**SMAC**

**SMArt systems Co-design**

**FP7-ICT-2011-7 – 288827 – CP IP**

**D1.1.2 State-of-the-Art on Multi-Domain CoSimulation Update**

Due date of deliverable: March 2014

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<td>Author(s): Giuliana Gangemi (ST), Mirko Guarnera (ST), Michelangelo Grosso (STP)</td>
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### Table 1: Revision Control and Change Tracking

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## Glossary

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<td>AMP</td>
<td>Amplifier</td>
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<tr>
<td>ASIC</td>
<td>Application Specific Integrated Circuit</td>
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<tr>
<td>BEM</td>
<td>Boundary Element Method</td>
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<td>EMC</td>
<td>ElectroMagnetic Compatibility</td>
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<td>EMI</td>
<td>ElectroMagnetic Interference</td>
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<td>ESD</td>
<td>ElectroStatic Discharge</td>
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<td>FEM</td>
<td>Finite Element Method</td>
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<td>HDL</td>
<td>Hardware-description Language</td>
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<td>HSPL</td>
<td>High Sound Level Microphone</td>
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<td>IO</td>
<td>Input Output</td>
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<td>IPEM</td>
<td>Integrated Power Electronics Module</td>
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<td>MCM</td>
<td>Multi-Chip Module</td>
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<tr>
<td>MEMS</td>
<td>Micro-Electro-Mechanical Systems</td>
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<td>MIC</td>
<td>Microphone</td>
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<td>MOR</td>
<td>Model Order Reduction</td>
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<td>MRI</td>
<td>Magnetic Resonance Imaging</td>
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<tr>
<td>PC</td>
<td>Personal Computer</td>
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<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
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<tr>
<td>PDM</td>
<td>Pulse Density Modulation</td>
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<td>RF</td>
<td>Radio Frequency</td>
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<td>RSM</td>
<td>Response Surface Model</td>
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<td>RTL</td>
<td>Register Transfer Level</td>
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<td>System-in-Package</td>
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<td>SoA</td>
<td>State-of-the-Art</td>
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<td>SPICE</td>
<td>Simulation Program with Integrated Circuit Emphasis</td>
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<td>SPL</td>
<td>Sound Pressure Level</td>
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<tr>
<td>TCAD</td>
<td>Technology Computer-Aided Design</td>
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<tr>
<td>THD</td>
<td>Time Harmonic Distortion</td>
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<tr>
<td>TLM</td>
<td>Transaction Level Modelling</td>
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<tr>
<td>TRAPPIST</td>
<td>Trajectory Approximation by Piecewise Interpolation of State-Dependent Transfer Functions</td>
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<tr>
<td>VHDL</td>
<td>Very high speed integrated circuit Hardware Description Language</td>
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<tr>
<td>VHDL-AMS</td>
<td>VHDL with Analog and Mixed-Signal extensions</td>
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<tr>
<td>VLSI</td>
<td>Very Large Scale Integration</td>
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1 Executive Summary

The present document is the update of the previous D1.1.1 B “State-of-the-Art on Multi-Domain CoSimulation” with the intent to sharpen up the activity of specification of the SMAC Projects and of the SMAC Platform with the purpose to:

- Make the SMAC projects final developments benefit of the Projects researches outcomes and experience (feedback loop).
- Document the Project changes that will influence the final results.
- Benefit and be aligned with the EDA market most recent novelties.

The D1.1.1 B made an inventory of which tools and modelling languages are used by the partners. Due to the balanced consortium this is a proper starting point for a state-of-the art analysis and gap analysis. For the key topics in SMAC both the SoA and gaps identification were updated. The initial SMAC objectives were considered still valid targets.

The definition of SMAC Platform was provided either in term of necessary tool flow and to be developed and simulation to be enabled either in term of abstraction level per design domain and per flow.

For demonstrating the SMAC platform the requirements for three use cases were generated:

- Respiratory sensor for an MRI Scanner. Target is to demonstrate smart micro-system design with large system integration. The MRI Scanner provides a harsh requirement with respect to (electro)magnetic fields, vibrations, noise and cooling aspects;
- Wearable sensor for reliable drift free limb tracking. Target is to demonstrate the platform capabilities for calculations on long term stability of smart micro-system sensors;
- High Sound Pressure Level Microphone for a noise dosimeter in harsh environments. Target is to demonstrate platform co-simulation capabilities on piezo-based sensors integrated in an electronics circuit in a harsh (noisy) environment.

Now the picture has changed in the following ways:

1) The multi domain facet of the project has been recognised to be emphasized. The Consortium looked more into the fluidics physical and a new demonstrator, a pico-projector has been put in place.
2) The figure of merit of the Wearable sensor for reliable drift free limb tracking had to be updated in order to be aligned with the most recent market requirements.
3) The Partner Philips had to withdraw from the SMAC consortium because of an internal reorganisation. Consequently the MRI scanner was not available any more as part of the demonstration activities.
4) A SMAC Dashboard has been specified in order to
   a. Provide a tangible representation of the SMAC Platform
   b. Define the standards for the EDA tools and models to be SMAC Compliant
   c. Support the usage of the SMAC Methodologies and the creation of a User Group
5) An Open source test case methodology has been specified in order to secure the confidentiality issues and to support the maximum impact of the SMAC project given such a methodology can be used either for training or dissemination
6) Collaboration with the H-INCEPTION project has been initiated in order to investigate the potential of the Accellera Vendor’s Extension to the IP-XACT standard for supporting multi-domain simulations.
2 Introduction

The SMAC project has replaced the former demonstrator with a Laser Steering pico-projector actuator. It regards the micro-scanners (or micro-scanning mirrors) constituting by far the most critical parts of a pico-projector system. Pico-projectors are very small device that can provide large image, overcoming the limitations of screen dimensions in portable devices. They are the natural solution for sharing information in social and business settings and can be used in many types of devices, such as mobile phones, cameras, laptops, head up displays, head mounted displays, gaming platforms, etc. Fig. 1 presents some of the possible market sectors.

The need to increase the dissemination of the SMAC platform have leaded to the idea to create a user group and a tangible way to distribute and use the SMAC platform. Vice versa the impact of the platform shall be more effective by exploiting its modular approach which enable the used to extend it by plugging additional extensions.

The above needs have leaded to conceive two additional activities: on one side a way to “package” the platform in order to distribute it creating a standard modular way to install and use it, not necessarily with all its functionalities but those tailored by the user, vice versa a definition for additional modules (either parsers or simulators or models) to be added and be classified as “SMAC compliant”. Such an instrument is the SMAC Dashboard. It will give the end user the opportunity to use the platform without being bothered by some low level details bound to the software installation and concentrate on the methodology definition and execution, which in the industrial design environments ends up to be a set of coded best practices and well-ordered steps.

Alongside the need to make the platform usable in a standard way, there has been the need to exchange test cases between the developers in order to test the tools under developments. The need to collaborate with the necessity to preserve IP properties have leaded to the idea of set of Open Source Test Cases which has ended up to become a general idea to support the dissemination of the SMAC ideas and the usage of the platform itself.

Finally the partners involved in projects SMAC and H-INCEPTION agreed to cooperate in the field of multi-domain simulation in support of the design of smart heterogeneous systems. Despite the different focus of both projects, there exists a substantial basis for cooperation, situated in the area of practical implementation of multi-domain simulation flows, where both projects identified weaknesses or gaps.

2.1 Characterization of the problem

2.1.1 Laser Steering pico-projector actuator design issues

The technologies used for Pico-projection are, mainly, three (Figure 1Laser steering, LCoS and DLP technologies): LCOS, DLP and laser steering. LCOS is similar to LCD but the back plane is silicon made. LEDs (monochromatic or rgb) are used as light sources. DLP (or MDM) uses micromechanical mirrors (one for each pixel) that are used to modulate (digitally) the light intensity for each pixel. The LCOS is the simplest technology, but achieve low resolutions, while DLP are complex and costly.
A third available technology is the Laser steering based on Lasers as light sources and MEMS Mirrors to scan the images. It works similarly to the CRT but, with laser steering, the deflection is obtained by moving the mirrors. Moreover the laser steering is focus free, and does not need any optics.

![Laser steering, LCoS and DLP technologies](image_url)

Laser steering systems have a simple architecture: three lasers (red, green, and one blue), each with a lens near the laser output that collects the light from the laser and correct the beam astigmatism. The light from the three lasers is then combined with dichroic elements into a single beam. Using a beam-splitter or basic fold-mirror optics, the beam is relayed onto a biaxial MEMS scanning mirrors that scan the beam in a raster pattern. The projected image is created by modulating the three lasers synchronously with the position of the scanned beam. All three lasers are driven simultaneously at the levels needed to create the proper color mix or each pixel. This produces brilliant images with the wide color gamut. The efficiency is maximized, since the lasers are only on at the level needed for each pixel. The contrast is high because the lasers are completely off for black pixels rather than using an SLM (spatial light modulator) to deflect or absorb any excess intensity.

There are two possible mirrors design solutions. The first one is to design a single mirror with two degrees of freedom (horizontal and vertical). The second one is to design two separated mirrors, one for the horizontal scanning, and one for the vertical scanning. The first solution requires very complex driving waveforms in order to induce the mirrors to work at different rate in the two axis. The second solution requires simpler driving waveforms and enables an easier optical module customization.

A raster-scanned laser projector does not have a projection lens. The projected beam directly leaves the MEMS scanner and creates an image on the surface. Because of the scanned single pixel design, light-collection efficiency is kept high by placing the collection lenses near the output of the lasers, while the output beam NA (numerical aperture) is very low. By design, the rate of expansion of the single-pixel beam is matched to the rate that the scanned image size grows. As a result, the projected image is always in focus.

The video processor and MEMS controller drives the scan engine. The horizontal scan motion is created by running the horizontal axis. The scan velocity changes sinusoidally with position. The controller uses feedback from sensors on the MEMS scanner to keep the system on resonance and at fixed scan amplitude. The vertical scan direction is driven with a waveform able to provide constant velocity from the top to the bottom of the image and a rapid retrace back to the top to begin a new frame. The bidirectional scans are shown in Figure 2.
Figure 2 Bidirectional scanner

Figure 3 presents the block diagram of the Pico-projector Actuator virtual prototype. The main involved components are the SystemC/TLM mirror actuator models, their controlling electronics and the current sensors used for feedback.

Figure 3 Block diagram of the Pico-projector Actuator virtual prototype

Among the possible problems affecting image quality, ripple is due to the beam steering mechanisms. Each time a complete frame is scanned, the retrace of the mirror to the initial position induces vertical vibrating modes leading to non-linear effects in the trace time. The visible effect is an uneven distribution of the distance between the traced horizontal lines, causing a number of lighter and darker horizontal stripes on the projected image.
2.1.2 SMAC Dashboard

After the presentation of the Project status to the EIAB and the second year review, some weaknesses of the SMAC platform have been pointed out:

- it still appears as a collection of tools and methods lacking uniformity and precisely identified borders and design flow integration specifications
- it is not supported by an active community of users
- it is not evident how the platform can be industrialized and maintained after the end of the project.

In order to tie together the SMAC concepts and requirements, the specifications of a collector tool and a global user interface, which has been called Dashboard, have been identified.

The main Dashboard specifications are reported in Section 5

2.1.3 Open Source Test Case

The SMAC Open Source Test Case represents a widely heterogeneous system composed by aggregating Intellectual Properties Cores (IPs) from different domains (all domains included in the SMAC platform are covered by this open-source test case).

The system exchanges information with the surrounding world by sensing the external acceleration applied to the physical system and communicates with a RF wireless components. Moreover, a serial interface is given to be used for program the system or to retrieve data from it.

2.1.4 Model and IP Annotation Standard

The SMAC platform is characterized by the large number of simulation scenario’s which must be supported along with the corresponding simulation flows. Depending on the abstraction level at which the designer wants to execute his simulations and depending on the simulation domains which must be involved, IP-blocks will be represented by specific models or model variants, implemented in different languages, or exposing different interfaces and “services”. Thanks to the availability of model transformation flows, in most cases, it will be possible to automatically generate the required models. However precise description of the capabilities of the models, as well as the detailed specification of the requirements for every flow will be key in order to automate the setup of target simulation tasks on the platform and making the whole construction “manageable”. 
IP-XACT is an XML-based standard for describing electronic intellectual property (IP). It provides a common database infrastructure for electronic design that the industry can use as an organizing principle for attacking a broad set of problems in electronic design, including the distribution of IP-blocks and the automation of design flows. To date, IP-XACT is focusing mainly on the digital domain. It however provides “hooks” for the extension of the framework, and recently a series of extensions were proposed in order to support mixed-signal simulation.

In order to evaluate these recent extensions for the purpose of multi-domain simulations, the SMAC and H-INCEPTION partners agreed on a cooperation. Section 7 provides an overview of the IP-XACT standard and the recent Accelera Vendor’s extensions. The strategy of the SMAC and H-INCEPTION are briefly compared and the objectives of the cooperation are explained.

2.2 Definitions

Throughout all the SMAC deliverables we are going to refer many times to names like test cases use case and demonstrators. In order to avoid any confusion regarding to what each term is referring to, we are going to give clear definitions. These definitions will propagate from D1.1.1 to all the other deliverables of the SMAC in order to achieve consistency.

**Test-cases** are components or subsystems employed to validate specific software tools (e.g., for abstraction or co-simulation) and models (by themselves or in interaction with others).

The tools and methodologies employed for simulating and interacting with each of them fall into the definition of a **test scenario**.

**Use-case scenarios** are real-world applications (including complete smart systems) developed by the consortium or third parties, and used to perform an evaluation of the capabilities of the SMAC outcome (methodologies and tools) through an analysis work, i.e., without actual design or simulation. They are mainly addressed in T6.5.

**Demonstrators** are hardware systems whose critical part design and modelling is enabled (either completely or partially) by the methodologies and tools developed within the Project: models of the target devices and their assembly are used to explore their pre-prototype behaviour in mission-like conditions.

**Virtual Prototype Platform (VPP)** is a modelling and simulation environment (VPP – Virtual Prototype Platform) that simulates the interaction of a sensor or actuator on one side (SystemC TLM / SystemC AMS model) together with the model of a control part on the other side which can be a MCU and associated peripherals (e.g., a DAC).

**SMAC Dashboard** Framework tying together methods and tools developed within the SMAC Project for smart system modelling and simulation, based on a common interface helping the user in the configuration and design activities.

**Open source test case** represents a widely heterogeneous system; composed by aggregating Intellectual Properties Cores (IPs) from different domains (all domains included in the SMAC platform are covered by this open-source test case).
3 Demonstrator Description

The smart system application development process starts with an analysis of the application’s system requirements, followed by the design on system level. During this process modelling and simulation methods play an important role. To validate the SMAC simulation platform two more general cases have been defined (demonstrators) and their top level requirements are described in this chapter:

- micro-scanner
- Wearable sensing equipment for reliable drift free limb tracking

Both demonstrators will integrate the same nano-electronics smart system for motion detection. The demonstration of respiratory sensing in an MRI scanner adds the harsh environment and will show the cooperation of the SMAC platform with external packages.

3.1 Pico-projector actuator (VPP)

The Virtual Prototype for the Pico-Projector is mapped inside the SMAC platform in the picture below.
horizontal deflection is performed by horizontally rotating the reflecting surface at its natural frequency. Conversely, vertical scanning is obtained by vertically rotating the mirror with a linear voltage at a lower speed. Each time a complete frame is scanned, the retrace of the mirror to the initial position induces vertical vibrating modes leading to non-linear effects in the trace time. The visible effect is an uneven distribution of the distance between the traced horizontal lines, causing a number of lighter and darker horizontal stripes on the projected image. A carefully developed compensation algorithm can be used on the controller to eliminate or, at least, to mitigate this effect. The ripple problem will be specifically targeted and a solution will be researched for eliminating or at least mitigating its effect so as to make it less annoying to the human eye (e.g., contrast ratio between adjacent lines of less than 1:100).

The LBS micro scanner developed by ST (or micro-scanning mirror) is a micro-opto-electromechanical system (MOEMS) in the category of micro-mirror actuators for dynamic light modulation. This mirrors act as laser reflectors and their behaviour has to be studied within the optical laws. This includes the movement of the mirrors (controlled by an electrostatic field controlled by a modulated electrostatic field, horizontally between 20 and 25 KHz an vertically around 60Hz), which is a thermo-mechanic issue in the hot air (in the range of 50-60°C), while the air molecules around the mirrors have to be looked at as a fluid. At a lower scale, the effect of air drag (the torsion of the fingers of the micro mirror) due to the air heating has to be studied as an acoustic phenomenon. SystemC/SystemC AMS and TLM models for the various parts will be developed and assembled, carefully taking into account acoustic, fluidic and thermo-mechanic effects and their mutual interactions.

3.2 Wearable Sensing Equipment for reliable drift-free limb tracking

The second demonstrator will use an array of MEMS sensor nodes attached to various body parts to track the relative displacement of limbs. Each node includes 3-axis MEMS gyroscope, accelerometer and magnetometer, and a 32 bit microcontroller; a Kalman filtering algorithm is going to be used to perform “sensor fusion”, so as to obtain an angular position estimation that is better from what can be obtained by means of a single sensor. Such an algorithm integrates the gyroscope reading, i.e., angular velocity, to compute the angular position in dynamic conditions, and corrects the computed values leveraging gravity and magnetic field readings. Once an absolute angular position is obtained (with respect to the gravity vector and to the magnetic North) for each body part, e.g., one node on the arm and one on the forearm, and taking into account the movement constraints of each body joint, it is possible to track the movement of a person’s limbs.

The system has been conceived to be scalable in terms of number of nodes, hence guaranteeing the possibility to monitor several body sections. During the algorithm and system design, special attention will be given to the aspects of immunity and compensation of environmental effects such as temperature and magnetic fields, thanks to the multi-physic simulation methodologies introduced with the SMAC platform.

The system requirements are the following:

- At least two sensor nodes, each one equipped with tri-axial gyroscope, tri-axial accelerometer, tri-axial magnetometer
- Each sensor node has to perform a preliminary sensor fusion based on Kalman filtering
- Each sensor node has to compensate temperature effects (between 0 and 50°C) and magnetic disturbance caused by vicinity to ferromagnetic elements
- The sensors shall transmit real-time data to a central unit able to display their relative positions in space
- Each sensor node’s maximum current shall be less than 100 mA at 3.3V.
- Each sensor node will be powered by battery
- The accuracy of limb tracking in static conditions shall be < 2°
- The opportunity of wireless data transmission will be investigated.

The general structure of the sensor node is depicted in Figure 5, together with the main environmental interactions involved in the application.

![Diagram](image)

**Figure 5: System partitioning of Wearable Sensing Equipment for reliable drift-free limb tracking**

Development and optimization of the demonstrator are based on a system-level model relying on accurate component representations and taking into account multi-physical effects. The availability of a prototyping platform is fundamental for supporting optimization strategies and the design of enhanced applications. A virtual system-level prototype enables firmware and software development and the evaluation of critical application effects before assembling a physical sample system, thus lowering development costs and shortening design time.

As a matter of fact, available system-level design techniques mostly rely on ad-hoc component models built from general equations and customized by means of data extracted from experimental characterization: a quite complex task in charge of system designers. Some examples can be found in the literature, where, e.g., accelerometers models have been developed by the users [1] [2] [3]. Conversely, the models to be used for this demonstrator are obtained by means of abstraction from low-level representations directly available from the device designers, taking into account the real physical and technological effects.

It should be also noted that while building the system-level model, the trade-off between accuracy and simulation speed needs to be carefully balanced: over-detailed component models may lead to prohibitive application development time, while “fast” sketchy models can lead to unreliable application designs whose real behaviour may prove to be different from the expected.

In addition, the methodology provided by the SMAC Platform allows evaluating the application performance without requiring expensive and large laboratory equipment: in the case of limb tracking, the usual laboratory setup for performance characterization includes costly vision-based systems employing a number of cameras,
markers on the body and complex motion tracking algorithms. Simulation of the system will allow evaluating the limb tracking accuracy in mission-like conditions.

The demonstrator is composed of a set of sensor nodes (initially two), based on the iNEMO M1 system-on-board manufactured by STMicroelectronics.

In the following, the main features of the sensors included in the iNEMO M1 system-on-board are presented. Regarding the 3-axis digital gyroscope L3GD20:

- 3 selectable full scales: ±250, ±500, ±2000 dps
- I2C/SPI digital interface
- 16-bit rate value data output
- 4 different user selectable ODRs: 95, 190, 380 and 760 Hz
- Integrated Low Pass and High Pass filters with selectable cut-off frequencies
- Embedded FIFO.

The main characteristics of the geomagnetic module LSM303DLHC are

- 3 magnetic field channels and 3 acceleration channels
- From ±1.3 to ±8.1 gauss magnetic full scale
- ±2g, ±4g, ±8g, ±16g dynamically selectable full scale
- 16-bit data output
- I2C digital interface
- Embedded FIFO.

The virtual prototype for a sensor node will include models for the MEMS accelerometer, magnetometer and gyroscope and the sensor fusion algorithms. The main building blocks will be abstracted to SystemC and SystemC-AMS and TLM modules to be simulated in the SystemVue framework at system level. In addition, a limb movement simulator environment will be used for synthesizing suitable inputs for the sensor models while injecting possible environmental perturbations. The latter will be useful for estimating system performance without requiring "real" prototypes and laboratory measurements. The requirements of the system model are the following:

- Integration of SystemC / SystemC-AMS / TLM models for tri-axial gyroscope, tri-axial accelerometer and tri-axial magnetometer for each sensor node
- Simulation of multi-physic interaction including mechanical (acceleration and angular velocity), electromagnetic (Earth’s magnetic field and disturbance fields) and thermal effects (sensor transfer functions)
- Integration of sensor fusion algorithms on each sensor node
- Integration of (at least) two sensor nodes in comprehensive system model in the SystemVue environment
- Modelling of acquisition, elaboration and data transmission latency
- Definition of limb movement simulator environment able to synthesize sensor input values
- Definition of system-level performance evaluation system
- Simulation elaboration time comparable to real time.
Figure 6 illustrates the SMAC Platform tools involved in the development of the demonstrator.

**Figure 6 Wearable Sensing Equipment Design as part of the SMAC Platform**

Purple arrow and box outlines identify tools and flows employed in the design and development of the Wearable Sensing Equipment.
4 State-of-the-art analysis and gap identification

A case based State of the art analysis has been examined in deliverable D1.1.1 here we are going to cover two more areas that correspond to the new demonstrator.

In the state of the art and gap analysis we need among others to answer to the following questions.

1) What tools are used today for the design of the test cases-demonstrators (not taking into account any SMAC work)?
2) What are the gaps in the flow today (i.e. what is making it hard today without any of the SMAC results)?
3) What gaps do you expect to be closed by SMAC project work, by using the SMAC platform?
4) From which task/deliverable will the solution to close these gaps will come?

4.1 Fluidics

For the Pico-projector actuator a fluidic modelling has to be considered, for inserting in the simulation chain the effects due to the air contained around the mirror, effecting his displacements. The models for microfluidics are a very challenging problem, because the differential equations to be solved are ones of the most complex. In fact in most of the FEM tools the microfluidics solvers are split in different parts, for having a controllable set of equations and for obtaining a simulation with reasonable times of processing.

One of the examples is given by Comsol, where in the Tutorial “Vibrating Micromirror with Viscous and Thermal Damping” (Model ID: 14731) it is modelled how micromirrors are used in certain MEMS devices to control optic elements. This model of a vibrating micromirror surrounded by air uses the Thermoacoustic-Shell Interaction user interface to model the fluid-solid interaction, and it thus includes the correct viscous and thermal damping of the mirror from the surrounding air. The resonance frequency of the mirror when under a torquing load is studied in the frequency domain by means of both frequency-response and eigenfrequency analyses. A simple RLC model is fitted to the system”, as reported in the Comsol documentation. This simple RLC model has the advantage of being fast, but will not include certain nonlinear effects to be considered for system simulation. Another possibility is to transfer the damping coefficients obtained by FEM into a more complex model generated with MEMS+. For each eigenmode a different set of damping coefficient would be required. The resulting model is able to consider fluidic-based damping effects together with nonlinear effects of the mechanics and electrostatics (e.g. disangement of comb fingers), while being at the same time compatible with EDA tools such as Cadence, Simulink or SystemC-AMS. Model-order-reduction methods can be further applied in an automatic method to the MEMS+ model in order to reduce even more the simulation time.

So the system can be modelled and the work inside SMAC will be to setup the needed model for the demonstrator device and, having the FEM results, to include them in the SMAC platform, adding the possibility of doing the integrated simulation with the surrounding system. In this way the classical solution given by actual vendors as Comsol, Ansys or Coventor, will be overcoming, giving to the designer the...
possibility of simulating his system in a real integrated way. The immediate benefit of this approach is related to the fact that now the simulations of fluidics are done in a separate environment, then the results are extracted and used for the simulation at higher level. Coventor was one of the first that started to introduce an integrated approach, but, in particular for fluidics, a lot of work has to be done yet for reaching the possibility of simulating the systems in an integrated platform. In terms of simulation quality and performances, a direct interaction between higher level and FEM results can give the possibility to the designer of generating more detailed models from the FEM engine, and use them for reaching more precise models and simulations at system level. It is also sure that an integrated platform can simplify the simulation procedures and reduce the simulation time, allowing the designer of doing a larger number of tests and so a better optimisation, for example, of the driving circuits or the read-out interfaces at electronic level, but also a better fitting of electronic requests of the MEMS. In particular this last aspect related to the decrease of simulation time will be taken in account in the SMAC platform, driving the efforts in the direction of the generation of precise models derived from FEM simulations, but in formats that can be efficiently used from higher engines and drastically reduce the simulation time.

4.1.1 Fluidics Domain flow Gap Identification

The SMAC platform will bring about a fundamental added value in today scenario of smart systems simulations in the integration perspective, as to our knowledge many tools are available to design and simulate the different components but they do not work together without the SMAC VPP framework.

Today the FEM analysis is almost completely disconnected from the simulation at electrical and system level. Even inside the FEM CAD Tools, to simulate together fluidics and electrical effects it is complex, or not possible too, because the solvers are different. Comsol, Coventor, Ansys are the CAD tools more diffused for fluidics simulation, all of them having specific sub-tools or solvers.

The gap is related to the impossibility of integrating the fluidic behaviour with, for example, the circuit that is driving the electrodes for managing the electrophoretic movement of a liquid in a microchamber. Coventor started to introduce some solutions, but they are not complete yet.

The SMAC approach has the goal of giving the possibility to the designer of having in the same platform the precise modelling at FEM level, together with the electrical and architectural model of the driving electronic circuit. In particular for fluidics, the work to be done is huge, and in SMAC it is not possible to reach the final solution. But the idea of the approach and the first steps in the right direction will be done.

In fact, the leitmotif in SMAC approach is to lay out a profound integration of some of the most important simulation languages and tools, which are today available in the field of microfluidic (in particular, FEM tools such as Ansys, Comsol, Coventor) or photonics (optical design software, Digital Signal Processing software, Advance Designing Systems software for electronic control, etc.). The planned integration will provide and extremely powerful tool to make the design and verification process, in the same time, quicker and more efficient than today.

- From the point of view of effectiveness, we observe that, in today activity without the SMAC platform, designers have to simulate, separately, different physics and engineering domains and translate respective results in different languages, to try to get an idea of the final behaviour of the device. In each step, design optimization brings about a trade-off between some fixed specifications and some other less desirable characteristics of the devices, which in that particular domain could
appear as “minor” problems. Nevertheless, the integration of all the functionalities could lead to an unexpected amplification of those detrimental features that appeared as “minor” problems when just one functionality per time was considered, so impacting negatively the behaviour of the whole system. High level integration is an extremely efficient tool to overcome all these inconveniences, allowing at every stage a more realistic simulation process.

- From the point of view of the **speeding up** of the process, high-level simulations bring about a rapid recognition of the most critical aspects of the device when considered as a whole. This can be performed even at quite precocious stages of the device design process. Once the most critical aspects are picked out, a strong and effective focus is possible, exactly on them. This effort concentration gives an advantage even at a single domain simulation level, speeding it up and orienting designer trade-off decisions on a more reliable base.

For these reasons, a global simulation of the overall system, as devised by the SMAC platform, will allow to fill a substantial gap with respect to today state-of-the-art, ensuring a much more efficient and rapid answer to any inconvenient feature, coming out at any steps of the design process.

### 4.2 Photonics

**UNOTT (optical medical device)**

To design an optical medical device, several domains will need to be considered. Figure 1 shows a typical setup of an optical medical imaging system. Tissue is illuminated by light source (e.g. Laser and LED). The backscattered light is imaged onto a photodetector array. The generated photocurrent is converted to voltage and sampled by ADC. Digital signal is processed in back-end such as DSP and FPGA. The system covers the domains of optics, tissue, sensor, analogue and digital. Conventional design methodology is to deal with these domains separately: model the light source and optical path using optical design software; model the interaction of tissue and photons using numerical simulation (e.g. Mote Carlo); model the sensor and define the size of photosensitive area by estimating the incoming light; model the subsequent analogue and digital circuits by estimating the incoming signal.
The state of the art of integrated optics design in SMAC platform is to avoid the fragmented design process. A hardware engineer will benefit from a unified model which handles all of these domains (or at least can handle Optics+Tissue+Sensor). Building such a model will need substantial experimental data to capture detailed information, especially the interaction of biological tissue and light. For example with different optical wavelength, the AC/DC ratio of the backscattered light is different, as shown in Figure 9.

**Figure 8 A typical setup of an optical medical imaging system**

**Figure 9 AC/DC ratio of the light scattered back from skin vs. optical wavelengths**
The model will be implemented in Matlab script and Verilog-A language, and can be used in Cadence, Matlab and ADS. Model input parameters are shown in Figure 1, including light power, wavelength, working distance, size of the sensor, spectral sensitivity etc. Most of the work will be reported in D3.4.2 and D4.4.3.

4.2.1 Photonics Domain flow Gap Identification

To design the test cases-demonstrators (photoplethysmography), a number of design tools have been used including optical design software (e.g. Zemax), numerical simulation (e.g. Monte Carlo) in C++, ModelSim, Cadence, VerilogA, and Matlab.

Typically an optical medical device covers the domains of optics, tissue, sensor, analogue and digital. Conventional design methodology is to deal with these domains separately: model the light source and optical path using optical design software; model the interaction of tissue and photons using numerical simulation (e.g. Monte Carlo); model the sensor and define the size of photosensitive area by estimating the incoming light using the experimental data; model and simulate the subsequent analogue and digital circuits using electronics design softwares. The results from one tool will be fed into the other so it is a very fragmented design process. Human error is also a factor when considering the tools is run independently.

The state of the art of integrated optics design in SMAC platform is to avoid the fragmented design process by developing a unified model to enable an automatic design process. Hardware engineers will benefit from the model which is capable of handling all of these domains (or at least can handle Optics+Tissue+Sensor). The model will be implemented in Matlab script and Verilog-A language, and can be used in Cadence, Matlab and ADS within the SMAC platform. Model input parameters are shown in Figure 8, including light power, wavelength, skin reflection coefficients, working distance, size of the sensor, spectral sensitivity etc.

The deliverables in WP3 and WP4 (i.e. D311, D312, D321, D322, D341, D342, D411, D412, D413, D421, D422, D423, D441, D442, D443) will be expected to close the gaps. Most of the work on the unified model will be reported in D3.4.2 and D4.4.3.
5 SMAC Dashboard

In this section we shall justify the effort to be spent on the SMAC Platform Dashboard explaining its purpose and specifying the functionality. The technical requirements and the Models and tools requirements specification in order to be SMAC compliant will be part of the D6.5.2 document.

5.1 Purpose

The SMAC Dashboard helps to tie together the SMAC concepts and requirements and to create a community of users that will at first strengthen and disseminate, and then preserve and further develop, the methods and tools for smart-system design and simulation developed in the Project framework.

The Dashboard lets a user (mainly identified as a system integrator) apply the SMAC methods and tools to its own design, facilitating the use of the right tools and the exchange of information between them. Not necessarily all users will use all tools (or will have all licenses), but the interface structure can be open-source and distributable, and once the basic structure and interface have been defined (including development language and supported operating systems), each partner in the consortium or external user will have the possibility of integrating tools by means of customized procedures.

5.2 Functionality Specification

The SMAC Dashboard shall:

- Provide a way to configure the available SMAC Platform tools for the user under an operating system (similarly to ST’s Unicad) and verify the setup
- Enable the creation of a new smart system through the instantiation of components linked to their representations at different abstraction levels
- Provide a way to launch model conversion tools (translation/abstraction/refinement)
- Enable simulation of a single component at a specific abstraction level
- Enable simulation or co-simulation of a set of component representations
- Support hierarchical design
- Manage simulation Projects linked to components and system representations
- Be scalable and enable the integration of additional tools and procedures
- Support management of archiving, backups, versioning and data transfers.

Additionally, the Dashboard should

- Support the user in the definition of testbenches (stimuli sources) and their management through different level of abstraction
- Be compatible with different operative systems (Unix, Linux, MS-Windows)
- Be compliant with industry standard flows such as ST’s Unicad
- Support the user in the management of application requirements and the use of the IP-XACT standard.
The main components of the Dashboard will be:

- The user interface, borrowing concepts and visual appearance form the already known SMAC representations (e.g., domain/abstraction level matrix)
- Command line scripts and configuration files, able to launch the required tools and set up the operating environments
- A component management system for the user’s design, handling hierarchies and properties (not necessarily interconnections, which are handled in each specific simulation/cosimulation tool)
- A simulation file management system able to link project files (e.g., SystemVue workspaces, Visual Studio solutions, etc.) to component representations and system views.
6 SMAC Open Source Test Case

The SMAC Open Source Test Case represents a widely heterogeneous system, composed by aggregating Intellectual Properties Cores (IPs) from different domains (all domains included in the SMAC platform are covered by this open-source test case).

The system exchanges information with the surrounding world by sensing the external acceleration applied to the physical system and communicate with a RF wireless components. Moreover, a serial interface is given to be used for program the system or to retrieve data from it.

6.1 Composition

The Test Case can be divided in functional and non-functional parts. The interconnection of the functional parts provides the description of the overall behavior of the platform, while non-functional components are used to model parameters such as energy and power consumption.

![Figure 10: Overview of the SMAC Open Source Test Case](image)

Figure 10 gives an overview of the composition of the Test Case system. In the picture it is possible to notice two different layers composing the model (i.e., the functional and non-functional layers). The figure shows also the interfaces and connections used to communicate among the components and with external devices.

Considering the different domains composing the horizontal dimension of the taxonomy proposed in Figure 2, the different design domains are highlighted by the use of different colors in Figure 1. Red is used for MEMS Sensors and Actuators, Black for Power Sources and green for Discrete & power devices domain. Grey indicates Analog and RF components, Blue is used for Digital Hardware and Yellow for Embedded Software. Interconnection and interfaces of functional components are depicted by the orange parts and the non-functional connections are highlighted by dashed lines.
Components modeling the functional description of the platforms are:

- the **MLite-CPU** is a general-purpose CPU, based on the MIPS architecture. It belongs to the Digital HW domain and the original model is described in VHDL. It is available on OpenCores as a sub-part of the Plasma project;
- a **Memory** is connected to the CPU and to the bus, it is used to contain the software that will be executed by the system. It belongs to the Digital HW domain and it is described in VHDL;
- a **Universal Asynchronous Receiver-Transmitter (UART)** provides a serial interface to the system. It is an open-source implementation of a UART components compatible with the 16550 standard. It is originally described in VHDL and available on OpenCores;
- a **C/C++ Software Application** is stored in the memory and executed on the CPU. It belongs to the Embedded Software domain;
- the **XYAxis** is an accelerometer that belongs to the MEMS Sensors design domain. Its description is provided as VerilogA implementation, obtained from a MEMS+ model and furnished by Coventor. It provides for the sensing of the external acceleration applied on the system over two directions;
- the interface to other smart sensor is provided by a **RF Transceiver**. It belongs to the Analog and RF domain and its original description is given in VerilogA;
- an **APB Bus** is used to connect the functional components of the platform. It belongs to the Digital HW domain; it is provided partially in VHDL and in SystemC.

Analog and MEMS components are wrapped by Analog-Digital and Digital-Analog Converters in order to be connected to the digital Bus.

Non-functional description is composed by two components:

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- The model of a **Power Source** that belongs to the Power Sources domain. It is a model of a photovoltaic panel with 25 cells, implemented as Matlab model;
- The model of an **Energy Storage Device** that belongs to the Discrete and power device domain. It is a Li-ion rechargeable battery implemented in Matlab and modeled with a simplified equivalent circuit model.

The correct interconnection of all components will be represented by an IP-Xact representation. This language and its extensions allow to model the connection through ports originally represented with different languages (e.g., VHDL, Verilog, SystemC, VerilogA, etc.). The IP-Xact representation allows to formally model the interconnections among the modules.

### 6.2 Objectives and required transformations

Considering the Simulation-levels dimension of taxonomy in Figure 11, the main objective is to obtain a model that allow to simulate the entire system at its highest level (i.e., transactional). However, the available components descriptions are currently described at lower levels.

Digital HW components are described at structural level by employing a hardware description language. Analog HW is described by exploiting MEMS+ and then translated in VerilogA. Thus, it is described at the physical simulation-level. The non-functional models are provided as Matlab models at structural level. Finally, the RF model is provided as Analog description using VerilogA at structural level.

Thus, in order to be represented in a homogeneous transactional description some transformations are necessary. In particular, Digital and Analog HW have to be abstracted into functionally equivalent C/C++ models. Network interfaces, such as the RF Transceiver, have to be described in SCNSL and connected to the SCNSL model of the network, in order to simulate more instances of the system, communicating with each other. Non-functional components have to be modeled in C/C++ and connected to the functional components in order to estimate non-functional parameters during the functional simulation.

### 6.3 Application

The application implemented by the test-case aims at exploiting completely the heterogeneity of components composing the platform. In particular, the Accelerometer senses the acceleration over two axis of the system. The data related to the acceleration are stored in the Memory model. The Software executing on the general-purpose CPU elaborates data provided by the Accelerometer and sends the results to other smart devices by using the RF Transceiver, for instance to send commands to connected actuators. The RF Transceiver is also used to receive data by other devices. The received data can be used by the software to compute the acceleration parameters. The UART component can be used to program the device. Through the serial interface it will be possible to communicate with the system, passing to it the software to execute or specific parameters for computation.

Possible utilization scenarios for this system are for fall detection or impact detection, for instance in automotive applications.
7 H-Inception Collaboration

The partners involved in projects SMAC and H-INCEPTION agreed to cooperate in the field of multi-domain simulation in support of the design of smart heterogenous systems. Despite the different focus of both projects, there exists a substantial basis for cooperation, situated in the area of practical implementation of multi-domain simulation flows, where both projects identified weaknesses or gaps.

Table 2: Comparison of the SMAC and H-INCEPTION approaches

<table>
<thead>
<tr>
<th></th>
<th>SMAC</th>
<th>H-INCEPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-domain</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Simulation Tools</td>
<td>Several tools</td>
<td>Single tool (SystemC + extensions)</td>
</tr>
<tr>
<td>Abstraction Levels</td>
<td>All levels (physical till transactional)</td>
<td>High level (transactional, functional)</td>
</tr>
<tr>
<td>Flows worked on</td>
<td>Creating several new flows</td>
<td>Extending existing flow</td>
</tr>
</tbody>
</table>

H-INCEPTION is focussing primarily on enabling multi-domain virtual prototyping early in the design phase relying on SystemC and extending it where required. SMAC, on the other hand, strives to cover a complete design cycle and as such covers work related to co-simulation with domain-specific simulators at lower abstraction levels as well as to abstraction flows allowing to bring multi-domain models together in a single higher-level engine.

However, both projects are confronted with the problem of having to manage a large number of connection types (arising from the multiple domains coverage), as well as to deal with some level of polymorphism on the interfaces which is essential to provide flexibility in composing models to support the multiple simulation scenarios that can arise during the design of a complex system. As IP-XACT was instrumental in facilitating the distribution of digital IP-blocks and their integration in design-flows [4], it naturally came out as candidate choice for the automation of multi-domain simulation flows envisioned both by SMAC and H-INCEPTION.

Originally intended only for the digital domain, it is clear that the IP-XACT standard [5] might require amendments or extensions in order to deal with the specific needs of multi-domain simulations. In September 2013, so-called “vendor extensions” were proposed for IP-XACT which allow to extend its scope towards multiple domains.

7.1 IP-XACT Overview

As described in [6], IP-XACT is an XML-based standard for describing electronic intellectual property (IP)—that is, blocks of electronic logic suitable for inclusion in complex integrated circuits, commonly known as systems on chips (SoCs). IP-XACT provides a common database infrastructure for electronic design that the industry can use as an organizing principle for attacking a broad set of problems in electronic design, including low-power management, embedded-software debugging, constraint-driven design, and high-level verification. It provides support for verification IP and interfaces (such as monitors), configurability data exchange, explicit
hierarchy support, and APIs for exchanging design metadata. Specifically, the IP-XACT standard comprises the following:

- Full RTL design support, including any component type, hardware description language, configuration, or connection type at this abstraction level;
- A set of architectural rules that defines constraints and guides the connectivity and use of each IP in a given platform;
- A set of bus definitions that describes the meaningful signal names of each bus type so they can be connected to compatible IP;
- A mechanism to define any bus structure in terms of signal names that the system can use to hook up other IP;
- A structure for describing the instantiation and connectivity of components or component models in a design;
- Methods for defining register information, memory maps, and address spaces;
- A way to separate platform-specific metadata required for a piece of IP that might not be part of the generic IP definition;
- A way to specify configuration options for a piece of IP and a way to select these options;
- A mechanism to specify and handle associations between a design’s configurable elements;
- A way to store persistent data that supports the iterative process of user configurations and the options used to derive them.
- A basic interface to enable configuration and generation scripts; and
- A mechanism for adding implementation constraints to IP descriptions to help the flow to synthesis.

The data-structures and programming interfaces defined in the IP-XACT standard cover mainly the digital and software aspects of IP-blocks and the related design flows. In particular, the current IP-XACT standard does not support the description of analogue or mixed-signal IP blocks, or any other domain beyond digital and software. The IP-XACT is nevertheless extensible and provides “extension containers” identified as the preferred location for new data-objects. The “Accellera Vendor Extensions for IEEE 1685-2009” [7] makes use of these containers to add some basic multi-domain features to the standard.

7.2 IP-XACT Vendor Extensions

The IP-XACT Vendor Extensions document [7] enables the use of the IP-XACT standard IEEE Std 1685™-2009 in domains that are not supported by the IP-XACT standard yet. More specifically, this proposal enables the use of the IP-XACT standard in analog and mixed signal flows, physical design planning flows, and power flows. The proposal dates from September 2013, and being very recent, practical usage guidelines are not available. In fact, the best way to effectively make use of the defined vendors extensions is a matter of active research, to which the SMAC and H-INCEPTION project are contributing. H-INCEPTION has a prominent role in this picture, having at least one partner directly involved in the responsible working group.

In order to accumulate experience and build expertise on the effective usage of the IP-XACT vendor extensions, SMAC and H-INCEPTION agreed to work together on several test-cases where IP-XACT extensions will be used to describe IP-blocks or complete designs covering several domains.
A initial survey of the IP-XACT Vendor Extensions revealed that it implements features allowing to match the existing multi-domain capabilities of behavioural modelling standards as VerilogA, VHDL-AMS, and SystemC. In particular support is provided for the definition of new disciplines which enable the management of domain-specific signals and ports. So it is expected that the IP-XACT extensions in [7] should allow to describe models for components operating in several domains. However, the extensions proposed in [7] do not cover the “measurement” aspect (defining how some quantity used at a given abstraction level is measured in terms of quantities used at the level below). As a result one can expect limitations of the currently defined extensions to cover abstraction and drill-down flows which are essential parts of the design process. Another consequence is that it will be difficult to represent transformation of variables (eg. Voltage to phase and vice-versa as in [8]) and implement automated flows instanciating “adaptors” for them.

7.3 Future Work

In order to accumulate experience and build expertise on the effective usage of the IP-XACT vendor extensions, SMAC and H-INCEPTION agreed to work together on the following test-cases provided by SMAC partners:

- EDALAB will provide extensive IP-XACT descriptions of the open-source test-case
- ONSEMI will build extended IP-XACT for the models in the dual-carrier substrate modelling framework
- ONSEMI will build extended IP-XACT models for the DC-DC converter test-case including ports for radiated EMI

MAGILEM from H-INCEPTION will provide its IP-XACT editing and generation environment to help the SMAC partners in their evaluation work.
8 Conclusion

In addition to the methodological activities specified in D1.1.1 we have specified the demonstrating activities necessary to validate the SMAC platform or at least large and meaningful portion of it.

- Pico-projector actuator (VPP)
- Wearable Sensing Equipment for reliable drift-free limb tracking

Supplementary work not foreseen at the beginning of the SMAC project but found out to be relevant to the project final scope has also been specified.

- SMAC dashboard
- Open Source test case
- Modelling Standard (in collaboration with the H-Inception funded project)

8.1 Impact of the Deliverable

As described in the Section 4, the present document has analysed the existing gap in the current design flow and where the EDA solutions have to be in order to enable the designers to work for the next generation SMART devices that include sensors or actuators the Fluidics and Photonics design domain.

Its purpose has been to clarify the limitations in today’s designs in terms of software tools, design flows, and identify the missing pieces for a multi-disciplinary, multi-physics simulation environment.

The analysis has leaded to the specification of new developments for the SMAC consortium. This deliverable will be used as a reference for the Project VPP Demonstrator (WP5) and the additional work done on the Optical Medical Device. The developments of the HIF suite and other necessary tools are done inside the WP2 and in WP3 all the modelling works.

It also defines the standardisation aspects of the SMAC Modelling works inside the WP3 and more generally it shall contribute in making the SMAC platform a tangible concept via the creation of a SMAC platform Dashboard and an Open Source Test case. Both items are part of the many actions to ensure a larger project impact, exploitation and dissemination.

The deliverables in WP3, WP2 and WP4 (i.e. D3.1.2, D3.2.2, D3.4.2, D4.1.2, D4.2.2, D4.4.2, D4.4.3, and D2.2.2) will be expected to close the gaps. Most of the work will be reported in D3.4.2 and D4.4.3 and D5.4.1 D5.4.2, D5.4.3 deliverables.
9 Bibliography


