A Model-Based Mission Definition Review: the NANOSATC-BR3 CubeSat Study Case

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The current nanosatellite from the NANOSATC-BR CubeSat Development Program, the CubeSat NANOSATC-BR3 (NCBR3), is in its concept studies phase of the development process. Being the third CubeSat developed between INPE and UFSM partnership, the NCBR3 mission has different objectives: to develop capacity building in the space sector; to study space radiation at the South Atlantic Magnetic Anomaly (SAMA) region with Brazilian data; to promote interaction between radio amateur community and small satellites, and to validate in space cutting-edge Brazilian technologies. The Project relies on the NASA life cycle phases and uses the systems engineering approach of the same space agency. According to NASA, after establishing the Concept Studies (Pre-Phase A) and as the last step of Concept and Technology Development (Phase A), it is suggested a Mission Definition Review (MDR). This review has the intention to estimate whether the proposed architecture is responsive to the performance and the functional requirements, as well as if requirements have been allocated to all functional elements of the mission. A successful and well-conducted MDR reinforces the project decisions and contributes as a baseline for the system acquisition strategy. In previous NANOSATC-BR missions, the reviews were organized through the traditional process known as document-based, which includes the use of extensive paperwork. By making the usage of documents for this type of review, revealed that several ambiguities and inconsistencies are more likely to occur. Also, it showed difficulties for configuration control in a Project involving many developers and stakeholders, such as students, professors, technicians, and scientists. With that in mind, this work proposes a method to perform Project reviews in a Model-centric approach, using the MDR of a CubeSat Project as a use case. The authors use a Model-Based Systems Engineering (MBSE) open-source software with an embedded Systems Engineering method. With the support of MBSE, the stakeholder analysis information can be broken down into operational and functional layers, allowing a global understanding of the mission. The results showed that using MBSE promotes a well-structured Review and facilitates the review process between all stakeholders with different backgrounds.

1. Introduction

The current study case is based on the development of the first review of the Project NANOSATC-BR3 (NCBR3) CubeSat. The Project takes part of a sequence of nanosatellite from the NANOSATC-BR CubeSat Development Program that aims on promoting growth in the Brazilian space area department. The NCBR3, third CubeSat, as the name suggests, is being developed by the National Institute for Space Research (INPE), through its Southern Space Coordination (COESU) in partnership with the Federal University of Santa Maria (UFSM), with support of the Brazilian Space Agency (AEB).

The NCBR3 is currently on the Concept and Technology Development, known as Phase A, by following the NASA Space Flight Project Life Cycle. As stated by [6], a small project, such as this one, may decide to combine the Mission Concept (MCR) and the System Requirements Review (SRR) with the Mission Definition Review (MDR). A MDR is a life cycle review that assesses whether the proposed mission architecture is responsive to the program functional and requirements have been allocated to all functional elements of the mission. [5] writes that the results of the reviews and measurement analysis are used to identify and record findings and discrepancies, and may lead to causal analysis and corrective or preventive action plans. These action plans are implemented, tracked, and monitored to closure.

In earlier projects the reviews were organized through the traditional process known as document-based, which includes the use of extensive paperwork. However, it was shown that several ambiguities and inconsistencies are more likely to occur, as well as, difficulties for configuration control in a Project involving many disciplines and groups. For this matter, Model-Based System Engineering (MBSE) software and systems engineering methodology is being applied. MBSE can be defined as a formalized application of modeling to assist system requirements, design, analysis, verification, and validation activities throughout all its systems engineer life cycle phases [3].

According to [2], a model-centric approach allows a easier form of traceability, more adaptability, stimulation of teamwork, and continuity to the project, in contrast to a pure document-centric approach. [1] also stated that applying MBSE since the beginning of development promotes a more consistent Project.

The main objective of this article is to promote the use of MBSE to support Project reviews contributing for a Model-centric approach, using the MDR of a CubeSat Project as a usage case.

2. Methodology

The applied methodology proposed by NASA (2016) indicates that a MDR takes place as a final review for the Phase A, component of the life cycle selected to escort the development of the NCBR3 CubeSat. This life cycle is composed by seven phases; starting with the Pre-Phase A: Concept Study and concluding with Phase F: Closeout.

The MDR, suggested by NASA, can be divided into four parts: Stakeholders Analysis and Needs Identification; Mission Analysis; Programmatic Requirements; and Concept.

To assist the review and adapt some parts in a model-centric approach, the authors, after interviewing stakeholders while focusing on the problem, documented, analyzed, and then implemented a MBSE software the operational capacities that projects stakeholders want to be able to perform.

The implemented MBSE method chosen was the Arcadia Method, stated by [7] as a structured engineering method focused on defining and validating the architecture of complex systems that are conveniently embedded into the Capella software. This method excels in comparison with other because of its unique approach, which is structured in different engineering perspectives, which establishes a clear separation between system context and needs modeling from solution modeling.

As presented in Figure 1, the method in use is divided into four different working layers: the Operational Analysis; Functional & Non-Functional Needs; Logical Architecture and Physical Architecture. Each layer may be composed of several different model views (or viewpoints). Model views may be seen as interrelated diagrams, which are different views of the same model, for example: Architectural, Hierarchical Breakdown or Scenario views.

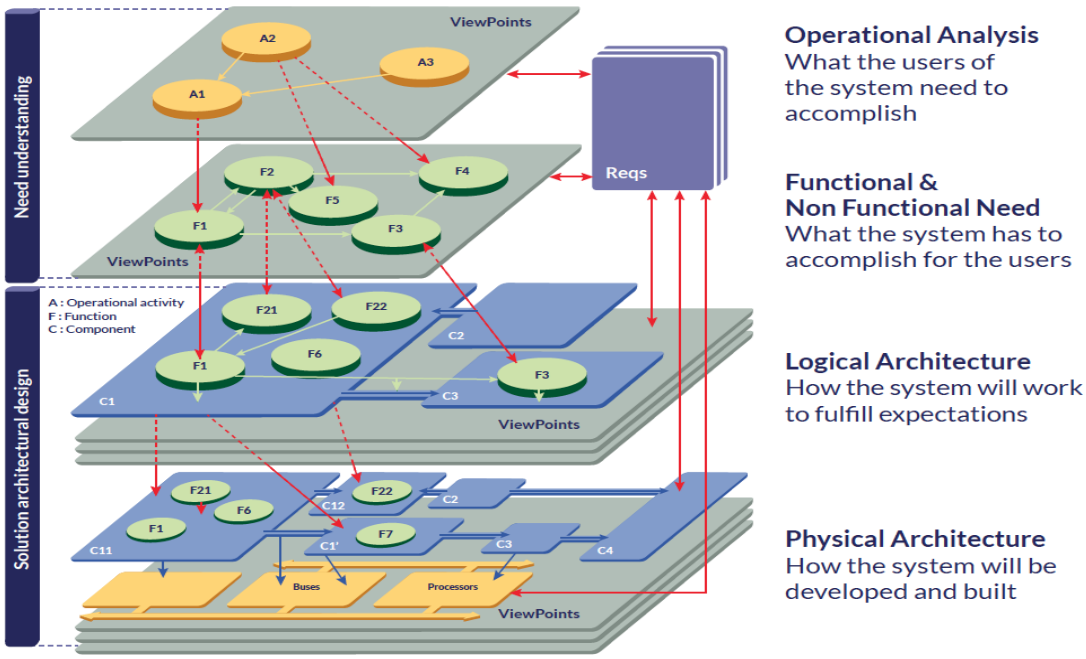

Figure 1: The Arcadia Method,[7].

Following [7] concepts, the Operational Analysis proposes a analysis of what the users and stakeholders need to achieve with the system by identifying the actors that must interact with the system, their activities and their interactions with each other. The next level is the Functional & Non-Functional Needs, that is the external functional analysis as a response to identify the system functions needed by its users, limited by the non-functional properties asked for. The Logical Architecture analyses the internal functional system, which are the sub-functions that must be carried out and put together, as well as, the identification of the logical components that carry out these internal sub-functions. For the last layer, the Physical Architecture, [7] explains that the goal of this level is the same as that of the logical architecture, except that it defines the final architecture of the system as it must be created, by adding implementation required functions and the technical choices, and highlights behavioral components that carry out these functions.

For the NCBR3 MDR, objective of this work, several model views were developed stating all of the previously mentioned modeling levels, composing the system concept. However, to meet article length size limitation, for this work it was chosen only the most comprehensive views.

3. Results and Discussion

Following the continuity of the previous missions of the NANOSATC-BR CubeSats Development Program, the NCBR3 CubeSat pre-proposed scientific mission objective is the study of space radiation and its effects on space systems. It also includes the development of capacity building in the space sector, the promotion of the interaction between radio amateur community and small satellites, and the validation of cutting-edge Brazilian technologies in space. Therefore, the group of stakeholders interviewed has needs related to these subject.

One of the first deliverables of a MDR is the Stakeholders Analysis and Needs Identification. According to [4], the stakeholder needs are transformed into a defined set of stakeholder requirements, that are able to be able to be implemented in the form of a model, a document containing textual requirement statements or both formats. In regard to the NCBR3 MDR, both forms were applied. After the primary needs from the NCBR3 stakeholders were elicited, they were analyzed and translated into stakeholders requirements through requirement analysis, and were later validated by the stakeholders.

In reference to the Arcadia Method, the first layer, Operational Analysis, pursues the stakeholders needs. The method proposes five main concepts through this level: the operational capability, operational entity, operational actor, operational activity, and operational interaction.

The Operational Capability model view, shown in Figure 2, correlates to the capabilities desired by each organization to provide a high-level objective being reached. This model view shows the interactions between stakeholders and entities with the operational capabilities. Operational capabilities can be correlated to high level stakeholders needs, actors represent stakeholders, and entities represent stakeholders organizations or external entities, such as space environment and earth. From this model view, all elements of the followings modeling levels may be traced back to these most primary needs, supporting validation process.

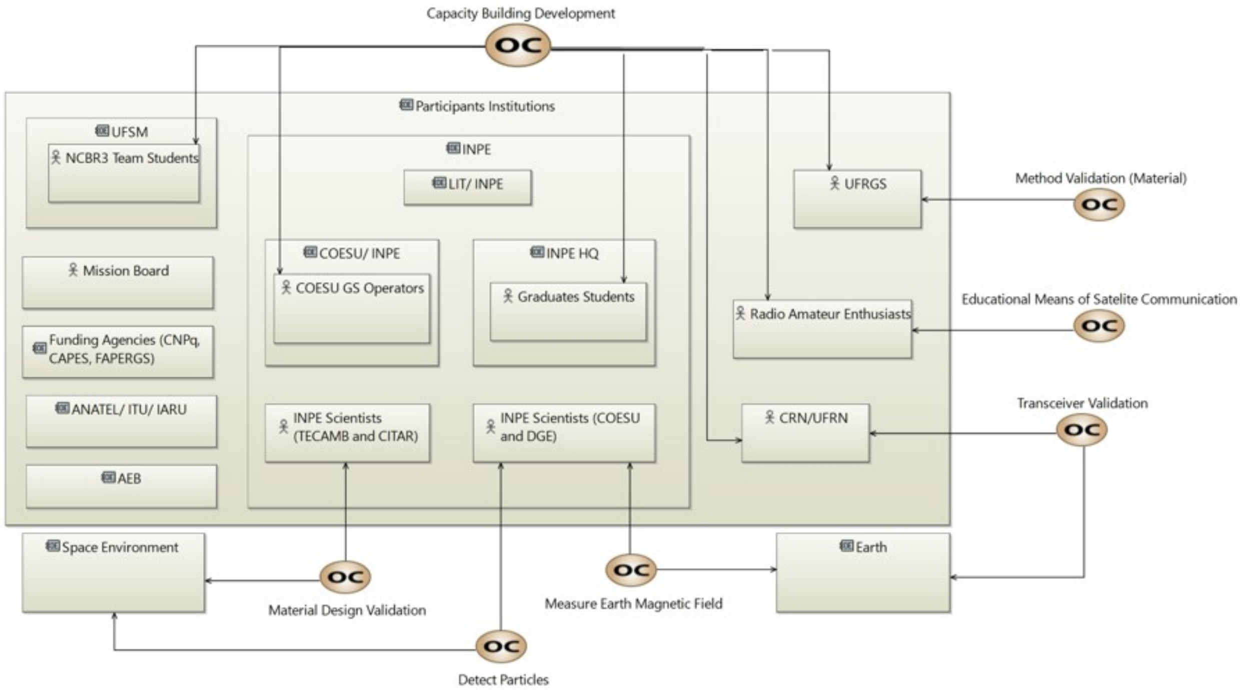

Figure 2: Operational Capabilities.

According to [7], a model has the primary objective of delivering reasonable answers for predefined questions. Therefor, for the sake of this work, the questions correspond to NCBR3 MDR deliverables.The questions of this model view are:

1. Which entities and stakeholder are involved?
2. Which are the main capabilities and their relation between the entities and stakeholders?
3. What are the educational, scientific and technological potential in a possible mission?

As it can be identified on Fig. 2, the model view highlights the most persistent operational capability evidenced by the number of its connections, which is the “Capacity Building Development”, confirming the continuity of one, if not the most important objective of the NANOSATC-BR CubeSats Development Program.

Continuing on the Operational Analysis layer, the next model view includes operational entities and actors previously identified, as well as the project’s operational activities and the interactions that connect them. Presenting a wide overview of what the users of the future system want to accomplish, the Operational Architecture, presented in Figure 3, contributes to a comprehensive visualization of which operational activities, decoupled from operational capabilities.

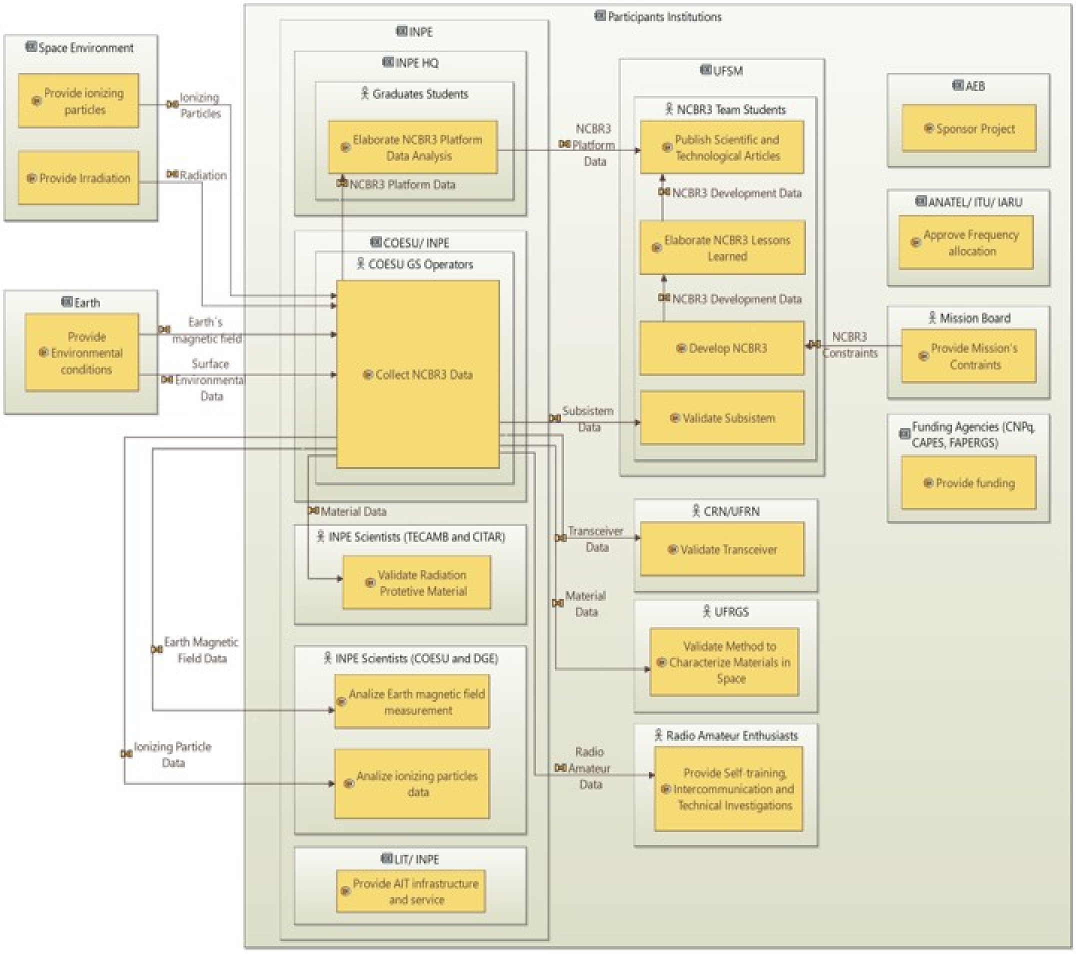

Figure 3: Operational Architecture.

The model view presented, answers the following questions considering the NCBR3 MDR:

1. What are the Needs, Goals and Objectives (NGO) of the Project?
2. Which are the main operational activities and their relation between the entities and stakeholders?

The initial assumption that can be made through this interpretation is that in future phases of the life cycle, the communication system between ground station (GS) and other entities shall be addressed with caution for an efficient and reliable transmission of mission data.

The next layer from the ARCADIA Method, known as Function & Non Functional Needs, analyzes what the system has to accomplish for the users. The main model view from this level is the System Architecture (Figure 4), the system in development is represented in dark blue, and external system in light blue. The green blocks represent the high level functions and the connections between indicates their relations.

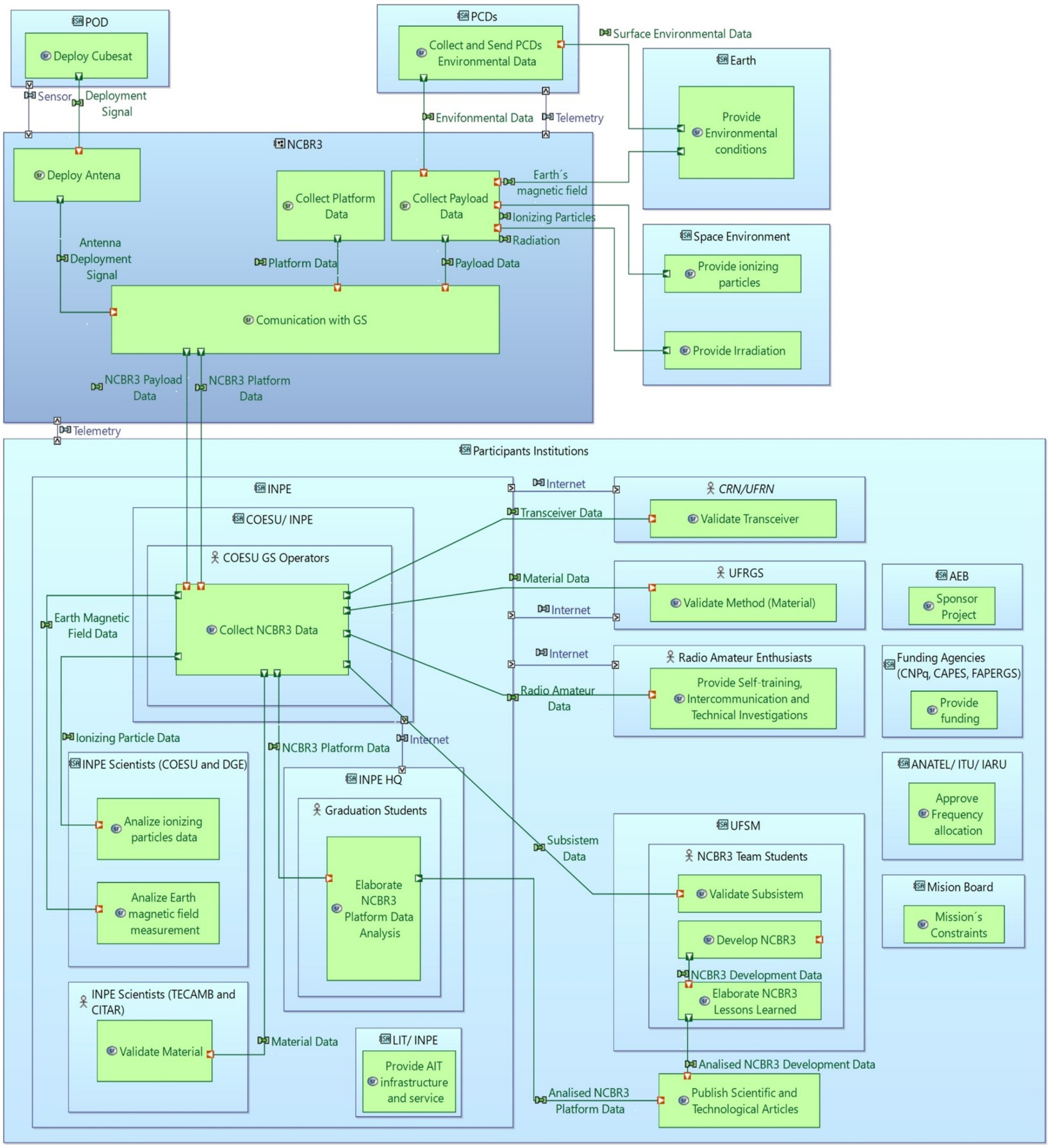

Figure 4: System Architecture.

The model view shows the relation between the system that will be developed with the entities and stakeholder, as well as the main functions of the system. This model view allows the development of the next layer, Logical Architecture.

The Logical Architecture modeling layer, as [7] describes, identify the logical components inside the system, their relations and their content, independently of any considerations of technology or implementation. The main model view from this layer is the Logical Architecture, shown in Figure 5.

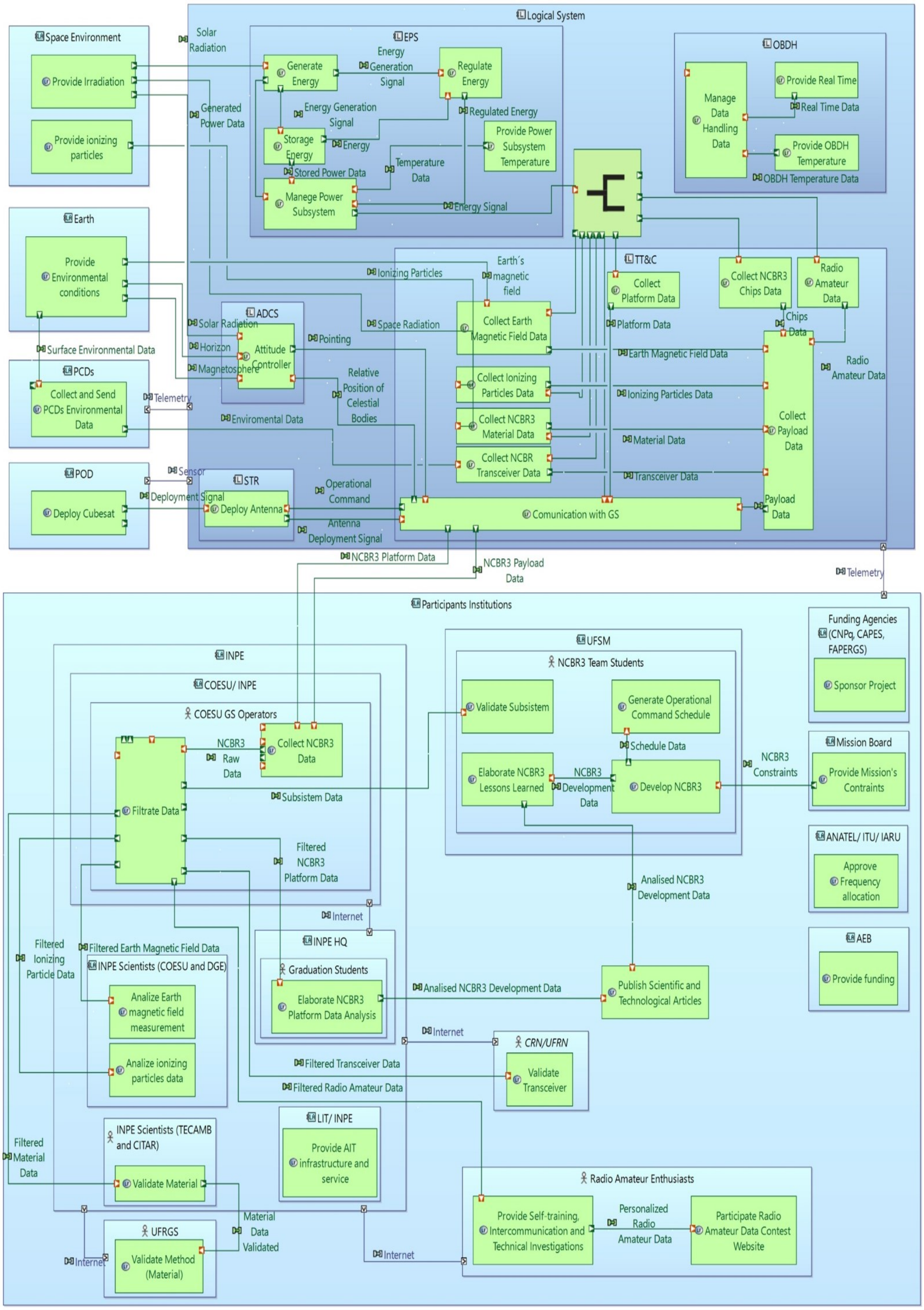

Figure 5: Logical Architecture.

The previous functions stated on the upper level, Function & Non Functional Needs, can be subdivided into internal sub-functions in this model view, while integrating the non-functional constraints that have been chosen for processing at this level. This model view allows to finely specify the responsibilities of each Logical Component elements, a structural element within the System, meaning that at this layer it can be identified the components of the work breakdown structure (WBS), a very important requirement for the MDR.

With both layers and with the help of a few external documents, the Mission Analysis part of the NCBR3 MDR can be accomplished by answering:

1. Which entities and stakeholder are involved?
2. Which are the main capabilities and their relation between the entities and stakeholders?
3. What are the educational, scientific and technological potential in a possible mission?

The last layer from the ARCADIA Method, the Physical Architecture, defines the final architecture of the system and how it is supposed to be build. The main model view developed at this layer, shown in Figure 6, is called Physical Architecture. This model view adds the functions required (identified by green blocks) for implementation, as well as the technical choices [7].

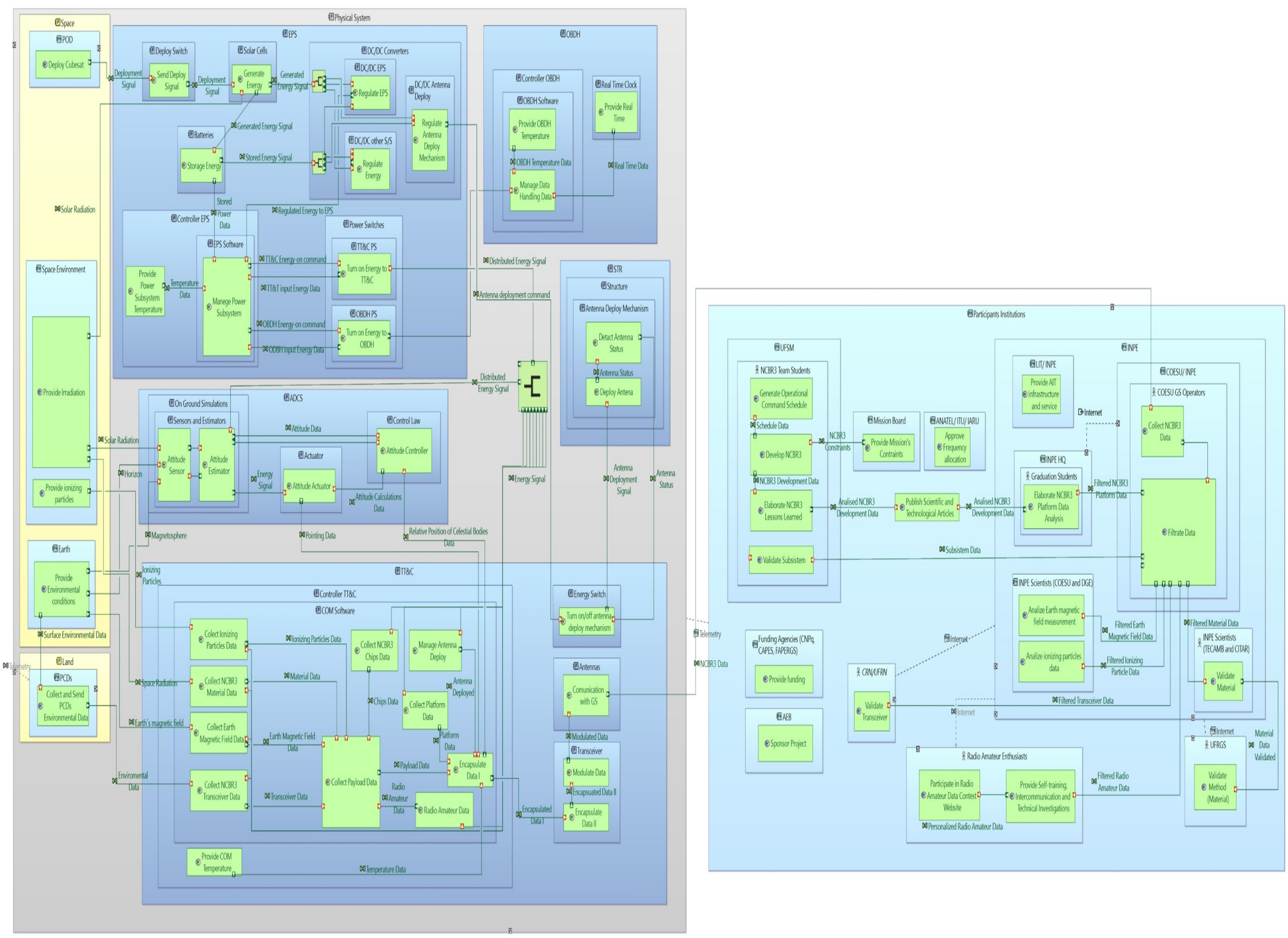

Figure 6: Physical Architecture.

In Figure 6, it can be noticed the external components of the system (yellow), such as the space environment around the nanosatellite and the surface environment, their behavior component (blue) and their functions (green). The functions presented on the physical system (gray) defines the ”real” concrete components that comprise the system.

With all layers, the last part of the NCBR3 MDR can be defined by answering:

1. What is the architecture and design of the Project?
2. What is the detailed payload?
3. What is the concept of operation of the mission?

The Table 1 show the analogy between the NCBR3 MDR deliverables and what was accomplish with modelling.

Table 1: MDR Deliverables in parallel to what was able to accomplish with the Method.

MDR	ARCADIA Method
Stakeholder Analysis	x
NGO	x
MoEs	-
Operational Activities	x
WBS/PBS	x
Mission Analysis	x
Trade-offs	x
Validate	x
Constrains	x
Cost	-
Schedule	-
Risk Analysis	x
Architecture and Design	x
Payload Details	x
Mission Objectives	x
Mission Justification	x

Many NCBR3 MDR deliverables were acquired through the use of the ARCADIA Method. However, the method does not comprehend to the extend of all NCBR3 MDR deliverables, some were structured without models, for example, the Programmatic Requirements. Still, models and Capella has the potential to assist in some Programmatic items, such as the Risk Analysis, since the software identifies critical points of the Project.

4. Conclusion

The proposed objective of this article was a study case of a Model-Based Mission Definition Review of the NANOSATC-BR3. It was shown how all layers of the ARCADIA MBSE Method through the Capella software can be applied to support the development of the MDR. Each model view created supports important deliverables suggested by NASA for this type of review. It also contributes for a less extensive paperwork, giving the first steps towards a Model-centric MDR, as a way to concentrate and unify the information, facilitating the visualization of the Project as a whole. As consequence, it eases the review process between all stakeholders with different backgrounds, as well as highlight indispensable information about the NCBR3 CubeSat system under development.

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