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Introducing a model-centric approach to a CubeSat Project: modelling Pre-Phase A

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Abstract. *To assist the latest nanosatellite from the NANOSATC-BR CubeSats Development Program, the work in development presents the first step of implementation of a model-centric approach to the NANOSATC-BR3 Project. For this purpose a Model Based Systems Engineering (MBSE) is being applied. The main objective of this article is to expose the initial phase of the ARCADIA Method with the usage of the Capella software, as well as inform its importance to the on-going Project.*

Keywords: Model Based Systems Engineering (MBSE); Systems Engineering; CubeSat.

1. Introduction

Capacity building for the space area is crucial for the Brazilian space program, considering it is a way to promote growth in the department. On that account, the National Institute for Space Research (INPE), through its Southern Regional Center (COESU) in partnership with the Federal University of Santa Maria (UFSM), with support of the Brazilian Space Agency (AEB) created the NANOSATC-BR CubeSats Development Program. As a means of an overall improvement of the Program, a Model-Based System Engineering (MBSE) software with an embedded systems engineering methodology is being applied at its latest Project, the CubeSat NANOSATC-BR3 (NCBR3). According to Bürger (2018), applying MBSE since the early stages of development promotes a more consistent Project.

The NCBR3 is the first nanosatellite from the program to introduce a model-centric approach instead of being purely document-centric, which allows a easier form of traceability, more adaptability, stimulation of teamwork, and continuity to the project (HARVEY et al., 2012). Currently, the NCBR3 is on the first phase of its life cycle, the Pre-Phase A: Concept Study, by following the NASA Space Flight Project Life Cycle. In accordance with NASA (2016), the Pre-Phase A´s purpose is to create a broad spectrum of ideas and alternatives for missions from which a project can be selected. For this matter, the usage of MBSE software is beneficial to develop and baseline top-level requirements, particularly the first layer called the Operational Analysis by the Arcadia Method (ROQUES, 2017).

The main objective of this article is to showcase the implementation of the first layer of the MBSE software and its pertinence to the NCBR3 Project.

2. Methodology

The applied methodology initiates by interviewing stakeholders through web conferences. In a way to maintain the focus on the problem, rather than on the possible solutions, these interviews were based on a previously prepared questionnaire created by the authors, aimed at articulating stakeholders' problem definition. Consequently, the operational capacities that the stakeholders want to be able to perform were documented, analyzed, and then implemented in the MBSE software.

MBSE is defined by INCOSE (2007) as a formalized application of modeling to assist system requirements, design, analysis, verification, and validation activities throughout all its systems engineer life cycle phases. The life cycle selected to escort the development of the NANOSATC-BR3 CubeSat was the NASA Space Flight Project Life Cycle. This life cycle is composed of seven phases; it starts with the Pre-Phase A: Concept Study and concludes with Phase F: Closeout.

As previously mentioned, the NCBR3 Project is currently in the Concept Study. Some of the activities planned by NASA (2016) for this specific phase are the identification of the program's stakeholders and users, and the development of the program's requirements based on user expectations. As a manner of assistance, the MBSE method chosen was the Arcadia Method, a structured engineering method focused on defining and validating the architecture of complex systems that are conveniently embedded into the Capella software (ROQUES, 2017). In comparison with other tools, Capella excels because of its approach, which is structured in different engineering perspectives, which establishes a clear separation between system context and needs modeling from solution modeling.

The method in use is divided into four different working levels, Operational Analysis, Functional & Non-Functional Needs, Logical Architecture and Physical Architecture, as presented in Figure 1.

Operational Analysis, the focus of this article, analyses the issues of operational users by identifying the actors that communicate with the system, their activities, and their interactions with one another (ROQUES, 2017). In other terms, is the level where the operational capabilities are defined, as well as, what the users and stakeholders need to achieve with the system are established. The model views developed at this stage have the highest level of abstraction of the Arcadia method, and the ones that are going to be exposed and analyzed are the Operational Capabilities, Operational Activities Interaction, and Operational Architecture.

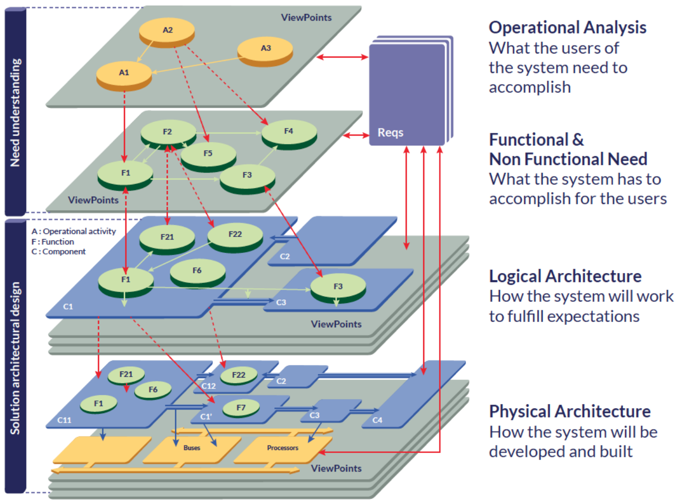

Figure 1. The Arcadia Method. [[Source: https://www.eclipse.org/capella/arcadia.html.](https://www.eclipse.org/capella/arcadia.html)]

3. Results and Discussion

The purpose of the nanosatellite mission stated by this article, NCBR3, is to contribute with previous missions of the NANOSATC-BR CubeSats Development Program, such as NANOSATC-BR 1 and NANOSATC-BR2. The first nanosatellite, NANOSATC-BR 1, has the scientific mission of collecting data from the Terrestrial Magnetic Field, mainly in the Magnetic Anomaly region of South America (AMAS) and in the Brazilian sector of the Ionospheric Equatorial Electrojet. This CubeSat has been in operation since 2014 and has tested its technological mission which was Integrated Circuits (ICs) designed in Brazil and financed by the CITAR-FINEP Project for radiation resistance. The second nanosatellite, NANOSATC-BR2, has the scientific mission of monitoring in geospace the intensity of the geomagnetic field and the precipitation of ionizing energetic particles. Since it was launched recently during the first semester of 2021, its technological mission hasn't been qualified yet.

The pre-proposed scientific mission objective of the NCBR3 CubeSat consists in studying space radiation and its effects on space systems. Therefore, the group of stakeholders interviewed has needs related to this subject. After several meetings with the guidance of simple and direct questions, primary needs from the stakeholders were elicited. Eventually, these needs will be analyzed and then translated into mission requirements through the requirement analysis, which will later be validated with stakeholders.

The Arcadia method proposes five main concepts through the first level, being the operational capability, operational entity, operational actor, operational activity, and operational interaction. The operational capability correlates to the capability of an organization to provide a high-level service leading to an operational objective being reached. Operational entity and operational actor are, respectively, an organization or an existing system whose role is to interact with the system, and a non-decomposable operational entity, such as a human. Operational activity qualifies as a process carried out to reach a precise objective and operational interaction is the connections through the operational activities.

The first developed model view, shown in Figure 2, identified as Operational Capabilities, has the purpose of situating the project to the operational capabilities that the stakeholders aim to have. This model view shows the interactions between stakeholders, crucial agents (both represented by actors in Figure 2), and entities (represented by DE in Figure 2) with the operational capabilities (represented by OC in Figure 2). In this way all elements at future levels can be traceable to the most primary needs. In this situation, the model view highlights the most persistent operational capability evidenced by the number of its connections, which is the “Capacity Building Development”. This fact confirms the continuity of the most important objective of the NANOSATC-BR CubeSats Development Program.

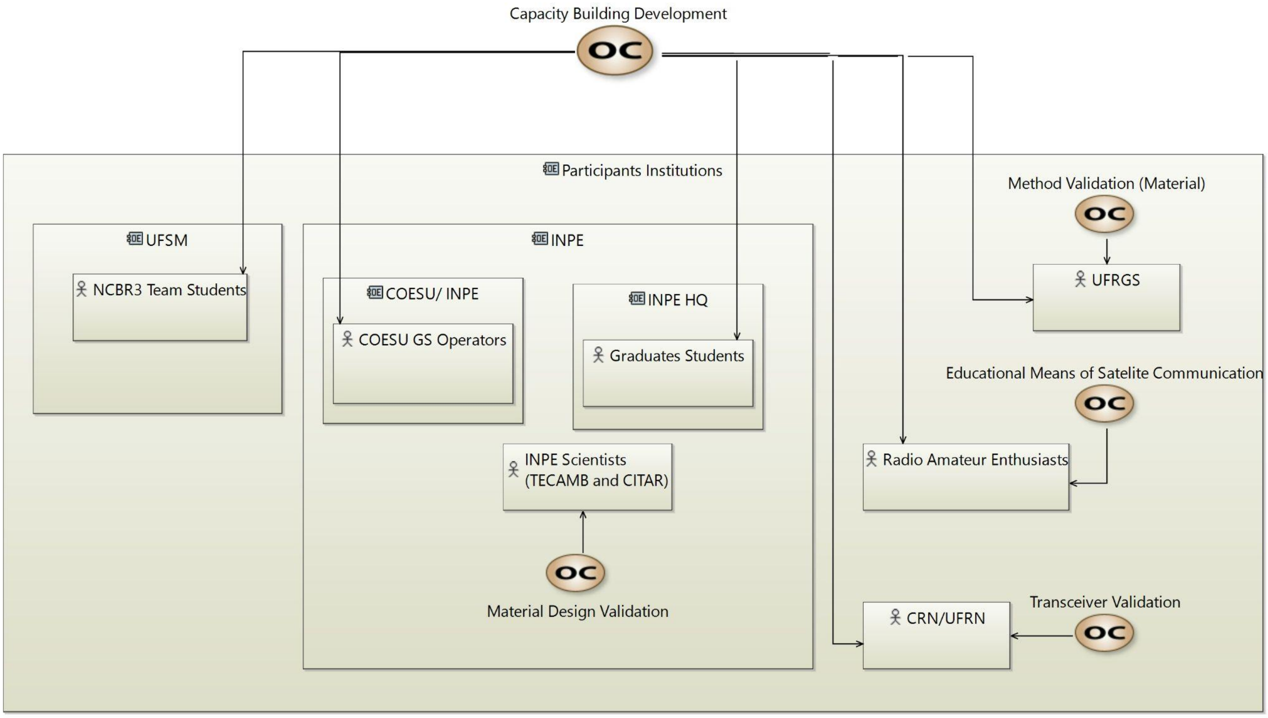

Figure 2. Operational Capabilities.

The Operational Activities Interaction model view (Figure 3), differently from the previous model, has the objective of situating the project operational activities, as well as the interactions that connect them. The model view allows the understanding of the different operational activities that lead to the Capacity Building Development, as well as the relationship between these activities. After analyzing the elaborated model view, it can be noticed that the satellite in progress has operational activities that occur in different phases of the project's life cycle. Part of it occurs before launching the CubeSat and the other during its operational phase. Both phases of satellite development can be quantified later by the number of publications generated.

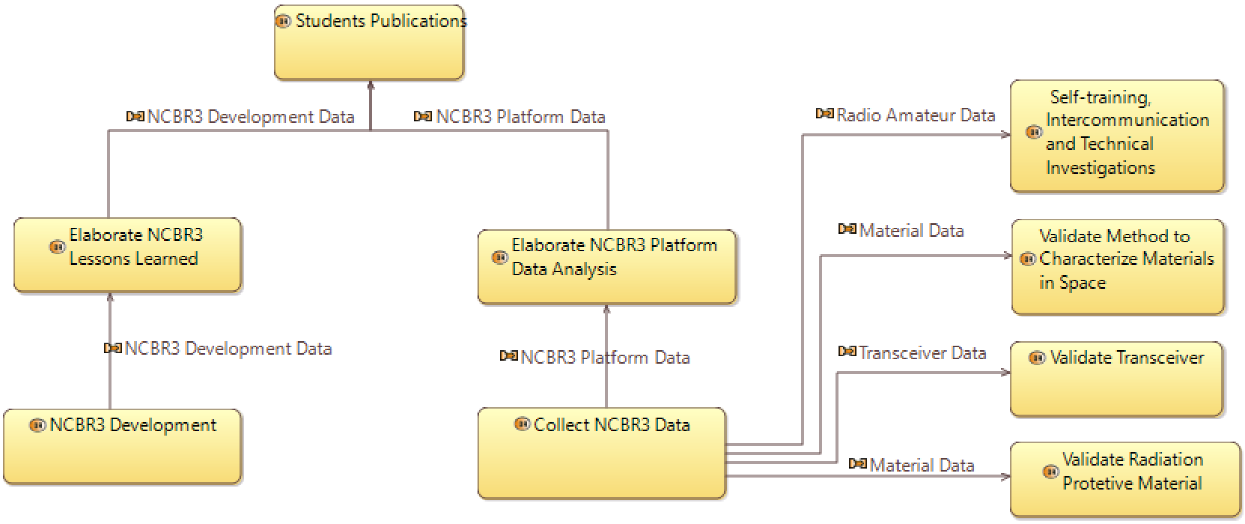

Figure 3. Operational Activities Interaction.

The final model view of this modelling layer is the Operational Architecture (Figure 4). This model view both operational entities and actors identified in the Operational Capabilities, as well as the activities and interactions created in the Operational Activities brought-up together, presenting a wide overview of what the users of the future system want to accomplish.

Since this model view includes elements of the previous ones , it allows a comprehensive visualization of which activities each entity or actor desires. This emphasizes the importance of some activities, for example: many interactions occur with the Ground Station (GS) Operators from COESU and its activity. The initial assumption that can be made through this interpretation is that in future phases of the life cycle, the communication system (between GS and other entities) shall be addressed with caution for an efficient and reliable transmission of mission data. These findings will later lead to non-functional requirements allocated to the ground to ground communication system, such as reliability.

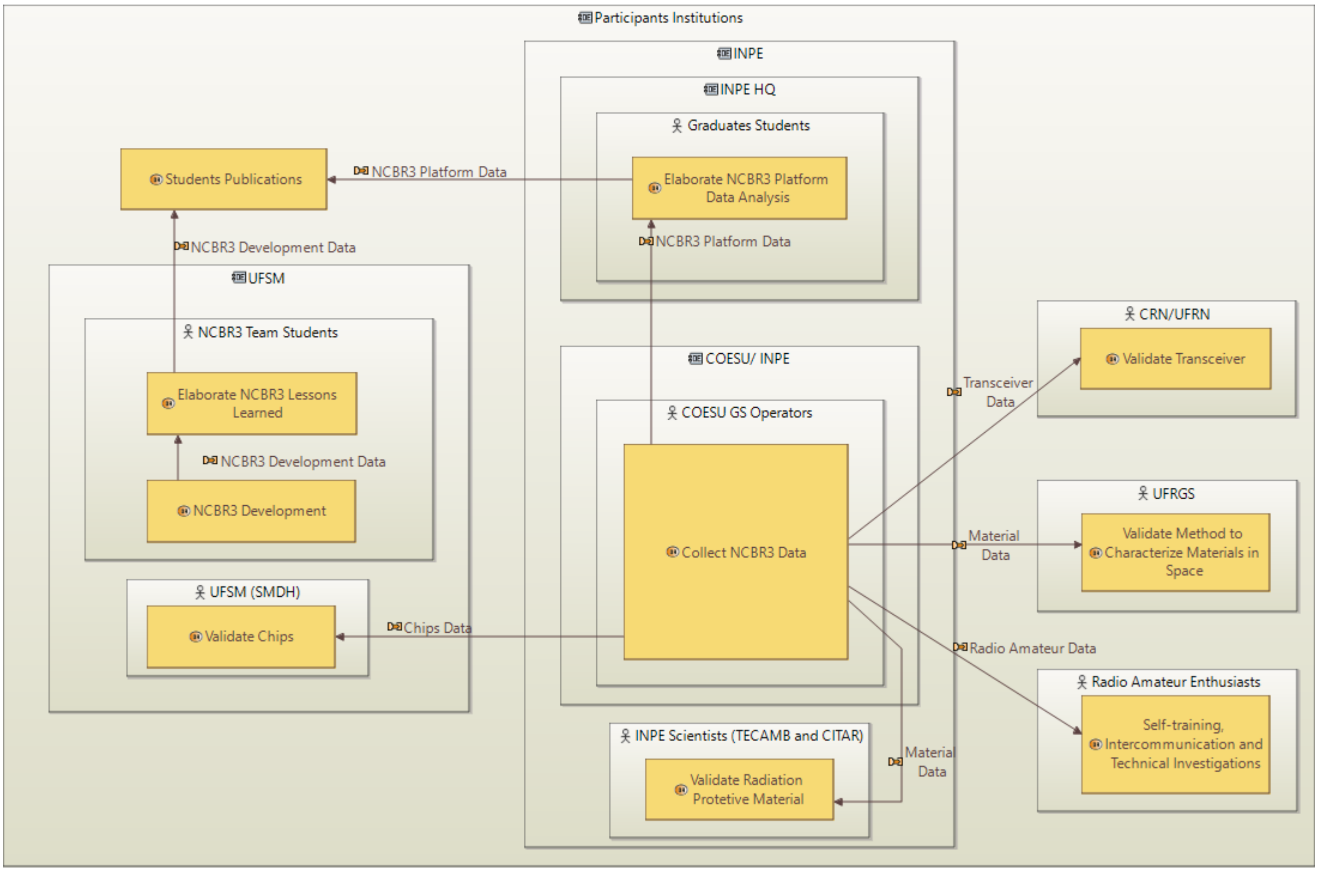

Figure 4. Operational Architecture.

4. Conclusion

The proposed objective of this article was to exhibit the implementation of the first layer of the Arcadia MBSE method through Capella software and its pertinence to the NANOSATC-BR3 Project. The first layer applied to the Project was Operational Analysis, containing three significant model views: Operational Capabilities, Operational Activities Interaction, and Operational Architecture. Each model view supports systems engineers and stakeholders by highlighting indispensable (and sometimes hidden) information about the needs that the NCBR3 CubeSat system will accomplish. The findings showed that the applied method not only provides a baseline of top-level requirements of the Project that defines the scope of the system, but also informs and correlates all possible mission alternatives that will compose a project. In addition, it is a way to concentrate and unify the information, facilitating the visualization of the Project as a whole.

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