



**HAL**  
open science

## Towards interoperability properties for tooling a software bus for energy efficiency

Alexis Aubry, Hervé Panetto

► **To cite this version:**

Alexis Aubry, Hervé Panetto. Towards interoperability properties for tooling a software bus for energy efficiency. 4th International Conference on Information Society and Technology, ICIST 2014, Mar 2014, Kopaonik, Serbia. pp.285-291. hal-01015621

**HAL Id: hal-01015621**

**<https://hal.science/hal-01015621>**

Submitted on 26 Jun 2014

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Towards interoperability properties for tooling a software bus for energy efficiency

Alexis Aubry<sup>\*,\*\*</sup>, Hervé Panetto<sup>\*,\*\*</sup>

<sup>\*</sup> CNRS, CRAN UMR 7039, France

<sup>\*\*</sup> Université de Lorraine, CRAN UMR 7039, Boulevard des Aiguillettes  
{alexis.aubry; herve.panetto}@univ-lorraine.fr

**Abstract**—This paper proposes a draft architecture for a software bus that deals with the interoperability challenges when having to interconnect, in a software platform, some software components/tools/methods/approaches for optimising energy efficiency. This platform will be developed in the framework of the French ANR Plate-Form(E)3 project. After having highlighted the challenging interoperability issues that are inherent to this type of platform, we are analysing a state-of-the-art for identifying the candidate technologies. An architecture based on one technology candidate for solving the basic interoperability challenge is then proposed.

## I. INTRODUCTION

The current context of increasing scarcity of fossil fuels and the associated price volatility strongly encourage the society for energy saving. Although significant efforts have been made in the industrial sector since 1973, according to estimation from the French institute CEREN<sup>1</sup>, the potential energy power saving could be up to 12 Mtoe<sup>2</sup> (about 23% of energy consumption in the industrial sector). These savings could be made on the following basis:

- About 2/3 of the savings can be made on plants using local optimisation approaches, conventional or experimental technologies.
- The remaining 1/3 of the savings can be achieved by conducting cross-cutting actions, using technology for recovery and transport of residual energy.

The local optimisation approach (process/plant scale) is already extensively studied, while the global optimisation approach (territorial area) is not addressed in the literature. In fact, no tool exists that is capable to achieve a cross-scale optimisation of energy and environmental efficiency. The aim of Plate-Form(E)3<sup>3</sup> project is to address this problem. The ANR Plate-form(E)3 (PFE3) project: Digital Platform for computation and optimisation of Energy and Environmental Efficiency at different scales for industry (component/process/plant/territory) must contribute to the optimisation of energy and environmental efficiency of industry and territories. Plate-form(E)3 will be realized by a prototype for assessing the impact of new technolo-

gies on a large scale. This framework will propose the integration of any energy sources and sinks across the territory, seeking potential interconnections between industries (territory scale), to optimise process efficiency (plant/process scale) and to facilitate the optimal design of new technologies (component level). The platform will interconnect some existing tools (open source or proprietary) implementing different specialised methods, models and algorithms. The issue of interoperability is thus important.

The goal of this paper is to present the analysis and synthesis of the state-of-the-art, relevant for resolving the different interoperability issues of the future Plate-form(E)3 system – prototype.

The first part of this paper is related directly to the definition of the interoperability problems in PFE3. Hence, it presents theoretical foundations for interoperability, the motivation for that work, scenarios and use cases that form the Plate-form(E)3 system architecture and its environment. The second part analyses the state-of-the-art, namely candidate technologies, models, tools, resources and frameworks for the resolution of the identified interoperability problems. Different types of candidate technologies are presented. Each of the technology analysis will consist of two sections. The first section presents the technology in detail. The second section analyses the relevance of the technology for PFE3. Finally a discussion is proposed for presenting an architecture based on the use of a standard for process simulation software (namely CAPE-OPEN) that is considered as one of the candidates for dealing with our interoperability issues.

## II. INTEROPERABILITY AND THE ASSOCIATED PROBLEMS IN PFE3

### A. Theoretical foundations for interoperability

IEEE defines interoperability as *the ability of two or more systems or components to exchange information and to use the information that has been exchanged* [1]. Hence, the diversity, heterogeneity, and autonomy of software components, application solutions and business processes, must be considered as potential sources of non-interoperability. In contrast to system integration, which basically deals with formats, protocols and processes of information exchange, the objective of interoperability is to have two systems invoking each other's functions or exchanging information with the consideration that they are not aware of each other's internal workings.

Furthermore, interoperability aims at correct and complete reasoning on the meaning of the information which

<sup>1</sup> CEREN, French Centre for Studies and Economic Research on energy

<sup>2</sup> Mtoe = Million Tonnes of Oil Equivalent

<sup>3</sup> [http://www.agence-nationale-recherche.fr/en/anr-funded-project/?tx\\_lwmsuivibilan\\_pi2\[CODE\]=ANR-12-SEED-0002](http://www.agence-nationale-recherche.fr/en/anr-funded-project/?tx_lwmsuivibilan_pi2[CODE]=ANR-12-SEED-0002)

is exchanged between two systems. Hence, it is sometimes called “semantic interoperability”. Main tools for the implementation of the semantic interoperability are ontologies, languages for ontologies’ representation, inference tools (engines) and semantic applications.

Semantic interoperability of systems means that the precise meaning of the exchanged information is uniquely interpreted by any system not initially developed for the purpose of this interoperation. A formal definition of semantic interoperability has been proposed in [2].

### B. Interoperability problems in PFE3

The goal of the Plate-Form(E)3 project is to provide a first prototype of a software platform in which some existing tools/methods/approaches have to be connected to solve dedicated use cases. This platform may then be considered as a software bus where any used application can connect. These use cases concern two types of scenario at two extreme scales.

The first type considers the process scale; the objective of the future interoperability solution at this scale is to facilitate engineering of a new component in the single process, to improve the general process performance, e.g. concerning the energy costs. In this first scenario, interoperability concerns the efficient (optimised) interconnection of unit operations (i.e. basic step in a process such as separation, crystallization, evaporation, filtration...) within a single process. Beside material flows, these interconnections may also need to consider flows of information, needed to optimise the process execution, taking into account the cost of energy.

The second type is related to the territory scale; the objective at this scale is to facilitate integrated energy management with a final goal to optimise the energy consumption in the specific territory. This will be enabled by the collaboration of the different plants in one defined territory. Two plants could collaborate to exchange the resources that are considered as excessive or even as a waste in one company, but could be used as energy source in another one (e.g. hot water, steam, heat, pressurized fluid, ..). In this second scenario, interoperability may also concern both material and information flows and their sustainable reuse by different facilities, inside a territory.

Thus, the tools that must be interconnected in Plate-Form(E)3 do not operate at the same scale, with the same business knowledge and on the same models but they must always be able to share information that they produce, ensuring the overall coherency of the whole. That means that these tools must be interoperable.

The above context can thus be defined through three generic and general scenarios that must be realised within two classical interoperability levels (technical and conceptual) [3]. Some scientific problems then arise when intersecting those scenarios with the interoperability levels.

So, we propose here to define these scientific problems, based on the consideration of the use cases at two levels of abstraction. First level considers the most generic interoperability scenarios. The second level takes into account the conceptual architecture of Plate-form(E)3.

#### 1) Generic scenarios and scientific problems

In order to highlight the underlying problems in setting interoperation between the specialised tools for modelling physical systems and their optimisation, it is important to

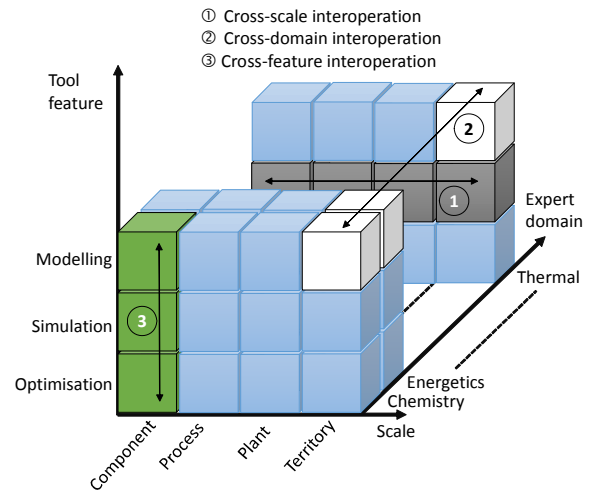


Figure 1. Plate-Form(E)3 interoperation framework[4]

identify the generic scenarios that realize this interoperation.

We have identified the following generic scenarios [4]: cross-scale interoperation, cross-domain interoperation, cross-feature interoperation (see Figure 1). Also, some first general assumptions on the possible approaches to address the problems at this generic level are given.

- Cross-scale interoperation: the different scales concern the component (optimal design of new technologies), the process/plant (optimisation for efficient energy management) and the territory (optimisation of potential interconnections between industries). The tools that will potentially be connected with the platform will be used at these different scales, producing models that need to be exchanged compromising the overall performance.
- Cross-domain interoperation: for modelling/simulating/optimising the physical systems through the platform, users use knowledge and domain-dependant tools that are specialised. Thus experts’ knowledge covers broad areas of physics for modelling thermal, thermodynamics, chemistry and energetics processes. We must also add the experts’ knowledge related to optimisation. Hence, to some extent, cross-domain interoperability is related to semantic interoperability.
- Cross-feature interoperation: physical systems modelled in Plate-Form(E)3 will be simulated and optimised through these models. Tools for modelling, simulation and optimisation need to be interconnected. This is the problem related to so-called syntactic interoperability. However, the semantics is not a priori excluded as a possible asset to achieve the interconnection of the above tools. Namely, semantics can be used to achieve syntactic interoperability.

For making the previous scenarios effective, there exist some barriers (conceptual, technological and organisational) [3] that define levels of interoperability to be studied. While organisational barriers are an issue mainly from

governmental and privacy perspectives, we will focus on technical and conceptual barriers as follows:

- Technical barriers are related to the incompatibility of information technologies (architecture & platforms, infrastructure, exchange formats syntax ...).
- Conceptual barriers are related to the semantic mismatches of information to be exchanged. These barriers concern the modelling at the high level of abstraction.

For highlighting the scientific problems linked to the Plate-Form(E)3 project, we propose to intersect the different generic scenarios with the interoperability levels.

Technical interoperability problems appear in each scenario. Solving these technical barriers is now easier and partly achieved by standard techniques and implemented interfaces. We can cite, for instance, XML (eXtensible Mark-up Language) and linked applications: SOAP (Simple Object Access Protocol) and WSDL (Web Services Description Language). We must therefore assess whether the candidate tools for integration into Plate-Form(E)3 use existing standards (CAPE-OPEN<sup>4</sup>, ...) or we must define such a standard. When connecting a new tool, we must be able to assess quickly its ability to interoperate with Plate-Form(E)3 at the technical level.

Conceptual interoperability problems concern:

- for the cross-scale interoperation scenario, the dynamics and the granularity of the used models that are not the same. Indeed, the models have not the same time scale when considering a territory or a component. Moreover, the different models represent heterogeneous aggregates of information depending of the scale of the modelled system (from territory to component). It is therefore necessary to formalize and finally assess the correlation between models outputs at a given scale and their use as inputs at another scale (with the same tool or not).
- for the cross-domain or cross-feature interoperation scenarios, the knowledge of several specific domains that are managed by the different tools to be connected through the platform. This heterogeneous knowledge produce semantically heterogeneous models that must be exchanged, stored, processed consistently with the purposes for which they have been built. Moreover, this raises the issue of the a priori evaluation of the ability to exchange ad-hoc models (related to a specific domain or a particular tool feature) without knowing in advance the tools that will be connected to the platform to process these models (and thus the business semantics of the related models that are shared through the platform).

### 2) General scenarios and scientific problems

General scenarios of interoperability are directly related to identified correlations between the different modules of Plate-Form(E)3. When scientific problems are defined at this level, generic scenarios are taken into account, namely, definitions of corresponding scientific problems are specialized with consideration of these correlations. It is proposed to distinguish between two types of interopera-

tions within Plate-Form(E)3 architecture: *custom* and *native*.

Custom interoperations are related to a fact that diversity of tools, of both closed and open architecture (both, commercial and custom), exists in the environment where these interoperations need to be achieved. More important, custom interoperations are related to a possibility to introduce some new tools of unknown capability to interoperate to the environment, probably even after the Plate-Form(E)3 prototype is released.

Native interoperations are the ones that occur between known groups of software tools or modules, whether of open or closed architecture, with natively ensured interoperation capability; or between the tools or modules where there is possibility to natively develop this capability.

Obviously, native interoperability is more related to software integration, while custom interoperability needs approaches with increased level of flexibility.

### 3) A preliminary architecture for the platform

A preliminary structure of the platform is represented in Figure 2. This structure is a conceptual solution to the scientific problems presented before and can be functionally defined as follows.

Coloured symbols represent different interoperability issues. While the dark colour (Process integration) indicates the problems of higher priority, the light one (GIS integration) represents problems that are of lower priority and level of detail. This decision is justified by the estimated level of complexity, which is greater when a process integration framework is considered.

For each of the illustrated connections, two different perspectives are considered: models (unifying models that consider a common perspective to the interoperable modules) and technical interoperability (including technical approaches, data formats, interfaces).

The *user interface* module allows one user to put some information into the system and to define the optimisation problem (optimisation criteria/objectives, constraints...). Moreover through this interface, the user can access to the different services offered by the platform and the other modules. This user interface must also give to the user all the information necessary for decision aiding by calling the visualisation module that gives some relevant indicators in a dashboard.

The *process integration module* is able to connect to and to call some external specific tools for modeling/simulating processes defined by the user. Moreover,

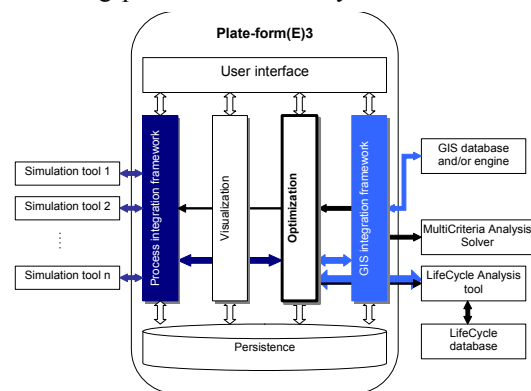


Figure 2. Preliminary structure of Plate-Form(E)3

<sup>4</sup> <http://www.colan.org>

this module must be able – for solving the energetic integration problem for processes – to integrate also all the obtained models in a coherent way without loss and misunderstanding. We can distinguish the integration when we are in a territory scale or when we are in a process/plant scale. Territory scale problem concerns the integration in terms of considering multiple processes of the different plants. In contrast, process/plant scale problem focuses on a single process, while different components (heat exchangers...) of the different existing simulation tools and libraries may be taken into consideration for its optimisation.

The *optimisation module* solves the mono-objective or multi-objective problem defined by the user through the user interface. For defining criteria and constraints, this module will connect with the model obtained by the integration module.

The *visualisation module* gives to the user, through the user interface, an illustration of the relevant indicators for decision aiding and decision itself, based on the results of the optimisation and the models that are given by the process integration module. This module can also connect to the GIS module if geographical data are relevant considering the predefined use case.

The *GIS integration module* will be invoked for territory scale use cases if geographical data are relevant for solving the optimisation problem or for helping the user for taking its decision. Some examples of the relevant data are plant locations, landscape features, such as declination or natural obstacles, energy network geo-data, transport routes, etc.

All information, regarding the functionality of Plate-form(E)3 is stored in a database for the *persistence*.

### III. STATE-OF-THE-ART

This section presents an overview of the list of candidate technologies, models, tools, resources and approaches that are considered relevant for resolution of interoperability problems, as defined in the previous section. The candidate technologies are foreseen as the possible building blocks of the future interoperability solution. This overview only presents the basic features of the technologies with arguments about possible relevance for the future interoperability solution.

Figure 3 gives an integrated overview of the proposed candidate technologies with regard to the different sub-problems. Indicated relationships illustrate already existing integration between technologies (“uses” relationship). It is important to highlight that this overview considers only Process Integration Framework of Plate-form(E)3 and the parts of Plate-form(E)3 architecture that are considered as core tools – related to integrated simulation and optimisation. Each analyse of technology will conclude with a discussion about the relevance of this technology for Plate-Form(E)3.

#### A. Candidate technologies for Process Integration Framework

##### 1) CAPE-OPEN : Open industry standard for process simulation software

CAPE-OPEN [5] is an open industry standard for interoperability of CAPE (Computer Aided Process Engi-

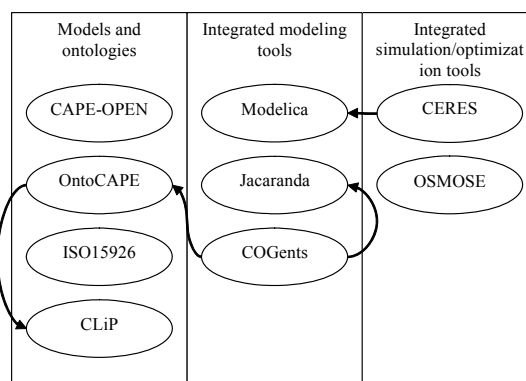


Figure 3. Overview of the proposed candidate technologies

neering) software tools; it is maintained by CAPE-OPEN Laboratories Network (CO-LaN). It was developed in a joint EU initiative Global CAPE-Open (1997-99), later also endorsed by IMS (which gave it a global reach). Initiative combined similar efforts of BP (EU project PRIMA) and BASF (German consortium IK-CAPE).

CAPE-OPEN defines rules and interfaces that allow CAPE applications or components to interoperate. This interoperation is achieved by combining the different so-called Process Modelling Components (PMC) in modelling the process in specific Process Modelling Environment (PME). PMC is a software component which is intended to carry out a narrow, well-defined function such as the computation of physical properties, the simulation of a particular unit operation, or the numerical solution of certain types of mathematical problems arising in process simulation or optimisation. Some examples of PMCs are heat exchanger design models, pump models, distillation models, mixer/agitator calculators, safety relief design calculators, etc. Process Modelling Environment (PME) is a software tool that supports the design of a process model either from scratch or from libraries of existing models, or both. They then allow the user to perform a variety of different tasks, such as process simulation or optimisation, using this single model of the process. Interoperation is supported by CAPE middleware, implemented by using Microsoft COM, OMG CORBA or .NET technology.

CAPE-OPEN is the ultimate solution for syntactic interoperability of process modelling and simulation tools, endorsed by the industries. It is supported by the wide range of the different existing tools, such as Aspen, ProSim, SimSci, Belsim and many others. It seems like a main candidate for a resolution of interoperability problem at process scale.

##### 2) CLiP : Conceptual Lifecycle Process Model

CLiP is a comprehensive data model for process engineering [6]. It is developed with an objective to generalize, extend and integrate different existing models for chemical engineering [7].

Both interoperability problems are related to a process paradigm. CLiP seems like a prime candidate for modelling chemical industry processes, since it generalize, extends and integrates different existing models. CLiP is also used as a basis for development of OntoCAPE ontological framework.



3) *OntoCAPE : Large-scale ontology for the domain of Computer-Aided Process Engineering (CAPE)*

OntoCAPE<sup>5</sup> captures consensual knowledge of the process engineering domain in a generic way such that it can be reused and shared. Some possible applications of OntoCAPE include the systematic management and retrieval of simulation models and design documents, electronic procurement of plant equipment, mathematical modelling, as well as the integration of design data from distributed sources. OntoCAPE can be characterized as a formal, heavyweight ontology, which is represented in the OWL modelling language. OntoCAPE has been subdivided in layers, which separate general knowledge from knowledge about particular domains and applications.

OntoCAPE is exhaustive semantic information model for data integration across the chemical process design. It can be a reference for integration and management of distributed design data, namely process designs of the different plants. Thus, it is considered as relevant for territory scale interoperability problem. Also, it is used as reference ontology for automated decision making related to configuration of the processes (see COGents).

B. *Candidate technologies for core Plate-form(E)3*

1) *Modelica: Multi-domain modeling language for component-oriented modeling of complex systems*

Modelica<sup>6</sup> is an object-oriented, declarative, multi-domain modelling language for component-oriented modelling of complex systems, e.g., systems containing mechanical, electrical, electronic, hydraulic, thermal, control, electric power or process-oriented subcomponents. Modelica is a modelling language rather than a conventional programming language. Its classes are not compiled in the usual sense, but they are translated into objects which are then exercised by a simulation engine. The simulation engine is not specified by the language, although certain required capabilities are outlined.

Modelica is used to develop platforms that could be applied for integrated modelling and simulation. Hence the relevance for territory scale interoperability problem. Examples of these platforms are OpenModelica<sup>7</sup> and JModelica<sup>8</sup>.

2) *OSMOSE : A tool for the design and analysis of integrated energy systems*

OSMOSE<sup>9</sup> (Acronym for Multi-Objective Optimisation of integrated Energy Systems) is a Matlab platform designed for the study of energy conversion systems. The platform allows linking several software, for flowsheeting (Belsim, Vali, Aspen Plus), energy integration (Easy, GLPK), optimisation (MOO), and lifecycle impact assessment (Ecoinvent). Among other features, OSMOSE offers a complete suite of computation and results analysis tools

(optimisation, sensitivity analysis, Pareto curve analysis ...).

OSMOSE is a solution for integrated energy management, which is a core of the interoperability problems at the territory level (second type).

3) *CERES Platform*

A CERES software platform is developed in scope of CERES-2 project<sup>10</sup>, funded by ANR. Its objective is to optimise waste and heat recovery in industrial processes and achieve energy integration. It is developed in C++ and it is using OpenModelica, actually Modelica API as modelling and simulation environment.

CERES is already considered as one of the main candidates for integration platform, in specific for addressing process-scale interoperability. Interfaces with simulation platforms will be additionally investigated. It seems that the efficiency of these interfaces could be significantly improved if CAPE-OPEN is considered as a wrapper.

C. *Other candidate technologies, approaches and tools*

1) *ISO15926<sup>11</sup> : Industrial automation systems and integration - Integration of life-cycle data for process plants including oil and gas production facilities*

While the above models consider processes in process industries as focal modelling paradigms, ISO15926 aims at providing artefacts for modelling technical installations and their components.

The objective of ISO15926 (developed as extension of STEP principles to long-life process plants) is to facilitate effective and efficient exchange and reuse of complex plant and project information, or in specific to mitigate the current high costs of rekeying and reformatting information to move it from one proprietary system to another. It is mostly related to providing models for equipment and their properties. ISO 15926 acts like an interpreter between two otherwise incompatible systems, by translating the descriptions of plant objects from one company's database to that of another. In doing so, the meaning of all the terms is being maintained, independently of the context.

Setup for the process industries with large projects involving many parties, and involving plant operations and maintenance could take a long time. Optimising existing processes by replacing an existing component (process-scale interoperability problem) or by adding components which could facilitate energy integration (territory-scale) assumes procurement of the installation component, or at least exchange of the information which is sufficient to define the requirements for this component. Obviously, establishment of the correspondences between process and equipment models could contribute to facilitating the collaboration between the relevant systems (e.g. for

<sup>5</sup> <http://www.avt.rwth-aachen.de/AVT/index.php?id=730&L=1>

<sup>6</sup> <https://www.modelica.org/>

<sup>7</sup> <https://www.openmodelica.org/>

<sup>8</sup> <http://www.jmodelica.org/>

<sup>9</sup> <http://leni.epfl.ch/osmose>

<sup>10</sup> [http://www.agence-nationale-recherche.fr/en/research-programmes/energie-durable/systemes-energetiques-efficaces-et-decarbones/funded-project-eesi/?tx\\_lwmsuivibilan\\_pi2\[CODE\]=ANR-10-EESI-0001](http://www.agence-nationale-recherche.fr/en/research-programmes/energie-durable/systemes-energetiques-efficaces-et-decarbones/funded-project-eesi/?tx_lwmsuivibilan_pi2[CODE]=ANR-10-EESI-0001)

<sup>11</sup> [http://en.wikipedia.org/wiki/ISO\\_15926](http://en.wikipedia.org/wiki/ISO_15926)

process modelling and procurement). Existing formal representations of ISO15926 [8] could reduce the efforts in making these correspondences.

### 2) COGents : Semantic approach to CAPE web service choreography

COGents project proposed the approach to dynamic CAPE services composition [9], where a number of software agents collaborate to configure a process model, according to the users' requirements, defined by using OntoCAPE ontology. Namely, agents are used as CAPE web services choreographers. Typical use of this approach is as following: The user defines a Modelling Task Specification (MTS) in OntoCAPE format to describe the unit he/she requires in term of functionality and parameters (of the underlying tool, e.g. HYSYS). Then, library and match maker agents find the appropriate unit operation using the generated MTS file.

COGents provide automated support for configuration/generation of process model, on demand, based on the user's requirements.

### 3) Jacaranda

Jacaranda<sup>12</sup> is a system for process synthesis, or automated process design, intended for conceptual or early stage design [10]. It aims to provide the support necessary for creative and exploratory design, helping the engineer to identify the important issues and constraints for a given design problem.

Jacaranda is a solution for automated process design. Therefore, it may be a candidate technology for generating cross-plant processes in territory scale interoperability problem. It is also used in COGents project as optimisation platform [9].

## IV. DISCUSSION

Based on the previous State-of-the-art, this section shows how CAPE-Open should be used in PFE3 as one of the candidate technologies for resolution of process-scale interoperability problem of PlateForm(E)3. In fact, CAPE-OPEN interfaces between CAPE (Computer-Aided Process Engineering) tools defined the primary means for establishing the systems interoperability in this domain. They are defined in EC sponsored effort (within two consecutive projects: CAPE-OPEN and Global CAPE-OPEN), with participating major industries and labs, thus gaining the global reach.

Today, CAPE-OPEN represents widely accepted approach, methodology and specification for making the different CAPE tools and components interoperable. Reference [11] provided the list of CO-compliant CAPE tools. This list is not exhaustive because of the date of the publication. More detailed and updated list is maintained at co-lan.org website. Majority of the candidate tools for process modelling and simulation in Plate-form(E)3 architecture already provide some level of support to CAPE-OPEN integration. However, the following archi-

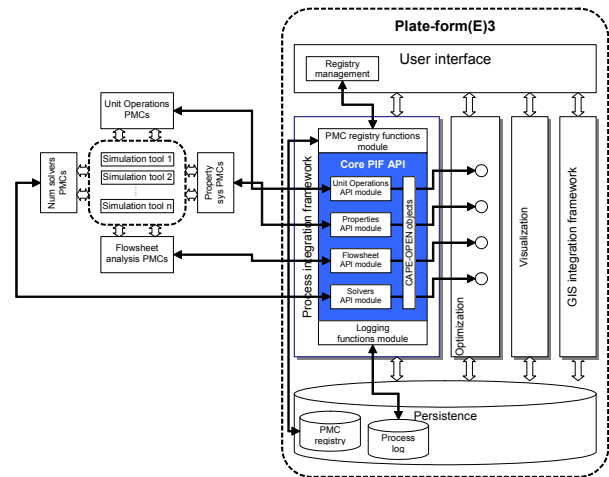


Figure 4. Process Integration Framework architecture in CAPE-OPEN context

ture is only a potential architecture that is not a final choice for the project.

In this section, a description of CAPE objects, by CAPE-OPEN standard is provided, together with the methodology and illustrations of some interfaces. The proposed architecture is made on basis of the high-level architecture, presented in figure 2. It elaborates in more detail a Process Integration Framework component of Plate-form(E)3, in context of possible use of CAPE-OPEN interfaces to exploit the external process modelling and simulation tools. This elaborated architecture is illustrated on Figure 4.

Process Integration Framework (PIF) is a part of the Plate-form(E)3 architecture whose role is to connect to and invoke some services offered by the external tools, used for process modelling and simulation. In context of CAPE-OPEN integration, Process Integration Framework should implement functions which are using CAPE-OPEN interfaces to access the above services. The functions are part of so-called Process Integration Framework Application Programme Interface (PIF API). It is assumed that this approach is possible under condition that the above tools are CAPE-OPEN compliant. This implies that before final selection of the technology used to implement Process Integration Framework, a detailed analysis of the CO-compliance of the final choice of process modelling and simulation tools (to embed to, or to use within Plate-form(E)3) must be carried out. Despite possible non-compliance situations, CAPE-OPEN must be carefully considered, since it is today's de facto industrial standard for interoperability of process applications. In this context, the PIF acts as Process Modelling Environment (PME), namely a client or a socket, as it uses the CAPE-OPEN interfaces in order to request services from the external software. The process modelling and simulation tools, namely their open components, act as Process Modelling Components (PMC), or servers or plugs, since they are applications, wrapped with the CAPE-OPEN interfaces in order to expose their functionality. The list of these functions, namely contents of PIF API should be defined based on the specific interoperability cases. At

<sup>12</sup> <http://www.ucl.ac.uk/~ucecesf/jacaranda.html>

this point, it is clear that they should be grouped according to the PMC classes they are communicating with.

Process modelling and simulation tools which are parts of Plate-form(E)3 landscape provide PMC classes which can be used by Process Integration Framework, namely respective API modules: Properties API module, Unit operations API module, Numerical solvers API module and Flowsheet Analysis API module. These modules are interfaces which are wrapping the native implementations of the respective relevant functions in Optimisation module. They are using CAPE-OPEN objects, such as Thermo, Unit, Numerics and Simulator Executive objects.

Two other modules are foreseen to provide supportive functions to PIF API. PMC registry functions module facilitate adding, editing and deleting PMCs, available to Plate-form(E)3 platform. Logging functions module track and store all activities related to using the different PMCs of the different process modelling and simulation tools, by the platform.

## V. CONCLUSIONS AND FUTURE WORKS

The work presented in this paper is a first step in dealing with interoperability issues when having to interconnect some tools/methods/approaches in a software bus for modelling/simulating/optimising processes for energy efficiency at different scales: component/plant/territory.

Based on an extensive state-of-the-art, a first architecture has been proposed based on CAPE-OPEN standard. The next step is to finalise the choice of the architecture (based on CAPE-OPEN standard or not), to develop this architecture and finally to extend it for dealing with interoperability issues when connecting some tools/models related to the different scales presented above.

### **Acknowledgement**

This work has been partially funded by the program SEED 2012 from the French National Agency for Re-

search ANR in the frame of the Plate-Form(E)3 project. The authors would like also to thank Dr. Milan Zdravkovic (University of Nis and Inglise D.O.O) for his support to this work.

## REFERENCES

- [1] IEEE. IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. Institute of Electrical and Electronics Engineers, 1990. ISBN: 1559370793
- [2] J. Sowa. *Knowledge Representation: Logical, Philosophical, and Computational Foundations*, CA:Brooks/Cole Publishing Co. 2000
- [3] INTEROP, Enterprise Interoperability-Framework and knowledge corpus - Final report, INTEROP NoE, FP6 – Contract n° 508011, Deliverable DI.3, May 21st 2007.
- [4] A. Aubry, J. Noel, D. Rahon, H. Panetto. A cross-scale models interoperability problem: the Plate-Form(E)3 project case study. 3rd industry Applications and Standard initiatives for Cooperative Information Systems for Interoperable Infrastructures, Sep 2013, Graz, Austria. Springer, OTM 2013 Workshops. LNCS 8186, pp. 57-61, Lecture Notes in Computer Science. 2013
- [5] J.P. Belaud, M. Pons. Open software architecture for process simulation: The current status of CAPE-OPEN standard. *Computer Aided Chemical Engineering*. Volume 10, pp. 847–852, 2002.
- [6] B. Bayer, W. Marquardt. Towards integrated information models for data and documents. *Computers & Chemical Engineering*. Volume 28, Issue 8, pp 1249–1266, 2004.
- [7] B. Bayer, R. Schneider, W. Marquardt. Integration of data models for process design - first steps and experiences. *Computers & Chemical Engineering*. Volume 24, Issues 2–7, pp 599–605, 2000.
- [8] R. Batresa, M. Westb, D. Lealc, D. Priced, K. Masakia, Y. Shimadae, T. Fuchinof, Y. Nakag. An upper ontology based on ISO 15926. *Computers & Chemical Engineering*, Volume 31, Issues 5–6, pp. 519–534, 2007.
- [9] B. Braunschweig, E. Fraga, Z. Guessoum, W. Marquardt, O. Nadjemi, D. Paen, D. Piñol, P. Roux, S. Sama, M. Serra, I. Stalker, A. Yang. CAPE web services: The COGents way. *Computer Aided Chemical Engineering*. Volume 18, pp 1021–1026, 2004.
- [10] E.S. Fraga, M.A. Steffens, I.D.L. Bogle, A.K. Hind. An object-oriented framework for process synthesis and optimization. Fifth International Conference on Foundations of Computer-Aided Process Design. pp. 446 – 449, 2000.
- [11] J.M. Nougues, D. Piñol, J.C. Rodríguez, S. Sama, P.Svahn. CAPE-OPEN as a mean to achieve interoperability of Simulation Components. 45th International Conference of Scandinavian Simulation Society, SIMS 2001.