# RECONFIGURABLE AND UPDATABLE PRODUCT-SERVICE SYSTEMS: THE PATH FOR SUSTAINABILITY AND PERSONALIZATION

Maria Marques
UNINOVA – Instituto de Desenvolvimento de Novas Tecnologias
FCT Campus
2829-516 Caparica, Portugal
mcm@uninova.pt

Carlos Agostinho
UNINOVA – Instituto de Desenvolvimento de Novas Tecnologias
FCT Campus
2829-516 Caparica, Portugal
ca@uninova.pt

Greg Zacharewicz
University Bordeaux
CNRS UMR 5218, IMS
F 33405 Talence Cedex, France
gregory.zacharewicz@u-bordeaux.fr

Ricardo Jardim-Goncalves
DEE/FCT
Universidade Nova de Lisboa
FCT Campus
2829-516 Caparica, Portugal
rg@fct.unl.pt

**ABSTRACT**

Driven by the market evolution from mass- production to mass-customization, servitization gained space as a way of answering consumers requirements while enabling the possibility of extending products life-cycle and reducing production costs and cope with growing environmental and sustainability concerns. This paper presents a prospective methodological approach for the development of reconfigurable and updatable product-service-systems identifying the main missing issues on available methodologies and tools. The methodology proposed includes the development of a PSS ontology enriched with the knowledge models needed to represent reconfiguration and updatability concepts. This methodology will supply models that will be simulated to consider the dynamicity of the proposed PSS in order to evaluate and support decision. Moreover, the insight coming from Social Sciences and Humanities is proposed as a critical cornerstone for the development of a reliable approach.

**Keywords:** Product-Service Systems, PSS Ontology, PSS User requirements, PSS business models, PSS Modeling and Simulation.

## 1 INTRODUCTION

Although some years have passed since the term servitization was coined by (Vandermerwe and Rada 1988) the notion of "adding value by adding services" is nowadays becoming almost business-as-usual

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for many companies. Driven by the market evolution from mass- production to mass-customization, servitization gained space as a way of answering consumers requirements while enabling the possibility of extending products life-cycle and reducing production costs. The possibilities for the development are almost endless and their market share as been growing especially among young generations for which consumption motivations are much more linked to the experience of usage of the product than to its ownership.

More recently, the demand for product customization together with the growing environmental and sustainability concerns demand for reconfigurable and updatable PSS. The main objective is to offer a personalized experience that satisfies customer requests and expectations while decreasing environmental impact and costs. This way PSS that have reconfigurable and/or updatable capabilities offer a wide range of opportunities from business point of view. These scenarios can gain from being compared an evaluated in simulations.

This paper starts by an analysis of existing models and methods for the design of product-service systems. Then, a brief overview of the state of practice and market is provided. It also sheds some light on the challenges that need to be addressed regarding reconfigurability and updatability of PSS to achieve sustainability and customization objectives.

## 2 SIMULATION TO SUPPORT PSS DESIGN AND DEVELOPMENT

At design step of PSS, modelling with formatted methods such as blueprinting can secure and make better understandable and repeatable the specification of the customer needs in term of PSS. Even so, a crucial question raises about the behaviour of such proposition regarding dynamic aspects. The validation of PSS scenarios would gain at being anticipated thanks to simulation.

Previous works have proposed PSS models to be simulated in different services scenario to evaluate and compare alternative PSSs from environmental and economic perspective such as in (H. Komoto, et al. 2005) and (Alix e Zacharewicz 2012). This evaluation of PSS scenarios, before development, was intended to validate concepts and to supply quantified arguments to convince about the interest of selected PSS for different stakeholders. Focusing on (Alix e Zacharewicz 2012) works, a service-based modelling framework with a graphical language based on G-DEVS discrete event formalism and running distributed simulation cases was proposed. The simulation of heterogeneous PSS behavioral components (including service and product production system, client behavior, etc.) was addressing interoperability by complying to established HLA standard (IEEE 2002) for distributed simulation. The simulation was giving indications to decision makers in order to choose between several PSS design scenarios the best for its realization.

Nevertheless, in the studied works, the behavior of the customer and actors remains one frequent missing piece, it was in the better case considered as simplified human behavior to interact with the simulation loop. It can be interesting to integrate more detailed customer habits but not only at the individual behavior level also considering the social networks impact. Also interoperability solving is mainly syntactic in the previous works. The support of ontologies would extend these works. Then the process that describes the steps to generate the PSS is also mostly static i.e. not able to be modified during run time. It appears interesting to consider potential reconfiguration of the process at run time. Lastly, it can be interesting to shift from the conceptual model to the simulation model thanks to model driven approach.

### 2.1 Model-driven approach

In the objective of updatable and reconfigurable functional models, a model driven approach can be considered to separate between the business and technical point of view in product-service systems design. MDSEA (Ducq et al., 2014) i.e. Model Driven Service Engineering Architecture, is a framework inspired from MDA (MDA, 2008) /MDI (Bourey et al., 2007) (Model Driven Architecture/ Model Driven Interoperability) to enable the definition of service system modelling based on three abstraction levels: business specific - BSM, technology independent – TIM - and technology specific - TSM, as well as the dedicated modelling languages at each level. Like MDA, it defines three layers of modeling to specify the PSS goals following a top-down approach, and extends MDA proposing which modeling language to be used at each layer. The MDI approach is more detailed but focuses only on IT aspects, while MDSEA supports the need for modeling the three types of components (IT, Organization/Human and Physical Means) which together form a "service system". In this sense, MDSEA can be considered as an adaptation of MDA/MDI approaches to the engineering context of product-related services in virtual enterprise environment.

With MDSEA, behaviour of PSS is expressed at business specific level using Extended Actigram Star (EA*) language, a business process modelling language that facilitates modeling business processes inside the enterprise and offering a sequential view of the PSS. Behaviour simulation is a complementary feature of model-driven engineering that complements MDSEA and enables early testing of the correct development of the PSS at both technology independent and technology specific levels. In this direction, the authors have developed previous work to transform process models into DEVS models, elected for its capacity to describe behaviour with discrete events, explicit states and time life variables (Bazoun et al., 2014).

## 3 RECONFIGURABLE AND UPDATABLE PRODUCT-SERVICE SYSTEMS

Product-services are becoming increasingly complex and diverse with advances being boosted by technology and customers' needs. Also, issues like sustainability and eco-friendliness are becoming more and more important, motivated both by consumers desire for a greener approach and by regulatory aspects introduced by governments around the world. Thus, to deal with rapid product-service obsolescence or inadequateness there is the need for changeable product-services.

Reconfigurable and updatable product-services (also known as changeable product-services), are those whose configurations can be changed, updated, or modified, with or without external influence after the product-service has been deployed. Typically, reconfigurable systems are designed to maintain a high level of performance by changing their configuration to meet multiple functional requirements or a change in operating conditions (Olewnik et al., 2004). A reconfigurable system is one in which the configurations can be changed repeatedly and reversibly.

Product-service reconfigurability is, in many cases, achieved by integrating multiple modes into the product (that are activated by the selection of specific functions and/or technologies in operation) or by developing new services (Liu, 2015). Motivation for this type of system comes from the inherent tradeoffs incorporated in an effort to resolve issues when involving conflicting objectives. In what regards updatability, modularity provides an effective means toward achieving flexibility, since modules can be replaced and updated. A truly modular architecture is one in which each module of the overall system accomplishes one specific function and the interfaces are well defined (Ulrich, 1995), hence, updatability is achieved by introducing the capability of component replacement and/or service adaptation or inclusion of new functionalities. Thus, overall reconfigurability and updatability requires full interoperability of the developed product-service. Yet, conceptual design, which aims to specify the principal solution from a design problem (Pahl et al. 2007), remains critical and difficult (Nagel et al. 2008). The development of updatable and reconfigurable functional models, which efficiently describes how the functional modes can be reconfigured and how components can be updated, remains a critical challenge to be solved with direct impact in product-service architecture.

### 3.1 PSS Ontology

A reference model is, by definition, "an abstract framework, based on unifying concepts, independent from standards and technologies that aims to provide common semantics across different implementations (OASIS, 2014)" within a specific domain. The main aim of developing reference models in industrial production applications consists in establishing a shared description of the industrial domains. This allows enabling the integrated description of complex industrial systems providing a common and generalized base of concepts and definitions. Appropriate semantic enabled systems may overcome classical vocabulary problems related to geographical distance or even to practices that led to the maintenance or creation of specific lexicon or knowledge related to a plant.

Big efforts towards standardization have happened in the recent past regarding models and ontologies for the enterprise (e.g. IDEFØ – released as a standard for Function Modeling in FIPS Publication 183 (NIST, 1993), PERA (Bernus and Nemes, 1996) – ANSI/ISO95, CIM-OSA (Fadel, 1994) – ISO19439). Also, approaches like GRAI (Chen and Doumeingts, 1996) and GIM (GRAI integrated Methodology) (Chen and Doumeingts, 1997) were developed to represent and analyze the operation of all or part of a production activity. Thus, semantic models or ontologies related to specific targets can be implemented with reasonable efforts with respect to a fully generalized description of the generic industrial domain. The key objective consists in generalizing, as much as possible, the envisaged agents and services in order to ensure transferability of the reference model, establishing the basis for the development of the reference ontology from existent knowledge sources with the strict cooperation between plant people and knowledge engineers. Inference mechanisms can be applied to derive implicit knowledge, for example for optimizing and decision support tasks where a pure algorithmic approach is practically impossible. The development of ontology mappings and inference rules, linked with the model objects, enable the realization of seamless access to the description of integrated production process sequence and product tracking. The use of examples, data, rules and related information will contribute for building a reliable and refined semantic model that can, afterwards, be tested with the help of prototyping agents devoted to this purpose.

The collaborative PSS design requires use of a number of tools. The bonding element between the classical engineering tools, PDM/PLM, social software, etc., could be a common ontology for PSS. Research on PSS has been carried out for many years and in various disciplines; however, even a consolidated set of terminologies has not been established. A common understanding of PSS is arising, but a common ontology has not been released beyond re-search schools. There were several attempts to develop and use PSS ontologies (e.g. (Rese, et al. 2012), (Wang, et al. 2011), (Annamalai Vasantha, et al. 2011), however, none of these attempts fulfil the requirements to serve as semantic bonding element and their application in industrial environment is not evident.

Thus, the PSS ontology to realize the PSS environment and interconnect various software approaches and tools is still missing. As a basis for integrating the various disciplines along the entire PSS lifecycle, the different engineering domains and tools, an overall PSS-ontology representing common technical glossary and describing the interdependencies of all related components is needed.

### 3.2 Business models for product-service systems

A product-service is then, as already previously mentioned, a shift in business strategy from a product-oriented to a service oriented focus, where instead of the product itself, the activity, its utility and performance associated with the use of the product are considered to be of more value to the customer (Tan, McAloone and Hagelskjaer, 2009). Thus, a consistent collection of data and knowledge, and its appropriate structuring so that it is used and useful, is fundamental to develop knowledge-based product-services that focus on meeting customers' needs by the “use” instead of the “ownership” of a product. Also important, and dependent on the knowledge acquired, is to define how business models will be structured. With this in mind three approaches can be:

- the ownership structure,
- the mode of producer/user interaction, and
- the reason why customers pay.

This classification divides product-services into product-, use-, and result-oriented PSS (Tukker 2004). Under the first category falls the traditional selling of a product accompanied by a maintenance or repair service. In use-oriented product-services, the customer pays only for the use of the product without having ownership, while in result-oriented category customer pays only for the provision of agreed results, and he may or may not have ownership. Most authors see product-services concept as a competitive strategy with increased value based on utilization rather than ownership, directly connected with the purposes of customer satisfaction and achieving sustainability. Yet, significant cultural and corporate challenges with respect to consumer, organization, and academia still exist. Particularly, for the consumer's side, cultural shift is necessary to place value on fulfillment of a need instead of the ownership of a product ((O. Mont 2002), (Manzini and Vezzoli, 2003)), especially in more traditional society models.

### 3.3 Path for Reconfigurable and updatable PSS

Taking into consideration the needs recognized in the above sections it is possible to identify the set of missing issues that still need to be covered for an effective development of reconfigurable and updatable PSS, namely:

- Establishment of PSS-ontology representing common technical glossary and describing the interdependencies of all related components;
- Definition of updatable and reconfigurable functional models, which efficiently describes how the functional modes can be reconfigured and how components can be updated and simulated;
- Social Sciences and Humanities approaches to smooth cultural and corporate challenges with respect to consumer, organization, and academia.

To achieve these challenging objectives authors suggest an approach starting from the requirements collected and prioritized industries and customers in regard to Product-Service Systems (PSS), including : personalization, reconfiguration and reuse of products and services, security, infrastructure (public or private), data collection and use of legacy software aspects. This study will lead to the definition of the a PSS Ontology and framework that fulfills the key dimensions and concepts and covers all the relevant actors. For providing this level of PSS, it is needed to have access to adequate knowledge about the end-user's process as well as a deepened knowledge about the product and the processes (e.g. related risks, cultural background of the customer due to the intensified customer relationship, etc.) including all lifecycle phases (e.g. lifecycle costs). To this end, explicit knowledge (explanations about products and processes), implicit knowledge (understanding products and processes) and tacit knowledge ("intuition" about products and processes) have to be identified.

On the top of the Ontology there is the need to develop the necessary knowledge-based models to represent product-services and their components, taking into consideration aspects such as interoperability and exchangeability to support reconfigurability and updatability. This work must include the selection of appropriate methods and techniques to model updatable and reconfigurable Product-Service System knowledge and the best ways to store it for re-use. The identification of the knowledge needed to evolve from traditional technical products to reconfigurable and updatable product-services is a key issue. Moreover, structuring this knowledge in an appropriate manner, to support the decision process when designing new reconfigurable and updatable PSS is also critical for the success of the approach. The use of simulation methods to support this step, enabling the test of several PSS different configurations, is of extreme importance.

Finally, the work of smoothing SSH barriers is directly linked with appropriate user requirements elicitation. This should be done based on a user-centred design approach, joining efforts between the stakeholders (end-users who are going to benefit from the PSS developed) and the technical domain experts. The direct involvement of the end users in the analysis, being active part of it and expressing directly their point of view through dedicated activities (e.g.: questionnaires, interviews, brainstorming sessions) is a key part of this work. In addition, also workshop with stakeholders including e.g. ergonomists, human factor specialists, medical staff (in case of medical applications), etc., need to be carried out. The inclusion of these experts, which are generally excluded from the design process of products, will ensure that the technological progress is actually accessible to the targeted end users. All the collected insights will result in a framework of the possible users determinants (e.g.: needs, opportunities and expectations).

Together with the work on user requirements identification there is the need to support companies in making a significant change in the system of gaining profit. Typically, companies resist in adopting the PSS concept mainly for three reasons: (i) limited experience in pricing such an offering, (ii) fear of absorbing risks that were previously assumed by customers, and (iii) lack of experience in structuring the required knowledge. The support from experts in business model development and technical staff is fundamental from a mind shift in traditional business making. The combination of the resultant user requirements with the vision of the company for the PSS is of extreme importance to select the most appropriate business model among the possible ones.

These basic elements should support the design and development of product-service systems using incremental innovation as a basic concept. To this end, the tools should focus on individual product-service components (designed to be modular and customizable). And include elements for component linking and for component replacement or adjustments.

Then these aspects will be integrated in simulation model to observe at run time the behavior of the PSS model in order to support decision regarding different PSS solutions. The individual product-service components will be coupled to form the PSS. Each component will have its own behavior then coupled with others to form a structural model for the simulation such as possible in G-DEVS with atomic and coupled models. Also the social organizations can be considered as complex networks of actors. They can be one part of the model, called during the PSS process realization at simulation time.

To support the development of reconfigurable and updatable PSS there is the need for appropriate tools. These tools should support the development of reconfigurable and updatable product-services containing the basic elements to enable reconfigurability and updatability.

Figure 1 illustrates the proposed approach starting from the ontology building (based on requirements, processes, products and components) and ending with the simulation results that will be used to chose the best design and subsequent fine tuning. The identified requirements, the defined business models and strategy and the production processes will be used to build relevant knowledge models that will feed BSM within MDSEA approach, as explained in section 2. Based on these inputs it is possible to define the BSM Service model (see Figure 1) which will be mapped into TIM and used as baseline to build three different technology independent models covering three different perspectives: IT systems, Organization/human aspects and Physical means involved within the production of the PSS.

Each TIM model will be mapped into a specific TSM model also representing the three different perspectives. Both TIM and TSM models will be used to build a Behaviour DEVS Model capable of simulate and test the correctness of the development of the PSS at both technology independent and technology specific levels.

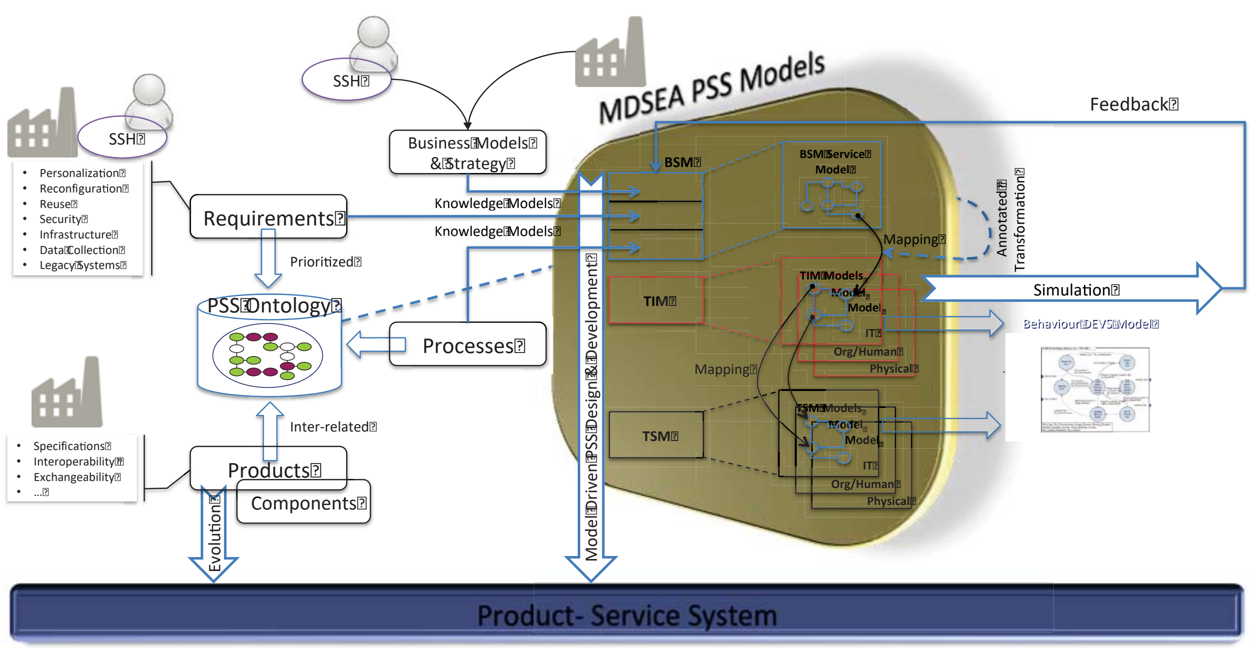


Figure 1: Model-driven approach for reconfigurable and updatable PSS.

In case the results of the simulation are not compliant with the requirements, the deviations should be analyzed and in order to define a new BSM capable of covering all the needs. This process is repeated until a satisfactory result is obtained enabling the development of a reconfigurable and updatable PSS.

### 3.4 Furniture sector: a case study for the development of reconfigurable and updatable PSS

European furniture industry constitutes a complex SMEs and Les network, which has been actively contributing not only to the sustainability of the sector but also to the furniture value-chain in a holistic point of view. Within this sector the main industrial challenges are related with the pursuit of innovation and quick market responses. Moreover, the overall ageing tendencies across Europe call for a careful consideration of specific target groups such as elderly, disabled or special needs people in terms of customization, reconfiguration and re-use of furniture,

Furniture sector plays a central role in our daily life, promptly incorporating the essence of identified requirements of target groups such as elderly, disabled or special needs people and contributing to improve users' health and safety as well. rapid deployment of the modularity, reconfiguration and re-use of personalized consumer/customized PSS is the main objective. As previously mentioned the insight from Social Sciences and Humanities, providing expertise in terms of individual requirements and safety requisites of the geriatric sector, ensure a structured approach for the identification and fulfillment of the requirements of the target group of people with special needs.

Thus, the first step is to obtain the subjective feedbacks and the specific requirements of the targeted end-users, in order to validate adequately the methods and tools. Using real scenario conditions, it is possible to quantify the usability and ergonomic characteristics of the prototypes developed. Both qualitative and quantitative measures allow the improvement and accuracy at the different stages of development. Feedback obtained will be collected to improve the usability and ergonomic characteristics, to be considered as an input in the further developments.

Moreover, the methodologies and techniques will be assessed in the development of new innovative products and new reconfiguration services along the whole consumer/customised products value chain and during its overall life cycle, including the aftersales stage.

The simulation is proposed before the implementation of the PSS. Here it permits to observe the behavior of these PSS models coupled with their environments. The "usage" of PSS is thus a crucial consideration in order to integrate the behavior of the users in the simulation models. To obtain more real situation of PSS use, it appears as an evidence that to simulate scenario with the human in the loop is only one model. This is done in the aim of observing the proper/or not synchronization of PSS users' needs with the delivery of services coming from the PSS. The result can lead to define proper orchestration models where the conversation of PSS and human will be described and tested. Then it will be stored as a partition to guide the implementation including defining the human machine interfaces.

## 4 CONCLUSIONS

This paper proposes a methodological approach for the design and development of reconfigurable and updatable PSS taking into consideration aspects such as ontology, knowledge models and personalized user requirements and industrial business objectives.

Authors identify the development of a generic ontology for PSS that can be enriched with knowledge models for reconfigurable and updatable PSS as a fundamental cornerstone in building the entire methodology.

Moreover, the analysis provided enables to conclude that the main barrier to the adoption of a PSS is related with existence of significant cultural and corporate challenges with respect to consumer, organization, and academia. Particularly, for the consumer's side, cultural shift is necessary to place value on fulfillment of a need instead of the ownership of a product. In the organization's side, a move from 'product thinking' to 'system thinking', and breakdown of the 'business as usual'. PSS requires manufacturers and service providers to extend their involvement and responsibility, and also the early involvement of professional customers and end-users in order to achieve a solution that responds to customer wants and needs. Again to prove the interest of PSS, the simulation is proposed to play scenario that will mix PSS and human interactions.

This paper proposes an appropriate SSH model-driven approach, based on MDSEA, to deal with these challenges focusing on the case provided by the furniture sector (a sector recognized as crucial in European manufacturing landscape). Authors intend to continue the work here presented as significant developments need to be addressed in order to test the methodology proposed in the context of the selected case study.

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## AUTHOR BIOGRAPHIES

**MARIA MARQUES**, PhD. Has completed her graduation in 2001 in Electrical and Computers Engineering at Faculty of Science and Technology of the Universidade Nova de Lisboa (FCT/UNL). She developed her Master of Science in the area of simulation methodologies to control distributed systems of road traffic management (FCT/UNL, 2005). In 2012 she obtained her PhD degree by FCT/UNL in the area of decision support systems for life-cycle management of industrial plants. She has published more than 20 papers in international peer review journals and conferences. Since 2003 she has been working as a researcher with strong coordination responsibilities in several international research projects at UNINOVA. Her main focus is in the area of decision in industrial environments, developing work on the topics of intelligent decision support systems, reasoning methods and expert systems. Her email address is mcm@uninova.pt.

**CARLOS AGOSTINHO,** PhD**,** is senior Researcher at UNINOVA center, he has an MsC in Computer Science and holds a PhD in the area of industrial information systems by the Faculty of Science and Technology of the NOVA University of Lisbon (FCT/UNL). He is deeply involved in the areas of Product and Process Meta-modeling, Interoperability and Harmonization using Standards since his participation in projects like CEN/AIDIMA/2002/004 funSTEP AP-DIS and IST-2001-52224 SMART-fm. He is quite experienced in research and coordination activities due to his work in several national and international research and development projects in UNINOVA since 2001, where he developed skills in the areas of model-based and semantic interoperability applying MDA/MDI technologies. Currently is research is targeting dynamic environments and how principles from complex systems can contribute towards a self-sustainable interoperability. His email address is ca@uninova.pt.

**GREGORY ZACHAREWICZ,** Eng., PhD, Habilitated, is Associate Professor at the University of Bordeaux. His research interests include Discrete Event Modelling (e.g. DEVS, G-DEVS), Distributed Simulation, Distributed Synchronization Algorithms, HLA, MDA, Short lived Ontologies, ERP, BPMN, and Workflow. He recently focused on Enterprise and Social Organizations M&S and Interoperability. He will be the General Chair of ACM SCS SpringSim 2018 and he is an IPC member and Chair in several M&S Conferences (SpringSim, SummerSim, WinterSim, I3M, etc.) and editorial board member of SCS Simulation journal. He is involved in several French, European and Transatlantic M&S related projects. His email address is gregory.zacharewicz@u-bordeaux.fr.

**RICARDO GONCALVES,** PhD**.** Ricardo Jardim-Goncalves holds a PhD degree and received his habilitation (Agregação) in Industrial Information Systems by the New University of Lisbon (UNL). He is an Associate Professor at the New University of Lisbon, Faculty of Sciences and Technology, and a Senior Researcher at UNINOVA – Instituto de Desenvolvimento de Novas Tecnologia. He has graduated in

Computer Science, with MSc in Operational Research and Systems Engineering. His research activities have been focused on Interoperability of Complex Systems. He has been researching in European Commission funded projects during the last 20 years, with more than 150 papers published in conferences, journals and books. He is principal researcher in GRIS (GRupo para a investigacão em Interoperabilidade de Sistemas; Group for Research in Interoperability of Systems) at UNINOVA (Instituto para o Desenvolvimento de Novas Tecnologias), CTS (Centro para as Tecnologias e Sistemas). He is project leader in ISO TC184/SC4. His email address is rg@fct.unl.pt.