes, and realized by means of PLM software solutions distributed on heterogeneous Business and Information and Communication Technology (ICT) environments. Consequently, for our research context, we have to considered “Technical Enterprise applications” which are defined the following way:

Any application supporting a business process related to product development, and used by several actors within the enterprise (by opposition to personal application). For example, product data and process management systems, all along the lifecycle of the product, are considered like technical enterprise applications, while individual tools such as office programs or Computer Aided Authoring tools are not considered as technical enterprise applications.

The previously provided interoperability definitions can be considered as relevant for technical enterprise applications interoperability given some adaptations:

(a) Ability of technical enterprise information systems to communicate with each other and exchange information.

(b) Conditions, achieved in varying levels, when technical enterprise information systems and/or their components can exchange information directly and satisfactorily among them.

(c) The ability to operate software and exchange information in heterogeneous technical, knowledge and organization networks (i.e., one large network made up of several different local area networks).

(d) Applicative enterprise technical Systems allowing several organizations and domains exchanging and sharing digital information, models and services in order to collaborate together effectively.

2.3 - Resolution of Interoperability Approaches

Interoperability needs have given rise to the development of many models, platforms and standards with associated underlying frameworks. However, as considered separately and sometimes as competitors, they don't exhaustively meet the needs related to the preparation and construction of continuous interoperability at an acceptable cost for the PLM. It is in particular due to the many problems identified that have been collected and evaluated over the long term through feedback from various projects on the subject, being operational, standardization or research projects.

The approaches for resolution of interoperability are classified as interoperability models, open standards, Information and Communication Technologies Interoperability Platforms and research initiatives on interoperability.

2.3.1 - Interoperability Models

Regardless of the PLM, numerous models for assessing interoperability (INAS) have been produced these last thirty years.

[6] Identified 38 of them, from the analysis of an initial set of 418 papers from digital libraries published from 1996 to 2018. For the 72 more relevant ones, 12 are related to the military

domain, 37 to the industry domain, 6 from the IT domain and 9 from other domains. Defining interoperability was done according to different layered framework models and following evolutions of paradigms used by communities and domains using information and communication technologies for complex systems. The main reference models - described just after in the following and referenced in the survey- are [NC3TA], [LISI], [OIM], [LCIM], [LCI], [ORBST] [SOSI], [AIF], [IMM], [MM-IRIS] and [ULSSIMM].

NC3TA - The North Atlantic Treaty Organization (NATO) developed a reference model for interoperability, within the frame of his workgroup on technical architectures, called NATO Consultation, Command and Control Technical Architecture (NC3TA).

Focusing on information exchange and addressing technical interoperability, it establishes interoperability degrees and sub-degrees for data exchange: 1) unstructured data exchange, 2) structured data exchange, 3) seamless sharing of data and 4) seamless sharing of information.

LISI - The Levels of Information Systems Interoperability (LISI) model was developed as one of the C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) Universal Reference Resources to define interoperability between information systems. It provides a mechanism to define the maturity of information systems and a way to proceed from one level to another.

LISI defines interoperability for information systems on the basis of a matrix crossing five levels (isolated, connected, distributed, integrated and universal systems) affecting four characteristics of information systems (processes, applications, infrastructures and data).

OIM - Acknowledging some limitations of the LISI model, [7] proposed the Organisation Interoperability Model (OIM) approach, related to organization of enterprise, in order to enhance interoperability of applications.

It is based on an interoperability model for organizations with five levels: Independent Organizations, Ad-Hoc Organizations, Collaborative Organizations, Integrated Organizations and Unified Organizations as describe in Figure 6.

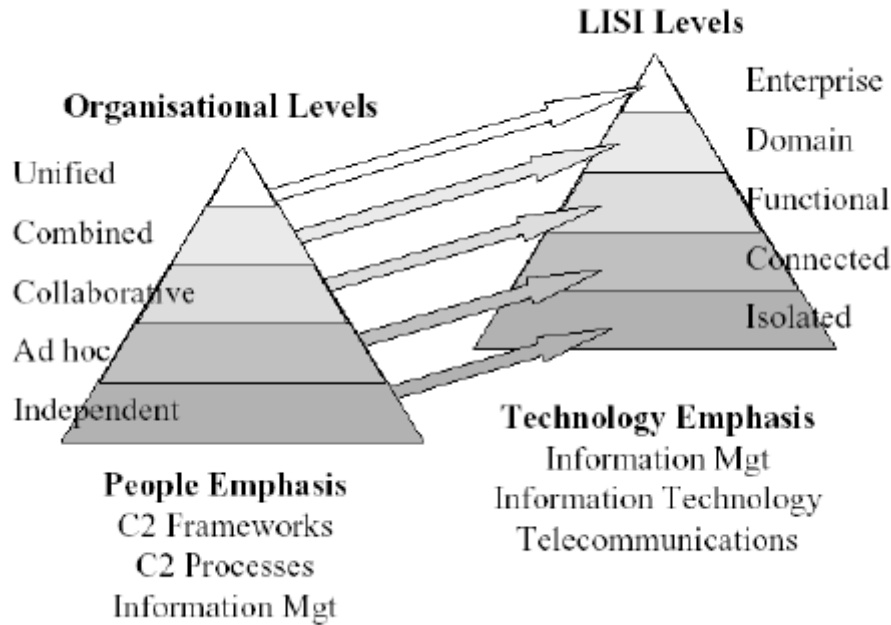


Figure 6: Organisation Levels Model mapped to LISI of Information

LCIM - The Levels of Conceptual Interoperability Model (LCIM) was proposed by NATO and adapted in (Tolk and Muguira 2003), in order to be able to address some aspects of organizational interoperability of applications, which were not addressed by previous models.

A conceptual framework with five levels was proposed. Each level characterizes how data are exchanged between applications and available interface documentation. The Enhanced LCIM model (2009) was derived from the LCIM model. It incorporates changes to address interoperability issues other than those related to data interchange, and also adds a pragmatic level, which establishes that the receiver of information not only knows what it means, but also understands how it should be used.

The considered levels are 0) system specific data 1) technical 2) syntactical 3) semantic 4) pragmatic 5) dynamic 6) conceptual

LCI – [7] establishes a reference model for coalition interoperability, the Layers of Coalition Interoperability (LCI) model, described by Figure 7. This model is intended to facilitate discussion on technical and organizational (political and military) support required for interoperable solutions. It is not intended to be a substitute for other models. The four lower levels of the model deal with technical interoperability. The knowledge/awareness level provides a transition between technical interoperability and organizational interoperability, which is represented by the top four levels. With the enhanced Layer of Conceptual Interoperability model and Layer of Coalition Interoperability model, it is not clearly defined if we are considering physical systems, information systems or organizational systems, but it appears clearly that organizations are playing an important role when willing to obtain the best level of interoperability.

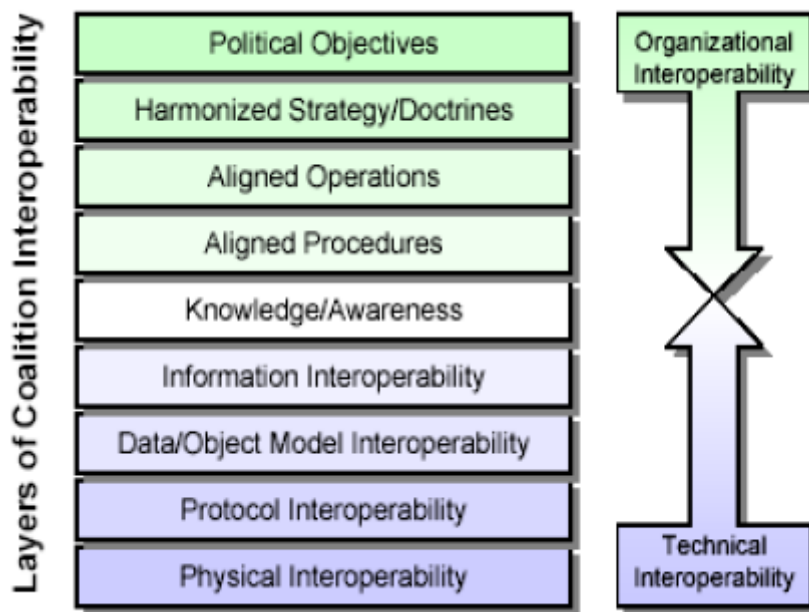


Figure 7 : The Layers of Coalition Interoperability

ORBST – [9] proposed technological framework for interoperability, considering that for eBusiness and eCommunities, the need for loosely coupling technologies in conjunction with asynchronous communication and higher semantic expressivity is mandatory if willing to achieve the semantic interoperability level. Data exchange technologies are classified according to their semantic explicitness, while software engineering technologies are classified according to looseness of coupling. Definition of seven levels is provided, including data, object, component, application, system, enterprise and community.

Three types of integration are considered: syntactic, structural and semantic.

All the types of integrations are to be considered for all the levels, but they are not balanced the same way concerning the need of semantic, structural or syntactic integration. The higher the level is, the higher the semantic integration part is important, while syntactic and structural integration parts decrease. Syntactic integration concerns mainly modelling languages, structural integration concerns mainly model transformation and semantic integration requires formal logic description. In association, Figure 8 shows an ontology spectrum, positioning the different technologies in terms of looseness of coupling and semantic explicitness. For eBusiness and eCommunities, it highlights the need for loosely coupling technologies in conjunction with higher semantic expressivity and asynchronous communication. Such a model of reference is very helpful for a community having to define frameworks and standards to use. Choice should be made according to the interoperability to achieve.

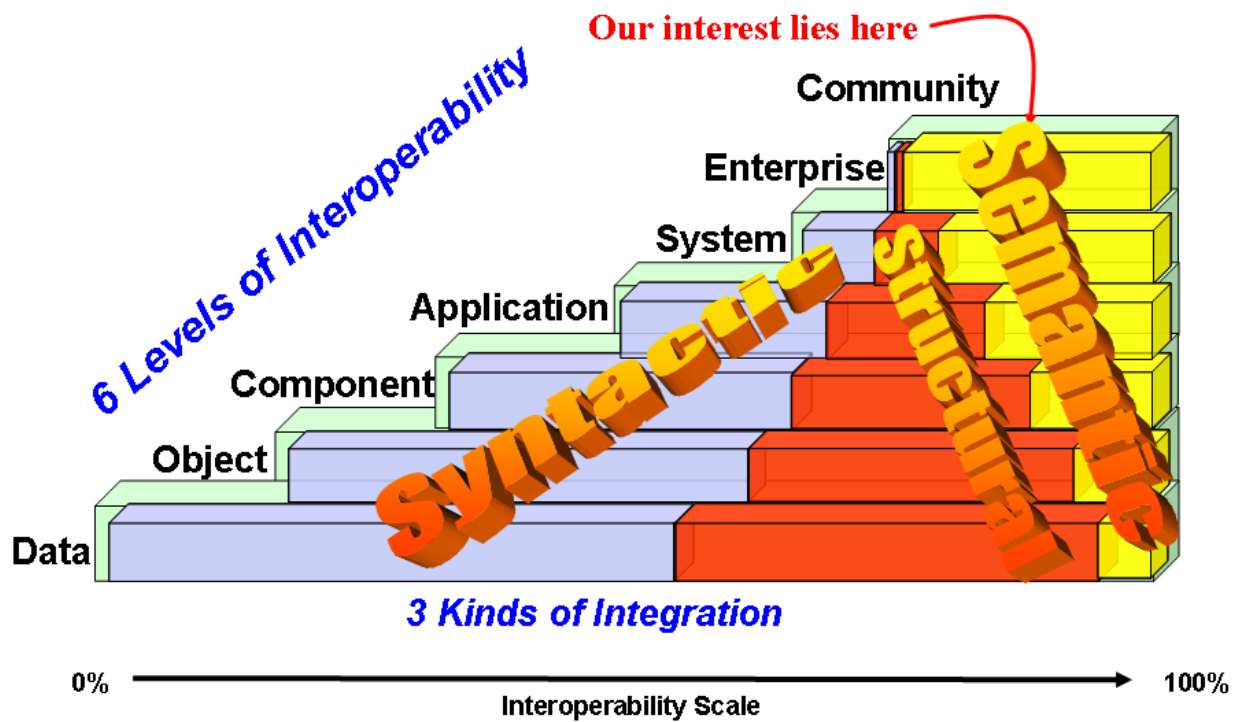


Figure 8: Dimension of Interoperability and integration (Obst 2008)

SOSI - The System of Systems Interoperability (SOSI) model, defined in [5], is based on the observation that interoperability in operations can't be achieved without:

- activities related to acquisition of a system (program management);
- activities creating and sustaining interoperability with focus on architecture, standards and Commercial Off-The-Shelves;
- activities related to operation, based on interactions between systems and with users, including operational support.

Figure 9 shows the three sorts of activities that must be further aligned for effective interoperability. The SOSI model defines three types of interoperability: programmatic, constructive, and operational.

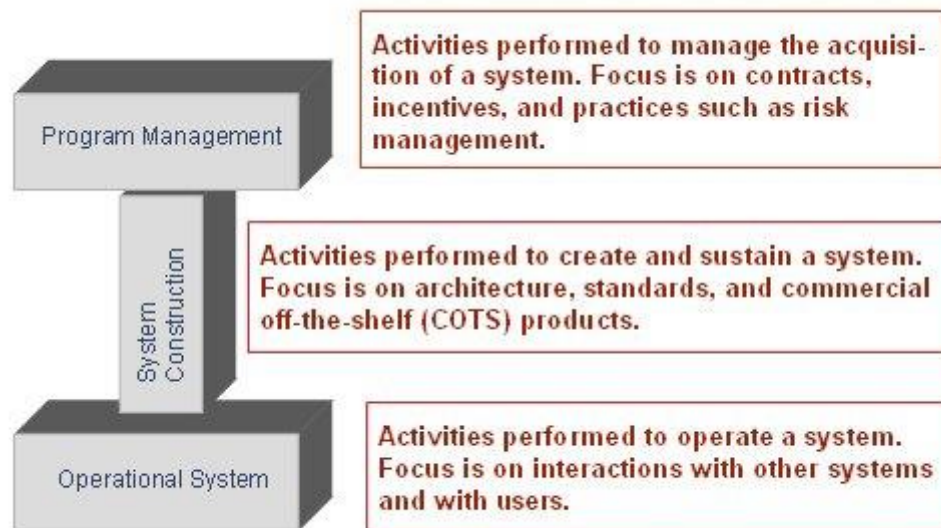


Figure 9: Systems Of Systems Interoperability model

As other previously presented models, the SOSI model distinguishes technical aspects of interoperability and those aspects of interoperability that are required between organizations. SOSI draws a further distinction between programmatic interoperability involving organizations responsible for system development, and operational interoperability, involving the organizations and individuals using the systems.

IMM – [10] proposes a conceptual framework, the Interoperability Maturity Model (IMM), distinguishing different interoperability systems, interoperability types and levels of maturity. The interoperability systems are:

- **Decision:** several decisional systems belonging to different partners are to be identified and it should be enable to make them work together
- **Information:** it concerns creation of relations between the different information systems of the partners
- **Physical:** several physical systems have to work together.

The interoperability types are conceptual (related to syntactic and semantic aspects of the information to be interchange), organizational (related to responsibility, authorization and organization definitions) and technological (related to compatibility aspects of information and communication technologies). Maturity is then defined at the intersection of these two axes, making distinction between several maturity levels. This is illustrated by Figure 10.

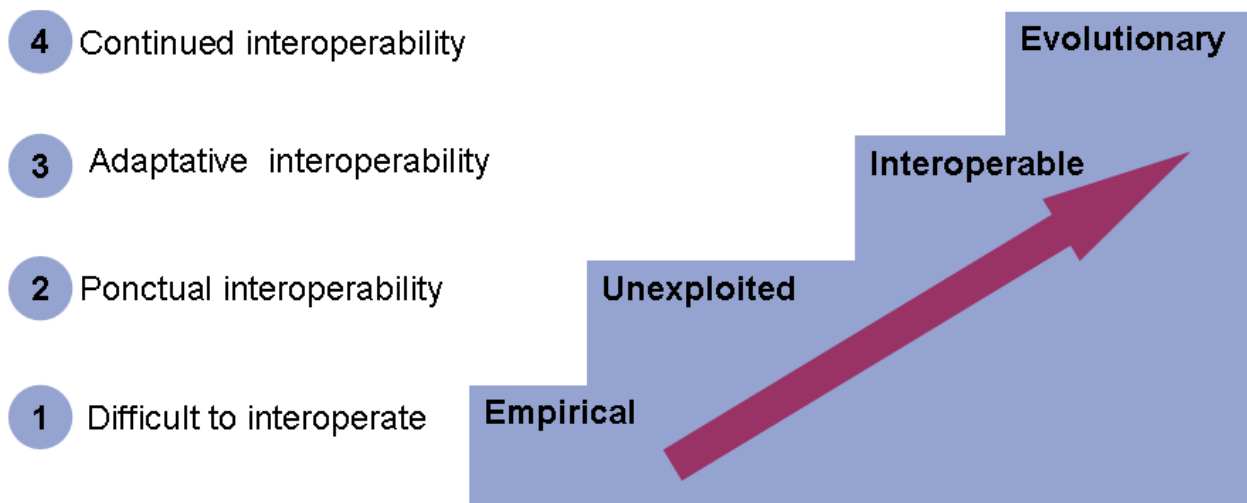


Figure 10: The Interoperability Maturity Model

AIF (ATHENA Interoperability Framework) - The high level ATHENA reference Model deals with a holistic approach to address interoperability of enterprise applications, taking into account enterprise modelling, ontology, model driven engineering, service oriented execution platform and cross organizational executable collaboration processes. It is one foundation of my research work on this thesis. This model was produced by the Enterprise Application Interoperability research community within the [IDEAS] Roadmap project, and then used within [ATHENA] research project but also within the other projects of the associated research cluster. It reflects that interoperability of applications must be achieved at enterprise, knowledge and technology levels, using semantic mediation between applications and between levels. Figure 11 illustrates it, describing considered layers: business, knowledge, applications and data.

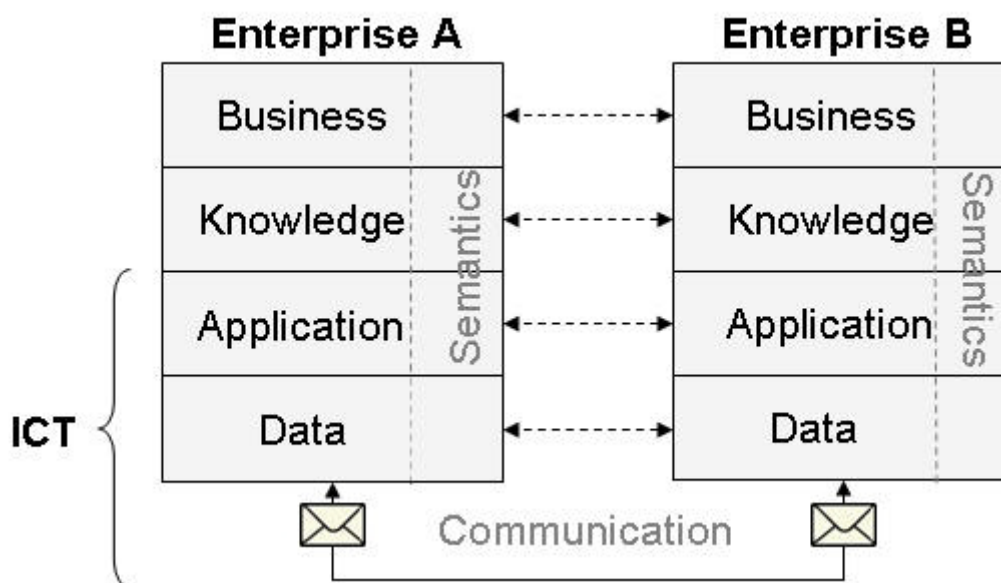


Figure 11: ATHENA Interoperability Model

Another outcome of the ATHENA project is the Enterprise Interoperability Maturity Model (EIMM), considering the different levels of maturity of an enterprise in terms of interoperability establishment, from the lowest to higher: performed, modelled, integrated, interoperable and optimizing (Figure 11).

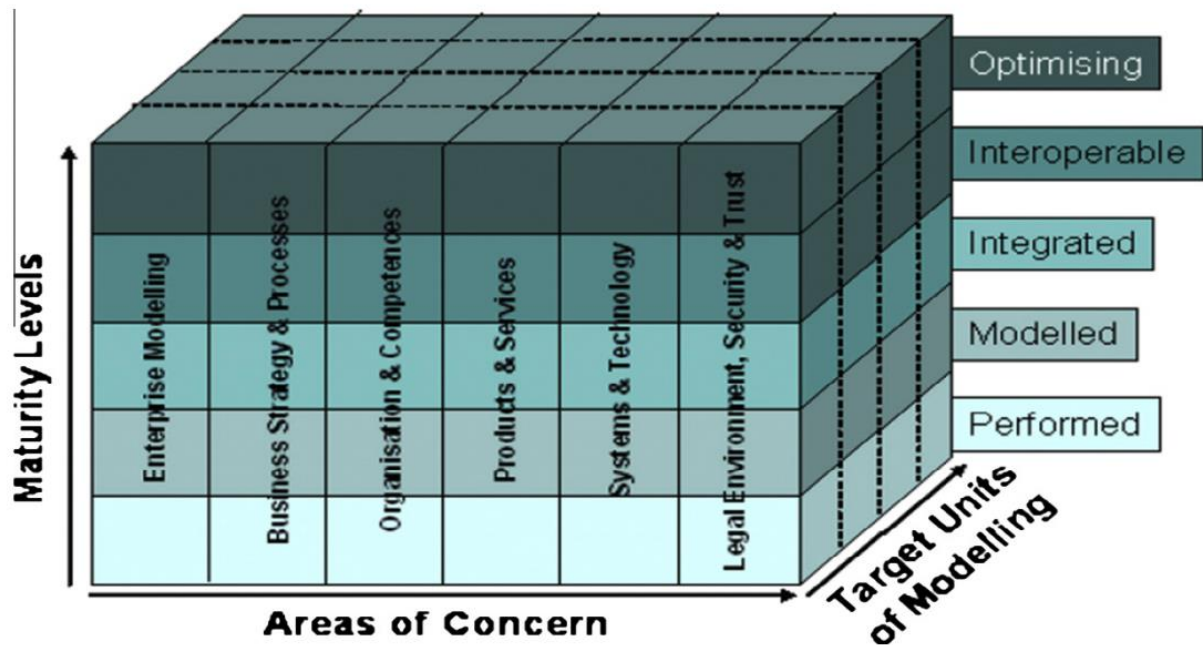


Fig 11: ATHENA Interoperability Maturity Model

MM-IRIS: The Maturity Model for Interoperability Potential Measurement (MM-IRIS 2013) is composed by a methodology and a reference set of parameters to measure the interoperability potential, which concerns the preparation level of an enterprise to establish an efficient collaboration with possible partners.

It first defines a set of enterprise views to be considered for interoperability: Business, Process Management, Human Resources, Knowledge, ICT (Information and Communication Technologies) and Semantic. It then considers that a project aiming at improving the maturity level of the enterprise have be run several phases, consisting in planning the project (conceptual and strategic aspects), defining and classifying the collaborations, measuring and collecting information about collaboration to consider, analysing the current status and then proposing improvements. Figure 12 provides a matrix crossing the different project phases with the different enterprise views.

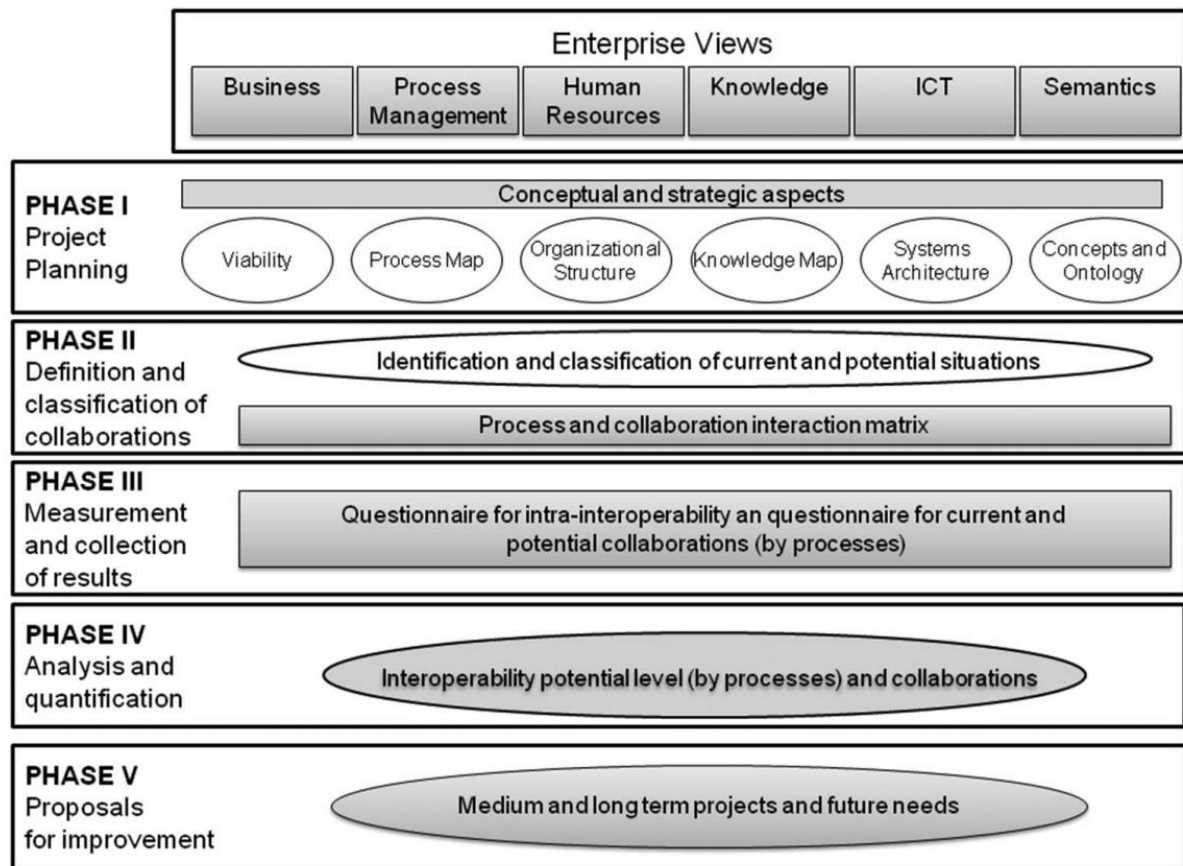


Figure 12: The Maturity Model for Interoperability Potential Measurement

ULSSIMM - The Ultra Large Scale Systems Interoperability Maturity Model [11] considers systems with the following characteristics:

- It evolved gradually.
- Its component systems are operationally and managerially independent.
- Its component systems are heterogeneous, changing and inconsistent.
- Its component systems are distributed all over the world.
- People and users can have a role as elements of the system.
- Failures are unpreventable and are converted to the norm.
- Its development and evolution continuously take place while it is operating and they should not stop the overall operation of the system.

The ultra large scale systems interoperability framework is based on a proposed interoperability maturity model, combining the parameters of the other interoperability models for the particular case of ultra large scale systems. It separately gives a solution for each parameter of the proposed maturity model based on appropriate technologies.

Conclusion concerning interoperability models

All these models are addressing particular interoperability aspects. The point is to be able to select the most relevant ones and to be able to use them together for preparing and building the expected interoperability. The analysis of these models shows that no one is addressing the needs for building PLM interoperability at scale, on a very long term period. In addition, they are very high level and very generic. It is needed to go deeper in details for the specific

domains to be considered and for actual implementation of interoperability. This is the motivation for considering standards for interoperability.

2.3.2 - Standards for Interoperability

During the previous 30 years, in addition to the Interoperability Reference Models, standards have also been considered as key interoperability enablers, as demonstrated by the continuous investment in standardization activities by the industry, not only for Manufacturing domain and Information and Communication Technologies, but also for many other domains, as various as e.g. eHealth (e.g. [12]), Cloud (e.g. [13]), Big Data (e.g. [14]), Culture (e.g. [15]) or eGovernment (e.g. [16]). For the manufacturing domain, different industries have been jointly developing common standards suited for PLM, including in the fields of automotive, aerospace, defence, ship, building, furniture, etc.

A definition of a standard (derived from ISO/IEC Guide 2:1996, definition 3.2) is the following:

“A standard is a document established in a consensual way and approved by a recognized organism, which provides, for common and repeated usage, rules, driving lines or characteristics, for activities or their results that provide guarantees for an optimal level of order in a given context.”

It's different from a “De facto” standard which is defined as [17]:

“A de facto standard is a custom, convention, product, or system that has achieved a dominant position by public acceptance or market forces (such as early entrance to the market). De facto is a Latin phrase meaning "concerning the fact" or "in practice".

It is important to point out that “de lego” standards may not be used at all or can be of an insufficient quality to be used, while “de facto” standards are always used, having already obtained a dominant position.

Numerous enterprises have been pushing specifications of their own proprietary products or processes to standardization in order to reinforce, to protect or to install their dominant position on the market. In such a case, they are most of the time forcing the consensus and are still keeping the control of the evolution of the specifications or of the processes.

It is the reason why numerous discussions are occurring concerning the definition of an “Open standard”, with some difficulties to agree due to diverging interests of the numerous concerned stakeholders and to the different ways to interpret the terms “standard” and “open”.

An open standard is publicly available and may come with access and usage rights to associated with it. Openness can also be related to how it was designed (e.g. open process). We can consider that the perfect combination for enterprise application interoperability within virtual enterprise is to work with de jure standards which are at the same time de facto and open standards, such as those provided for and used by the Internet. It allows balancing power of the different members of an ecosystem through a win-win situation, which is an important prerequisite for long term collaborations.

For computer dependent technologies, these different kinds of standards can be specialized according to such or such used technology or artefacts. It may refer to systems, hardware, file formats, protocols, programming languages, etc. When considering disciplines or organizations, the standards can be computer independent or computer dependent, in order to

support computer aided activities. In this last case, it is most of the time targeted to produce formal requirements which are specific proprietary solutions independent, through usage of standardized and open formalisms.

Numerous standardization frameworks exist, which are most of the time combining these different types of standards, but usually focus on one dominant aspect: information, service, process or architecture. Numerous standardization organizations exist today, being “official” standardization bodies such as the International Standardization Organization (ISO), or simple international or national consortia.

The important standard related organizations contributing to PLM interoperability are those related to the WEB, to eBusiness, to Software and System Engineering and to the considered domains and disciplines (e.g. manufacturing). They are important because they are providing relevant models of reference which are to be used by the different stakeholders and actors involved for establishing end to end PLM collaborations within the virtual enterprise. As the considered vertical domain is manufacturing, organizations providing manufacturing standards dedicated to eBusiness are also important. In addition, some organizations are related to a more specific domain, such as Aeronautic, Space and Defence, or Supply Chain.

Other key players are solutions providers who choose or not to implement the standards with the appropriate level of compliance. Implementor forums are implying the different actors in order to qualify the adherence to standards and the effective resulting interoperability.

When considering these standards, they are addressing the different types of interoperability which are distinguished by the previously presented interoperability models: data interoperability, service invocation and composition, process, transversal collaboration, semantic, structural, syntactic, etc. Standards can also be categorized as vertical standards, i.e. be a given industry specific, or horizontal standards, i.e. shareable by any industry, as proposed by the Object Management Group [OMG].

For preparing interoperability within a given digital business ecosystem, a list of standardization related organizations is to be established for ensuring proper liaisons with strategic governance of the information system. As an example, Table 18 provides the list of some of the organisations considered for PLM interoperability in the Aeronautic, Space and Defence Industry. Some deal with horizontal manufacturing standards (i.e. not restricted to Aeronautic, Space and Defence Industry, e.g. [SCOR] or [STEP]). Other deals with horizontal business standards (i.e. not restricted to industry, e.g. [BPMN]) and underlying technological standards related to usage of interconnected computers and software systems (e.g. [CORBA]). Their PLM related role indicates why they are considered for establishment of PLM interoperability. In addition, creation date and eventually dissolution date are indicated, as the considered organization may have a limited duration of life, which also impact PLM interoperability.

As willing to holistically support the eBusiness collaboration between organizations, interconnecting their internal business processes and supporting applications, all relevant kinds of standards for interoperability are to be considered and organized in order to cover the full spectrum of needs. Recapitulation of identified standards to consider with the used categorisation is reflected on Table 9.

First they are classified as enterprise architecture, business, enterprise solutions and Information & Communication Technologies (ICT) standards.

For Enterprise Architecture, sub categories are modelling language, process and framework.

For business, we are distinguishing process, service, message and data standards, which are all crossed with the different phases of the life cycle of a product, except ISO 15288 (System Engineering Process Framework) which is cross lifecycle.

The coverage of the different phases of the lifecycle of a product is also ensured for Cyber Physical Systems, Virtual Manufacturing or Digital Threads related standards (too young domain at this stage for having mature standards to assess), Supply Chain standards (suppliers can deliver equipment and services as well, e.g. for engineering) or training which is needed for any actors at any phase of the life cycle.

Enterprise solutions are related to the different families of enterprise solution software being vertical (a given domain or discipline) or horizontal (a function which can be used for any domain or discipline). The Information & Communication Technology (ICT) standards can cover process, service, message or data centric technologies, as well as Cloud technologies.

The standards classified in the Table 9 are those listed in Table 17, which gives the details of the standards, while Table 18 gives the details of standards related organizations.

Enterprise Architecture	Modeling Language	[ArchiMate], Unified Architecture Framework [UAF]		
	Process	[TOGAF] NATO Architecture Framework [NAF]		
	Framework	[UAF]		
Business		Product Life Cycle phase		
	Phases >>	Design	Production	Support
	Process	System Engineering Process Framework [ISO 15288]		
		Engineering Change Order [ECO] and Management [ECM]		ASD Integrated Logistic Standards [S1000D] [S2000] [S3000L][S4000P] [S5000F] [S6000T]
	Service	PDMEnablers PLM Services		
	Message	[PDT.net]		
	Data	[STEP] [AP233] [AP242] [AP203] [AP214]	[ISA 95], [AP214] (Product Planning) [STEP NC]	[AP239] [PLCS] ASD [SX001G], [SX000i], [SX002D]
	Digital Thread & VM	[QIF], [AP242], [AP238], [ISA 95], [RAMI 4.0], [PERA], [MT Connect]		
	CPS			
	Supply Chain	[SCOR]		
Training	[SCORM], Tin Can API			
Enterprise Solution	Enterprise Workflow System: WS-RM, XPD, BPSIM, Wf-XML or BPMN1/BPEL or BPMN2 Enterprise Service Bus: XML, SOAP, WSDL, CORBA Enterprise Repository: LDAP Horizontal Enterprise Portal portlets: JSR168, JSR286, WSRP			
Information and Communication Technologies	Process	Modeling languages and exchange format: BPMN2, XPD, SPEM2, UML/SysML		
	Service	Service description languages : CORBA IDL, WSDL, APIs, UML/SysML, OSLC		
	Message	SOAP, UML/SysML		
	Data	languages and syntaxes for data and schemas : XSD/XML, STEP EXPRESS/P21, OWL and RDF (Multi syntax), XMI, JSON/JSON Schema, UML/SysML		
	Cloud	Standardized components on multiple and hybrid clouds		
Service modelling: Open-SCA (service composition & interaction) , USDL/SoaML/CloudML (multi-view services), EMMML (mashups) Infrastructure management: OCC, CIMI; portability: TOSCA; data management: CDMI; Infrastructure: OVF (virtual machines)				

Table 9: Considered standards distribution per domains

Conclusion on standards

Standards and standardisation are a complex topic. Too many standards aiming at supporting interoperability are proposed, which are developed by various competing organisations, for different specific domains and for different purpose, as reflected by the used classification in this section. The arising question is to be able to identify relevant and consistent sets of standards to be used jointly for preparing and building the expected continuous operational interoperability. On other issue comes from the fact that standards are only specifications. Building interoperability also requires the availability of information and communication technologies on the shelves, if possible implementing these specifications and relying on languages targeted by these specifications for realization. Here come the Information and communications interoperability platforms.

2.3.3 - Information and Communication Technologies Interoperability Platforms

In addition, the PLM standards can be tight to various Interoperability Information and Communication technology platforms, based on sets of open standardized specifications and languages. The most impactful and successive ones the last 20 years are:

- 1) The STEP standard, which deals with Product Data Exchange, Sharing and Long term archiving. It provides different parts, some being technical: data syntaxes, schema description languages, visual representation of the schemas, transformation language, standardized interface for accessing to a model repository, bindings to implementation languages. It also provides a set of application protocols, which describe for a given domain and disciplines a reference neutral model supporting the expected information flows between the functions to be covered by applications supporting the domain.
- 2) The Common Object Request Broker Architecture, relying on the Object Management Architecture, defined by the Object Management Group. It aimed at developing a market of interoperable software products, and had been smoothly abandoned in favour of eBusiness XML interoperability standards, with Service Oriented Architecture. It led the Object Management Group to address the interoperability considering various realization technologies, by focussing on Model Driven Architecture for building interoperability.
- 3) The XML standards for eBusiness and Service Oriented Interoperability, Web 2.0 and then Web 3.0
- 4) The stack of Internet standards for Linked data and for Semantic Web
- 5) The Model Driven Architecture
- 6) The micro service emerging frameworks

In addition, most of the development platforms based on specific languages and supported by different providers have been integrating implementation of the different standardized protocols and Enterprise platform related services (e.g. Java Enterprise Edition or by SUN Microsystems then by Oracle), .Net (Microsoft), Perl, Python, etc.). Java for Enterprise (J2EE) had been the platform delivering most of the realizations of the open standards, though specifications opened to the Java Community. It changed with Oracle when it bought SUN, concerning the economic model and the global strategy. Today, the Java ecosystem is evolving with polyglot reactive platforms aiming at developing micro services applications

deployed on distributed hybrid multi-cloud applications (GraalVM, Quarkus, etc.) Similar directions are being adopted by other development platforms, in particular .Net.

Finally, for some families of enterprise software component products, some standardized specifications have been emerging driven by various organizations. Those relevant for PLM interoperability are Enterprise Workflow System, Enterprise Service Bus, Enterprise Horizontal Portal, Product Data Management Systems or Enterprise Directories.

Conclusion on the Platforms

Here we are facing the same issue than for models and standards: many platforms aiming at supporting interoperability are available on the shelves and are effectively in used. However, due to the competition on the market, they are competing and most of the time incompatible or closed, being voluntarily or not. Indeed, providing open and interoperable solutions may go against business strategy, e.g. for protecting intellectual property and know how, or for making the clients captive. When selecting the strategy to deliver open and interoperable solutions based on standards, the issue may come from the quality of standards or from their effectiveness for actually support the expected interoperability.

As such difficulty is not new, and as there is an actual need for interoperability, we may expect that the topic has been addressed by the research community. Here come the research initiatives related to interoperability

2.3.4 - Research Initiatives related to the interoperability topic

First, considering that the interoperability topic is cross domain and strategic, we may expect that some European Projects addressed it and made publicly available some results with as outcome some available solutions on the shelves in order to contribute to the Europe competitiveness.

Typing “Interoperability” as a research term on the database of European Research projects [18] in April 2021 returns 2157 results. As stated previously, interoperability is to be defined in the context of the kind of systems or domains which are considered. Hence combining the research with terms reflecting our domains of interest: “enterprise”, “Product Lifecycle Management”, “System Engineering”, “Semantic”, “IoT”, “Virtual Manufacturing” and “Cyber Physical”, we obtained the following results:

Enterprise and Interoperability	226
Interoperability and Product Lifecycle Management	8
Interoperability and System Engineering	20
Interoperability and Semantic	354
Interoperability and IoT	171
Interoperability and Virtual Manufacturing	1
Interoperability and “Cyber Physical”	85

Table 10: Statistic for European Research projects dealing with interoperability per topics

These results should be analysed with care, as it is based on a syntactic and quite simple search. However, it reflects that Interoperability is a topic which has been motivating many research projects over the years, in combination with successive topics. Those associated with “semantic”, “enterprise” and “IoT” and “Cyber Physical” are numerous. We have less projects concerning System Engineering, Virtual Manufacturing or Product Lifecycle Management.

For going deeper in the analysis of what these projects delivered, an important issue comes from the fact that very often, all the results are not made publicly available, and that the publicly available deliverables don't remain available a long time after the end of the projects. In addition, projects are often delivering huge number of documents which are not easy to exploit, or prototypes which are not of an industrial quality, i.e. they are not suited for being used in the enterprise without an industrialisation phase. Such industrialisation phase often doesn't occur when dealing with interoperability, in particular because the issues are not only related to technologies.

However, it was possible to assess the results and the way of working of several projects which delivered some valuable outcome and return on experience.

The three following projects are such identified research projects, belonging to research clusters, which are related to the interoperability of Technical Enterprise Application and address particular important viewpoints: [**The Advanced Information Technology in Design and Manufacturing**], [IDEAS] and [DBE].

The Advanced Information Technology in Design and Manufacturing (ESPRIT Project 7704 1996) initiative (AIT) aimed at European manufacturing users of information technology building a consensus among on their future requirements as applied to the design and manufacturing processes, reaching agreement on these requirements with the IT vendors and initiating the necessary IT-related R&D in order to meet these long-term needs. It was expected that this heavy orientation towards 'user-pull' will have a strong influence in shaping the future direction of advanced IT developments for the manufacturing sectors involved in the project. It led to the creation of a cluster of projects, involving the members of the Advanced Information Technology for Design and Manufacturing (AIT) consortium formed in the autumn of 1993 by 17 European automotive and aerospace companies. According to the requirements defined during the AIT pilot phase, AIT-IP capitalises on emerging object oriented concepts such as those defined by the STEP and OMG committees. AIT-IP proposed further to implement a platform supporting integration business cases found today in the design, engineering and manufacturing processes of AIT partners. Several other projects, such as RISESTEP, relied on the framework defined by the AIT project (4 400 000 Euros)

European Research for Enterprise Application Interoperability was initiated with the **Interoperability Development for Enterprise Application and Software** (IDEAS), with many programs since then implementing this roadmap and relying on the Network of Excellence Interop and associated European Virtual Laboratory for Enterprise Interoperability (I-VLab). This initiative aims at developing networked research with critical mass in the Enterprise Interoperability (EI) domain and associated domains (Future Internet and Enterprise Systems Applications). Created in March 2007 as an AISBL (Association Internationale Sans But Lucratif) under Belgian law, I-VLab co-ordinates more than 30 institutions from 11 countries (including China) and over 150 researchers. About 22 research projects are concerned, run during the 6th or 7th European Research Framework Programs and H2020 (<http://interop-vlab.eu/deliverables/>)

Digital Business Ecosystem (DBE) [(Grant agreement ID: 507953) started in November 2003 and ended in January 2007 is an FP6-IST project with an overall budget of € 13 903 024 (cf. <https://cordis.europa.eu/project/id/507953>). DBE aimed at providing Europe with a recognized advantage in innovative software application development by its SME industry, launching a disruptive technology paradigm for the creation of a digital business ecosystem for SMEs and software providers thus improving their value network. An open-source distributed environment will support the spontaneous evolution, adaptation and composition of software components - which also embed business rules - and services allowing SMEs, that are solution and e-business service providers, to cooperate in production of components and applications adapted to local business needs. This can only be achieved with a vision leading to a paradigm shift: the complexity of distributed software production and the new forms of networked business require a multi-disciplinary approach based on biology, physics and social sciences mechanisms and models. DBE transposes from living organisms mechanisms like: evolution, adaptation, autonomy, viability, introspection, knowledge sharing, selection, and will lead to emergence of novel architectures and technologies, business processes and knowledge. The DBE aimed at changing the way SMEs and EU software providers use and distribute their products and services. The DBE is based on the key finding that with such an evolutionary and self-organising system Europe could harness the complexity of software production and its SME software industry could regain competitiveness. [1] reports the results of the initiative.

Analysing these projects, in addition to those that Airbus contributed to in order to deal with the expected interoperability; we didn't identify projects delivering valuable results which led to industrialisation of solutions supporting effective preparation and building of continuous operational interoperability required for PLM. We also identified serious limitations for research projects as being a way to address these issues, related to practices and rules put in place which prevent to produce effective outcome.

2.4 - Limitations

Despite the many legacy reference models, standards, dedicated technologies and research activities, successfully preparing and building continuous operational PLM interoperability at an acceptable cost, considering increasingly rapid changes in organizational and technological contexts, remains a challenge.

It is true in particular when willing to rely on PLM standards. [RISESTEP] and [SAVE] demonstrated the feasibility of sharing digital mock-up units widespread within heterogeneous applications distributed in networked enterprises by relying on a combination of manufacturing data exchange standard and distributed software standard. However the results were never applied or industrialized. [IDEAS] and [ATHENA] partners received the assessment of these results in order to solve the problem and were proposed a way to deal with dynamic and heterogeneous requirements engineering when dealing with interoperability for enterprise applications. However they didn't succeed in addressing it.

Analysing the reason for these failures pointed out the importance but also limitations of the current legacy interoperability standards and associated frameworks. If not associated in an appropriate way, they are not ensuring the operational continuous interoperability of technical enterprise applications within virtual enterprise at an acceptable price. Heterogeneous relevant legacy solutions, being standards or frameworks, are to be federated, aggregated, combined, configured, completed and sometimes improved in order to reach the seamless interoperability objective.

For the PLM purpose, interoperability is to be addressed in a holistic way, considering not the problem at the scale of the enterprise but at the scale of interacting digital business ecosystems and domains of knowledge. Indeed, the adoption of a PLM approach involves many disciplines and stakeholders which have to collaborate relying on accurate processes and methods.

In addition, the concerned disciplines are those associated to domains involved in the lifecycle of enterprise applications and their infrastructures, such as knowledge representation by ontology, software engineering, enterprise modelling and finally product data exchange, sharing and long term preservation.

As most of interoperability solutions, being models, standards or technical platform for are partial solutions and were not designed in order to be combined, their joint usage is quite challenging and requires a new innovative approach for enterprise technical applications interoperability within the virtual enterprise. The related performed state of the art and state of the practices demonstrated that this need wasn't addressed, or only partially, by overlapping, redundant and incompatible solutions not designed for addressing the long term data retention needs coupled with a mastered change process which prevent the disruption of operations, the accelerated obsolescence of the used solutions or the inefficient collaboration when relying on model based and computer aided approaches.

It was the motivation for developing and proposing the Federation of Interoperability Framework (described in chapter 3), as a way to continuously and pragmatically address the encountered issues through successive research, standardization and research projects contributing to a shared vision for PLM interoperability, and keeping track of the various issues which were already addressed and of those which were never addressed a satisfactory way. It relies on identified independent legacy enablers to be used jointly - here stands the idea of federation - and aims at unleashing the identified brakes, being scientific gaps, anti-patterns, bad practices or common behaviours.

The identified issues come from the analysis of the operational, standardization and research context when willing to achieve the expected interoperability for PLM or digital collaboration within and between manufacturing organizations. Table 11 provides the list identified issues which have been continuously collected following Federation of Interoperability Frameworks approach.

ID	Designation	Description
I-01	Multiple formalisms and non-preservation of the semantic	Multiple formalisms and non-preservation of the semantic between applicative components but also engineering artefacts when using model driven approach leads to poor communication between systems and loss of data
I-02	Break with legacy system	New paradigms are leading to breaks with legacy systems and creation of silos
I-03	Multiple dissociated boundaries	Virtualization leads to multiple dissociated boundaries for the different concerned systems: organizational, decisional, knowledge domain and technological system

I-04	Non alignment of identifications, decompositions and types	Non alignment of representations of a same real thing within different interconnected systems, in terms of identification, decomposition and typing makes data exchange and sharing difficult.
I-05	Application development logic	Application Development logic when systematically using Commercial Off-The-Shelves leads to “black box” which is going against applications interoperability and reduces the level of maturity of enterprises.
I-06	Cost to establish and maintain interoperability	The cost for establishment and maintenance of interoperability are too important with current practices, architectures and non-flexible technologies.
I-07	Diverging interest concerning interoperability	Diverging interests concerning stakeholders concerned by enterprise applications interoperability is going against the adaptation of relevant solutions.
I-08	Non flexible and reconfigurable solutions	Non flexible and reconfigurable solutions components are too often used.
I-09	Babel syndrome	Babel syndrome is not considered enough
I-10	Closed solutions	Closed solutions are going against interoperability.
I-11	Standards oriented according a single viewpoint	The standards are often oriented according to a single viewpoint, which is going against a global solution.
I-12	Standards oriented according a single type of model	Standards are often oriented according to a single type of model (information, service or process), which is going against a global solution.
I-13	Interoperability considered too late	Interoperability is considered too late, leading to overcost.
I-14	Important cost of creation of ontology for semantic mediation	Important cost of creation of ontology for semantic mediation is often not considered by researchers.
I-15	Complexity	Complexity of the systems concerned by PLM is challenging when willing to achieve interoperability
I-16	Sliding of formalism usage	As soon as formalism is created to cover such or such phase of lifecycle of application, a trend exists to use this formalism for the following phases of the lifecycle, leading to multiplication of languages and technological silos. We call it “sliding of formalisms" usage.

I-17	Impact of COTS parameterization	Impact of Commercial Off-The-Shelves parameterization during deployment and exploitation phase is most of the time not considered, while operational interoperability concerns only applications used in operational environments and not software products.
I-18	Legacy components not considered by conceptual frameworks	Most of the innovative model driven approaches proposed by research are not considering reuse of legacy implemented solutions and operational application, which imply retro-engineering and retro-conceptualization
I-19	Missing or insufficient governance of standards	For numerous organizations, there is missing or insufficient governance of standards
I-20	Graphical and textual languages	The drawback of graphical formal languages and their association with textual languages without conceptual alignment leads to inappropriate and useless sets of emerging standards.
I-21	Federation of systems	Federation of managed resources being controlled and filtered by several heterogeneous systems is not addressed by interoperability research.
I-22	Data exchange: not only translation but transposition	Data exchange is too often considered as simple translation while it requires transposition within several contexts using different independent sets of business rules.
I-23	Numerous incompatible and coexisting frameworks	Several incompatible and coexisting frameworks dealing with or impacting interoperability lead to technological silos.
I-24	Secured collaboration	Too often interoperability is considered as decoupled from security. However any interoperability solution should be coupled with security solutions in order to be usable in operation. Interoperability should also consider the impact of heterogeneous security policies between collaborating partners and of heterogeneous adopted security solutions
I-25	Controlled access to information and data	Too often, solutions provided for interoperability consider open solutions allowing exporting or publishing data for an application, but not the means for controlling and tracing who is accessing which data and information. It is an issue when considering constraints related to the protection of the intellectual property, the protection of personal data or the export control.

I-26	Dynamic networked organisation	Too often, interoperability is addressed for a one to one application collaboration, when it should be addressed in a more holistic way as collaboration in a dynamic network of interconnected applications, used in networked enterprises and realized by software systems distributed in interconnect networks of machines.
I-27	Process interoperability issue related to synchronicity	A problem for interoperability between running instance of processes is to be able to synchronize activities in terms of provided outputs from the activities of one process being awaited and expected as inputs from activities of another process, with the appropriate sequences.
I-28	Assessment of PLM standards and Testability of their implementation	Enterprises don't know how to specify interoperability from the business cases they have to support, making it impossible to plan testing and to qualify their collaboration chains.
I-29	Cross life cycle interoperability involving production and support	Most of the time, Interoperability for Product Lifecycle management is not addressed simultaneously and holistically by design office, production and customer support, leading to silos preventing the expected interoperability, within companies and within standardisation activities
I-30	Silos between Production and Design offices	Design offices and Production are not considering the Product from the same perspective, creating silos between PLM related solutions and standards.
I-31	Flat semantic models not suited for modular modelling of composite systems	Semantic web technologies are not supporting properly the ability to deal with modular modelling of composite systems, as relying mainly on classes, properties and individuals. It is consequently not suited when willing to address structural interoperability
I-32	System models not suited for semantic preservation	Containments, being for structuring models (modules, packages) or for modelling systems (model element as container) are depicting implicit links without the ability to associate any business semantics concerning the relation between the container and the elements it contains

Table 11: Interoperability issues

Some of the issues are quite obvious, well known and already described within the literature.

Some are particularly important when dealing with the PLM interoperability topic.

It is the case for:

1. The preservation of the semantic when using multiple formalisms, being for exchange of data between applications or for the chain of tools used in a model driven approach (I-01)
2. The multiples dissociated organisational, knowledge domains, applicative or technical boundaries which are usually not considered together (I-03)

3. The non-alignment of identifications, decompositions and types resulting from the previously mentioned boundaries, but also from the multiple viewpoints of the different stakeholders with their particular viewpoints and concerns (I-04)
4. The application development logic which very often doesn't ensure interoperability by design (I-05)
5. The sliding of formalism usage from their original phase of the life cycle of software system development to usage in operation. It is the case for conceptualisation languages which are used for Knowledge Management Systems or of modelling languages which are becoming executable in Business Operational Environments (I-16)
6. The impact of COTS parameterization, which is usually insufficiently considered. The interoperability to be considered is the one between applications, which results from the deployment in a specific business and computing context. Such deployment requires parameterization which constraints usage and behaviour of the software systems realizing the applications. It means that achieving operational interoperability is not only on the hand of software vendors, but also the concern and the responsibility of the support functions of the enterprise in charge of the governance, specification and usage of the application components and of the data assets (I-017). The fact that legacy components are not considered by conceptual interoperability frameworks. Most of the frameworks are considered standalone, without considering that other frameworks were used for legacy systems, or that several frameworks may be used within a company or within the extended enterprise. So these frameworks don't respond to the need of mastering the evolutions or the heterogeneity (I-18)
7. The non-alignment between textual and graphical representations for several visual modelling languages. Graphical representations only provide views on the actual models, and are not suited for being interpreted by computers. So any information provided by a visual representation must be an explicit part of the underlying model and of its computable representation, which is most of the time textual when dealing with data exchange in order to be also readable and interpretable by people. In the reverse, visual representations should not induce false interpretation of the underlying model. This is not the case for several standardized languages or for visual modelling solutions implementing these languages
8. The insufficiently considered federation of systems when having to deal with PLM interoperability. Each organization having to share product and process data with a PLM context being autonomous, techniques and approaches for the integration of applications and software are inappropriate but often used (I-21). In the approach proposed by the Federation of Interoperability Framework, the issues are not necessarily scientific gaps requiring research activities for the progress of the State of the Art, but also some practices leading to non-interoperability and having to be solved by improving the state of the practice. If both the state of the art and the state of the practice have to be addressed jointly, some particular issues have been the starting point of dedicated research projects, thesis or research activities which contributed and will contribute to the evolution of the State of the Art.
9. The preservation of the semantic (I-01) was initially addressed by the thesis "Interoperability of Enterprise Technical Applications", with a proposed innovative approach: the Extended Hypermodel for Interoperability [20] [P27], described in Chapter 4, and then regularly improved in order to address its limitations.

10. Data exchange implying not only translation but transposition (I-22) was raised during the SEINE project aiming at specifying a PLM Hub based on open PLM standards. It is illustrated in Figure 11. When considering, for a given product, its structure defined in the Product Data Management (PDM) system of an Original Equipment Manufacturer (OEM), and an equipment provided by a Sub Contractor of level 1, which is by itself a product defined in a dedicated Product Data Management B, the decomposition tree of the equipment within the Original Equipment Manufacturer's Product Data Management system is a view of the equipment tree within his specific context resulting from a transposition and not only from a language translation. It implies several operations such as export in a neutral language (operations 1-2), fusion with transposition in the Original Equipment Manufacturer context in the neutral language (operation 3) and then import/export operation with translation between the neutral language and the language of the Product Data Management system A (operations 4-5). So Product data exchange can't be reduced to a simple language to language translation. In the research project SEINE, the neutral language was the one of the Application Protocol 214 ("Core data for automotive mechanical design processes") Reference Model (RM) of the STEP standard.

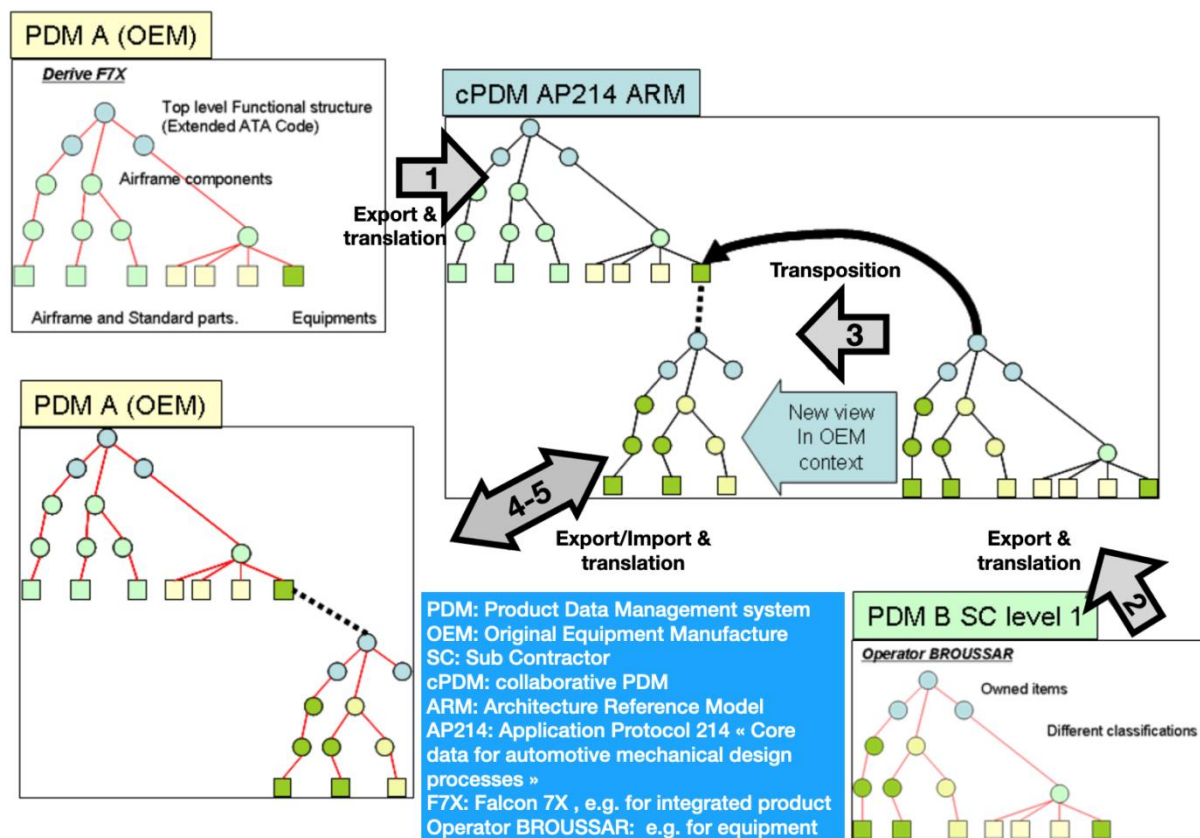


Figure 13 Data exchange implying not only translation but transposition

11. Decoupling of security and interoperability (I-24) motivated the work performed for the CRESCENDO project, and was extended in IMAGINE. The description of proposed security features is part of Chapter 3.

12. Interoperability, which is too often addressed for one to one application collaboration (I-26), was mainly addressed by IMAGINE and led to considering standardized application protocols as a Dynamic Manufacturing Network protocol. This is described in chapter 4. IMAGINE also addressed the issue (I-30), by studying how to assess and test combined

usage of standards dealing with Enterprise-Factory integration and those dealing with Product Data Interchange (SIP and [20]).

13. Process interoperability issues related to synchronicity (I-27) motivated the thesis “A formal framework for Process Interoperability in Dynamic Collaboration Environments” with as scientific outcome several research articles on the proposed formal framework and contribution to IMAGINE and SIP.
14. Missing approach for the assessment of PLM standards and Testability of their implementation was observed in several PLM Hub projects (Phenix and BoostAerospace), and identified (I-28).

It is a major issue when expressing the interoperability needs and specifying the expected solutions precisely enough for

- 1) Driving the implementation of standard based services and interfaces with clear and detailed enough specifications;
- 2) Being able to defined and plan tests of unitary solution components and of integration tests between the applications realized with these solutions.

Performed state of the art and state of the practice demonstrated that no accurate methodology was available for supporting accurate assessment of PLM standards for supporting required end to end collaboration processes for PLM within a networked organisation, and for specifying properly what is expected from vendors of solutions, and consequently for planning and realizing unitary and integration tests. As a consequence, vendors are interpreting and redefining requirements in a way that doesn't correspond to the expectations and leading to non-interoperability. This issue motivated the launching of the Standard Interoperability research projects, with as research outcome the Interoperability Testbed and related scientific articles. This is developed in chapter 5.

2.5 - Conclusion

In the considered business context, i.e. manufacturing domain taking advantage of information and communication technologies and the Internet, interoperability is mandatory for supporting PLM, continuously evolving model based practices, and more and more connection between the products and the systems supporting them at each phase of the lifecycle of the products.

After defining precisely what is the required interoperability between technical enterprise applications for PLM and reviewing the various legacy enablers resulting from important and continuous research efforts, the actual needs for preparing and building the expected continuous operational interoperability at an acceptable price are far from being covered, as demonstrated by the various interoperability issues which have been continuously collected and addressed by the research activities described in chapter 1.

Within an evolving environment where complexity is continuously growing, interoperability issues have been collected, pointing out the need for an innovative strategic and holistic long term approach combining the legacy interoperability enablers a federated way and the governance of the research and standardisation activities in order to achieve the targeted interoperability.

The Federation of Interoperability Frameworks is such an approach. It is described in the following chapter.

Chapter 3 - Federation of Frameworks

3.1 - Proposed Federated Interoperability Framework Motivation

The Federation of Interoperability Frameworks (FIF) that I proposed aims at preparing and building a continuous operational PLM interoperability at an acceptable price, despite the continuously changing context for Business practices and Information and Communication Technologies.

The approach was proposed after assessing the outcome of research projects addressing Interoperability of Enterprise Application (in particular ATHENA and IDEAS) and PLM interoperability (in particular RISESTEP and SAVE) addressing the exchange and sharing of digital mock up units within the extended enterprise based on joint usage of open standards for distributed software systems and for manufacturing data exchange and sharing.

By federating legacy interoperability standards, models and platforms, the proposed approach allows a digital business ecosystem collaborating on a given product to prepare and build the expected continuous interoperability between the applications supporting the development processes of this product.

The performed state of the art and state of the practices demonstrated that this need wasn't addressed - or only partially - by overlapping, redundant and incompatible solutions not designed for addressing the long term PLM needs, such as long term data retention with semantic and context preservation.

Another motivation for this approach is to identify actual scientific gaps which are to be addressed in order to achieve the expected interoperability, and to be able to integrate and to validate the proposed component solutions in the context where they have to be delivered, deployed, integrated, tested and used as part of global framework and working environment, while decommissioning the deprecated parts which are not of use anymore.

For such a reason, the approach includes the support of innovative processes allowing to define, to design and to generate collaborative platforms which will be required for communication, experimentation and demonstration of the business cases to be supported for research, standardization and operational PLM projects. The experimental platforms include an operational PLM working environment, but also all the capabilities for developing and sustaining this environment for long term duration, going beyond the duration of each research project duration or life duration of the used components.

3.2 - Federation of Interoperability Frameworks Principles

The interoperability enablers considered are those defined by ATHENA, i.e. Enterprise modelling, Ontology, Model Driven Architecture and Service Oriented execution platform. They are extended by the relevant open international standards related to PLM and contributing to the interoperability it requires. The considered standards distributed per domains are given by the Table 9. It is considered that mature open standards are those which come with both freely available and open source implementations of industrial quality - what we call a commodity on the web - and Commercial of the Shelves (COTS) products. As a consequence, Open Source is also considered as an interoperability enabler, as it contributed to building the maturity of an open standard [P28].

The Federation of Interoperability Frameworks consists in:

1. Qualifying the expected ideal system relying on the legacy Interoperability models

Considering the different legacy models for interoperability, the characterization of an ideal collaborative PLM system, which can be considered as an Ultra Large Scale System, is the following:

Characterization of ideal collaborative system
NC3A: Seamless exchange of information
LISI: distributed information systems
OIM: collaborative organizations
LCIM: semantic integration
MITRE: semantic integration with loosely couple technologies and asynchronous communication
IMM(s): adaptive and continued interoperability with evolutionary decision, information and physical systems; mature selected architectures of references

Table 12: federated usage of Interoperability models

2. Identifying the causes of non-interoperability, called brakes as they prevent the establishment of the expected continuous operational interoperability. It includes but it is not restricted to scientific gaps. A list of interoperability brakes, which is extensible by nature if willing to take into consideration the continuous evolution of business practices and technologies, is provided in table 11.

3. Identifying the interoperability principles to be applied: in order to respond to the set of identified issues which prevent to obtain an effective interoperability of technical enterprise applications within an eBusiness environment, a set of principles are to be defined for defining the interoperability framework to be applied in a mature digital business ecosystem. For PLM interoperability, 10 principles were identified which have to be considered in the “Interoperability of Technical Enterprise Interoperability thesis”, depicted in Figure 14.

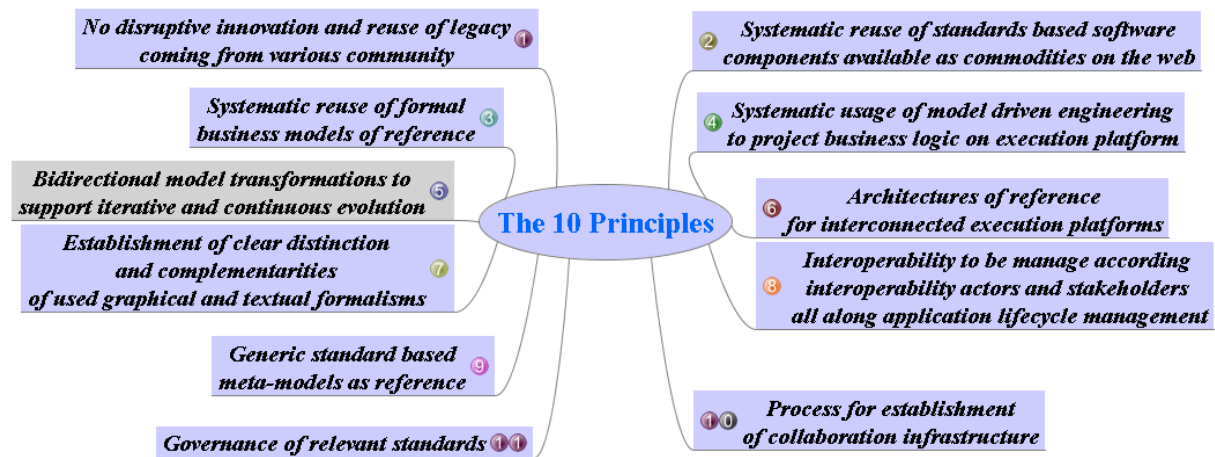


Figure 14: Federation of Interoperability frameworks principles

4. Identifying the scientific gaps to be solved in a way that the proposed innovative solution can be integrated within the FIF, responding to the interoperability needs in a holistic way as part of a global solution.

The Federation of Interoperability Frameworks has been defining principles to be considered when dealing with PLM. It includes:

- a) the usage of a holistic model driven approach based on “projection” of enterprise models on service oriented execution platforms;
- b) the reuse and continuous transformation of legacy applications, technologies and standards;
- c) the systematic reuse of standards based software components available as commodities on the web, and of formal business models of reference ;
- d) the systematic inclusion of the standards in a model driven engineering approach leading to project models on execution platforms;
- e) the support of bidirectional model transformations which are required due to the continuous evolution of each application environment and consequent iterative projects;
- f) the usage and aggregation of the different relevant architectures of reference for the operational execution platforms and their modelling and development environments;
- g) the usage of graphical representations aligned conceptually with the formal language dedicated to modelling, for handling the complexity of the considered systems of systems and supporting the communication between the different stakeholders and automates ;
- h) the usage of reference models based on generic standardized meta-models;
- i) the shared usage of appropriate standardized generic processes for establishment of collaborative infrastructures;
- j) the consideration through governance activities of lifecycle and evolutions of the used enabling standards.

For continuous improvements, extensions, adaptations and innovation, the FIF approach is iterative and the FIF was designed in order to be evolutionary. The adopted iterate approach is described in the next section.

3.3 - Federation of Interoperability Frameworks on long term

FIF aims at addressing interoperability needs for PLM, i.e. continuous interoperability on a long term duration exceeding the lifetime of used Information and Communication Technologies and the lifetime of the organization and of their processes for developing a product. It also means that many disciplines and industrial domains are concerned; leading to a complexity and to a functional coverage exceeding what can be addressed by a single project, in particular if willing to address all the identified issues. However, the enterprise application interoperability community is considering that interoperability requires adoption of a holistic approach. In addition, the interoperability standards, the models and platforms the FIF is federating have their own durations of life which are to be considered, even if quite longer than those of organisations and Information & Communication Technologies.

For all these reasons, the Federated Interoperability Framework was designed having in mind a continuous long term activity, which consists in successive research, standardization and operational projects covering together the full innovation cycle from the first new idea to the operational usage and to the best shared best practices at an international level. The approach is also a modular approach, allowing delivering results from ideation to standardization, with successive deliverables and reusable solution components (standard, software solution component, application component, business process, methodology, etc.) which can be aggregated together and reconfigured dynamically according to a changing context. It should also support deprecation of some components and replacement by alternative solutions.

Doing so, it allows to mimic the situation of an actual enterprise digital working environment which is continuously transformed and to study principles and approaches for continuous reconfiguration and evolution of a working environment within a changing context.

The resources allocated to the projects being limited compared to those allocated to the industrial projects. Hence the combination of enterprise modelling, service oriented execution platform and model driven engineering relying on free open source solutions based on open standards allows to define and to generate automatically experimental collaborative platforms quicker and with less resources, in order to support the research and the demonstration of its results. With the FIF approach, cPlatform can be reused, improved, extended and adapted for each project. Using the FIF approach allowed to produce successive versions of the cPlatform, each being dedicated to specific functional topics, interoperability aspects, PLM phases or discipline. Each participation to a project aimed at addressing an identified critical interoperability brake, at contributing to the state of the art concerning some interoperability topics and at assessing, extending and improving the Federated Interoperability Framework.

Despite the changes and the long term period, the approach remains the one initially defined despite the continuous changes of used technologies and context of usage. Such evolutionary nature, with ability to incremental changes and low cost, preserving interoperability, is what is expected for PLM interoperability. This evolutionary nature plus other expected qualities can be demonstrated by considering the successive projects where it has been applied. They were the opportunity to apply and to demonstrate research results within a continuous innovation cycle, with a continuous adaptation of the FIF to the successive emerging interoperability needs and challenges associated to the evolution of the Computer Aided Product Development practices and of associated secured digital collaboration.

Figure 15 provides a timeline of the successive projects which contributed to the development of the FIF, with the successive versions of the cPlatform. It also indicates the thesis on Interoperability [20] and the assessment of usability of the Federated Interoperability Framework for Virtual Manufacturing (VM) and Cyber Physical Systems (CPS). If considering the business context as depicted in chapter 2 and this timeline, it demonstrates that the projects, relying on the FIF, were able to cover the successive innovative transformations of the manufacturing industry, from replacement of handmade drawings by computer aided drawing to the usage of digital twins with cyber physical systems.

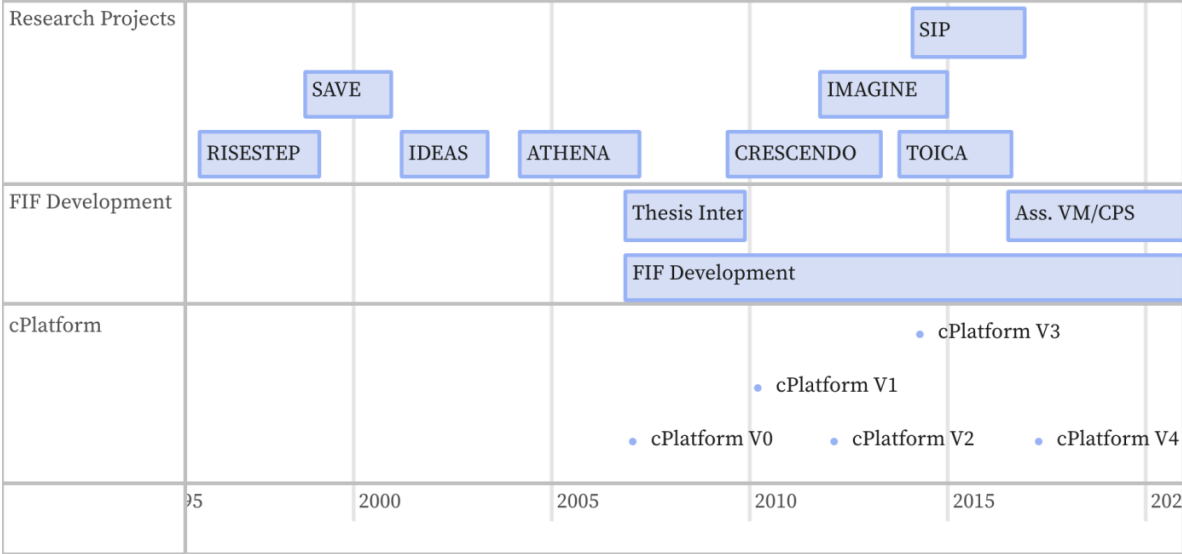


Figure 15: FIF and cPlatform timeline

Figure 16 indicates the successive PLM standards and related technologies which have been considered by the research related to the FIF before 2009. Table 9 provides all the standards

which have been used, analysed or assessed by projects using the Federation of Interoperability Frameworks from 1997 to 2021. It demonstrates that the projects, relying on the FIF, were able to cover the evolution of PLM standards based on the successive interoperability related technologies as each project was able to deliver results improving both the state of the practice and the state of the art concerning PLM standards based interoperability.

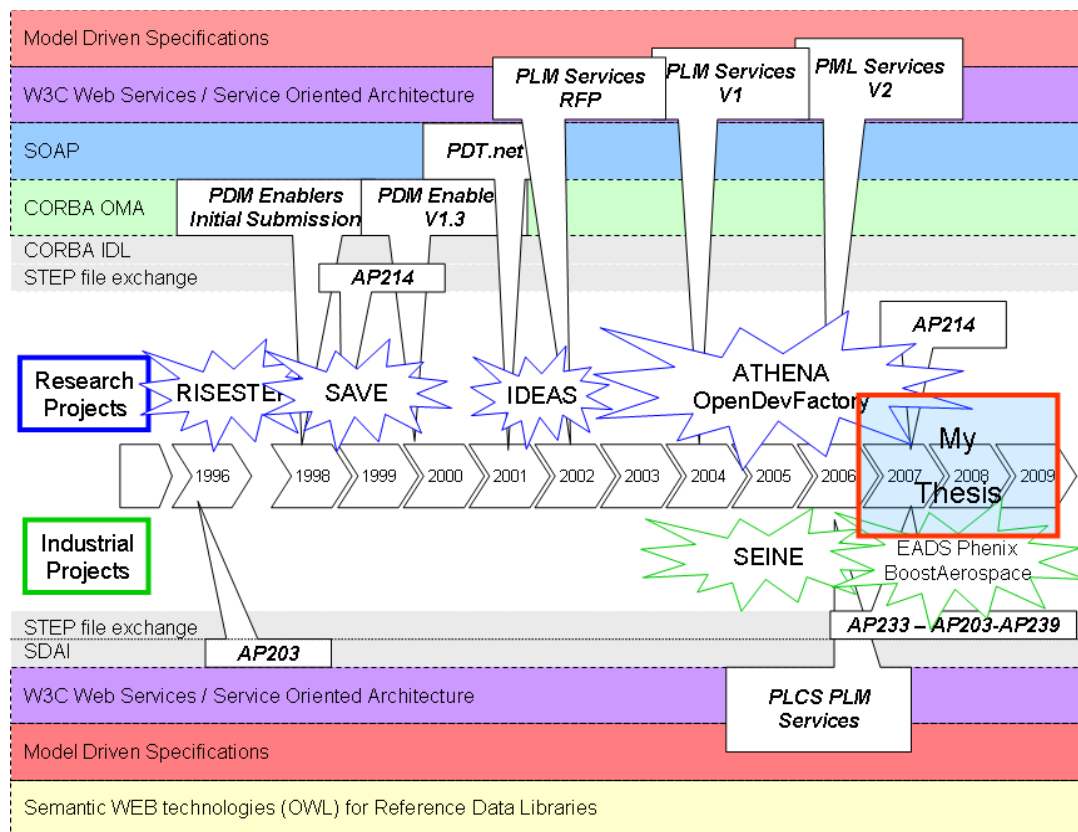


Figure 16: PLM standards timeline

If considering the Information & Communication Technologies used for producing the cPlatform required for each project, the FIF provided the approach for the continuous evolution, improvement and extension of the cPlatform for adaptation to the evolving context. This can be demonstrated by comparing the successive architectural definitions of the cPlatform described in the next sections.

3.3.1 - cPlatform Version 0

The initial version of the cPlatform was created during the ATHENA project, in order to respond to some identified risks concerning the availability of a demonstrator to use, exploit and extend after the end of the project. Such a situation was faced in previous projects (RISESTEP, SAVE) with as a consequence to restart from scratch all the prototyping already performed, leading to an important waste of time and resources when willing to focus on the main research topic. In addition, the technical choices made by solution providers were not aligned with the business expectations and requirements, in particular for the requirement related to the usage of PLM standards providing application protocols, or for the usage of standardized interfaces for distributed applications or systems.

So the idea was, relying on ATHENA principles and enablers, to produce an experimental platform for Networked Product Development, i.e. development of a Product by a network of

organisations. The building blocks identified are open source free software products implementing relevant open standards and of sufficient quality for building easily a demonstrator. This is illustrated by Figure 17.

By relying on the Java implementation of the Common Object Request Broker Architecture Component Model [CCM], the idea was to use an application server on top of which the business logic, derived from PLM standards, will be deployed using a model based approach. CPlatform version 0 was more a specification than an actual platform.

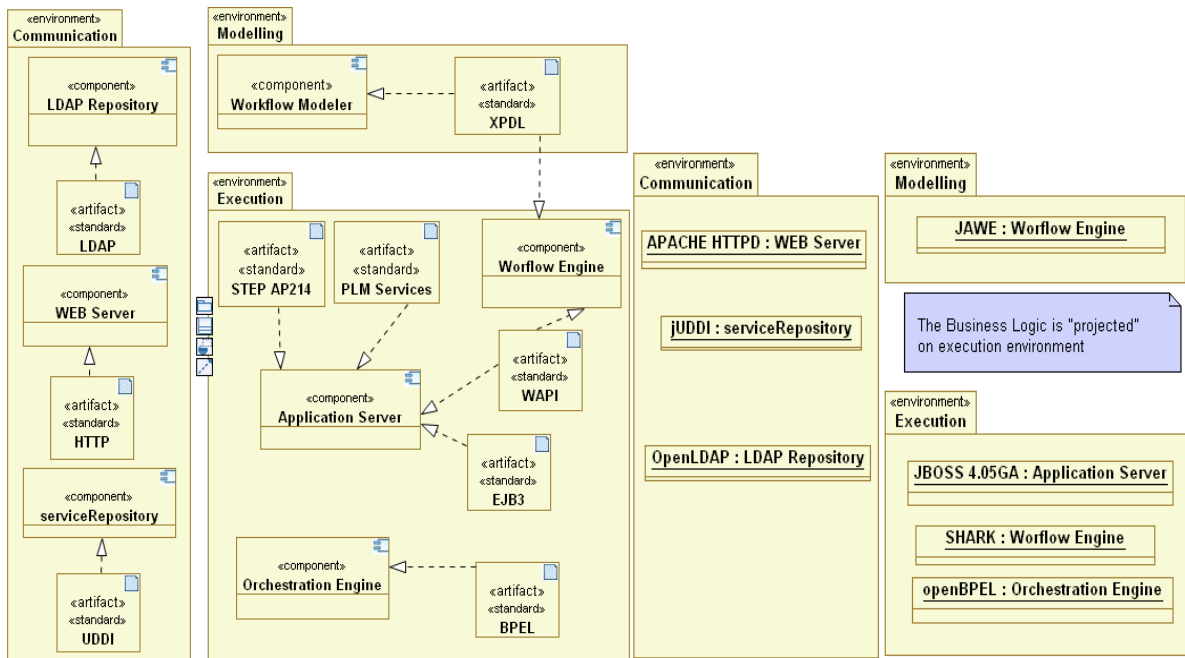


Figure 17: cPlatform v0 architectural description

3.3.2 - cPlatform version 1

The cPlatform version 1 was produced after assessing in the project OpenDevFactory how to take advantage of an open source free Model Driven Architecture generation platform, AndroMDA, supporting generation of business logic on top of an application server supporting the Enterprise Java Beans (EJB) specifications. Universal Description Discovery and Integration (UDDI) components and LDAP components were removed, and an Enterprise Service Bus was added, as illustrated in Figure 18.

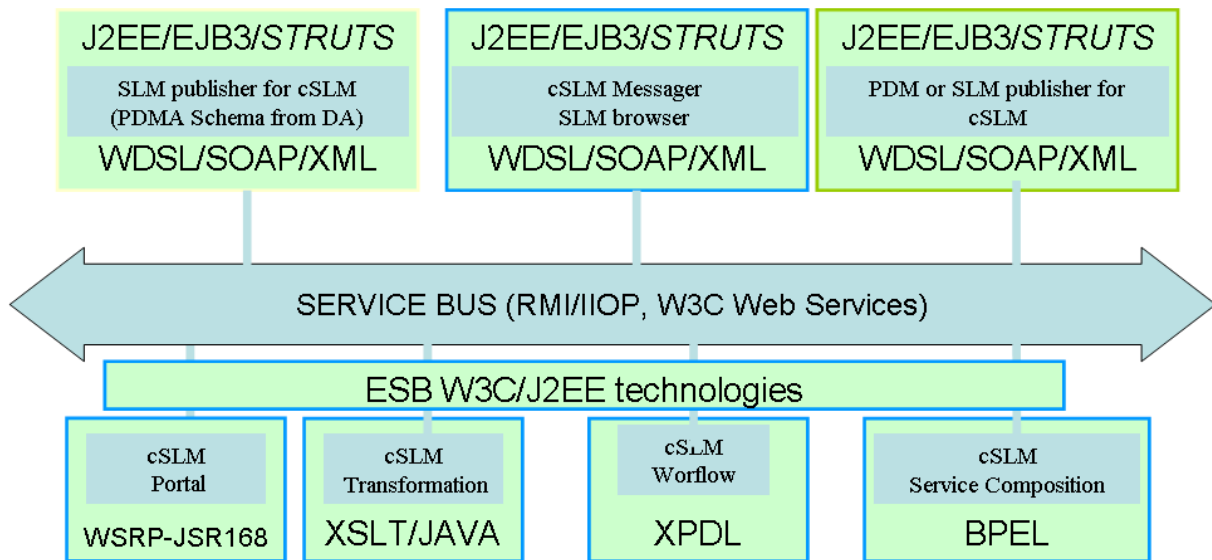


Figure 18: cPlatform v1 architectural description

In terms of model driven approach, the application protocols to be supported were used to derive the business logic in the MDA platform, including business objects and Creation/Remove/Update/Delete service for people.

It generates automatically the user interface, object model, interaction sequences with the user, persistence in a database and remote access through web services for other applications. Figure 19 reflects how the model logic was created in AndroMDA, including front end use cases, business services and business objects. It also describes the targeted execution platform: a single application server node, the organisation of business logic model and what is derived from the in terms of platform independent model and finally the application platform connected to a PLM collaborative hub through an enterprise service bus.

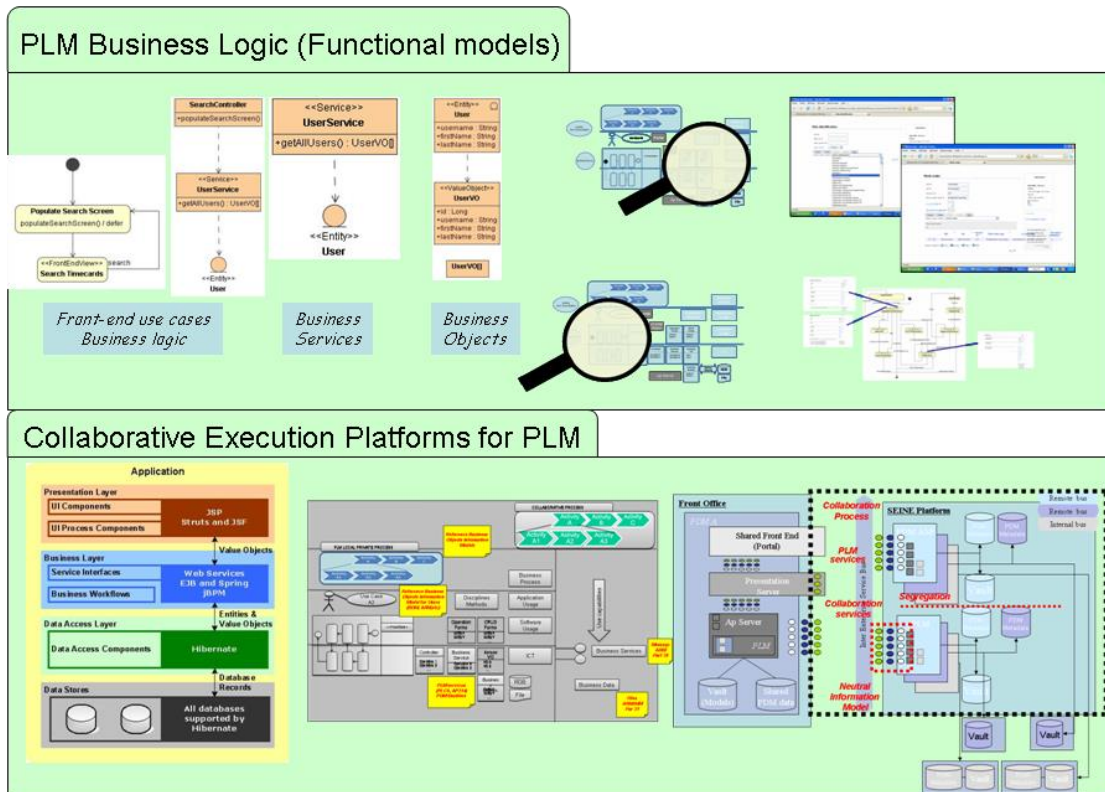


Figure 19: cPlatform v1 Business Logic and Execution Platform

Fig 17 illustrates how an interaction diagram, using a modeling profile called BPM4STRUTS, was derived from a BPMN process describing usage of the PLM. From this derived model, it was possible to generate the screens and the navigation between screen for running the described process

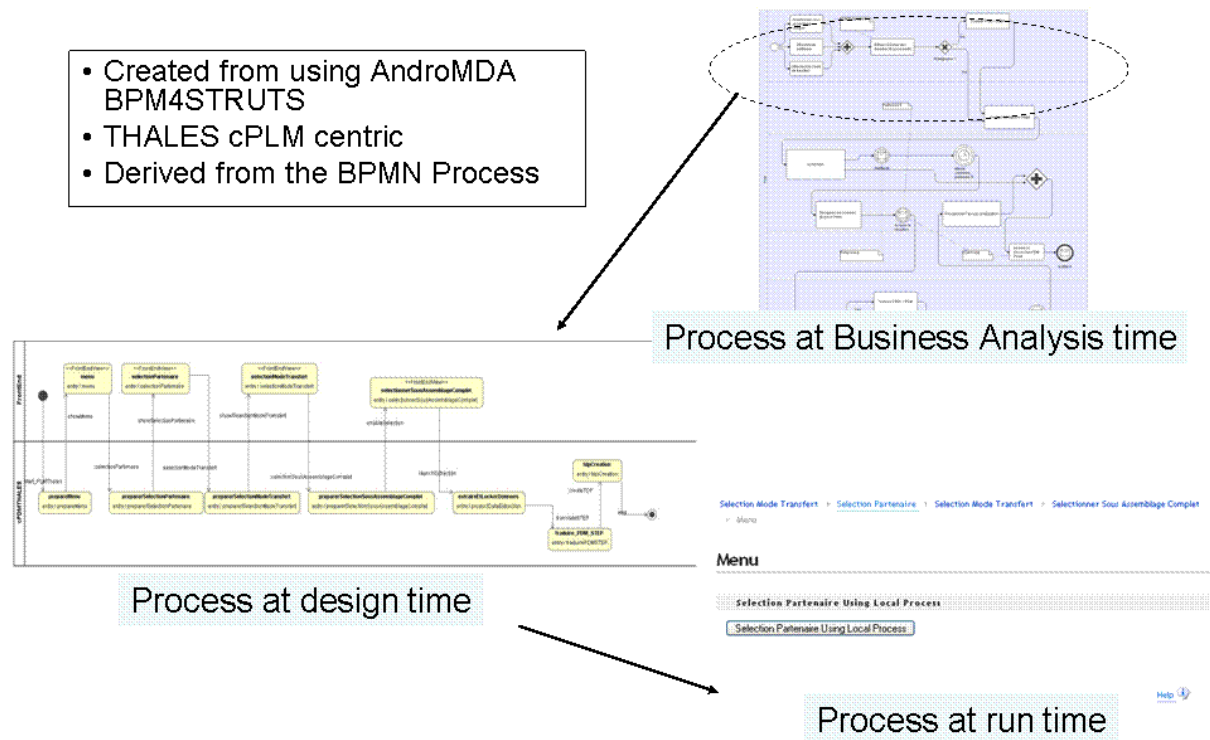


Figure 20: cPlatform v1 model generated interactions

3.3.3 - cPlatform version 2

An important feedback from business concerning the proposed solutions was related to insufficiently considered security for being able to collaborate over the web. Indeed, ATHENA partners considered that the security was not inside the scope of the research project. Secured collaboration was addressed through the Crescendo project, in order to address the issue I-24. The required infrastructure was virtualized on a physical machine on the Internet (Machine as a service), where several virtual machines were deployed in order to simulate a multi-server architecture, in order the cPlatform to be deployed out of the private information systems (back end) of the collaborating organizations (Figure 21).

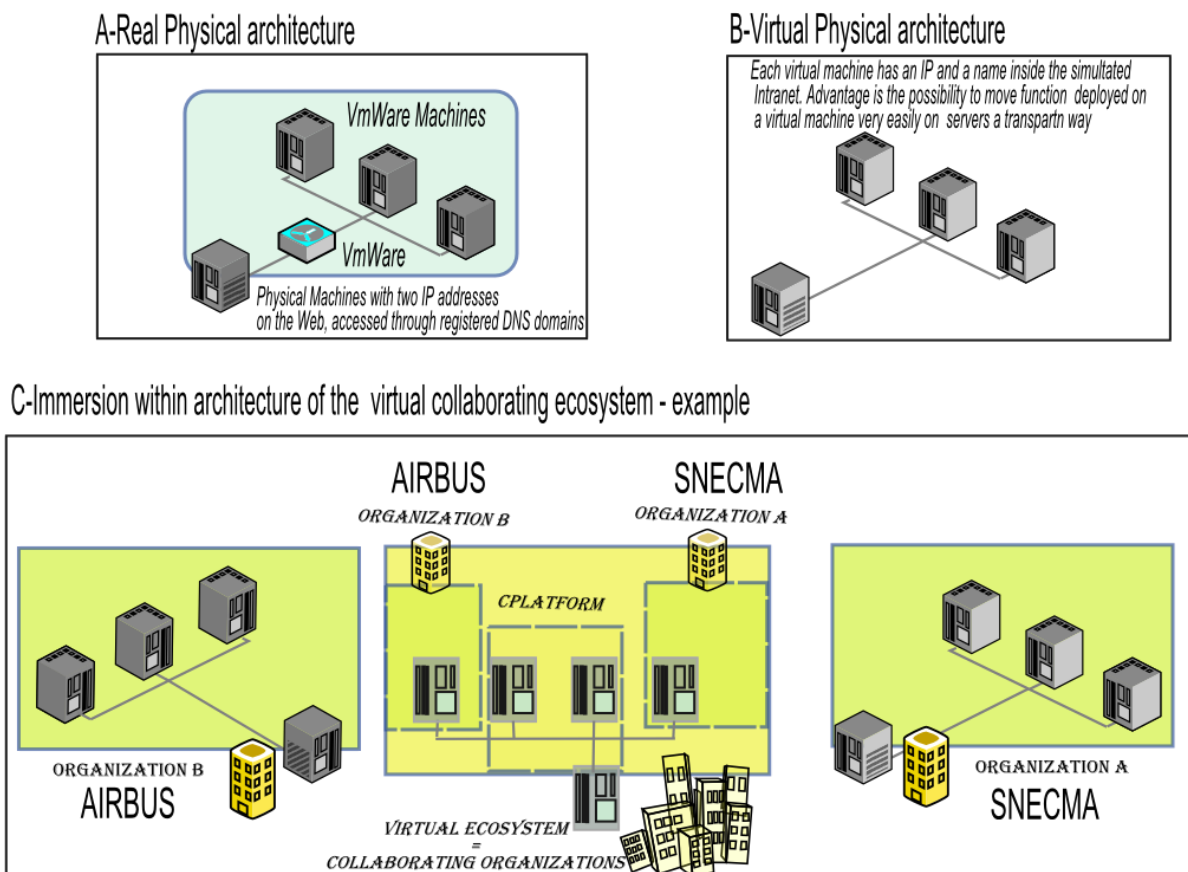


Figure 21: cPlatform v3 virtualization

An Enterprise Portal Server was used to virtualize the collaborating organization, hiding the actual distribution of systems realizing the applicative components realizing the enacted services. The proposed architecture addressed the security:

- 1) at the physical layer, by using secured machine as a service plus the operating system secured communication capabilities such as firewall and appropriate network parameterization
- 2) at the business layer through role based access to the applicative and informational resources supported by an enterprise horizontal portal supporting portlets open standards (cf. Table 9), and connected through and Enterprise Services Bus implementing enterprise service bus open standards to the different servers realising the applicative services (Figure 22). The

access rules between the layers had to be aligned according to the security policy to be applied.

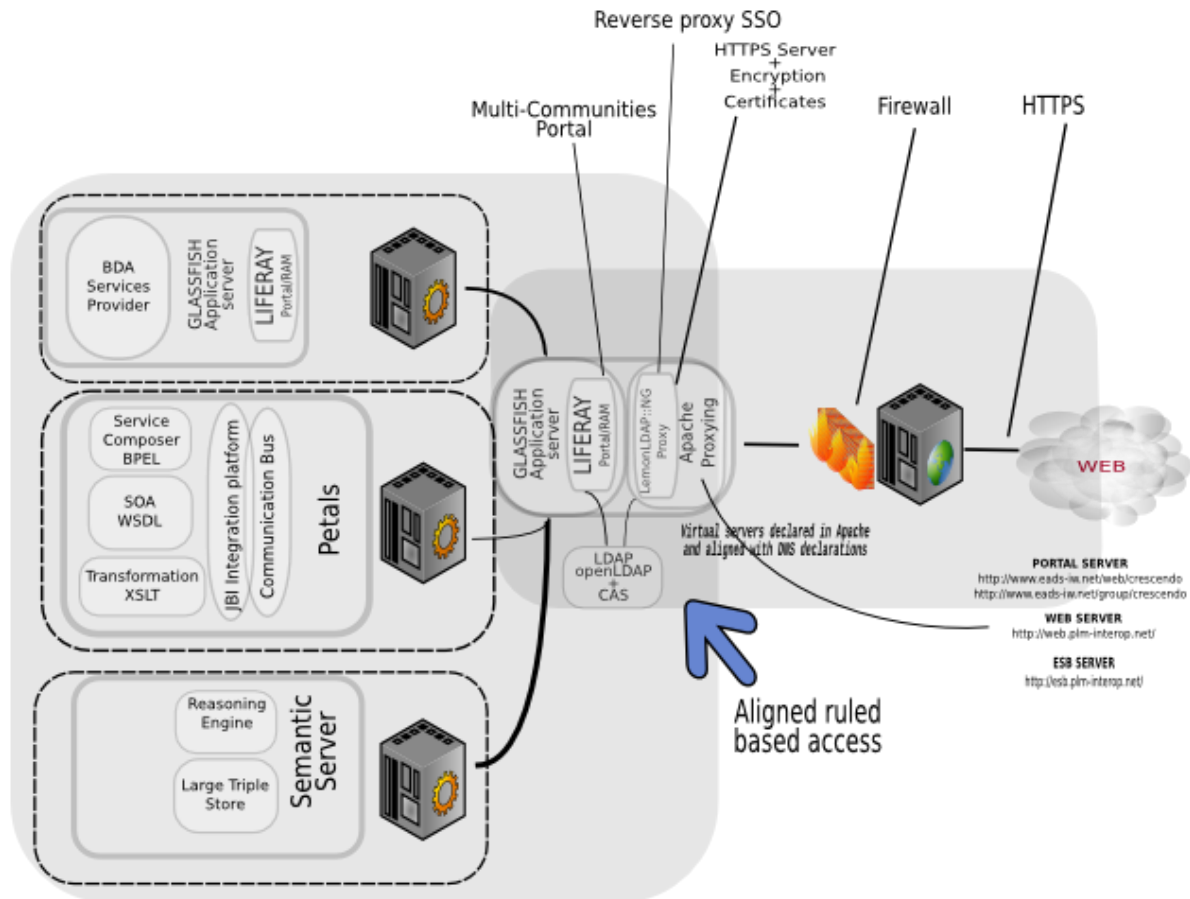


Figure 22: cPlatform v3 virtualization

3.3.4 - cPlatform version 3

In order to address the issue 26, the cPlatform V3 extended the previous one, by providing complementary functional and applicative building blocks related to management of the Dynamic Manufacturing Network services, which aims at defining the profiles of each enterprise partners being member of the collaborative networks, in terms of delivered services and supported application protocols for exchanging or sharing product and process data.

The cPLM workflow was the object of the development of a complementary demonstration component, SharkIne, dealing with the interoperability of processes in terms of synchronisation of collaboration points between private processes of each partner to be connected for an effective collaboration. This was based on the master thesis “A formal framework for Process Interoperability in Dynamic Collaboration Environments”. Figure 23 provides the applicative architectural view of this version of the cPlatform, while Figure 24 completes this view with the used open standards and the functionalities delivered by the additional components.

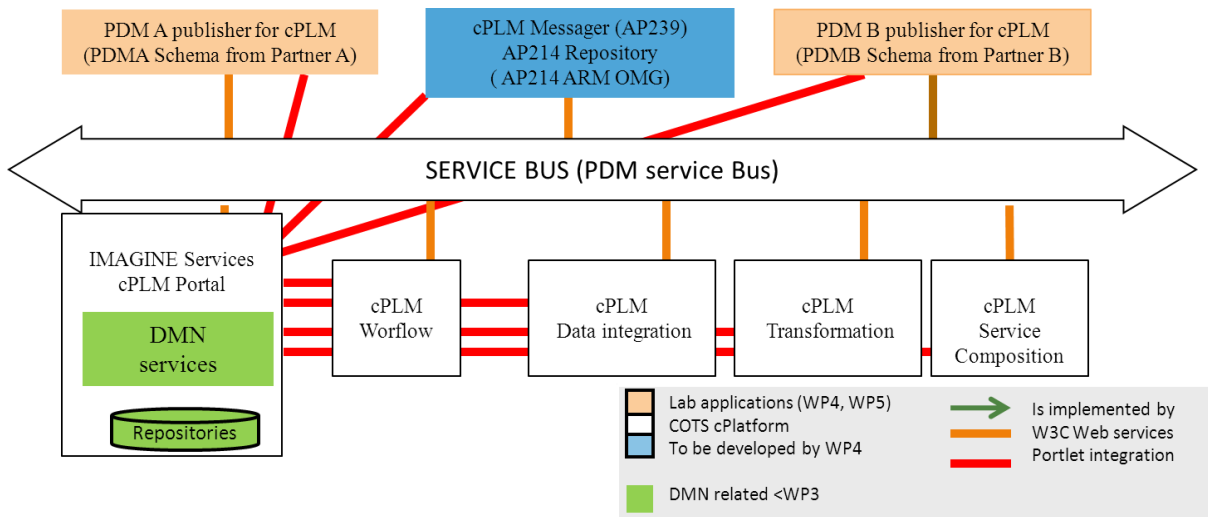


Figure 23: cPlatform v3 applicative architectural description

A complementary component aiming at supporting data integration based on semantic web standards was added to the previous version of the platform. The function of this component is to integrate heterogeneous data hosted by the different application servers in order to be consumed by the DMN services.

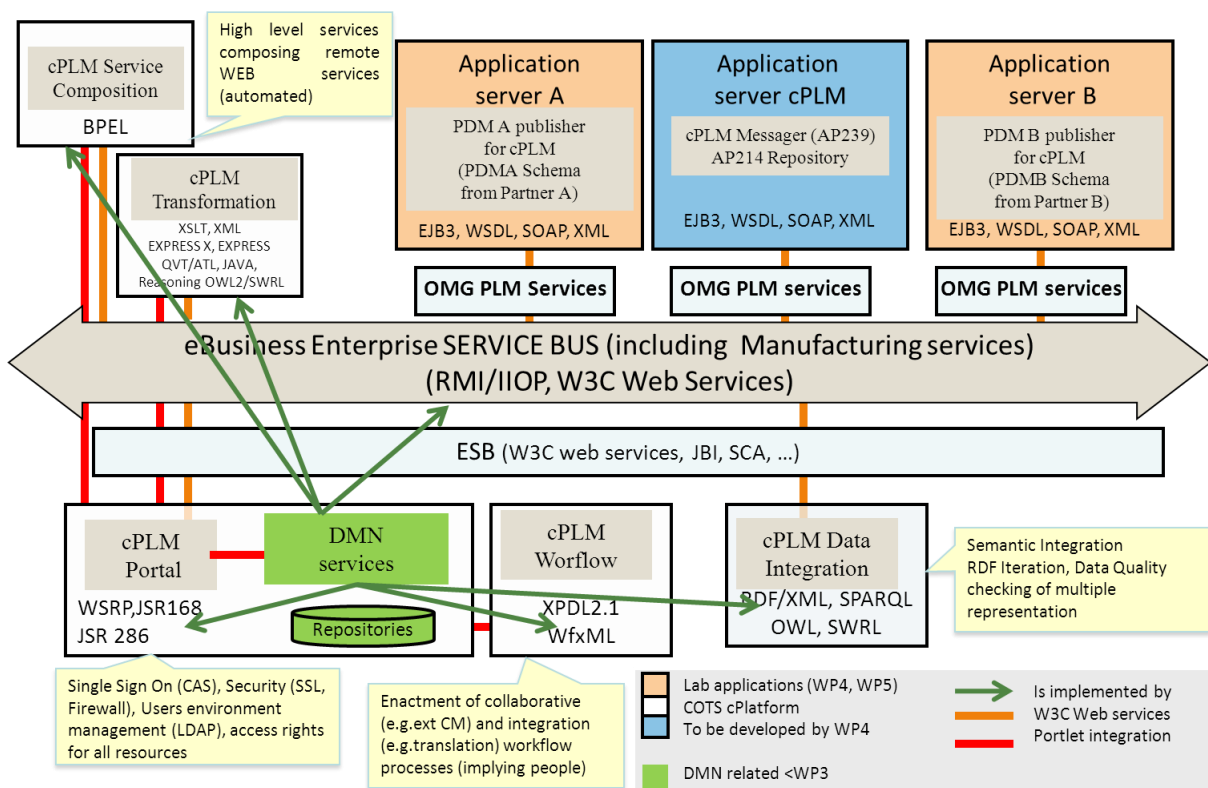


Figure 24: cPlatform v3 applicative with used open standards

There was no progress in terms of Cloud infrastructure or concerning the adopted model driven approach for this version of the cPlatform.

3.3.5 - cPlatform version 4

When applying the results of the ATHENA project on operational projects related to PLM harmonization, a missing approach for the assessment of PLM standards and testability of their implementation was identified (I-28).

The cPlatform V4 (Figure 25) extended the previous version providing complementary services in order to be able to assess a PLM standard.

It was done first by checking that the collaborative process which implements this standard is accurate for the support of the business needs.

It is performed by enacting this process in a collaborative process orchestrator which distributes the tasks between the business actors and the different application components implied in the collaboration scenario.

In this phase, application components are realized by open components of reference generated in order to implement the standard in full compliance for a targeted level of compliance.

They can be available on the shelves, or generated automatically using a model based approach. During the process, test data sets and business scenarios are produced and stored, which will be reusable when willing to test actual COTS or applications which will replace one or several reference component in order to test if it can play the same role in the collaboration digital process, demonstrating its compliance to the standard but also its ability to cover the targeted collaboration scenarios previously formalized and validated by the business.

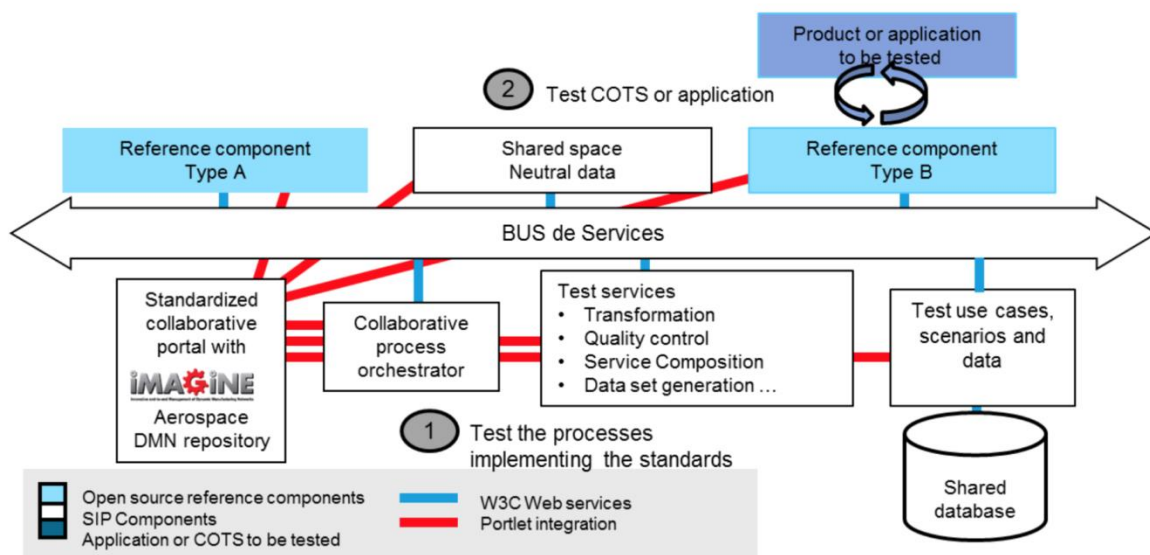


Figure 25: cPlatform v4 architectural description with test services and repositories

The automated generation of reference components reuses (Figure 26) the model based approach defined by the FIF, projecting the business logic defined by the PLM standards on execution platforms. In this new version, the technical infrastructure and the organizational

contexts are also modelled, relying on ArchiMate and extending the DMN profiles as defined in IMAGINE. They will be used in order to generate automatically the targeted infrastructure and parameterization of role based access to applicative services and data relying on virtualisation technologies.

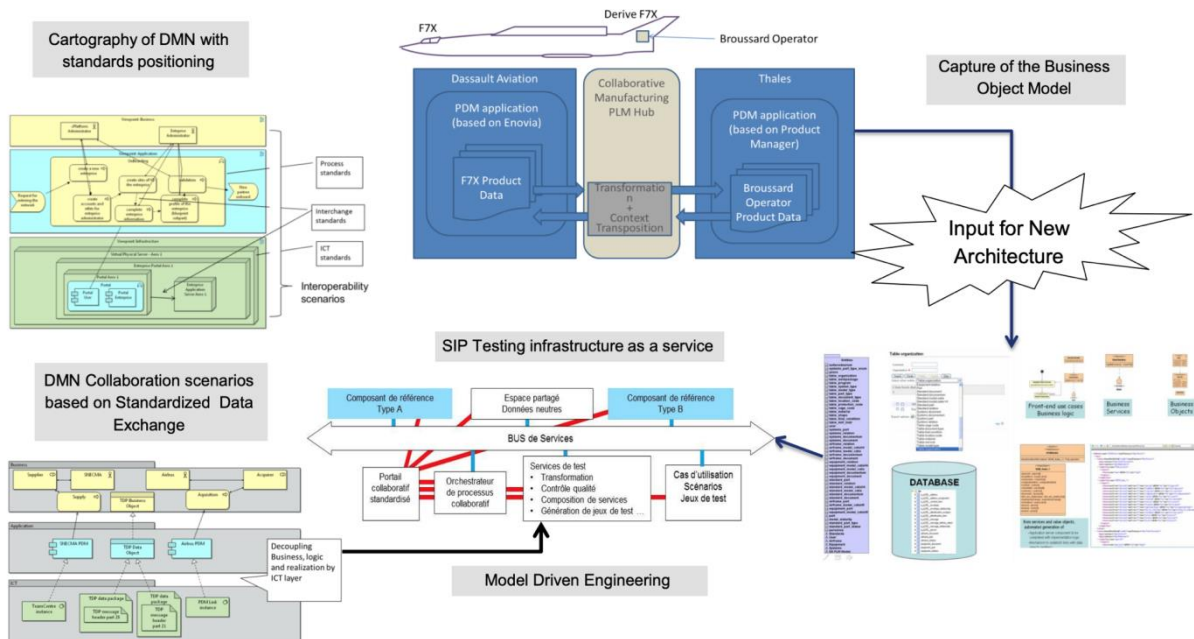


Figure 26: cPlatform v4 Model based approach

In terms of building blocks, the virtualization solutions for the business context is the same as in the previous version in terms of horizontal enterprise portal, and was extended with a machine and network virtualization system (realized with Proxmox as free and open source system) for virtualization of the machines and of the network (Figure 27).

Compared to the previous version, usage of Cloud technologies was extended, with the potential usage of a cluster of physical machines, and the ability to define a distributed network of networks simulating actual interconnected information systems across several companies, with the possibility of implementing the security policies of each of them. This is particularly important if willing to assess the impact of heterogeneous security policies on interoperability.

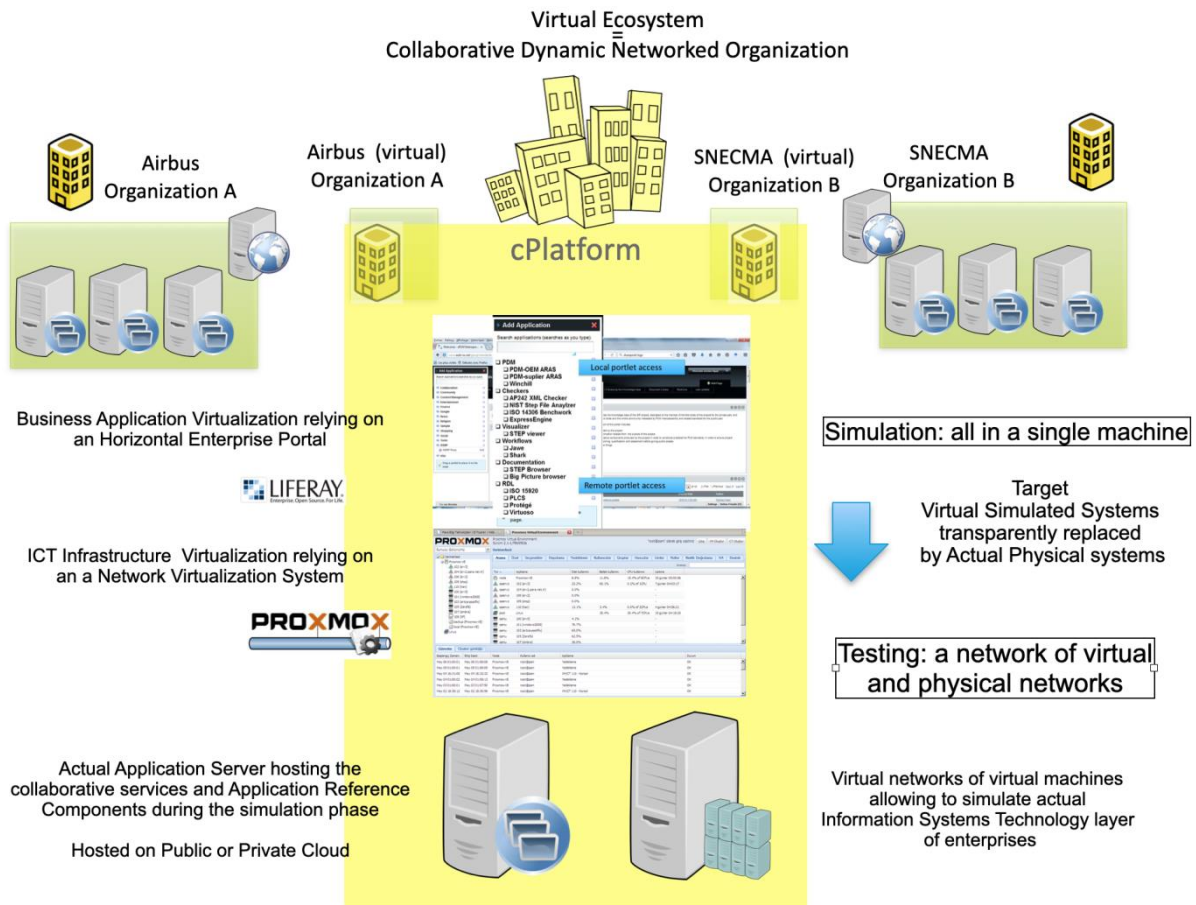


Figure 27: cPlatform v4 Architectural view of virtualisation solution

3.4 - Analysis and conclusion

The fact that the considered projects were able by using the FIF approach to produce these successive versions of the cPlatforms - supporting the evolving needs and context to be covered for PLM interoperability - demonstrates the evolutionary nature of the FIF and the accuracy of the proposed approach.

The adopted architectural principals support reusability, and allow the easy reconfiguration and extension of the platform in order to support the various business and technical scenarios to be considered in the various research projects where the FIF has been used. They also supported the establishment of the continuous interoperability required by PLM at an acceptable price.

By combining 1) a model based approach for projection of business logic on top of an execution platform 2) usage of open source free components implementing open standards 3) the ability to model and to simulate the collaboration context and to reuse the different produced components over the time, the approach demonstrated to be cheaper and effective for a given project and on long term than approaches based on proprietary solutions, business models for data exchange or sharing protocols provided by vendors. As an illustration, the SAVE project, with a duration of 26 months and a budget of several millions of Euros allows to produce a demonstration without reusable prototypes for 14 business objects. Using the FIF approach and cPlatform during the SIP project, only a few weeks were needed for developing

a demonstrator and a testbed for more than 900 objects, with reusable components for testing applications in context or software product solutions in terms of interoperability.

Further assessments have been performed in order to apply the FIF and to extend the cPlatform for supporting the assessment of PLM standards related to Virtual Manufacturing, Cyber Physical Systems and Industrial Internet of Things [P00].

All the interoperability issues mentioned in Table 13 were addressed simultaneously, by combining the different enablers and selecting the appropriate interoperability solutions in combination.

Associated publications	P00, P27_37
Related Projects	RISESTEP, SAVE, IDEAS, ATHENA, CRESCENDO, IMAGINE, SIP, OpenDevFactory, SEINE
PhD and master 6 student supervised	Malik Khalfallah, PhD, Emna Moones PhD, Olivier Demarez, David Hasson, Jonas Martin, Ludovic Duchemin, Sophie Gatoux
Demonstrators	cPlatform, JawIne, SharkIne, ArchiMagIne, STEP Mapper, Software Factory, etc
Addressed Interoperability Issues	I-02, I-08, I-10, I-13, I-14, I-18, I-21, I-23, I-24, I-25

Table 13: Federation of Interoperability Frameworks outcome

However, many interoperability issues are not addressed by Federation of Interoperability Frameworks itself, and are requiring complementary improvement of the state of the art.

Chapter 4 - Semantic Preservation

4.1 - The problem

Using the PLM standards for exchanging, sharing and archiving the manufacturing Product & Process between applications, or using the model based approach with the successive bidirectional transformations from Computer Independent Model to Execution platforms, an identified issue constituting and actual research gap is related to semantic preservation and data loss (I-01).

Indeed, due to the fact that used languages don't have the same expressivity and don't rely on the same paradigms (e.g. object oriented language versus procedural language) or terminology (a same concept can be expressed by different terms), it is consequently not possible to establish a one to one equivalence between all the modelling constructs of the languages from which bidirectional transformation can be implemented. As a result, some data are not translated and consequently lost during the considered processes. Figure 28 illustrates this issue for exchange of data between applications through a neutral model and during model transformations starting from an application protocol formalized with the Express language to the UML language for application design to Java and XML for implementation of application components and operational data exchange.

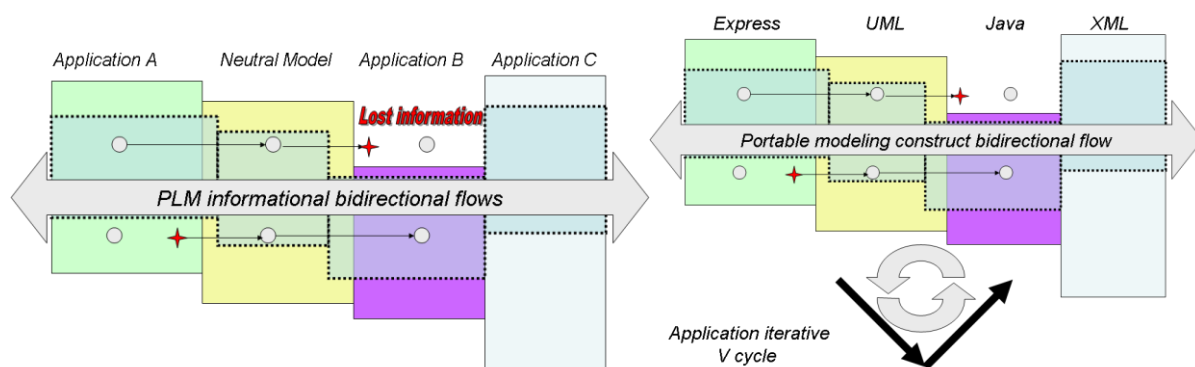


Figure 28: Data loss illustration in PLM and Model Driven Engineering processes

So the goal is to find an innovative way for preventing or mastering the data loss and preserving business semantic between the models used by the different platforms, being conceptualization, design, development or execution. It should also preserve the business semantic between the different applicative components used inside a single application, such as database, application server or presentation server, or several federated applications. This issue is a key issue because it is not possible to obtain pragmatic interoperability by applying previously defined principles, if the semantic preservation is not insured.

As a constraint, it should make it possible to use jointly legacy standardized languages and interoperability frameworks, being at conceptualization, modelling, design, development or execution phases. In addition, when using a model driven approach, it should be possible to trace, to link and to make coherent the different representations of used business concepts and

objects, between the different digital artefacts produced during the lifecycle of an application. Usual bindings and mappings, proposed by the different communities, are far from being sufficient: they don't avoid loss of information and they are restricted by technological silos, incompatible paradigms and organizational boundaries.

4.2 - The proposed innovative approach

The innovative proposal for addressing this problem is the extended hypermodel for interoperability. The starting point for extended hyper models is to consider that, for a given business concept, it does not matter for the user if it is formalized with such or such formal language. We have simply different representations of the same concepts or of the same things, using heterogeneous languages which are used with different intentions and for different purposes: data exchange, reasoning, design, programming, etc. For example, considering the “person” concept, it could be formalized within different environments based on heterogeneous languages, such as respectively the Unified Modeling Language (UML) for software design, the Ontology Web Language (OWL) for description relying on descriptive logic available for smart agent on the Semantic Web , the eXtended Markup Language (XML) for serialization of documents or EXPRESS for defining schemas used for application protocols. The used modelling constructs will be respectively a UML class, an OWL class, an XML entity and an EXPRESS Entity, with eventually different names and identifiers. But whatever the used language and construct, it remains a representation of the same concept, a person.

The idea is then to consider that it should be possible to capture the fact that this concept, modelled using such a Modeling construct within an environment, is modelled using such other modelling construct within another environment. In addition, as it still remains the same concept, a “person”, used formalism should be as transparent as possible concerning the business semantic, as interpreted by people. Referring [21] which provides clear distinction between conceptual information models and concrete instantiation models, the idea is to consider that within a model driven approach, concrete models are those used for conceptualization, design, development and execution. The glue remains the conceptual model, which will ensure the semantic preservation.

The term “hypermodel” is used within the work described by [22] and which led to software freely available on the web, “Hypermodel”³³. This tool allows working on a model formalized as an XML schema, within an UML environment, and possible annotation using OWL. The same concept is “multi – represented”: it can be considered an XML entity or a UML class. It is represented as an UML class within dynamically created UML diagrams. The term “hypermodel” is also used in research related to model based learning [23] [24]and is defined as a combination of aspects of open ended exploratory tools with content-specific text and multimedia. “Hypermodel” tool is mixing heterogeneous interactive representations both textual and visual of the same subject. So a hyper-model can be considered as a multi-representation of the same model, using different formalism and media, but preserving the semantic.

“Hypermodel” as defined by [22] is limited to only three languages, which are all dealing with entities and informational viewpoints. It was not developed in order to address interoperability of enterprise applications. As the intent is to extend it to other languages and modelling constructs (services, processes) with as specific purpose PLM interoperability, the derived concept was called “Extended Hypermodel” for interoperability.

The approach considers grounds. A **ground** is a concrete environment where a model is formalized. It is constituted by a set of configured versioned software components, which ensure conformance with a given standard (versioned) providing one of the formalisms we want to consider within the hypermodel.

The approach considers landscapes. A **landscape** is a set of grounds. The landscape of a given standard is the set of available grounds enabling usage of this standard (versioned), and with appropriate conformance. The landscape of a hypermodel is the set of environments, related to the standardized languages considered by the hypermodel, which are allowing traveling of hypermodels without data loss.

The approach considers models of products and associated processes, often adopting the system paradigm. A model of a system is a description or specification of this system and its environment for a certain purpose. A model is often presented as a combination of drawing and text. The text may be in a modelling language or in a natural language.

The approach also considers that the hypermodels should be formalized using a suited mathematical representation when willing to study and to characterize different combinations of languages. Hyper-graphs were chosen. A hyper-graph is “a generalization of a graph, where edges can connect any number of vertices. Formally, a hyper-graph H is a pair $H = (X, E)$ where X is a set of elements, called nodes or vertices, and E is a set of non-empty subsets of X called hyper-edges or links...

While graph edges are pairs of nodes, hyper-edges are arbitrary sets of nodes, and can therefore contain an arbitrary number of nodes. However, it is often useful to study hyper-graphs where all hyper-edges have the same cardinality: a k -uniform hyper-graph is a hyper-graph such that all its hyper-edges have size k . (In other words, it is a collection of sets of size k .) So a 2-uniform hyper-graph is a graph, a 3-uniform hyper-graph is a collection of triples, and so on... Unlike graphs, hyper-graphs are difficult to draw on paper, so they tend to be studied using the nomenclature of set theory rather than the more pictorial descriptions (like 'trees', 'forests' and 'cycles') of graph theory.”

A hypermodel (HM) is consequently represented as a hyper-graph, providing a multi-representation of a model using the different standardized modelling language implied within a community governing interoperability of its applications.

XM is the set of concrete constructs, specific to the formalisms aggregated by the hypermodel, allowing to model a concept or to represent a real thing. Each business concept and each real thing is represented by a subset of XM , which is a hyper-edge of the hypermodel. The subset contains all the nodes representing the concept or the real thing.

Figure 29 describes the different hyper-edges based on generic descriptive business concepts (associated to a colour), derived from ontology modelling concepts: class, property and individual. Each hyper-edge is grouping nodes which are used to represent the business concepts or real thing for a given formalism (associated to a form).

A generic descriptive business concept is a concept that is suited for providing a simple description of the real world by persons which are not computer scientists.

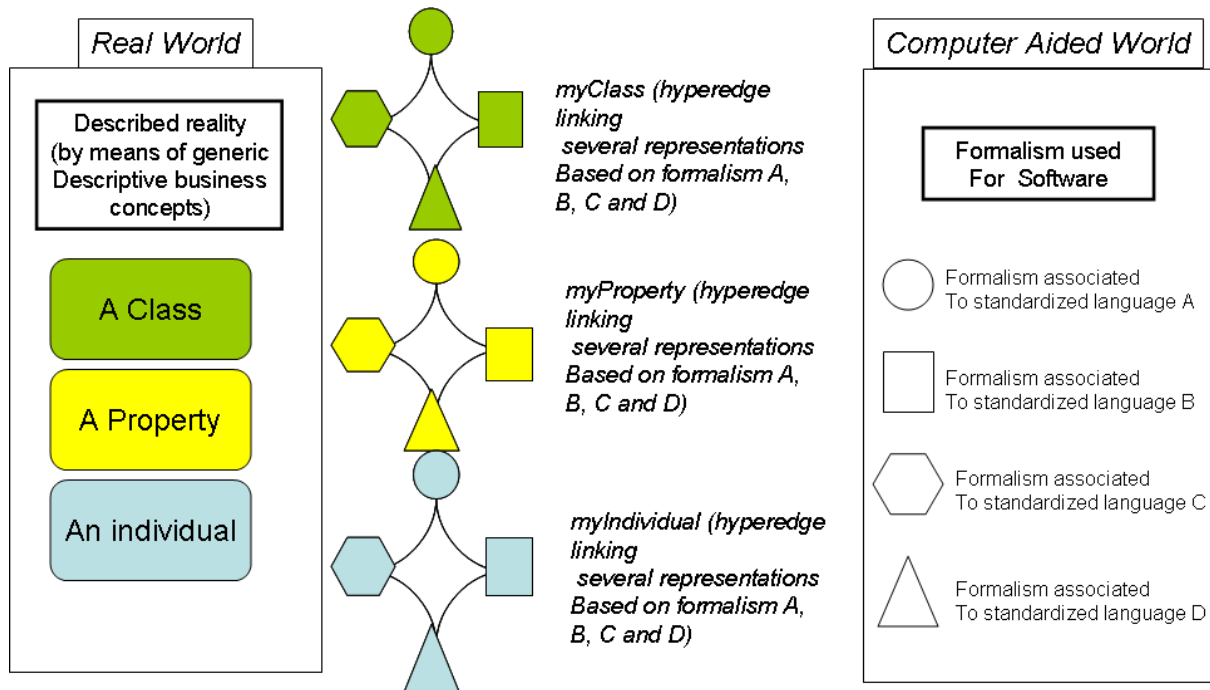


Figure 29: basic hyper-edge of an extended hypermodel

It is expected that it will be possible to concretely formalize an extended hypermodel within several grounds, and to transfer an extended hypermodel from one ground to another without information loss, through an accurate set of transformation based on standardized data exchange and transformation. It is what is called a hypermodel “travelling”, i.e. the ability to change place while remaining the same, like illustrated by Figure 30.

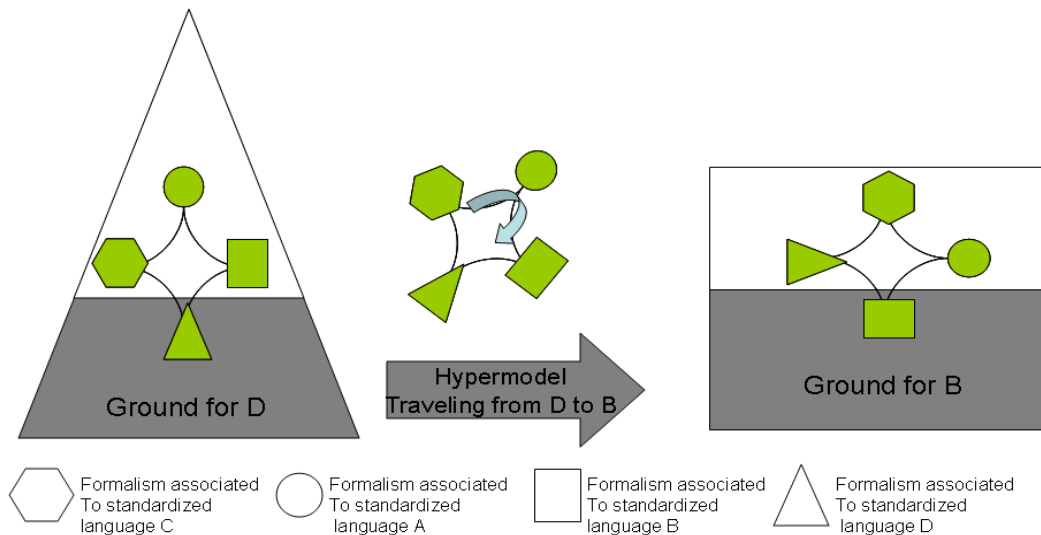


Figure 30: Hypermodel traveling between grounds

As willing to avoid development of a new modelling language for extended hypermodels and associated grounds, legacy platforms belonging to the several federated grounds should be able to process them, being for edition, validation, completion or other automated usage. In other words, it should be possible for an extended hypermodel to be multi-represented within all the grounds constituting the landscape of the hypermodel. As a consequence, the hypermodel will be constituted of hyper edges for classes, of hyper edges for properties and of hyper edges for individuals. Between the representations of an individual in a given ground, a “same as” relation exists, each being typed according to the modelling construct used in this ground, as illustrated in Figure 31.

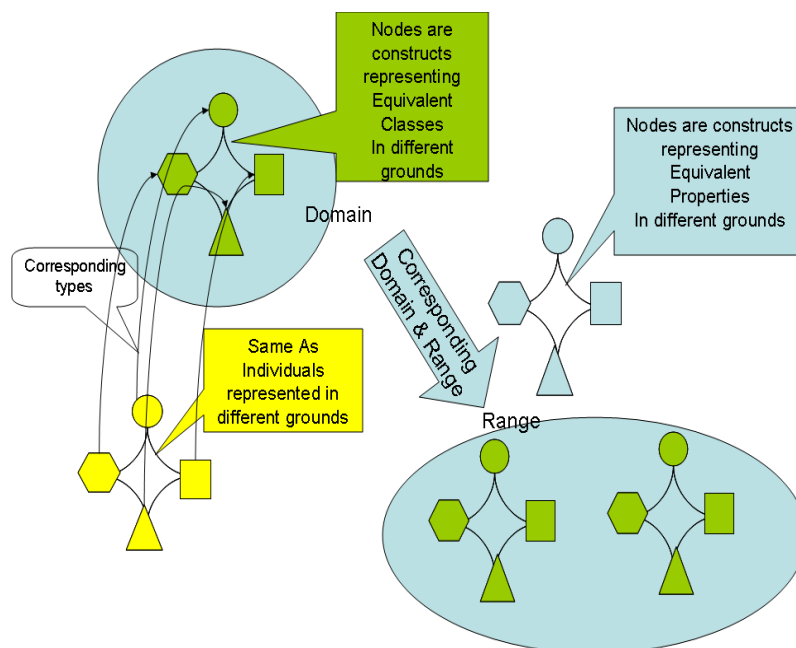


Figure 31: graphical representation of hyper-edges representing relationships between modelling concepts

Once the different generic constructs have been defined, the next step will be to establish the equivalence between the different languages of the considered landscape in order to support the model driven engineering process. Once validated on several ground, it will be possible to defined different operations in order to ensure the travelling between environments.

From an existing model formalized with one language, we can realize the completion of the hypermodel by generating representation for the other languages.

From a hypermodel, we can validate that all asserted representations are correct and complete.

To make a model travel, it should be exported, transposed (file syntax and formalism changed) and then imported. For most of legacy tools, the export, transposition and translation will have to be developed.

In some cases, grounds will not provide a way to capture how the model is represented within the other grounds. In such a case, traveling will be performed by means of bidirectional translations. In such a case, it should be done on models using only the constructs for which equivalence exists, in order to avoid loss of data.

The proposed approach has been applied and assessed for the relevant standards to be considered for PLM Interoperability within the Manufacturing ecosystems, with a particular focus on European Aeronautic, Defence and Space community (Table 9).

It has been applied to data, service and process modelling languages for conceptualization, design and execution used in the successive versions of the cPlatform and covering the different business, functional and technological scopes of the research projects and activities contributing to the development of the Federation of Interoperability Frameworks, relying on the same way to represent the extended hypermodel usage context, illustrated by Figure 32. The business working environment is represented with a modelling platform through a set of Business models which federate conceptual business models based on business standards, and consider federated organizations, their applications and the underlying execution platforms realizing the applications. The models are used to generate business logic components which are deployed and enacted on the collaborative product development platform (cPlatform). By using an extended hypermodel for interoperability, each deployed component encompasses the various representations which were used to generate it, and can be queried in order to regenerate these models with supported bi-directional model transformation without data loss and with semantic preservation.

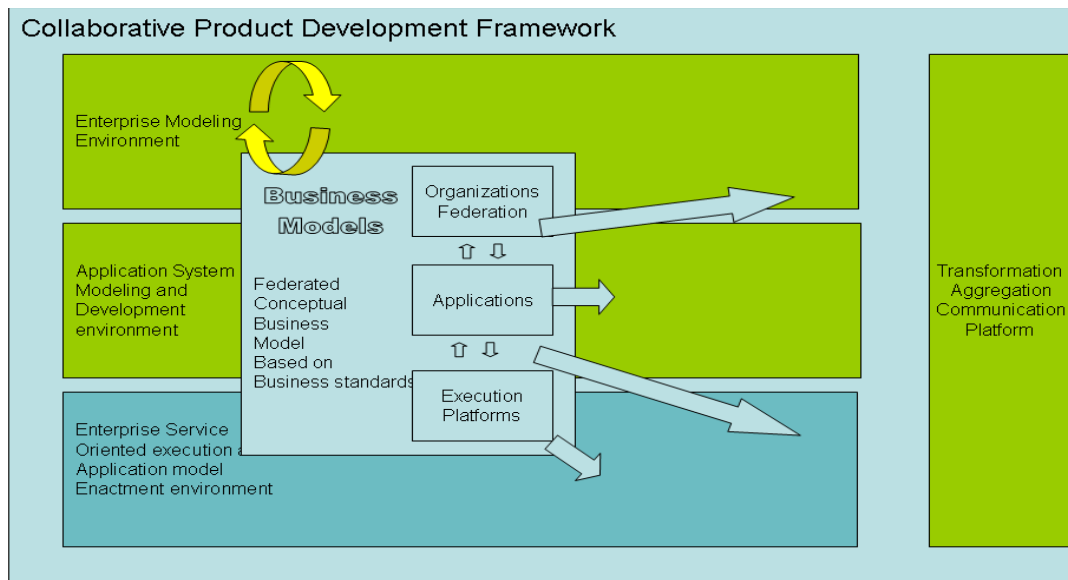


Figure 32: Extended hypermodel usage context

Three particular relevant languages have been considered for their relevance for the proposed approach:

1) the Ontology Web Language which was designed for producing ontology on the web in order to contribute to the development of the Semantic Web, which aimed at improving the syntactic web. It is an open standard with available implementations of references, open source or Commercial of the shelves. It supports annotations and consequently platforms implementing OWL can be used as grounds for interoperability. In addition many communities have been producing knowledge representation of their domain relying on OWL. So OWL is quite relevant in the conceptualization phase of an application, but also for any application in operation publishing its data in a knowledge base relying on Semantic Web and Linked Data standards

2) the Unified Modeling Language is an open and de facto standard for software system design and meta modelling, with many open source and Commercial of the Shelves implementations. It supports annotations, so it is accurate for producing hypermodels. Finally, many UML modelling platforms are based on the Model Driven Architecture defined by the Object Management Group, and can then support Model Engineering approach considering Computer Independent Model which capture the business logic, the Platform Models which capture the underlying software and hardware architecture are defined, the Platform Independent Models allowing to capture the definition of an application within the business context, and the Platform Specific Model which contextualize the application definition for the realization of the targeted execution platform, and support the automated generation of software components and their deployment on actual operational technical environment. This approach fits with the standardized enterprise architecture modelling approaches and languages aiming at defining the working environment of enterprises.

3) Java and associated development platforms. Java is one of the most used languages, and it was designed for supporting the develop everywhere and deploy anywhere objective. In

addition, the Java Development Platform provides implementation of the standards for applications servers, with a separation of concerns between the business logic and applicative technical services. It also supports annotations and is consequently accurate for the hypermodel approach.

It means that relying on some on the shelves technologies which are open and de facto standards, the innovative hypermodel approach for interoperability can be applied.

4.3 - Demonstrations, results and Limitations

Several demonstrators have been produced, standalone or integrated in the cPlatform, which were also used for assessing the approach and allowed to identify some limitations.

Figure 33 illustrates the application with Eclipse Europa and EMF Papyrus as UML 1.4 ground, and Protégé 3.3 with Jambalaya and Pellet as OWL 1.1 ground, where STEP Application Reference Models (ARM) and Application Integrated Model(AIM) were imported relying on a dedicated EXPRESS/P21 transformation to OWL. As a result, we obtained ARM and AIM hypermodels allowing to generate automatically components to be deployed on the cPlatform for assessing this PLM standard and testing its implementations.

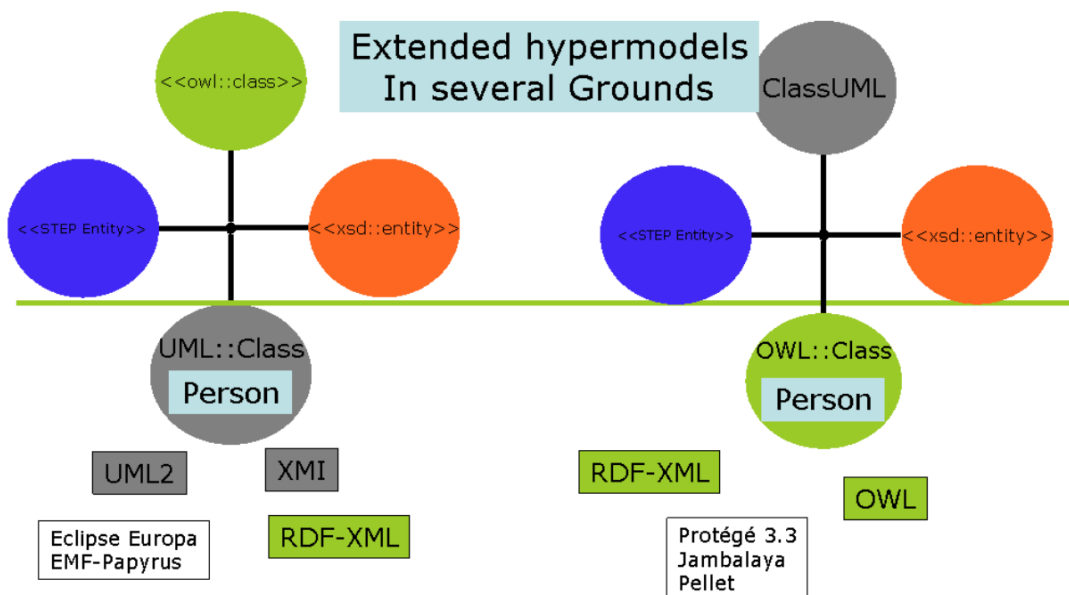


Figure 33: Extended hypermodels in UML and OWL grounds

During the experimentations, it was demonstrated that the approach works pretty well, as soon as dealing with flat models, like semantic graphs of models relying on the Part 21 data description language which is a part of STEP.

It was also applied within the scope of the new STEP architecture, with the introduction of the usage of SysML for describing, aggregating and making consistent the Application Activity Models, Application Reference Models, Application Integrated Models and Integrated Resource Models of the standard. In particular it is possible to propose a SysML alternative representation of an activity model in IDEF0, preventing data loss but also preserving

semantic and usage intent. Translation can be done bi-directional way. It has been successfully extended to ArchiMate 3.1 and UML2.4.

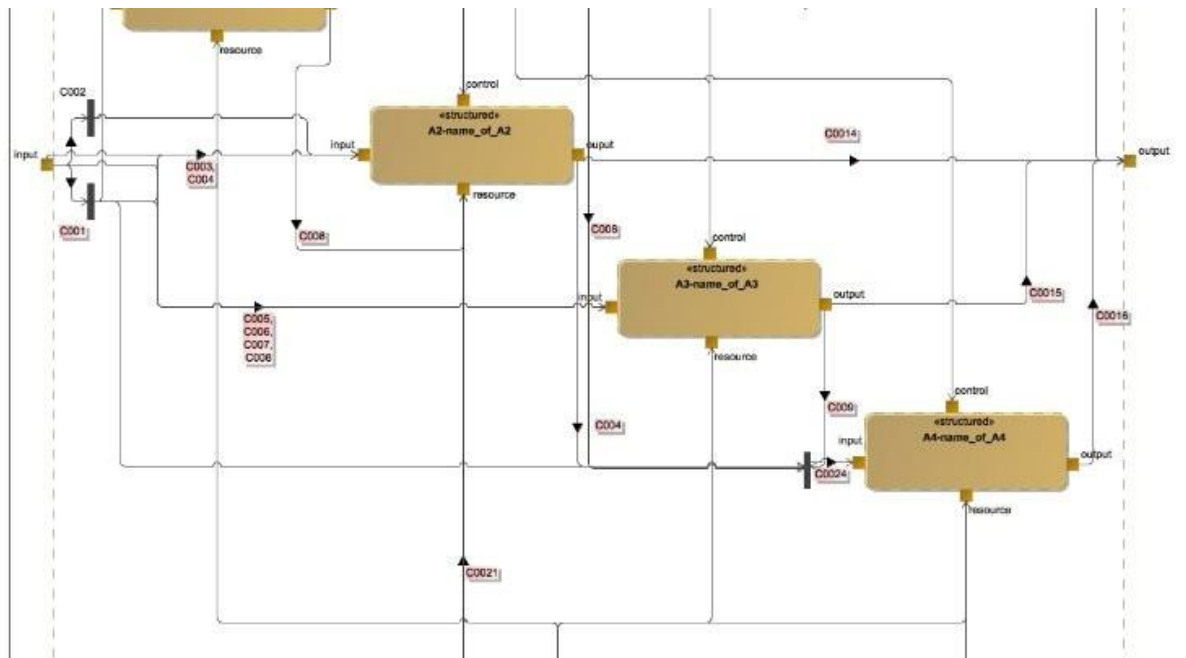


Figure 34: SysML alternative representation of an activity model in IDEF0²

However, several issues have been identified from the experimentation which led to new innovative proposals for improving the extended model for interoperability.

Firstly, having to consider system engineering and system modelling within a PLM context, a product is usually an assembly of components, each assembled part having its own definition and representations as a model artefact, realized by data.

It is also a system of interest, which is to be considered in different environments: market, design office, production, support and operating environments.

It implies to be able to model complex systems and the way they are composed, but also to be able to deal with all the model artefacts which have to be produced following the appropriate PLM collaboration processes.

As a consequence, the standardized system modelling languages and platforms support both the ability to provide the representation of a composite system - relying on composition and composite diagrams with representations of connected parts - and the ability to deal with composite (modular) representation of a system relying on modules, packages and associated composite data serialization.

In both cases, we are relying on containers, where no explicit links exist between a container and the elements it contains.

So it means that it is not possible to derive an explicit semantic graph capturing the exact semantic of the relations between the contained elements and the container, except “is

² <https://www.linkedin.com/pulse/equivalent-idef0-sysml-models-dr-nicolas-figay/>

contained” and “contains” which reflects more the structure of the model than the structure of the modelled system (I-31). As a consequence, we also can’t derive hyper-nodes for the extended hypermodel for interoperability from such models and data structures.

Secondly, the ability to aggregate and compose models of the parts implies an agreement on the way to decompose the models, including the different levels of granularity to consider between the partners. It is one of the identified interoperability brakes. The extended hypermodel for interoperability is focussing on the semantic interoperability for flat semantic graphs (I-32), and can’t due to the previous limitation be a solution for unleashing this brake.

4.4 - Hyper-models mixing Modular Composite Models and Semantic Graphs

A way to extend the FIF in order to address the two first issues was proposed in [P01], relying on modelling over UML2/SysML and introducing mereotopology³.

Usage is illustrated with a comprehensive use case combining Manufacturing 4.0 and PLM (Product Lifecycle Management) of the future.

The idea is to be able to take advantage of the structural features of a UML modelling platform (modularisation, structural decomposition relying on packages) when modelling with any other modelling language which doesn’t have such structural features (e.g. ArchiMate).

This provides a way for extending the hypermodel for interoperability in order to deal also with structural interoperability.

For a given domain specific language, we can use both produce the models for being able to model over UML2/SysML on a system modelling grounds based on these standards, and derived an ontology in OWL2 in order to be able to take advantage of semantic web grounds based on semantic web standards.

It means that we can make travel a model realized with a Domain Specific Language (DSL) between system engineering grounds and semantic web grounds, preserving the semantic of the DSL but being to take advantage of the functionalities and services which can be provided by these two technology families.

For UML/SysML2, this concerns in particular the modular and composite modelling (Figure 35), which is not supported by OWL2 technologies.

For OWL2, this concerns in particular reasoning relying on descriptive logic or on business rules, which is not supported by UML/SysML2 technologies. The approach can be extended to other kinds of technologies and associated grounds, such as those related to data analytics, big data, artificial intelligence or graph related technologies (Figure 36).

³ In formal ontology, a branch of metaphysics, and in ontological computer science, mereotopology is a first-order theory, embodying mereological and topological concepts, of the relations among wholes, parts, parts of parts, and the boundaries between parts.

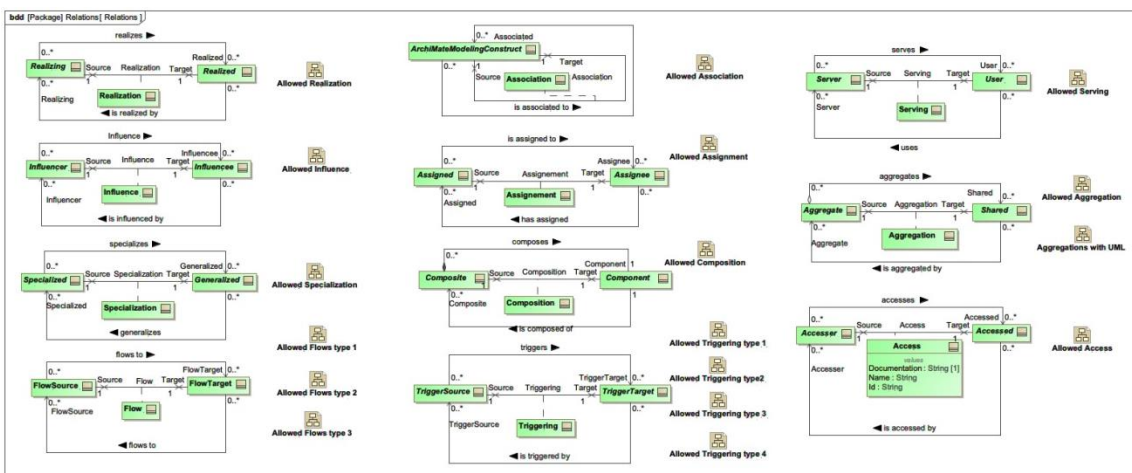
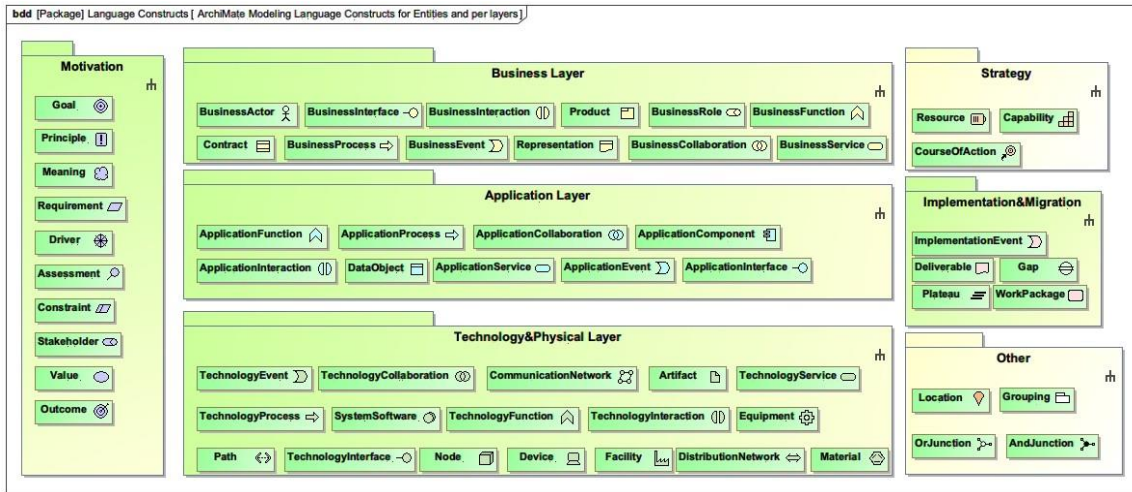


Figure 35: ArchiMate over SysML for modular and multi-language composite modelling

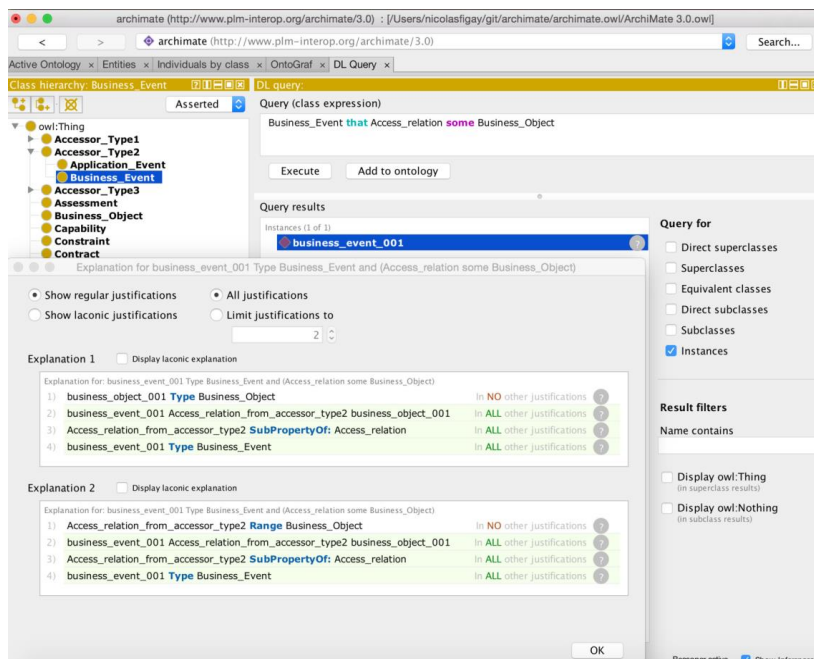


Figure 36: ArchiMate Derivation in OWL2 for Knowledge Base with reasoning support

4.5 - Conclusion

The associated publication is [P27]. Some identified limitations have been addressed, in particular the limitation of using graphs when dealing with complex systems of systems [P01] and limitation of systemic approach when relying on virtualization [P23].

From the last developments and experimentations related to the extended hypermodel for interoperability, new interoperability needs emerged which are not yet addressed.

It is needed to make the rules and constraints associated with models to travel consistently between different grounds, without preventing interoperability or consistency between obtained results when using them with different reasoning or checking technologies. It is particularly important when considering the raise of both Model Based System Engineering technologies and Semantic technologies with reasoning engines. The link is also to be established with new graph related technologies and standards, for taking advantage of the capabilities they provide without creating technological silos.

It provides new opportunities to use, assess and extend the proposed approach.

An identified scientific gap was also identified, when willing to build a hypermodel for linking system modelling based on SysML or UML grounds, and enterprise modelling relying on ArchiMate 3.1 modelling grounds. It is related to combined usage of systemic and virtualization. This points out some limitations of usage of the paradigm underlying system modelling when willing to address PLM interoperability, as it leads to no preservation of a system boundary across the layers considered by enterprise modelling and the viewpoints of the different concerned actors. This issue, demonstrated in [P33], is to be addressed.

Associated publications	P01, P27, P23, P33
Related Projects	ATHENA, SIP
Demonstrators	Derivation of ontology from ArchiMate, ArchiMate over UML model, STEP Mapper
Addressed Interoperability Issues	I-01

Table 14: Semantic preservation outcome

Chapter 5 - Dynamic Networking

This section presents the contribution to the State of the Art for PLM interoperability related to the Dynamic Manufacturing Networking, for enterprises constituting Dynamic Manufacturing Networks (DMNs).

5.1 - The problem

When willing to put in place PLM within the digital business ecosystem working around a given manufactured product, the alignment between the different functions of the enterprise (design office, production, support, logistic) and the alignment between the partners must be ensured concerning the cross organizational processes to put in place

1) with the accurate flows of digital artefacts between the partners, their private processes and the applications supporting these private processes

2) according to the role they are playing in the cross organizational processes: Original Equipment Manufacturer (OEM), equipment provider, sub-contractor, operator, support service provider, etc.

This is illustrated in the next figure with as an example of product an Aircraft, with as considered equipment engines and nacelles provided by various equipment suppliers, and as clients operating aircraft airline companies.

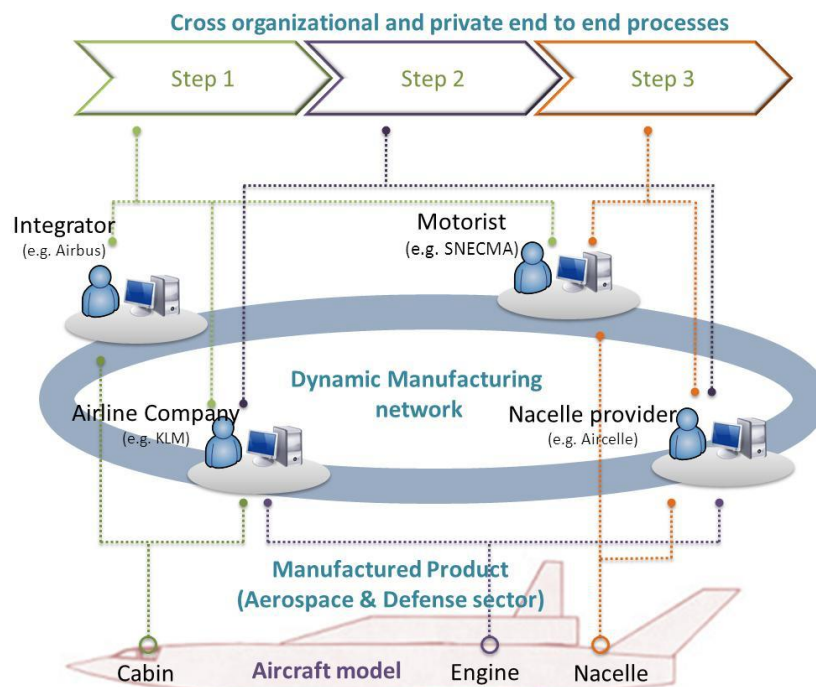


Figure 37: Dynamic Manufacturing Network for a given product

Much of the time, organizations, being partners or functions, try to impose their processes, their internal standards and their tools to the others, depending on the balance of power between them. Considering PLM, it often leads to using the proprietary formats of the software products they bought and they try to impose on their partners. Unfortunately, such behaviour brings a lot of problems, such as inefficient collaboration and creation of silos

leading to non-interoperability. What explain such a situation is the growing complexity of the software products and their high pace of change, itself due to the quicker and quicker evolution of Information and Communication technologies. As a consequence, organizations have to face obsolescence of their applications, being under the pressure of the software vendors who don't support old solutions anymore - or at a very high price - or under the pressure of the competition, which continuously innovates relying on new processes, solutions and technologies.

Considering that the life duration of many industrial products is longer than the duration of life of software technologies, PLM processes have to insure Product & Process data exchange, sharing and long term retention despite the heterogeneity of the software solutions used by the supply chain partners (level 1 to n) and on a long time period.

Standardisation bodies aim at addressing such a need by providing neutral and open processes, protocols and formats. In order to ensure they are properly implemented by software solution providers, Implementation Forums have been put in place by Industry consortia for qualifying PLM solutions in terms of interoperability, i.e. ability to exchange or share data relying on these standards considering such or such collaboration scenarios.

However, PLM interoperability is not about software products, but about the capabilities of the members of collaboration for supporting the targeted collaboration processes, i.e. the availability of qualified internal processes, people and applications for participating in open standards based collaborations. Also, implementer forums are usually dedicated to the collaboration based on a single standard, and not on a set of standards required for covering the whole functional scope addressed by PLM when willing to address cross-lifecycle interoperability, which becomes more and more important, in particular when considering the current trends related to Virtual Manufacturing, Cyber Physical System, Digital Twins or Digital Threads.

Considering the state of the practice in industry and the state of the art, qualification of active resources according to a process is addressed more by production than by design. For state of the practice, it is reflected by the "Enterprise-Control System Integration" (ISA 95/ ISO/CEI 62264), which provides a model which includes the description of a process with the definition of the participant roles and the assignment of qualified actors, being people or machines.

[25] points out the approach defined by the IMAGINE research project, which aims at establishing a Dynamic Manufacturing Network (DMN) for which partners, products, end to end processes, and quality insurance are defined by the mean of a blueprint models, a blueprint model gathering the "modularize the knowledge needed to help manage enterprise resources, product lifecycle, supply chains, partners relationships, operational planning, manufacturing process execution, compliance regulation and compliance issue for the DMN. Blueprinting will provide "intelligence" and improved visibility for an integrated supply chain in a variety of ways, e.g. including the reduction of operating costs, providing valuable new or enhanced capabilities, increased regulatory compliance, and improved alignment of operations with business goals and metrics". Blueprint metamodel is aggregating several standards, including ISA 95 (Enterprise Factory Integration) and STEP AP 236 (STEP for Furniture).

5.2 - The proposed innovative approach

The proposed innovative approach consists in

- 1) Transposing the Dynamic Manufacturing Network blueprints approach from production - as the considered Dynamic Manufacturing Network is a network of factories - to the design office (Figure 38). The physical product is then replaced by the virtual digital product, i.e. the digital definition of the product relying on various representations and models. The factories are replaced by design offices.
- 2) To integrate the Dynamic Manufacturing Network blueprints approach as a part of the Federation of Interoperability Frameworks for PLM as an enabler for interoperability, and delivering associated cPlatform services closely related to the model based approach promoted by and the principles provided with the Federated Interoperability Framework
- 3) to extend the set of relevant PLM standards to be considered by including those related to enterprise - control system integration, in order to support better end to end processes between design offices and factories. It means that the cPlatform associated with the Federated Interoperability Framework should be extended with new application components based on open standards, in particular Manufacturing Execution Systems based on the “Enterprise-Control System Integration”.

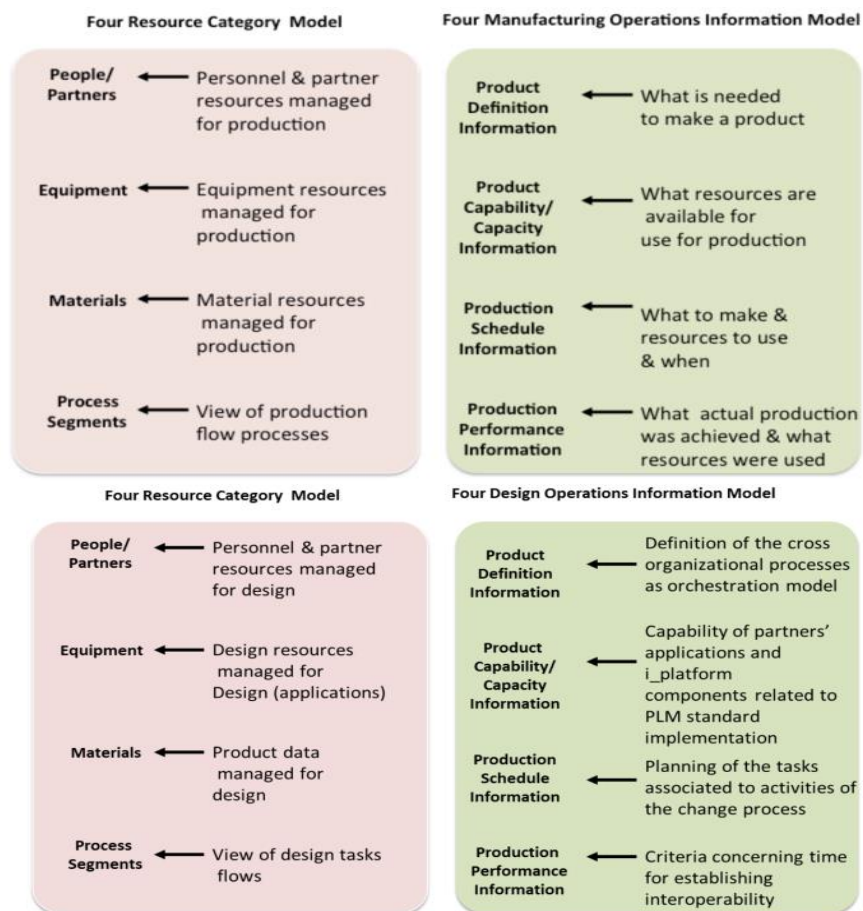


Figure 38: DMN blueprint Transposition from Manufacturing to Design

The partner blueprints capture the organizations which are members of the network, people which are members of the organizations, the end-to-end processes which are supported for a

given set of roles, and the qualification of the partner according to these processes. It captures unique capabilities in the Dynamic Manufacturing Network of a partner to play a given end-to-end process with a given role. It includes

- a) the Company Background (contact information as member of the network)
- b) People (person, groups)
- c) Processes (end-to-end process they can participate to with a given role for a given product)
- d) Qualifications (name of standards actually supported with regards to supported end-to-end processes)

The product blueprints are based on an engineering description of the Product Breakdown, very close to the engineering bill of material that will be used later in the life cycle of an industrial project for the production orders.

The breakdown of the aircraft is based on the STEP 242, and includes product definition information, and all the design activities and associated capabilities needed for performing changes on any configuration item. It includes assemblies, parts, sub-components, equipment, configuration items, associated documents, associated file formats, needed data processor, information coverage for each file.

More precisely, it includes

- a) Resource Definition Information (kind of data & software resources needed for design activities)
- b) Product Definition Information (resources & segments required to make the product definition)
- c) Design Schedule Information: minimizes design time and costs, by proving a design facility with information regarding what to make, when, with which staff, and on which equipment.
- d) Design Capability Information (applications, methods & tools).

The end-to-end processes blueprints are Enterprise workflow models based on the XML Process Description Language for Enterprise Workflow Systems, with extension concerning qualification of expected resources based on ISA95 (Enterprise Factory Integration).

It formalizes the end-to-end processes supported by the PLM Hub:

- a) Plan tasks related to change process activities (It establishes plans for the whole change activities described as follow)
- b) Issue change (provide/collect issues about the product),
- c) Request change (investigate how change issues can be addressed with involvement of all the concerned stakeholders)
- d) Order change (order to realize the change and update consequently product data in the Product Data Management system referential)
- e) Provide required data (required for being able to perform the change)

The quality assurance blueprints are capturing expected quality of end-to-end processes, of the used standards, of the actual process participants and of the Manufacturing PLM hub in terms of secured transportation process and in terms of data transformation process. It structures a collection of metrics for measuring quality of processes and associated participants for product data exchange and sharing

- a) End-to-end process models (conformance class of all participants and information coverage of any information flow make possible to play the process without information change)
- b) Actual process participants: all the process participants have the expected conformance class for playing one or several roles in the end-to-end process
- c) Secured transportation process (all security constraints are fulfilled all along the process and all along the network)
- d) Data transformation process (data transformation between specific and standardized format doesn't change the information or make it possible to be exchanged or shared).

The end to end cross organisational processes considered are the configuration management process under the control of the change management process, plus the Technical Data Package exchange.

The main concerned actors are

- 1) PLM Hub operators, who will have to develop, operate and maintain the collaborative infrastructure, based on the cPlatform and supporting the DMN methodology
- 2) Dynamic Manufacturing Network member: a Dynamic Manufacturing Network member who wants to enter the collaborative environment, to collaborate through the hub for one or several products and playing one or several roles in a set of cross organizational processes. Different sub-categories exist for Dynamic Manufacturing Network members:
 - a. System integrator: company specialized in bringing together component subsystems into a whole and ensuring that those subsystems function together. Usually, the sub-components are purchased by the integrator and retailed under that purchasing company's brand name. E.g. An Airbus is sold with a SNECMA engine under the Airbus name, when the original engine manufacturer (OEM) is SNECMA. Notes that an Original Equipment Manufacturer can also be an integrator, selling components of the engine which are manufactured by other companies.
 - b. Original Equipment Manufacturer (OEM): the OEM manufactures products or components that are purchased by another company who will integrate it in an integrated product that will be sold under this company's brand name (e.g. SNECMA, Aircelle)
 - c. One PLM Hub cross organizational process participant: role associated to an orchestration model of cross-organisational process, enacted on a PLM Hub. The participant can be a person, an organization or an application. The participant is usually abstract for a process model (e.g. Integrator, Original Equipment Manufacturer) , and concrete when the process model is enacted (e.g. Airbus, SNECMA for the Engine of the Airbus 380 product)

In such a context, several processes are considered.

The first process to be considered is related to the PLM Hub management, and is named P0. It is subdivided in P0-1 for the set-up of the PLM Hub, P0-2 for operating the PLM Hub and P0-3 for managing changes in the PLM hub.

P0-1 consists in designing, deploying and making the cPlatform accessible to the aeronautic community over the web

P0-2 consists in operating the PLM hub, and providing support to any partner willing to enter the DMN, collaborate and eventually leave the DMN.

P0-3 consists in managing changes in the PLM Hub, as making the cPlatform evolve in terms of realization components, functionality or cross organizational processes to add or to change in the portfolio of processes supported by the cPlatform. The other processes to consider are those related to the DMN.

Collaboration processes are:

P1 - On boarding: this is the on boarding process, and is related to all the activities required to enter the DMN, including connection of legacy front-end applications to the PLM Hub.

P2 - Enactment: As soon as properly connected to the hub with appropriate implementation of standardized product and process data exchange protocols and service contract interface, the partners are ready to collaborate, running instances of the cross organizational processes connected to their own specific processes, being internal or dedicated to extended enterprise.

P3 - Leaving: If willing to leave the DMN as collaboration is not needed anymore, or because the partners want to collaborate through another PLM Hub, the process P3 is related to leaving the Dynamic Manufacturing Network. It consists in disconnecting applications from the PLM hub and removing all the blueprints of the leaving partner from the cPlatform Dynamic Manufacturing Network repositories and databases.

The demonstration has been achieved through

- 1) prototyping of a PLM Hub extended with Dynamic Manufacturing Network functionalities, relying on the legacy previous version of the cPlatform and applying the principles and approach developed with the Federated Interoperability Framework
- 2) experimentation by running collaboration scenarios on top of the living laboratory obtained through the enactment of the cPlatform on the Cloud. It included the registration of new company on the cPlatform plus the modelling and enactment of a cross organizational Technical Data Package, relying on two components extending respectively an open source enterprise workflow modeller and an enterprise workflow system engine based on open standards of the Workflow Management coalition (JaWine and SharKine)
- 3) modelling of a DMN relying on Enterprise Modeling based on the ArchiMate modelling language, and then derivation of the workflow processes on an Enterprise Workflow System including modeller and engine extended with Dynamic Manufacturing Network features. A dedicated ArchiMate modelling client was developed as an Enterprise Portal portlet with a controlled access to the different views of the Dynamic Manufacturing Network filtered by mean of roles and predefined viewpoints

5.3 - Analysis and Conclusion

What was demonstrated is

- 1) the relevance of the Federation of Interoperability Frameworks approach for preparing and building continuous operational interoperability at an acceptable cost in a changing environment by relying on the cPlatform, which was easily reconfigured and extended with Dynamic Manufacturing Network functional and applicative components

- 2) The accuracy of the approach for qualifying the members of a Dynamic Manufacturing Network and for progressively extend and improve the set of collaborative cross organisational processes which can be run by the Dynamic Manufacturing Network members
- 3) the relevance of using the ArchiMate Enterprise Modeling language as a way to aggregate the different Dynamic Manufacturing Network blueprint templates in order to give an holistic view of the Dynamic Manufacturing Network state, including members of the Dynamic Manufacturing Network collaborating for a given product typed according their role and the parts or configuration items they are working on, the processes they are participating to - cross organizational or private- , the applications supporting these processes and the technology realising these applications. It corresponds to what is called a Dynamic Manufacturing Network within the Federation of Interoperability Framework context.

The obtained results from this experiment were

- 1) The proposal of a new and innovative concept, the Dynamic Manufacturing Network within the scope of Federation of Interoperability Frameworks, suited when willing to deal with PLM interoperability and for extending the FIF and associated cPlatform. The related scientific publications are P05, P07 and P14 ;
- 2) the opportunity for studying the introduction of manufacturing production standards in the set of PLM standards to be used for cross lifecycle interoperability supporting end to end processes including design office and production;
- 3) the opportunity for assessing the extended hypermodel for interoperability by including ArchiMate models as one of the representations to consider for a Product or of a Dynamic Manufacturing Network;
- 4) business cases and a problematic related to process interoperability within a Dynamic Manufacturing Network, which was the opportunity to launch the thesis "A formal framework for Process Interoperability in Dynamic Collaboration Environments";
- 5) through introduction of ISA 95 (Enterprise Factory Integration) standard, the opportunity for defining business cases and a problematic related to PLM interoperability relying on ISA 95 and to launch the thesis "Proposal of a methodological approach of multi-level interoperability in a collaborative PLM environment" ;
- 6) the opportunity to study impact of autonomous networks underlying the cPlatform, through a collaboration with LAAS and two PhD students ;
- 7) the opportunity to start investigating PLM interoperability needs for virtual manufacturing, Cyber Physical Systems and Digital twins.

In terms of limitations of the results, what came out from their assessment is

- 1) when considering the FIF extended with the Dynamic Manufacturing Networking, an important issue is still not addressed, concerning the missing approach for assessing if a standard is relevant to support a given process and for derivation of the test plan for qualifying applications or software products.
- 2) no open source implementation of reference exists at this stage for ISA 95. It raises the question of interoperability of standards which are not mature enough.
- 3) the way the cPlatform deals with cloud and virtualisation is reaching some limits being for managing living labs based on the cPlatform, or considering the emerging Cloud infrastructure as a service

The FIF extended with the Dynamic Manufacturing Networking, and the associated version of the cPlatform, provided an excellent starting point for addressing the scientific gap related to missing test based approaches and for extending the scope of PLM interoperability to applications and standards supporting production and the collaboration with design or support. It was addressed through the SIP project, and the related scientific contribution, the PLM Interoperability Testbed, is developed in the next section.

Associated publications	P00, P01, P02, P03, P04, P10, P12, P15, P16, P17, P18, P19, P21, P22, P23, P25, P29, P36
Related Projects	IMAGINE
1 PhD supervised and collaboration for supervision of 2 others PhDs	Malik Khalfallah, Code Diop and Aymen Kamoun.
Demonstrators	cPlatform with extension for DMN based on SharkIne, JaWine and ArchiMagine
Addressed Interoperability Issues	I-21, I-26

Table 15: Dynamic Networking outcome

6 - The PLM Interoperability Testbed

6.1- The problem

Considering the Return on EXperience (REX) from IMAGINE and PLM harmonization program at Airbus, some difficulties were encountered concerning the deployment and effective usage of PLM standards within a DMN, the identification of business value from using a PLM standard, the ability to assess the alignment of a given PLM standard with the targeted collaboration or the ability to specify how standards have to be implemented by software solution providers in a way they can be tested as the realization of an application of a DMN. It constitutes an important brake to be addressed when willing to prepare and to build continuous operational interoperability based on open PLM standards at an acceptable price.

Indeed, considering both the state of the art and the state of the practice, no relevant approach exists for addressing such a need, but only partial solutions addressing a subset of the needs.

It is in particular the case of the best practices produced and applied by the European Telecommunications Standards Institute (ETSI) for solving the challenge of interoperability [36].

“It concerns the specification and validation of base standards and the development of test specifications related to the technologies considered by the ETSI. The techniques are pragmatic (for example, validation of standards through interoperability events) as well as technical (for example, the use of languages ... to define test scenarios). They have the added benefit that these techniques are applicable well beyond the world of standardization. Good practice started in standardization can be carried through into proprietary development processes. The ETSI experience is that the application of these best practices does indeed help to develop interoperable standards, which in turn leads to interoperable products.”

However, it addresses more the interoperability at the technology layer while PLM interoperability concerns simultaneously organisational, applicative and technological layers. [28] Proposed a manufacturing B2B interoperability testbed, which was too closely related to XML technologies. In association with some standards such as the UML Model Language or the Business Process Modeling Notation, some Model Interchange Working Groups have been set up producing test data sets and testing campaigns for qualifying software products ability to interchange models. Many standards, in particular STEP, have been coming with parts dedicated to certify the conformance of software solutions. However, about no vendors accept to be certified, even if some of them accept to participate in the Implementor forum, driven by associations or institutes (GALIA, AFNET, PROSTEP, AIDIMA, NIST, etc.) and under the pressure of industry (Automotive, Aeronautic Automotive, Furniture, etc.). Here again, the focus is more on model interchange and technologies, and adopted practices are not model based.

Also, none of the identified practices are relying on a model based automated generation of the testbed platform itself, which will reproduce the environments where the software solutions will be deployed, connected, enacted, operated and used. Some partial solutions exist for automated deployment coming from DevOps.

“DevOps is a set of practices that combines software development (Dev) and IT operations (Ops). It aims to shorten the systems development life cycle and provide continuous delivery with high software quality.”

Once again, it concerns mainly software and the Information & Communication technology layer of the working environment of an enterprise. Software engineering also comes with test based development practices based on Continuous Integration, with the following workflow: running tests locally, compiling code in Continuous Integration and deploying a component from Continuous Integration. Continuous Integration solutions implement continuous processes of applying quality control.

It motivates the launching of the Standard Interoperability PLM (SIP) research project for defining an innovative approach unleashing this brake, following the principles defined by the FIF and contributing to the extension of the FIF related practices and enablers, with a new version of the cPlatform.

6.2 The proposed innovative approach

The proposed innovative approach aims at assessing standards and their implementations on top of an experimental test bed platform simulating a complex Dynamic Manufacturing Network at an acceptable price.

“A testbed is a platform for conducting rigorous, transparent, and replicable testing of scientific theories, computational tools, and new technologies...The term is used across many disciplines to describe experimental research and new product development platforms and environments. They may vary from hands-on prototype development in manufacturing industries such as automobiles (known as "mules"), aircraft engines or systems and to intellectual property refinement in such fields as computer software development shielded from the hazards of testing live.”

Considering the aeronautic industry, some specific testbeds are created for aircrafts called Iron Bird.

“An iron bird is a ground-based test device used for prototyping and integrating aircraft systems during the development of new aircraft designs. Aircraft systems are installed into the iron bird so their functions can be tested both individually and in correlation with other systems. Some iron birds also include a flight deck so that testing can include pilot inputs and simulated flight profiles, and can be used in pre-flight pilot training. Others are used for testing of propulsion systems. Iron birds can also be used after aircraft certification for troubleshooting ongoing issues and for testing of proposed modifications prior to fleet integration.”

The proposed innovative approach consists in making the analogy between a Dynamic Manufacturing Network and a complex system, such as an aircraft, and to extend the FIF and the cPlatform in order to be able to use the cPlatform as a testbed. The testbed will be used for prototyping and integrating PLM system components during their development as part of a Dynamic Manufacturing Network.

PLM components are installed into the testbed so their communication function based on standardized interfaces can be tested both individually and in correlation with the other application components. Testing can include users inputs and simulated collaboration, and can be used on training for PLM standards based collaboration. Testbed can also be used after deployment of PLM solutions for troubleshooting ongoing issues and for testing of proposed modifications prior to deployment and integration in operation.

Following the FIF principles, the PLM interoperability testbed is an evolution of the cPlatform and of the DMN software factory aiming at supporting the new FIF proposed processes. These processes include the assessment of PLM standards relevance for the expected end-to-end collaborations and the specification of the PLM standards implementation by software solution providers in a way that supports continuous integration and testing within a Dynamic Manufacturing Network.

A first evolution of the cPlatform described in fig 22 consists in a functional extension of the cPlatform with

- 1) test services including transformation, quality control, service composition and data set generation
- 2) management system for test use cases, test scenarios and associated test data, which will be stored in a shared database.

These two extensions aim at supporting continuous integration and continuous quality checking of the different components of the working environment of a Dynamic Manufacturing Network. they are relying on legacy standard technical components of the previous version of the cPlatform.

A second evolution of the cPlatform infrastructure is related to the usage of virtualisation and cloud technologies which were identified as potential interoperability enablers, as it allows to simulate the actual working environment for complex multi-partners digital and secured collaborations at scale using limited resources in terms of machines. After assessing the various infrastructure virtualization technologies for machines and networks, in full alignment with the FIF approach, it led to the realization of a new version of the cPlatform with the architectural description provided by Fig 24.

A third evolution concerning the Dynamic Manufacturing Network software factory is related to a new joint usage of Model Driven Architecture with Enterprise Modeling. For making it possible to simulate various Dynamic Manufacturing Network and to configure the cPlatform for supporting the assessment of many standards for various collaboration scenarios, the Model Driven Architecture technologies coupled with Dynamic Manufacturing Network modelling using the standardized enterprise modelling language ArchiMate were identify as enablers for designing and realizing a Dynamic Manufacturing Network Software Factory. The defined approach is described in chapter 3.3 and illustrated by Fig 23.

While the information and service models are derived from PLM standards, both the business context to be reflected in the enterprise applications and the realisation infrastructure where they have to be run are generated from Dynamic Manufacturing Network blueprint templates in ArchiMate.

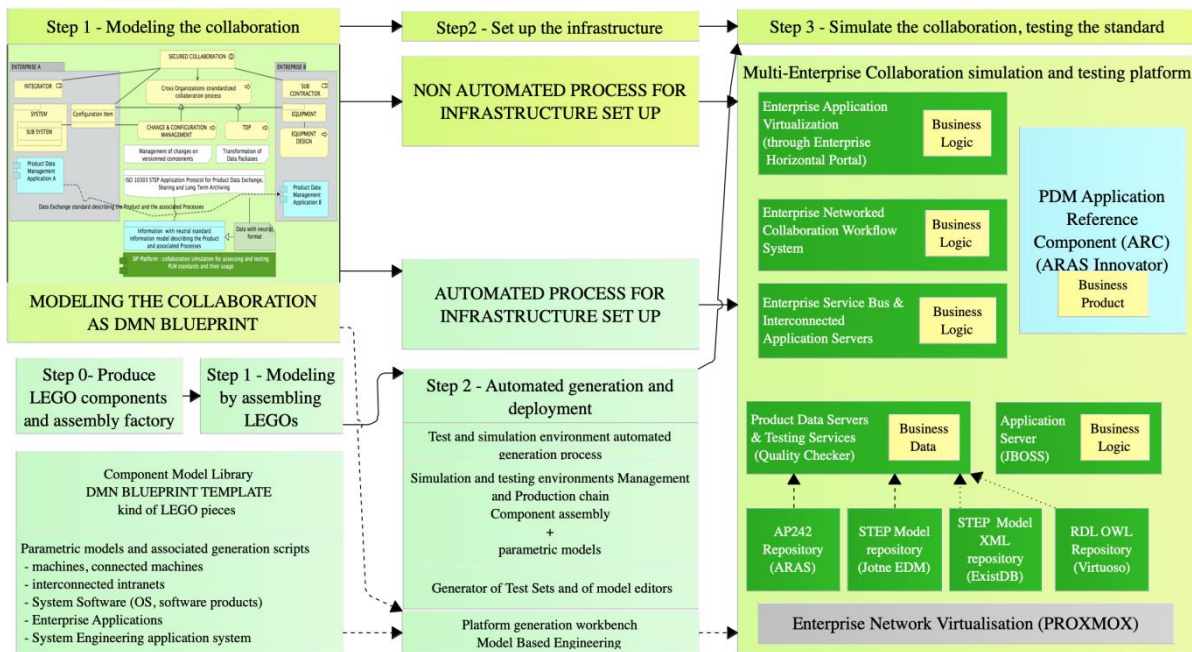


Figure 39: Two phases approach for the DMN Software Factory

As automation is relevant only for well-defined and qualified components for a cPlatform, a two phase approach is adopted.

During the first phase, the components are deployed, configured and integrated manually, and represented as parametric DMN blueprint templates in ArchiMate.

Once validated and qualified, the manual process is automated and included in the DMN Software Factory automated process library. This is illustrated by Fig 35.

Step 1 consists in modelling the collaboration by means of DMN blueprints.

Step 2 consists in setting up the environment where the simulation will be simulated - also called infrastructure of the collaboration- as defined by the DMN. Doing so, the applied process will be captured and validated.

Step 3 consists in simulating the collaboration for testing the PLM standards. In the second phase, from the gained experience, modular model components will be derived from the initially produced DMN blueprints (Step 0) in order to be able to define a DMN by assembling (Step 1) these modules (also called LEGO components, due the analogy with LEGO parts).

The set up process will then be fully automated on the basis of the produced parametric models and of the tool chain put in place in order to support this automated process. This could be completed by usage of tools automating the generation of test data.

In terms of process, a three phases approach was defined for implementing a cross organizational collaboration between two partners within a DMN. Considered collaborations are defined the following way.

One partner plays the role of the Original Equipment Manufacturer (OEM) and the other plays the role of an equipment supplier. The collaboration to be realized by end to end

collaboration processes including the private processes of the OEM and of the supplier, interfaced by a standardized cross organizational collaborative process (SPc).

This last process consists mainly to exchange Work Request and Work result with the associated required information flows between applications supporting the private processes. The application of the OEM is called O, the one of the supplier is called S.

The information flows are realized by data exchange or sharing between the software systems realizing these applications, each software system being an instance of a software product. For O, it is product A. For S, it is product B. This is described by Fig 36.

We have then to consider that the collaboration will rely on the usage of a given standardized Application Protocol, APxx.

We are here generalizing the approach proposed by STEP, by considering that each application or software product can be categorized according to a given Conformance Classes (CC).

Hence, we can consider the conformance class of the OEM's application, CC(O), and the conformance class of the supplier' application, CC(S).

A conformance class aggregates subsets of an AP Reference Model, which depend on sets of assigned (applications) or implemented (software products) Unit of Functionalities.

The information and data flows to be implemented are the relevant ones for supporting the collaboration.

It is not required using all the concepts defined in an application protocol, but just the sufficient subset for covering the expected collaboration and for reflecting the distribution of functions to be performed between partners and applications for a given product component. It is the reason we consider the Information Coverage concept.

It is associated with each flow to implement between two applications. It is the subset of concepts in an application protocol needed for realizing this flow.

The interest of considering the Information Coverage comes from the fact it allows to precisely specify what needs to be implemented in terms of standardized exchange in order to cover just what is needed for supporting the collaborations to be supported, no more.

It means that implementation of the standardized interfaces by software vendors can be done progressively relying on a set of Standardized cross organizational collaborative processes (SPc) adopted by the members of a Dynamic Manufacturing Network or by a given digital business ecosystem mature in terms of interoperability.

It can also be very useful for specifying formally the different business cases and derived use cases to be realized for a collaboration.

In terms of process, it means that for a DMN blueprint, we have to define all the information flows between applications which are required to support a collaboration.

The Conformance class is to be defined for each application. The Information Coverage is to be defined for each flow.

The assessment of a PLM standard within a given DMN will consist in checking that

- 1) all the needed entity types to be used for defining exchanged artefacts are defined in the application protocol 2
- 2)) the Information Coverage is included in the intersection of the Conformance Classes of the applications having to communicate. In addition, it will be possible to assess the global consistency of the Application Protocol usage in the DMN by querying the DMN repository, and to enforce the consistency by defining rules and constraints when defining the DMN templates for collaborations.

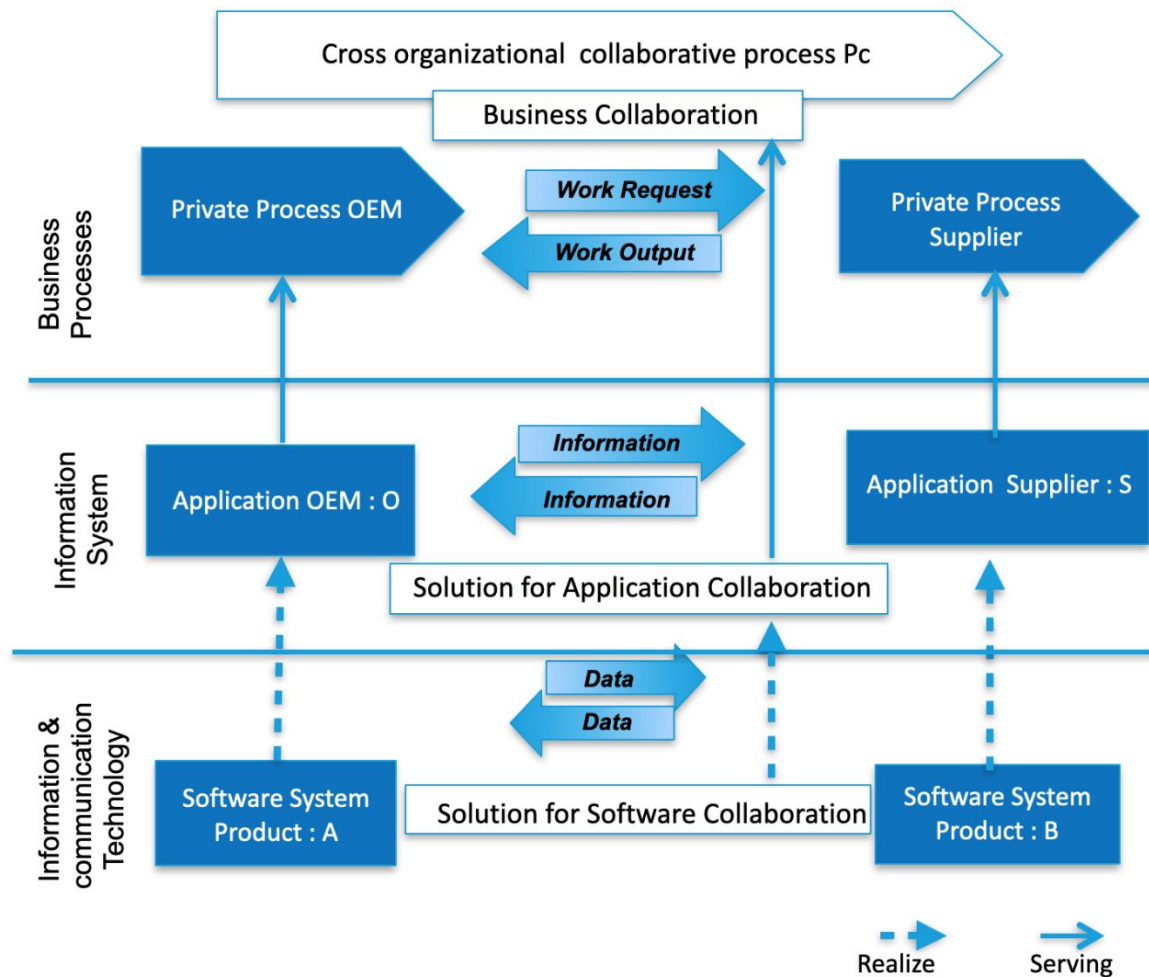


Figure 40: Standards Interoperability PLM methodology

We can now start to describe the three phases for using the testbed for PLM collaboration in a DMN using a given Application Protocol.

The first phase is the simulation phase. It aims at validating that a standard responds to cross organizational collaborative process needs in terms of Product & Process data exchange between Original Equipment Manufacturer (OEM) and the members of the supply chain related to a given manufactured product. The goal here is not to test the actual applications of OEM and Suppliers, but the adherence of the standard with Product & Process data exchange needs. On Figure 40, the Dynamic Manufacturing Network blueprint model (light blue) for the targeted collaboration (blue) is represented. It includes Conformance Class of the applications, and Information Coverage of the information flows.

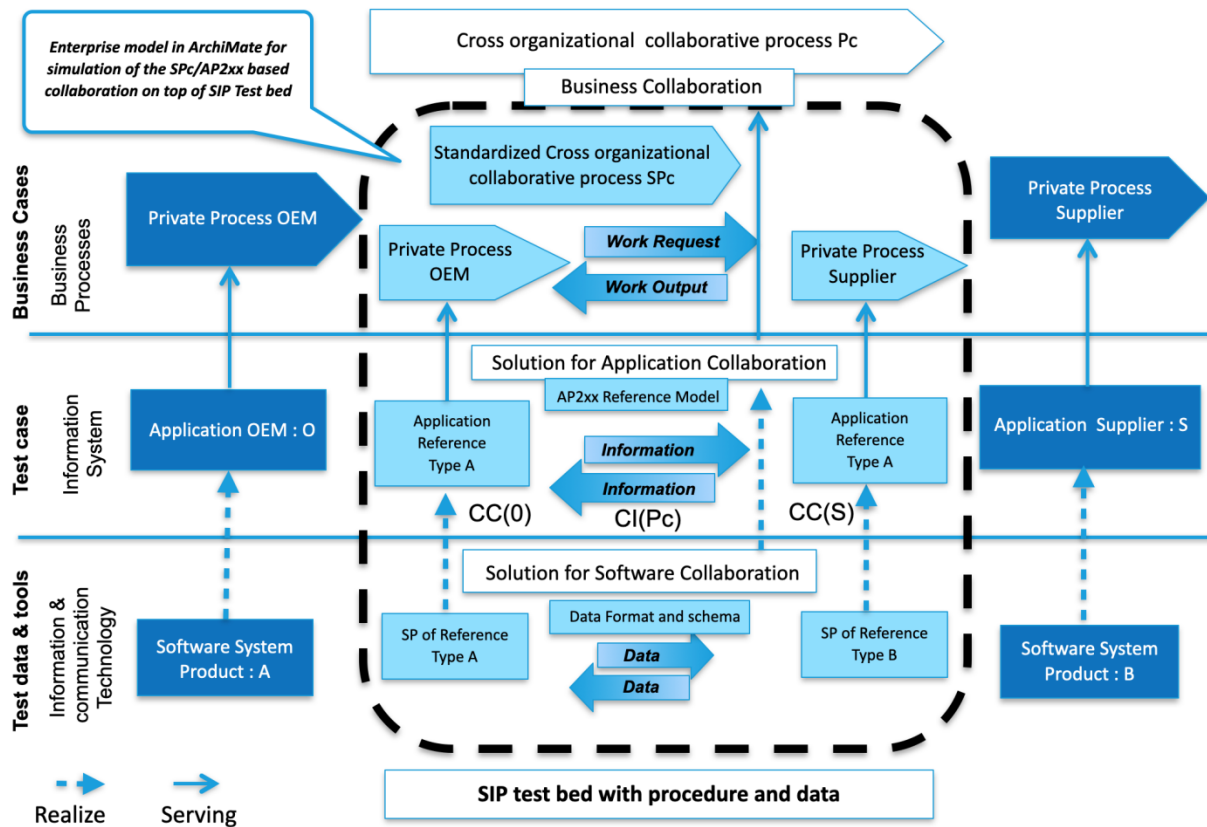


Figure 41: DMN collaboration blueprint template

It will also be one element of a generic and shared portfolio of cross organization collaboration scenarios from which it will be possible to derive associated testing procedures, and test data sets, reusable for continuous integration. For this, the Dynamic Manufacturing Network blueprint, formalized by means of ArchiMate is used as the input of the Dynamic Manufacturing Network Software Factory. In this phase, each application is realized by means of an Applicative Referenced Component, which is one of the LEGO building blocks of the Dynamic Manufacturing Network Software Factory.

The second phase consists in testing actual software solutions, within the role of Applicative Referenced Components used in the first phase. These components are replaced by applications or software systems to be tested. They can then be tested by replaying the testing scenarios, for unitary testing or integration testing. This testing phase for standard implementation validation will result in a set of qualified applications supporting the targeted collaboration process through the usage of the PLM standards. It is illustrated by Figure 41.

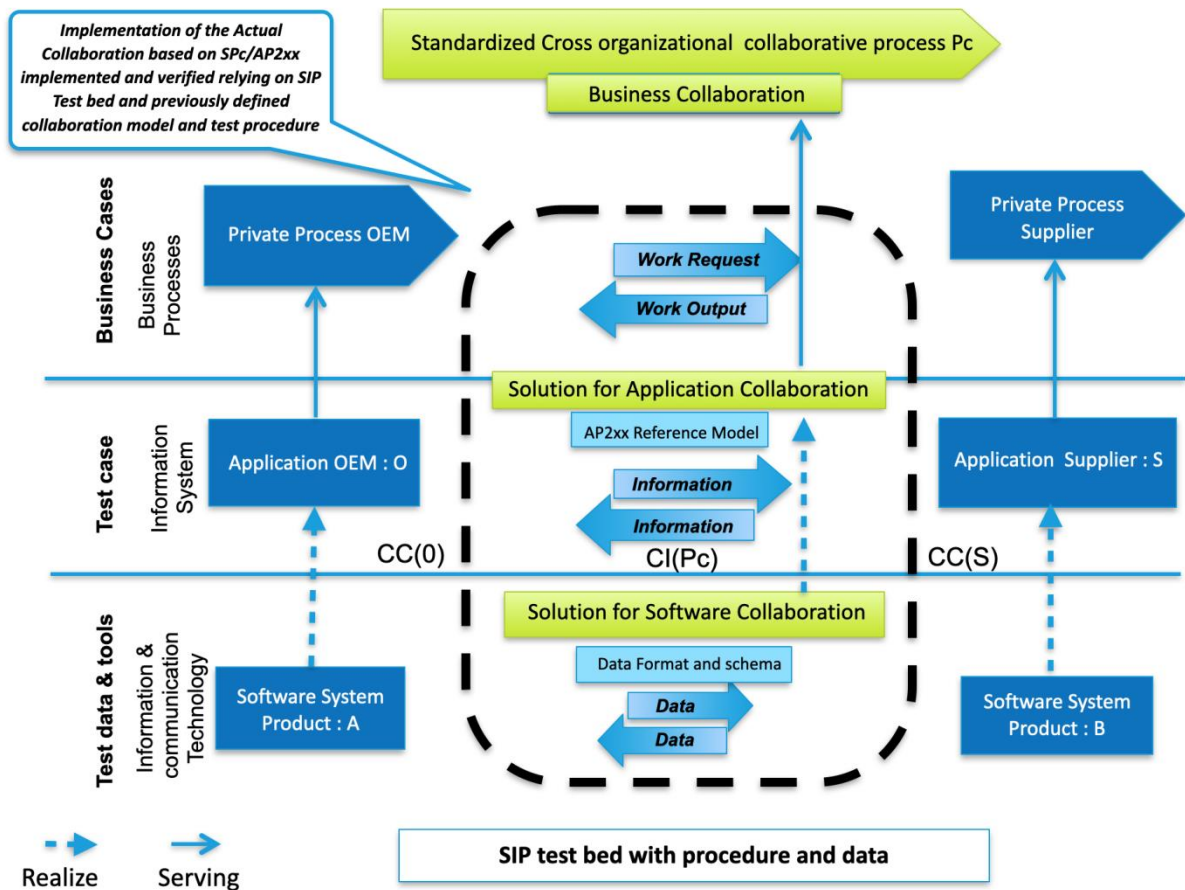


Figure 42: Testing actual solutions by replacing the Applicative Reference Components

The third phase consists in monitoring interoperability of actual applications, by tracking issues and being able to take actions when non-interoperability is detected, or to deal with interoperability maintenance when some changes must occur. This is possible due to the adopted virtualisation approach, which allows to seamlessly connecting the actual application on the testbed. Consequently the test bed can be used as a monitoring solution to detect interoperability issues and to be able to address them very quickly. The Dynamic Manufacturing Network model is then used as a digital twin of the Dynamic Manufacturing Network. It is illustrated by Figure 42.

6.3 - Analysis and conclusion

The proposed approach has been used for assessing several PLM standards and testing some of their implementation, in close relationship with the PLM standardisation community and research community:

- 1) The “Enterprise-Control System Integration” standard (ISA95) for covering collaboration implying an Enterprise Resource Planning System and a Manufacturing Execution System. The demonstration was made through the PhD thesis of Emna Moones: “Proposal of a methodological approach of multi-level interoperability in a collaborative PLM environment” and was the opportunity for several scientific publications [P10][P18].
- 2) The “Managed model based 3D engineering” standard (STEP AP242), relying on implementation based several implementation technologies (XML Schema and Schematron

and EXPRESS on top of the Meta Object Facilities) and in order to assess the usage of the protocol for an actual business case implying Dassault Aviation.

- 3) The “Open Services for Lifecycle Collaboration” standard (OSLC) for assessing the maturity in terms of interoperability of the OSLC community.
- 4) The “Multidisciplinary Analysis and Design” standard (STEP AP209) for assessing the relevance of the proposed approach for simulation. It was the opportunity of a scientific publication [P13][P20]
- 5) The “Modelling and Simulation information in a collaborative Systems Engineering Context” standard (STEP AP243), in order to assess how to include service based approach in STEP

It demonstrated the applicability of the proposed approach for various PLM standards and Business cases, in particular when considering that all these assessments were performed on a two years period with very limited resources.

In terms of scientific results, the approach has been the opportunity for publishing several research papers, in particular [P00].

In terms of limitations of the results, we faced the limitation of the adopted modelling language, ArchiMate, in terms of modular modelling of composite systems and polyglot enrichment which are being addressed with the work on extended hypermodel for interoperability.

An important difficulty is related to the access to relevant data sets for building appropriate test scenarios and procedures. It is particularly true if considering the new trends related to Virtual Manufacturing, Industrial Internet of Things or Cyber Physical Autonomous Systems. These trends are bringing new challenges in terms of interoperability, due to the growing complexity of the underlying technologies and infrastructures.

Associated publications	P00, P01, P02, P03, P04, P10, P12, P15, P16, P17, P18, P19, P21, P22, P23, P25, P29, P36
Related Projects	SIP
1 PhD supervised and collaboration for supervision of 2 others PhDs	Malik Khalfallah, Emna Moones
Demonstrators	DMN Software Factory, ARAS import/export with AP242, Quality checker on top of XML database, AP242 Quality Checker on top of Eclipse
Addressed Interoperability Issues	I-28

Table 16: Interoperability testbed outcome

Chapter 7 - Conclusion and perspectives

The interoperability required for the digital continuity in the Manufacturing Domain has been an important but challenging concern during the last 20 years, due to the rise of Information and Communication technologies which have been continuously changing the way of working or doing business. It is true in particular within the manufacturing industry with the successive innovative transformations from the Computer Aided Design in the 90's to the current usage of Digital Twins.

Various limitations exist for legacy interoperability solutions, being interoperability models of reference, integration platforms or open PLM standards. In particular, they are partial, fragmented, heterogeneous and overlapping solutions addressing some particular viewpoints, but they don't support the required holistic approach allowing to prepare and to build the expected continuous operational interoperability at an acceptable cost and for long time duration.

The first contribution is an original approach for the **Federation of Interoperability Frameworks and solutions**, allowing to select the relevant interoperability solutions and enablers and to use them jointly in order to unleash the identified interoperability brakes, which prevent to reach the expected continuous operational interoperability at an acceptable cost for PLM. Focussing on the cause and impact of non-interoperability, it provides a way to prepare - relying on governance - , and to build - relying on architecture best practices - the expected interoperability.

The second contribution is an original approach aiming at **semantic preservation** and at preventing data loss when having to translate data between languages used in the different communication chains to put in place being for PLM processes or for Model Based Approach used by the software factories used by the Federation of Interoperability Framework. It is based on the extension of the hypermodel concept for interoperability, which deal with multiple representations of a same thing for different usage. After relying on the usage of hypergraphs which can travel between the different grounds of the collaboration landscape, and allowing preserving the semantic of flat semantic graphs, it was extended in order to deal with modular representations of composite systems of systems through the proposal of using Domain Specific Language over open and standardized System Modelling languages.

The third contribution is an original approach aiming at building qualified dynamic networked organisations in terms of PLM interoperability, by **Modeling of the dynamic networking of companies collaborating for manufactured products**. This is based on blueprint templates allowing capturing the actual capabilities of a member of the network and to compare it with what is expected from any participant of a cross organisational process to be run in a collaborative PLM environment based on PLM standards.

The fourth contribution is an original approach aiming at assessing the PLM standards with a Dynamic Manufacturing Network and at testing their implementation relying on collaborative platforms with a PLM Hub. It relies on an approach for building **PLM interoperability test bench**, as a functional extension of a collaborative platform built for the Federation of Interoperability Frameworks and solutions.

However, all the brakes are not addressed, and both practices and emerging technologies bring new problems that require advancing the state of the art and supporting digital

transformation. Three short-term perspectives concern PLM interoperability in relation to the Cloud, Artificial Intelligence (AI) and autonomous connected products.

1. **Collaborative PLM over Distributed and Heterogeneous Clouds**: Current cloud trends are leading to the increasingly frequent use of orchestrated containers for elastic solutions based on micro services. This brings new complexity, both in terms of technology and governance. Which standards are required, existing or to be developed, to be federated with those already identified to maintain PLM interoperability in digital ecosystems? One particular aspect is related to the impact of virtualization on the ability to prepare and build interoperability.
2. **Collaborative PLM and AI technologies**: Current trends in artificial intelligence, whether Deep Learning or Knowledge Bases, pose the question of publishing or upgrading data describing the products and associated processes towards these types of solutions. How to preserve the semantics and the interpretation context of the data to integrate them into a controlled chain of collaboration? A particular aspect is related to the ability to produce multiple representations of business rules exchangeable between technology platforms, such that the information produced by AI systems is consistent with the source data coming from PLM platforms.
3. **Extensive PLM test bench for autonomous connected products with digital twins**: current trends concerning "makers", in connection with the extension of open source to the hardware and with additive manufacturing processes, create an unprecedented new situation: complete products based on innovative technologies are made available off the shelf, with design models and manufacturing processes to build them quickly at very low costs, as perfect prototypes of new kind of products that need to communicate or interact with their environments. While being representative of the new complexity to be understood for these types of products, they are not subject to the constraints encountered for other industrial products concerning access to data, which are generally confidential or difficult to access. They are therefore the components of choice to constitute new types of test beds for the PLM interoperability to be established for autonomous connected systems and digital twins. The product design models can be reused to derive digital twins of these products, for their monitoring, configuration or remote control in the various contexts reflected by a collaborative PLM platform built according to the principles of the Federation of Interoperability Framework and solutions approach.

These subjects are likely to give rise to new interoperability problems, the resolution of which will be done relying on the global approach defined with the Federation of interoperability frameworks and solutions, making it possible to integrate research activities into shortened cycles for innovation, for a better adaptation of enterprises to the new collaboration context resulting from the evolution of information and communication technologies.

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References of considered standards

The standards are those which have been considered by my research for assessment when having to prepare and build continuous operational interoperability for PLM, for manufacturing domain and more particularly Aeronautic, Space and Defence Industry. Some of them have been elected as relevant building blocks to be used using the Federation of Interoperability Frameworks approach.

Acronym	Designation
STEP	ISO 10303 STandard for the Exchange of Product model data
AP203	ISO 10303-203:(1994, 2005, 2011) Configuration controlled 3D designs of mechanical parts and assemblies
AP214	ISO 10303-214:(2001, 2003, 2010) Core data for automotive mechanical design processes
AP242	ISO 10303-242:(2014, 2020) Configuration controlled 3D designs of mechanical part and assemblies
STEPNC	AP238 2007 Application interpreted model for computerized numerical controllers
AP238	AP238 2020 Model based integrated manufacturing
EXPRESS	ISO 10303-11:2004-Part 11 Description methods: The EXPRESS language reference manual
EXPRESS-X	ISO 10303-14:2005 -Part14 Description methods: The EXPRESS-X language reference manual
SDAI	ISO 10303-22:1998-Part 22 Implementation methods: Standard data access interface
P21	ISO 10303-21:2016-Part 21 Implementation methods: Clear text encoding of the exchange structure
PDME	OMG's PDM Enablers v1.3, November 2000
ECO	ProSTEP recommendation: Engineering Change Order (ECO)PSI 3-2 (Draft) Version 0.9
ECM	ECM Recommendation Part 0 (ECM) Version 2.0, issued Aug. 2009 Replacements: Version 1.0 VDA 4965 – Part 0 Version 3.0, issued Jan. 2010 Replacements: Version 2.0
ISA95	ISO/IEC 62264 Enterprise-Control System Integration, the international version of ISA 95
MDA	OMG Model Driven Architecture
CORBA	OMG Common Object Request Broker Architecture
OMA	OMG Object Management Architecture
OSLC	OASIS Open Services for Lifecycle Collaboration
OPC UA	OPC Foundation Open Platform Communication Unified Architecture
QIF	ISO 23952:2020 Quality Information Framework
RAMI	EC PAS 63088:2017 Smart manufacturing - Reference architecture model industry 4.0
PERA	Purdue Enterprise Reference Architecture
NIST RM	Current Standards Landscape for Smart Manufacturing Systems
MT Connect	ANSI/MTC1.4-2018 MT Connect
ArchiMate	Open Group ArchiMate 3.1
OWL	W3C Ontology Web Language 2
WRM	Wfmc's Workflow Reference Model Workflow Management Coalition

	Document Number TC00-1003 Document Status - Issue 1.1
XPD	XML Process Description Language
BPSim	Business Process Simulation Interchange standard
BPMN2	Business Process Model and Notation Version 2.0.2
SPEM2	Software & Systems Process Engineering Metamodel Version: 2.0
PDME	Product Data Management Enablers Version 1.3, OMG, November 2000
UAF	OMG Unified Architecture Framework 1.1
TOGAF	The Open Group Architecture Framework 9.2
ISO15288	ISO/IEC/IEEE 15288:2015 Ingénierie des systèmes et du logiciel — Processus du cycle de vie du système
S1000D S2000M S3000L S4000P S5000F S6000T SX001G SX000i SX001G SX002D SX004G SX005G	International specification for technical publications using a common source database ASD/AIA S2000M – INTERNATIONAL SPECIFICATION FOR MATERIAL MANAGEMENT ASD/AIA S3000L International procedure specification for Logistic Support Analysis (LSA) ASD S4000P International specification for developing and continuously improving preventive maintenance AIA/ASD S5000F International specification for in-service data feedback ASD/AIA S6000T International specification for training analysis and design ASD/AIA SX000i International guide for the use of the S-Series Integrated Logistics Support (ILS) specifications ASD/AIA SX000i International guide for the use of the S-Series Integrated Logistics Support (ILS) specifications Glossary for the S-Series ILS Specifications, Issue 2.0, December 2018 Common Data Model for the S-Series ILS Specifications, Issue 2.0, December 2018 Unified Modeling Language (UML) model reader's guidance, Issue 1.0, August 2016 S-Series ILS specifications XML schema implementation guidance, Issue 1.0, December 2017
ReIF	OMG Requirements Interchange Format 1.2
JT	ISO 14306:2017 Industrial automation systems and integration — JT file format specification for 3D visualization
SCOR	SCM Supply Chain Operation Reference Model
RDF	W3C Resource Description Framework 1.1 as a set of recommendations: Primer , Concepts and Abstract Syntax , XML Syntax , etc.
JSON-LD	JSON-LD 1.1 A JSON-based Serialization for Linked Data W3C Recommendation 16 July 2020
SHACL	Shapes Constraint Language (SHACL) W3C Recommendation 20 July 2017
SKOS	SKOS Simple Knowledge Organization System Reference W3C Recommendation 18 August 2009
SPARQL	SPARQL 1.1 Query Language W3C Recommendation 21 March 2013
IRI	IETF Internationalized Resource Identifiers (IRIs) January 2005 - rfc3987
WSDL	Web Services Description Language (WSDL) 1.1 W3C Note 15 March 2001
SOAP	SOAP Version 1.2 Part 0: Primer (Second Edition) W3C Recommendation 27 April 2007 SOAP Version 1.2 Part 1: Messaging Framework (Second Edition) W3C Recommendation 27 April 2007 SOAP Version 1.2 Part 2: Adjuncts (Second Edition) W3C Recommendation 27 April 2007 SOAP Version 1.2 Specification Assertions and Test Collection (Second Edition) W3C Recommendation 27 April 2007 Simple Object Access Protocol (SOAP) 1.1 W3C Note 08 May 2000
DOM	Document Object Model (DOM) Level 3 Core Specification Version 1.0 W3C Recommendation 07 April 2004 Extended by UI Events W3C Working Draft, 04 August 2016
XMLSchema	W3C XML Schema Definition Language (XSD) 1.1 Part 2: Datatypes W3C Recommendation 5 April 2012 W3C XML Schema Definition Language (XSD) 1.1 Part 1: Structures W3C Recommendation 5 April 2012 XML Schema Part 0: Primer Second Edition W3C Recommendation 28 October 2004 XML Schema Part 1: Structures Second Edition W3C Recommendation 28 October 2004 W3C XML Schema Definition Language (XSD): Component Designators W3C Candidate Recommendation 19 January 2010

Schematron Relax NG	ISO/IEC 19757-3:2020 Technologies de l'information — Langages de définition de schéma de documents (DSDL) — Partie 3: Validation basée sur des règles à l'aide de Schematron (revisions in 2006, 2016) ISO/IEC 19757-2:2008 Technologies de l'information — Langage de définition de schéma de documents (DSDL) — Partie 2: Validation de grammaire orientée courante — RELAX NG (revisions in 2003, 2006, 2008)		
CORBA	Common Object Request Broker Architecture Version: 3.4 Publication Date: February 2021 3.4 February 2021 https://www.omg.org/spec/CORBA/3.4/ 3.3 October 2012 https://www.omg.org/spec/CORBA/3.3/ 3.2 October 2011 https://www.omg.org/spec/CORBA/3.2/ 3.1.1 July 2011 https://www.omg.org/spec/CORBA/3.1.1/ 3.0.3 March 2004 https://www.omg.org/spec/CORBA/3.0.3/ 2.6.1 June 2002 https://www.omg.org/spec/CORBA/2.6.1/ 2.5 September 2001 https://www.omg.org/spec/CORBA/2.5/ 2.4.2 October 2000 https://www.omg.org/spec/CORBA/2.4.2/ 2.3.1 October 1999 https://www.omg.org/spec/CORBA/2.3.1/ 2.2 July 1998 https://www.omg.org/spec/CORBA/2.2/ 2.1 September 1997 https://www.omg.org/spec/CORBA/2.1/ 2.0 February 1997 https://www.omg.org/spec/CORBA/2.0/ 1.2 December 1993 https://www.omg.org/spec/CORBA/1.2/ 1.1 December 1991 https://www.omg.org/spec/CORBA/1.1/ 1.0 August 1991 https://www.omg.org/spec/CORBA/1.0/		
CCM	CORBA Component Model Version: 4.0 Publication Date: mars 2006 4.0 mars 2006 https://www.omg.org/spec/CCM/4.0/ 3.0 mai 2002 https://www.omg.org/spec/CCM/3.0/		
OMA	OMG's Object Management Architecture		
MDA	Object Management Group Model Driven Architecture (MDA) MDA Guide rev. 2.0 OMG Document ormsc/2014-06-01 The MDA is supported by the Unified Modeling Language™ (UML®), the MetaObject Facility™ (MOF™), XML Metadata Interchange™ (XMI®), and the Common Warehouse Metamodel™ (CWM™). For details, view the MDA specifications page		
BPMN	2.0.2 January 2014 https://www.omg.org/spec/BPMN/2.0.2/ 1.2 January 2009 https://www.omg.org/spec/BPMN/1.2/ 1.1 January 2008 https://www.omg.org/spec/BPMN/1.1/ 1.0 March 2007 https://www.omg.org/spec/BPMN/1.0/		
UML	OMG's Unified Modeling Language Version: 2.5.1 Publication Date: December 2017 2.5.1 December 2017 https://www.omg.org/spec/UML/2.5.1/ 2.4.1 July 2011 https://www.omg.org/spec/UML/2.4.1/ 2.3 May 2010 https://www.omg.org/spec/UML/2.3/ 2.2 January 2009 https://www.omg.org/spec/UML/2.2/ 2.1.2 October 2007 https://www.omg.org/spec/UML/2.1.2/ 2.0 July 2005 https://www.omg.org/spec/UML/2.0/ 1.5 March 2003 https://www.omg.org/spec/UML/1.5/ 1.4 September 2001 https://www.omg.org/spec/UML/1.4/ 1.3 February 2000 https://www.omg.org/spec/UML/1.3/ 1.2 July 1999 https://www.omg.org/spec/UML/1.2/ 1.1 December 1997 https://www.omg.org/spec/UML/1.1/ ISO/IEC 19505-2:2012 Information technology — Object Management Group Unified Modeling Language (OMG UML) — Part 2: Superstructure (revised in 2016) ISO/IEC 19505-1:2012 Technologies de l'information — Langage de modélisation unifié OMG (OMG UML) — Partie 1: Infrastructure		
MOF	OMG's Meta Object Facility Version: 2.5.1 Publication Date: octobre 2016 2.5.1 October 2016 https://www.omg.org/spec/MOF/2.5.1/ 2.4.2 April 2014 https://www.omg.org/spec/MOF/2.4.2/ 2.0 January 2006 https://www.omg.org/spec/MOF/2.0/ 1.4 April 2002 https://www.omg.org/spec/MOF/1.4/ ISO/IEC 19502:2005 Information technology — Meta Object Facility (MOF) (revised in 2016)		
XMI	OMG's XML Metadata Interchange Version: 2.5.1 Publication Date: juin 2015 2.5.1 June 2015 https://www.omg.org/spec/XMI/2.5.1/ 2.4.2 March 2014 https://www.omg.org/spec/XMI/2.4.2/ 2.1.1 December 2007 https://www.omg.org/spec/XMI/2.1.1/ 2.0 May 2003 https://www.omg.org/spec/XMI/2.0/ ISO/IEC 19503:2005 Information technology — XML Metadata Interchange (XMI) (revised in 2016)		

CWM	OMG's Common Warehouse Metamodel Version: 1.1 Publication Date: mars 2003
UAF	OMG' Unified Architecture Framework Version: 1.1 Publication Date: April 2020 1.1 April 2020 https://www.omg.org/spec/UAF/1.1/ 1.0 October 2017 https://www.omg.org/spec/UAF/1.0/
SysML	OMG System Modeling Language Version: 1.6 Publication Date: June 2010 1.6 December 2019 https://www.omg.org/spec/SysML/1.6/ 1.5 May 2017 https://www.omg.org/spec/SysML/1.5/ 1.4 August 2015 https://www.omg.org/spec/SysML/1.4/ 1.3 June 2012 https://www.omg.org/spec/SysML/1.3/ 1.2 June 2010 https://www.omg.org/spec/SysML/1.2/ 1.1 November 2008 https://www.omg.org/spec/SysML/1.1/ 1.0 November 2007 https://www.omg.org/spec/SysML/1.0/ The SysML® v2 RFP was issued on December 8, 2017
BPEL	Web Services Business Process Execution Language Version 2.0 OASIS Standard 11 April 2007
ebXML	OASIS Electronic Business using eXtensible Markup Language ebXML Business Process Specification Schema Technical Specification v2.0.4 approved 1/12/2006 ebXML Collaborative Partner Profile Agreement (CPPA) v2 [OASIS 200206] approved 1/11/2002 ebXML Message Service Specification v2.0 [OASIS 200204] approved 1/8/2004 ebXML Messaging Protocol Binding for RegRep Version 1.0 approved 9/3/2021 ebXML Messaging Services v3.0: Part 1, Core Features approved 1/11/2007 ebXML Registry Information Model (RIM) v2.0 [OASIS 200203] approved 1/04/2002 ebXML Registry Information Model (RIM) v3.0 approved 1/05/2005 ebXML Registry Services and Protocols v3.0 approved 1/05/2005 ebXML Registry Services Specification (RS) v2.0 [OASIS 200202] approved 1/04/2002 ebXML RegRep v4.0 approved 26/01/2012 OASIS ebXML Messaging Services 3.0 Conformance Profiles approved 24/4/2010 OASIS ebXML Messaging Services Version 3.0: Part 2, Advanced Features approved 20/05/2011
XACML	eXtensible Access Control Markup Language (XACML) Version 3.0 OASIS Standard 22 January 2013
MQTT	MQ Telemetry Transport - MQTT V3.1 Protocol Specification MQTT and the NIST Cybersecurity Framework Version 1.0 Committee Note 01 28 May 2014 Web site at https://mqtt.org/
oData	OData Version 4.01. Part 1: Protocol OASIS Standard 23 April 2020 OData Version 4.01. Part 2: URL Conventions OASIS Standard 23 April 2020 OData JSON Format Version 4.01 OASIS Standard 11 May 2020 OData Common Schema Definition Language (CSDL) XML Representation Version 4.01 Committee Specification 02 14 November 2019
OSLC	OASIS' Open Services for Lifecycle Collaboration (from OpenService.net) OSLC Core Version 3.0. Part 1: Overview Committee Specification 01 04 April 2017 OSLC Core Version 3.0. Part 2: Discovery Committee Specification 01 04 April 2017 OSLC Core Version 3.0. Part 3: Resource Preview Committee Specification 01 04 April 2017 OSLC Core Version 3.0. Part 4: Delegated Dialogs Committee Specification 01 04 April 2017 Specification URIs OSLC Core Version 3.0. Part 5: Attachments Committee Specification 01 04 April 2017 OSLC Core Version 3.0. Part 6: Resource Shape Committee Specification 01 04 April 2017 OSLC Core Version 3.0. Part 7: Vocabulary Committee Specification 01 04 April 2017
PPS	OASIS Production Planning and Scheduling Production Planning and Scheduling (PPS) Version 1.0 Committee Specification 01 29 September 2011
SOA-RA	OASIS' Reference Architecture Foundation for Service Oriented Architecture Version 1.0 Committee Specification 01 04 December 2012
SAML	Security Assertion Markup Language (SAML) v2.0 Approved: 01 Mar 2005
OpenID	OpenID Connect Core 1.0
UDDI	OASIS UDDI Version 3.0.2 UDDI Spec Technical Committee Draft, Dated 20041019
WSRP	Web Services for Remote Portlets Specification v2.0 Public Review Draft, [7 June 2006]
XPDL	Wfmc XML Process Definition Language

WSRM	<p>Web Services Reliable Messaging TC WS-Reliability 1.1 OASIS Standard, 15 November 2004</p> <p>Schema for Features, Property, and Compositor constructs , v1.1, 2004-June-07</p> <p>Schema for ServiceRefl type v1.1, 2004-June-07</p> <p>Schema for WS-Reliability Protocol Headers for SOAP 1.1 & SOAP 1.2 protocols, v1.1, 2004-Aug-04</p> <p>Schema for WSRM features and properties, v1.1, 2004-Aug-03</p> <p>Errata for WS-Reliability v1.1 – CD 1 (April 2005)</p> <p>Application Notes for WS-Reliability v1.1 – CD 1 (Reliability of Responses - March 2007)</p> <p>Profile Template for WS-Reliability 1.1 Version1.0 CD 01 (April 2007)</p> <p>Deployment Profile of Information Appliances Services for WS-Reliability1.1 Version1.0 CD 01 - April 2007)</p>
BPSIM	Business Process Simulation Specification Document Number WFMC-BPSWG-2016-1 Document Status – Release December 21st, 20
JCR168	Portlet 1.0 SR-000168 Portlet Specification (Final Release) October 7, 2003
JCR286	Portlet 2.0 JSR-000286 Portlet Specification 2.1.0(Close of Maintenance Review: 13 August 2015)
JCR 318	Enterprise Java Beans 3.0 SR-000318 Enterprise JavaBeans 3.1 Final Release Specification for Evaluation 3.1 Eval
JCR 5	SAX Java API for XML Parsing Version 1.0 Final Release
Open-SCA	Service Component Architecture Assembly Model Specification Version 1.1 Committee Specification Draft 09 /Public Review Draft 04 13 September 2011
USDL	Unified Service Description Language (Seems not to be a released specification)
SoaML	Service Oriented Architecture Modeling Language Version:1.0.1Publication Date: mai 2012
EMML	Enterprise Mashup Markup Language by Open Mashup Alliance (created in 2009, seems not active anymore since 2011)
OCCI	<p>Open Cloud Computing Interface, set of open community-lead specifications from 2009 to 2016</p> <p>GFD.221 – Open Cloud Computing Interface – Core describes the formal definition of the OCCI Core Model</p> <p>GFD.222 – OCCI Compute Resource Templates Profile describes a profile for maximum interoperability and best practices</p> <p>GFD.223 – Open Cloud Computing Interface – HTTP Protocol defines how to interact with the OCCI Core Model using the RESTful OCCI API</p> <p>GFD.224 – Open Cloud Computing Interface – Infrastructure contains the definition of the OCCI Infrastructure extension for the IaaS domain. The document defines additional resource types, their attributes and the actions that can be taken on each resource type</p> <p>GFD.226 – Open Cloud Computing Interface – JSON Rendering defines how to interact with RESTful OCCI API (see GFD.223) using a JSON rendering format.</p> <p>GFD.227 – Open Cloud Computing Interface – Platform contains the definition of the OCCI Infrastructure extension for the PaaS domain. The document defines additional resource types, their attributes and the actions that can be taken on each resource type.</p> <p>GFD.228 – Open Cloud Computing Interface – Service Level Agreements contains the definition of the OCCI Infrastructure extension for handling Service Level Agreements. The document defines additional resource types, their attributes and the actions that can be taken on each resource type.</p> <p>GFD.229 – Open Cloud Computing Interface – Text Rendering defines how to interact with RESTful OCCI API (see GFD.223) using a TEXT rendering format for backwards compatible reasons.</p> <p>From Open Grid Forum, An Open Global Forum for Advanced Distributed Computing management</p>
CIMI	<p>DMTF</p> <p>DSP0263 2.0.0 Cloud Infrastructure Management Interface (CIMI) Model and RESTful HTTP-based Protocol An Interface for Managing Cloud Infrastructure”2016-07-27</p> <p>DSP0207 2.0.0 Cloud Infrastructure Management Interface Primer 2016-08-04</p> <p>ISO/IEC 19831:2015 Cloud Infrastructure Management Interface (CIMI) Model and RESTful HTTP-based Protocol — An Interface for Managing Cloud Infrastructure</p>
EC2	de-facto standard Amazon Elastic Compute Cloud (Amazon EC2) is a web service that provides secure, resizable compute capacity in the cloud
CDMI	ISO/IEC 17826:2016 Information technology — Cloud Data Management Interface (CDMI) (Defines interoperability mechanisms for cloud storage systems)
OVF	<p>Open Virtualization Format , published as ISO 17203</p> <p>DSP0243 2.1.1 Open Virtualization Format Specification 27 Aug 2015</p> <p>DSP0265 1.0.0 Profile to Enable Automated Deployment of OVF Packages 27 Jun 2013</p>

Table 17: Details of the standards considered for research on PLM Interoperability

PLM Standardization related organizations

The organisations are those which have been considered as having a particular role concerning the considered standards, being for developing, governing or deploying them within the industry. They are stakeholders and members of the digital business ecosystem to be considered when willing to prepare and build continuous operational PLM interoperability on the expected long term duration.

Organization Acronym, Name and Role	Standards considered for PLM Interoperability (c.f. Table 17 for details)
<p>ISO TC184 SC4 Industrial data PLM related Role: Product & Process data exchange, sharing and long term archiving, including application protocols, framework and set of languages</p>	<p>STEP framework and Application Protocols including Application Activity Model in IDEF0, Application Reference Model and Application Integrated Model with ARM-AIM mapping EXPRESS, EXPRESS-X, SDAI, Part21</p>
<p>CIMDATA: one of the leading independent global strategic management consulting and research authority focused exclusively on PLM and the digital transformation it enables.</p>	<p>Provides reference definition for PLM</p>
<p>ISO TC 184 SC 5 Interoperability, integration, and architectures for enterprise systems and automation applications PLM Related Role: Application protocols for Production System related to enterprise and product definition</p>	<p>IEC 62264:2013 (ISA95) with an activity model (diagram) and an information model</p>
<p>OMG MANTIS Manufacturing Technology and Industrial Systems PLM related Role: Task force delivering standardized interfaces for Distributed Product Data Management and Modeling Systems</p>	<p>PDM Enablers, PLM Services: interface model for distributed systems</p>
<p>OASIS PLCS (2008-2017) Product Life Cycle Support PLM related Role: Provided application protocol dedicated to through life support for product with as major activities 1) Manage information to support a product 2) Generate support solutions 3) Commission support system 4) Provide support.</p>	<p>PLCS: initially ISO 10303 part 239 recommended practices and Reference Data Libraries. Reintegrated in ISO SC4 TC184 since 2017</p>
<p>INCOSE International Council on Systems Engineering created in 1990 PLM Related Role: Life cycle of systems of interest and supporting systems</p>	<p>System Engineering Handbook Contribution on various standards - ISO 15288, SysML</p>
<p>ASD STAN Aeronautic, Space and Defence STANdardization created in 1970 PLM related Role: European aerospace industry Integrated Logistic Support standards</p>	<p>Standards (various models) for Integrated Logistic Systems: S1000D, S2000, S3000L, S4000P, S5000F, S6000T, SX001G, SX000i, SX002D</p>
<p>AIA Aerospace Industries Association, an American trade association representing manufacturers and suppliers of aeronautic, space and defence PLM related Role: The AIA Business Technology Interoperability Committee (BTIC) establishes clear policy regarding common information exchange practices</p>	
<p>ProSTEP German globally active industry driven independent association with 180 member companies from industry, IT and research. Creation in 1993 PLM related Role: Focuses on the digital transformation in product creation and production, through Implementor Forum and standard development support</p>	<p>ReqIF, JT and STEP benchmarks, AP242 Maintenance, Long Term Archiving ECO ECM</p>
<p>NIST US National Institute of Standards and Technology, founded in 1901 PLM related Role: Interoperability testing, white paper, research, support of industry</p>	<p>NIST-SP 500-291 The NIST Cloud Roadmap SP 800-145 The NIST Definition of Cloud Computing NIST Big Data Interoperability Framework</p>
<p>AFNET Association Francophone des utilisateurs du Net. Fondé en 1982 PLM related role: Implementor forum for STEP PLM Support Industry for standardization and usage of standards</p>	<p>Support for development and implementation testing of AP242, AP239, JT</p>
<p>ASD SSG Strategic Standardization Group - Created in 2009 Role: Strategic Governance of PLM standards for ASD in Europe</p>	<p>Radar Chart for surveyed, promoted or to be developed standards for PLM inside the ecosystem</p>

Phenix PLM Harmonization for Enhanced Innovation and Excellence (2007-2014) PLM related Role: Strategic Governance of PLM standards within the Airbus Group in alignment with ASD SSG.	
ASCM Association for Supply Chain Management, created in 2019 - From APICS (1957) which merged with the Supply Chain Council (1996-2014) PLM related Role: production and dissemination of standards for supply chain	SCOR
Open Group , a global consortium that seeks to "enable the achievement of business objectives" by developing "open, vendor-neutral technology standards and certifications, created in 1989 PLM related Role: standards for governance and planning of enterprise transformation	ArchiMate TOGAF
For Information and Communication technologies	
W3C World Wide Web Consortium, an International community where Member organizations, a full-time staff, and the public work together to develop Web standards, created in 1994 PLM Related Role: producer of underlying technologies used for many PLM standards, in particular Linked Data , Semantic Web , Web Services , Electronic Documents.	OWL, RDF, SKOS, SPARQL, IRI, RDF Schema, JSON LD, SHACL WSDL, SOAP XML , DOM , XML Schema, Schematron, Relax NG
OMG Object Management Group, an international, open membership, not-for-profit technology standards consortium, created in 1989 PLM related Role: Production of specifications related to Architecture Framework, Middleware, Modeling Languages and Model Driven Architecture	CORBA, CCM, OMA, MDA, BPMN, UML, SysML,UAF
OPC Foundation Open Platform Communication Foundation, created in 1999 PLM related Role: Open Platform used for Virtual Manufacturing	OPC-UA
OASIS Organization for the Advancement of Structured Information Standards created in 1993 PLM Related Role: Definition of various eBusiness, Manufacturing and Product Lifecycle Management standards	BPML, ebXML, XACML, MQTT, oData, OSLC, PPS SOA-RA, SAML, TOSCA, UDDI, WSRP
Wfmc Workflow Management Coalition (1993-2019) PLM related Role: Standardization of Workflow System model of reference and protocols for exchange , sharing and simulation	WSRM, XPD, BPSIM
JCP Java Community Process PLM related Role: specifications for the Java Platform	JCR 168 (Portlet 1.0), JCR 286 (Portlet 2.0), JCR 220 (Enterprise JavaBeans 3.0), JCR 5 (SAX)
DMTF Distributed Management Task Force creates open manageability standards spanning diverse emerging and traditional IT infrastructures including cloud, virtualization, network, servers and storage PLM related Role: IT infrastructure for PLM over the cloud	CIMI, OVF
CIMDATA present itself as the leading independent global strategic management consulting and research authority focused exclusively on PLM and the digital transformation it enables.	PLM glossary
GALIA Groupement pour l'amélioration des liaisons dans l'industrie automobile. Au-delà de la mise à disposition de standards et de l'organisation de formations, GALIA propose d'autres services : audit et conseil, homologation de solutions	Livre Blanc sur le standard d'échanges de données mesure (version française) White Paper on the measurement data exchange standard (English version)
AIDIMA enjoys a great prestige to national and international level, so much in Europe as in the remainder of the world, especially United States, Canada, Japan and Latin America. It forms part of the Commission of Technology and Innovation of the European Union of the Furniture (UEA), and heads various European projects of innovation, also as diverse European working parties of normalization. AIDIMA is member founder of the European Association of Technological Institutes of the Furniture (EURIFI), Company that has presided	Contributor to STEP AP236, also called FUNSTEP

Table 18: PLM Interoperability related Standardization Organizations