# EXECUTIVE SUMMARY

## ARCHEO-E2E

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# DOCUMENT STATUS SHEET

| Version | Date | Pages | Changes |
|---|---|---|---|
| 1.0 | 18/01/2013 | 19 | First version. |
| 1.1 | 27/02/2013 | 23 | Updated version after FCR. |

# TABLE OF CONTENTS

# LIST OF TABLES AND FIGURES

# 1. INTRODUCTION

## 1.1. SCOPE

This document is the Executive Summary of the ARCHEO-E2E project, performed under ESA contract 4000104547/111NL/AF by a consortium led by GMV and including the following institutions:

- GMV (Spain)
- Aresys (Italy)
- Universidad de Valencia (Spain)
- Universitat Politècnica de Catalunya (Spain)
- IPSL / Laboratoire de Météorologie Dynamique (France)

The output of the ARCHEO-E2E Project consists of the following Technical Notes:

- ARCHEO-E2E-TN-001 - EO Missions and Elements Categorization
- ARCHEO-E2E-TN-002 - EO E2ES Reference Architecture
- ARCHEO-E2E-TN-003 - Generic Building Blocks Technical Specification
- ARCHEO-E2E-TN-004 - EO E2E Common Semantics and Dictionary
- ARCHEO-E2E-TN-005 - Reference Architecture Evaluation Methods and Criteria
- ARCHEO-E2E-TN-006 - Design Development Process using a Reference Architecture
- ARCHEO-E2E-TN-007 - Reference Architecture Concept Evaluation
- ARCHEO-E2E-TN-008 - Reference Architecture Roadmap

A compilation of the above Technical Notes is also available in the form of a Final Report (GMV-ARCHEO-E2E-FR-001).

## 1.2. ABSTRACT

End-to-end mission performance simulators for Earth Observation missions are a useful tool to assess the mission performance and support the consolidation of the technical requirements and conceptual design, as well as to allow end-users assessing the fulfillment of requirements by the mission. ESA is currently starting the development of these end-to-end simulators during the mission feasibility studies, so that if the mission is approved, the simulator will evolve into a support tool for the detailed design definition, preparation and validation of operations, data processing and higher-level mission products generation.

However, at this stage, the evolution of the design and the processing algorithms may require modifying or even replacing the components of the original simulator, what usually translates into a complex and costly reengineering process. ESA has promoted several activities in order to reduce this reengineering process, such as for example a simulation framework able to support the development of the simulator throughout the mission life cycle.

The ARCHEO-E2E activity is framed into this context, and it has the main objective of defining a Reference Architecture for Earth Observation end-to-end mission simulators. The rationale behind this Reference Architecture is promoting reuse in the development of mission performance simulators by:

- Categorising past, current and planned Earth Observation missions to identify the main elements affecting mission performance and impacting the simulator architecture.
- Identifying the architecture elements required to model the mission depending on the type of mission and instrument, and proposing a generic Reference Architecture that could be adapted for the different mission particularities.
- Describing the architecture elements, in particular those that can be generalized for the various mission categories.
- Evaluating the Reference Architecture by comparing the development of an end-to-end simulator using this new concept vs. ad-hoc simulator development.
- Defining a roadmap to reach an operational concept for the development of end-to-end simulators based on the presented Reference Architecture.

# 2. REFERENCES

## 2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]:

**Table 2-1: Applicable documents**

| Ref. | Title | Code | Version | Date |
|---|---|---|---|---|
| [AD.1] | End to End Simulation Architecture for EO Missions: Statement of Work | TEC-xxx/09-290/xx | 1.0 | 21/01/2011 |

## 2.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.X]:

**Table 2-2: Reference documents**

| Ref. | Title | Code | Version | Date |
|---|---|---|---|---|
| [RD.1] | ESA – Living Planet Program [http://www.esa.int/esaLP/index.html] | - | - | Sept. 2012 |
| [RD.2] | Report for Mission Selection: CoReH2O | ESA SP-1324/2 | - | May 2012 |

## 2.3. PROJECT DOCUMENTS

The following documents are produced in the frame of this activity. They are referenced in this document in the form [PD.X]:

**Table 2-3: Project documents**

| Ref. | Title | Code | Version | Date |
|---|---|---|---|---|
| [PD.1] | EO Missions and Elements Categorization | ARCHEO-E2E-TN-001 | 1.0 | 29/03/2012 |
| [PD.2] | EO E2ES Reference Architecture | ARCHEO-E2E-TN-002 | 1.0 | 29/03/2012 |
| [PD.3] | Generic Building Blocks Technical Specification | ARCHEO-E2E-TN-003 | 1.0 | 29/03/2012 |
| [PD.4] | EO E2E Common Semantics and Dictionary | ARCHEO-E2E-TN-004 | 1.0 | 29/03/2012 |
| [PD.5] | Reference Architecture Evaluation Methods and Criteria | ARCHEO-E2E-TN-005 | 2.0 | 14/01/2013 |
| [PD.6] | Design Development Process using a Reference Architecture | ARCHEO-E2E-TN-006 | 1.0 | 14/01/2013 |
| [PD.7] | Reference Architecture Concept Evaluation | ARCHEO-E2E-TN-007 | 1.0 | 14/01/2013 |
| [PD.8] | Reference Architecture Roadmap | ARCHEO-E2E-TN-008 | 1.0 | 14/01/2013 |
| [PD.9] | Final Report | ARCHEO-E2E-FR-008 | 1.0 | |

# REFERENCES (paper)

[1] ESA, *ARCHEO-E2E Statement of Work* (2011), TEC-xxx/09-290/xx.
[2] ESA, Statement of Work for the BIOMASS End-to-End Mission Performance Simulator (2010), EOP-SFP/2009-05-1390.
[3] ESA, Statement of Work for the CoReH2O End-to-End Mission Performance Simulator (2010), EOP-SFP/2009-06/1397.
[4] ESA, Statement of Work for the PREMIER End-to-End Mission Performance Simulator (2010), EOP-SFP/2010-02-1450.

# 3. ACRONYMS

| | |
|---|---|
| E2E | End to end |
| EO | Earth Observation |
| E2ES | End-to-End Simulators |

# 4. RATIONALE FOR A REFERENCE ARCHITECTURE

The purpose of end-to-end mission performance simulators for Earth Observation Missions is to help in the assessment of different system implementation options, the development of retrieval algorithms at different data levels and the detailed design as well as the scientific preparation of the mission. In particular, end-to-end simulators (E2ES):

- Enable the generation of simulated Level-1 and Level-2 output data.
- Support the assessment of the end-to-end performance of the mission on the basis of Level-1 and Level-2 products simulated for selected test scenarios.
- Support the assessment of the impact of individual error sources on the output of an ideal system, both separately and simultaneously.
- Support the assessment of the performance of the retrieval algorithms and of their associated assumptions.

Usually, the first release of the simulator is developed as a prototype tool to support the initial performance assessment of the mission in Phase A. For the E2ES to evolve and support the detailed mission design during later phases, its architecture has to allow growth along two possible directions, as shown in Figure 4-1.

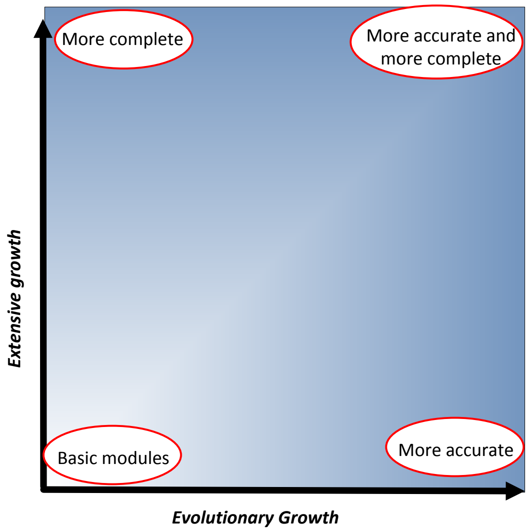


**Figure 4-1: Possible growth of the E2ES architecture**

These two directions of potential growth are:

- Extensive growth, to include more effects and achieve a more complete simulation.
- Evolutionary growth, to achieve more accuracy in the simulator.

Therefore, the idea is to define a Reference Architecture that contains the basic modules for the E2ES, while providing the required flexibility to support both extensive and evolutionary growth. This, coupled to a simulator framework and a repository of models (or building blocks - BB), will allow defining and implementing the E2ES faster and with less effort. This concept is illustrated in Figure 4-2.

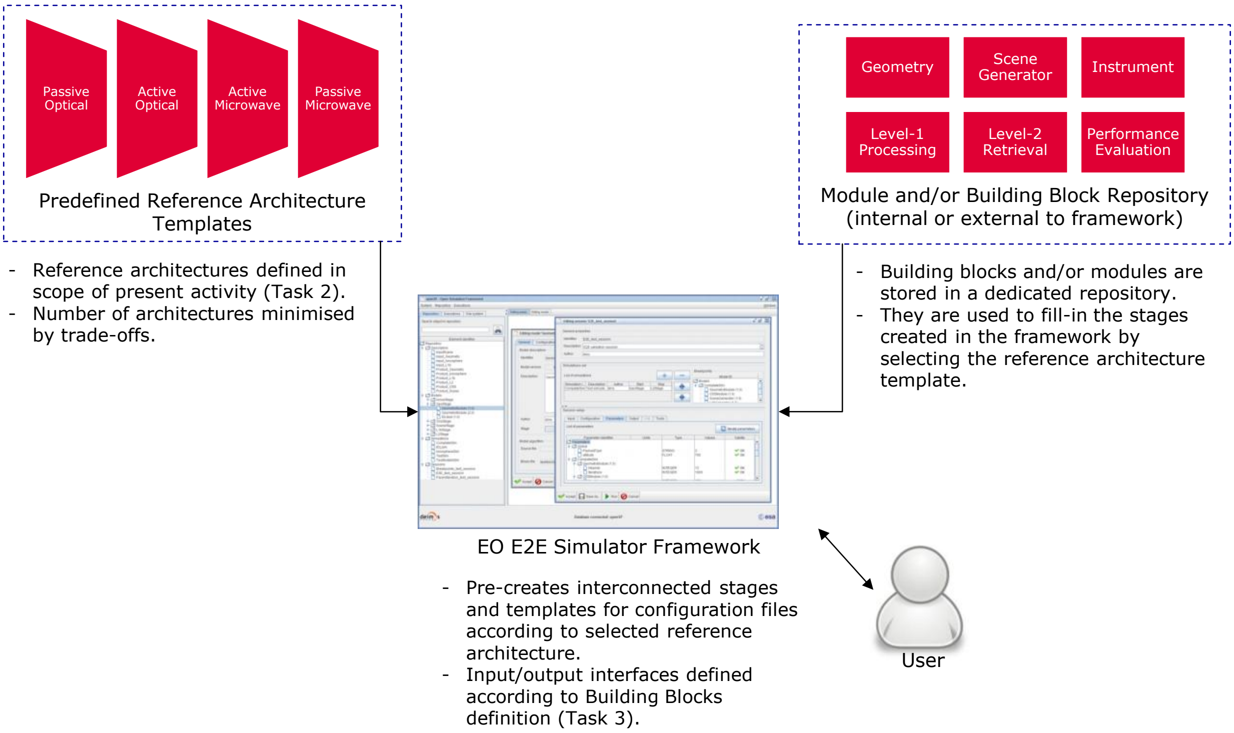


**Figure 4-2: Proposed solution for the implementation of the Reference Architecture concept**

The initial steps in the definition of the Reference Architecture have involved categorizing past, current and planned Earth Observation missions to identify the main elements affecting mission performance and having an impact over the simulator architecture. Then, the architecture elements required to model the mission depending on the type of mission and instrument have been identified, to finally propose a generic Reference Architecture that could be adapted for most EO missions.

# 5. MISSION AND INSTRUMENT SURVEY AND CATEGORISATION

A detailed review of past, current and planned Earth Observation missions and instruments has been performed to analyse the different options and their implications on the definition of the reference architecture, such as the possibility of using common blocks or defining independent processing chains.

With respect to mission categorisation, a number of criteria have been investigated, such as: number of satellites in the mission, number of instruments on-board the spacecraft, scientific objective of the mission (see Figure 5-1), links with other missions, orbit characteristics, observation geometry/scanning method, etc. It shall be noted that these criteria are interconnected. For instance, a mission consisting of a single instrument mounted in a single platform will usually have a single scientific target.

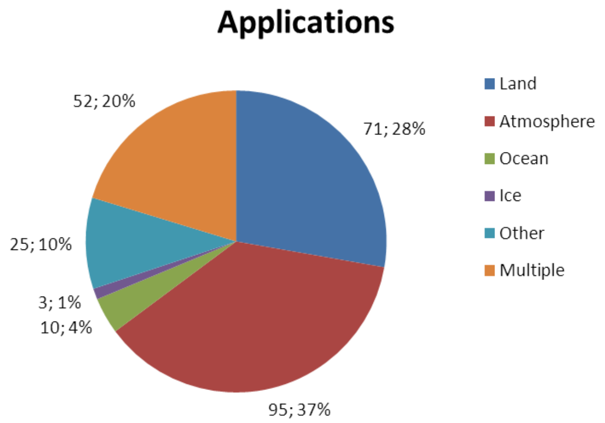


**Figure 5-1: Example of statistical analysis of the surveyed missions: area of applications.**

Taking into account the above mentioned criteria, different mission classifications have been defined and analysed (see Figure 5-2), and the impact over the E2ES architecture has been evaluated. The conclusion is that, while the mission characteristics affect the E2ES architecture at a very high level, the instrument type has a big impact at lower level, i.e. at building blocks level

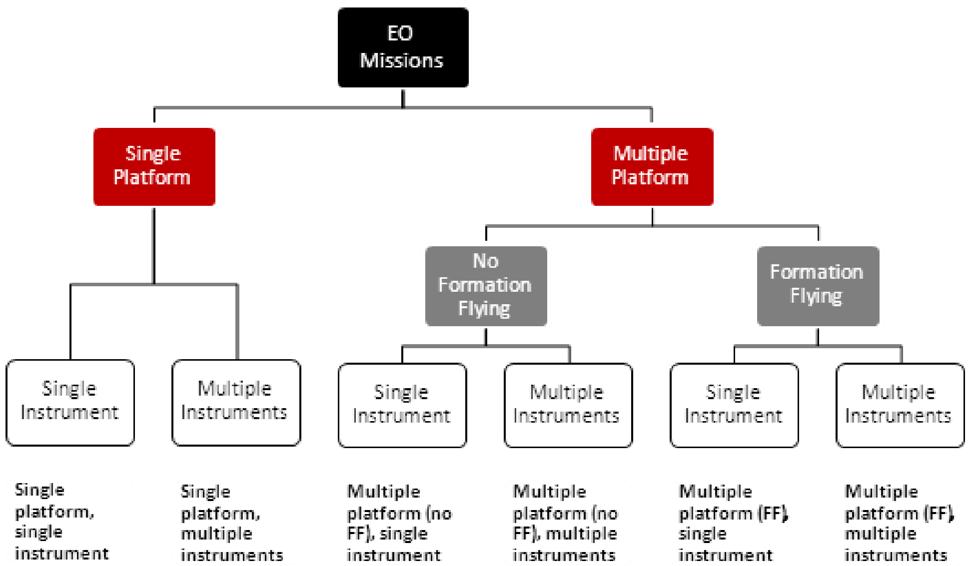


**Figure 5-2: Categorization of Earth Observation Missions by number of satellites and number of instruments in the mission**

After analysing the different instruments, and based on the experience of the team, the instrument classification selected is the one shown in Figure 5-3, in which the classification criteria is the region of the spectrum being used and the passive/active condition. This classification is, therefore, the one that has driven the development of the Reference Architecture.

The four main categories that have been defined are active microwave, passive optical, passive microwave and active optical. These cover most of the missions past, present and future, with the first two instrument types being the most common ones at least among European missions. An additional category, "others", includes instruments that fall outside any of these categories, such as magnetometers and gravimeters.

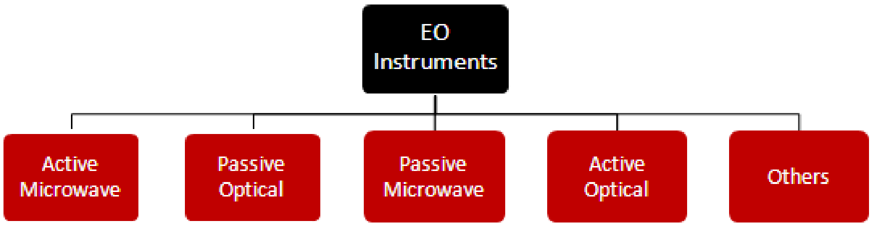


**Figure 5-3: Categorisation of Earth Observation Instruments**

Each of these instrument categories has been analysed and commonalities or "generic" elements have been identified. While there may be different options for the modelling of the different instruments, the priority has been to follow those solutions that exploit commonalities with other types of instruments.

# 6. REFERENCE ARCHITECTURE FOR E2E SIMULATORS

The Reference Architecture should cope with the categories of missions and instruments identified, but at the same time take into account the characteristics of a framework supporting future simulator developments (based on the proposed Reference Architecture). In particular the OpenSF framework has been considered as the reference framework, although this fact hasn't conditioned the definition of the Reference Architecture.

These two conditions - the application of the reference architecture to all types of missions/instruments and the use of a simulation framework - support the decision of defining certain elements at high level that would be present in all simulators, independently of the category of the mission and the type of instrument. In the reference architecture concept these high-level elements are called modules, and they could be identified as the simulator Stages (or even more, simulator Modules) of the framework.

Regarding the definition of the high-level reference architecture, one of the premises has been to keep it as simple as possible, defining very few variations with respect to the nominal solution, if possible. This allows having more coherence between the different simulators that will be implemented based on the architecture, being their reuse for other missions favoured, even if they are quite different.

Thus, the approach has been to define very few high-level architectures, depending on the type of mission (multi-instrument, multi-platform…). Then, the type of instrument has impact on the second layer, when analysing the building blocks and internal architecture of the different high-level modules.

The main premises of the Reference Architecture, illustrated in Figure 6-1 are:

- The Reference Architecture defines a series of six high-level modules and the interfaces among them that are common to all type of missions and instruments.
- Although the reference architecture is generic, it is flexible to be adapted for the different mission particularities.
- Depending on the type of instrument to be simulated each of the six high-level modules will have an internal architecture broken down in building blocks. This internal architecture is, for most cases, generic across instrument types.
- Different implementations of the same building blocks account for mission parameters, evolution of algorithms throughout the different mission phases, etc.
- Some of the high-level modules and lower-level building blocks will be generic across missions and instruments.

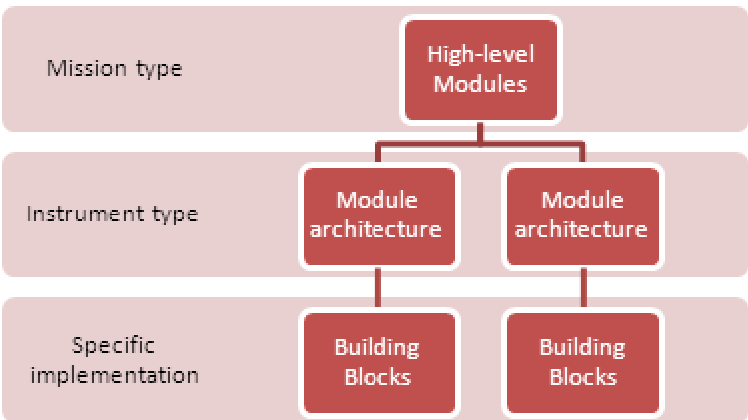


**Figure 6-1: The Reference Architecture Concept**

Including the high-level modules and the lower-level building blocks, the E2ES can be decomposed in three main elements:

- Modules (or Building Blocks): software objects that implement the chosen models.
- Data: input/output information for the models; exchanged among then different Modules.
- Configuration: defined by the user depending on the simulation to be run. Divided in:

- Configuration parameters, used to configure the Modules in order to process the data under the desired conditions (i.e. instrument characteristics, data sampling, etc.).
- Activation flags, used to enable/disable the execution of a subset of models or to select the algorithm to be adopted when the E2ES is run. These activation flags could also be used to select a particular implementation of the building block if it is shared by different types of instruments.

## 6.1. HIGH-LEVEL ELEMENTS OF THE REFERENCE ARCHITECTURE

The identification of the high-level elements of the Reference Architecture has been done from the categorization of missions and analysis of commonalities, and takes into account the project team's experience in the design and implementation of E2ES. Each of these high-level modules, six in total, implements a certain functionality of the E2ES, and has defined interfaces and configuration parameters. Table 6-1 summarises the purpose of each module and its main interfaces.

| Module | Purpose | Configuration | Inputs | Outputs |
|---|---|---|---|---|
| Geometry | Simulates SC orbit & attitude & observation geometry of each instrument | -Orbit & AOCS configuration | N/A | -Geometry data<br>-Estimated orbit/attitude |
| Scene Generator | Simulates scene to be observed and environmental effects needed for generation of stimuli to enter instrument model. | -Scene configuration | -Geometry data | -Stimuli |
| Instrument | Simulates sensor behavior, having different outputs depending on type of instrument. | -Instrument configuration | -Stimuli<br>-Geometry Data | -Raw data |
| Level-1 Processing | Generates level-1 products, from level-1a to level-1c. | -Processing configuration | -Raw data<br>-Estimated orbit/attitude | -Level-1 products |
| Level-2 Retrieval | Performs retrieval of geophysical parameters objective of the mission/instrument. | -Retrieval configuration | -Level-1 products | -Retrieval products |
| Performance Evaluation | Performs analysis of simulator outputs to evaluate mission performances. It could be run at different points of the simulation chain. | -Orbit & AOCS configuration<br>-Scene configuration | -Stimuli<br>-Raw data<br>-Level-1 products<br>-Retrieval products | -Performance reports |

**Table 6-1: Details of the high-level modules of the Reference Architecture**

Although the data flows between these high-level modules and even their order of execution could vary depending on the type of mission and instrument at which they are applied to, Figure 6-2 shows the typical generic data flow that is considered as the main Reference Architecture.

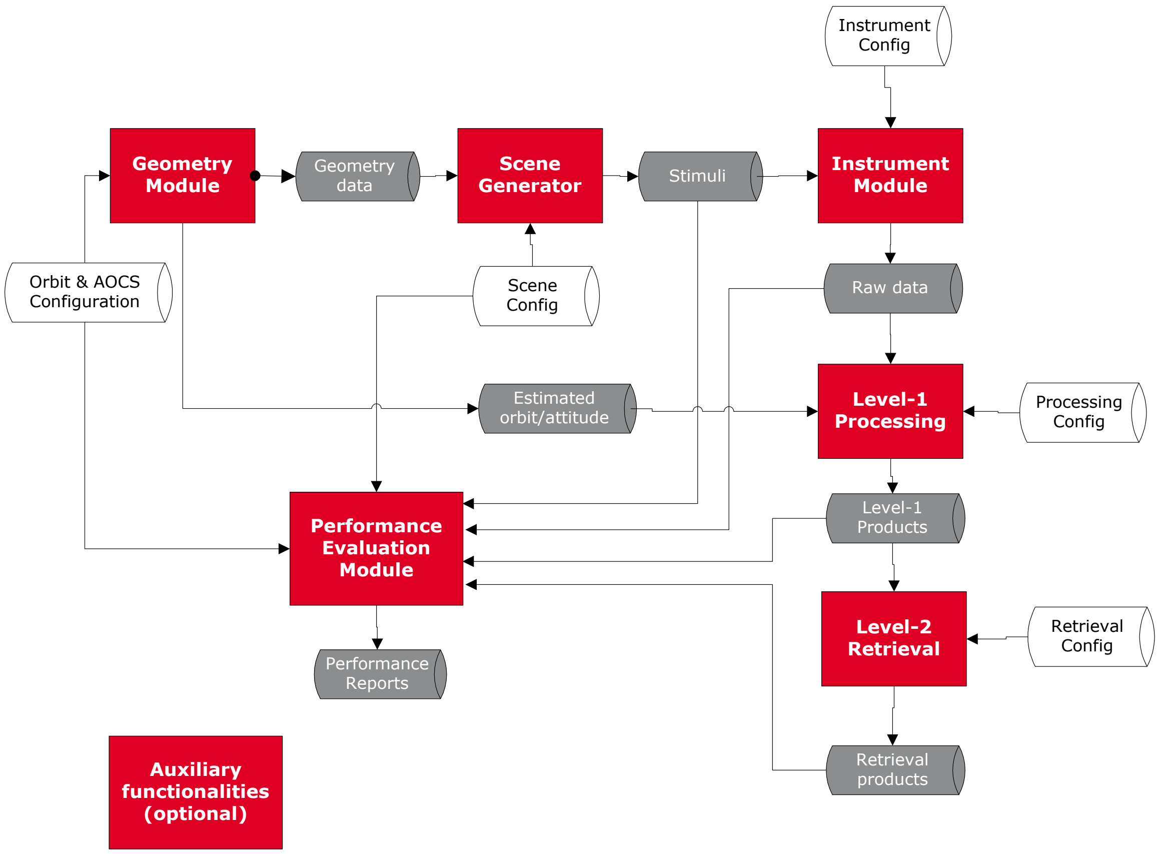


**Figure 6-2: Generic data flow at the highest level of the Reference Architecture**

The concept of the Reference Architecture, as proposed, is flexible enough to accommodate particularities of certain mission. The following are the main three variations of the Reference Architecture that have been identified:

- Nominal Reference Architecture, valid for the following categories:
  - Single instrument missions, independently on the number of spacecraft and formation flying conditions.
  - Multiple instrument missions, if each instrument is simulated in a different E2ES.
- Multiple instruments, identical biophysical parameter to be analysed. The modules of Scene Generation and Retrieval are identical for both instruments.
- Multiple instruments, different biophysical parameter to be analysed. Only the Geometry Module is shared between the two instruments.

Although the focus of this activity are the E2E mission performance simulators for Phase A, the generic architecture presented in Figure 6-2 would also be applicable to simulators during more advanced mission phases. This is important because the E2E simulator is also intensively used in later phases (C/D) of the project to support Ground Segment activities e.g. to provide test data to verify ground processor development and interfaces.

Since these activities require that the E2E simulator generates data formatted as it will be on the real interface between satellite system and ground system (i.e. Space Source Packets), the Reference Architecture presented in Figure 6-3 foresees an additional module called "Onboard Data Generation". This module takes outputs from the Geometry Module and the Instrument Module to generate raw data in the form of auxiliary packets (e.g. orbit, attitude…), image packets and transfer frames. This module will not be present in Phase A/B simulator.

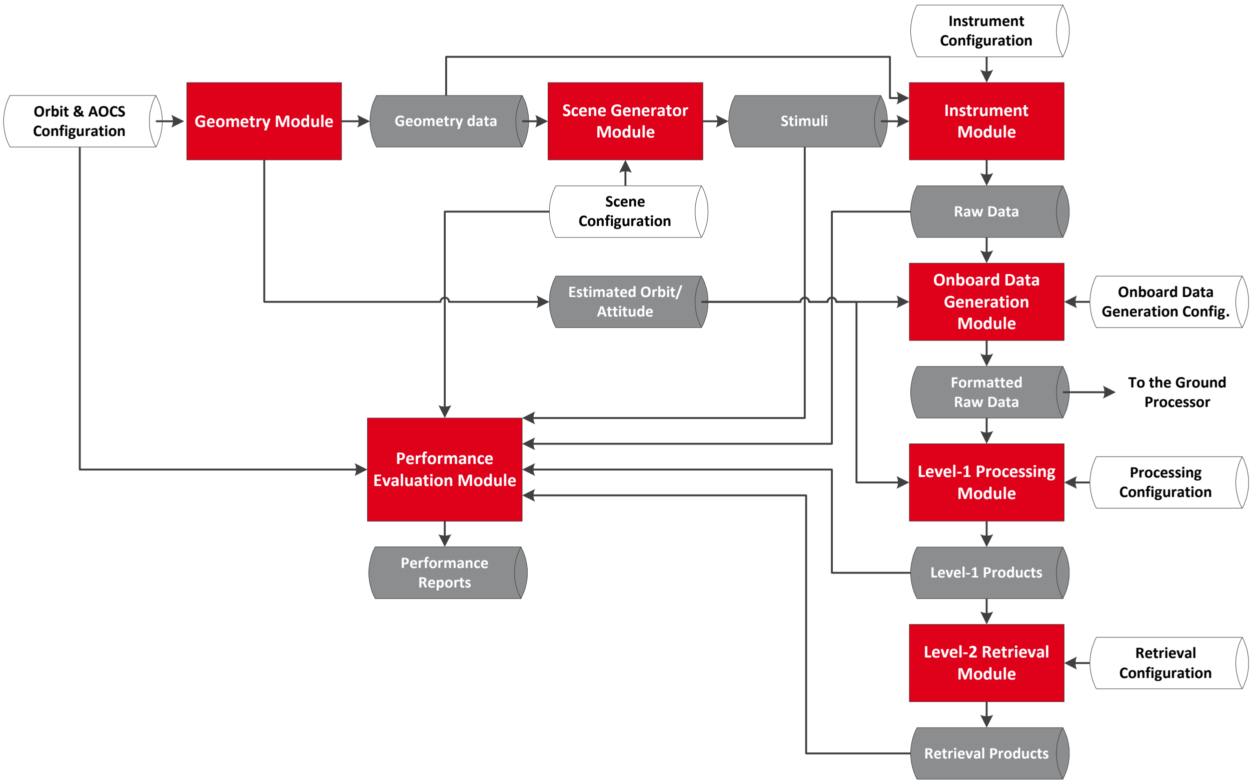


**Figure 6-3: Generic data flow at the highest level of the reference architecture (including onboard data generation).**

## 6.2. BUILDING BLOCKS

Following the Reference Architecture concept presented, each of the different high-level modules has been broken down in a series of building blocks. The granularity of the building blocks has been determined after the identification of the elements to be modelled and a thorough analysis of commonalities. Once the preferred option (or options) for the definition and implementation of a building block has been identified, the building block itself has been defined.

To ensure the adequate level of detail in the definition of the building blocks, a custom template has been developed (see Figure 6-4:). This level of detail is important to allow composability (i.e. reuse) of the architectural elements, both at syntactic (engineering) level and at semantic (modelling) level.

| Building Block Description | | |
|---|---|---|
| **General Information** | | |
| **Building Block Name:** | *Write the Building Block name here* | |
| **Instrument Type:** (*tick all that apply with ☑*) | | |
| ☐ Generic | ☐ Active Microwave | ☐ Passive Optical |
| ☐ Passive Microwave | ☐ Active Optical | |
| **Module:** (*tick applicable module with ☑*) | | |
| ☐ Geometry Module | ☐ Scene Generator Module | ☐ Instrument Module |
| ☐ Level-1 Processing Module | ☐ Level-2 Retrieval Module | ☐ Performance Evaluation Module |
| **Higher-level Building Blocks:** | | |
| *If applicable, list the higher-level building blocks up to the Module-level.* | | |
| **Functional Description:** | | |
| *Include a short functional description of the building block.* | | |

**Figure 6-4: Partial template for the definition of Building Blocks**

## 6.3. CONSIDERATIONS ON THE SIMULATION FRAMEWORK

The definition of the reference architecture and of the generic building blocks is not affected by the selection of the simulation framework, as no requirement has been imposed in the interfaces of the architecture and input/output of the building blocks. However there are a number of aspects related to the simulation framework that have implications on the way the Reference Architecture can be interpreted and on the definition of the scope of the building blocks. These aspects refer to issues such as the interconnection of the modules, the level of reusability, the flexibility in the implementation, the timing of the execution, the disk access, etc. This impact has been evaluated and the features of the simulation framework that affect the interpretation of the reference architecture and the building blocks have been identified.

The solution recommended for a simulation framework supporting the Reference Architecture concept is somewhere between a strictly sequential execution of monolithic modules and the use of building blocks as library elements that can be easily interconnected to build a high-level module.

# 7. EVALUATION OF THE REFERENCE ARCHITECTURE

The use of the Reference Architecture for the development of new simulators has the potential of reducing the reengineering process associated to the evolution of the simulator throughout the different mission phases. Moreover, the identification of common elements for different types of instruments also enables reuse of the architectural elements across several mission simulators. The next logical step to evaluate the Reference Architecture to gain an understanding of the advantages of the Reference Architecture approach with respect to the current approach. Thus, the goals of this evaluation are:

- Quantify the benefits expected from the use of the reference architecture.
- Detection of problems that may arise due to the use of the reference architecture.
- Clarify and prioritize requirements for the adoption of the reference architecture.

This evaluation will be done in three different areas:

- Analyse the process of designing and developing an E2E simulator for a specific EO mission by applying the Reference Architecture.
- Evaluate the proposed Reference Architecture concept compared to ad-hoc E2E simulators development.
- Assess the capabilities of existing simulation frameworks and repositories to support the Reference Architecture and propose, if applicable, improvements to both of them.

While establishing a software architecture is one of the most important steps in the process of designing a system, scenarios are one of the most important tools for putting an architecture into practice. Thus, it seems logical to exercise the evaluation of the Reference Architecture concept in the frame of specific mission scenarios. The three mission scenarios under which the proposed Reference Architecture has been evaluated are:

- The FLEX mission, one of the two candidate Earth Explorer Opportunity missions currently in Phase A. The FLEX mission aims to provide global maps of vegetation fluorescence to improve our understanding of the amount of carbon stored in plants and their role in the carbon and water cycles. [RD.1]
- The CoRe-H2O mission, one of the three candidate Earth Explorer Core missions, that has undergone a consolidation phase and for which a specific end-to-end simulator has already been developed. CoRe-H2O would be dedicated to making global measurements of freshwater stored in snow on land surfaces and snow accumulated on glaciers and ice caps. [RD.2]
- The SEOSAT/Ingenio mission, a Spanish Earth Observation mission currently in Phase C. SEOSAT is a high resolution imager that has the goal of guaranteeing a regular coverage of areas of national interest, offering a high operational capability in the acquisition of high resolution images. SEOSAT/Ingenio has been chosen as an scenario since the architecture of its E2E simulator differs from the Reference Architecture much more that the Earth Explorers. In addition, the fact that several version of the simulator have been developed will allow assessing the evolution capabilities of the Reference Architecture together with the evolution of the simulator

To perform this evaluation a number of criteria have been defined. However, since there is no benchmarking available the application of these criteria will be done relative to the reference scenario considered (e.g. comparison of the development of a simulator using a dedicated architecture vs. the Reference Architecture concept).

The evaluation process shows some interesting outcomes for the three scenarios evaluated. The Reference Architecture shows of great use under certain circumstances, and shows some limitations in others. For example:

- For FLEX, the main conclusion if that the definition of the Reference Architecture is of great help in the definition of the simulator, however the use of a framework based on input/output data access can lead to suboptimal solutions since it would imply extremely large simulation times and thus would make the E2ES impractical.
- For SEOSAT, the main conclusion is that the Reference Architecture would have been very appropriate for the development of the prototype, which had requirements comparable to those of a Phase A E2E simulator. However it is not evident the benefit of using the RA for the final SEOSAT E2E simulator.
- For CoReH2O, the main conclusion is that the Reference Architecture would have been very appropriate for the development of CoReH2O E2ES according to the Phase A requirements.

# 8. CONCLUSIONS OF THE EVALUATION PROCESS

The evaluation performed over the Reference Architecture has shown an important potential for the different scenarios evaluated. With respect to the comparison with ad-hoc developments, both comparisons - with the SEOSAT and the CoReH2O end-to-end simulators - have confirmed that the Reference Architecture would have been very appropriate for the development of the simulators according to the Phase A requirements. Both simulators could have benefited from having a well-defined architecture and benefited from reusing existing and validated Building Blocks. In the case of CoReH2O, there was much time devoted to the definition of the interfaces through the development of the simulator, and according to the evaluation exercise, this time could have reduced and concentrated at the beginning of the project by adapting the Reference Architecture to the specific mission. In the case of SEOSAT, the Reference Architecture could have been adopted at the beginning, saving not only design time, but also maintenance time because of the inherent modularity.

The aspect where the Reference Architecture could introduce some disadvantages is in terms of performance. Modularity certainly has many advantages (distribution of the implementation, maintenance, potential of reuse, etc.) however this same modularity could drive a less than optimal implementation in terms of execution time. This is more likely not an issue in Phase A simulators, which are nevertheless the focus of ARCHEO-E2E, but could become an issue with simulators for later phases and would have to be address on a case by case basis.

Another aspect closely related to the time performance is the potential need for parallelization. In principle, the Reference Architecture supports parallelization of the implementation, however strict performance requirements may require a different approach to the architecture of the simulator. This is foreseen to happen for simulators beyond Phase A (as identified, for example, for the SEOSAT E2ES), and in principle should not be a disadvantage for using the Reference Architecture in Phase A.

With respect to the impact of the framework (in this case OpenSF) over the E2ES, some issues have been identified. One of the main concerns is the implications over the parallelisation, which is expected to affect simulators beyond Phase A. While this could be solved by the implementation of the individual high-level modules, it is not clear how OpenSF would support this. Another aspect affecting time performance has been identified by the evaluation done in reference to the FLEX E2ES. The possibility of using Montecarlo simulation for studying the impact of instrument error propagated in the retrieved Level-2 products imposes a strong constraint on the simulation framework, since a large number of cases are studied in Montecarlo-type simulations or parameter sensitivity analysis. The use of a simulation framework like OpenSF is sub-optimal with this requirement as the continuous access to disk memory when writing/reading data would imply extremely large simulation times and thus could impractical. Nevertheless, it is expected that future solid state drives will speed-up the data writing/reading process. Alternative possibilities exist for studying the effects of instrumental noise in the retrieval of fluorescence. One of these possibilities consists in the functional propagation of errors using classical statistical error propagation techniques.

In addition to the nominal evaluation process, and in order to incorporate as much feedback as possible on the applicability of the Reference Architecture, a small questionnaire was sent to the ESA responsibles for the EarthCARE and SMOS E2E simulators. This questionnaire captured some impressions on the adequacy of the Reference Architecture for these simulators.

For the EarthCARE simulator, the generic Reference Architecture (figure 4-4 in [PD.2]) was considered to follow very closely the concept defined a few years ago for the EarthCARE simulator (which at the time was based on scripts and FORTRAN code). Moreover, if the EarthCARE simulator were to be developed today, the Reference Architecture would certainly fit its needs and having the Reference Architecture would have simplified the process of defining the optimal architecture of the E2ES. It is also worth mentioning that the EarthCARE E2ES architecture was the first ESA E2ES to define this architecture, which was later followed by other ESA E2ES.

With respect to the evolution of the architecture, the experience on EarthCARE shows that so far (EarthCARE has recently entered into Phase C/D) there has not been any need to redefine the architecture. The changes that are currently ongoing, as expected, are the replacements of the Instrument, Level-1 Processing and Level-2 Processing modules by more robust models developed by Industry and the EarthCARE scientists.

Regarding potential limitations, the main issue mentioned is not related to the Reference Architecture itself, but to the framework itself. As mentioned before, parallel processing may become a need for E2ES if demanding processing performances are identified. In the case of EarthCARE, it is not yet defined what sort of mechanism would be needed in the framework to set-up the parallel processing, and therefore it is not clear yet it this could have an impact on the architecture of the E2ES. It is true that this is an aspect that needs to be carefully considered, given that the Reference Architecture should be expandable to allow for the evolution of performance requirements. However this aspect is very closely related to the framework and cannot be evaluated in isolation. It is therefore important to establish the parallel processing performance of the framework supporting the Reference Architecture.

The definition of the E2ES architecture in a modular way has been deemed to be crucial for an easier management of the integration of the modules received by the different subcontractors, since this allows the developers of each module working on their implementation without interfering with the other modules. Another advantage of this modularity is that the architecture allows for expandability and evolution towards different uses of the simulator. For example, the Level-1 models in the EarthCARE E2ES have been defined in such a way that with a minimum effort on recoding they can be used in the EarthCARE Ground Segment.

For the SMOS simulator, it was considered that the definition of the E2ES could have benefited from the generic Reference Architecture (figure 4-4 in [PD.2]). In fact, the Reference Architecture proposed is a "cleaned up" version of the architecture of the SMOS E2ES, and the availability of the Reference Architecture would have reduced the time devoted to maintenance and evolution – even more than the time devoted to development.

An important aspect identified is that it is indeed important that the Reference Architecture includes provision for an "Onboard Data Handling" module, as shown in the evolved Reference Architecture (figure 4-6 in [PD.2]). This module takes care of anything which happens to the simulated instrument data (assuming Source Packets) between the Instrument and L1-Processing modules, as well as the processing of ancillary data. The provision for this module ensures representativeness of the architecture for Phase C/D as it allows defining any format and content of data exchange between the Instrument and L1-Processing modules.

The main potential limitation identified would be in the case that the simulator needs to deal with complex onboard architectures where instruments work in synergy or need to exchange information (e.g. instrument 1 is working in a specific mode depending on what instrument 2 is doing or measuring). This would certainly be something to be assessed on a case-by-case basis, and would probably need the definition of a single module handling both instruments.

With respect to having a modular architecture, the impression based on the experience of SMOS is that while maintenance and development of the E2ES is certainly faster, there could be issues related to the computational performance, expected to be lower for a modular system. For the particular case of SMOS this is acceptable, but it should certainly be assessed for each individual case.

# 9. REFERENCE ARCHITECTURE ROADMAP

Once the Reference Architecture has been defined and the composing building blocks have been detailed, and after having a positive evaluation of the Reference Architecture, the next logical step is to set a roadmap to reach an operational EO E2E Reference Architecture.

From the work done in ARCHEO-E2E it seems logical to derive the need for two different but interconnected roadmaps to be developed in parallel:

- A Roadmap for the Improvement of the Framework Infraestructure and Model Repository
- A Roadmap for the adoption of the Reference Architecture

In addition, it is foreseen that the activities contemplated in these two roadmaps will evolve at the same time as the development of new E2E simulators takes place. All the mentioned activities are expected to make use of the outcome of ARCHEO-E2E. This concept is illustrated in Figure 9-1.

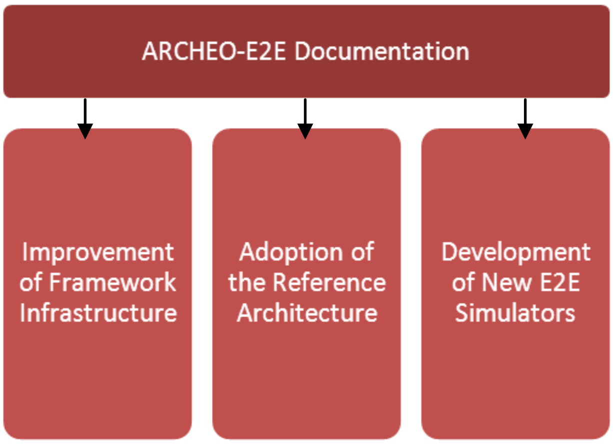


**Figure 9-1: Concept of Parallel Reference Architecture Roadmap**

Thus, the roadmap defined consists of the following activities, ordered sequentially in time:

- Include the Reference Architecture documentation as applicable document in the ITTs of future E2E simulators for Earth Observation missions at phase A/B1. It is up to ESA to determine how mandatory will be to follow the RA while it is not still available an appropriate framework version and the associated repository of BBs.
- Also in the next ITTs related to EO E2E Simulators, it should be required to implement the modules identified as generic (possible candidates to be incorporated to the Reference Architecture) following the rules defined in the Reference Architecture.
- Release an activity to review the already existing E2E simulators at ESA, as well as other available libraries (EE CFIs or other tools), in order to feed the repository reusing available modules with reduced modifications. This activity may be limited since an extensive survey has already been performed in the frame of the ARCHEO-E2E project, so it could make more sense to do this activity at the beginning of the development of each independent module.
- In parallel with the former activity, an ITT/RfP shall be issued to update the OpenSF framework with the aim of incorporating the Reference Architecture requirements that are not currently supported. Possibly, an additional ITT/RfP for the improvement of OSSR shall also be issued.
- Once the reuse from existing sources is completed, either coming from the ad-hoc activity being released or from E2E simulators starting in the close future, it is necessary to implement the rest of identified BBs from scratch. This activity can be part of the same project in which the reuse of existing libraries is analyzed or can be done separately. But in both cases, it shall be done after the first task is finalized (or it is about to finish).
- Depending on the budget available for these activities, the scope of each project could be limited, and priorities shall be assigned to the building blocks to be incorporated to the Reference Architecture. The Geometry and Scene Generator Modules are assigned with the highest priority for all kind of simulators/missions.

When all these activities are accomplished, the Reference Architecture can be considered as operational and mandatory reference for the development of future Earth Observation E2E Simulators. The simulator framework will guide the user in the process of defining the specific simulator design and it will provide useful templates and models to feed that design from the very early steps of the E2E Simulator activity.

# 10. CONCLUSIONS

An extensive review of Earth Observation missions and their instruments has allowed deriving a Reference Architecture for end-to-end mission performance simulators. The use of this Reference Architecture for the development of new simulators has the potential of reducing the reengineering process associated to the evolution of the simulator throughout the different mission phases. Moreover, the identification of common elements for different types of instruments also enables reuse of the architectural elements across several mission simulators.

The Reference Architecture has been defined and the building blocks identified and described by means of a standard template. Then, this architecture has been evaluated across three different real mission scenarios to Analyse its benefits and drawbacks. The final step has been to define a roadmap to reach an operational Reference Architecture, including the identification of priorities in implementing generic building blocks and improvements to the existing simulation framework and model repository.

END OF DOCUMENT